U.S. Department
of Transportation
**Federal Aviation
Administration**

Hot Mix Asphalt Paving Handbook

AC: 150/5370-14
Date: 10/15/91

Advisory Circular

U.S. Department
of Transportation
Federal Aviation Administration

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Subject: HOT MIX ASPHALT PAVING HANDBOOK

Date: 10/15/91
Initiated by: AAS-200

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1. PURPOSE. This advisory circular (AC) provides guidance on asphalt paving operations including plant operations, transportation of materials, surface preparation, laydown and compaction.

2. BACKGROUND. Agencies and contractors share common concerns about the problems of properly constructing asphalt pavements. Training is a major problem in a decentralized industry such as asphalt paving, where many procedures and contractors operate on too small a scale to make long-term investments in personnel development; and, as a result, the knowledge and field experience of field personnel is not current. In order to address this problem, the Transportation Research Board (TRB) developed an asphalt paving handbook under the auspices of several Federal and industry agencies. The handbook is aimed at governmental agency personnel and contractor employees involved in the construction of asphalt pavements. It concentrates on field practices—at the asphalt plant during mix production and at the paving site during mix laydown and compaction. The handbook is included in this AC as Appendix 1.

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APPENDIX 1—HOT MIX ASPHALT PAVING HANDBOOK

PREFACE

Each year, more than $20 billion is spent in the United States to construct asphalt pavements for highways and airports. Asphalt paving contractors, public agencies, and the pavement research community share concerns about the problems of properly constructing these pavements. Pavement experts agree that highway and airport agencies and their pavement contractors not only have difficulty incorporating research findings into field practice, but also have difficulty in consistently applying proven procedures from earlier research experience. Training is a problem in such a decentralized industry, where many producers and contractors operate on too small a scale to make long-term investments in personnel development; and, as a result, the knowledge and experience of field personnel is often not up-to-date.

A working group of industry, government, and academic officials assembled by the Transportation Research Board (TRB)* agreed that a step towards addressing some of these problems would be the development of an asphalt paving handbook, widely accepted by major segments of the paving industry. Field manuals and handbooks have been available from many agencies, but none has been adopted by all major industry segments; and, as a result, personnel from contractors and specifying agencies may be confused by conflicting recommended practices. A single manual could reduce this confusion and assist in the promulgation of good practice based on available research and experience.

In 1988, the TRB Executive Committee accepted the recommendation for the preparation of such a handbook, and with financial support from the American Association of State Highway and Transportation Officials, the Federal Aviation Administration, the Federal Highway Administration, the National Asphalt Pavement Association, and the U.S. Army Corps of Engineers proceeded with its development. The handbook is being technically approved and distributed as a general guide for asphalt paving construction not only by its financial sponsors but also by the American Public Works Association and the National Association of County Engineers**. Each agency followed its individual process and submitted the manuscript for review by its technical experts.

To undertake this project, the National Research Council appointed a study committee chaired by Jon A. Epps, Dean of the College of Engineering, University of Nevada - Reno. The committee, with members knowledgeable in the various aspects of asphalt pavement construction practices and representing agencies, producers, and contractors, commissioned James A. Scherocman to draft the handbook under its direction. The final version incorporates changes made in response to comments received from members of the committee, approving organizations, and from other individuals appointed to review the draft in accordance with the National Research Council's report review guidelines.

This handbook covers the state of the art of asphalt paving operations including plant operations, transportation of materials, surface preparation, laydown, and compaction. It is aimed at the field personnel who are responsible for these operations, both contractor personnel who do the work and agency personnel who oversee and inspect the work. It is hoped that the handbook will create a better understanding of the processes involved and thereby result in improved asphalt pavement construction.

The handbook is not intended to cover administration, contracting procedures, site investigation, geometric design, structural design, or mix design, although some general information is included concerning contract administration and mix design. Therefore, in these areas existing agency policies and procedures will have precedence.

The work was performed under the overall guidance of Thomas B. Deen, Executive Director, and Robert E. Skinner, Jr., Director for Special Projects. Herbert A. Pennock managed the project. Special appreciation is expressed to Judith A. Klein for editing the handbook.

July 31, 1991

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*The Transportation Research Board is a unit of the National Research Council, which serves as an independent advisor to government on scientific and technical questions of national importance. The Research Council, jointly administered by the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine, brings the resources of the entire scientific and technical community to bear on national problems through its volunteer advisory committees.

**This publication was approved as a Guide by the American Association of State Highway and Transportation Officials Executive Committee on December 8, 1990. This document is also being published as Federal Aviation Administration Advisory Circular AC 150/5370-14 and as the U.S. Army Corps of Engineers publication UN-13 (CEMP-ET).

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SECTION ONE BACKGROUND

PURPOSE AND ORGANIZATION OF HANDBOOK

The purpose of this Hot-Mix Asphalt Paving Handbook is to describe the production and placement of asphalt mixtures from a practical viewpoint. It is written for two different, yet similar, groups of individuals. The first group includes the governmental agency personnel, consisting of people who carry such titles as resident engineer, county engineer, municipal engineer, project engineer, and plant or paving inspector. The second group includes the contractor's employees. Individuals who are part of this category carry titles such as project superintendent, plant or paving superintendent, and plant or paving foreman. The handbook concentrates on field practices--at the asphalt plant during mix production and at the paving site during mix laydown and compaction.

Part One provides a brief review of project organization, followed by the role of mix design relative to mixture behavior during manufacture, paving, and compaction. The importance of quality control on the part of the contractor and quality assurance on the part of the governmental agency is considered, together with the differences between method-type specifications and end-result-type specifications.

Part Two discusses the process of producing mix in an asphalt plant. The aggregate stockpiling techniques are discussed, along with the operation of the cold-feed bins. Handling of the asphalt cement and delivery of this material to the mixer is outlined. The handbook covers both drum and batch plants used for blending and mixing of the asphalt cement and aggregate.

The operation of a drum mix plant is analyzed, with emphasis on the heat-transfer process that occurs inside the drum and the methods used to blend the asphalt cement with the aggregate, both inside and outside the drum. The delivery of the mix from the drum to the surge or storage silo is discussed, together with procedures to deposit mix in the silo and discharge the material into the haul truck. The three different types of emission-control equipment used on plants are examined.

Components of batch plants are identified and discussed. Emphasis is placed on operation of the screen deck, hot bins, aggregate weigh hopper, asphalt cement weigh bucket, and pugmill.

The use of reclaimed asphalt pavement (RAP) in both drum and batch plants is described. Emphasis is placed on entry location and potential problems with normal plant operation when RAP is used in the mix.

Part Three focuses on the laydown site, where the delivery of the mix to the paver is discussed. Methods presented include depositing the mix into the paver hopper directly from the truck, depositing the mix on grade in a windrow, and using a windrow elevator or other device. The preparation of the existing pavement surface for placement of the mix is reviewed, with emphasis on the application of a tack or prime coat. The operation of the paver is reviewed in detail. The functions of the primary parts of the tractor or drive unit (hopper, wings, slat conveyor, and augers) are analyzed. The principle of the free-floating screed and the forces acting on the screed are examined. The use of automatic screed controls on the paver is also discussed.

This handbook reviews the construction techniques used to build transverse and longitudinal joints. It also looks at the compaction process: the importance of compaction, the equipment used to compact the mix, and the rolling techniques used to achieve the required degree of density in the mix. The final section of the handbook reviews some of the more common problems that may exist during and after the placement operation: surface waves, checking, shoving, tearing, nonuniform surface texture, screed marks, and auger shadows.

The format used in this handbook includes developing an understanding of the processes being described and differentiating between proper and improper construction methods. Recognition of a problem or potential problem, a description of the possible cause of the problem, and a discussion of probable solutions are important sections of the handbook. The handbook is written for those individuals actively involved in the construction of asphalt pavements.

TERMINOLOGY

Hot-Mix Asphalt

The term hot-mix asphalt (HMA) is used generically to include many different types of mix that are produced at an elevated temperature in an asphalt plant. The category of HMA is divided into three different types of mixes, depending primarily on the gradation of the

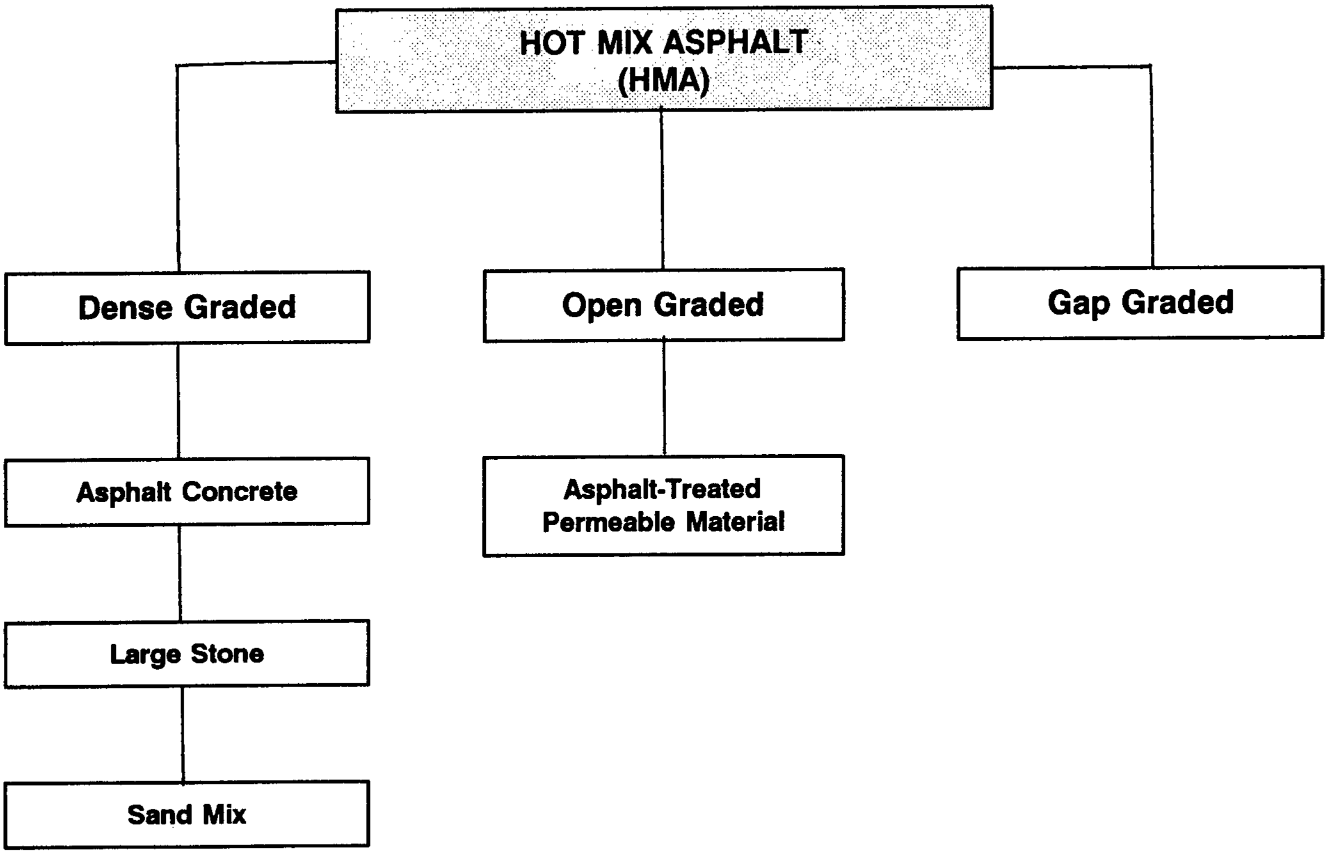

Figure 1-1. Types of HMA mixes.

aggregate used in the mix (Figure 1-1). The three mix types are: (a) dense-graded, (b) open-graded, and (c) gap-graded. Within the dense-graded category are three different types of HMA mixes: dense- or continuously graded, large-stone mix, and sand mix. The open-graded classification includes open-graded mixes and open-graded asphalt-treated permeable materials.

Dense-Graded Asphalt Concrete

Dense-graded asphalt concrete consists of a uniform or continuous aggregate grading with an asphalt cement binder. It is also called asphaltic concrete or bituminous concrete.

The information provided in this handbook emphasizes the production, placement, and compaction of conventional asphalt concrete mixtures. All asphalt concrete mixes are, by definition, hot-mix asphalts. All HMAs, however, are not asphalt concrete (Figure 1-1). The vast majority of the processes and procedures discussed in this handbook are applicable to the other types of HMA mixes. Because of differences in the gradation of aggregates used in mixes and the type and amount of asphalt cement blended with the aggregate, some changes in the mix production, placement, and compaction operations may be needed for each mix type to produce a durable HMA mixture.

Large-Stone Mixes

By definition, a large-stone HMA mix is one that contains some coarse aggregate that has a nominal size greater than 1 in. In essence, this mix is still a dense-graded material but has a greater percentage of larger size coarse aggregate in the mix. The mix design cannot be done using the standard 4-in. Marshall or Hveem design molds. For the Marshall mix design method, molds having a diameter of at least 6 in. should be used to prepare the mixture samples. In addition, the amount of compactive effort applied to the laboratory specimens must be increased proportionately to achieve the proper air-void content in the specimens. The measured stability and flow values for the 6-in. specimens will also be greater than for the standard 4-in. specimens.

For plant production of large-stone mixes, some additional equipment wear may occur in the batch plant dryer and the drum mixer because of the use of the larger aggregate. Further, additional wear may be experienced on the slat conveyor and the augers of the paver. Because of the large-size aggregate, the compactive effort applied to the mix must be monitored to prevent excessive fracture of the larger aggregate pieces during the compaction process. Vibratory rollers, pneumatic-tire rollers, and static steel-wheel rollers can all be used. If a vibratory roller is used, however, the applied force (amplitude) should be at the lowest level that achieves compaction without extending the number of passes and the frequency of the vibration should be at the manufacturer's maximum rating for the amplitude selected.

Sand Mix

Sand mix is an asphalt mix that is made without coarse aggregate. Typically, 100 percent of the aggregate passes the 3/8-in. (9.5-mm) sieve and the majority of the particles also pass the No. 4 (4.75-mm) sieve. The asphalt cement content of this HMA mix is higher than dense-graded mixes because of the large amount of surface area of the fine aggregate. Unless manufactured sand or an angular natural sand is used in the mix, the stability of this type of mix is typically very low.

Sand mix can be produced in a batch plant or drum mix plant without any significant changes in the plant operation. Transport and placement of the mix is also standard. Under the compaction equipment, however, sand mix may tend to shove and check under steel-wheel rollers, especially when constructed in relatively thick layers (greater than 2 in.). Vibratory rollers operated in low amplitude and pneumatic-tire rollers with low tire contact pressure and high contact area are usually used to compact a sand mix course.

Open-Graded Mixes

An open-graded asphalt mixture is one that consists primarily of coarse aggregate, a minimal amount of fine aggregate, and asphalt cement binder. The main purpose of this mixture is to provide a very open surface texture; one that will allow water to drain into the mix and that provides a significant amount of large aggregate (macrotexture) for contact with a vehicle traveling over the pavement surface.

The mix design procedure for the open-graded mix is different from that for a dense-graded HMA material because of the lack of fines in the mix. Although film thickness is greater for the same maximum size aggregate size, the asphalt content is typically less. The production of the open-graded mix in the plant is similar to a dense-graded mix with one major exception. Open-graded mixes that contain excess asphalt cement or that are heated to very high temperatures will tend to drain (lose some of the asphalt cement film thickness around the aggregate particles) while stored temporarily in a surge silo and during delivery to the paver by a haul vehicle. The placement of an open-graded mix is usually conventional. The compactive effort needed with this type of mix is generally less than that needed for dense-graded mixtures. Because the open-graded mix is normally placed as a relatively thin surface course layer, two or three passes over the mix with a static steel-wheel roller is all that is usually necessary to properly set this high air-void-content material. When used as a very thin friction course, a single pass may be sufficient.

Open-Graded Asphalt-Treated Permeable Material

An open-graded asphalt-treated permeable material is designed primarily to allow for the passage of a large quantity of water through the mix as quickly as possible. The purpose of this layer is to provide a drainage course within the pavement structure. The mix design consists of coarse aggregate particles with 0-4 percent passing the No. 200 (75 μm) sieve. In addition, the size of the coarse aggregate is usually about 1 in., although mixtures with maximum size between 2 and 2-1/2 in. have been used. The asphalt cement content of the mix is very low, typically between 1.5 and 2 percent, because of the lack of surface area of the coarse aggregate.

The production of the open-graded asphalt-treated permeable material in a batch or drum plant is similar to that of a dense-graded HMA material, except for the possibility of a drain-down of the binder if the mix is produced at too high a temperature or if the mix is held for a long period of time (more than an hour) in a surge silo. Drainage of the asphalt-cement film from the aggregate particles can also occur in the haul vehicle during transport to the paving site. Placement of the mix is in the normal manner through the paver. The mix, when placed in thick (greater than 6 in.) lifts, can be relatively unstable under compaction equipment. State DOTs ensure stability by requiring use of crushed aggregate, use of a stiff grade of asphalt cement, and control of temperatures before rolling. Typically only two or three passes of a steel-wheel roller or a combination of steel-wheel and pneumatic-tire rollers are necessary to properly compact the mix. In general, a vibratory roller should not be used on an open-graded asphalt-treated permeable material.

Gap-Graded Asphalt Mixes

A gap-graded asphalt mix is essentially the same as an open-graded mix; however, the amount of fine aggregate incorporated into the mix is usually greater than the amount of fine aggregate used in the open-graded mix. The aggregate gradation in the middle-size aggregate [that between the No. 4 (4.75-mm) and the No. 30 (600-μm) or No. 40 (425-μm) sieves] is missing or present only in small amounts. The production, placement, and compaction of a gap-graded HMA mix is similar to the processes used for an open-graded mix. Draining of the binder from the aggregate during temporary storage and transport is normally not a major problem because of the amount of fine aggregate used in the mix.

WORKMANSHIP

Three major factors directly affect the ultimate performance of an HMA pavement: (a) the structural design of the pavement layers, (b) the mix design, and (c) the workmanship or construction procedures used to produce, place, and compact the mix. The ultimate durability of an asphalt mixture and pavement structure is directly dependent on the quality of the workmanship used to construct the project. The best set of specifications, if not followed, will not assure a good, long-lasting pavement. The best mix design, if not duplicated in the plant, will not provide the desired life of the pavement under traffic. The most modern and sophisticated equipment, if operated improperly, will not produce a mixture that withstands the effects of the environment and applied loads, nor will it provide the desired ride quality.

Poor workmanship can be one of the more significant factors responsible for premature distress of an asphalt pavement. Most asphalt pavements do not fail uniformly from one end of a job to the other end. Within the length of a project, failure normally starts at one or more isolated locations and either remains localized or spreads over a wider area.

Many times, poor workmanship evolves from an ignorance of (a) the specifications, (b) proper construction techniques, or (c) proper operation of equipment. On some projects, untrained or poorly trained personnel produce, place, and compact mix without a complete understanding of what is required: the materials, processes, and procedures to be used to construct the asphalt pavement properly. On some jobs, however, problems come from a lack of attention to the specification requirements. For reasons of expediency (in order to get the job done before the completion date, for example) shortcuts are taken that can reduce the quality of the mix being placed.

Marginal practices also have the potential to reduce the service life of HMA. Many examples exist. Sometimes weather forecasts for rain are ignored when a project is behind schedule or there is a rush to get the job completed. When the rain comes and some truckloads of mix are on the way from the plant to the paver, the tendency is to shut the plant down but to lay the mix that is en route. Another example is when a roller breaks down at the paving site but the compaction process continues without a change in the production rate at the plant or a slowdown in the speed of the paver. In order to keep up, the remaining rollers merely speed up to keep from falling too far behind the laydown machine. Only after it is determined that the broken roller may be out of service for several hours and no replacement roller is available is it typically decided to alter the production and placement process to accommodate the reduced number of rollers. Problems such as these are encountered regularly at a construction site. The manner in which they are resolved directly relates to the quality of the pavement being constructed.

This handbook does not directly address workmanship but it is inherent in all of the discussions that follow. Performing a task properly assures that the asphalt concrete mix produced, placed, and compacted has a better chance of performing well under traffic. Ignorance of the correct procedures, or disregard for the specifications, typically will reduce the ultimate life of the HMA. Good specifications, mix design, and materials cannot overcome poor workmanship. The ultimate goal is to use both good specifications and good workmanship to build a durable HMA pavement.

SECTION TWO
PROJECT ORGANIZATION

INTRODUCTION

The most essential part of project planning and organization is communication. The project documents are written instructions that describe in detail the requirements. The preconstruction conference initiates verbal communication between the representatives of the agency and the contractor personnel. It sets the tone for both the working relationship and direct communications during the execution of the project.

It is difficult, if not impossible, to produce high-quality work if open lines of communication do not exist between the contractor's people and the agency's personnel. Likewise, safety on the job cannot be maintained if communication between all parties is inadequate.

PROJECT DOCUMENTS

Project documents illustrate and describe work to be done under the contract. Specific definitions of these and other terms that apply directly to a project are normally included in the first section of the governing standard specifications.

- Plans: The drawings that show the location, character, dimensions, and details of the work to be done.
- Standard Specifications: The directions, provisions, and requirements for performing the work illustrated and described in the plans. The items in the standard specifications relate to or illustrate the method and manner of performing the work or describe the qualities and quantities of materials and labor to be furnished under the contract.
- Special or Supplemental Specifications: Approved additions and/or revisions to the standard specifications.
- Special Provisions: Additions or revisions to the standard or supplemental specifications that are applicable only to an individual project.

A number of other documents are often incorporated by reference into the standard specifications, supplemental specifications, and special provisions. Material specifications and test procedures from the American Association of State Highway and Transportation Officials (AASHTO) and the American Society for Testing and Materials (ASTM) are often listed in the specifications and become part of the contract documents just as if the whole text were written into those specifications. Additional documents, such as the *Manual on Uniform Traffic Control Devices* (MUTCD) and the Occupational Safety and Health Administration (OSHA) regulations are also treated in the same manner when referenced in the specifications.

Many of the material specifications and test methods that are written by AASHTO or ASTM for national use are modified for use under local conditions. Governmental agencies often publish their own material specifications and test methods. These publications typically are referenced in the contract documents and become part of those documents. Inspection manuals or guidelines are normally for use by the agency's representatives and usually are not part of the contract documents.

If there is a discrepancy between the instructions and specifications in any of the contract documents, a definite hierarchy exists among the four major forms of documents. The order of priority, from the highest to the lowest, for the contract documents is usually defined as the special provisions, the plans, the special or supplemental specifications, and, finally, the standard specifications. The order of priority corresponds to the document's specific applicability to a particular project or contract.

The plans and specifications need to be accurate and complete, and they should leave little room for assumptions or for later reinterpretation. In addition, the plans and specifications need to define the responsibilities of the representatives of the agency as well as the contractor personnel. If method specifications are to be used, the type and frequency of the inspection and testing procedures must be given explicitly. If quality assurance-quality control specifications are to be used, the requirements for the contractor to monitor its own work and for the agency personnel to do the necessary acceptance testing must be provided in detail. Accurate and complete contract documents save many hours of later discussion between the agency's representatives and the contractor.

PRECONSTRUCTION CONFERENCE

A preconstruction conference is often held before work commences on a project. During this meeting, the overall tone is set for the job, preferably one of cooperation. It is generally the responsibility of the agency's representatives to outline the scope of the project and to discuss the information provided in the contract documents. In addition, it is also the responsibility of the agency personnel to discuss any unusual aspects of the job--items that are not routine construction practices. A list of personnel who will be assigned to the project should be provided to the contractor.

The individuals representing the contractor should be familiar with the job and be able to speak with authority about what is to be accomplished. A progress schedule for the job should be presented and discussed with the agency's personnel. Any questions about the information in the contract documents should be raised and clarification requested, if necessary. A listing of key contractor personnel who will be assigned to the project should be provided, with clear lines of authority established.

The people in attendance at the preconstruction conference should not assume that all of the other individuals present understand fully and are in complete agreement with the proposed progress schedule. Agreement is needed on the methods to be employed to complete the project on schedule, with a minimum of delays and change orders. Because continuity of the asphalt-paving operations is critical to providing a quality pavement, the discussion between the agency and the contractor personnel should include such items as material sources, plant production rates, haul distances and routes, paving widths and speed, and the type and operation of the compaction equipment. If known, a list of equipment that is to be used on the project should be supplied by the contractor to the agency.

The role of each person on the project, for both the agency and the contractor, should be discussed and made clear. This requires that the supervisory personnel define the tasks, authority, and responsibility of each of the key individuals to be involved in the work.

Sampling methods and frequencies should be discussed. Test methods to be used should be reviewed to assure that all individuals understand the purpose of each test, the location and the personnel who are to conduct the test, the time frame for the return and communication of the test results, and the procedures to be used if failing test results are obtained. If not adequately covered in the specifications, the use of duplicate or split samples (one for testing by the contractor and one for testing by the agency) needs to be considered, as well as procedures for retesting inadequate materials. The details of the quality control program, both on the part of the contractor and the agency, should be discussed so that everyone is aware of "who, what, why, when, and how."

One of the most important items to be discussed at the preconstruction conference is job safety. Safety is not only a legal and financial responsibility of all the people on the project but a moral responsibility as well. This topic should include not only the safety of those individuals working on the job (both contractor and agency personnel) but also the safety of the traveling public. Clear responsibility for maintenance of all traffic control devices such as signs, pavement markings, and flagging should be delineated. The name of the person responsible for safety for the contractor should be provided to the agency so that rapid and clear communications can be accomplished if safety problems occur. All personnel involved in the project must be required to comply with all safety standards applicable to the type of construction and asphalt paving work to be carried out.

ONGOING COMMUNICATION

Communication cannot stop once the preconstruction conference is concluded. The quality of the work completed and the safety of those performing and inspecting the construction are directly related to the quality of the communication between the agency and the contractor. It is important that the individuals in daily charge of the project for both the agency and the contractor meet periodically, both on a formal and on an informal basis, to discuss the progress and quality of the work done to date and the schedule for future work.

Formal Meetings

The frequency of the formal meetings depends on the scope and the size of the paving job. On a major project, the "update" meetings should occur at least twice a week. Key personnel from both the agency and the contractor should be present. The discussion should include such items as the quantity of work completed, the test results obtained, and any problems that have occurred. The meeting should also focus on what is yet to be accomplished: the schedule for the coming weeks. Changes to be made in the progression of the work, including personnel changes, different equipment use and construction methods, and mix design information, should all be discussed. Problems that have occurred and that are anticipated should be communicated to both parties and solutions explored.

If formal meetings are needed, they should be held on a regularly scheduled basis, such as every Monday morning at 8:00 a.m. at the project office. Everyone who is supposed to attend the meeting should be there and be on time. The meeting should be conducted jointly by the agency and the contractor and should be used as a forum for positive input to the job. A list of all individuals in attendance should be prepared, along with written minutes of the meeting. These minutes should be completed and distributed to all involved people as quickly as possible.

Informal Meetings

Informal meetings should be held on a daily basis between the two individuals in charge of the job for the agency and the contractor. Ideally, these meetings should occur at a regularly scheduled time, but can be held on the job site; at the asphalt plant or at the paver. The purpose of the informal meetings is twofold. First, the discussion should include what occurred the day before, such as work completed, test results, and problem areas. The topics should include what is going to happen in the next several days; an update on the information exchanged at the last formal meeting.

Asphalt paving projects, like many construction projects, are not always built as originally scheduled. Changes occur because of material supply, equipment breakdown, contractor and subcontractor schedules, and weather conditions. When such changes do occur, it is important that they be communicated between the contractor and the agency and between the agency and the contractor. Communication is a two-way process. The informal meetings on a daily basis provide a forum for the exchange of such information.

Communication Form

Communications should be oral and written. Much information can be communicated in oral form. Important information should be followed up in written form. In some cases, formal letters should be written by the contractor and by the agency when conditions on the project change substantially. Often a less formal note can be written to confirm the data that had already been communicated orally. In addition, personnel for both the agency and the contractor should keep daily diaries of events that occur. If something happens that is important enough to remember later on, it is important enough to take the time to write it down immediately after it happens so that the information is accurate and complete.

PROJECT RECORDS

It is important that accurate and complete records be kept for all construction projects. This is true for both the project engineer and staff and for the contractor's general superintendent, plant and paving superintendents, and all foremen. Trying to reconstruct events at a later time without written notes and complete test data is usually frustrating and often results in conflicting opinions as to exactly what happened. One procedure should constantly be followed: if in doubt about whether the information is important or beneficial, write it down.

Plant Reports

The results of all daily and periodic tests conducted at the asphalt plant should be recorded. Although different forms may be used, both the project inspection personnel and the contractor employees should collect essentially the same type of information. Further, the contractor personnel should complete their own records, even if not required to do so by the agency.

Some of the data that should be shown on the form include: (a) project number and location information, (b) weather conditions, (c) source of materials used on the project, (d) job-mix formula information, (e) aggregate gradation and asphalt content test data, (f) mix test results, (g) the amount of each material (aggregate, asphalt cement, and additives) used, (h) the number of tons of asphalt mix produced, and (i) location on pavement where daily production was placed. Any additional information required by agency specifications, such as the moisture content of the individual aggregate stockpiles, should also be reported on the form.

It is important to record the date, time, and location of all samples taken, and the name of the individual taking the samples. If, for example, aggregate gradation is determined from samples taken at two different places (from the cold-feed belt and from the extracted mix), the sampling location must be marked on the report. Similarly, if asphalt content is normally determined by nuclear gauge and occasionally checked by extraction, the procedure used to measure the mix property should be recorded.

Most forms should have a "Remarks" area. This portion of the form should be used to indicate any unusual occurrences or test results that took place during the day. Failing test results should be highlighted on the form. Additional comments about the possible cause of the deficiency should be written under "Remarks." Any corrective action or changes to the mix materials, plant-operating parameters, or test procedures should be indicated. The results of those actions or changes should also be indicated on the form.

Pavement Reports

Information on what occurred on the pavement during the mix placement and compaction operations also must be recorded. Again, the data gathered may be reported in a different style by the paving inspector and by the contractor's superintendent, but essentially the same information should be reported by both. This will allow for more meaningful discussion later if deficiencies develop in the test results or in the performance of the mix under traffic.

Some of the data that should be shown on the paving-site form include: (a) project number and location, (b) weather conditions, (c) the type and number of tons of each mix placed and the exact location of that mix--layer number, thickness, lane, and station number, (d) the type and make of equipment used by the contractor, (e) the density results obtained, and (f) the smoothness results obtained. In addition, other data should be reported, such as the type, amount, and location of any tack coat material placed; the location (both transversely and longitudinally--station number) of any tests taken; and a running total of the tons of each mix laid on the project.

All samples taken must be marked properly to indicate the location from which the material was gathered, the time and date of the sampling, the reason that the sample was taken, what quantity of material the sample represents, and the name of the person who took the sample. If a nuclear gauge is employed to determine the relative density of the mix, any calibration procedures used to check the reliability of the gauge should be referenced.

The "Remarks" area on the pavement report form should be used to report any unusual conditions or test results that occur during the day. Failing test results should be highlighted on the form and an explanation provided, if possible, as to both the cause of the deficiency and the steps taken to correct the problem. The result of the corrective action should also be given.

Daily Diary

All project supervisors, both agency personnel and contractor employees, should keep a detailed daily diary. This document should be used to record any changes that are made in the mode of operation of the asphalt plant or the laydown and compaction equipment. It should be the place to report any different or unusual events that occur on the job. It can be used to document other events, such as a listing of visitors to the project. It should also be used to record the reasons for delays in paving (e.g., because of an equipment breakdown or poor weather conditions). The purpose of the daily diary, then, is to save for possible later reference the nonroutine events that happened during each paving day.

For the information in a diary to be accurate and meaningful, the data must be recorded in the book shortly after the events occur. Ideally, the diary should be updated at least twice a day: once near midday and again at the end of the day. If job conditions and schedules preclude making the midday entry, the events of the day should always be written down upon completion of each day's activities. It is not practical to try to recall and record what happened on Monday when it is the following Wednesday evening or the end of the week.

The information contained in the diary must be detailed and complete. It should contain as much detailed information as possible. If a conversation is held with other project personnel concerning project activity, regardless of whether they are agency inspection personnel or contractor employees, the date and location of the conversation should be recorded. The names and titles of any people involved in the discussion should be written down, as well as the topics reviewed. The outcome of each conversation, if it affects the progress or the results obtained from the mix manufacturing and placement operations, must be stated. Who told whom to do what, and what was the reply? That is the type of information that should be included in the daily diary.

The importance of the information contained in each daily diary cannot be overemphasized. Many claims and lawsuits have been settled on the basis of information written in a diary. If one person involved in a dispute can present information written in timely fashion in a diary and the other individual can only rely on memory to reconstruct the important events, the writer usually will have an advantage in the settlement of the disagreement. The information may also be useful for follow-up research, determining reasons for premature failures, etc.

SAFETY

The old saying "Safety is Everyone's Business" is certainly true on an HMA paving project. From the contractor's superintendent, to the front-end loader operator at the asphalt plant, to the truck driver, to the raker behind the paver, every individual who works for the contractor must be aware continuously of the need to practice safe work habits. Likewise, every person who works as a representative of the agency, from the project engineer, to the inspector at the plant, to the ticket taker at the paver, must be aware of safe work habits.

Communication is one of the keys to a safe work environment. Every individual should know what is expected and know how to perform the assigned tasks. Proper training in the operation of a piece of machinery is essential for equipment operators, for example. Retraining is necessary at frequent intervals because the longer a person continues to perform the same task, day after day, the more likely he or she is to do things by "remote control" and ignore surrounding events. Everyone, regardless of title or job function, must be aware continuously of the need for safe work practices. Occupational Safety and Health Administration regulations must be known, understood, and followed by each person involved in the construction project.

Safety talks are a good way to start the day for both contractor and agency personnel. Several different organizations publish short, concise safety presentations that can be completed in 2 or 3 min. People need to be reminded that they are operating in a potentially dangerous environment, both at the plant and the laydown site. Daily talks are one way of accomplishing the task of continuously reminding them. Further, if an unsafe work practice is noticed, corrective action should be taken immediately, even if the paving operation has to be shut down until the unsafe practice is changed.

The people most likely to be hurt on an asphalt paving project are those individuals who are new to this type of work. Without adequate advance training, these people do not fully understand all the differences between following safe work practices and taking foolish chances. Often new employees, working either for the agency or for the contractor, want to show that they are capable and can perform the tasks assigned to them. At times their enthusiasm to excel and to please other people can overcome their awareness of proper safety practices.

Another class of individuals who often suffer needless injuries are people who have been around the plant and the paving operations for many years and who are "comfortable" being around the equipment. Sometimes these people perform their duties by rote. They typically take short cuts because they have survived without injury for many years. Safety should be as much a part of these individuals' day as it is for the new people on the job.

Working around an asphalt plant is a potentially hazardous occupation. Functioning equipment parts, high temperatures, noise, and moving delivery and haul trucks all add to the possibility of an accident occurring. It is possible, if an individual is not trained to perform a particular function, for him or her to get burned by hot asphalt mix, to be sprayed with hot asphalt cement, to have a hand caught in a piece of machinery, or to be struck by a moving vehicle.

Working around an asphalt paving site is also a potentially hazardous occupation. Individuals who are working on the pavement around the paver (e.g., the ticket taker, truck dump person, the screed operator, and the rakers) are susceptible to being hit by passing traffic. Further, these same people have the potential to be hurt by equipment being used in the paving operation. People can be injured by the haul trucks backing into or pulling away from the paver, as well as by compaction equipment. In addition, all of the paving personnel have the possibility of being burned by the hot asphalt mix.

Constant care and vigilance is needed to prevent accidents and injury. The Occupational Safety and Health Administration, the National Asphalt Pavement Association, state DOTs, and others have published manuals that deal with safety at the asphalt production plant and around a paving operation. These manuals should be made available to all plant and paving personnel, both for the agency and for the contractor, and should be required reading. Safety is everyone's business on a construction project.

SECTION THREE
MIX DESIGN AND THE JOB MIX FORMULA

INTRODUCTION

Hot-mix asphalt has two primary ingredients: binder and aggregate. The asphalt binder is usually asphalt cement, which is obtained from the refining of crude oil. Asphalt cements are graded either by penetration or by viscosity. The aggregate used typically is a combination of coarse and fine materials, with mineral filler as needed. The aggregates are often available locally, either from a pit or from a quarry. The mix design system determines the correct proportion of asphalt cement and aggregate needed to produce an asphalt mix that has the properties and the characteristics to withstand the effects of traffic and the environment for many years.

Mix design is performed in the laboratory generally using one of two methods. The more common mix design method is the Marshall method. This procedure is followed by approximately 75 percent of the state highway departments as well as the U.S. Department of Defense and the Federal Aviation Administration. The second procedure is the Hveem method. This method is used by many public agencies in the western United States.

Another mix design procedure is the asphalt-aggregate mixture analysis system (AAMAS) recently published by the National Cooperative Highway Research Program. In this method, the traditional empirical means of determining HMA mixture strength (or stability) have been replaced by more rational test procedures. Mix properties such as resilient modulus, indirect tensile strength and strain at failure, and creep modulus values are determined to estimate the performance of the asphalt mix in the pavement under traffic. Test results are used to home in on an optimal mix design that will produce pavements resistant to distresses such as fatigue and thermal cracking, rutting, stripping, and age hardening.

On an asphalt paving project, the mix design can be developed by one of three different entities: by the governmental agency, by the contractor, or by a consultant; depending on the requirements of the project specifications. Regardless of who completes the laboratory mix design phase of the job, the result of the mix design process is a job mix formula (JMF). The JMF is to be followed by the contractor in manufacturing the asphalt mix for the project.

This section discusses briefly the properties of the asphalt cement and the aggregates used to produce an asphalt mix. It also will review some of the differences that can exist between laboratory- and plant-produced mixes and differences between the job mix formula values and the plant test results.

MATERIAL PROPERTIES

Properties of the Asphalt Cement

Asphalt Cement Grade

The penetration of an asphalt cement is determined at a temperature of 77°F. In general, the harder the asphalt cement (the lower its penetration) the stiffer the mix made with the material. At a given temperature a mix containing 60-70 penetration-grade asphalt cement typically will be stiffer and will require somewhat more compactive effort by the rollers to achieve the desired density than will a mix made using a 120-150 penetration-grade asphalt cement. Thus the stiffer mix must either be placed at a higher temperature or a greater compactive effort must be applied by the rollers to achieve a given degree of density.

The viscosity of an asphalt cement is typically determined at two different temperatures: 140°F and 275°F. A viscosity-graded material must fall within a range of values at the lower temperature and meet a minimum viscosity requirement at the higher temperature. In general, a mix containing an AC-20 asphalt cement will be stiffer, at a given temperature, than will an AC-10 asphalt cement and require slightly more compactive effort to reach a certain level of density.

For a particular asphalt cement prepared from a given source of crude oil by a given refining method, there is a relationship between the penetration of the material and its viscosity. This relationship does not hold, however, for different asphalt cements made from different crude oils or by different refining processes. Thus, an 85-100 grade asphalt cement might possibly meet the viscosity specifications for either an AC-10 or an AC-20 grade material. The same is true for a viscosity-graded asphalt cement; an AC-20 material might have a penetration as low as 40 or as high as 110, for example.

Different asphalt cements of the same penetration or viscosity grade may harden (decrease in penetration and increase in viscosity) to different degrees during the mixing process in a drum or batch plant. A mix manufactured with an asphalt cement that does not harden much during the mixing process might be more tender under the compaction equipment, at a given temperature, than will a similar mix made with an asphalt cement that hardens to a greater degree in the batch plant pugmill or inside the drum mixer.

Temperature-Viscosity Characteristics

The degree of change in viscosity of an asphalt cement with a change in temperature is a very important characteristic. The temperature susceptibility of the asphalt cement is defined as the change in the flow properties of the material with a change in temperature. An asphalt mix made with an asphalt cement that is highly temperature susceptible typically will be more tender and tend to move more under the breakdown rollers than will a mix made with an asphalt cement of low temperature susceptibility. An asphalt cement that has a flatter slope on a viscosity-temperature chart than another asphalt cement is less temperature susceptible. Two asphalt cements of the same penetration grade thus can have considerably different characteristics at elevated temperatures. Although similar in consistency at 77°F, two 85-100 penetration asphalt cements may have different flow properties at 275°F. Similarly, two asphalt cements that have the same viscosity at 140°F can also have significantly different viscosities at 275°F.

Thus, during the mixing and compaction process, two binder materials of either the same penetration grade or the same viscosity grade can contribute to different stiffness characteristics in the mix and may influence the degree of tenderness of the mix and the compactive effort needed to obtain a predetermined level of density. The asphalt cement that is more temperature susceptible--has the steeper slope (higher ratio of change in viscosity for a change in temperature)--will have a greater effect on the properties of the mix. The true effect of the asphalt cement properties on the cohesiveness of the mix, however, depends on and is interrelated with many other properties of the mix, including the characteristics of the aggregate, the concentration of coarse aggregate, and the amount of laboratory compaction used to determine the asphalt cement content and the field compaction requirement.

Laboratory Mix Design

For the Marshall laboratory mix design process, the selected mixing temperature and compaction temperature for the mix are determined by the viscosity of the asphalt cement. The mixing temperature is selected as the temperature at which the asphalt has a viscosity of 170 ± 20 centistokes, and the compaction temperature is chosen as the temperature at which the asphalt cement has a viscosity of 280 ± 30 centistokes. The temperature at which each of these two viscosity values occurs is determined by plotting the viscosities measured at both 140°F and 275°F and interpolating the appropriate temperature from the graph.

Using the viscosity of the asphalt cement to determine the laboratory mixing and compaction temperatures provides binder materials that are of equal stiffness even though those materials may have different degrees of temperature susceptibility. This permits the mixing procedures in the laboratory to be standardized and a particular level of air voids to be obtained in the mix with a given compactive effort of the Marshall hammer.

For the Hveem laboratory mix design method, the mixing temperature for the asphalt cement is determined by the grade of the material. A range of temperatures, for both the asphalt cement and the aggregate, is given, depending on the penetration or the viscosity grade of the binder material. For compaction of the Hveem specimens, a standard temperature of 230°F is used, regardless of the grade of the asphalt cement used.

Plant-Produced Mix

The grade of asphalt cement used will influence, to some degree, the mixing temperature selected. In general, the lower the penetration or the higher the viscosity of the binder material, the higher the temperature to which the asphalt cement should be heated in order to pump the material properly (normally about 300°F). The temperature susceptibility of the asphalt cement is not a factor in the production of the mix.

The temperature susceptibility of the asphalt cement may, however, be a factor during the compaction process. In general, a mix containing a highly temperature-susceptible asphalt cement will stiffen more quickly with a change in temperature than will a mix made with an asphalt cement of lower temperature susceptibility. This means that the compactive effort applied to the mix by the rollers might need to be altered to achieve the same degree of density. In addition, the mix containing the more temperature-susceptible asphalt cement might initially be somewhat more tender and tend to check and shove more under the rollers. The degree of tenderness, however, is also greatly affected by other mix characteristics besides the properties of the binder material.

A change in the source of asphalt cement used on a project, even though it is from the same supplier, can affect the properties of the mix, particularly during the compaction process. It is possible that a mix that can be densified properly with one amount of compactive effort from the rollers might become more tender (or more stiff), requiring a different degree of compactive effort, if the properties of the asphalt cement changed because of a change in the asphalt cement source.

Project personnel are not normally notified by the supplier when a change in the source of the asphalt cement is made. If the specifications call for the use of an AC-20 viscosity-graded asphalt cement, an AC-20 will be delivered. The properties of one AC-20, however, can be very different from the properties of another AC-20 asphalt cement. It is good practice, therefore, for the contractor to request that the asphalt cement supplier provide a temperature-viscosity graph for each load of material delivered to the plant. These graphs should be reviewed as each load of asphalt cement is unloaded. If the temperature-viscosity characteristics of the binder material have changed significantly, adjustments may need to be made in the plant-mixing and mix-compaction processes.

Properties of the Aggregates

Various properties of the aggregate will have various effects on the properties of the final asphalt mix. The aggregate properties of interest include shape, surface texture, particle size, absorption, gradation, voids, and percent and gradation of material passing the No. 200 (75 μm) sieve.

Shape

The shape of the individual aggregate particles affects the properties of the mix. Aggregate that is rounded is more easily displaced by an applied load. Aggregate that is angular (usually produced by crushing) will have a greater degree of interlock when a load is applied and will be more resistant to displacement by that load. Crushed aggregate mixes may require a greater compactive effort to obtain the required level of density than mixes containing rounded gravel. In addition, the amount of surface area for each aggregate is, in part, a function of its shape. An aggregate that has a greater surface area will require a greater amount of asphalt cement to obtain a given film thickness around the aggregate particles.

Surface Texture

The smoother the surface texture of an aggregate particle, the greater will be its tendency to be tender under the compactive effort of the rollers. A mix containing an aggregate that has a rough surface texture, similar to the particle with an angular shape, will generally require more compactive effort to densify to a given air void content.

Maximum Particle Size

Aggregate having different maximum particle sizes can have different degrees of workability. Typically the larger the maximum size of aggregate in a mix in relation to the layer thickness and the greater the amount of large aggregate in the mix, the more difficult it is to compact the mix. Further, if the nominal maximum aggregate size exceeds one-half of the compacted thickness of the pavement layer, the texture of the mix can be affected and the degree of density obtained in the mix by the compaction equipment may be reduced.

Although a relatively minor factor for most mixes in comparison with the other aggregate properties, the maximum particle size can be a significant factor in the properties of the asphalt concrete mix when large-stone (greater than 1-in. nominal maximum size) mix is being produced. This is particularly true in regard to density, and a field compaction test strip may be necessary to determine the degree of density that can be achieved in the large-stone mix.

Absorption

The amount of asphalt cement that is absorbed by the aggregate also may have a major effect on the properties of the asphalt mixture. If the aggregate particles have high asphalt absorption, the asphalt content in the mix must be increased to compensate for the binder material that is drawn into the pores of the aggregate and is unavailable as part of the film thickness around those particles. If that asphalt content correction is not made, the mix can be dry and stiff. The amount of compactive effort needed to achieve density in the mix would have to be increased and the mix would have a tendency to ravel under traffic.

Gradation

The maximum size of an aggregate gradation is the smallest sieve through which the entire amount (100 percent) of the aggregate is *required* to pass. The nominal maximum size of an aggregate is the smallest sieve through which the entire amount (100 percent) of the aggregate is *permitted* to pass. For example, if 100 percent of an aggregate passes the 1-in. (25-mm) sieve and 90 to 100 percent of the same aggregate may pass the 3/4-in. (19-mm) sieve, the maximum size of that aggregate would be 1 in. and the nominal maximum size would be 3/4 in.

The gradation of the coarse and fine aggregate has a great effect on the properties of all HMA mixtures. The potential effects can be evaluated using 0.45 power gradation paper. This graph paper, which was developed by the Federal Highway Administration in 1962 for asphalt concrete mixes, is shown in Figure 1-2. Using this graph, an estimate of the densest grading of the combined coarse and fine aggregate, on a percent passing basis, will plot as a straight line, as shown in this figure. As illustrated, if 100 percent of the aggregate in a particular asphalt concrete mix passes the 3/4-in. (19-mm) sieve, the estimated densest gradation of aggregates for that mix would lie on the line that extends from that point at the upper-right portion of the graph to the zero point at the lower-left corner of the graph. This line is called the maximum density line.

The maximum density line can be used to estimate several properties of the asphalt concrete mix before the asphalt cement is added to the aggregate in the actual laboratory mix design process. In this regard, it provides some guidelines for the voids in mineral aggregate (VMA) content of the mix. In general, an aggregate gradation that is close to the maximum density line, particularly below the No. 4 sieve, will have a lower VMA content than will the gradation of the same aggregate that is farther away from the maximum density line--either above or below the line.

Many factors besides gradation have an effect on the VMA content of the mix. In particular, the shape of the aggregate as well as the surface texture of the aggregate will cause the aggregate to have a different VMA content even though several different aggregates may have the same gradation when plotted on 0.45 power gradation paper. A mix that contains angular aggregate compared to rounded aggregate will typically have a higher VMA content. Further, a mix that contains aggregate with a rough surface texture will usually have a higher VMA content than will a mix that contains smooth textured aggregate, for the same gradation. In addition, the properties of the fine aggregate generally have a greater effect on the VMA content of the mix than do the properties of the coarse aggregate. Thus the 0.45 power gradation paper maximum density line should be used only as a guide in determining a starting point for the actual laboratory mix design process.

Use of the sieve with 100 percent passing as the origin for the maximum density line can lead to the use of an improper line. As shown in Figure 1-2, a mix with 100 percent passing the 3/4-in. (19-mm) sieve and 99 percent passing the 1/2-in. (12.5-mm) sieve would have the same theoretical maximum density line as a mix that has 100 percent passing the 3/4-in. sieve and only 88 percent passing the 1/2-in. sieve. The properties of two mixes made with aggregates of these two gradations, however, could be considerably different. For this reason, a modification is normally made in the starting location for the maximum density line. As shown in Figure 1-2, the modified maximum density line is drawn from the sieve on which some aggregate is first retained. In the example shown, if the amount of material passing the 3/4-in. sieve was 100 percent and the amount of aggregate passing the 1/2-in. sieve was 99 percent, the latter value would serve as one end for the modified maximum density line. If only 88 percent of the aggregate passed the 1/2-in. sieve, that value would be employed as the starting point for the modified maximum density line.

Also as originally developed, the aggregate gradation that has the maximum density will generally contain a high amount of material passing the No. 200 (75-μm) sieve when plotted on the 0.45 power paper. In Figure 1-2 this value is approximately 8 percent. This amount is higher than the amount of fine aggregate normally permitted to pass the No. 200 sieve; most mixes contain from 2 percent to 7 percent passing that sieve. For this reason, use of the graph paper may be further modified to use the actual amount of aggregate passing the No. 200 sieve as the other end point for the maximum density line instead of the zero point on the graph. This line is called the gradation reference line and is illustrated in Figure 1-3.

The gradation reference line is drawn on the upper right from the sieve on which any aggregate is first retained--has a percent passing that is less than 100 percent. The line is drawn through the percent passing the No. 200 (75-μm) sieve that is actually in the mix. In Figure 1-3, the amount of aggregate passing the No. 200 sieve is assumed to be 3 percent. Using these two points, as shown in Figure 1-3, provides the maximum density line for the actual mix being manufactured.

In Figure 1-3 two different gradation reference lines are shown. The first line is for a mix with 100 percent passing the 3/4-in. (19-mm) sieve, 99 percent passing the 1/2-in. (12.5-mm) sieve, and 3 percent passing the No. 200 (75-μm) sieve. The second is for a mix with 100 percent passing the 3/4-in. (19-mm) sieve, 88 percent passing the 1/2-in. (12.5-mm) sieve, and 3 percent passing the No. 200 (75-μm) sieve. Both of these mixes would have the same maximum density line (as shown in

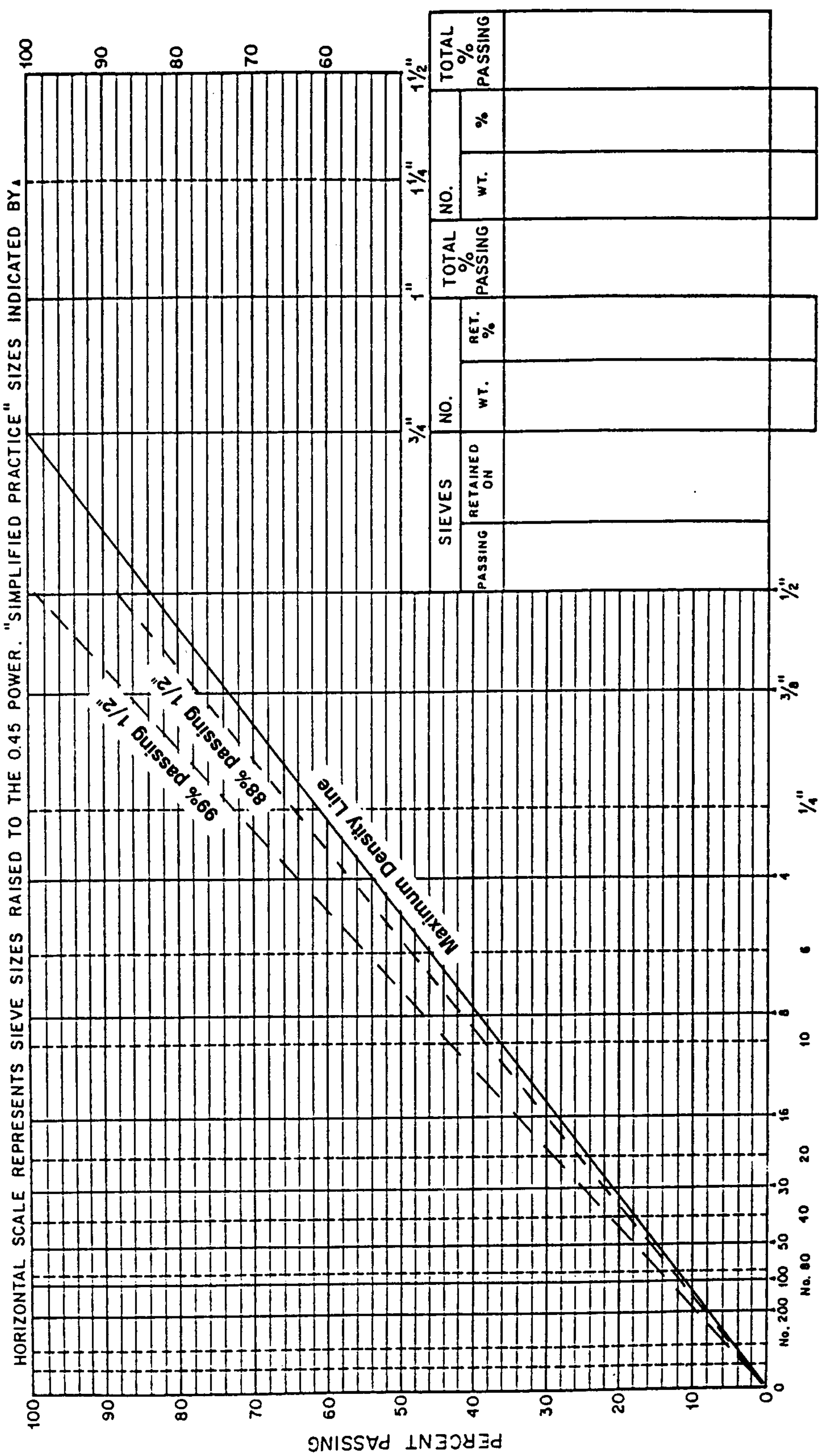

Figure 1-2. Possible maximum density lines using FHWA 0.45 power gradation paper.

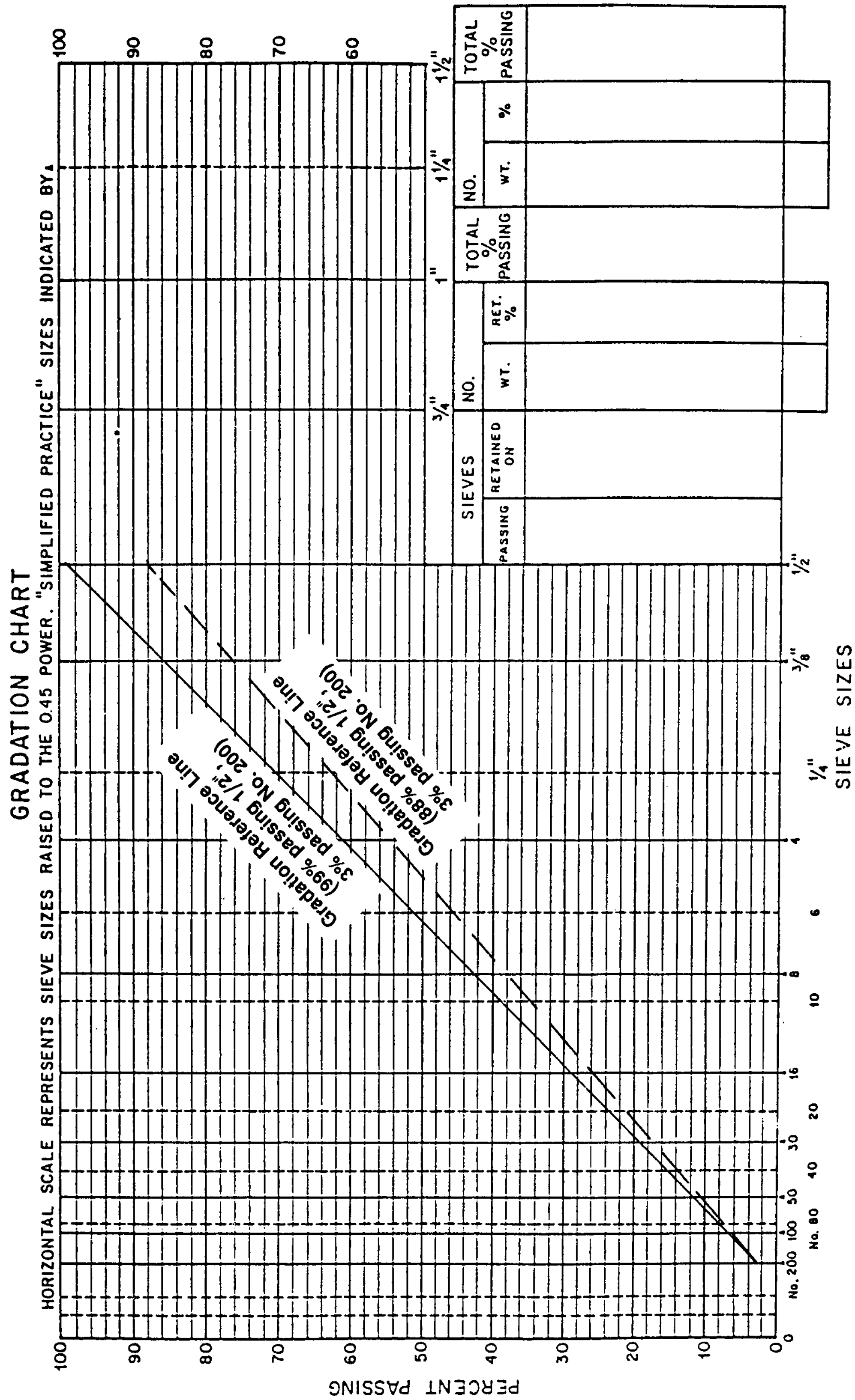

Figure 1-3. Gradation reference line.

Figure 1-2). They have different gradation reference lines, however, because of the amount of material retained on the largest sieve.

Blends of aggregate that are finely graded are more workable and easier to compact than are blends of material that are coarsely graded. As shown in Figure 1-4, when plotted on the 0.45 power gradation paper the finer blend of aggregate (Gradation A) will fall above the gradation reference line--to the fine side of the line, with greater percentages of material passing each particular sieve than for a coarsely graded combination of aggregate. Coarse graded aggregates (Gradation B) are normally more difficult to compact, but may result in more rut-resistant pavement layers.

Voids in Mineral Aggregate

The voids in mineral aggregate (VMA) of a mix can be defined as the volume of intergranular void space between the aggregate particles of a compacted paving mixture that includes the air voids and the effective asphalt content, expressed as a percent of the total volume of the sample. This room within the aggregate gradation is at a minimum for a combination of coarse and fine aggregate that has a gradation that is close to the gradation reference line (Gradation C in Figure 1-5). A mix with a low VMA content will become very sensitive to total fluids content: asphalt cement content plus any moisture in the mix. During placement and compaction, the mix will tend to check and shove. Under traffic, the mix will tend to rut and bleed if the asphalt content is high and will tend to ravel if the asphalt content is low.

An aggregate gradation that crosses the gradation reference line, particularly in the fine aggregate portion of the gradation (Gradation D in Figure 1-5), will also have a tendency to have low VMA contents. Aggregate blends that have a pronounced hump in the grading curve usually will be more tender than are mixes that are more continuously graded, either above or below the gradation reference line. The hump occurs because a large amount of fine aggregate passes one sieve, such as the No. 30 (600-μm) sieve, and is retained on the next sieve, the No. 50 (300 μm). The hump also typically takes place, using a different series of sieves, between the No. 40 (425-μm) and the No. 80 (180-μm) sieves.

The effect of the hump on the compactive effort needed to obtain density depends on the severity of the hump; the more pronounced the hump, the lower the VMA, and generally the more tender the mix. A mix with a hump in the fine aggregate portion of the total grading curve may easily achieve the desired density level in the laboratory when made and compacted in steel molds. That same mix, however, may be difficult to compact to the required air void content on the pavement; it normally will be tender and may check and shove under the compaction equipment.

The 0.45 power graph paper can be used to evaluate the potential for problems with the mix during the placement and compaction operations. During the production of the mix, the results from the extraction test should also be plotted. Gradations that resemble Gradations A or B in Figure 1-4 typically should produce durable mixtures that can be placed and rolled without major problems. Gradations that look like Gradations C or D in Figure 1-5, however, may produce asphalt concrete mixes that are tender and check or shove during the compaction operation.

Percent Passing No. 200 (75-μm) Sieve

The amount of material passing the No. 200 (75-μm) sieve can have a variable effect on the ability to densify a particular blend of coarse and fine aggregate. As the amount of aggregate passing the No. 200 sieve increases, the workability of the blend of aggregate increases, up to a certain point. Beyond that level, as the amount of fine aggregate that passes the No. 200 sieve increases, the stiffness of the mix normally will increase.

Initially, the incorporation of some aggregate passing the No. 200 (75-μm) sieve fills the voids in the total aggregate gradation and makes the blend more continuously graded. This tends to decrease the voids in mineral aggregate content of the material combination and make the blend of aggregate more workable. If an excess of aggregate passing the No. 200 sieve is present, this additional fine material pushes the other aggregate particles apart, decreasing the contact between the coarser aggregate particles and altering the compactability of the aggregate blend. For most asphalt concrete mixes, the amount of aggregate passing the No. 200 sieve should typically be in the range of 3 to 6 percent.

Gradation Passing the No. 200 (75-μm) Sieve

Not only does the amount of aggregate passing the No. 200 (75-μm) sieve have an effect on workability, the gradation of that material can have a dramatic effect on the tenderness of the blend of aggregate. If the majority of the aggregate that passes the No. 200 sieve is relatively coarse (larger than about 40 μm), most of this material will fill the voids in the coarse aggregate, decreasing the void content of the aggregate blend and altering the optimal asphalt content in the mix. If, however, the material passing the No. 200 sieve is ultra-fine (a signifi-

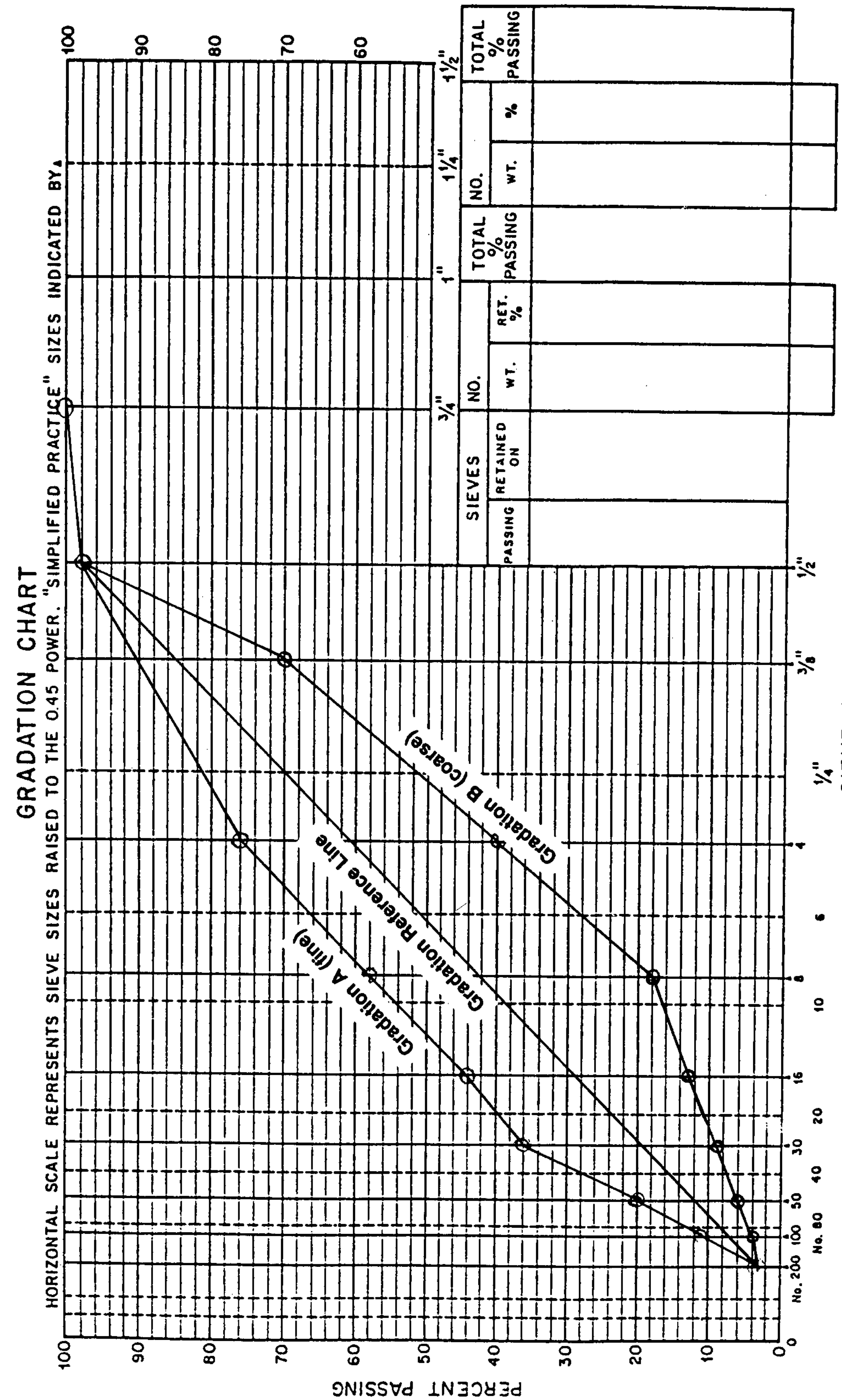

Figure 1-4. Comparison of fine and coarse mixes.

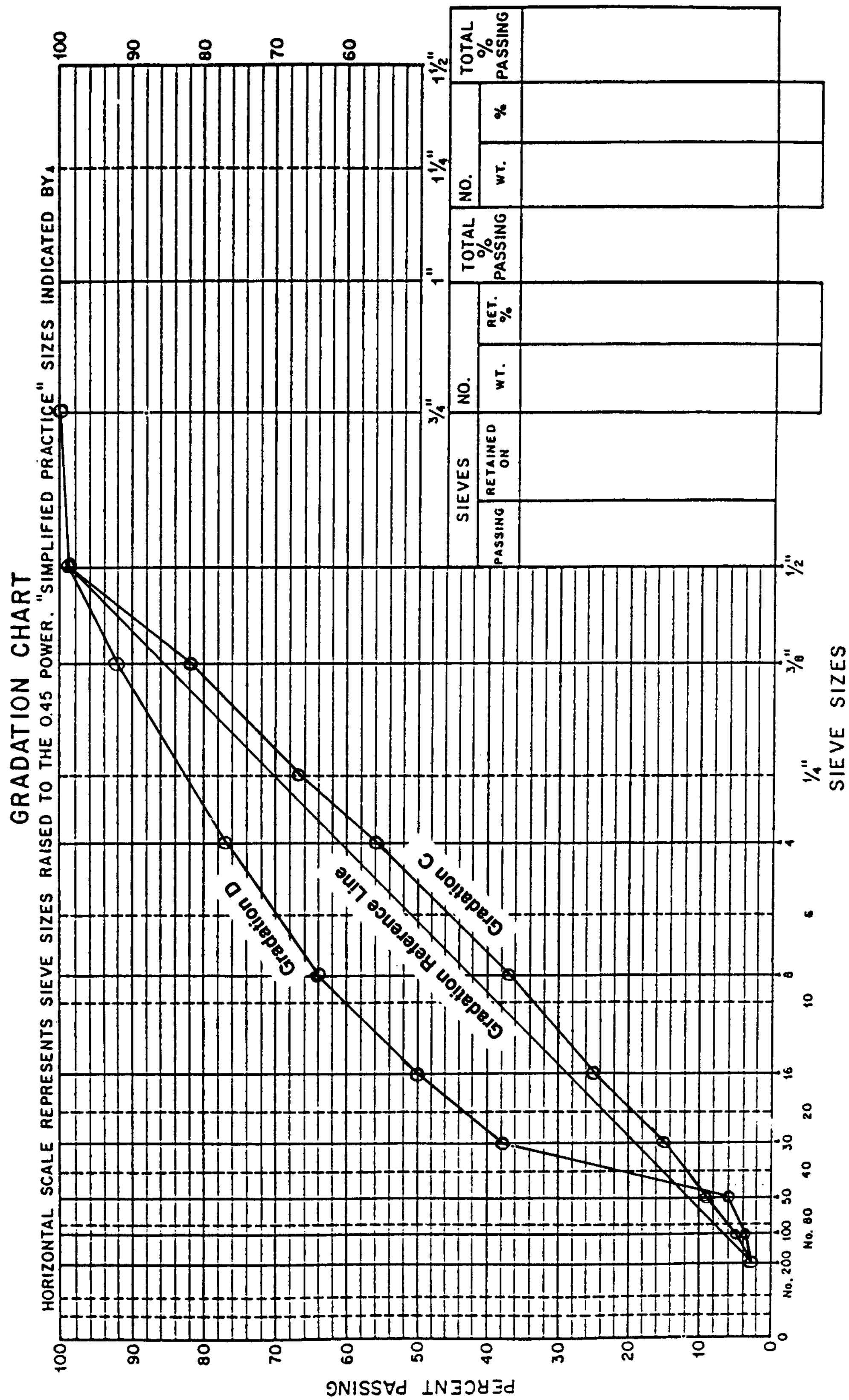

Figure 1-5. Aggregate gradations with low VMA values.

cant portion of the aggregate smaller than 20 μm, with some material as fine as 2 to 5 μm in size), this material can act to extend the volume of the asphalt cement and can become part of the asphalt cement film around the aggregate particles.

It is sometimes useful to conduct a hydrometer analysis to determine the gradation of the filler material that passes the No. 200 (75-μm) sieve. That gradation affects the workability of the total blend of aggregate just as gradation of the aggregate retained above this sieve does. The actual effect depends, however, on the proportion of the material that is relatively coarse compared with the portion of the material that passes the No. 200 sieve that is ultra-fine (smaller than 20 μm). The finer the filler material, the greater the effect on the workability of the total aggregate blend. This gradation of the aggregate passing the No. 200 sieve is particularly important if a baghouse is used on the plant and the collected fines are returned to the plant for re-incorporation into the mix.

MIX DESIGN PROCEDURES

To produce an asphalt mix design, asphalt cement and aggregate are blended together in the laboratory. The characteristics of each component, the relative proportion of these two materials, and the air void content of the compacted mix determine the physical properties of the mix. Two common, but empirical, methods of mix design are in use: the Marshall method and the Hveem method. Both methods have the same purpose: to determine the "optimum" asphalt cement content for a particular combination of aggregate. Details on these two methods can be found in the Asphalt Institute Manual MS-2.

Marshall Method

The Marshall method of mix design, which is limited to mixtures containing aggregates that have a maximum size of 1 in. or less, uses three test procedures to determine the properties of the mix: a determination of the bulk specific gravity, measurement of Marshall stability and flow, and analysis of specimen density and voids content. The stability value gives a measure of the load under which the specimen fails, and the flow value provides a measurement of the deformation of the specimen at failure. Mixes that have low stability and high flow values are too plastic and tend to distort (rut and shove) easily under load. Mixes that have very high stability and very low flow values are brittle and may crack readily. A density and voids analysis is conducted to determine the air void content, the amount of voids in the mineral aggregate, and the unit weight of the material.

The "optimum" asphalt cement content of the mix is determined from a family of plots based on mix properties measured at different asphalt contents. Unit weight, stability, flow, air void content, and voids in mineral aggregate content are plotted against asphalt content. The "optimum" asphalt cement content is usually calculated as the average asphalt content at the point of maximum unit weight, maximum stability, and at an air void content of 4 percent. In addition, the flow value must be between certain limits and the voids in mineral aggregate content must be above a minimum value. In some cases, the "optimum" asphalt cement content is selected based only on the amount needed to achieve 4 percent air voids in the mix, and the other mix properties are checked at that asphalt cement content to see if they comply with the specification requirements.

The optimum asphalt content is a function of the amount of compactive effort used to densify the mix. Typically, two different compactive efforts (50 blows per side and 75 blows per side) are used in the laboratory to simulate the amount of compaction that will take place under both the compaction equipment at the time of construction and under traffic with time. The higher compactive effort (75 blows) will result in a lower optimum asphalt content in the mix for any given aggregate gradation.

Use of the Marshall method to determine the job mix formula for mix production does not mean that the mix produced will perform satisfactorily during placement and compaction or long-term under traffic. Mixes that have high Marshall stability values may still shove under the rollers and/or undergo permanent deformation (rutting) when subjected to heavy loads. Mixes that have adequate VMA, however, normally perform significantly better than mixes made with the same aggregate and asphalt cement but that are low in VMA content.

Hveem Method

The Hveem mix design method uses a series of tests to determine "optimum" asphalt cement content. Those test procedures include use of the centrifuge kerosene equivalent test to determine an approximate asphalt content, preparation of test specimens at a range of asphalt contents both below and above the approximate optimum asphalt content, a stability test to evaluate the resistance to deformation, and a swell test (rarely run) to determine the effect of water on the volume change and permeability of the specimen.

The Hveem stability test measures the lateral pressure that results from the application of a vertical load. The higher the Hveem stability, the more resistant the mix is to distortion. The amount of air voids in the mix is determined from both the measured bulk specific gravity of the mix and the maximum specific gravity of the mix, which is calculated from the specific gravity of the asphalt cement and the specific gravity of the aggregate in the mix. An appropriate allowance is made for the amount of asphalt cement absorbed by the aggregate.

Compliance of the job mix formula with the Hveem mix design criteria does not guarantee that the mix will not be tender during the construction process or that it will be durable over time and traffic. The Hveem method is used primarily to pick an asphalt content for the mix in order to fit inside a range of mix properties.

AAMAS Method

The asphalt-aggregate mixture analysis system method of mix design, recently published by the National Cooperative Highway Research Program, should provide mixtures that are better able to perform under traffic. The resilient modulus value, indirect tensile strength, and creep modulus value are more related to the distress mechanisms that affect the durability of an asphalt pavement: fatigue, permanent deformation, moisture damage, disintegration, and low-temperature cracking.

LABORATORY- AND PLANT-PRODUCED MIXES

Differences may exist between the properties of an asphalt mix designed in the laboratory and the "same" job mix formula produced in a batch or drum mix plant. It is important to look at those differences and understand how and why the test properties or characteristics conducted on mix produced in a plant might vary significantly from the results predicted from tests conducted on laboratory-produced material.

Asphalt Cement

In an asphalt cement storage tank, the binder is held in bulk and usually is circulated continuously by a pump. The amount of aging and hardening that occurs during storage is minimal. In the lab, the asphalt cement can be heated in an oven for various periods of time. It usually is handled in small quantities in containers that are open to the air. Although some hardening does occur during this laboratory mixing process, the degree of hardening is generally less than that which occurs during mix production at the asphalt plant. The degree of hardening that may take place in the laboratory, however, is quite variable.

Asphalt cement is normally produced in a refinery by a steam distillation/vacuum process. The light products in a barrel of crude oil are driven off at various temperatures, leaving behind a soft residue. Some of the light products can remain in the asphalt cement, however, depending on the type of refining procedure used and the type of crude oil processed. If a single-stage refinery is operated, a considerable amount of the lighter products (light ends) can remain in the asphalt cement.

Aggregate

In the laboratory, gradation of the aggregate to be incorporated into the mix can be determined by conducting either a dry-sieve or a wet-sieve analysis. If the aggregate is clean, the difference between the two test results will be minimal. If the aggregate is dirty and has a great amount of fine material clinging to the coarse aggregate particles, there may be a considerable difference between the dry and wet gradations. For this reason, the aggregate gradation used in the laboratory should represent the actual gradation of the aggregate to be used in the mix at the plant.

In the field, the materials are incorporated into the mix as received from the aggregate supplier. If there is a considerable amount of fines clinging to the coarser material, those fines are put into the cold-feed bin with the coarser material and delivered to the dryer or drum mixer. This change in gradation does not normally exist in the laboratory, particularly if a washed aggregate gradation is used in the mix design. Thus, a difference in aggregate gradation, from lab to field, can exist.

As the aggregate passes through a batch plant dryer or drum mixer, its gradation is usually changed to some degree. The amount of the change (an increase in the amount of fines in the mix) is a function of many variables but is primarily related to the hardness of the aggregate. As the abrasion resistance of the aggregate decreases, the amount of fines generated inside the dryer or the drum normally increases. For a hard, durable aggregate, the amount passing the No. 200 (75-μm) sieve may increase no more than 0.2 percent when processed. If a soft aggregate is used, the amount of the aggregate passing the No. 200 sieve may increase by as much as 1 or 2 percent.

All materials will vary in gradation from the average value for the percent passing each sieve. This is recognized by assigning allowable tolerance values, about that average value, to each sieve size. Thus, the aggregate in the cold-feed bins can be expected to fall within a range of gradations instead of on an exact gradation. In the laboratory, however, the aggregate is sieved into different fractions and then recombined to an exact gradation curve. The degree of precision in the lab is significantly greater than what occurs at an asphalt batch or drum mix plant.

The aggregate used to make laboratory samples is completely dry; there is essentially no moisture in the material. For aggregate heated in a batch plant dryer, it is possible to reduce the moisture content to about 0.1 percent, by weight of the aggregate, but in most cases the moisture content in the aggregate will range up to 0.5 percent, depending on the amount of moisture in the incoming aggregate, the production rate of the dryer, and the aggregate discharge temperature. Rarely will the aggregate discharged from a typical dryer be completely without some retained moisture. For aggregate processed through a drum mix plant, the moisture content in the mix at discharge typically is less than 1.0 percent but can be higher, depending on the same variables as for the batch plant. Although there should be no more than 0.5 percent moisture retained in the plant-produced mix, differences will exist in the amount of moisture between the lab- and plant-produced mix.

In the lab oven, the aggregate is uniformly heated throughout, and the coarse and fine portions of the aggregate will both be at approximately the same temperature. In the plant dryer or drum mixer, the coarse aggregate usually is heated to a lower temperature than is the fine aggregate and there is often a distinct temperature differential between the two fractions of aggregate. In a batch plant, the temperature is generally equalized during pugmill mixing. In a drum mix plant, however, a heat balance is not always obtained unless the material is held in the surge silo for a period of time.

If a wet scrubber is used on either a batch or drum mix plant, any fines captured are carried out of the dryer or drum mixer and wasted. These fines are no longer part of the aggregate gradation. If a baghouse is used as the emission-control device on either type of plant, some or all of the collected fines can be returned to the mix. If the fines from the baghouse are wasted, a slightly different aggregate gradation will exist in the mix, similar to that which occurs when the plant is equipped with a wet-scrubber system. If all of the baghouse fines are returned to the mix, the gradation of the aggregate still may be different from the gradation of the aggregate tested in the laboratory because the baghouse will collect ultra-fine aggregate particles not normally separated from the other aggregate particles during the laboratory mix design procedure. Thus the type of emission-control equipment used on the batch or drum plant can significantly affect the properties of the asphalt mixture. The amount of fines can change the filler/asphalt ratio and thus also change the stiffness of the resulting asphalt mix. The change in the type and amount of fines normally is not taken into account in the laboratory mix design procedure.

Baghouses operate at different efficiencies, depending on the pressure drop between the dirty and clean side of the filter bags. If the bags are clean and the pressure drop is small, the fines-laden exhaust gases will pass through the fabric filter and some of the very fine particles will go out the plant stack. As the bags become more heavily coated with material and as the pressure drop increases, more of the fines are captured on the coating already on the bags. Thus, as the loading on the bags is increased, the baghouse actually becomes more efficient and a greater volume of fines as well as a finer gradation of material is returned to the mix in either a batch or drum mix plant. The change in the amount of fines captured and sent back to the plant can be substantial.

If the plant is equipped with only a dry collector (knockout box or cyclone), most of the fines returned to the mix will be larger than the No. 80 or No. 100 (180-μm or 150-μm) sieve. With the use of a fabric filter, particles as small as 5-μm size (smaller than the asphalt cement film thickness on the aggregate) can be reincorporated into the mix. These ultra-fine particles, which do not exist separately during the laboratory mix design procedure, can act like extra asphalt cement, causing the mixture to look greasy and become tender. Thus, a stable mix in the lab can be soft and tender in the field if the baghouse is returning ultra-fine aggregate particles back into the plant. For any plant equipped with a fabric filter, not only the quantity of the baghouse fines needs to be known, but also the gradation of those fines should be determined.

If RAP is incorporated into the mix, this material is normally mixed in the laboratory until it is thoroughly heated and blended with the new aggregate. In the plant, however, the amount of mixing and heat transfer that occurs from the new aggregate to the reclaimed material is a function of many variables, such as the amount of RAP in the mix, the point of introduction of the RAP, the temperature of the new aggregate, and the amount of mixing time available. In addition, the reclaimed material may add a significant amount of fines [percent passing the No. 200 (75-μm) sieve] to the mix.

Finally, both Marshall and Hveem mix design procedures are limited to 1-in.-maximum-size aggregate. For larger-size aggregate that is often used in base course layers, modifications to the aggregate gradation or sample size must be made. This causes differences in the properties of the mixes produced in the laboratory compared with plant-manufactured mix. For mixes containing 1.5 in. maximum aggregate, a 6-in. mold should be used. A method is being developed to use 6-in. specimens in lieu of the standard 4-in. specimens.

Mixing Process

As the mix time increases in a batch plant pugmill, the degree of aging of the asphalt binder also increases. For relatively short wet mix times (28 to 35 sec), the average asphalt cement will decrease 30 to 45 percent in penetration. For longer wet mix times (up to 45 sec), the penetration of the asphalt cement may be up to 60 percent less than the original value. Higher mixing temperatures increase the degree of hardening of the asphalt cement. Thus, the mix produced in a batch plant pugmill can be much stiffer than the same material produced in the laboratory with essentially unaged asphalt cement unless the laboratory binder material is continually reheated.

The amount of hardening of the asphalt cement that occurs in a drum mix plant may be less, more, or the same as that in the pugmill of a batch plant. The degree of hardening is quite variable and is a function of the thickness of the asphalt cement film around the aggregate particles, as well as many other factors. Less hardening generally occurs during the coating process as the moisture content of the incoming new and reclaimed aggregate increases, as the volume of aggregate in the drum increases, as the mix discharge temperature decreases, and as the production rate of the plant increases.

The laboratory mixing process is accomplished by hand or by machine, with the time necessary to blend the asphalt cement and aggregate together dependent on the efficiency of the mixing process. Usually several minutes are required to obtain complete coating of the aggregate. During this period, the asphalt cement is exposed to the air and some hardening takes place. The degree of hardening is a function of the aggregate temperature and the mixing time. The change in asphalt cement properties will not be the same as the change that will occur during mix production in a batch or drum mix plant. Thus, the stiffness of a mix produced in the laboratory will probably be less than that of a plant-manufactured mixture.

Asphalt mix samples obtained from the plant or from the pavement before compaction may be sent in loose condition to a district or central laboratory for future testing. The amount of hardening that occurs in the binder material depends on the time between the manufacture and testing, as well as on the storage conditions (temperature and the availability of oxygen). The process of reheating the sample, including the time and temperature of heating and any remixing of the sample if compaction is not completed in the field, also can have a significant effect on the measured properties of the mix. Thus, the laboratory handling process can affect the differences found between plant- and laboratory-prepared samples.

Compaction

Several methods, including Marshall hammer, California kneading compactor, and gyratory shear compactor, are commonly available to compact asphalt concrete specimens in the laboratory. The purpose of any lab compaction process is to simulate, as closely as possible, the degree of density produced in the field by the rollers and the density of the mix after some time under traffic. This simulation includes such factors as air void content, aggregate particle orientation, and void distribution. Intra-laboratory and inter-laboratory test results have indicated that the degree of compaction obtained in the lab can be highly variable.

The compaction process in the laboratory is very quick, usually completed within 2 or 3 min. This is in direct contrast to actual roller operations in the field, which use an infinite variety of roller combinations, roller passes, and roller patterns and in which final density levels might not be attained until 30 min or longer after the mix is placed by the paver. Also, during the laboratory compaction process, the mixture temperature is relatively constant. On the pavement, the temperature of the material is continually decreasing with time. In the lab, the compaction effort is usually applied before the mix temperature drops to 240°F (Marshall) or 220°F (Hveem). In the field, the mix may cool to 175°F or less before the compaction process is completed.

In the lab, the asphalt mix is compacted against a solid foundation, whereas in the field a wide variety of base types and stiffnesses are encountered. An asphalt mix can be placed as part of a newly constructed pavement as the first layer on top of a soft subgrade soil or as the surface course on a full-depth asphalt concrete pavement structure. The material can be used as an overlay on a distressed asphalt pavement or as resurfacing on a portland cement concrete (PCC) pavement.

The ability to obtain a particular level of density in an asphalt mixture depends in part on the rigidity of the base being laid over and on the type of compaction equipment used. The differences between some pavement base conditions and laboratory base conditions can be significant. A test section will establish the compactive effort necessary to obtain specified density in the asphalt mix.

SUMMARY

The objective of any mix testing on plant-produced asphalt mixtures is to compare the test results to the laboratory job mix formula. The attempt is made to make the plant-produced mix equal the laboratory job mix formula. This is most often difficult to accomplish because of all the variables that exist at the plant--from the type of plant used to the operating conditions at each particular plant. Major differences between laboratory and plant mixes often exist in the gradation of the aggregates, the degree of hardening of the asphalt cement, and the addition of fine aggregate from the emission-control equipment, to focus on only a few of multiple factors. In addition, compaction conditions are considerably different between the laboratory and the mix under the various rollers in the field.

The job mix formula produced in the laboratory, therefore, should be treated only as an initial mix design, used primarily to pick an asphalt cement content. The desired properties of the mix should be checked and verified on the plant-produced, laboratory-compacted asphalt mixture. Daily tests should be run to determine the characteristics of the mix actually being manufactured (mix verification). All of the mix values should be within the range required by the mix design process. If the test results on the plant-produced mix indicate compliance with the job mix formula requirements, the plant should continue to operate. If one or more of the mix properties is outside the desired range, an investigation should be made quickly to determine the cause and the extent of the deficiency. In most cases, however, the plant should not be shut down nor drastic changes made in the mix design on the basis of only one set of test results. In addition, if major differences in gradation exist between the aggregate used in the laboratory mix design process and the aggregate used in the plant, the job mix formula should be adjusted and/or the mix design should be rerun.

Problems that develop in the batch or drum mix plant and on the pavement during the laydown and compaction process are discussed in the section on mat problems in Part Three. Many of these problems, such as checking and shoving, can be related to deficiencies in the mix design used to create the job mix formula and to differences between the JMF mix properties and the properties of the mix actually produced in the plant.

Part Two

ASPHALT PLANTS

PART TWO
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Part Two Contents (continued)

SECTION ONE
TYPES OF ASPHALT PLANTS

INTRODUCTION

The purpose of a hot-mix asphalt plant is to blend together aggregate and asphalt cement to produce a hot, homogeneous asphalt paving mixture. The aggregate used can be a single material, such as a crusher run aggregate or a pit run material, or it can be a combination of coarse and fine aggregates, with or without mineral filler. The binder material used is normally asphalt cement but can also be an asphalt emulsion or one of a variety of modified materials. Various additives, including liquid and powdered materials, can also be incorporated into the mixture.

There are two basic types of plants currently in use in the United States: batch plants and continuous mix plants. Within the continuous mix plant category, there are two different types of facilities: the older continuous mix plant and the modern drum mix plant. Within the drum mix plant category, both parallel flow and counter flow plants are operated. Each plant type fulfills the same ultimate purpose, but the operation and flow of the materials through the plant is different. The asphalt mixture, however, should be essentially similar regardless of the type of plant used to manufacture it.

A brief description of the flow of materials and the operation of batch plants, continuous mix plants, and drum mix plants is provided in this chapter. A more detailed discussion of drum mix and batch plants follows. The equipment and procedures common to both types of plants (aggregate stockpiling and cold-feed systems, asphalt cement supply system, surge silos, and emission-control equipment) are described jointly. The operations of the parallel-flow drum mixer as well as the batch plant counter flow dryer and mixing tower are discussed in separate sections. The old-style continuous mix plants are not covered in a separate section, because very few of them are still in operation.

BATCH PLANTS

The major components of a batch plant are the cold-feed system, asphalt cement supply system, aggregate dryer, mixing tower, and emission-control system. The plant tower consists of several elements: hot elevator, screen deck, hot bins, weigh hopper, asphalt cement weigh bucket, and pugmill. These components are shown in Figures 2-1 and 2-2.

The aggregate used in the mix is removed from stockpiles and placed in individual cold-feed bins. Each different size aggregate is proportioned out of its bin by the size of the opening of the gate at the bottom of each bin or by use of a variable-speed belt feeder. Generally, belt feeders beneath each bin deposit each aggregate on a gathering conveyor located under all of the cold-feed bins. The gathering conveyor transports the combined aggregate to the charging conveyor, which carries it up to the aggregate dryer.

The dryer operates on a counter flow basis. The aggregate is introduced into the dryer at the upper end and moves down the drum both by the drum rotation (gravity flow) and by the flight configuration inside the rotating dryer. The burner is located at the lower end of the dryer, and the exhaust gases from the combustion and drying process move toward the upper end of the dryer, against the flow (counter to the flow) of the aggregate. As the aggregate is tumbled through the exhaust gases, the material is heated and dried. Moisture is removed and carried out of the dryer as part of the exhaust gas stream. The hot, dry aggregate is discharged from the dryer at the lower end.

The hot aggregate is transported to the top of the plant mixing tower by a bucket elevator. Upon discharge from the elevator, the aggregate normally passes through a set of vibrating screens. The finest aggregate material goes directly through all the screens into the No. 1 hot bin. The coarser aggregate particles are caught by the different size screens and deposited into one of the other hot bins. The separation of aggregate in each of the hot bins depends on the size of the openings in the screen that is used in the screen deck and the gradation of the aggregate in the cold-feed bins.

The aggregate is held in the hot bins until it is discharged from a gate at the bottom of each bin into a weigh hopper. The correct proportion of each aggregate is determined by weight. If reclaimed material is used in the mix, it typically is entered into the weigh hopper as an additional aggregate.

At the same time that the aggregate is being proportioned and weighed, the asphalt cement is pumped from its storage tank to a separate weigh bucket located on the tower just above the pugmill. The proper amount of material is weighed into the heated bucket and held

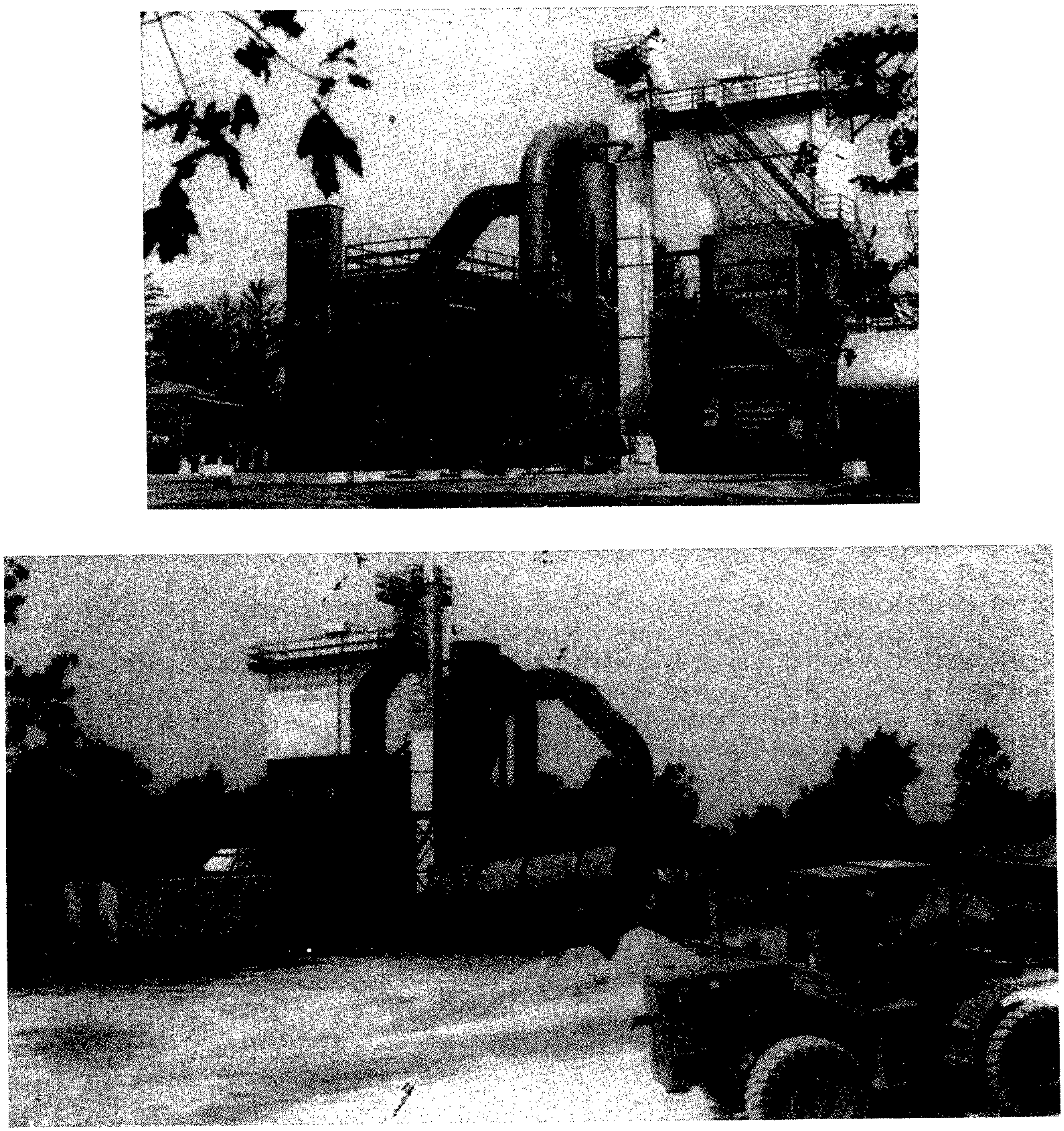


Figure 2-1. Typical batch plants *(Barber-Greene)*.

until it is needed in the pugmill.

The aggregate in the weigh hopper is emptied into a twin shaft pugmill, and the different aggregate fractions are mixed together. After this brief dry-mix time, the asphalt cement from the weigh bucket is discharged into the pugmill and the wet-mix time begins. The mixing time for the blending of the asphalt cement with the aggregate should be no more than that needed to completely coat the aggregate particles with a thin film of the asphalt cement material. The total time in the pugmill, made up of dry-mix time and wet-mix time, can be as short as 28 sec, in most cases.

When mixing is complete, the gates on the bottom of the pugmill are opened and the mix is discharged into the haul vehicle or into a conveying device that carries the mix to a silo and eventually into the truck. For most batch plants, the time needed to open the pugmill gates and discharge the mix is approximately 7 sec. Thus, the

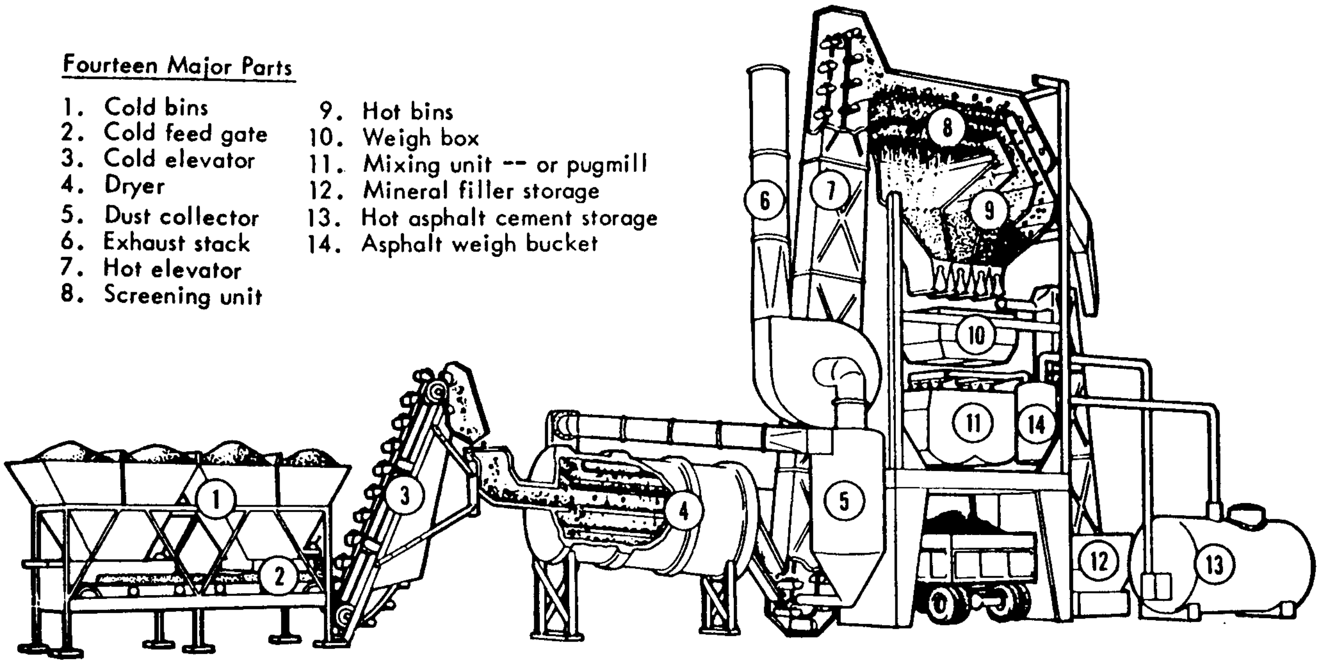


Figure 2-2. Batch plant components *(Asphalt Institute)*.

total mixing time for a batch would be about 35 sec (dry-mix time + wet-mix time + mix discharge) in most cases.

The plant is equipped with emission-control devices, both primary and secondary collection systems. Either a wet-scrubber system or a dry-fabric filter system (baghouse) can be used as the secondary collection system to remove particulate matter from the exhaust gases that flow out of the dryer and send clean air to the atmosphere through the stack.

If RAP is incorporated into the mix, the material is placed in a separate cold-feed bin from which it is delivered to the plant. It can be added to the new aggregate in one of three locations: the bottom of the hot

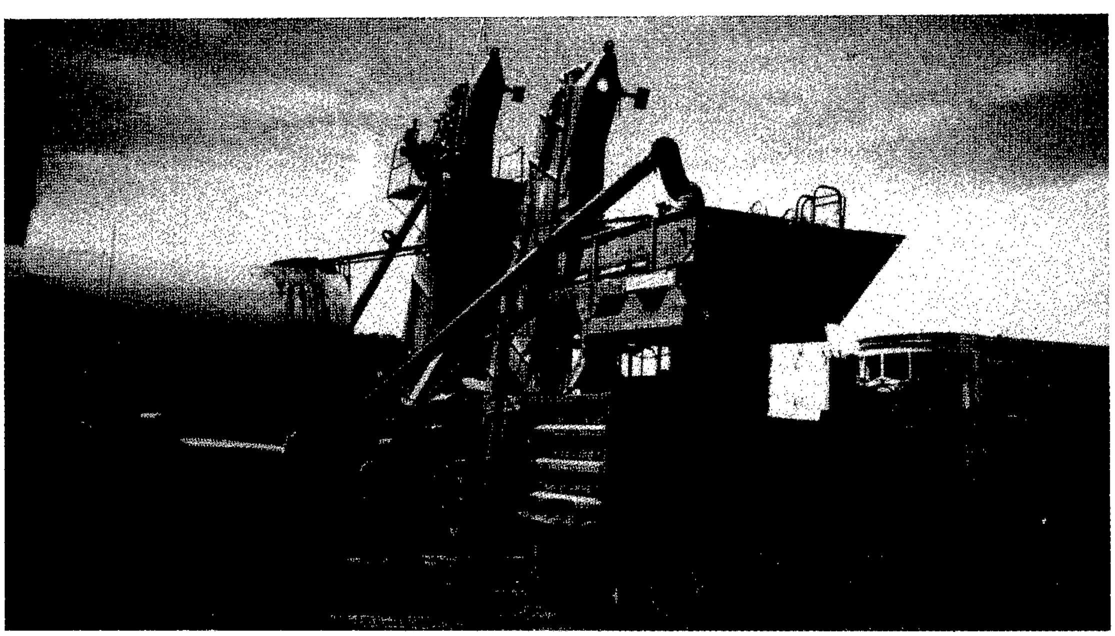


Figure 2-3. Continuous-mix plant *(J. Scherocman)*.

elevator, the hot bins, or the weigh hopper, with the last location being the one most commonly used. Heat transfer between the superheated new aggregate and the reclaimed material begins as soon as the two materials come in contact and continues during the mixing process in the pugmill.

CONTINUOUS MIX PLANTS

An old-style continuous mix plant is shown in Figures 2-3 and 2-4. The components of this type of plant include the cold-feed system, asphalt cement supply system, aggregate dryer, hot-bucket elevator, screen unit, hot bins, mixing unit and holding hopper, and emission-control system.

The cold-feed bins are similar to those used on a batch plant, and typically a constant-speed feeder belt is located under each bin. Material is proportioned from each bin by the size of the discharge gate opening and deposited on the gathering conveyor. The aggregate is transferred to a charging conveyor for delivery to the dryer. Inside the dryer the moisture in the combined aggregate is removed as the material is heated from ambient temperature to the desired mixing temperature. The dried and heated aggregate is then carried up an inclined bucket elevator to the screen deck, where it is divided into various sizes and temporarily held in small hot bins.

The aggregate is continuously removed from the bins, proportioned according to the desired gradation in the mix, and transported to the pugmill. The asphalt cement is kept in a storage tank and then pumped to the mixing tower, where it is sprayed on the aggregate. The asphalt cement, measured by volume instead of weight, is mixed continuously with the aggregate as the two materials are moved toward the discharge end of the pugmill by the mixing paddles. Mixing time can be increased or decreased by changing the retention or dwell time of the aggregates in the pugmill, usually by altering the setting of the pugmill discharge end gate or by reversing one or more sets of paddles.

Because the mixing is a continuous process, a small-capacity, temporary holding hopper is provided at the discharge end of the mixer to store the material until it can be delivered into a haul truck. For emission-control purposes, the plant is equipped with a primary dry collector and a secondary wet collector or a baghouse.

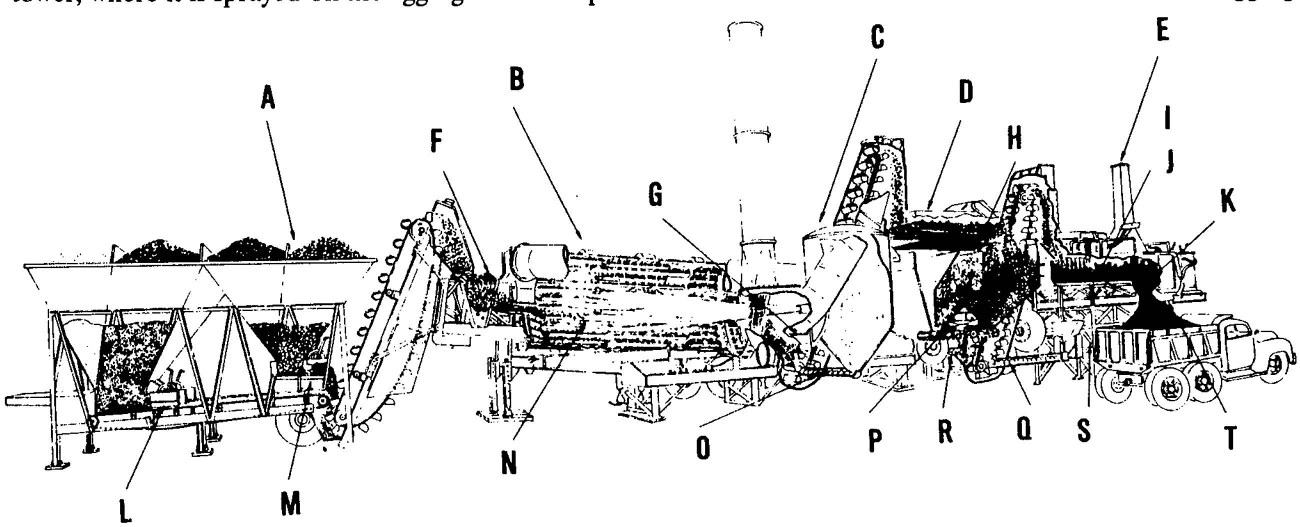
If a recycled mix is being produced, the RAP material is placed in a separate cold-feed bin and transported to the pugmill by a charging conveyor. This material is added proportionately, by volume, to the new aggregate that has been superheated in the dryer. The heat transfer and mixing of the two materials is accomplished as they move through the pugmill.

DRUM MIX PLANTS

Parallel-Flow Drum Mixer

The parallel-flow drum mix plant, shown in Figures 2-5, 2-6, and 2-7, is a form of the old-style continuous mix plant. It consists of five major components: the cold-feed system, asphalt cement supply system, drum mixer, surge silo, and emission-control equipment.

The cold-feed bins are used to proportion the material to the plant. Variable-speed feeder belts are used under each bin. The amount of each aggregate



A Cold aggregate storage and feed; B Dryer; C Dust collector; D Gradation control unit; E Mixer; F Grizzly; G Fan; H Vibrating screen; I Transfer pump; J Pugmill; K Pugmill jacket; L Belt feeder; M Reciprocating feeder; N Flights; O Collected fines; P Gates; Q Mineral filler feed; R Aggregate sample point; S Metering pump; T Discharge Hopper

Figure 2-4. Continuous-mix plant components *(Asphalt Institute)*.

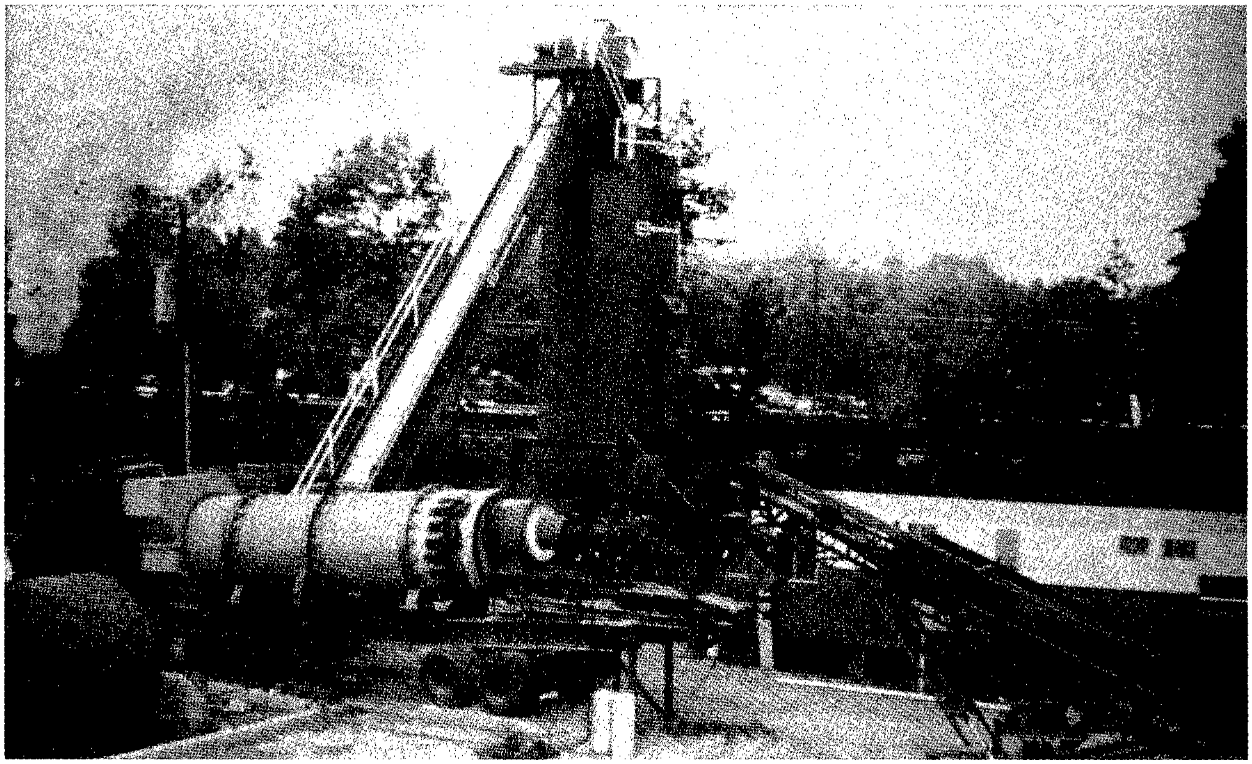


Figure 2-5. Typical drum mix plant *(Barber-Greene)*.

drawn from each bin can thus be controlled by both the size of the gate opening and the speed of the belt feeder to provide accurate delivery of the coarse and fine material. The aggregate on each feeder belt is deposited onto a gathering conveyor that runs beneath all of the cold-feed bins. The combined material is normally passed through a scalping screen and transferred to a charging conveyor for transport to the drum mixer.

The charging conveyor is equipped with two devices that are used to determine the weight of the aggregate being delivered to the plant: A weigh bridge under the conveyor belt measures the weight of the aggregate passing over it at an instant of time, and a sensor is used to determine the speed of the belt. These two values are used to compute the wet weight of aggregate, in tons per hour, entering the drum mixer. The plant computer, with the amount of moisture in the aggregate provided as an input value, converts the wet weight to dry weight to control the amount of asphalt cement needed in the mix.

The conventional drum mixer is a parallel-flow system; the exhaust gases and the aggregate move in the same direction. The burner is located at the upper end (aggregate inlet end) of the drum. The aggregate enters the drum either from a charging chute above the burner or on a slinger conveyor under the burner. The aggregate is moved down the drum by a combination of gravity and by the flight configuration inside the drum. As it travels, the aggregate is heated and the moisture removed. A dense veil of aggregate is built up near the midpoint of the drum length to assist in the heat-transfer process.

If RAP is added to the new aggregates, it can enter the drum in one of two locations: it can be combined with the new aggregate at the burner end of the drum (the single-feed method, which is very seldom used), but most often is deposited from its own cold-feed bin and gathering/charging conveyor into an inlet located at the center of the drum length (split-feed system). In the latter process, the reclaimed material is protected from the high-temperature exhaust gases by the veil of new aggregate upstream of its entry point.

The new aggregate and reclaimed material, if used, move into the rear half of the drum. The asphalt cement is pulled from the storage tank by a pump, fed through a meter where the proper volume of asphalt cement is determined, and then through a pipe into the rear of the drum. The asphalt cement is injected onto the aggregate. Coating of the aggregate occurs as the materials are tumbled together and moved to the discharge end of the drum. Mineral filler and/or baghouse fines are also added into the back of the drum, either just before, or in conjunction with, the addition of the asphalt cement.

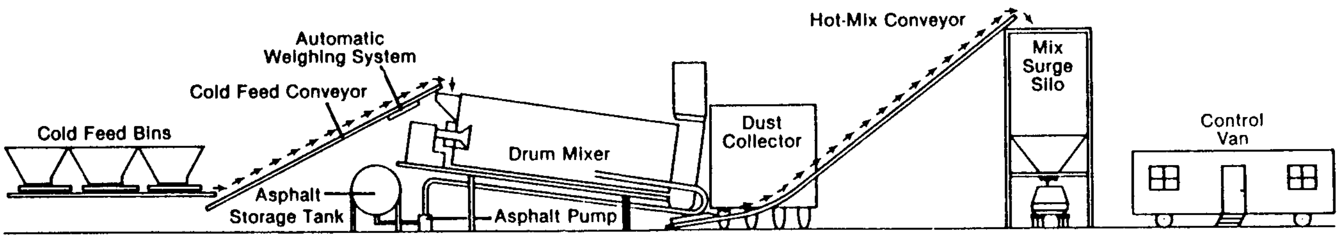


Figure 2-6. Drum mix plant components *(Asphalt Institute)*.

The asphalt mix is deposited into a conveying device (a drag slat conveyor, belt conveyor, or bucket elevator) for transport to a surge silo. The silo converts the continuous flow of mix into a batch flow for discharge into the haul vehicle.

In general, the same type of emission-control equipment is used on the drum mix plant as on the batch plant. A primary dry collector and either a wet-scrubber system or a baghouse secondary collector can be used. If a wet-scrubber system is used, the collected fines cannot be recycled back into the mix and are wasted. If the baghouse is used, the collected fines can be returned in whole or in part to the mixing drum or they can be wasted.

In the late 1980s, a number of variations to the conventional drum mix plant were introduced to the hot-mix asphalt-paving industry. One of these plant types is the "coater" plant. For this type of drum mixer (which is really a type of continuous mix plant instead of a drum mixer), the asphalt cement injection pipe has been removed from the drum. This modification removes the asphalt cement from exposure to the high-temperature exhaust gases and reduces both hydrocarbon and visible emissions from the plant. The uncoated aggregate, which is heated and dried inside the parallel-flow drum, is discharged into a single- or dual-shaft mixing chamber, where it is sprayed with asphalt cement. The blending of the asphalt cement and the aggregate takes place as the materials move from one end of the mixing unit to the other. When mixing is complete, the material is delivered to the device used to transport it to the silo. Figure 2-8 is an illustration of the "coater" type of drum mix plant.

Counter Flow Drum Mixer

A recent development in continuous mix plant design is the counter flow drum mix plant. The development of this plant type is an effort to improve the heat-transfer process inside the drum and to reduce plant emissions.

As shown in Figure 2-9, the aggregate enters the drum from the upper end, whereas the burner is located near the lower end of the drum, similar to its position on a batch plant dryer. The aggregate moves down the drum against the flow of the exhaust gases--in a counter flow direction. No asphalt cement is introduced into the aggregate within the main portion of the drum. An

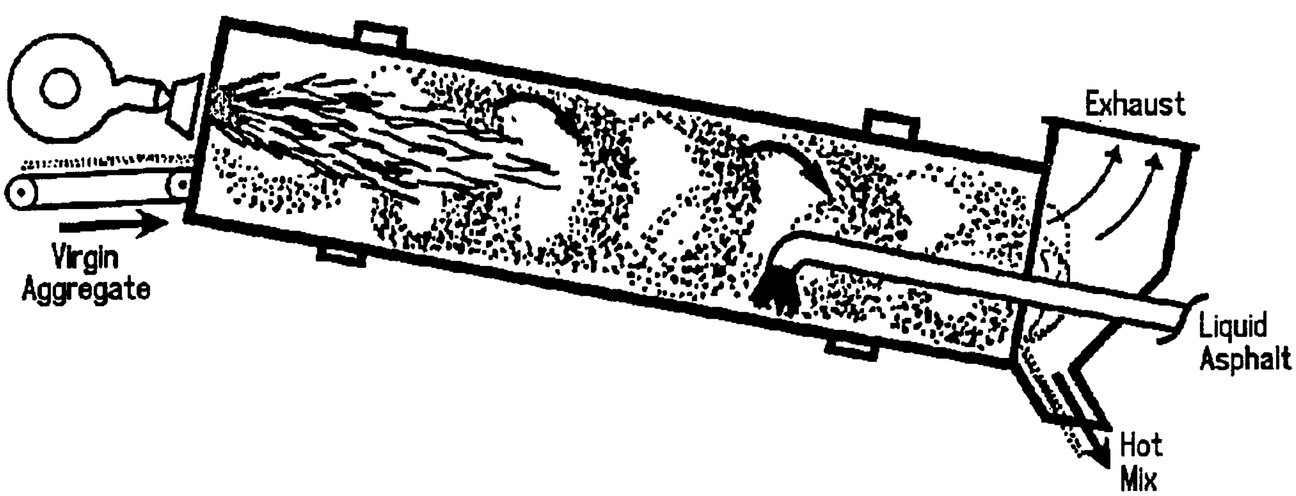


Figure 2-7. Parallel-flow drum mix plant *(Astec)*.

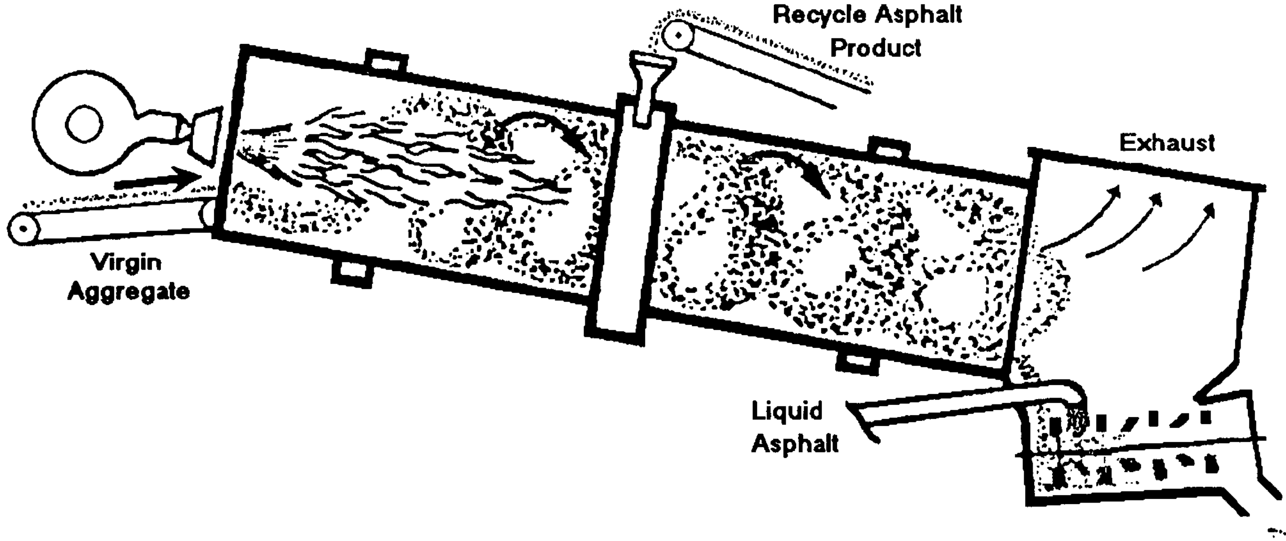


Figure 2-8. Drum mix coater cutaway *(Astec).*

extension to the drum is used, as shown in Figure 2-10, to provide for the mixing of the heated and dried aggregate with the asphalt cement. This mixing takes place behind (downstream of) the dryer in a separate mixing chamber or zone, out of contact with the exhaust gases from the burner.

If RAP is used in the asphalt mix produced in a counter flow drum mix plant, it is introduced into the drum downstream of the burner. Thus the RAP does not come in contact with the high-temperature exhaust gases from the burner and visual hydrocarbon emissions are not generated. The reclaimed material is heated by overheating the new aggregate in the upper end of the counter flow dryer and blending the two materials together in the lower portion of the drum, between the burner and the discharge end of the mixing unit.

In some counter flow drum mix plants, the mixing section is placed on the outside of (around) the primary drum, as seen in Figures 2-11 and 2-12. The asphalt cement in this double barrel plant is introduced into the aggregate after the aggregate is discharged from the inner drum into the outer drum. The blending of the two materials occurs as the aggregate and asphalt cement are conveyed back uphill in the outer drum by

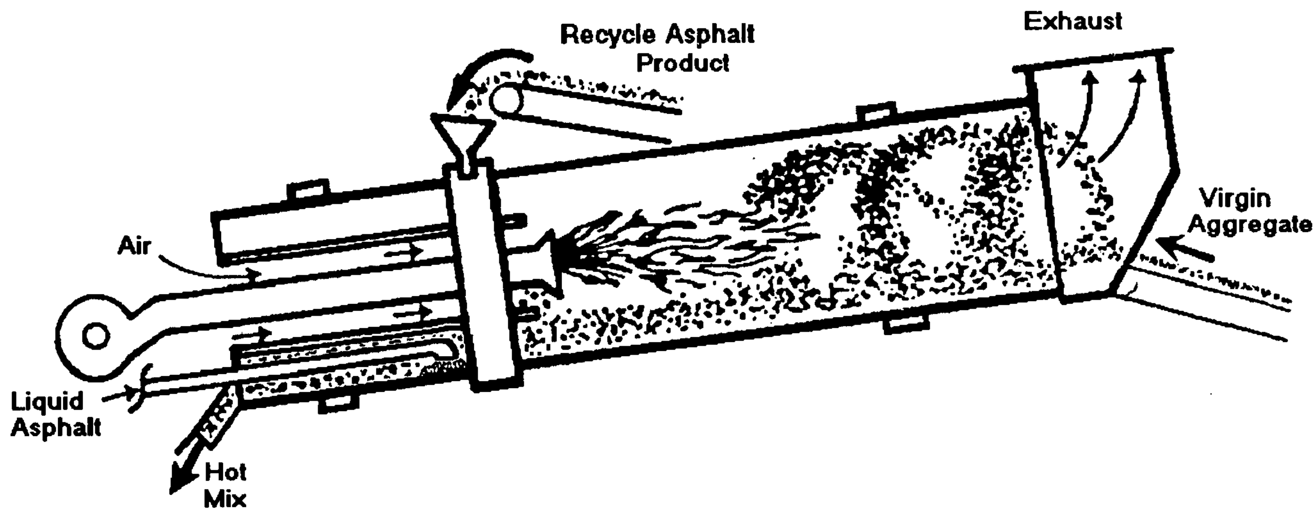


Figure 2-9. Counter flow drum mixer components *(Astec).*

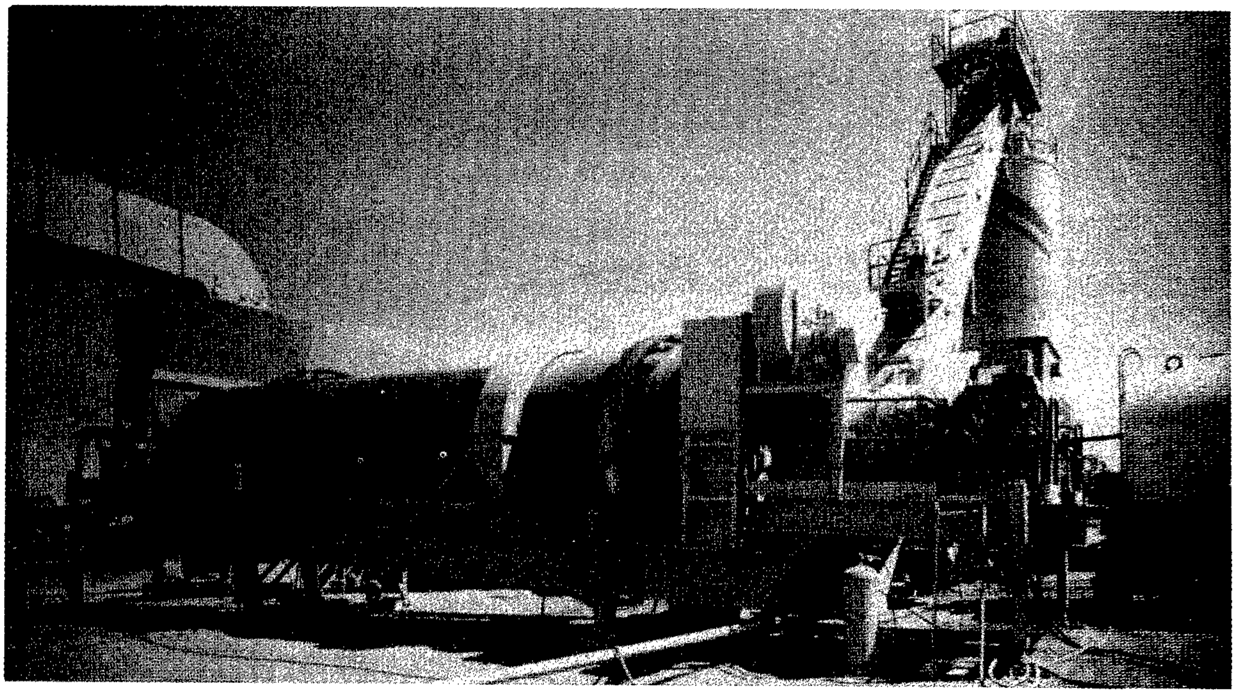


Figure 2-10. Counter flow drum mixer *(Gencor)*.

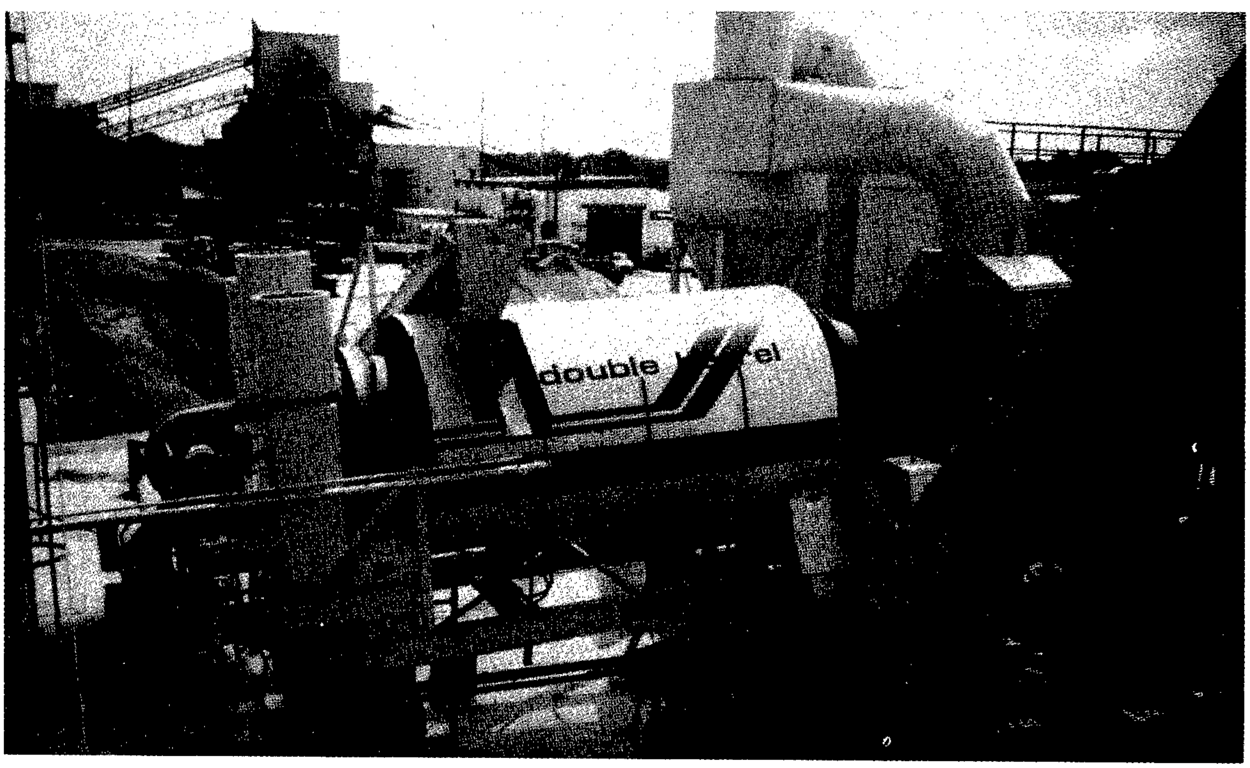


Figure 2-11. Double barrel plant *(Astec)*.

a set of mixing paddles attached to the inner drum. The inner drum rotates, whereas the outer drum is stationary.

As in the normal counter flow drum mixer, the RAP material in the double barrel process enters the drum between the inside and outside dryer drums, away from the exhaust gases from the burner. This keeps the RAP from contact with the high-temperature exhaust gases and thus reduces the possibility of the generation of blue smoke during the recycling process.

Because the number of "coater" parallel-flow drum mix plants and counter flow drum mix plants in use is limited, and because their operation is essentially similar to that of a drum mixer and a dryer, no further discussion of the operation of these types of continuous mix plants will be undertaken in this manual.

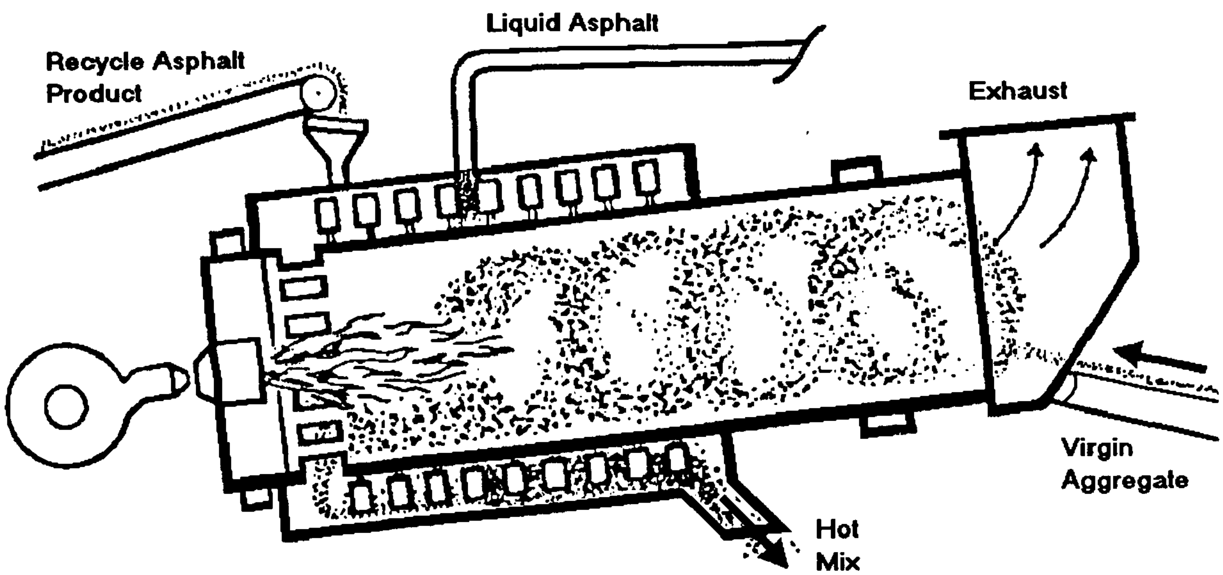


Figure 2-12. Double barrel drum mixer *(Astec)*.

SECTION TWO
AGGREGATE STORAGE AND HANDLING

INTRODUCTION

The information discussed in this section concerns the stockpiling and the handling of both new aggregate and RAP material for use in any asphalt plant. This section discusses proper stockpiling techniques, both for placement of the aggregate in the stockpile and for removal of the aggregate from the stockpile. Care must be taken to minimize possible segregation of the aggregate, both coarse and fine, during the stockpiling and handling process.

This section also contains a review of the discharge of the aggregate from the cold-feed bins onto the individual bin feeder conveyor belts, as well as the passage of the aggregate onto the gathering conveyor and the delivery of the aggregate, sometimes through a scalping screen, to the charging conveyor and finally to the batch plant dryer or to the drum mixer. There is also a discussion, in the section on drum mix plant operations, of the use of a weigh bridge system on the charging conveyor to determine the amount of aggregate being fed into the drum.

This section reviews delivery of RAP from its cold-feed bin to the batch or drum mix plant. It points out that the charging conveyor can deposit the reclaimed material into three locations on a batch plant and two locations on a drum mix plant. There is an examination of calibration of the cold-feed system, with information provided on the proper methods to use to check the rate of aggregate delivery from the individual cold-feed bins and over the weigh bridge system.

AGGREGATE STOCKPILES

Quality control of hot-mix asphalt, regardless of whether a batch or drum mix plant is used to manufacture the mix, begins with the stockpiles of aggregate that are to be processed through the plant and incorporated into the mix. The aggregate should be stored on a clean surface, with the different sizes of coarse and fine aggregate kept separated. Care should be exercised both during the stockpiling process and during the removal process to minimize segregation of the aggregate in each pile. If segregation of a particular size of coarse or fine aggregate does occur, an effort should be made to blend the segregated materials together before the aggregate is delivered into the cold-feed bins. This is difficult to do, however, and care must be taken with this operation to prevent the segregation problem from becoming worse.

Aggregate should be stockpiled on a clean, dry, stable surface and should not be allowed to become contaminated with foreign materials such as dust, mud, or grass. Fugitive dust in the aggregate stockpile area should be controlled so that the dust does not coat the surface of the aggregates and does not alter the gradation of the material in each stockpile. The stockpiles should be constructed to be free draining to ensure that the moisture content of the aggregate is as low as possible. Paved stockpile pads have been used to facilitate drainage and provide a solid working platform. Excess moisture in the aggregates, particularly in the fine aggregates (sand), increases the cost of drying the aggregates and reduces the production capacity of the plant. The moisture content of each aggregate size should be determined at least twice a day and the average moisture content of all the aggregates entered into the plant computer system.

In order to reduce the amount of moisture that accumulates in the aggregate, especially from rain, it is often cost-effective to cover the aggregate stockpiles. This cover typically is in the form of a roof or a shed. Sometimes only the fine aggregate (sand) stockpile is covered because the fine aggregate usually has a higher moisture content than the coarser aggregate.

The stockpiles of the various aggregate sizes should be kept separated--by physical barriers, if necessary--at all times. The cold-feed bins and feeders are calibrated to provide a specific amount of each different size aggregate from each bin. If the various materials are blended in the stockpiles, a combination of sizes will occur in each cold-feed bin. This blending of the aggregate will cause variations in the gradation of the HMA produced by a drum mix plant and can cause problems with unbalanced hot bins in a batch plant.

Segregation of the stockpiled aggregate is a major concern. Many aggregate problems are caused by mishandling of the aggregate during stockpiling and loadout operations. Whenever possible, aggregate should be stockpiled by individual size fractions. A well-graded or continuously graded material can easily segregate if mishandled. Aggregate of larger size, par-

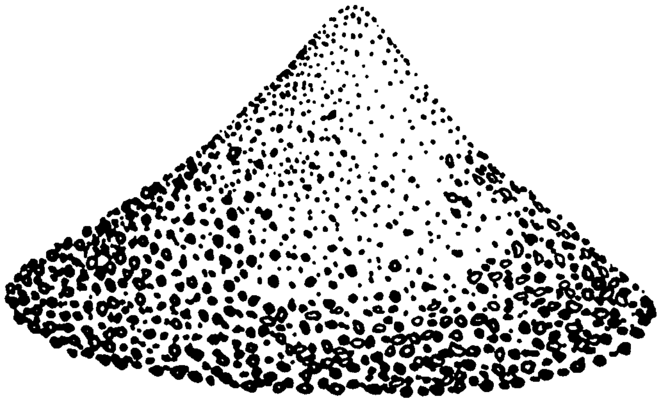


Figure 2-13. Segregated stockpile *(Asphalt Institute).*

ticularly when combined with smaller sizes of stone, has a tendency to roll down the face of a stockpile and collect at the bottom, as shown in Figure 2-13.

Prevention of segregation begins with the construction of the stockpile. As illustrated in Figure 2-14, stockpiles should be constructed in horizontal or gently sloping layers. If trucks are used to carry the incoming aggregate to the plant site, each load should be dumped

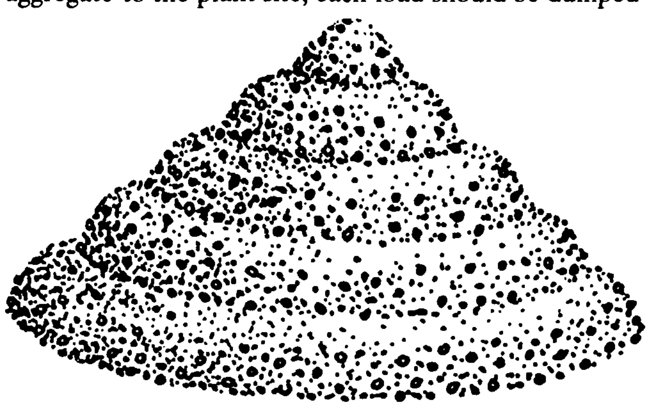


Figure 2-14. Layered stockpile *(Asphalt Institute).*

in a single pile as seen in Figure 2-15. Any construction procedure that results in the aggregate being pushed or dumped over the side of the stockpile should be avoided, because these practices may result in segregation. Trucks and loaders should be kept off of the stockpiles, because they cause aggregate breakage, fines generation, and contamination of the stockpile.

Aggregate coming off of the end of a stacking conveyor or radial stacker can be segregated by the wind. Aggregate being stockpiled by a stacker can also be broken by the fall from the stacker. Segregation and breakage can be minimized by use of a rock ladder.

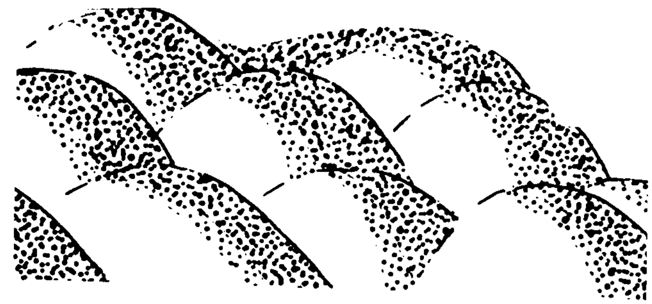


Figure 2-15. Truck dump stockpile *(Asphalt Institute).*

Proper operation of the front-end loader used to load haul trucks or charge the cold-feed bins of the asphalt plant will also reduce the aggregate segregation and gradation variation problems. As shown in Figure 2-16, a stockpile of continuously graded aggregate will be segregated when produced by a stacker. The outside edge of the stockpile will be coarse, and the aggregate below and slightly behind the head pulley will be fine. Significant changes in gradation can result from burrowing straight through the stockpile. The loader operator should remove the aggregate in a direction perpendicular to the aggregate flow and should work the entire face of the stockpile. This practice will minimize aggregate gradation changes in the mix produced by the asphalt plant.

The loader operator should be careful when cleaning the edges of the stockpile so that yard material is not pushed or dumped into the stockpile, contaminating the stockpile. When loading out of a stockpile, the loader operator should make sure that the loader bucket is in the stockpile and not in the yardstone.

When loading from a stockpile built in layers, the loader operator should try to get each bucket load by entering the lower layer at the approximate midpoint of that layer and scooping up through the overlying layer. This results in half the aggregate being from each layer. This procedure also reblends the aggregate, which, in turn, reduces segregation. Removal of aggregate from a stockpile should be planned so that a minimum amount of aggregate is disturbed with each bucket load. This is accomplished by rolling the bucket up, instead of pulling or scooping the bucket up through the stockpile. Removal of aggregate from the bottom of a large stockpile of aggregate will result in the coarse aggregate rolling down the face of the pile and gathering at the bottom and will increase the average moisture content of the aggregate.

Besides working the face of the stockpile, the loader operator should practice good stockpile management. A good practice is to rotate stockpiles so that the first

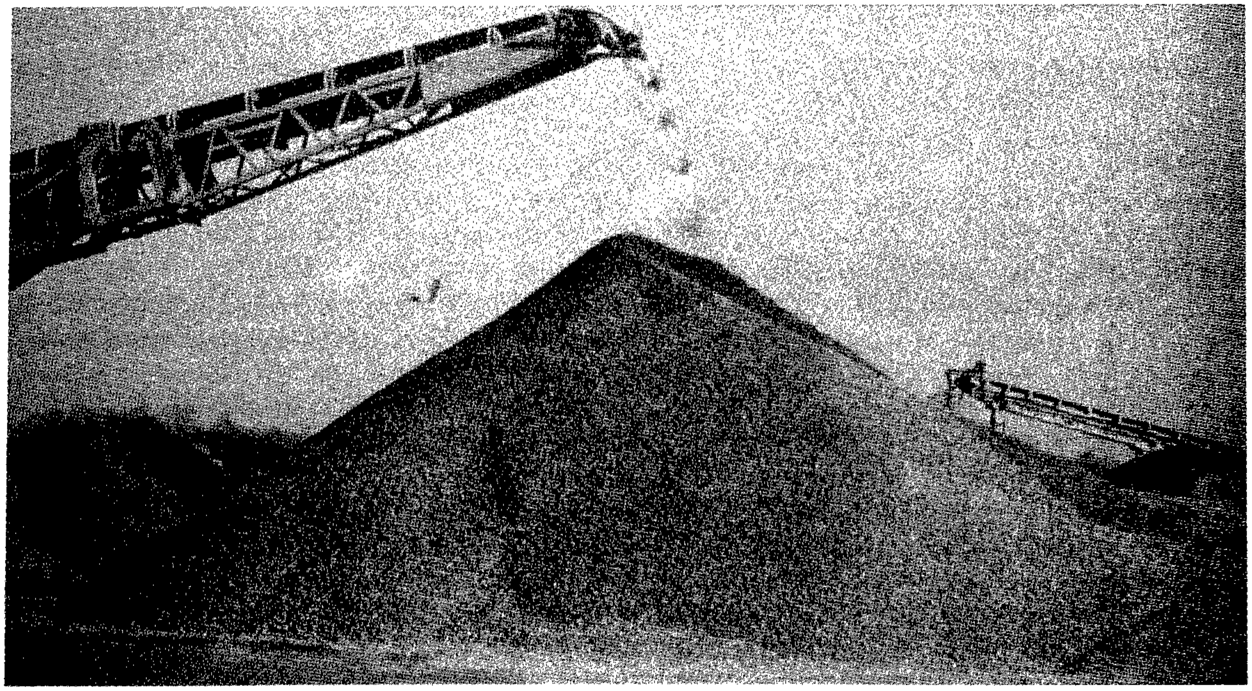


Figure 2-16. Conveyor delivery of aggregate *(J. Scherocman).*

material put into the stockpile is removed first. Areas of the stockpile that are segregated should be reblended by the loader operator at the stockpile. The operator should definitely not feed one or two loads of coarse aggregate and then one or two loads of fine aggregate into the cold-feed bins in an attempt to blend the aggregate. This type of procedure will cause significant problems in meeting the required aggregate gradation in the mix, no matter what type of plant is used to produce the mix. The best approach to minimizing segregation, however, is to use proper stockpiling techniques in the first place, instead of relying on the loader operator to attempt to blend segregated materials adequately.

Generally, RAP should be stockpiled using the same techniques described for new aggregate. In hotter climates, however, it may be desirable to limit the height of the RAP stockpile in order to reduce the tendency for the material to consolidate and bind back together under its own weight. Typical maximum RAP stockpile heights are in the range of 10 to 12 ft for mixtures having relatively high asphalt contents.

Separation of the larger particles from the smaller RAP pieces will typically occur more readily than with new aggregate because the reclaimed material will usually contain a greater variety of particle sizes than will individual new aggregate sizes. Normally this is not a problem because the RAP pieces will usually break down inside the drum mixer or in the batch plant pugmill during the heating, drying, and mixing process. If a significant amount of large chunks of RAP (pieces greater than 2 in. in size) are fed into the plant at one time, however, those chunks may not be properly heated and mixed with the new aggregates and asphalt cement. Thus, care should be taken to assure that the RAP material that is fed into the plant is as consistent in gradation, from coarse to fine, as possible. It is often necessary to screen out and then crush the largest pieces of RAP to assure proper heat transfer and mixing of the reclaimed and new aggregates inside the drum mixer.

COLD-FEED SYSTEMS FOR NEW AGGREGATES

The cold-feed systems on an HMA batch and drum mix plant are typically similar. Each consists of cold-feed bins, feeder conveyors, a gathering conveyor, and a charging conveyor. On most drum mix plants and on a few batch plants, a scalping screen is included in the system at some point. If RAP is also being fed into the plant to produce a recycled mix, an additional cold-feed bin or bins, feeder conveyor and/or gathering conveyor, scalping screen, and charging conveyor are necessary to handle the extra material.

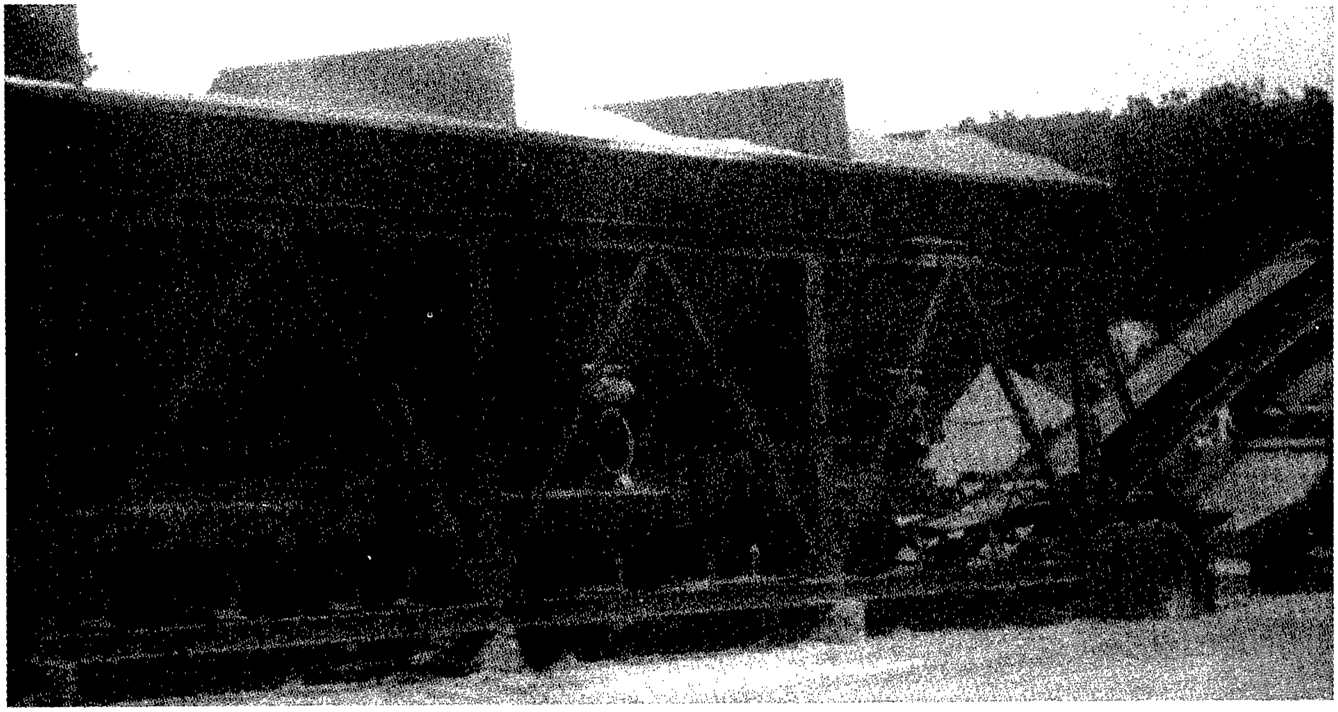


Figure 2-17. Cold-feed bin with dividers between bins *(Barber-Greene)*.

Cold-Feed Bins and Feed Conveyors

The flow of aggregates through a plant begins at the cold-feed bins, as seen in Figure 2-17. The plant is equipped with multiple bins to handle the different sizes of new aggregates used in the mix. Most cold-feed bins are rectangular in shape, have sloping sides, and have a rectangular (Figure 2-18) or trapezoidal (Figure 2-19) opening at the bottom. A bulkhead or divider should be used between each cold-feed bin, as shown in Figure 2-17, to prevent overflow of the aggregate from one bin into an adjacent bin. As seen in Figure 2-20, if no bulkheads are used between the bins, aggregates that should be in one bin can combine with the aggregates of a different size in the adjacent bin. This commingling of aggregate sizes can significantly alter the gradation of the mix being produced, particularly in a drum mix plant, where no screens are used to resize the aggregate after it is dried. If bulkheads are not in place between the cold-feed bins and mixing of the different size aggregates is a problem, these devices should be installed. Care should be taken not to pile aggregate higher than the top of the bulkheads.

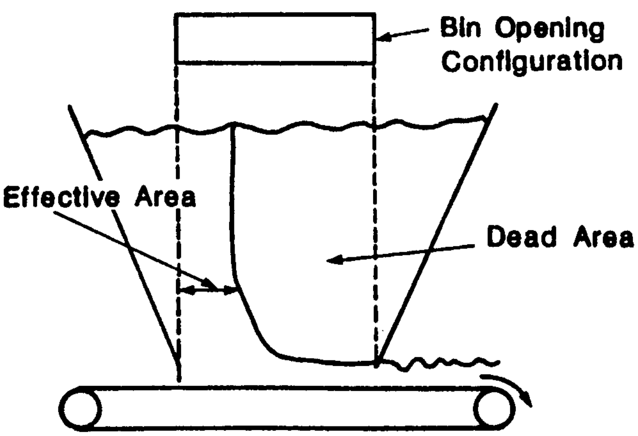


Figure 2-18. Cold-feed bin with rectangular opening *(Astec)*.

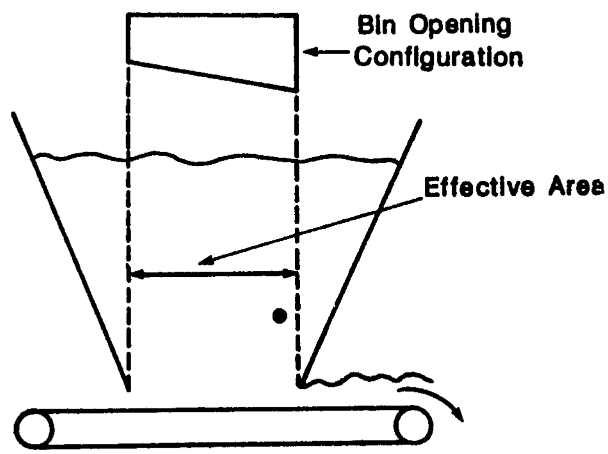


Figure 2-19. Cold-feed bins with trapezoidal opening *(Astec)*.

Figure 2-20. Overfilling cold-feed bins *(J. Scherocman)*.

Each cold-feed bin is equipped with a gate to control the size of the discharge opening on the bin and a conveyor belt to draw aggregate out of each bin at a controlled rate. On some plants, the speed of the conveyor belt under the bin is not variable. The amount of aggregate that is withdrawn from the bin is determined by the setting of the gate opening. The degree of control exercised over the amount of aggregate withdrawn from each bin is thus governed by the number of gate settings on each feeder gate. The size of the gate opening is set by raising or lowering the gate by a hand or electric-powered crank or wheel, or by unbolting, moving, and rebolting a sliding plate on one end of the bin.

Most cold-feed bins are equipped with variable-speed belt feed conveyors under each bin, as shown in Figure 2-21. The gate opening for each bin is set to deliver a relative amount of aggregate in proportion to the amount of each aggregate needed in the mix; the more of a particular aggregate required, the larger the opening of the bin discharge gate. The speed of each individual conveyor is then set to determine the exact amount of each material withdrawn from the bin. If small changes are needed in the amount of material to be delivered from one bin, the speed of the feeder conveyor can be increased or decreased to accommodate the change. Theoretically, it is possible to withdraw aggregate from the bin using the full range of the belt speed, from 1 to 100 percent of the maximum belt speed. In practice, only 20 to 80 percent of the maximum belt speed (ideally, 50 percent) should be used when determining the size of the bin gate opening. This will allow the plant operator some leeway to vary the production rate of the plant for changes in operating conditions without having to change the setting of the gate opening.

If a large change is needed in the feed rate for a particular size of aggregate, however, the gate opening at the discharge end of the bin needs to be adjusted. The speed setting of each belt feeder is displayed on the operator's console in the plant control trailer and is typically shown as a percentage of the maximum belt

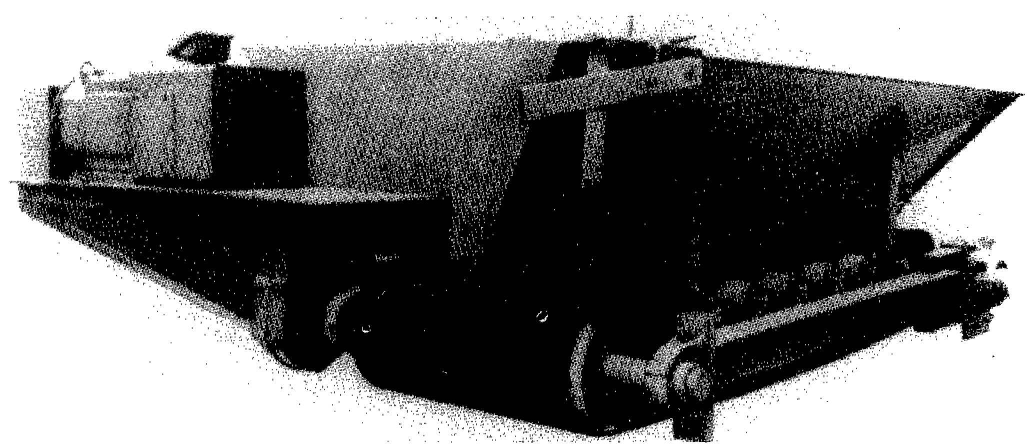


Figure 2-21. Cold-feed bin belt feeder *(NAPA)*.

Figure 2-22. Discharge from cold-feed conveyor to gathering conveyor *(J. Scherocman)*.

speed. If the feeder belt under a given cold-feed bin is operating at a level less than 20 percent or more than 80 percent, the gate setting may need to be changed to allow the belt to operate closer to the center of its speed range for the selected production rate.

The speed setting for each individual belt feeder is adjusted independently to allow the proper amount of aggregate to be pulled from each particular bin. Once determined, the speed of all the belt feeds is synchronized so that a change in the speed of one belt feeder is proportional to the change in the speed of all the other belt feeders. Thus, if the production of the plant is increased from 250 to 350 tons per hour, a change in the master control setting causes a corresponding proportional change in the speed of all the feeder belt conveyors.

Each cold-feed bin and its companion feed conveyor should be equipped with a "no flow" device that will alert the operator when no aggregate is coming out of the cold-feed bin. If the bin is empty or if the aggregate has bridged over the discharge opening in the bin and no material is being discharged onto the gathering conveyor, the "no flow" sensor (typically a limit switch) indicates the condition by sounding an audible alarm or automatically shutting down the plant after a preset time.

Gathering Conveyor

As shown in Figure 2-22, aggregate deposited from each belt feeder is dropped onto a gathering conveyor that collects the aggregate discharged from each of the bins. The speed of the gathering conveyor, which is located beneath all of the individual feed conveyors, is constant. The amount of aggregate deposited on this conveyor is a function of the size of the gate opening and the speed of the feeder conveyor under each cold-feed bin.

To reduce the amount of buildup that may occur on this conveyor, particularly when the various aggregates are wet, the coarser aggregates should be placed on the belt first. The sand, which typically has the higher moisture content, if placed on the conveyor belt first, can stick to the belt and may need to be continually removed. This may affect the gradation of the aggregate in the mix.

Scalping Screens and Devices

On drum mix plants it is desirable to insert a scalping screen into the cold-feed system to prevent oversize material from entering the mixer. Scalping can sometimes be accomplished successfully by placement of a screen over the top of the cold-feed bins. In many cases, however, this screen is only a grizzly-type device

Figure 2-23. Scalping screen *(Barber-Greene)*.

with large openings. Because of the large volume of aggregate that is delivered at one time from the front-end loader to a cold-feed bin, a screen that has small openings cannot properly handle the flow of aggregate from the loader bucket to the bin. Thus, scalping screens employed on top of the cold-feed bins are normally used only for the larger size coarse aggregate and for reclaimed material.

A scalping screen is most often placed somewhere between the end of the gathering conveyor and the drum to remove deleterious materials such as tree roots, vegetable matter, and clay lumps, as well as oversize aggregate (Figure 2-23). It is not normally necessary to pass quarry-processed aggregates through a scalping screen, although it is always good practice to do so to prevent any extraneous oversize material from entering the drum and the mix. A scalping screen should be used as part of the cold-feed system on a batch plant if the screens have been removed from the mixing tower or if the screens are bypassed. The size of the openings in the smallest screen (the bottom screen if a double-deck screen is being used) is typically slightly bigger than the maximum size aggregate used in the mix.

Scalping devices can be tailored to the needs of each individual plant. Typically only a single-deck scalping screen is used. Some plants employ a two-deck scalping screen, which controls two different top-size aggregates without changing the screen (Figure 2-24). If both screens are being used, a flop gate at the lower end of the second screen is used to redirect the aggregate caught on the bottom screen to the charging conveyor. The flop gate can be operated either manually or automatically. The openings in the screen can be either square or slotted. The advantage of the use of the slotted screen is that a smaller screen area can be used to handle a given volume of material.

Some scalping screens are equipped with a bypass chute. This allows the aggregates on the gathering conveyor to be deposited directly on the charging conveyor without passing through the screen. This

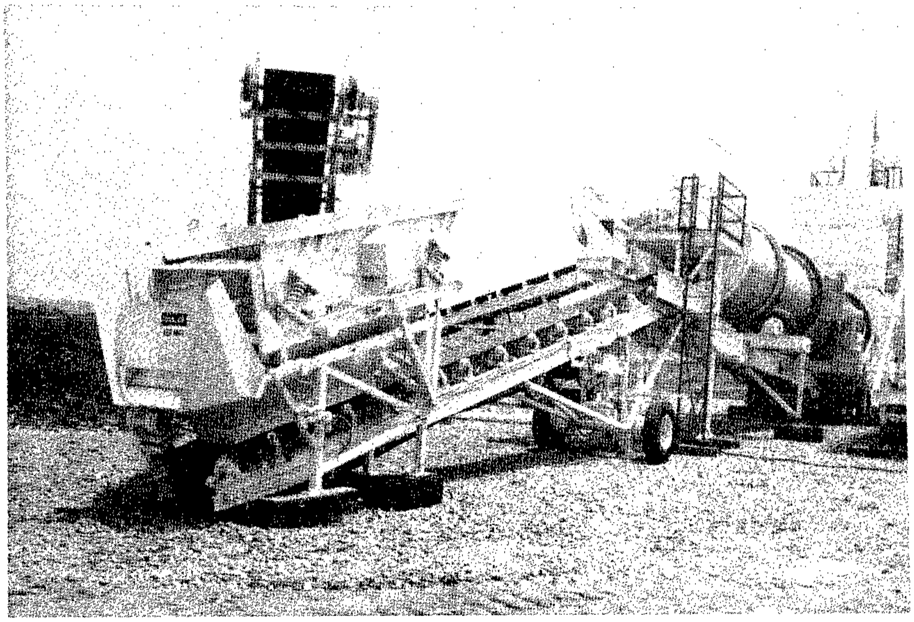


Figure 2-24. Double-deck scalper *(Astec)*.

procedure is sometimes used when quarry-processed aggregate or aggregate free of any deleterious material is fed to the plant.

Instead of a scalping screen at the end of the gathering conveyor, one make of cold-feed bins includes a small scalping screen under each cold-feed bin, which is illustrated in Figure 2-25. The aggregate from a particular bin falls off the belt feeder and onto the scalping screen. Properly sized material passes through the screen and onto the gathering conveyor. Oversized pieces are rolled down the screen into a reject chute that deposits the aggregates in a pile for subsequent disposal. Because the size of these individual-bin scalping screens is quite small, if they become blinded or clogged, the proper amount of aggregate will not pass through the screen onto the charging conveyor. Thus the operation of such scalping screens should be monitored on a regular basis.

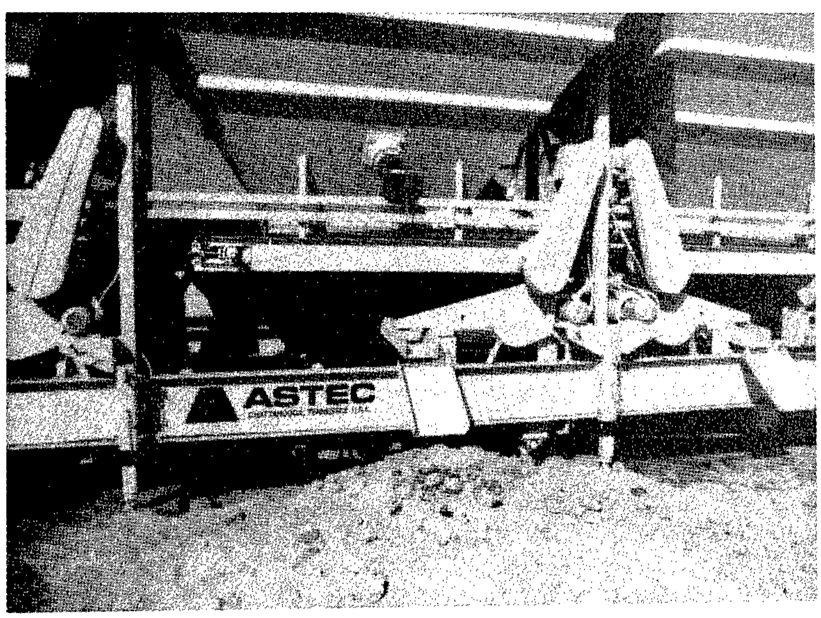


Figure 2-25. Individual scalping screen under each bin *(Astec)*.

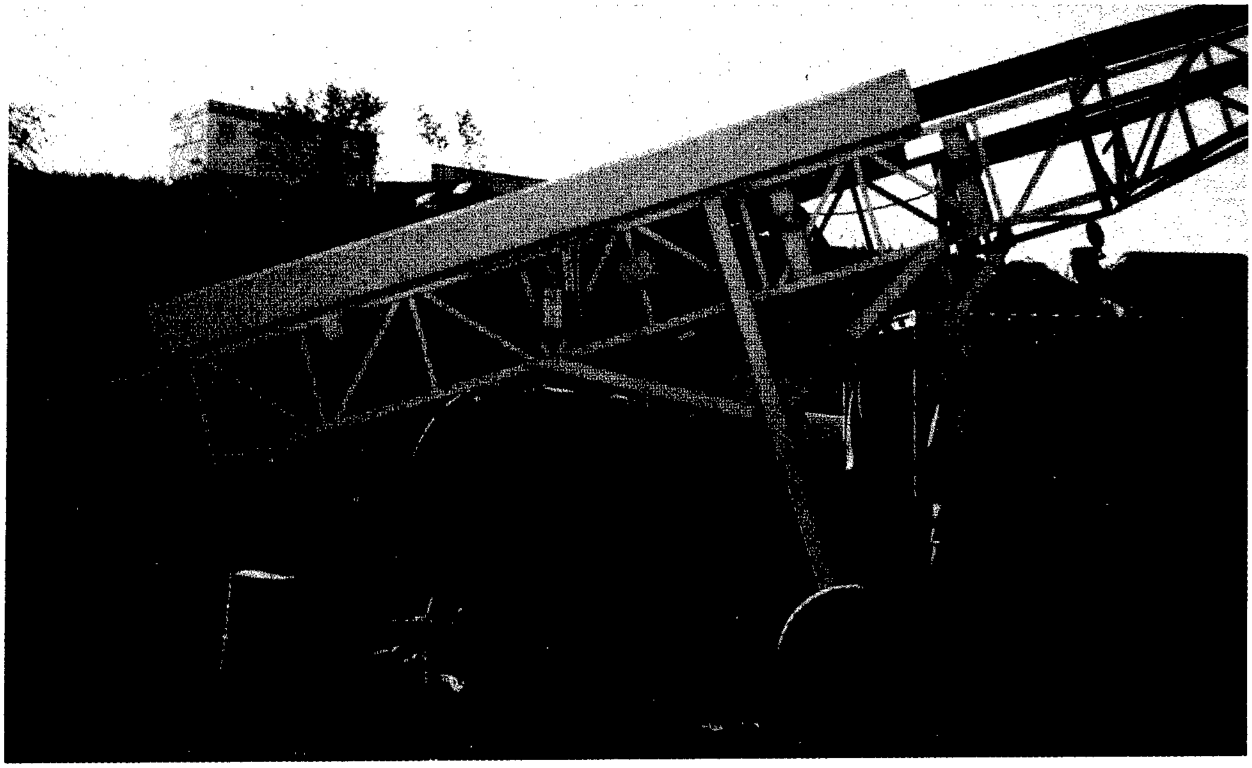


Figure 2-26. Charging conveyor with weigh bridge system *(J. Scherocman)*.

Charging Conveyor

Batch Plants

The combined coarse and fine aggregates are discharged from the gathering conveyor onto the charging conveyor for transport to the drum. For a batch plant, this conveyor delivers the aggregate to the inclined chute at the upper end of the dryer. The charging conveyor is a simple belt that operates at a constant speed but carries a variable amount of aggregate, depending on the volume of aggregate delivered from the cold-feed bins. The conveyor should normally be equipped with a device (scraper blade or brush) to clean off the belt as it revolves.

Drum Mix Plants

For a parallel-flow drum mix plant, the charging conveyor carries the aggregate to a charging chute above the burner on the drum or to a slinger conveyor under the burner. From one of these two entry points, the aggregates are introduced into the mixing drum. For this type of plant, the charging conveyor contains a weigh bridge system (shown in Figure 2-26) that measures the amount of aggregate, in tons per hour, being fed to the drum mixer. The weigh bridge, or belt scale, determines the weight of aggregate passing over the weigh idler. The charging conveyor operates at a constant speed that is independent of the other conveyors. The weigh bridge itself is located near the midpoint of the charging conveyor.

A weigh idler, as seen in Figure 2-27, is the heart of the weigh bridge system. This idler is different from the fixed idlers on the conveyor frame. It is free to move

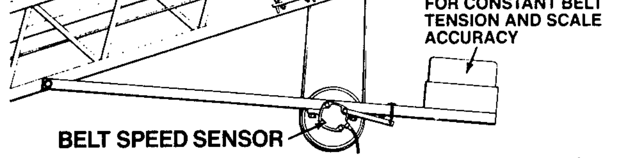


Figure 2-27. Weigh bridge idler and gravity take up *(Barber-Greene)*.

and is attached to a load cell. As the aggregates pass over the weigh idler, the weight of the material is recorded as an electrical signal in the computer control system. The weight value by itself is meaningless, however, because it covers only an instant of time. Thus the charging conveyor is also equipped with a belt speed sensor, as shown in this same figure. This device, usually located on the belt takeup pulley, is a tachometer, which, coupled with the diameter of the pulley, measures the actual speed of the conveyor belt.

To obtain an accurate belt speed reading, it is essential that the charging conveyor belt be tight around the gravity takeup pulley, as shown in Figure 2-27. Any slippage of the belt over the speed sensor will result in an erroneous reading and an incorrect wet aggregate weight input value to the drum mixer. Some conveyors are equipped with an air-actuated takeup system that is located on the tail shaft pulley and operates in a manner similar to the gravity takeup system. Its purpose is to keep the belt tight and eliminate the potential problem of inaccurate belt speed sensor readings.

The information from the weigh idler on the belt scale and from the belt speed sensor is combined to determine the actual weight of aggregate, in terms of tons per hour. This value is the wet weight of the aggregate and includes the moisture in the aggregate. The wet weight of this material is converted to dry weight by the plant computer in order to add the proper amount of asphalt cement to the mix, using a manual input of the average moisture content in the combined coarse and fine aggregates.

The moisture content of each of the aggregates being fed into the plant should be checked regularly and the average amount of moisture in the incoming aggregate determined. The determination should be made whenever the moisture content of the aggregate stockpiles has changed, such as after a rain, or a minimum of twice a day. This frequency can be reduced to a minimum of once a day during periods of consistent dry weather conditions.

If the aggregates being carried on the belt are relatively dry, all the aggregates that pass over the weigh bridge will enter the drum. If the moisture content of the aggregate is high, however, some of the fine aggregate may stick to the charging conveyor belt. This "extra" material will not be fed into the drum, but will remain on the belt. If not removed by a scraper, the additional material will continually be detected by the weigh bridge and the plant computer will calculate a greater weight of aggregate entering the drum than is actually occurring. This will cause the computer to signal the asphalt pump to deliver additional asphalt cement to the plant to compensate for the additional aggregate. Thus the belt scraper or brush should be in place, continually cleaning the charging conveyor belt as it carries aggregates to the mixing drum.

Individual-Bin Weigh Bridges

On a few plants, the individual cold-feed bins may be equipped with weigh bridge systems located on the individual-belt feeder conveyor. For this type of setup, the conveyor belt under each individual cold-feed bin must be longer than belt feeders without the weigh bridge. Usually a plant with individual cold-feed weigh bridges will not have a weigh bridge installed on the last feeder conveyor closest to the drum mixer. Another standard weigh bridge is installed on the charging conveyor. This latter system provides data on the combined weight of all the aggregates, the same as the weigh bridge system on most drum mix plants.

The plant computer and controls are able to display the amount of aggregates pulled from each cold-feed bin. The amount of material delivered from the bins equipped with individual weigh bridges is read directly, after the amount of moisture in each aggregate fraction is deducted. The weight of aggregate discharged from the last bin is determined by subtracting (by use of the computer) the amount of aggregate weighed by the individual feeders from the total aggregate weight measured by the weigh bridge located on the charging conveyor, adjusted for moisture content.

COLD-FEED SYSTEMS FOR RECLAIMED ASPHALT PAVEMENT

The cold-feed system for handling RAP is essentially the same as the conventional cold-feed system for new aggregates. On most plants, as shown in Figure 2-28, this is done through the use of a separate cold-feed bin. The bin (or bins) is similar to the cold-feed bins used for new aggregates except that all four sides of the RAP feed bins are usually much steeper. The steeper sides allow the asphalt-coated aggregates to be discharged from the bins more easily. This is particularly important in hot weather, when the RAP can become sticky. The steeper sides reduce the tendency of the reclaimed material to bridge the opening at the bottom of the bin.

If a separate cold-feed bin arrangement is used for the reclaimed material, there is normally a variable-speed belt conveyor under each bin. The bins are also provided with a gate that can be set at various openings. The RAP, typically delivered to the bin by front-end loader, is discharged onto the feeder conveyor. If only one cold-feed bin is used, the RAP on the feeder conveyor is transferred to a charging conveyor. If more than one cold-feed bin is employed, the feeder conveyor under each bin delivers the RAP to a gathering conveyor and then to the charging conveyor. The RAP then should be passed through a scalping screen to remove

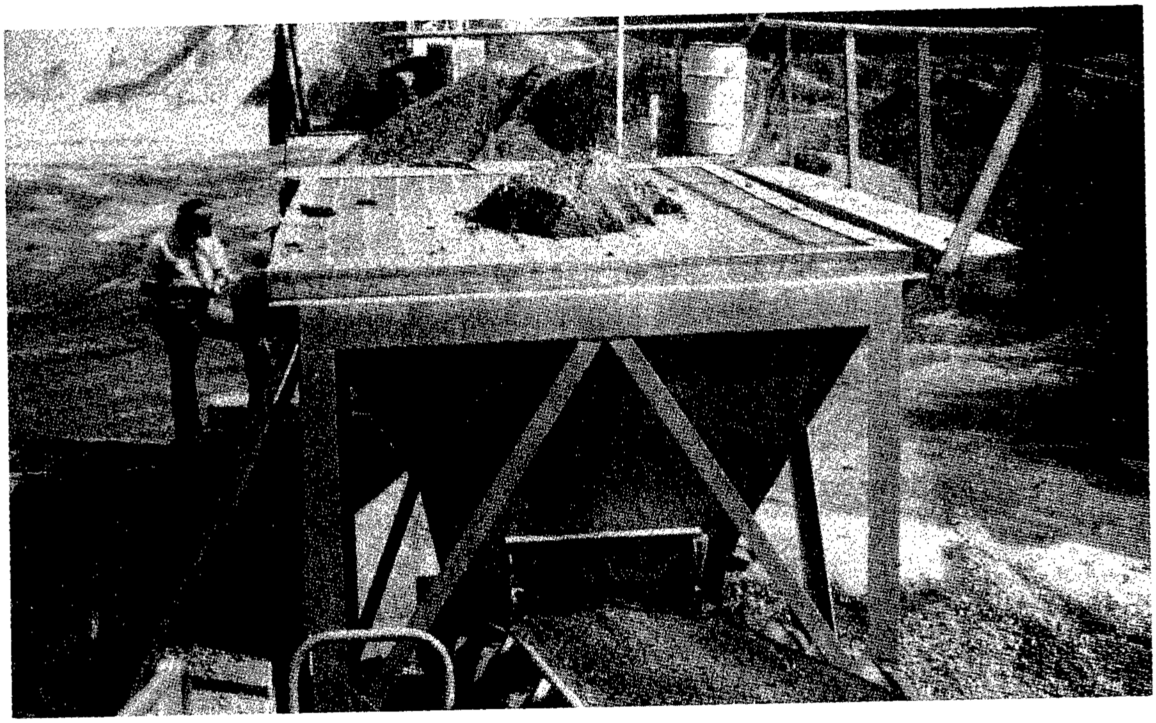


Figure 2-28. RAP bin *(J. Scherocman)*.

any oversized pieces of asphalt mixture or deleterious material. An alternative setup is to place a scalping screen or fixed-bar grizzly over the cold-feed bin itself and thus remove any oversize and foreign material before it enters the bin. Another alternative setup is to place a small crusher in the system between the cold-feed bin and the charging conveyor to reduce the size of any oversize RAP pieces.

After exiting the scalping screen, the RAP is dropped onto the inclined conveyor for transport to the plant. If it is being carried to a batch plant, the material can be delivered to the boot (bottom) of the hot elevator, to one of the hot bins at the top of the plant, or to the weigh hopper. If the reclaimed material is being transported to a drum mix plant, the charging conveyor will be equipped with a weigh bridge system that measures the weight of the material passing over it as well as the speed of the belt itself. This weight, in tons per hour, includes the moisture in the RAP. The average moisture content value is manually input into the plant controls and the dry weight of the RAP calculated by the plant computer. The information determined from

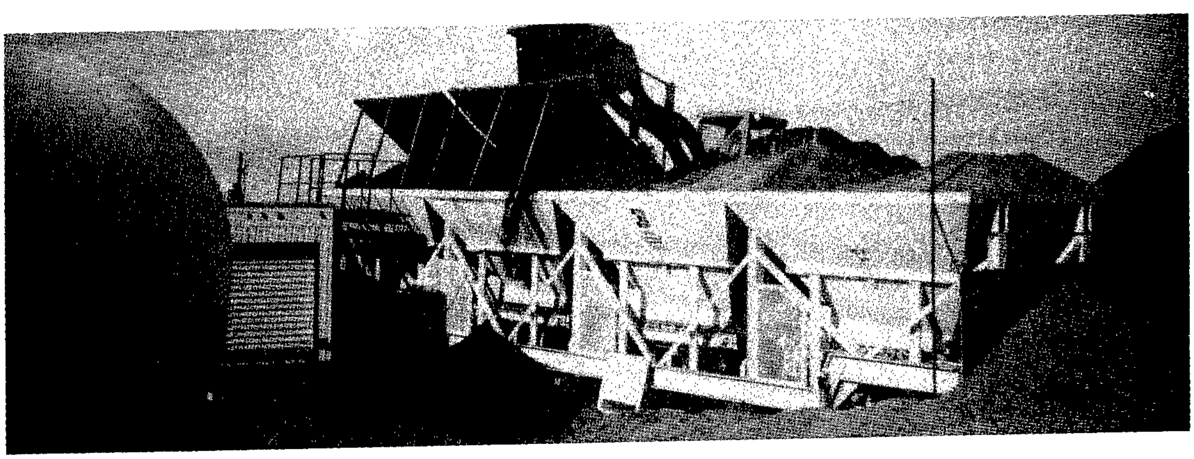


Figure 2-29. RAP & virgin feed bins *(J. Scherocman)*.

the weigh bridge system on the RAP charging conveyor is combined with the data from the new aggregate weigh bridge system to determine the plant input tonnage.

Single-Feed Drum Mix Plants

A very limited number of drum mix plants have only one set of cold-feed bins. Some of the bins are used to hold the new aggregates and the other bins are used to handle the RAP, as shown in Figure 2-29. For one type of plant, the new and reclaimed aggregates are both fed at the same time into the burner end of the drum mix plant. In this case, the RAP is handled exactly like the new aggregates. It can be deposited underneath or on top of the new aggregates, depending on which cold-feed bins are selected to hold the asphalt-coated aggregates. The reclaimed material is often deposited on top of the new aggregate so that it can be exposed to a water spray (used to reduce potential emission problems) when traveling up the charging conveyor.

Split-Feed Drum Mix Plants

Most parallel-flow drum mix plants are equipped with a split-feed system to handle the RAP. Typically, a separate cold-feed bin and conveyor system is used to feed this material into the drum mixer through a rotary center inlet. On some plants, however, a separate cold-

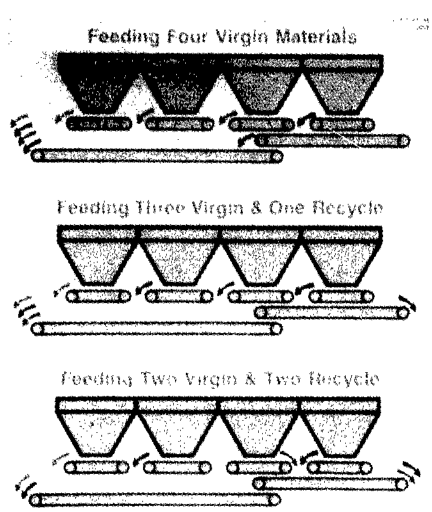


Figure 2-30. Feeding virgin and reclaimed aggregate *(Astec)*.

feed bin is not used for the reclaimed material. In this case, the material is placed in one or more of the conventional cold-feed bins. The gathering conveyor under the bin or bins is modified, however, by dividing it into two different belts, each moving in a different direction, as illustrated in Figure 2-30. The gathering conveyor under the feeder belts for the new aggregate carries this material to a charging conveyor moving to the burner end of the drum mix plant. The gathering conveyor under the feeder belts for the reclaimed aggregate transports the RAP to a separate charging conveyor that carries the RAP to an inlet location near the midpoint of the mixing drum length.

Regardless of what cold-feed bin system is used for the RAP, a weigh bridge and speed sensor are employed to measure the amount of reclaimed material moving up the charging conveyor and into the drum. Although using the same cold-feed bin system to handle both new and reclaimed asphalt pavement saves the cost of a separate cold-feed bin or bins for the RAP, the chance of bridging the opening at the bottom of the bin increases because of the shallower angle of the sides of the conventional cold-feed bins.

ADDITION OF HYDRATED LIME

In order to reduce the occurrence of moisture damage, hydrated lime is sometimes added to the mix at a rate of 1 to 2 percent by weight of aggregate. This material may be added in one of two different forms: as a dry powder or as a slurry. If it is used as a slurry, it is typically proportioned as one part hydrated lime to three parts water. The lime can be added by mixing it with the aggregate on the cold-feed belt or by introducing it into the rear of the drum similar to a conventional mineral filler. When the hydrated lime is added in dry form to the aggregate, the specifications usually require that the moisture content of the combined coarse and fine aggregate be at least 3 percent to assure that the lime is adequately attached to the aggregate particles as the aggregate enters the drum mixer. The addition of lime as a mineral filler is discussed in Section Four.

The dry lime or slurry is added to the aggregate as it moves along the gathering conveyor or up the charging conveyor. The lime is normally placed on top of the aggregate and then is mixed with the aggregate using one of several different methods. That mixing may take place when the aggregate passes through the scalping screen, through a set of plows or mixing paddles on the belt, or in an in-line pugmill placed in the cold-feed system between the gathering conveyor and the charging conveyor.

CALIBRATION

The rate of aggregate flow from a cold-feed bin should be determined to ensure that the proper proportion of each aggregate is delivered from the bin to the plant to obtain the proper gradation for the mix. The method used to calibrate the cold-feed bins depends on the type of plant being used and on the type of feed conveyor under each bin.

Each cold-feed bin should be calibrated at a flow volume that will be within the range of material that will be delivered from the bin during mix production. Ideally, the bin should be checked at rates that are approximately equal to 20 percent, 50 percent, and 80 percent of the estimated operational flow rate.

If a cold-feed bin is equipped with a constant-speed feeder belt, the only way to change the amount of aggregate delivered from the bin is to vary the size of the gate opening. In this case, the size of the gate opening at which the calibration procedure is conducted depends on the proportion of aggregate to be drawn out of the bin. If, according to the mix design information, 25 percent of the total amount of the aggregate needed in the asphalt mix should come out of one bin, that bin should be calibrated at the gate opening size that will typically provide that rate of flow. In addition, the calibration procedure should be completed at both the next larger and the next smaller gate setting to allow for small changes in production rate. If significant changes in production rate are anticipated, the cold-feed bins should be calibrated at whatever gate openings are needed to provide the proper amount of that size aggregate to the plant.

Many cold-feed bins on batch plants and the vast majority of the cold-feed bins on drum mix plants are equipped with a variable-speed feeder belt in addition to a means to change the size of the gate opening under the bin. The gate opening on the cold-feed bin should be set at a level to deliver the proper amount of aggregate at the desired plant production rate. In addition, the bin should also be calibrated at three different feeder belt speeds: 20 percent, 50 percent, and 80 percent of the range of speed of the feeder belt. The best operating conditions for the cold-feed bin would be to provide the proper amount of aggregate from the preset gate opening with the feeder belt operating at 50 percent of its maximum speed. This would permit the plant operator some latitude to increase or decrease the production rate of the plant without having to change the setting of the gate opening at the bottom of the cold-feed bins.

The calibration of each cold-feed bin is accomplished by drawing aggregate out of a bin for a specific period of time and determining the weight of the aggregate delivered in that time interval. In most cases, a truck's empty (tare) weight is determined. Aggregate is withdrawn from the cold-feed bin and delivered, usually by means of a diverter chute on the charging conveyor, into the truck. After a set period of time, the flow of the aggregate is stopped and the truck is weighed to determine the amount of aggregate delivered. For cold-feed bins equipped with only a constant-speed feeder belt, the weighing process is accomplished for a variety of gate opening settings. For cold-feed bins that are equipped with variable-speed feeder belts, the calibration process is repeated at different gate opening settings as well as at at least three different belt speeds per gate opening.

On a drum mix plant, the weigh bridge must also be calibrated. This is accomplished by running aggregate over the weigh idler for a given period of time. Instead of being delivered to the drum mixer, the aggregate is diverted into an empty, tared truck. After the selected time period has passed, the aggregate flow is terminated and the amount of aggregate in the truck is measured by weighing the truck. The weight determined is compared with the weight of aggregate calculated by the plant computer system. To be correct, the two weights should be within the tolerance band set by the particular government agency and typically within 1.0 percent of each other (assuming that the weigh bridge is accurate to 0.5 percent and that the truck scale is also accurate to 0.5 percent).

For many drum mix plants, the weigh bridge should be calibrated at a production rate that is near the estimated normal production rate for the plant. If the drum mixer is going to run at 90 percent of capacity, the calibration of the weigh bridge should be completed at three production rates: 70, 85, and 100 percent of capacity. This calibration, however, will probably not be correct if the plant is run at a much lower capacity, such as 60 percent. In this case, the calibration procedure should be repeated at the lower production rate (bracketing the estimated rate with one rate above and one rate below the most probable production level).

Because of the differences in the operating procedures of different makes and models of cold-feed bins and asphalt plants, it is difficult to generalize the exact calibration procedure that should be used. The calibration instructions provided with the plant should be followed.

SUMMARY OF AGGREGATE HANDLING OPERATING TECHNIQUES

Several key items should be monitored when viewing the handling of new and reclaimed aggregates, both in the stockpiles and when being fed into a batch or drum mix plant. They are:

- The stockpiles should be built on a clean, dry, and stable foundation. Positive drainage for each pile should be provided. Aggregate of different sizes should be stockpiled separately from one another.
- The moisture content of each aggregate should be determined at least twice each day, and more often if moisture conditions change. The average moisture content of the incoming aggregate to the plant dryer or drum mixer should be inputted into the plant control system in order to permit proper setting of the burner controls, to calculate the dry weight of the incoming aggregate, and to determine the plant production rate. To reduce the moisture content of the aggregate in the stockpiles, covering of the aggregate piles--particularly the fine aggregate--with a roof should be considered.
- Stockpiles should be built in horizontal or gently sloping layers. Any stockpiling procedure that results in aggregate being pushed or dumped over the side of a stockpile should be avoided in order to prevent segregation. Travel on stockpiles by trucks and front-end loaders should be minimized to prevent aggregate breakage and the generation of fines.
- The front-end loader should work the full face of the stockpile, removing the aggregate in a direction perpendicular to the flow of the aggregate into the stockpile. The front-end loader operator should go straight into the stockpile, roll the bucket up, and then back out instead of scooping up through the stockpile. This will minimize segregation caused by the larger-size aggregate rolling down the face of the stockpile. The front-end loader operator is the key in providing a consistent proportion of material to the plant and in minimizing segregation.
- If the coarser aggregate stockpiles are segregated, the loader operator should not place one bucketful of coarse material and then a bucketful of finer material in the cold-feed bin. The segregated materials should be blended by the loader (or by other means) before the material is introduced into the cold-feed bins.
- Cold-feed bins that are kept relatively full of aggregate should be separated by a bulkhead between each bin at the top of the bins so that aggregate that is supposed to be in one bin cannot overflow into an adjacent bin.
- The discharge end of the feeder conveyor should be equipped with a "no flow" device to indicate to the plant operator when inadequate aggregate is being delivered from a cold-feed bin.
- If the plant is equipped with variable-speed feeder conveyors, those conveyors should be run at a speed that is between 20 percent and 80 percent of the maximum belt speed. Ideally, the speed of the feeder conveyor should be in the middle of the speed range to allow for small increases and decreases in plant production capacity without the necessity of changing the cold-feed bin gate-opening settings. The feeder conveyor should be calibrated at the speed at which it will typically run.
- A scalping screen should be placed in the cold-feed charging system of a drum mix plant or a batch plant operated without screens to remove any oversize and deleterious material from the aggregates.
- For drum mix plants, the weigh bridge should be checked to see if the weigh idler is free to move and that the conveyor belt is tight around the gravity takeup pulley to assure an accurate belt speed sensor reading.
- The cold-feed bin(s) used for RAP should have steep sides to prevent the material from bridging the gate opening at the bottom of the bin.
- The reclaimed aggregate feed system, both on a batch and on a drum mix plant, should include a scalping screen over the cold-feed bin or at some other point in the material flow process.
- Cold-feed bins should be calibrated. For bins equipped with constant-speed feeder belts, the flow of aggregate from the bins should be determined at three different gate opening settings: one at the plant production rate, one greater than the estimated rate, and one lower than the estimated production rate.
- For cold-feed bins equipped with variable-speed feeder belts, the bins should be calibrated at three different gate openings as well as at three different belt speeds. The belt speeds should be approximately 20 percent, 50 percent, and 80 percent of the range of the possible belt speeds.
- The weigh bridge on the charging conveyor of a drum mix plant must also be calibrated. This should be accomplished by collecting and weighing the amount of aggregate that passes over the weigh bridge in a set amount of time and comparing that weight with the weight determined by the plant computer system. For the weigh bridge to be calibrated properly, the two weights should be within 1.0 percent of each other.

SECTION THREE
ASPHALT CEMENT SUPPLY SYSTEM

INTRODUCTION

This section discusses the asphalt cement supply system, which consists of two major parts. The first includes one or more storage tanks to store the asphalt cement until it is needed by the mixing plant. The second is a pump and meter system used to draw asphalt cement from the storage tank in proportion to the amount of aggregate being delivered to the batch plant pugmill or drum mixer.

STORAGE TANKS

All asphalt cement storage tanks, as shown in Figure 2-31, must be heated to properly maintain the correct temperature of the asphalt cement to assure that its viscosity is low enough so that it can be pumped and mixed with the heated and dried aggregate. Most asphalt cement storage tanks are heated with a hot oil system and are equipped with a small heater to heat and maintain the temperature of the heating oil. The hot oil is circulated through a series of coils inside the asphalt cement storage tank, as shown in Figure 2-32, and the heat is then transferred from the oil, through the coils, to the asphalt cement. This heat-transfer process reduces the viscosity of the asphalt cement, causing it to flow upward and circulate, and causing new, lower-temperature asphalt cement to come in contact with the heating coils. Thus, the hot oil system, through a set of thermocouples and solenoid valves, maintains the proper temperature of the asphalt cement, generally in the range of 300°F to 350°F, depending on the grade and type of asphalt cement being used.

A lesser-used style of asphalt cement storage tank is the "direct fired" tank. In this system, the asphalt cement is heated by direct heat exchange from the combustion source through a series of heat tubes to the asphalt cement. Care needs to be used with this type of tank to prevent overheating of the asphalt cement immediately adjacent to the heat tubes.

All storage tanks should be completely insulated and heated, and all the lines for both asphalt cement and heating oil should be insulated to prevent loss of heat. Both the line used to fill the tank from the asphalt cement transport truck or rail car and the discharge line from the tank to the plant should be located near the bottom of the tank. The return line from the pump

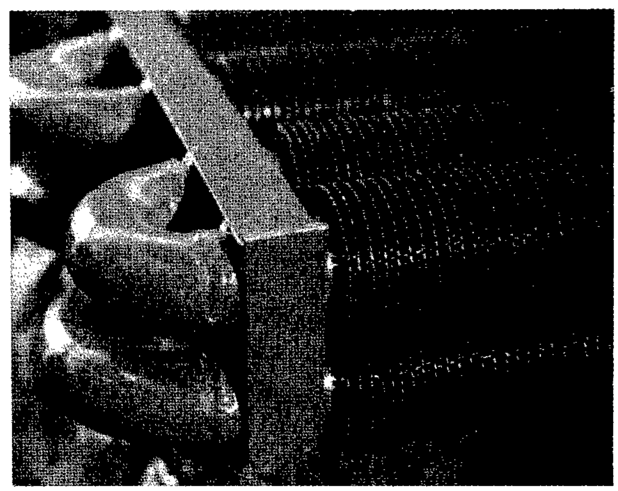


Figure 2-32. Finned hot-oil tubes *(Heatec)*.

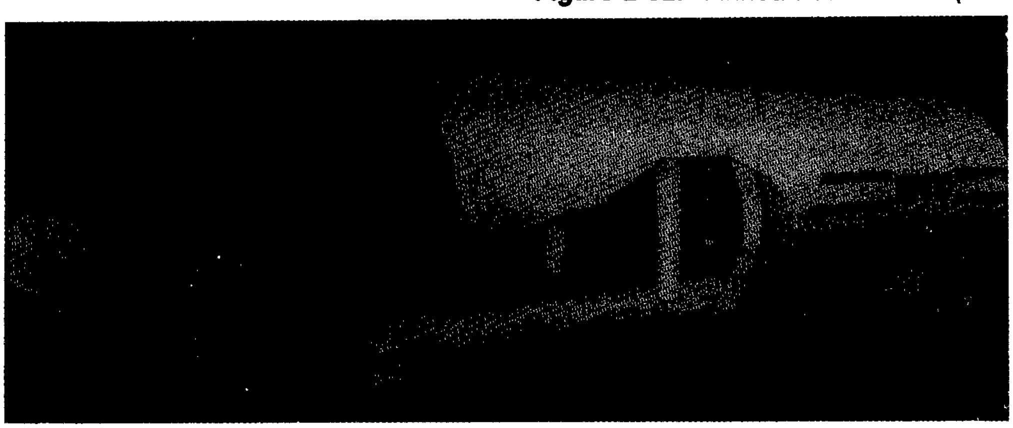


Figure 2-31. Asphalt cement storage tank *(Heatec)*.

should be located so that the asphalt cement enters the tank at a level beneath the surface level of the asphalt cement stored in the tank and does not fall through the air. This will reduce the oxidation of the asphalt cement during the circulation process.

If the HMA plant is equipped with more than one asphalt cement storage tank, the capability should exist to pump material from one tank to another. It is important that the plant operator know from which tank material is being pulled, especially if more than one grade or type of asphalt cement is being stored in different tanks.

All asphalt cement storage tanks contain a "heel" of material at the bottom of the tank. This asphalt cement, located beneath the heating coils, usually does not circulate efficiently. The volume of material in the "heel" depends on the type and style of the storage tank, the location of the heating coils, and the amount of time since the tank was last cleaned. It is recognized, however, that some asphalt cement will typically remain in the bottom of an "empty" tank. It is possible, therefore, that placing asphalt cement of one type or grade into a tank that previously contained a different type or grade can cause an alteration of the properties of the asphalt cement to the point at which it no longer meets specifications.

The capacity of an asphalt cement storage tank can be calculated from its diameter and length measurements. The amount of material in the tank can be determined using a tank "stick." The stick measures the distance from the top of the dome or the top of the tank down to the level of the asphalt cement in the tank (the point at which the tank stick just touches the top of the material). This distance is noted and the capacity of the asphalt cement remaining in the tank below this level is determined from the tank manufacturer's calibration chart.

When asphalt cement is delivered from a transport vehicle into a storage tank, it is very important to ensure either that the tank is clean or that it already contains the same type of material as is being pumped into the tank. If the tank is empty at the time the new material is being added, the tank should be checked to ensure that no water has accumulated in the bottom. If asphalt cement is loaded on top of an asphalt emulsion or on top of a layer of water in the tank, violent foaming of the asphalt cement will occur, creating a very severe safety problem. Care should be taken to assure that all valves are in the proper position to prevent pressure from building up in the lines and causing an explosion and possibly severe burns.

PUMP AND METER SYSTEM

Batch Plants

For batch plants, two different systems typically exist to transfer asphalt cement from the storage tank to the weigh bucket near the pugmill. The type of system depends on the location of the return line: whether one or two asphalt cement lines are present from the pump to the weigh bucket.

In the single-line process, as shown in Figure 2-33, two lines extend from the storage tank to the pump, but only one line extends from the pump to the weigh bucket. The pump is a constant-volume, constant-speed unit that runs continuously. Asphalt cement is always being pulled from the storage tank through the pump and circulated back to the tank. When asphalt cement is needed in the weigh bucket, a valve on the end of the line at the top of the weigh bucket opens and material is discharged into that bucket. When the proper amount of asphalt cement is in the bucket, determined by weight (not volume), that valve is shut and a pressure relief valve at the pump is opened. The asphalt cement then passes through the pump but is recirculated back to the storage tank, in the second line, instead of being sent to the plant. A variation of this system allows the asphalt cement to circulate through the pump itself instead of being returned back to the storage tank.

In the dual-line process, one line is used to deliver asphalt cement to the weigh bucket and the second line is used to return the "excess" asphalt cement back to the storage tank. The asphalt cement passes through the pump to a three-way valve at the bucket. When asphalt cement is needed in the weigh bucket, the valve opens and the material is discharged into the bucket. When the preselected weight is reached, the valve closes and the asphalt cement is recirculated in the second line back to the storage tank.

Because the amount of asphalt cement used in most batch plants is measured by weight, no correction is needed for the temperature of the asphalt cement. On a few old batch plants, however, the amount of asphalt cement delivered is determined by volume. In this case, the amount of asphalt cement delivered to the pugmill must be corrected, based on both the temperature and the specific gravity of the asphalt cement. This can be accomplished using the procedure given in ASTM Specification D 4311.

Drum Mix Plants

Asphalt Cement Delivery

For most drum mix plants, three different systems exist to pull the asphalt cement from the storage tank,

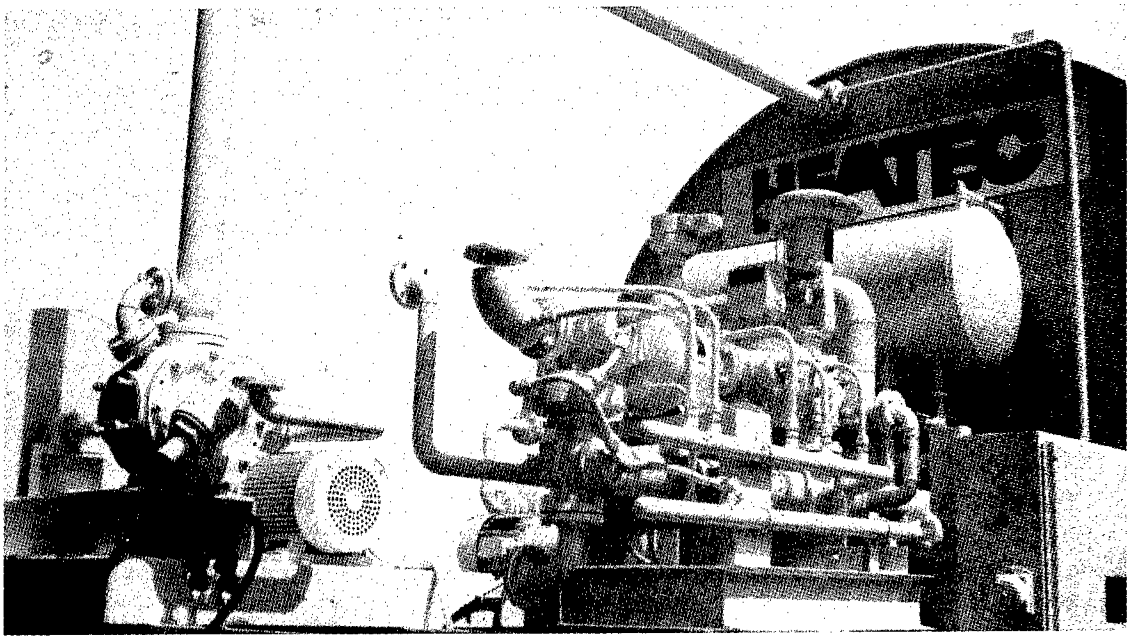


Figure 2-33. AC single-line circulating system *(Heatec)*.

meter it, and pump it to the plant. Those three processes include: (a) a constant-volume pump with a variable-speed motor, (b) a constant-volume pump with a constant-speed motor with a metering valve, and (c) a variable-volume pump with a constant-speed motor. The use of a particular pump and meter system is dependent on the make, model, and date of manufacture of the plant and on the choice made by the individual plant owner.

For the system that uses a variable-volume pump driven by a constant-speed motor, the amount of asphalt cement pulled from the storage tank is controlled by changing the volume of asphalt cement being pumped. The volume needed at the pump is determined by the plant computer in proportion to the amount of aggregate being fed into the plant. As the amount of aggregate entering the drum mixer increases, the volume of asphalt cement pulled through the pump also increases. When the plant is not using asphalt cement, the material continually passes through the pump and meter and through a three-way valve that is set to circulate the asphalt cement to the storage tank instead of to the plant. This process is shown in Figure 2-34.

A second system incorporates a fixed-displacement (constant-volume) pump driven by a variable-speed motor. The quantity of asphalt cement delivered to the meter is varied by changing the speed of the variable-speed motor. The amount of material sent to the plant is also dependent on the aggregate feed rate. A three-way valve in the system downstream of the meter allows the asphalt cement to be recirculated back to the tank when it is not needed by the plant.

The third system consists of a constant-volume pump driven by a constant-speed motor. In this setup, the same volume of asphalt cement is pulled from the storage tank at all times. A proportioning valve is placed in the line between the pump and the asphalt cement meter. The position of the valve determines the volume of material sent through the meter. The propor-

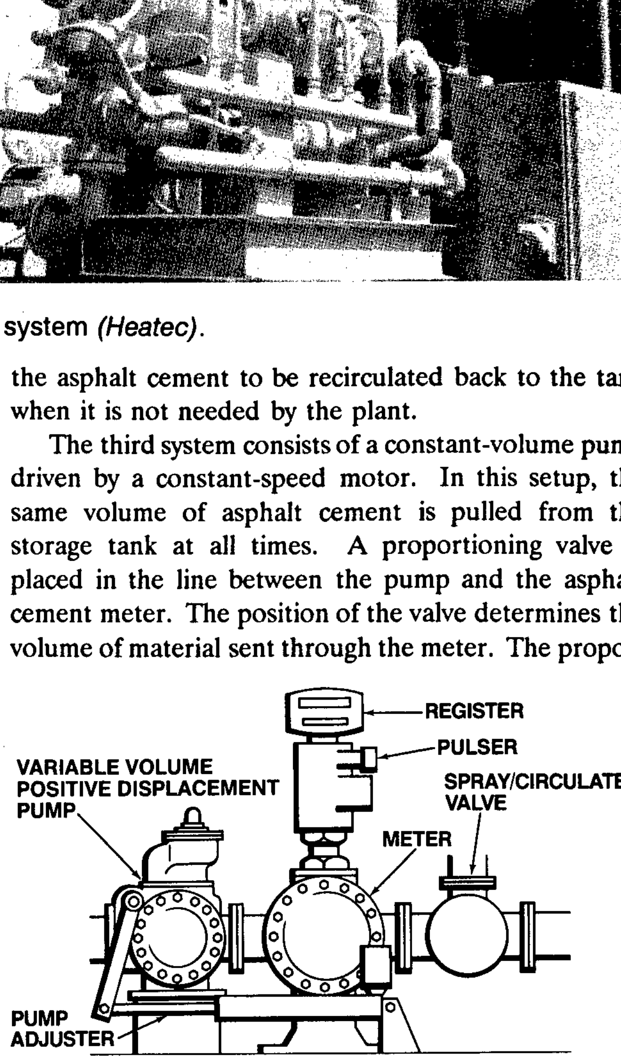


Figure 2-34. Schematic asphalt pump system *(Barber-Greene)*.

tioning valve sends some of the asphalt cement through the meter and the rest back through the recirculating line to the storage tank. The system also has a valve downstream of the meter that allows the asphalt cement sent through the meter to be recirculated to the tank. This valve is used during the warm-up period for the meter and during the calibration process. Again, the position of the proportioning valve is determined by the aggregate feed rate into the drum mixer, both of which are controlled by the plant computer.

Temperature Compensation

Asphalt cement expands when heated. Thus the volume of asphalt cement at 325°F will be somewhat greater than its volume at 275°F. This latter volume will be more than the volume at 60°F, which is the standard temperature for determining the volume of asphalt cement using conversion charts that are based on the specific gravity of the asphalt cement. If the specific gravity of the asphalt cement and its temperature are known, the volume measured at the elevated temperature can easily be converted to the "standard" volume at 60°F using the procedure given in ASTM Specification D 4311.

The volume of asphalt cement moving through the meter changes with temperature. Some meters are set to measure the temperature of the asphalt cement moving through the system and send that information together with the volume data to the plant computer. The specific gravity of the asphalt cement is set manually on the controls. The computer then calculates the volume of asphalt cement being fed into the plant at the standard temperature of 60°F and converts that amount to a weight that is displayed on the plant console.

On some meters, a temperature-compensating device, as shown in Figure 2-35, is installed directly on the meter stand itself. As the temperature of the asphalt cement changes, the meter senses the change and, based on the specific gravity of the asphalt cement, calculates the volume of asphalt cement, at 60°F, passing through the meter. This corrected volume (and corresponding weight) is then sent to the plant console for display.

Regardless of the system employed, the asphalt pump system must be capable of changing the volume of asphalt cement sent through the meter in direct response to the demand of the aggregate supply. The response of the pump system must be directly related to the change in the amount of material measured by the aggregate weigh bridge system. In addition, the volume of asphalt cement measured at any given temperature must be converted to the volume of asphalt cement at 60°F. At this standard reference temperature, the weight of the asphalt cement can be determined in terms of tons of material per hour, the same as for the aggregate feed rate. The total of the aggregate input (new aggregates, and reclaimed aggregates, if used) and the asphalt cement weight provides the production rate for the drum mixer, in tons of HMA per hour. The asphalt pump system is time delayed so that the asphalt cement increase or decrease reaches the drum at the same time that the increased or decreased material flow reaches that point in the drum.

ADDITION OF LIQUID ANTISTRIP MATERIALS

Liquid antistrip additives are typically added to the asphalt cement to improve the adhesion of the binder material to the surface of the aggregate. The additives can be placed in the asphalt cement at several different locations. The additive can be in-line blended with the asphalt cement as that material is pumped out of the tank truck or tank car and into the tank. The additive can also be added to the asphalt cement in the tank,

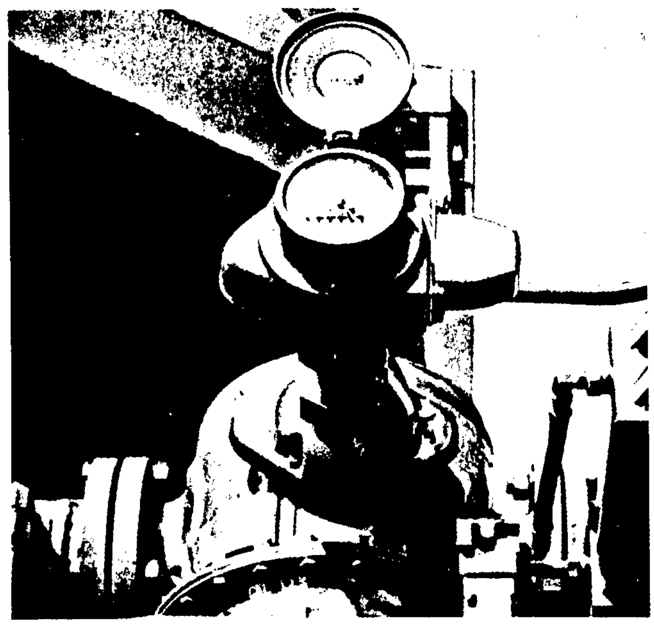


Figure 2-35. Temperature-compensating meter *(Barber-Greene)*.

with the two different materials circulated together for a period of time before the treated asphalt cement is sent to the drum mixer. The most common method, however is to add the liquid antistrip material to the asphalt cement, using an in-line blender, as the binder material is pumped from the storage tank to the rear of the drum mix plant.

CALIBRATION

The pump and meter system on the batch or drum mix plant needs to be calibrated to assure that the proper amount of asphalt cement is being delivered to the mix. For a batch plant operation, the amount of asphalt cement needed is measured by weight (although a few older batch plants measure the asphalt cement by volume) by placing the asphalt cement in the plant weigh bucket. For a drum mix plant, the amount of asphalt cement is measured by volume as it is pumped through a meter into the rear of the drum.

For a drum mixer, the amount of asphalt cement is calibrated by pumping the material into an empty container, the tare weight of which is known. Most often, an asphalt distributor truck is used for this purpose. The actual weight of the material delivered to the container is determined. The weight of the material that the metering system indicates has been delivered is then determined by multiplying the corrected volume delivered from the meter totalizer by the specific gravity of the asphalt cement. With some systems, this calculation is done automatically. The actual weight is compared with the metering system-calculated weight. The values should be within the required tolerance band (typically 1.0 percent) for the asphalt cement supply system to be in proper calibration.

SUMMARY OF ASPHALT CEMENT SUPPLY OPERATING TECHNIQUES

The asphalt cement supply system, composed of the storage tank and the pump/meter system, should be checked as follows:

- The asphalt cement in the storage tank should be kept at a constant temperature, normally between 300°F and 350°F. The tank should be properly insulated. All hot oil lines should be insulated and the asphalt cement lines jacketed and insulated.
- The asphalt cement fill line, discharge line, and recirculation line should all enter the tank so that the asphalt cement added or removed from the tank is charged or discharged below the surface of the material in the tank.
- The volume of asphalt cement in the tank must be converted to a standard volume at 60°F when a tank stick check is made of the amount of material in the tank.
- The amount of asphalt cement used in a batch plant is measured by weight so that no volume correction for temperature is needed.
- A correction for temperature must be made for the volume of asphalt cement passing through the asphalt cement meter on a drum mix plant if the meter is not equipped with an automatic temperature-compensating device. The correction is based both on the actual temperature of the asphalt cement and its specific gravity at 60°F.
- The asphalt cement supply system should be calibrated by weighing the amount of material delivered in a known amount of time. The "corrected" amount is determined in conjunction with the knowledge of both the temperature and the specific gravity of the asphalt cement.

SECTION FOUR
DRUM MIX PLANT

INTRODUCTION

This section is concerned with the processing of the aggregate and the asphalt cement inside the parallel-flow drum mixer. It reviews the methods used to introduce the aggregate into the drum. The operation of the burner is discussed, along with the three-step heating, drying, and heating process that occurs as the aggregate moves down the drum. The importance of the veil of aggregate across the whole cross section of the drum is stressed. The methods for introducing the asphalt cement into the drum and onto the aggregates are considered, as well as the systems used to deliver both mineral filler and/or baghouse fines into the drum.

The addition of RAP into the drum, primarily by use of a split-feed system for the new aggregate and the RAP, is discussed. Information is provided on the factors that affect the production rate of the plant. Finally, the relationship between the mix discharge temperature and the exhaust gas temperature as it exits the drum is analyzed in order to determine the efficiency of the heat-transfer process inside the drum mixer.

AGGREGATE ENTRY

One of the two ways to introduce new aggregate from the charging conveyor is by means of a charging chute located above the burner. The aggregate is delivered into a sloped chute and slides by gravity into the drum. The chute, shown in Figure 2-36, is angled to push the aggregate away from direct contact with the burner flame and toward the rear of the drum.

The aggregate can also be deposited on a slinger conveyor belt that is located beneath the burner, as illustrated in Figure 2-37. On some plants, the speed of this conveyor can be changed and is often increased when a combination of new aggregate and RAP is being fed into the burner end of the plant. The greater speed of the slinger conveyor allows the combined aggregate to be deposited farther down the drum, away from the flame.

BURNER SYSTEM

The burner provides the heat necessary to dry and raise the temperature of the aggregate. Burners are rated by a Uniform Burner Rating Method that is based on eight criteria: (a) percent excess air, (b) percent leakage air, (c) percent casing (shell) loss, (d) fan gas temperature, (e) percent moisture removed from the aggregate, (f) mix discharge temperature, (g) use of No. 2 fuel oil, and (h) the specific heat of the aggregate. The maximum output for the burner under these conditions can be found on the rating plate attached to each burner. The actual operating conditions for the burner may be different from the conditions used to rate the burner, however.

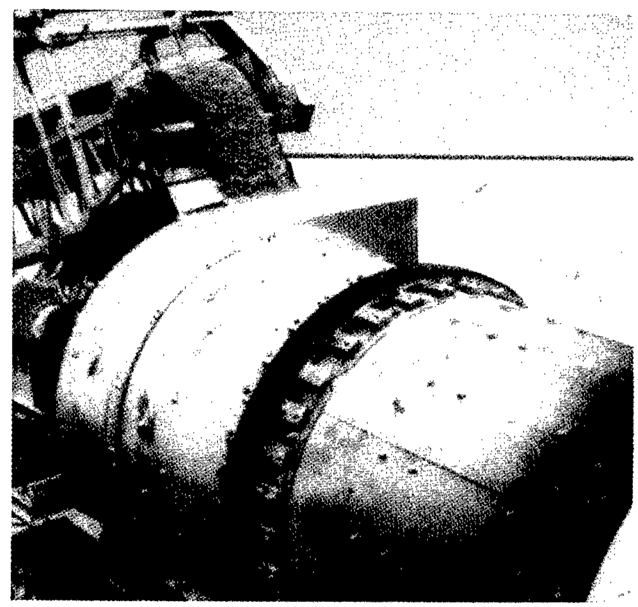


Figure 2-36. New aggregate feed through charging chute *(Cedarapids)*.

Fuel

Most burners are designed to burn more than one type of fuel with only minor changes in the burner settings. Three types of fuel are used: gaseous, liquid, and solid. Gaseous fuels include both natural gas and liquid petroleum gas. Liquid fuels include propane, butane, No. 2 fuel oil, heavy fuel oil (Nos. 4 through 6), and reclaimed oil. Pulverized coal and pelletized biomass are examples of solid fuels.

The fuel selected should be at the proper consistency for complete atomization at the time of combustion. No. 2 fuel oil will burn at ambient temperatures, without

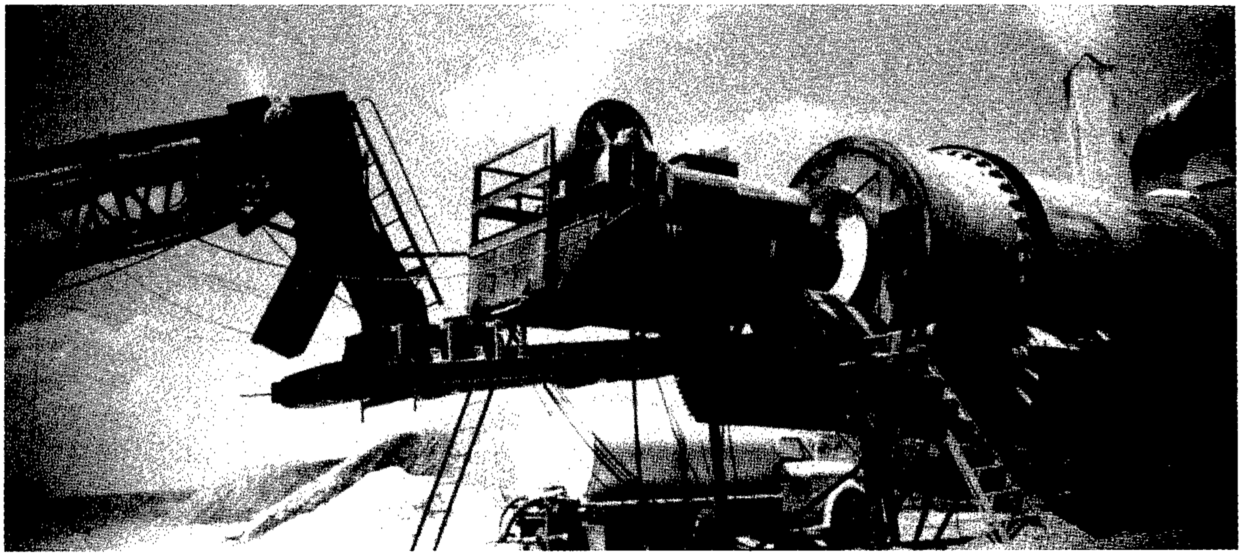


Figure 2-37. New aggregate feed through slinger conveyor *(J. Scherocman)*.

preheating, because it has a viscosity less than 100 saybolt seconds universal (ssu). For proper atomization, heavy fuel oil, such as No. 5 or No. 6, must be preheated before burning to reduce the viscosity below 100 ssu in order to atomize the fuel properly for complete combustion of the fuel. Some reclaimed oil, which has been filtered and dewatered, burns well. Other reclaimed fuel, contaminated with heavy metals, hazardous waste, and/or water, burns erratically and incompletely and generally should not be used in an HMA plant burner. Incomplete combustion is not normally a problem when gaseous fuels are used.

Unburnt fuel can cause difficulty with the burner, the plant, and the mix, and is a waste of money as well. It can cause clogging of the burner nozzle, difficulties in lighting the burner, and increased maintenance costs. Incomplete combustion can result in unburnt fuel entering the emission-control equipment: coating and blinding the filter bags in a baghouse (increasing the opportunity for a baghouse fire) or covering the wastewater pond surface with fuel if a wet-scrubber system is used. It also reduces the amount of heat available to dry the aggregate, and thus increases fuel consumption and operating costs. Further, it can lower the temperature of the exhaust gases, which can result in condensation in the baghouse.

Unburnt fuel can change the properties of the HMA. First, the fuel can reduce the viscosity of the asphalt cement binder material and reduce the amount of hardening that the binder undergoes during the mixing process. It can also impinge directly on the surface of the coarser aggregate particles, resulting in the formation of a brown stain on the aggregate and a reduction of the film thickness of the asphalt cement on those surfaces. These two problems can affect the stiffness and the stability of the asphalt mix produced by the asphalt plant.

Unburnt fuel problems can be recognized in several ways. A flame eye, which is an electronic device used to sense the color of the burner flame, can be employed to monitor the hue of the burner flame and shut down the burner if the color is not proper to indicate complete combustion of the fuel. A uniform, constant roar from the burner is usually a good sound (although it is possible to have a problem with unburnt fuel even when the noise of the burner is constant). A "coughing," "sputtering," "spitting" burner provides an indication of possible incomplete combustion of the fuel. If fuel is condensing on the filter bags, the pressure drop across the baghouse will increase and the bags will be stained with fuel. When a wet-scrubber system is used, the water in the wastewater pond surface will be covered with an oil sheen.

Burners

The primary function of the burner is to blend the proper amounts of air and fuel together to obtain complete combustion of the fuel. Two primary types of burners are used on aggregate dryers and drum mixers. Most plants are equipped with a burner that requires from 30 to 45 percent of the air needed for combustion to be forced through the burner by a blower on the

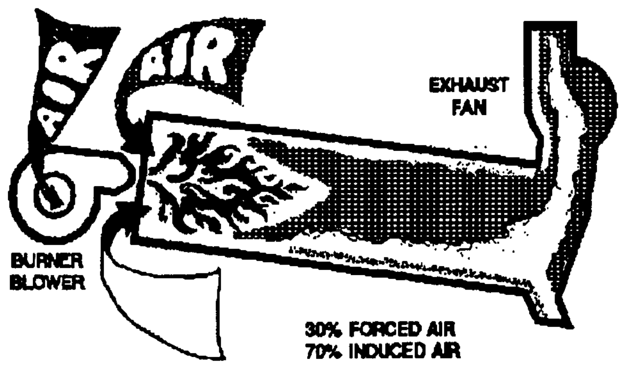


Figure 2-38. Induced forced burner *(Astec)*.

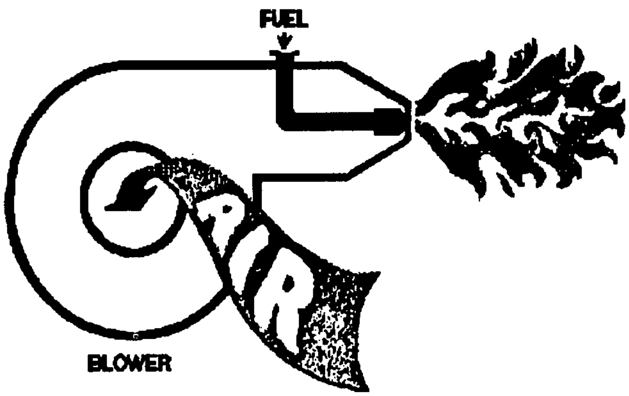


Figure 2-39. Forced-air burner *(Astec)*.

burner itself. The remaining 70 to 55 percent of the combustion air is pulled by the exhaust fan on the plant into the combustion zone around the burner. This type of equipment, a combined induced and forced draft burner, is shown in Figure 2-38. Some burners operate with all of the air needed for combustion being forced through the burner by a blower. This second type of burner, shown in Figure 2-39, is known as a force draft, a total air, or 100 percent air burner. These latter burners are generally much quieter than are the induced draft burners and are more fuel efficient.

Some burners must be adjusted by the plant operator (a) as the amount of aggregate inside the dryer or drum mixer changes, (b) as the amount of moisture in the aggregate increases or decreases, and (c) as the aggregate discharge temperature is changed in order to control the drying and heating of the material. Most burners are equipped with an automatic device that controls the fuel input to maintain a relatively constant discharge temperature for the aggregate (or for the mix in a drum mixer).

A lack of either air or fuel will reduce the efficiency of the burner. Usually the availability of air is the limiting factor. The exhaust fan, besides providing the induced air, must also pull the moisture vapor (steam) created in the drying process and the products of combustion through the dryer or drum mixer. The capacity of this fan is a controlling factor in the heating and drying of the aggregate. The volume of the exhaust gases (air, moisture vapor, and combustion products) pulled by the fan is constant, depending on the setting of the damper in the system.

The efficiency of the system is also affected by air leaks in the system. Because the fan pulls a constant volume of exhaust gases, at a constant damper setting, through the system from the burner and through the fan, any air that enters the system downstream of the burner reduces the amount of secondary air that can be pulled by the fan. Air leaks should be eliminated in order to provide the proper volume of air at the burner to combust the fuel completely. A damper, operated manually or automatically, should also be placed in the ductwork to control the amount of air entering the system.

HEAT-TRANSFER PROCESS

Temperatures Inside the Drum

The temperature of the burner flame exceeds 2500°F. The temperature of the exhaust gases just before they enter the emission-control equipment should be in the range of 250°F to 320°F, depending on the discharge temperature of the mix. Typical temperature profiles for the exhaust gases and the aggregate along the length of the drum are shown in Figure 2-40. The difference in the exhaust gas and the mix discharge temperatures represents the efficiency of the heat-transfer process and the amount of heat that is available to dry and heat the aggregates. Perfect heat transfer would require that the mix temperature and the exhaust gas temperature be equal at the point at which the mix is discharged from the plant.

A measure of the efficiency of the heat-transfer process is, therefore, obtained by comparing the mix discharge temperature with the temperature of the exhaust gases at the time the gases exit the drum. It is often difficult, however, to determine the temperature of the exhaust gases accurately at this location; this temperature differential is normally measured in the ductwork at a point between the end of the drum mixer and the entry of the exhaust gases into the emission-control equipment. This is done by means of a thermocouple attached to the ductwork upstream of the point where

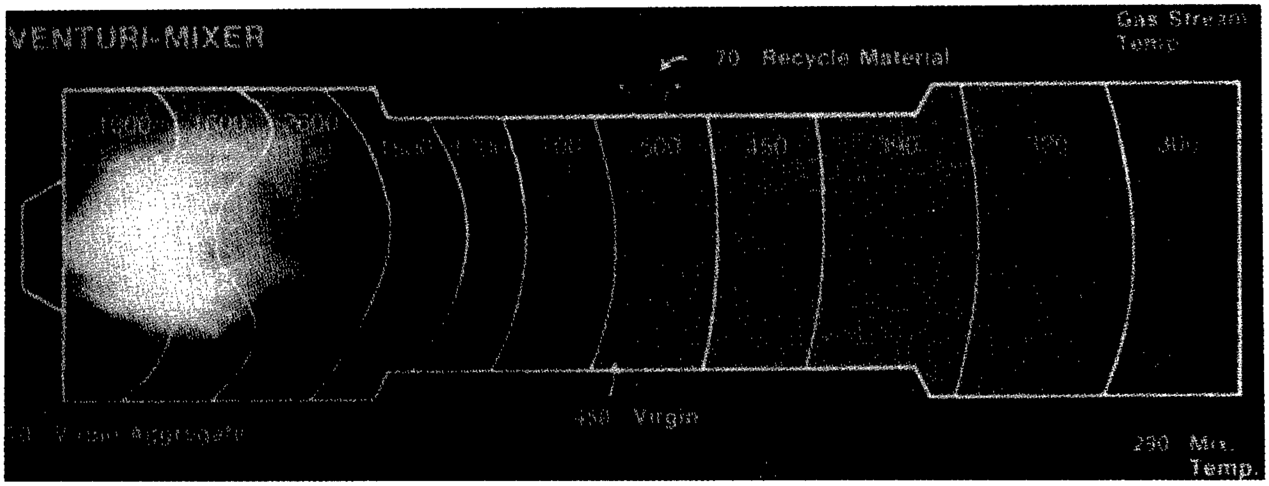


Figure 2-40. Drum temperature profiles *(CMI)*.

the exhaust gases are drawn into the wet-scrubber or baghouse system. For efficient operation of the drum mixer, the temperature of the exhaust gases, before entry into the emission-control system, should be within 20°F of the mix discharge temperature.

A comparison cannot normally be made between the mix discharge temperature and the temperature of the exhaust gases at the point at which they exit the plant stack. If a wet scrubber is employed on the plant, the water used to impinge on the dust particles in the exhaust gases will naturally cool the gases. For both wet-scrubber and baghouse emission-control systems, any leakage air that is drawn into the ductwork and emission-control equipment between the end of the drum and the stack will reduce the temperature of the exhaust gases before they leave the stack. Thus, the comparison between the mix discharge temperature and the exhaust gas temperature must be made in the ductwork before the gases enter the emission-control equipment. The comparison should not be made between the mix discharge temperature and the stack temperature, particularly for plants equipped with a wet-scrubber system.

For example, if the exhaust gas temperature in the ductwork is 360°F and the mix discharge temperature is 280°F, the veil of aggregate inside the drum is probably incomplete and the drum is being operated inefficiently. This causes several problems: increased fuel use, possible separation of some of the very fine aggregate particles from the rest of the aggregate in the drum, and increased deterioration of the filter bags, if a baghouse is used.

The temperature of the exhaust gases must also be controlled at the location where the asphalt cement is injected. Certain asphalt cements, depending on the source of the crude oil and the refining process used to produce the material, may contain small amounts of volatile material or "light ends" that can be driven off at temperatures as low as 600°F. Visible emissions can be avoided if the temperature of the exhaust gases is below this value at the location where the asphalt cement enters the drum.

Exhaust gas temperatures will normally be higher when a recycled mix is being produced. This is related to the reduction in the density of the veil of aggregate upstream of the reclaimed material entry point (when a split-feed system is being used) and less efficient heat transfer. The greater the amount of RAP used in the recycled mix, the lesser amount of new aggregate, and the less complete the veil of material ahead of the reclaimed material entry point. In order to prevent the production of visible emissions (blue smoke) during recycling, the temperature of the exhaust gases should be below about 400°F at the point the reclaimed material enters the drum to prevent the generation of visible emissions from the plant stack.

Flight Design

The aggregate fed into the burner end of the drum mixer moves down the length of the unit by a combination of gravity flow and the lifting flights as the drum rotates. Factors that affect the length of time for an individual aggregate particle to pass through the drum include: the length and diameter of the drum, the slope of the drum, the number and type of flights inside the drum, the speed of rotation of the drum, and the size of the aggregate particles. In general, it takes about 4 to 8 min for an incoming aggregate particle to reach the

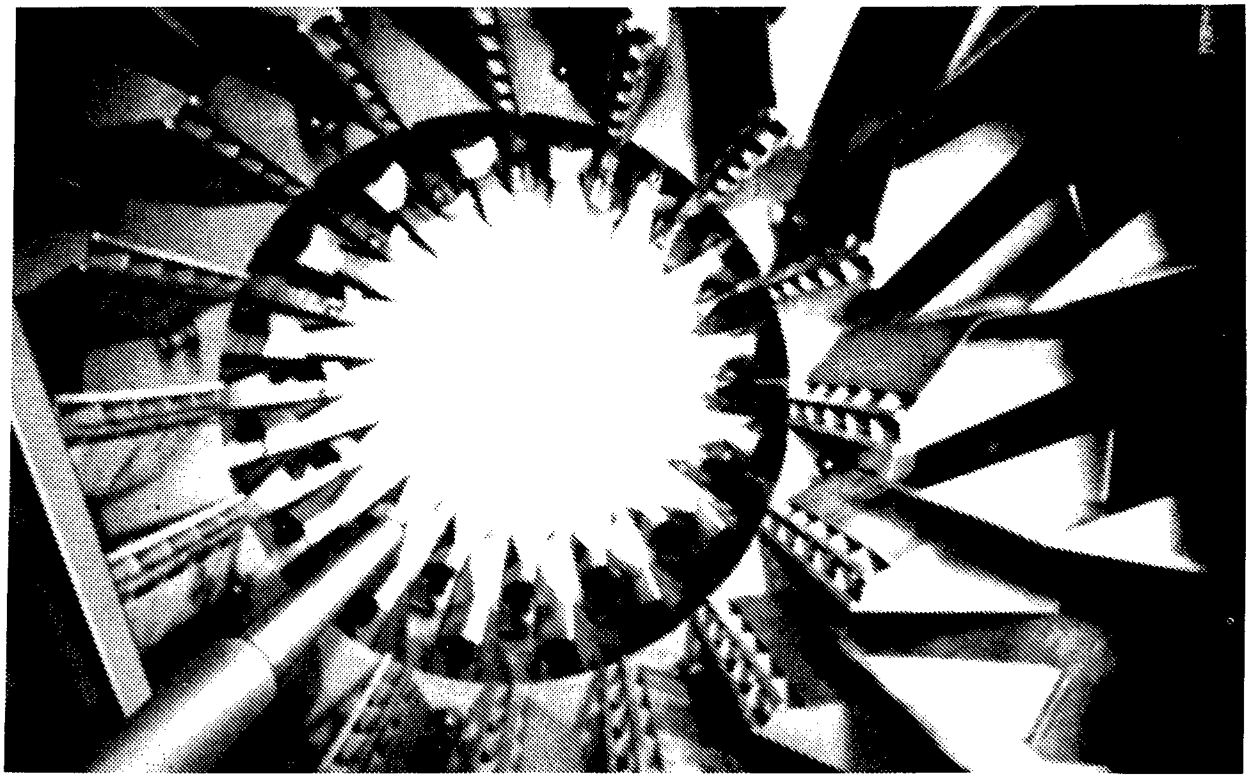


Figure 2-41. Rotary drum mixer flights *(J. Scherocman)*.

discharge end of the drum.

Each drum plant manufacturer uses a different pattern, shape, number, and location for the flights inside the drum, as shown in Figures 2-41 and 2-42. Although named differently by the various manufacturers, the flights used in the various sections of the drum generally serve the same purpose: to expose the aggregate to the heat from the burner gases without dropping it through the flame, to remove the moisture from the aggregate, to coat the aggregate with asphalt cement, and to heat the coated material to the proper discharge temperature.

Because the drum mixer operates on a parallel-flow basis, to protect the asphalt cement from the high temperatures, the burner flame should be short and bushy and not extend very far into the drum. The burner flame must have enough room, however, to expand and combust the fuel completely. The incoming aggregate cannot be deposited directly into the fire or it will quench the flame. Thus, the first flights at the upper end of the drum are used to direct the aggregate into the drum beyond the tip of the flame.

The next flights are used to lift some of the aggregate from the bottom of the drum, and begin to tumble the material through the exhaust gases. As the aggregate moves down the drum, an ever greater amount of aggregate is lifted and tumbled. Near the midpoint of the length of the drum, a veil of aggregate is developed across the whole cross-sectional area. This veil is essential to accomplish the heat transfer from the exhaust gases so that the drying and heating of the aggregate can take place. The more complete the veil, the more efficient and effective the heat-transfer process, the less fuel consumed, and the lower the particulate emissions from the plant.

Near the drum midpoint, some drum mixers are equipped with devices to retard the flow of the aggregate down the drum. A ring can be inserted inside the drum to reduce the diameter at that point. A buildup of aggregate occurs in front of the ring, creating a heavier veil of material. Some drum manufacturers install "kicker" or reverse-angle flights at this same location to intercept the aggregate and turn it back upstream, concentrating the aggregate in one area in order to increase the density of the veil and improve the heat transfer. Although restricting the diameter of the drum in some fashion is beneficial in order to increase the density of the veil of aggregate inside the drum, the

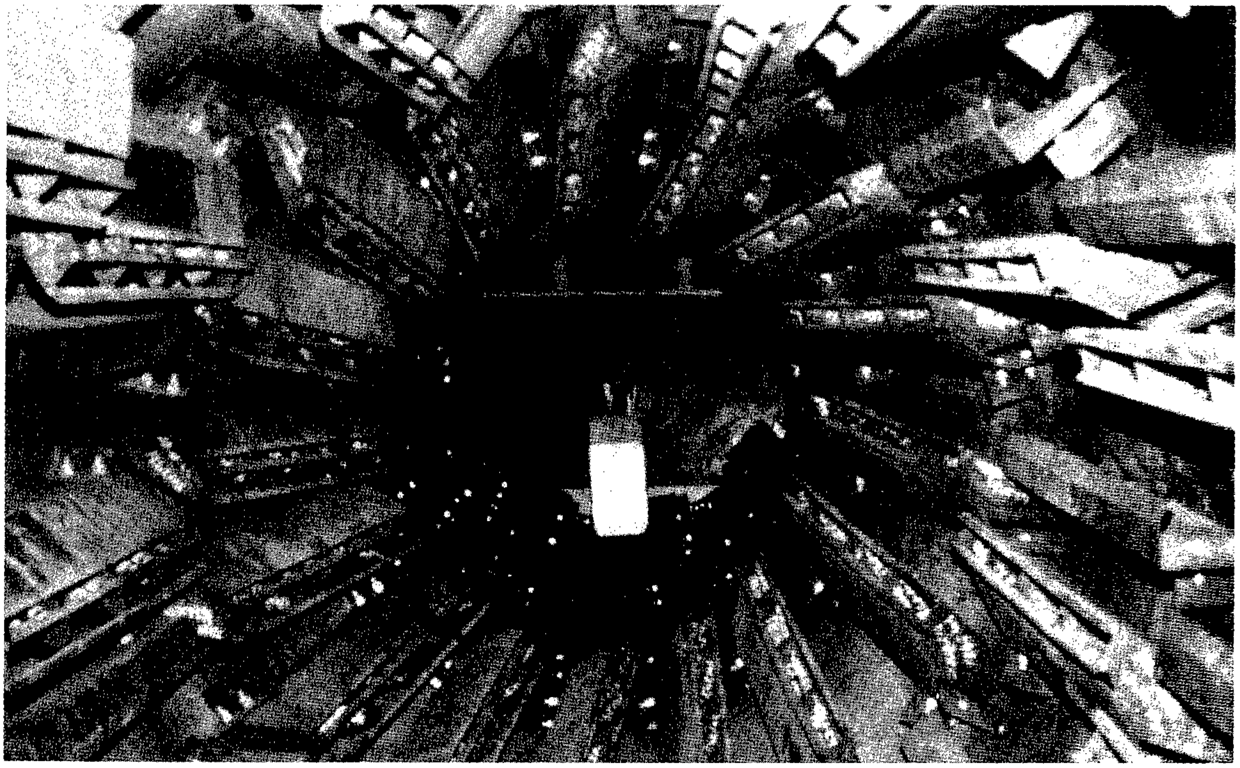


Figure 2-42. Drum flights *(J. Scherocman)*.

reduced cross-sectional area also causes the velocity of the exhaust gases to increase, thereby potentially increasing the amount of emissions from the drum mixer.

Farther down the drum length, the asphalt cement is injected into the drum and mixing flights are used to combine the aggregate with the asphalt cement. These flights also allow the asphalt cement-coated particles to continue to be heated by the exhaust gases, complete the heat-transfer process, and raise the mix temperature to the desired level for discharge. At the rear of the drum, discharge flights are employed to deposit the material into the discharge chute for transport to the surge silo.

As mentioned previously, the actual design of the flights that may be present inside a particular mixing drum will be different for the various makes, models, and date of manufacture of the drum. The primary purpose of the flights is to accomplish the proper transfer of heat from the exhaust gases to the aggregate and to blend the aggregate and asphalt cement together adequately. As the flights inside the drum wear from the abrasive action of the aggregate moving through the drum, the efficiency of the heating and drying process can be reduced. Thus, the condition of the flights should be checked on a regular basis. (The amount of wear on the flights depends on the operating conditions for the plant and the type of aggregate being processed.) Worn and missing flights should be replaced as necessary. In addition, if proper heat transfer is not being completed, the type and location of the flights used inside the drum can be altered to improve the veil of aggregate moving across the cross section of the drum at its midpoint.

Early drum mix plants were constructed with a 4:1 length-to-drum-diameter ratio that was used for batch plant dryers; an 8-ft-diameter dryer was 32 ft in length. The current trend is to use longer drums to obtain more complete heat transfer from the exhaust gases to the aggregate and to reduce emission problems, particularly when a recycled mix is being produced. Some current drum mixers have length-to-diameter ratios of 5:1 and 6:1. Thus, an 8-ft-diameter drum mixer might be 40 to 48 ft in length.

Increasing the Veil of Aggregate

To increase the density of the veil of new aggregate, kicker flights, dams, donuts, or retention rings are

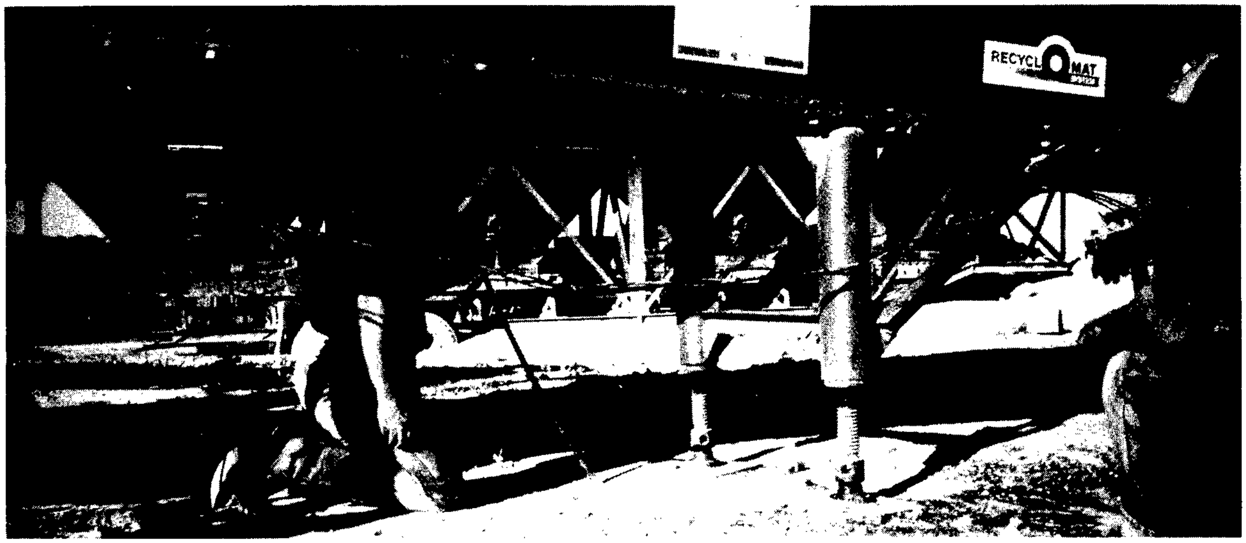


Figure 2-43. Adjustable drum leg supports for changing drum slope *(J. Scherocman)*.

employed to retard the flow of material down the drum. Another method used to achieve the same effect is to lower the slope of the drum, as shown in Figures 2-43 and 2-44. The reduction in slope (from a maximum of 6 percent to a minimum of 2 1/2 percent, or 3/4 in./ft to 5/16 in./ft) increases the dwell or residence time of the aggregate in the drum and thus provides more time to complete the heat-transfer process. The additional aggregate retained in the drum because of the lower slope also causes a denser veil of material across the drum cross section, further improving the degree of heat transfer.

Lowering the slope of the drum does not normally cause a change in the plant production rate. Although it takes somewhat longer for an individual aggregate particle to travel through the drum when the slope is decreased, the actual production rate should be unchanged in terms of tons per hour. Power requirements

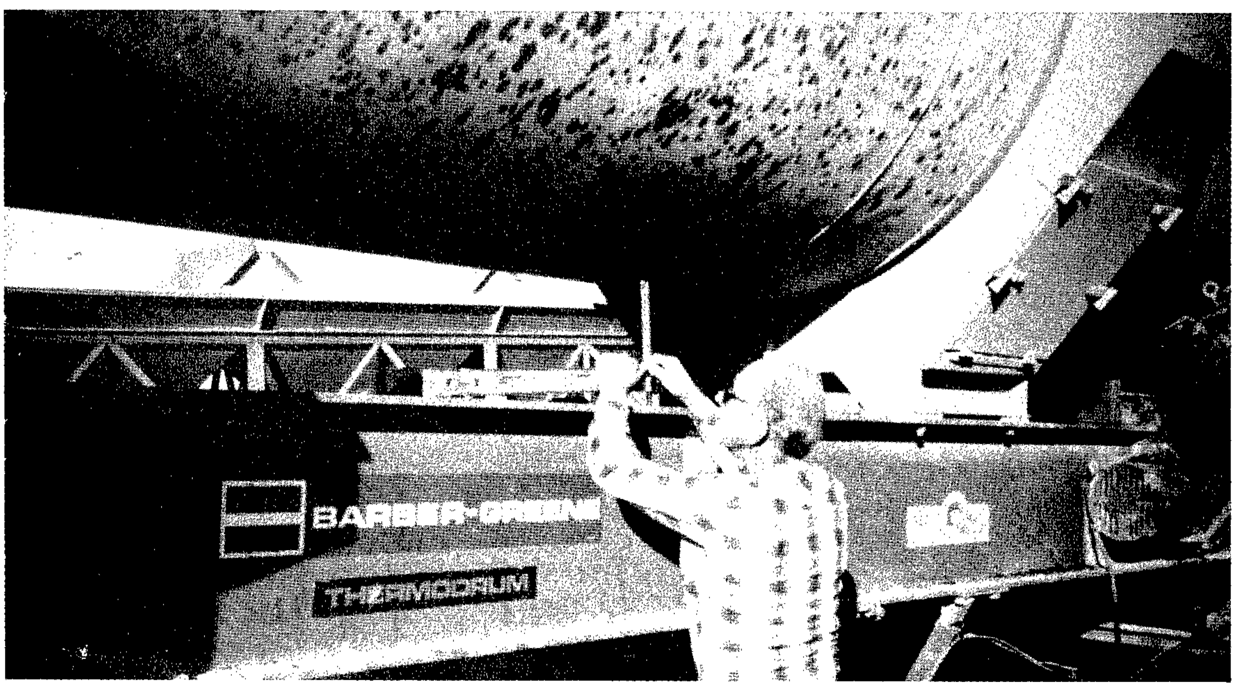


Figure 2-44. Measuring drum slope *(J. Scherocman)*.

for the electric motors used to turn the drum are increased because of the extra weight of aggregate in the drum. The net result, however, is a better veil of aggregate, more complete heat transfer, and a reduction in the temperature of the exhaust gases at all locations in the drum.

Several manufacturers have developed drum mixers that change in diameter along the length. The drum is one diameter at one or both ends and a smaller diameter in the center portion of the drum, as shown in Figure 2-45. The change in diameter allows more room for combustion of the burner fuel and provides for development of a denser veil of aggregate in the drum by squeezing the same volume of material that was tumbling in an 8 1/2-ft diameter drum, for example, into a 7-ft-diameter section, significantly increasing the density of the aggregate veil. In this case, the reduced diameter works in the same manner as the installation of a ring inside the drum. This heavier veil improves the efficiency of the heat-transfer process. The velocity of the exhaust gases, however, is also increased because of the smaller diameter, potentially increasing the amount of particulate emissions carried out into the emission-control equipment and also possibly reducing production levels.

Heat Transfer

While the exhaust gas temperature is being reduced as these gases move down the drum, the temperature of the aggregate is increasing as it travels in a parallel direction. The heat-transfer process takes place in three ways. The first is convection; heat energy is transferred from the exhaust gases to the aggregate. The second is radiation; heat energy is transferred from one heated aggregate particle to another aggregate particle and from the shell and flights of the drum to the aggregate. The third is conduction; heat energy is transferred within the aggregate particles.

The aggregate enters the drum at ambient temperature and begins to be heated immediately. As the material moves down the drum, its temperature is increased until it reaches a point upstream of the drum midpoint, where its temperature remains relatively constant because the heat from the exhaust gases is being used to evaporate the moisture in the aggregate. The amount of time the aggregate temperature remains constant depends in part on the amount of moisture in the incoming material. The porosity of the aggregate is also a factor, with the more porous material taking longer to remove all the moisture from the internal pores in the aggregate. Finally, because of its lesser mass and greater surface area per unit weight, the fine aggregate (sand) is typically heated more quickly than the coarse aggregate.

Once most of the moisture has been removed from the aggregate, its temperature begins to rise again. After the aggregate is coated with asphalt cement, mixing flights are employed in most drum mix plants to tumble the mix, partially exposing the material to the exhaust gases. The mix reaches the required discharge temperature as it approaches the end of the drum. Thus the aggregate, as it proceeds down the drum, undergoes a heating, then a drying, and then another heating cycle. The moisture content of the aggregate decreases gradually in the front portion of the drum and then more rapidly as it reaches the temperature needed to vaporize water. If the dwell time in the central portion of the drum is long enough, the moisture content of the mix at discharge can be reduced to less than 0.2 percent. The moisture content of the mix at discharge is almost always less than 0.5 percent.

ASPHALT CEMENT INJECTION

On a few older drum mix plants, the asphalt cement supply line enters from the front of the drum, at the burner end. The diameter of the pipe used depends on

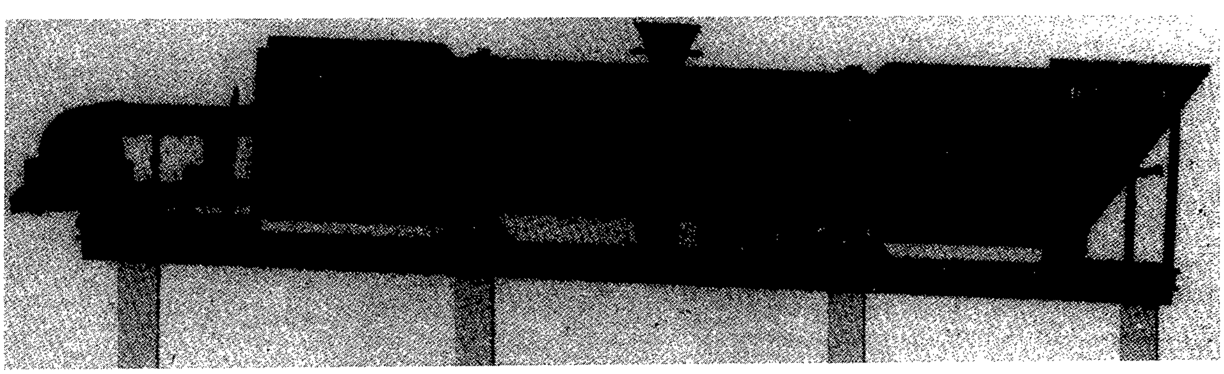


Figure 2-45. Dual-diameter drum *(Caterpillar-CMI)*.

the capacity of the plant, with a 2- to 4-in. line typically used. The asphalt cement is not normally sprayed through a nozzle but is injected into the drum merely by passing out of the end of the pipe. The actual point of discharge varies, but tends to be toward the midpoint of the drum length rather than close to the burner.

One advantage of early asphalt cement introduction is quick capture of the dust particles in the aggregate by the binder material. This action reduces the amount of particulate carryout by encapsulating the fines in the asphalt cement. Three disadvantages are present: the asphalt cement may be hardened more by exposure to the higher-temperature exhaust gases, the production of blue smoke from volatilization of the light ends from certain asphalt cements can be increased because of these higher exhaust gas temperatures, and an increase in the moisture content in the mix at discharge may occur because the asphalt cement coats the aggregate particles before all the water in the material is removed.

On most parallel-flow drum mix plants, the asphalt cement is injected through a pipe coming in from the rear of the drum, as illustrated in Figures 2-46 and 2-47. The location of the asphalt cement entry in many cases is at a point approximately 40 to 30 percent of the length of the drum from the mix discharge end of the mixer (60 to 70 percent of the way down the drum from the burner end). At this location, the small amount of moisture remaining in the aggregate causes the volume of the binder to expand by foaming and helps to coat the aggregate. In a drum mix plant, coating rather than mixing may be the more appropriate term for the blending of the asphalt cement with the aggregate.

If the moisture content in the aggregate is still high at the point where the asphalt cement is injected, the coating of the aggregate particles may be delayed until more moisture is removed. When the average moisture content of the incoming aggregate is very low (less than 1 percent), incomplete coating of the aggregate may occur. In this latter case, it may be necessary to add water to the incoming aggregate on the cold-feed belt or to change the design of the flights inside the drum in order to improve the aggregate coating by the asphalt cement.

If the asphalt cement being used contains volatile material and results in excessive blue smoke emissions, it may be necessary to pull the asphalt cement supply pipe toward the mix discharge end of the drum. This change reduces the exposure of the asphalt cement to the higher-temperature exhaust gases and decreases the generation of visible hydrocarbon emissions. If the veil of aggregate at the mid length of the drum is adequate, however, it should not be necessary to pull the asphalt cement line back. The movement of the supply line can decrease the uniformity of the coating of the binder on the aggregate if it is too close to the discharge end of the drum.

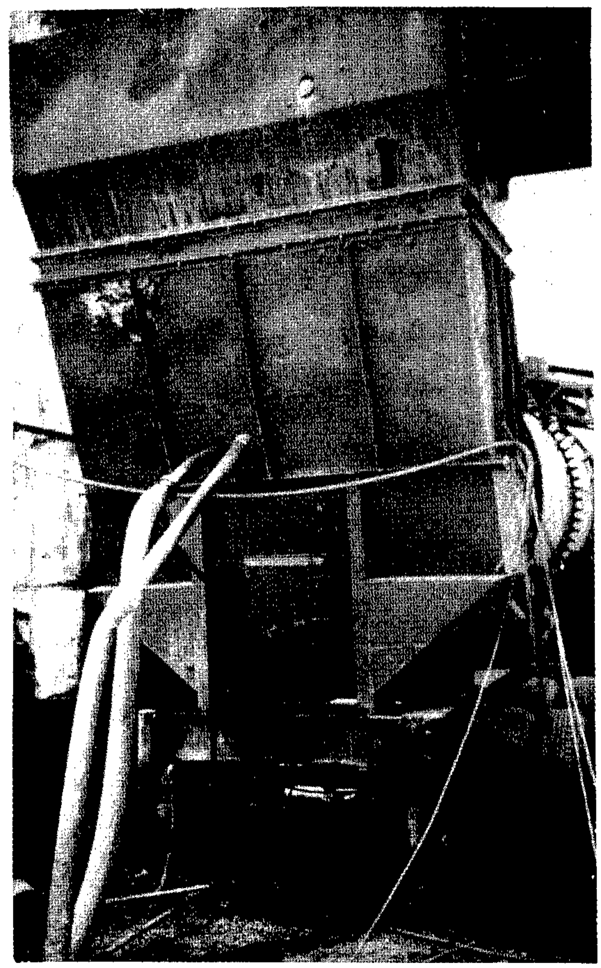


Figure 2-46. Asphalt and fines feed lines *(J. Scherocman)*.

Some drum mix plants, however, have the asphalt cement injection line completely removed from the drum. The aggregate is heated and dried in the drum but exits uncoated. The aggregate is discharged into a

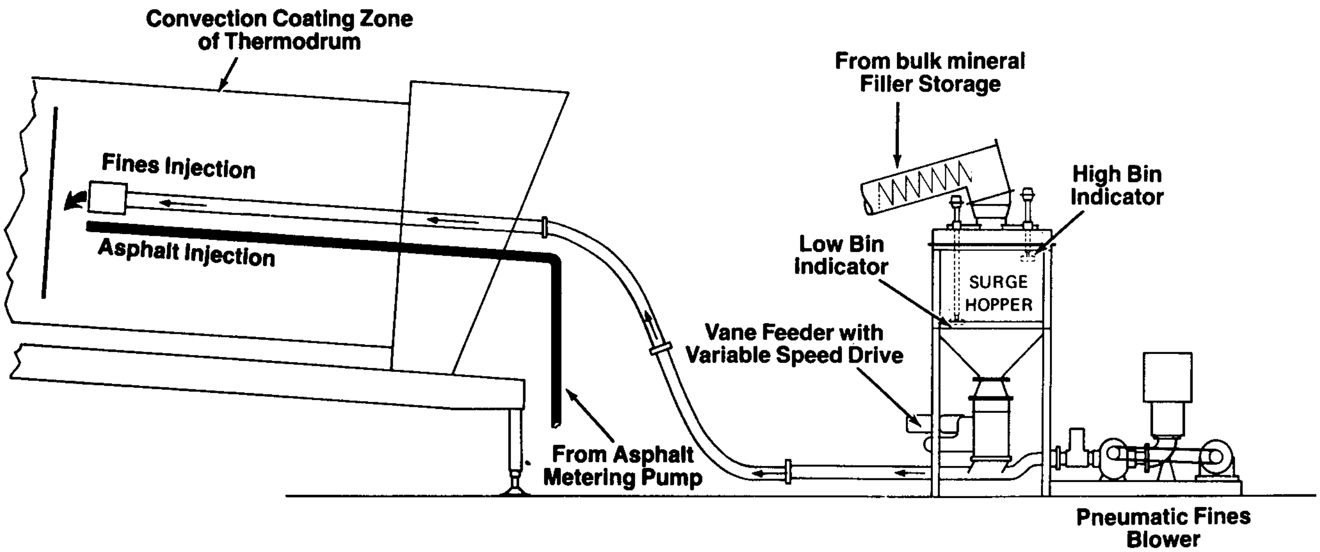


Figure 2-47. AC line discharge end and mineral filler feed system *(Barber-Greene)*.

single- or twin-shaft coater unit (screw conveyor), where the asphalt cement is sprayed on it, as shown in Figure 2-48. The mixing of the materials occurs as the aggregate and asphalt cement are moved along the drum mix coater. The blended material is then deposited into a transfer device for transport to the surge silo. The drum mix coater plant is a return to the original continuous mix plant technology.

MINERAL FILLER AND BAGHOUSE FINES FEED SYSTEM

Two types of aggregate fines, mineral filler and material collected in a dry emission-control system, can be fed into a drum mix plant, either individually or in combination with one another. The basic equipment needed to handle each type of material is essentially the same. The primary differences between the various systems concern the degree of sophistication in the controls used to meter the materials.

Mineral Filler

Mineral filler-type material, such as hydrated lime, portland cement, fly ash, or limestone dust, is stored in a silo or other appropriate container and is delivered to the plant through a vane feeder system or small weigh hopper located at the bottom of the silo, as seen in Figure 2-47. The speed of the feeder is related to the amount of new and reclaimed aggregate being delivered to the drum. The silo is normally equipped with an aerating system to keep the mineral filler from packing into a tight mass and bridging the opening to the feeder. If the flow of filler is restricted, the vane feeder will still rotate, but no material will be sent to the plant.

The mineral filler-type material can be delivered to the charging conveyor on the cold-feed system and delivered into the drum as part of the aggregate. This is not recommended for several reasons. First, there is a problem of dusting of the filler material when it is

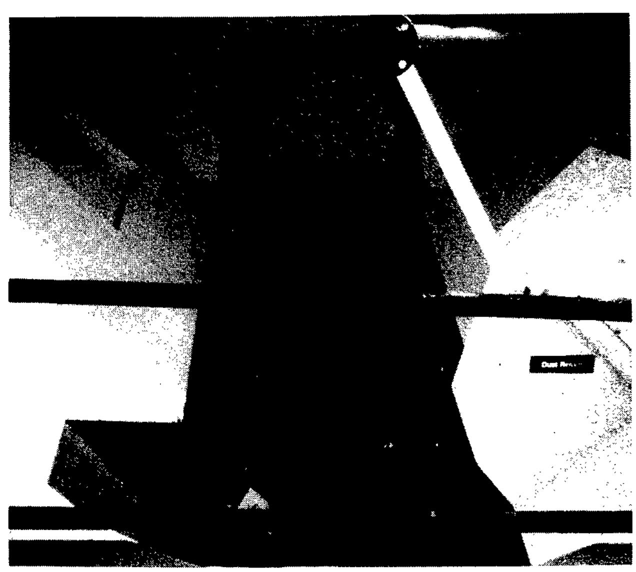


Figure 2-48. Mixing auger in "coater" drum mix plant *(Astec)*.

deposited on the incoming aggregate. Second, the very fine filler has a tendency to become airborne easily inside the drum (picked up in the exhaust gas air stream) and carried either to the discharge chute on the drum or into the emission-control equipment. Thus, some of the filler can be carried out of the drum mixer instead of being incorporated into the mix.

It is also possible to blend the mineral filler-type material with the asphalt cement in the storage tank before the combined materials are fed into the plant. This is rarely done, however, because of problems of separation and settlement of the heavier mineral filler (higher specific gravity) from the lighter asphalt cement whenever plant production is interrupted.

The mineral filler from the vane feeder thus typically enters the delivery pipe and is conveyed pneumatically through the line and into the rear of the drum. The filler can be discharged in one of several ways: deposited from the line onto the aggregate at the bottom of the drum or fed into a mixing device, where it is coated with the asphalt cement before it is dropped into the drum, as shown in Figure 2-49.

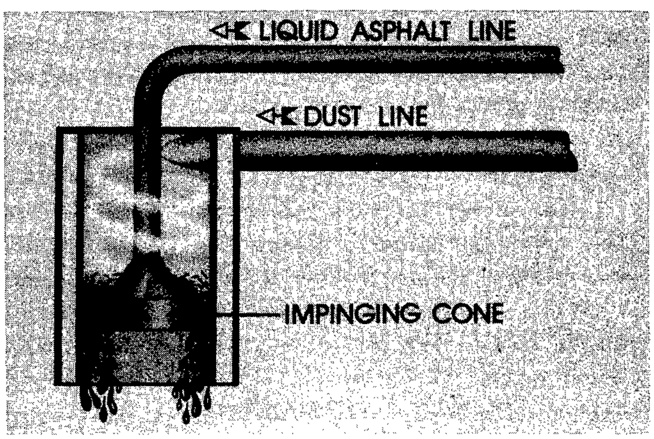


Figure 2-49. AC-MF-BH fines mixing device *(Astec)*.

If the mineral filler is discharged directly into the drum mixer, it can be either upstream or downstream of the asphalt cement injection point. If the filler is placed into the drum upstream of the asphalt cement entry point, it is usually dropped directly on the aggregate in the bottom of the drum. Because the filler is dry and of very small particle size, it is easy for this material to be caught in the exhaust gas air stream. If this occurs, some portion of the filler will remain in the mix, but a major portion of the material, depending on drum operating conditions, can be carried out of the drum and into the emission-control equipment.

If the mineral filler is discharged from its feed pipe into the drum after the asphalt cement has been injected into the drum mixer, a greater portion of the filler is usually captured in the mass of asphalt cement and aggregate. Because it comes into contact with the asphalt cement very quickly after exiting its feed pipe, the mineral filler has less chance of becoming airborne and being carried out of the drum. If the mineral filler and asphalt cement are blended together in some form of mixing device as the asphalt cement is being introduced into the drum, minimal carryout of filler material normally occurs.

Baghouse Fines

If a baghouse (fabric filter) is used as the emission-control equipment on the plant, either all or a portion of the material captured in that device can be fed back into the drum mixer. The fines captured in the baghouse are carried, usually by a screw conveyor, through an air lock and then fed pneumatically through a pipe into the rear end of the drum, as seen in Figure 2-50.

The baghouse fines are typically not metered but are returned on a continuous basis and discharged into the drum in a fashion similar to that of mineral filler. Occasionally a surge of fine material may be carried back to the drum mixer. If plant operating characteristics cause such surges of baghouse fines to occur regularly, the fines should be collected in a small surge silo and then metered back into the plant using a vane feeder system. (If the baghouse fines are not needed to satisfy mix design requirements, they can be wasted instead of being returned to the mix.)

The returned fines must be incorporated into the asphalt mixture and not be allowed to recirculate back to the baghouse. This is accomplished by ensuring that the fines are kept out of direct contact with the high-velocity exhaust gases and are quickly coated with asphalt cement. If the fines are carried back to the baghouse, they will be caught and again returned to the drum mixer. Soon the baghouse will be overloaded with fines, because new fines are continually being generated by the plant. The baghouse will become plugged and will not operate properly. It is essential, therefore, that any mineral filler and/or baghouse fines be coated with asphalt cement before they can be picked up by the exhaust gases and carried out of the mixer.

The amount and gradation of the baghouse fines returned to the asphalt mix inside the drum can have a significant effect on the properties of the mixture produced. Before any fines are returned to the mix, a laboratory analysis should be conducted to determine the characteristics of the baghouse fines and the change in mix properties that may occur when various quantities of baghouse fines are returned to the mix, or wasted.

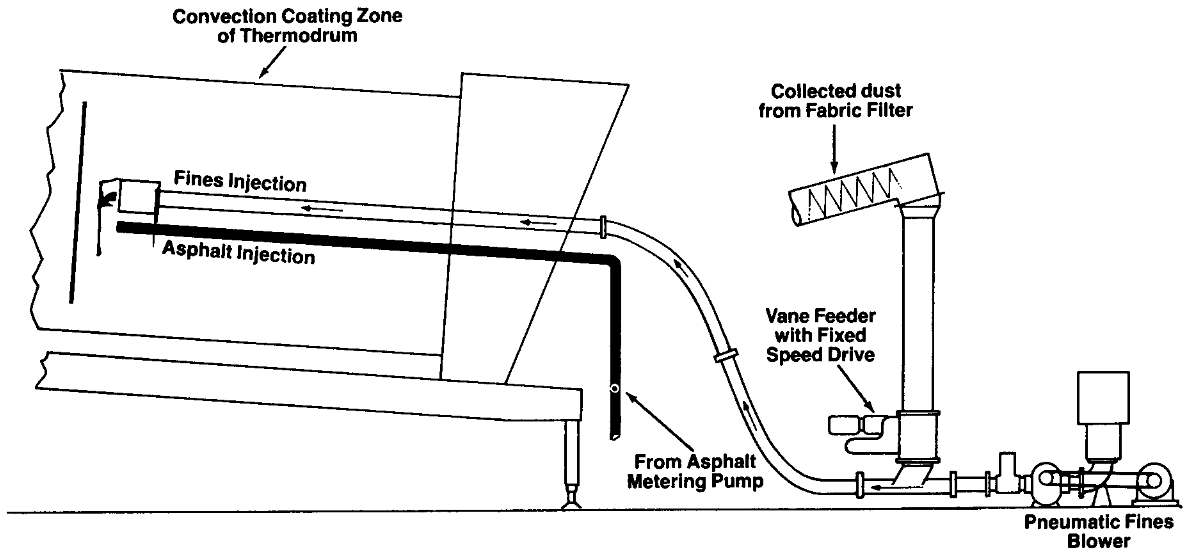


Figure 2-50. Baghouse fines feed system *(Barber-Greene)*.

RECLAIMED MATERIAL RECYCLING SYSTEMS

Single-Feed

On the few remaining plants that use a single-feed system to deliver both the new aggregate and the RAP to the burner end of the drum mixer, several methods are used, alone or in combination, to protect the asphalt-coated material from direct contact with the flame and to reduce the generation of visible hydrocarbon emissions. One method is to spray water on the combined aggregate on the charging conveyor before it enters the drum. The degree of protection offered by the additional water on the surface of the aggregate depends on the amount of moisture already in and on the reclaimed material, the amount of water applied (typically between 1 and 4 percent by weight of reclaimed aggregate), and the position of the reclaimed material on the charging conveyor--underneath or on top of the new aggregate.

A second procedure is to increase the speed of the slinger conveyor under the burner in order to throw the combined aggregates farther down the drum. The more the asphalt-coated materials are kept from the flame, the less hydrocarbon emissions are generated.

A third method uses a heat shield to reduce the contact of the combined aggregate with the flame, as shown in Figure 2-51. This device spreads the flame out around the circumference of the drum and decreases the concentration of heat at any one point near the flame. The performance of the heat shield is dependent on its location inside the drum, the amount of RAP in the mix, the moisture content of new and reclaimed aggregate, and the required mix discharge temperature. The efficiency of the heat shield can be determined by the amount of blue smoke that is generated during the recycling operation.

Split-Feed

Because of inherent emission-control problems using the single-feed method, split-feed systems, in which the RAP is fed to the drum mixer separately from the new aggregates, are most often used to produce recycled asphalt mixes. The new material is delivered to the burner end of the drum mix plant in a conventional manner. The RAP is delivered into a separate entry point near the midpoint of the drum length, as shown in Figure 2-52.

A variety of designs are used for the intake system to introduce the RAP into the drum. Typically, the drum has a series of ports or entry chutes, illustrated in Figure 2-53, cut into the shell to allow the RAP to be introduced from the charging conveyor as the drum turns. At the point that the RAP enters the shell, a short length of the flighting is often removed or configured so that the asphalt-coated material can easily be added to the new aggregate. The RAP begins heating as soon as it enters the port. The combined aggregate is picked up by the flights, and the heating and drying of the new material and the RAP is continued.

When reclaimed material is charged into the drum at its midpoint, less new aggregate is placed into the drum at the burner end, reducing the density of the veil of aggregate upstream of the RAP entry and decreasing the amount of heat transferred from the exhaust gases to the new aggregate. Thus, the temperature of the gases

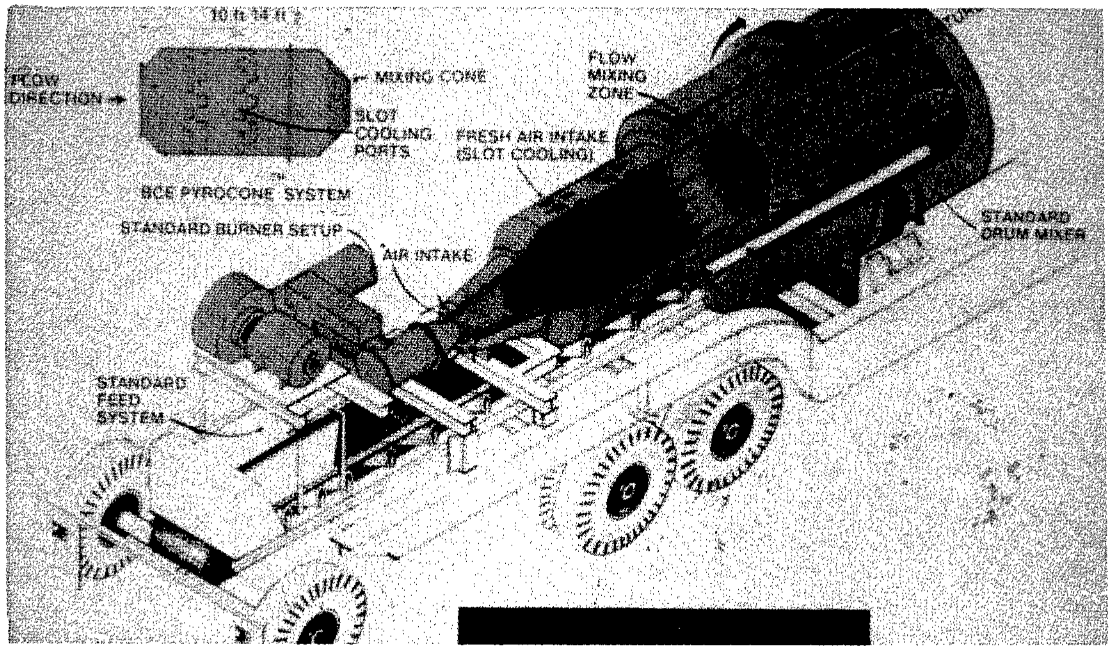


Figure 2-51. Heat shield inside drum *(Boeing)*.

at the point they come in contact with the RAP is higher and the chance to burn the asphalt coating on the reclaimed aggregate is increased. This problem increases in severity as the amount of RAP used in the recycled mix increases. Methods to reduce the exhaust gas temperature involve ways to increase the density of the veil of new aggregate upstream of the RAP entry location as well as to raise the temperature of the RAP before it comes into contact with the heated new aggregate.

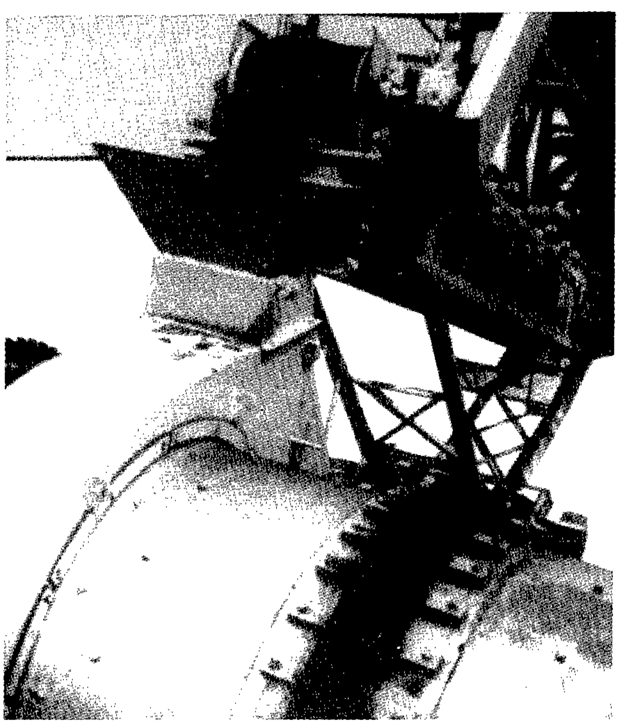


Figure 2-52. Center rotary drum inlet *(Cedarapids)*.

Normally, if 20 percent or less RAP is being incorporated into a recycled mix and a split-feed system is used, minimal hydrocarbon emissions are produced, depending on the adequacy of the veil of new aggregate inside the drum and the discharge temperature of the mix. As the percentage of RAP becomes greater, and as the moisture content of the RAP increases, the potential for emission problems increases. When the amount of RAP used exceeds 50 percent, by weight of mix, the emission of blue smoke during the recycling process can become significant. A combination of procedures, outlined above, is needed to assure adequate heat transfer from the exhaust gases to the new aggregates before those gases come in contact with the reclaimed material.

Only under ideal and carefully controlled production conditions may it be possible to incorporate up to 70 percent reclaimed aggregates in a recycled mix without major visible emission problems. Because of the reduction of production rates and the emission-control problems that occur when high percentages of RAP are used

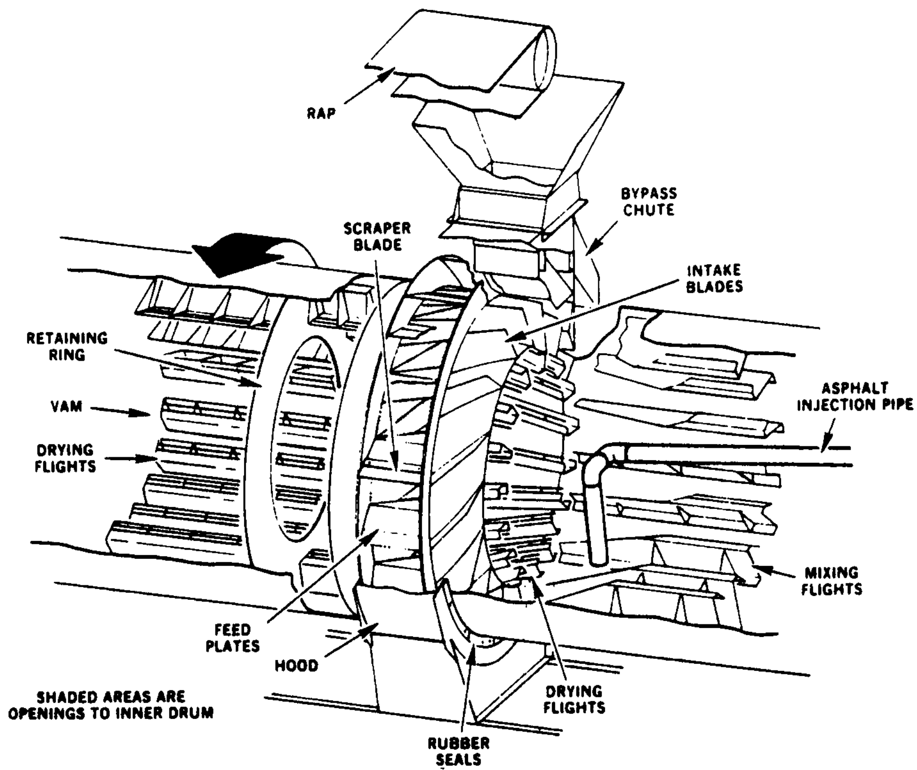


Figure 2-53. RAP material center feed *(Cedarapids).*

in a recycled asphalt mix, it is normally good practice to limit the amount of reclaimed material processed through a split-feed drum mix plant to approximately 50 percent of the total aggregate weight.

PRODUCTION RATES

Hot-mix asphalt drum mix plants are rated by the number of tons of mix that can be produced per hour. The production capacity is usually related to the incoming aggregate temperature, the mix discharge temperature, the specific heat of the aggregate, and an average aggregate moisture content removal of 5 percent, with the plant operated at sea level. Plant capacities are also affected by a number of other variables including drum diameter, fuel type, exhaust gas velocity, capacity of the exhaust fan, amount of excess air at the burner, estimated air leakage into the system, and atmospheric conditions. Aggregate gradation may be a factor with mixes containing a large percentage of coarse aggregate because they are more difficult to heat uniformly than mixes incorporating a balance of coarse and fine aggregate particles.

Drum Diam. & Length (ft)	Surface Moisture Removed (%)								
	2	3	4	5	6	7	8	9	10
5x22	178	140	116	100	84	79	74	63	58
6x24	278	220	178	158	137	121	116	100	89
7x30	420	336	273	236	205	184	163	147	137
8x32	541	430	352	305	263	236	210	194	173
9x36	719	578	478	410	357	315	284	257	236
10x40	956	761	630	541	473	430	378	341	315

Figures for each size dryer are for asphalt concrete mix capacities.
Examples of the effects of moisture content on plant production rates are for one manufacturer's drum mix plants.

Figure 2-54. Nominal drum mix capacities (tons per hour) *(Barber-Greene).*

One of the variables that has the greatest effect on the actual production rate is the average moisture content of the coarse and fine aggregate. The moisture content of the fine aggregate is usually higher than that of the coarse aggregate. The average moisture content is thus a function of the amount of moisture in the coarse aggregate and its percentage in the mix, plus the amount of moisture in the fine aggregate and its percentage in the mix.

If, for example, 60 percent of the mix consists of coarse aggregate, then 40 percent of the mix is fine aggregate (assuming no mineral filler is used in the mix). If the moisture content of the coarse material is 3.0 percent and that of the fine aggregate is 8.0 percent, the average moisture content in the combined aggregate is calculated to be: (60 percent x 3.0 percent) + (40 percent x 8.0 percent) = (1.8 percent) + (3.2 percent) = 5.0 percent. If the amount of moisture in the fine aggregate was only 6.0 percent, the combined (average) moisture content of the cold-feed materials would be: (60 percent x 3.0 percent) + (40 percent x 6.0 percent) = (1.8 percent) + (2.4 percent) = 4.2 percent.

As the average percentage of moisture in the aggregate increases, the production capacity of a drum mixer of a given diameter decreases because of the limited maximum capacity of the exhaust fan. At a constant average incoming moisture content, the production rate increases as the drum diameter increases. The theoretical relationship between average moisture content, drum diameter, and the calculated drum mix plant production rate (at a mix discharge temperature of 270°F) is shown in Figure 2-54 for different models for one particular make of plant, at a given volume of exhaust gas flow and set of operating conditions for each size of plant. (Similar charts are available from manufacturers of other makes of drum mixers.)

Using this figure, at an average moisture content of 5 percent, a drum mix plant having a diameter of 6 ft would have a theoretical production capacity of 158 tons of mix/hr. If a drum 8 ft in diameter were used instead, the manufacturing rate would increase to 305 tons of mix/hr. For a drum mixer 10 ft in diameter, the capacity would increase to 541 tons of mix/hr at 5 percent moisture removal.

As the moisture content in the aggregate decreases from 5 percent to 3 percent, the production rate for a drum mixer that was 8 ft in diameter would increase to 430 tons of mix/hr from 305 tons/hr. If the aggregates have a higher moisture content (for example, 8 percent), the same 8-ft-diameter plant would only be able to manufacture 210 tons of asphalt mix/hr. Thus, the average moisture content of the aggregate directly affects the capacity of a drum mix plant.

The mix discharge temperature, held constant at 270°F in the example above, also affects the production rate of the plant; as the mix discharge temperature decreases for a given aggregate moisture content and drum size, the volume of mix that can be manufactured in a given period of time increases. In Figure 2-55, for a drum mix plant from one manufacturer that is 7.33 ft in diameter and 28 ft in length, with 5 percent moisture removal, the production rate will increase from 255 tons/hr at a mix discharge temperature of 300°F to 300 tons/hr at a temperature of 250°F. When the moisture content on the incoming aggregate is relatively high, the production rate changes are not as great when the mix discharge temperature is decreased. At 8 percent average moisture content, the production capacity of the same plant increases from 175 to 200 tons/hr as the mix discharge temperature decreases from 300°F to 250°F.

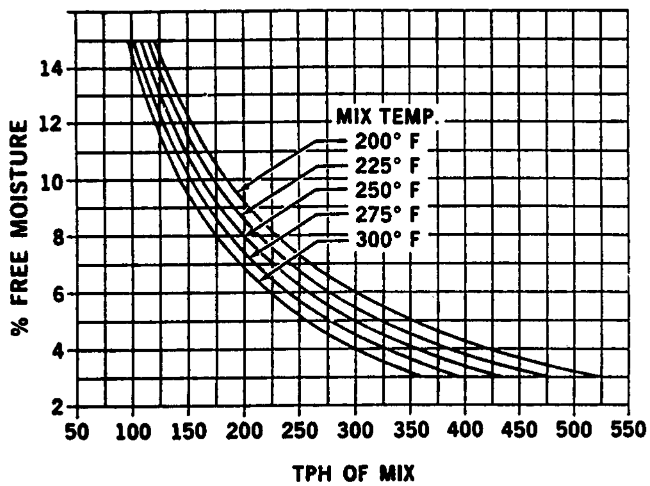


Figure 2-55. Moisture content-mix temperatures, as they affect production rate *(Cedarapids)*.

The production rate of a drum mix plant is also affected by the volume of the exhaust gases being pulled through the system by the exhaust fan. As the volume of gases being pulled through the drum decreases and as the velocity of those gases also decreases, the production capacity of the drum mixer will be reduced.

The production rate of recycled mixtures, for those plants that operate on a split-feed system, is also a function of the volume of reclaimed material being fed into the drum mixer. For these plants, as the amount of RAP delivered to the drum becomes greater than 50 percent of the total aggregate feed, the capacity of the plant is decreased, as shown in Figure 2-56, for one particular make of drum mix plant. This is caused by the lack of an adequate amount of new aggregate in the upper end of the drum mixer to provide for proper heat transfer from the burner exhaust gases to the new aggregate. This, in turn, reduces the heat transferred from the new aggregate to the RAP material.

Using Figure 2-56, a recycled mix that is made up of 60 percent RAP and 40 percent new aggregate, with the weighted moisture content in the combined materials at 5 percent, would have an index number of approximately 0.70. The index number means that the plant could produce only 70 percent as much mix/hr, at a 60/40 blend of reclaimed and new aggregate, as could the same plant producing mix using all new aggregate. Thus, if the plant could manufacture 308 tons/hr at 5 percent moisture removal with 100 percent new material, it would theoretically have a capacity of only 308 x 0.70 = 216 tons/hr when 60 percent reclaimed aggregate is incorporated into the mix. As the amount of RAP used in the recycled mix increases above 50 percent, the amount of mix that can be produced in a drum mix plant is reduced in proportion to the increasing amount of reclaimed material used.

The index number above provides a means of estimating the effect of the introduction of RAP into the drum mixer on the production rate of the plant. The actual production rate for a drum mix plant will depend on a variety of factors including the volume of gases being pulled through the system and the temperature of those gases. In addition, several of the newer types of continuous-mix plants, such as the counter flow drum mixer, are generally more efficient in the heat-transfer process and thus can process amounts of RAP above 50 percent with less effect on the production rate of the plant.

PLANT EFFICIENCY

Mix and Stack Temperatures

If perfect heat transfer could take place inside the drum, the temperature of the mix upon discharge from the parallel-flow drum mix plant would be equal to the temperature of the exhaust gases at the same point. This equilibrium point would mean that the heat transfer is in balance and that the drum mixer is running at maximum possible heat-transfer efficiency. Under normal operating conditions, if the veil of aggregate inside the drum is complete, the exhaust gas temperature, measured at the drum exit or before the gases enter the emission-control system, should be within 20°F of the temperature of the mix (assuming that no leakage or cooling air is added in the ductwork between the end of the drum and the point at which the gas temperatures

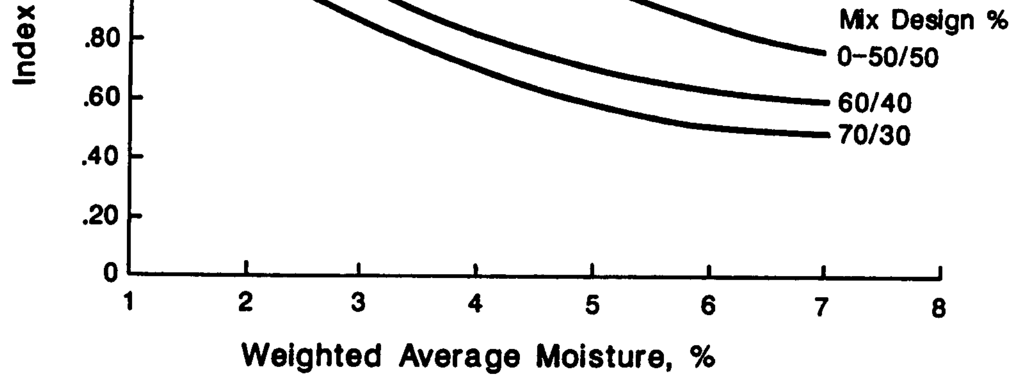


Figure 2-56. Effect of amount of reclaimed material on drum mix plant production *(Barber-Greene)*.

are measured in the ductwork). Thus, if the mixture discharge temperature is 280°F, the measured exhaust gas temperature should be less than 300°F. This small temperature differential implies that the drum mixer is operating efficiently and that minimum fuel/ton is being burned.

If the exhaust gas temperature is found to be more than about 20°F above the mix temperature, the heat-transfer process inside the drum is not as efficient, primarily because of the lack of an uniformly dense veil of aggregate across the cross section of the drum. Temperature differentials of up to 100°F between the mix and the exhaust gases are sometimes found, indicating that the plant is not being maintained or operated properly and that emission control might be a problem. The degree of operating inefficiency is related to the difference in the two temperatures (mix discharge and exhaust gas) before entry into the emission-control system.

During the production of a recycled asphalt mixture in a single-feed drum mixer, the heat transfer between the exhaust gases and the new and reclaimed aggregates should be similar to that for a mixture using all new material. Thus, for this process, the exhaust gas temperature should be within the 20°F temperature difference if the plant is operating correctly. If a split-feed-type plant is being employed, the difference in the two temperatures might be greater than 20°F, depending on the proportion of RAP introduced at the center inlet point. As a higher percentage of reclaimed aggregate is incorporated in the recycled mix, the temperature differential increases. When 50 percent of the recycled mix consists of RAP, the temperature of the exhaust gases may be more than 70°F above the mix discharge temperature.

The efficiency of the heating and drying operation, therefore, can be judged in part by observing the temperature differential that exists between the mix upon leaving the drum and the exhaust gases measured in the ductwork. Because both temperatures usually are recorded continuously and are displayed on the plant control console, this method of monitoring the plant production process is easy to accomplish.

High exhaust gas temperatures can also lead to significant, premature corrosion on one side of the ductwork between the discharge end of the drum mixer and the primary collector. This corrosion is another indication that the efficiency of the plant operation needs to be monitored and that the temperature of the exhaust gases at the time they exit the drum mixer must be controlled.

Mix Discharge Monitoring

A second way to judge the efficiency of the drum mix plant operation is to observe the asphalt mixture as it is discharged from the drum. The appearance of the mix, whether it consists of all new aggregate or a blend of new and reclaimed aggregate, should be uniform across the width of the discharge chute. The color of the aggregate particles should be consistent and the finer aggregate particles should be evenly distributed throughout the mixture.

If the fuel used by the burner is not being completely combusted, the coarser aggregate particles in the mix may appear to be covered with a dark brown stain instead of with the proper film thickness of asphalt cement. In addition, the adhesion of the asphalt cement binder to the aggregate may be reduced and the mix would have an increased tendency to strip when tested for potential moisture damage.

If the veil of aggregates inside the drum is not complete, the exhaust gases will travel down one side of the drum, depending on which direction the drum is turning, at a higher velocity than on the other side of the drum. Fine dust-sized particles are picked up in the gas stream and carried to the rear of the drum. As the exhaust gases change direction to enter the ductwork, the larger dust particles drop out of the gas. These uncoated particles are discharged on one side of the mixture as it exits the drum. A steady stream of light brown, uncoated, fine aggregate particles on one side of the asphalt concrete mix discharge chute thus provides an indication that the veil of aggregate inside the drum is incomplete.

If a dry, powdered additive such as hydrated lime is being added to the incoming cold aggregate at the burner end of the mixer, it is possible for very fine material to be picked up in the exhaust gases shortly after it is charged into the plant. When the aggregate veil is proper, the fine material will be trapped in the tumbling mass of aggregate and incorporated into the mix. If the aggregate veil is incomplete, however, the powdered material can be carried down one side of the drum and then dropped into the bottom of the drum at the mix discharge point, depending on the size of the particles relative to the exhaust gas velocity. The powdered material will then be visible on one side of the asphalt mixture as it is discharged from the drum, as illustrated in Figure 2-57. Thus, this method of adding the mineral filler-type material should not be used unless that filler is well blended with the incoming aggregate before the two materials are charged into the drum mixer.

Figure 2-57. Unmixed hydrated lime at mix discharge chute *(J. Scherocman).*

Typically a high stack temperature in comparison with the mix discharge temperature will be accompanied by a stream of light-colored fines on one side of the mix discharge chute. Both of these phenomena are indications that the drum mixer is not operating efficiently. The plant operator should alter the production process to achieve a denser veil of aggregate in the drum. The plant should be operated at the most efficient production rate, irrespective of demand; the plant should be shut down when the silos are full and restarted when mix is needed once again.

SUMMARY OF DRUM MIXER OPERATING TECHNIQUES

When observing the operation of the drum mixer, a number of factors should be considered to assure that the plant is operating properly. Those factors include:

- The sound of the burner should be monitored. A uniform, constant roar is desirable. A coughing, sputtering, or spitting sound may mean that the burner is not able to combust the fuel that it is trying to burn completely. Brown stains or a lesser asphalt cement film thickness on the coarser aggregate particles at the discharge end of the drum mixer also indicate unburnt fuel problems.
- The density of the veil of aggregate inside the drum near the midpoint of the length is the key to the efficient operation of the drum mixer and economical fuel usage. The completeness of the veil can be determined from a comparison of the discharge temperature of the mix with the temperature of the exhaust gases at the stack. The stack temperature should be no more than 20°F higher than the mix discharge temperature if the veil of aggregate inside the drum is complete across the cross-sectional area of the drum (assuming that no cooling air is added in the emission-control system). Greater differences in temperature indicate that the plant is not being operated efficiently.
- The presence of light brown, uncoated fine aggregate on one side of the mix in the discharge chute is also an indication that the veil of aggregate is incomplete across the drum circumference.
- The generation of visible hydrocarbon emissions from the stack further indicates that the temperature of the exhaust gases inside the drum is too high at the point where the asphalt cement is injected into the drum.
- The density of the veil of aggregate inside the drum can be increased through the use of kicker flights, dams, donuts, or retention rings near the midpoint of the drum length. It can also be increased by lowering the slope of the drum to increase the dwell or residence time of the aggregate in the drum.
- The mineral filler and/or baghouse fines should be added through the mix discharge end of the drum. These materials should be coated with asphalt cement or captured in the mix before they are exposed to the exhaust gases moving down the drum.
- If RAP is added to the drum through a split-feed system, the difference in the mix discharge temperature and the exhaust gas temperature measured at the stack will typically be greater than 20°F and will usually increase roughly in proportion to the amount of RAP added to the mix.
- Plant production rate is determined at a given mix discharge temperature and at an average moisture content in the aggregate, usually 5 percent, at a given elevation (sea level). An increase in the moisture content and/or an increase in the mix discharge temperature decreases the capacity of the drum mixer in terms of tons of mix produced per hour.

- Production rates for recycled asphalt concrete mixes, up to a RAP content of 50 percent, will normally be similar to the production rates for mixes containing all new aggregate. Above that amount of reclaimed material per ton of mix, the production rate of the parallel-flow drum mixer will decrease as the amount of reclaimed material increases.

SECTION FIVE
SURGE AND STORAGE SILOS

INTRODUCTION

The primary purpose of a silo on a batch plant is to allow the plant to continue to produce material when trucks are not available to accept mix from the pugmill. For a drum mix plant operation, the main purpose of the silo is to convert a continuous mixing operation into a discontinuous truck-loading process and to hold the mix temporarily until the next transport vehicle is available.

This section discusses the conveying devices that are used to transport the mix from the batch plant pugmill or from the drum mixer to the silo. It also reviews the methods used to deliver the mix into the top of the silo in order to prevent segregation from occurring. Further, discussion of discharge of the mix from the silo to the haul trucks emphasizes reducing the segregation that might occur in the mix during the truck-loading operation.

CONVEYING DEVICES

A variety of conveying devices are used to carry the hot-mix asphalt from the discharge chute on the drum mixer or from the hopper under the pugmill of a batch plant to the surge silo. The most popular equipment is the drag slat conveyor, as shown in Figures 2-58 and 2-59. In this system, a continuous set of flights connected together by a drag chain pull the mix up an inclined metal conveyor. The amount of mix that can be carried by the drag slats depends on the spacing between the slats, the depth of the individual flights, the width of the flights, and the slope of the conveyor, as well as the size and speed of the drag chain and the power of the drive motor. On some drag slat conveyors, the speed of the conveyor can be altered to change the capacity of the device to match the output of the drum mixer more evenly.

A belt conveyor can also be used to deliver the mix to the silo, as seen in Figure 2-60. This belt is essentially the same as those that carry the incoming aggregate into the drum except that it is able to withstand the increased temperature of the hot material. As shown in Figure 2-61, a bucket elevator is also used on some plants. This device is similar to the equipment used on batch plants to carry the hot aggregate from the discharge end of the dryer to the top of the mixing tower.

The type of conveying equipment employed is seldom a major factor in the uniformity of the mix delivered to the silo. The important point is the manner in which the mix exits from the device and enters the top of the silo.

BIN GEOMETRY

Silos come in a variety of shapes. The majority of the silos currently in use are circular, but silos that are oval, elliptical, rectangular, and square have been used. The shape of the silo can affect the amount of segregation that occurs both upon loading and unloading the silo. Less segregation of a given mix is generally found from a circular silo than from silos of other shapes.

For circular silos, the probability of segregation problems with mixes containing larger-size coarse aggre-

Figure 2-58. Drag slat conveyor *(Standard-Havens)*.

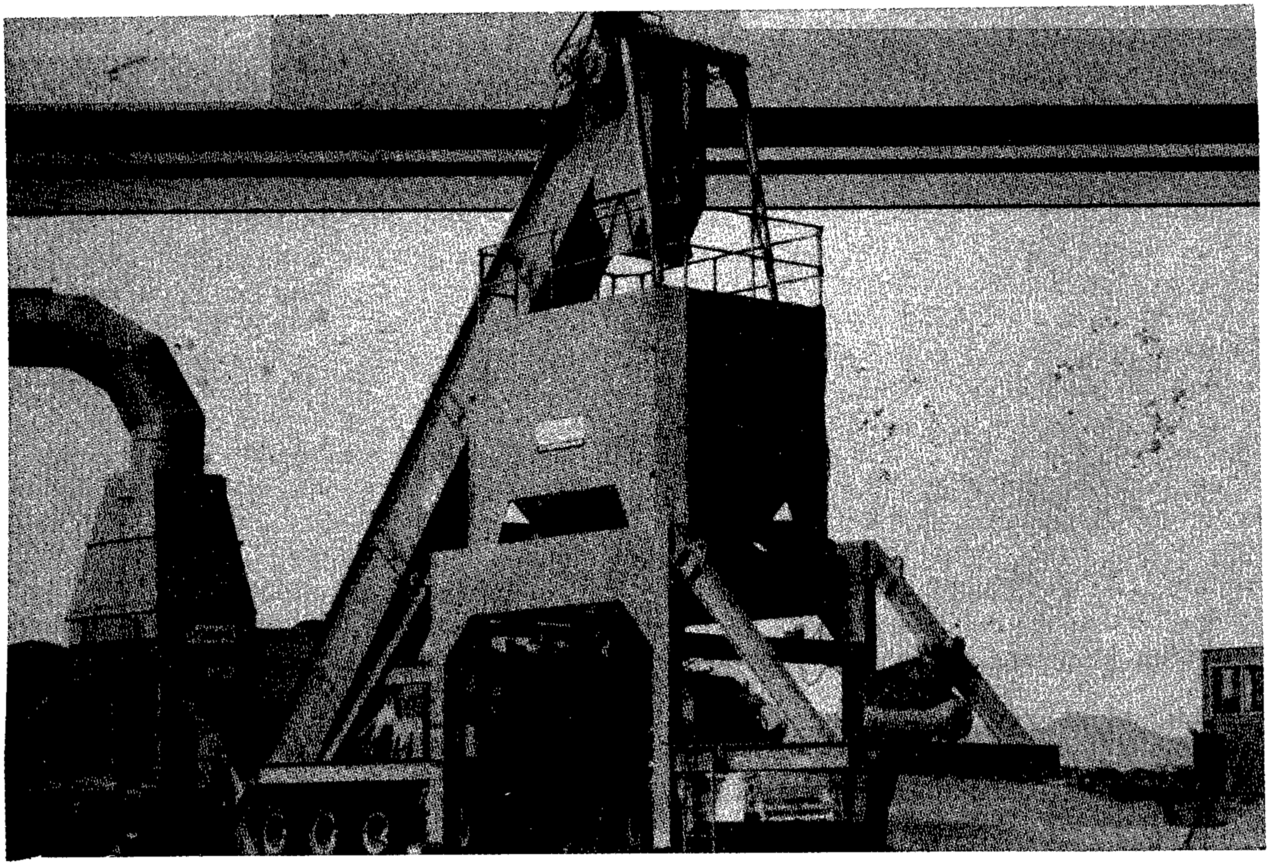


Figure 2-59. Drag slat conveyor *(Cedarapids)*.

gate increases as the diameter of the silo increases. In general, however, the silo geometry is not a major factor in segregation; the manner in which the silo is operated (loaded and unloaded) has a greater effect on the uniformity of the mix and the amount of segregation.

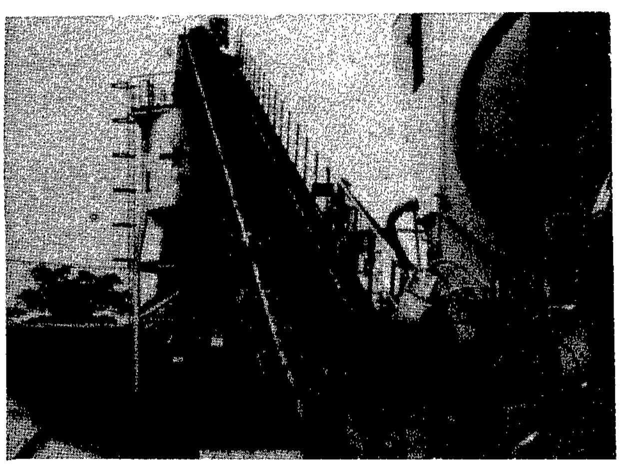


Figure 2-60. Hot mix belt conveyor *(J. Scherocman)*.

TOP OF THE SILO

Mix Delivery

Segregation most typically occurs in mixes that contain a significant proportion of large aggregate and/or are gap graded. The actual separation of the large and small particles occurs when the asphalt mix is placed in a conical pile and the bigger particles run down the side of the pile, collecting at the bottom edge. Segregation can also occur when all the mix is thrown to one side of the silo, allowing the coarser pieces to run across the surge silo to the opposite wall.

Prevention of longitudinal (side-to-side) segregation on the roadway begins at the top of the silo. Mix delivered to the top of the silo by slat conveyor, belt conveyor, or bucket elevator will be discharged to the far side of the silo by the natural centrifugal force of the conveying device, as illustrated in Figure 2-62, unless some means is employed to redirect the flow into the center of the silo. On some silos, a series of baffles is used to contain and change the direction of the material. Other silos are equipped with a splitter system to divide the

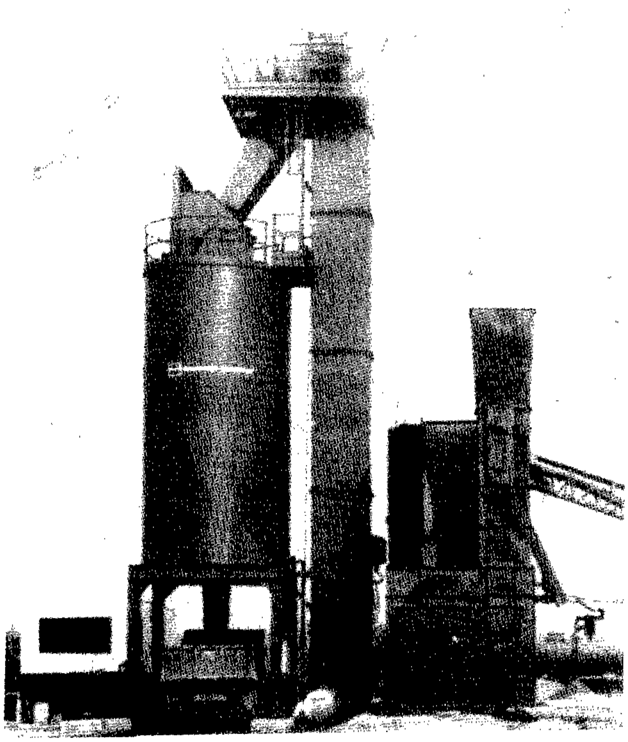


Figure 2-61. Hot-bucket elevator charging surge bin *(Barber-Greene)*.

mix that is delivered, causing a portion of the mix to be placed in each part of the silo. In general, use of the baffle and splitter systems can reduce the tendency for longitudinal (side-to-side) segregation on the roadway but does not always eliminate it. The use of a batcher system provides a better means to reduce the segregation problem.

Longitudinal segregation will occur on one side of the lane being paved because the coarser aggregate particles will roll to one side of the silo. Loading the haul truck with the vehicle facing in the opposite direction to its normal loading pattern should cause the longitudinal segregation to move from one side of the lane to the other side. If this occurs, the cause of the side-to-side segregation is in the loading of the mix into the silo from the conveying device: drag slat conveyor, conveyor belt, or bucket elevator.

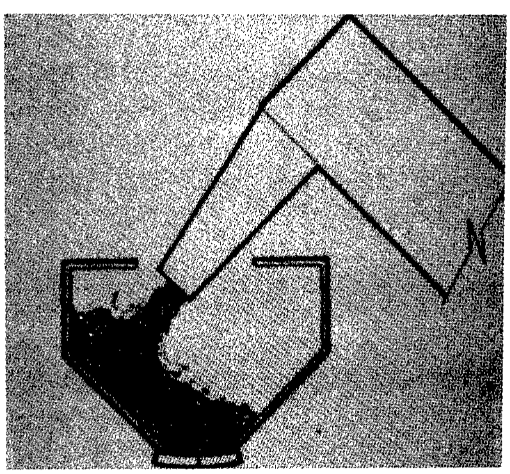


Figure 2-62. Improper delivery of mix to batcher *(NAPA)*.

Batcher

The most effective means to reduce segregation is to employ some form of temporary holding hopper or batcher at the top of the silo to momentarily store the mix being transported by the conveying device. This hopper, shown in Figure 2-63, collects the continuous flow of mix. When the hopper is nearly full and the hopper gates are opened, the mix is deposited in a mass into the silo. The mass of mix will hit the bottom of the empty silo or the top of mix already in the silo. Upon contact, the mix will splatter in all directions uniformly, minimizing segregation.

The system functions well unless the silo is almost full. In this case, the mix, when released from the hopper, does not fall very far. When it hits the mix already in the silo beneath the hopper, the falling mix lacks the momentum to spread out over the area of the silo, and a conical pile is formed instead. This pile can be the beginning of a segregation problem as more mix is deposited on top of it. Most silos are equipped with high silo indicator warning systems that alert the plant operator to cut off the flow of incoming mix when the silo becomes too full.

The batchers may not prevent a segregation problem if the mix is delivered to it improperly. In some cases, the transporting devices place the mix all on one side of the hopper, as shown in Figure 2-62. This causes rolling of the coarse aggregate in the batcher itself. It also causes the mix to be dropped off-center into the silo. Thus, even though the silo may be equipped with a batcher, the mix must be deposited uniformly into the center of the hopper and the mix must be delivered from the batcher into the center of the silo to prevent segregation of mixes with a large portion of coarser aggregate.

Sometimes, the plant operator improperly leaves the gates on the bottom of the batcher wide open. This defeats the purpose of the batcher and allows the mix to dribble in to the silo in a continuous stream. In other cases, the batcher may be emptied more often than necessary; when it is only partially full. This continual dumping of the hopper reduces the mass of material

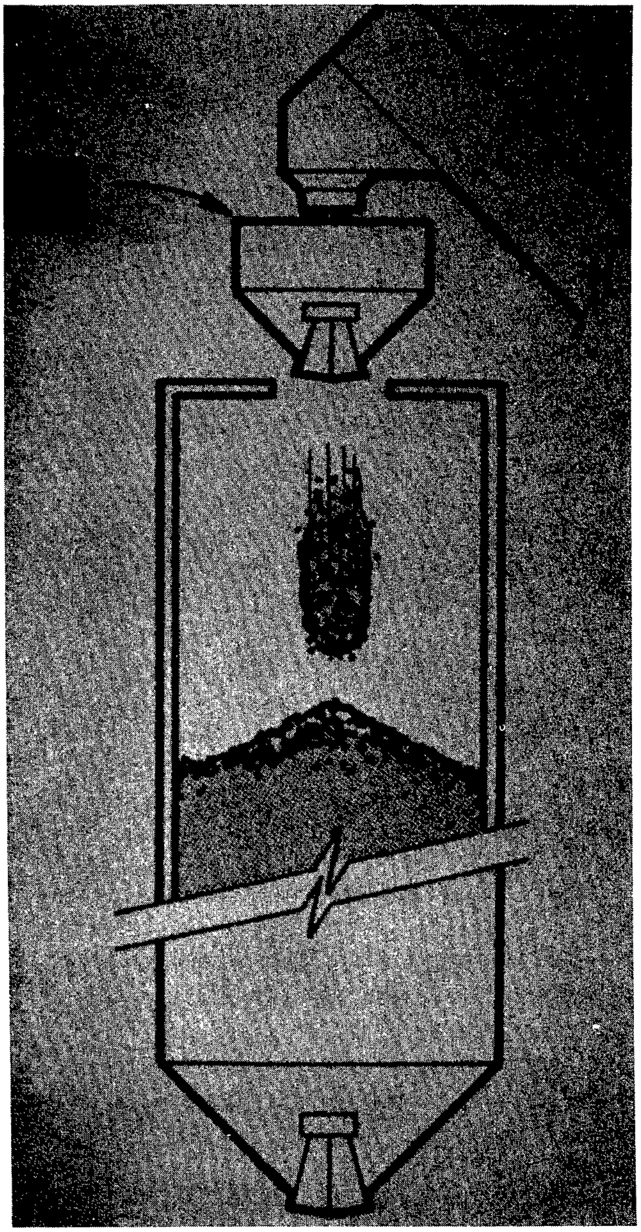


Figure 2-63. Silo batcher *(NAPA)*.

dropped into the silo and increases the opportunity for a conical pile of mix to form. Further, the timer device should be set so that the gates of the batcher are closed before the batcher is empty; some mix should remain in the batcher. This will allow the mix to fall in a mass and reduce segregation. A timer can be used to regulate the opening and closing of the batcher gates and permit the batcher to be used properly.

Rotating Spreader Chute

Mix can also be introduced into the silo using a rotating spreader chute, as shown in Figure 2-64. This device revolves around at the top of the silo and deposits the mix in a circle around the circumference of the silo. The flow of the asphalt mix is continuous, but the development of conical piles of mix is minimized by spreading the material out over a wider area. Because the chute on the rotary spreader is subject to extensive abrasion from the mix, it must be checked periodically to assure that no holes have developed in the device. Depending on the location of the hole, mix could either be deposited all in the center of the silo or all around the outside circumference of the silo. Because of maintenance problems with this equipment, the rotating chute system is rarely used.

SURGE VERSUS STORAGE

A silo can be used, during the normal daily operation of the plant, to store asphalt mix between the arrival of trucks at the plant. In this case, the silo is typically termed a surge silo. If the silo is to be employed for holding the mix for longer periods of time (overnight or for several days) the silo may be termed a storage silo. A storage silo can easily be used as a surge silo. A surge silo may not be suitable for use as a storage silo.

Several differences exist between a surge and a storage silo. First, the capacity of a storage silo is typically greater than the capacity of a surge silo. Second, the surge silo is usually insulated but not heated. The silo used for mix storage is always insulated and usually heated, either completely or partially. Third, the gates at the bottom of the storage silo are heated and sealed when mix is to be held for a long period of time, in order to reduce the amount of air that can pass up into the mix through the gates. The gates at the bottom of the surge silo are not normally heated or sealed.

The primary operation of both types of silos is similar. Only the ability to store quantities of mix for longer time periods without significant changes in the properties of the mix differentiates the two types of equipment. Whichever type of silo is used, the mix that is held in the silo and then delivered to the haul truck should meet the same mix specifications and requirements as the mix discharged directly from the pugmill on a batch plant or as the mix at the discharge end of the drum mixer, before passage into and out of the silo.

Insulation and Heat

Most surge silos are insulated. The purpose of the insulation is to reduce the loss of heat from the mix as it temporarily resides in the silo. The type of insulating material used and its thickness varies among the various manufacturers.

The cone at the base of the surge silo is usually heated. This is done to prevent the mix from sticking to the wall of the cone and building up. The heat can be provided by electrical or hot-oil systems. In some cases, the vertical walls on the silo are also heated. The heating allows the mix to retain the desired temperature for an extended period of time. If the silo is to be used strictly as a surge silo and is emptied of mix at the end of each production day, heating of the silo walls is usually unnecessary, but the cone is usually heated.

Storage

Occasionally it is necessary to retain an asphalt mixture in the silo for a longer time period, such as overnight or over a weekend. Usually this can be accomplished quite successfully without undue hardening or temperature loss in the mix. A well-insulated silo is required, but heating of the silo vertical walls is generally unnecessary. Mixes stored for several days in silos equipped with heated cones have shown only minimal oxidation and temperature loss. The amount of hardening that occurs is related to the amount of mix in the silo. The large mass of mix in a full silo will age less than will a small volume of mix in a nearly empty silo. In addition, the amount of temperature loss in the stored mix will depend on a number of factors including the initial mix temperature, the gradation of the material, and environmental conditions.

Asphalt mix (except open-graded mix) may be stored for as long as a week when kept in a heated, air-tight silo. An inert gas system can be employed to purge the silo of oxygen, but this is rarely done. The gates at the bottom of the silo as well as any openings at the top of the silo must be well sealed to prevent the movement of air into and through the mix. The silo must be completely heated and well insulated. Further, it is sometimes advisable to remove a small amount of mix (at least 2 or 3 tons of material) from the silo every day or every other day during the storage period to assure that the mix at the bottom of the cone does not set up and become impossible to discharge. Although mix can be stored for relatively long periods of time, it is rarely necessary to do so with continuous operation of the plant. Most silos, therefore, are used either as surge silos or periodically as storage silos for overnight storage of the asphalt material.

The mix held for more than two or three days in a surge or storage silo should be tested to assure that it meets all the same requirements as asphalt mixes delivered directly to the paving site. This testing should include measurement of the mix temperature upon discharge from the silo and the viscosity and/or penetration of the asphalt cement recovered from the mix. As long as the mixture meets these specifications, the length of time the material is held in the silo should not be restricted. If an open-graded mixture is being stored, however, care must be taken to keep the mix storage temperature low enough so that the asphalt cement does not flow off of the aggregate and collect at the bottom of the silo.

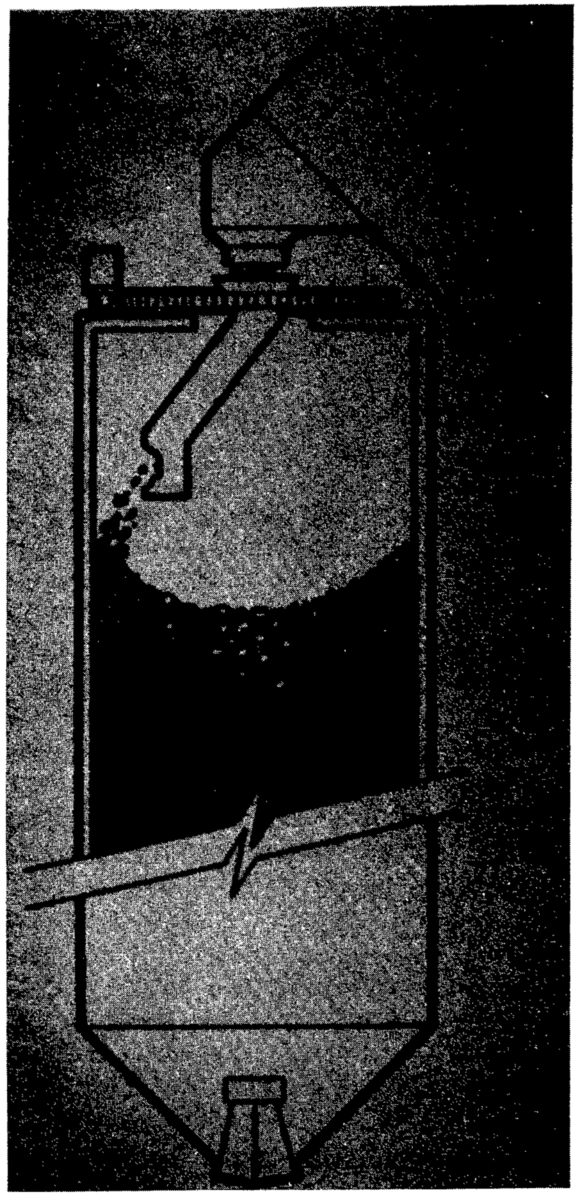


Figure 2-64. Batcher spreader chute *(NAPA)*.

THE CONE, LOADOUT, AND SEGREGATION

Silo Cone

As shown in Figure 2-65, the bottom of the surge silo is shaped like a funnel or cone. The angle of the cone varies with the different manufacturers, but is usually between 55° and 70°. This slope assures that the mix is deposited as a mass into the truck. The angle needs to be steep enough, and the gate opening large enough, to assure that the larger aggregate particles do not roll into the center of the cone (rathole) as the mix is drawn down, causing segregation.

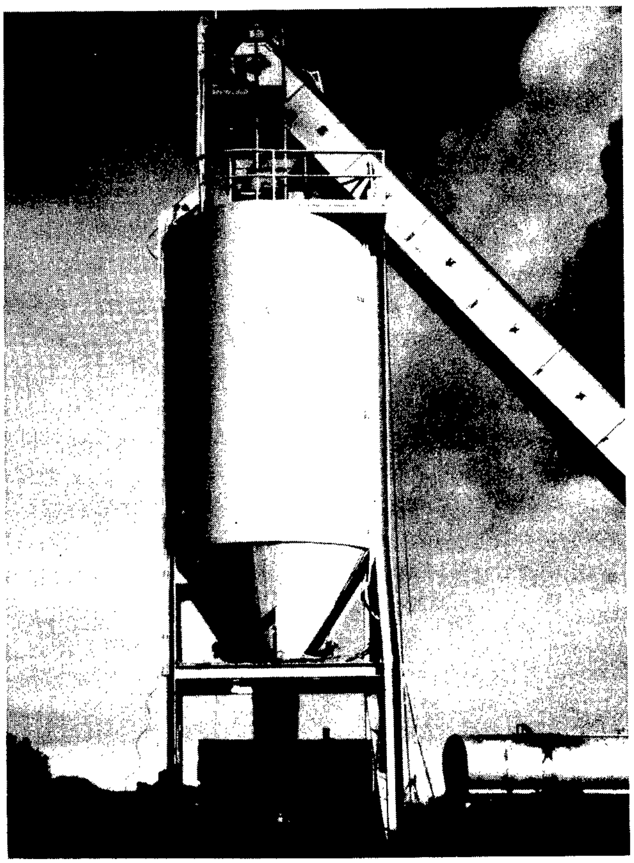


Figure 2-65. Discharge cone at bottom of silo *(J. Scherocman)*.

The vast majority of the surge silos have low silo indicator systems that warn the plant operator when the level of mix in the silo is near the top of the cone. By keeping the volume of mix in the silo above this minimum level, segregation will be minimized. As very coarse mixes or gap-graded mixes are pulled below the top of the cone, there can be a tendency for the largest aggregate particles to roll into the center of the crater.

Loading and Segregation

Just as it is important to deliver mix into the silo in a mass, it is also important to deposit the asphalt mix in a mass into the haul truck. The gates on the bottom of the cone should be opened and closed quickly. It is also necessary for the gates to open completely so that the flow of mix is unrestricted. There is only one reason to cut off the flow of mix into the vehicle once that delivery has started: to divide the delivery of the mix into different sections of the truck.

If all the mix is placed in the haul vehicle in one drop from the silo, segregation of the larger aggregate particles can occur. If the mix is deposited into the center of the truck bed, the material will build up into a conical-shaped pile, as illustrated in Figure 2-66. Because the growth of the pile will be restricted by the sides of the truck, the bigger aggregate particles will roll toward the front and the tailgate of the truck bed. These pieces accumulate at both ends of the load and are then delivered into the hopper on the paver from the truck bed. The pockets of coarse material then appear in the mat behind the laydown machine at the end of the truckload of mix. In reality, some of the large aggregate pieces come from the end of one truckload and also from the beginning of the next truckload of mix.

This segregation problem can be minimized by dividing the delivery of the asphalt mix from the silo into multiple drops, each delivered to a different section of the bed of the hauling vehicle. If a tandem axle or triaxle dump truck is being used, about 40 percent of the total weight of the mix to be hauled should be loaded into the center of the front half of the truck. The truck should then be pulled forward so that the next 40 percent or so of the total load can be deposited into the center of the back half of the bed, near the tailgate.

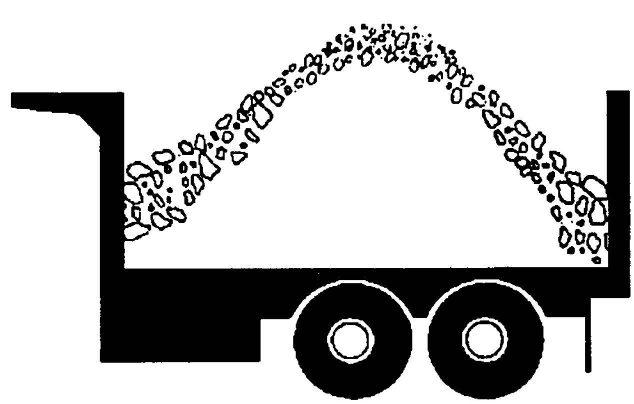


Figure 2-66. Incorrect truck-loading sequence *(NAPA)*.

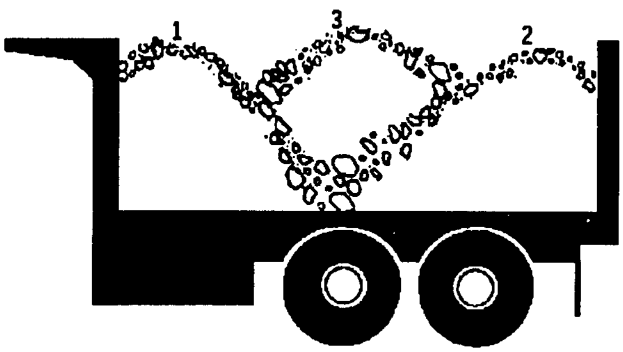


Figure 2-67. Correct truck loading sequence *(NAPA)*.

The vehicle should then be moved backwards again so that the remaining 20 percent of the mix can be dropped into the center of the bed, between the first two piles. This loading sequence is shown in Figure 2-67.

If a larger truck is used to deliver the mix, the number of drops of material from the silo should be increased to distribute the mix along the length of the truck bed. The first drop of mix should be into the front portion of the bed and the second drop should be near the tailgate. The remaining mix should be delivered in evenly divided drops into the rest of the length of the truck bed. In no case should the truck be loaded continuously by the truck driver moving forward under the silo as the mix is being discharged. This operation will cause the coarse aggregate particles to collect at the tailgate of the truck and increase the amount of segregation that will occur.

The objective is to minimize the distance that the coarser aggregate pieces can roll. This significantly reduces the chance for segregation in the mix. This procedure, however, requires that the truck driver reposition the truck under the silo after each drop so that the asphalt mix is spread more evenly on the truck bed. In any case, the truck should not be loaded in one drop of mix from the silo, even if the mix does not have a tendency to segregate. Multiple discharges are very beneficial in keeping the mix uniform. Some plants are equipped with controls to deposit the mix automatically into the haul truck at predetermined amounts and intervals.

The silo discharge operator should be able to determine the time it takes to deliver the proper amount of mix, per drop, into each haul vehicle. This can be done by timing the discharge of the mix and comparing the time with the weight of mix delivered. Because trucks are a variety of sizes, the time per drop of mix may be different from truck to truck, but after a little practice, the operator should be able to judge accurately the time needed to place the proper amount of material in each truck bed. This amount can also be confirmed visually by watching the height of the growing pile of mix in the truck as the loading continues.

The operator should not be allowed to "top off" or dribble mix into the haul vehicle. The gates on the silo should not be opened and closed continually to deliver only small amounts of mix to the truck. This occurs most frequently in plants where the surge silos are placed directly over the truck scales. Because the operator can quickly determine the amount of mix actually in the truck bed by observing the scale readout on the control console, the tendency is to load the vehicle right up to the legal limit. This is done by using multiple drops of small quantities of mix at the end of the main delivery. If the discharge of mix from the silo is timed, however, this procedure is unnecessary and the potential for mix segregation is reduced.

Loading Hopper

Some silos have a loading hopper or batcher under the cone. If the capacity of the batcher is significantly smaller than the capacity of the haul vehicle and if the truck position is changed between batches of mix, the amount of truckload-to-truckload segregation may be decreased somewhat through the use of the batcher.

SUMMARY OF SILO OPERATING TECHNIQUES

Segregation usually begins at the surge silo, in the loading and unloading process. The items that should be monitored include the following:

- The conveying device from the discharge chute of a drum mix plant or from the hopper under the pugmill of a batch plant must deposit the mix into the center of the silo if a batcher is not used, or into the center of the batcher at the top of the silo.
- Longitudinal (side-to-side) segregation is caused by loading the silo to one side and by the coarser aggregate particles rolling to the opposite side inside the silo.
- If longitudinal segregation is present behind the paver, several haul trucks should be loaded under the silo facing in the opposite direction from their normal loading pattern. When these truckloads of mix are unloaded at the paver, the location of the segregation should change sides in the lane being paved. If this happens, the cause of the side-to-side segregation is probably in the procedure used to place the mix into the silo from the conveying device.
- A batcher should be used at the top of the silo. The batcher should not be operated with its gates wide

open, allowing the mix to pass right through it. The batcher should be filled up with mix and then should drop the mix in a mass into the center of the silo. Further, the gate on the bottom of the batcher should be closed before all of the mix is discharged from the batcher.

- If the silo is to be used for overnight storage of asphalt mix, the cone should be heated and the silo walls insulated. If mix is stored for more than two days, a small quantity of mix should be withdrawn from the silo at least every other day to prevent plugging of the cone.
- If the mix is stored for more than two or three days, the mix should be checked upon discharge for temperature and for the penetration and/or viscosity of the recovered asphalt cement from the mix. The mix should meet the same specification requirements as a mix placed immediately after manufacture.
- Truckload-to-truckload segregation is usually caused by the procedure used to load the trucks under the silo. The truck should never be loaded in only one drop of mix into the center of the truck bed. Multiple drops of mix are necessary, with the first drop located near the front of the bed and the second drop of mix near the tailgate. Additional drops of mix should be made at intermediate points between the first two drops.
- The truck should never be loaded by slowly driving the truck forward as mix is being delivered from the silo. This will cause the coarser aggregate particles to collect at the tailgate of the truck and significantly increase the amount of segregation that occurs.
- The plant operator should not "top off" or dribble mix into the truck bed in small drops to fill the truck to legal capacity.

SECTION SIX
EMISSION CONTROL

INTRODUCTION

This section discusses the three types of emission-control equipment found on batch and drum mix plants: dry collectors, wet collectors, and baghouses. The dry collector is usually placed in front of one of the other two types of collectors and is termed a primary collector. The wet collector (wet scrubber) and the baghouse (fabric filter) are secondary collectors through which the exhaust gases flow after passing through the primary collector. The primary collector is used to remove the larger fine particles from the exhaust gases and reduce the loading on the secondary collector, which is used to capture the very fine particles. The operation of each of the three emission-control devices is reviewed.

FINES CARRYOUT

All batch and drum mix plants have a small amount of fines aggregate carryout from the dryer or the drum mixer. In order to meet federal and state air quality codes, emission-control equipment is necessary to capture particulate emissions that might otherwise be released to the atmosphere. In addition, some emission-control devices permit the plant operator to control the amount of fines returned to the asphalt mixture.

The velocity of the exhaust gases inside a dryer or drum mixer is primarily a function of the diameter of the drum, the capacity of the exhaust fan, and the speed of the exhaust fan. A minimum volume of air is needed for proper operation of the burner. This air, combined with the products of combustion from the burner and the moisture vapor from the aggregate, moves through the dryer or drum mixer at a velocity that varies with the operating conditions of the plant. The amount of fines carryout increases as the exhaust gas velocity increases.

In a drum mixer, the amount of fines carryout can be reduced significantly by encapsulating or coating the aggregate with the asphalt cement early in the drying process. The farther up the drum the asphalt cement is injected, the more fines are captured in the asphalt cement before they can become airborne. Typically the amount of fines carryout increases as the asphalt cement pipe is positioned farther down toward the discharge end of the drum.

The amount of fines carryout is a function of the amount of very fine material in the new aggregate; the size, weight, and moisture content of the fines; and the amount of very fine particles in the reclaimed aggregate (if used in a drum mix plant). It is also related to the operation of the drum--the production rate (density of the aggregate veil), the location of the asphalt cement injection pipe (for a drum mixer), and the velocity of the exhaust gases. The amount of carryout can vary widely with a change in the properties of the incoming aggregate and the production process.

The efficiency of the emission-control equipment is the amount of particulates that are captured by the equipment versus the amount of particulate matter that enters the emission-control equipment. If 1000 particles/min enter a baghouse, for example, and 990 of those particles are caught in the baghouse, the collection system is 99 percent efficient. The efficiency can be determined, in part, by observing the amount of particulates being emitted from the stack. This is done by checking the opacity of the exhaust gas beyond the end of the steam plume (if one is present). If a dust trail is seen, the operation of the emission-control equipment must be checked.

PRIMARY DRY COLLECTOR

Dry collectors are not used or needed on all asphalt plants. If employed, the dry collector can be one of several types, which may be used in combination with each other. When used in combination, the first collector is referred to as the primary and the second collector is known as the secondary collector. The original dry collector was a cyclone device that forced the exhaust gases to swirl inside the collector. The dust in the gases was removed by centrifugal force; it was thrown to the side of the cyclone as the gases moved in a circular motion. The operation of a cyclone-type dry collector is shown in Figure 2-68.

Most dry-collector systems in use today have an expansion chamber combined with a baghouse. The expansion chamber or knockout box has a greater cross-sectional area than the ductwork through which the exhaust gases pass between the dryer or the drum mixer and the secondary collector. A typical knockout box (dry cyclone) used in combination with a baghouse is shown in Figure 2-69. The exhaust gas velocity decreases significantly when it reaches the increased area of the

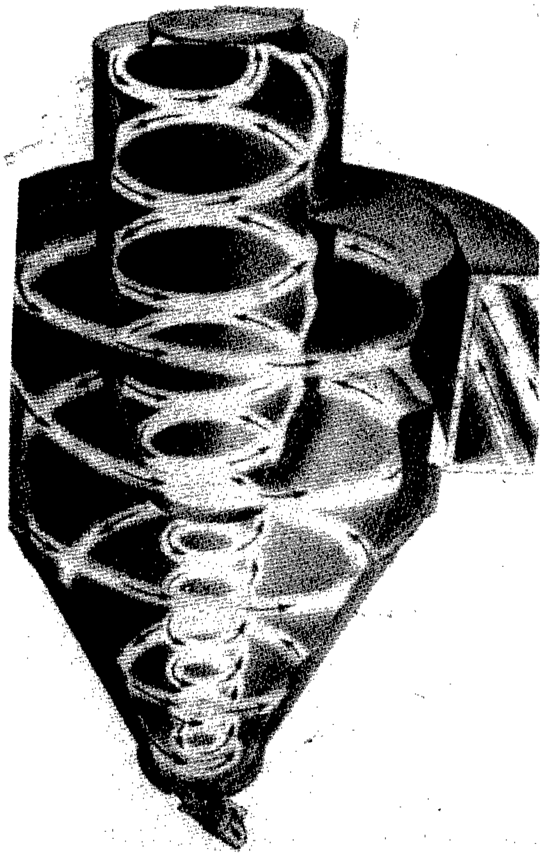


Figure 2-68. Cyclone operation *(Cedarapids)*.

dry collector. The largest and heaviest of the fine particles fall out of the gas stream, in proportion to the reduction in the speed of the exhaust gases and as the velocity is decreased. These particles drop to the bottom of the expansion chamber. The collected particles can either be returned uniformly to the batch plant or to the drum mixer, either alone or in combination with the fines collected by the baghouse, or they can be wasted.

The efficiency of the primary collector depends in part on the size of the fine particles in the exhaust gases and on the type of collector used. Primary collectors can have an efficiency (the percentage of the amount of fines removed from the exhaust gases compared with the total amount of fines in the gases) as low as 50 percent for a knockout box to as high as 70 to 90 percent when a dry cyclone is used. Thus, only a portion of the fines in the exhaust gases are removed by this equipment. The main purpose of the primary collector is to improve the operation of the secondary collector by reducing the fines loading on the wet scrubber or the baghouse.

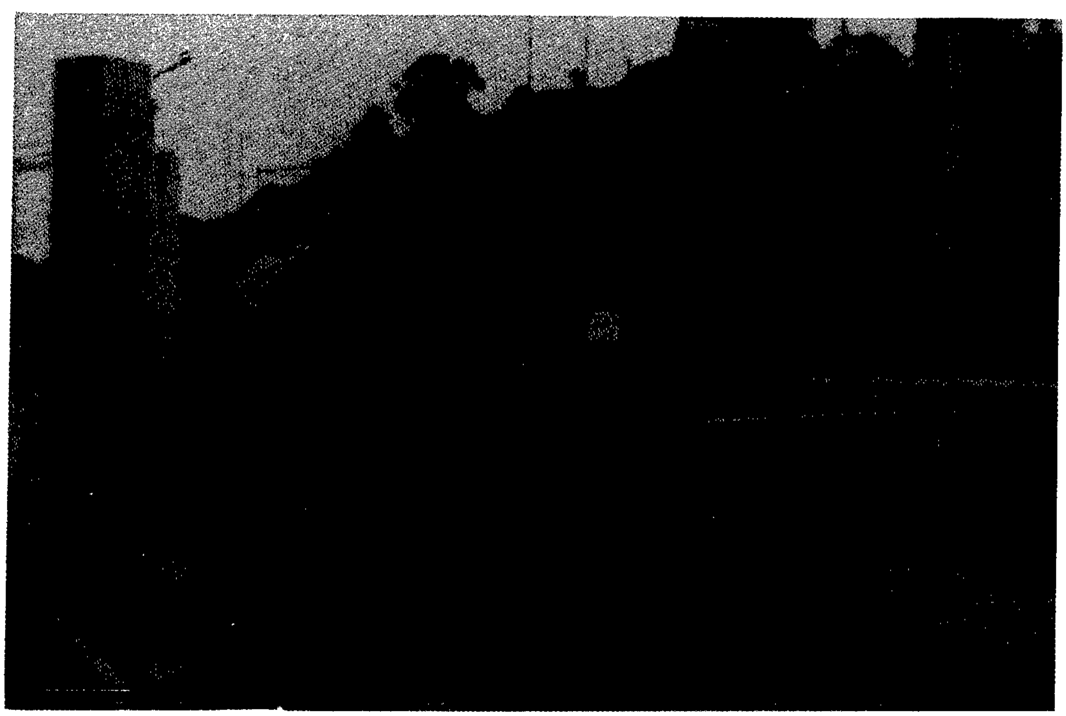


Figure 2-69. Dry collector and baghouse *(H&B)*.

WET COLLECTOR

After moving through a primary dry collector, the exhaust gases on most newer plants equipped with a wet collector system are forced through a narrowed opening, or venturi, as shown in Figure 2-70. When the gas flow is concentrated in a small area, it is sprayed with water from multiple nozzles and the fines are wetted. The exhaust gases and wet fines then travel into the separator section of the collector.

The exhaust gases are sent into a circular motion around the circumference of the unit, as seen in Figure 2-71, and the wetted fines, which are relatively heavy, are removed from the gas stream by centrifugal force and fall to the bottom of the collector. The clean gas continues to swirl around the collector until it reaches the end, when it passes out the stack to the atmosphere.

Depending of the size of the fines particles in the exhaust gases, a wet-scrubber system is usually 90 to 99 percent efficient in removing particulates from those gases. In addition to being related to the size and amount of the fines present, the efficiency is a function of both the cleanliness and the volume of water used to spray the exhaust gases. If the water sprayed is clean and free from sediment and if all of the nozzles in the scrubber are open and working, the amount of fines removed by the wet-collector system will increase.

The cleanliness of the water and the condition of the nozzles is related to the size of the settling pond used to collect the water discharged from the scrubber. The water and fines, in the form of a sludge, are sent from the bottom of the collector through a pipe to the first section of the pond, where the heaviest fines settle out of the water. The cleaner water at the top of the pond in this first section is drawn off through an outlet on the opposite side of the pond. Additional settling of the fines occurs in each succeeding section of the pond. The efficiency of the settlement process is directly related to the size of the settling pond; the bigger and deeper the pond, the more water available, and the more time for the fines to separate and settle before the water is pumped from the pond back to the wet-scrubber unit.

As the settling pond fills up with fines, the time that the water remains in the pond and the amount of settlement that can occur will decrease. When a pond becomes too shallow, dirty water will be sent back to the scrubber. In order to maintain a supply of clean water for use in the fines collection equipment, the sediment on the bottom of the pond must be removed periodically. In addition, water lost from the pond through evaporation and leaks in the piping system should be replaced as necessary.

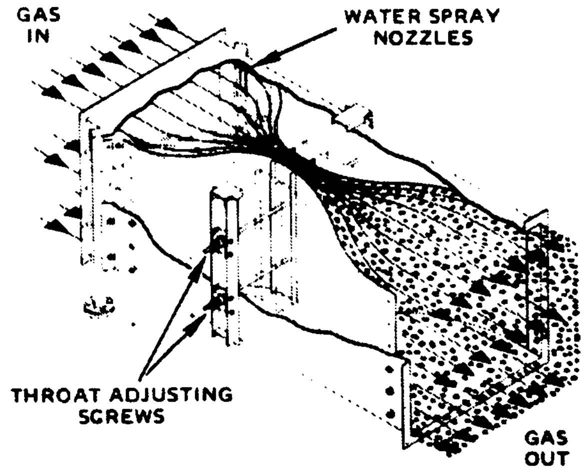


Figure 2-70. Venturi collector *(Cedarapids)*.

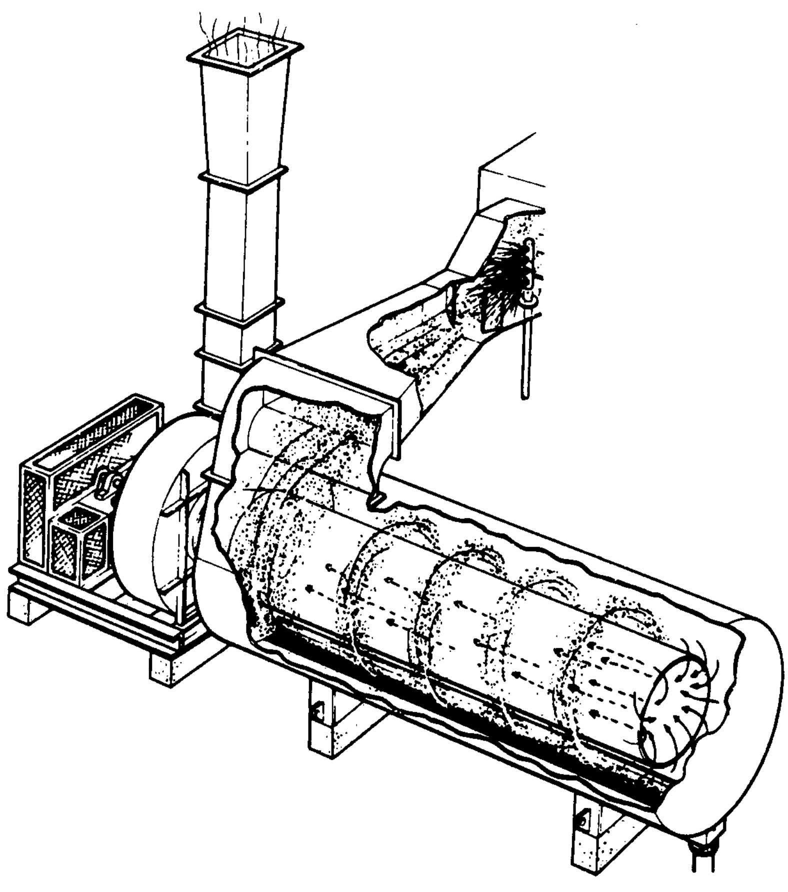


Figure 2-71. Venturi separator *(Cedarapids)*.

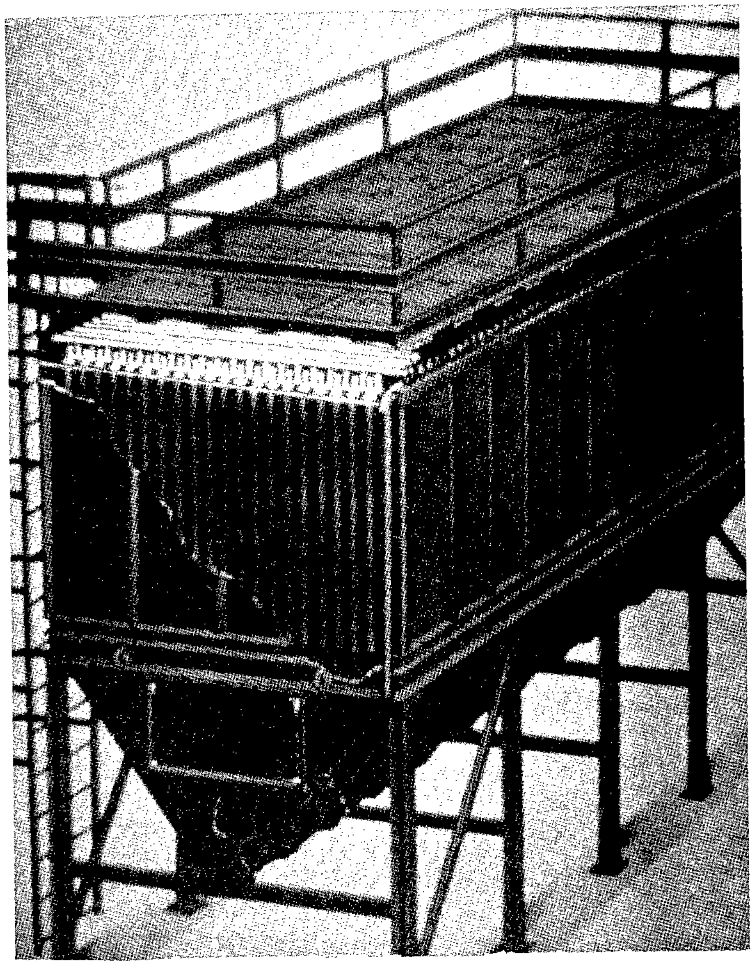


Figure 2-72. Baghouse fabric dust collector *(Barber-Greene)*.

Any fines that are removed from the exhaust gases by the wet scrubber are no longer available for use in the mix. The gradation of the mix produced in the batch or drum mix plant is thus not the same as the gradation of the incoming new and/or reclaimed aggregate. In most cases in which the amount of fines carryout is not great, the change in gradation will be small, but if a large volume of fines is captured in the exhaust gases, a significant change can occur in the aggregate gradation, particularly in the very fine particle sizes.

BAGHOUSE

The exhaust gases that pass through the primary collector can be pulled by the exhaust fan on the plant through another type of secondary collector called a baghouse or fabric filter, as shown in Figures 2-72 and 2-73. (Although baghouses can be operated without a primary collector, this generally reduces the efficiency of the system and is not normally done.) The material used as the filter cloth is usually a special type of synthetic fiber that is resistant to high fines loadings, high humidity, and high temperature while undergoing multiple cycles of bending and flexing. The fabric is dense enough to catch the particulates while still permitting the air to pass through. This synthetic fiber material will char and disintegrate if subjected to exhaust gas temperatures above 450°F for extended periods of time.

The fabric is fabricated into a cylindrically shaped bag and is placed on a circular metal framework or cage that is closed on the bottom but open on the top, as shown in Figure 2-74. The filter bags on the cages are arranged in rows inside the baghouse, as illustrated in Figure 2-75. The number of bags needed depends on the size of the dryer or drum mixer, the diameter and the length of each individual bag, and the air-to-cloth ratio required to meet emission-control specifications. In general, 1 ft^2 of filter cloth area is needed to clean 5 to 7 ft^3/min of exhaust gas. The most common air-to-cloth ratio in use is 6:1.

Each baghouse has a clean air side and a dirty air side, as shown in Figures 2-76 and 2-77. The exhaust fan pulls the dirty air from outside the filter fabric through the material to the inside. The fines are caught on the outside surface of the bag and the cleaned exhaust gases, relieved of the dust, are carried out the top of the bag and to the stack. The fines build up on the outside of the bag with time and form a dust cake or coating on each bag. The degree of coating determines the efficiency of the filter; if the bags are too clean, only the coarser fines will be caught and the finer particles will pass through the fabric; if the bags are too dirty or blinded, the exhaust gases will be unable to pass through the dust cake and the baghouse will stop operating. The thickness of the dust cake is generally determined by the frequency of the filter bag cleaning cycle.

To remove a portion of the built up dust on the filter bags, the bags must be cleaned periodically. Bags are cleaned in rows or in groups so that most of the baghouse is in the collecting mode while a few bags are being cleaned. The cleaning occurs by flexing or shaking the bags, backflushing them with a pulse of clean air, or by a combination of both procedures, as shown in Figure 2-78. The most common procedure is the pulse jet system, with a cleaning cycle occurring for only 1/10 sec approximately once every 3 min. The particulates

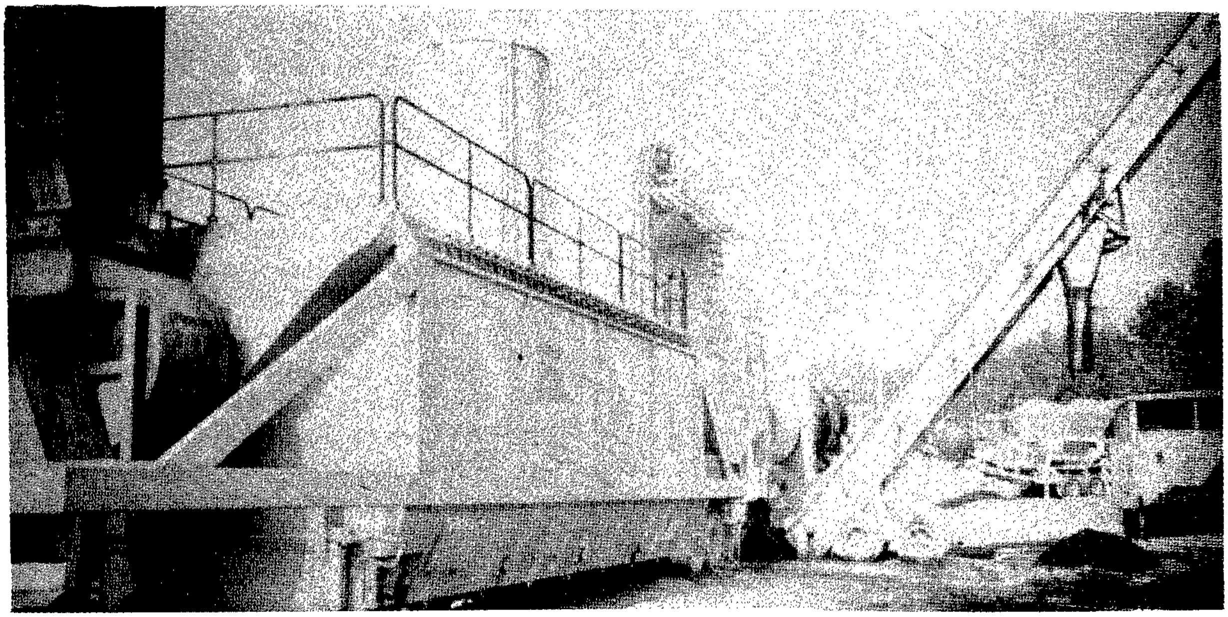


Figure 2-73. Baghouse fabric dust collector *(J. Scherocman)*.

removed from the bags fall to the bottom of the house and are collected for return to the plant or are wasted.

A baghouse can remove up to 99.9 percent of the fines in the exhaust gas stream. This efficiency is measured in part by the amount of pressure drop--generally in the range of 2 to 6 in. of water column--between the dirty side and the clean side of the bags. If the pressure drop is too low (1 to 2 in.), the bags are too clean and some of the very fine dust particles will pass through the filter and up the stack. If the pressure drop is too high (greater than 6 in.), the fines buildup on the bags is excessive, the exhaust gases will be restricted from passing through the fabric, and the capacity of the dryer or drum mixer will be reduced.

The efficiency of the baghouse will be affected if the temperature of the exhaust gases entering the baghouse is below the dew point--the temperature of the exhaust gas at which point the moisture begins to condense, as shown in Figure 2-79. The moisture, combined with the fines in the exhaust gases, forms a mudlike coating on the outside of the bags that cannot easily be removed during the bag-cleaning cycle. If this happens, the pressure drop across the bags increases significantly, reducing the efficiency of the baghouse and even choking off the burner flame in extreme cases. To prevent this from occurring, the baghouse must be preheated by running the burner on "low fire" without aggregate in the drum before mix production is commenced each day.

The synthetic fiber bags, when subjected to temperatures above 450°F for extended periods of time, can char, disintegrate, and then burn. To prevent this, temperature sensors and automatic shutdown devices are installed in the ductwork upstream of the baghouse. The sensor is typically set at a temperature of 400°F. If the temperature of the exhaust gases exceeds this value, the sensor sends a visual and/or audible signal to the plant operator or may automatically shut off the fuel flow to the burner. Some baghouses are fitted with automatic fire extinguisher devices if a fire does occur in the emission-control equipment.

The gradation of the asphalt mix produced in a batch or drum mix plant may change depending on whether any or all of the baghouse fines are returned to the

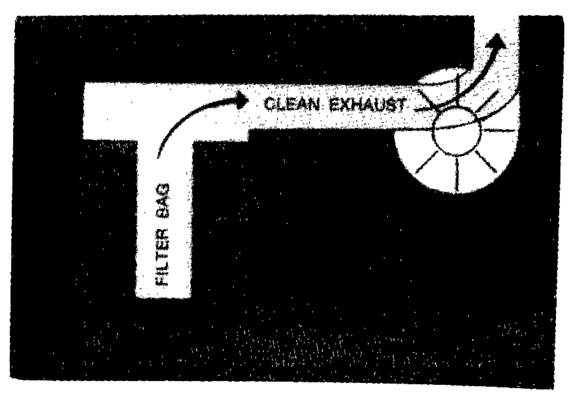


Figure 2-74. Baghouse fabric collector *(Barber-Greene)*.

plant. If the collected dust is returned, the mix gradation will be approximately the same as the gradation of the incoming new and reclaimed aggregate (assuming minimal degradation of the aggregate during processing through the dryer or drum mixer). If the baghouse fines are wasted, there may be a considerable change in the mix gradation. If the fines are returned, it is very important that they be introduced into the batch or drum mix plant continuously and uniformly.

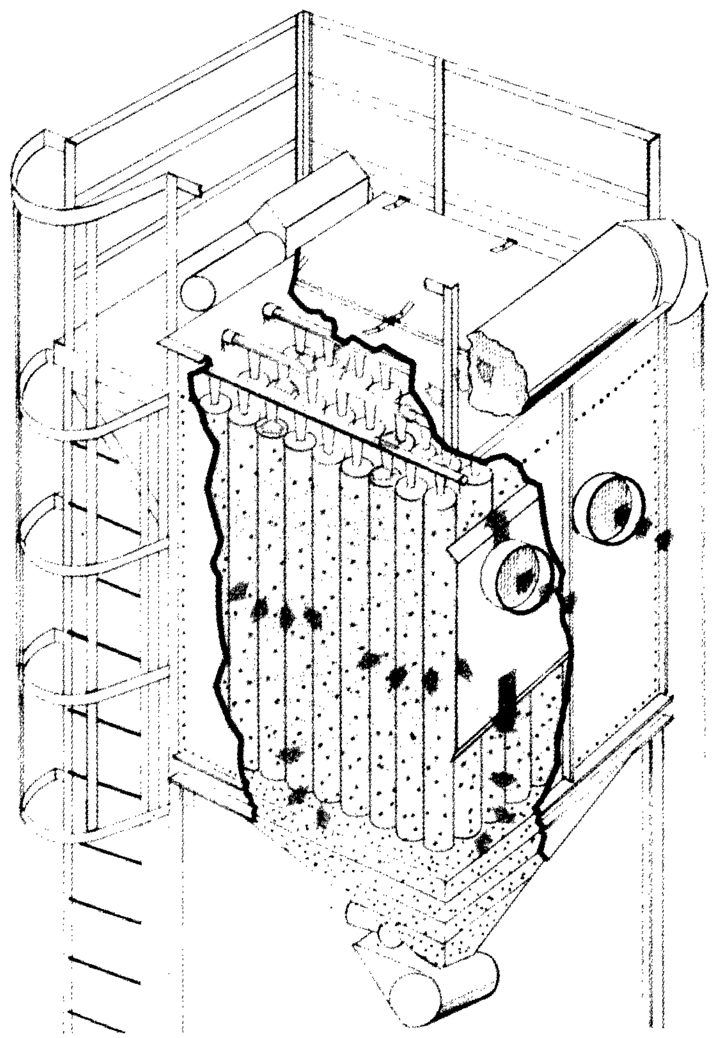


Figure 2-75. Rows of filter bags in baghouse *(ICA)*.

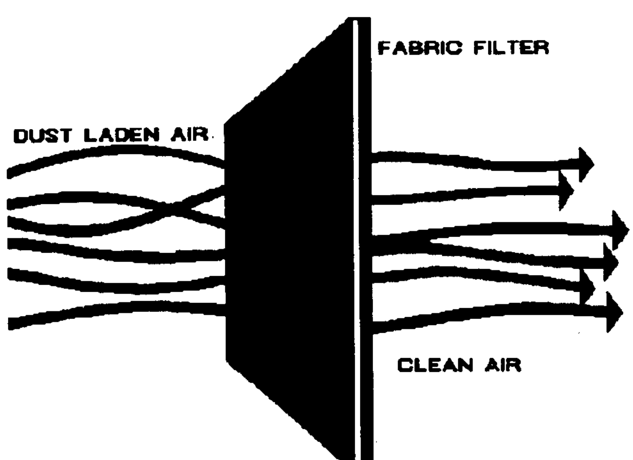


Figure 2-76. Clean air-dirty air sides of a filter *(Barber-Greene)*.

FUGITIVE DUST

The primary source of emissions from a batch or drum mix plant is the fines carryout present in the exhaust gases during the aggregate heating and drying process. Additional emissions are possible, however, in the form of fugitive dust. This is fine material that leaks from the plant through holes in the equipment or ductwork while the plant is operating.

For a batch plant, the three most likely sources of fugitive dust are the hot elevator, the plant screens, and the pugmill. As the aggregate is delivered from the hot elevator to the screen deck, it passes over the vibrating screens. This movement creates dust, as does the mixing of the aggregate in the plant pugmill during the dry mix cycle. Fugitive dust can be eliminated by completely and tightly enclosing the screen deck area and by keeping the dry mix time in the pugmill to a minimum. In addition, a scavenger air system (fugitive dust-evacuation system) creates a negative air pressure inside the plant housing and reduces the amount of dust carryout during plant operations. This system usually consists of ductwork with adjustable dampers extending from the screen deck, hot bins, weigh hopper, and pugmill sections to the inlet of a fugitive dust fan, which then blows the dust into the secondary collector. On some plants, a fugitive dust fan is not used. In this instance, the ductwork extends directly to the inlet of the secondary collector.

For both a batch plant and a drum mix plant, holes in the emission-control equipment, primarily in the ductwork between the end of the dryer or drum mixer and the dry or wet collector, may allow the escape of fine aggregate particles. These holes should be patched to permit all of the dust in the exhaust gases to be drawn into the emission-control collectors. Further, the holes should be eliminated in order to prevent the exhaust fan from drawing in excess (leakage) air and reducing the amount of air available for combustion at the burner.

SUMMARY OF EMISSION-CONTROL OPERATING TECHNIQUES

The following items should be monitored when observing the operation of the emission-control equipment:

- The discharge of the exhaust gases from the stack should be observed for a dust trail at the end of the steam plume. If one exists, the operation of the emission-control equipment should be checked.
- If a wet scrubber is used, the spray nozzles in the venturi should be checked to assure that all are open and spraying water.
- The cleanliness of the water being returned to the spray nozzles from the pond should be checked at the point at which the water is drawn from the pond by the water pump.
- If a baghouse is used, the pressure drop across the bags should be in the range of 2 to 6 in. of water column.
- The temperature of the exhaust gases entering the baghouse should be less than 400°F. An automatic shutoff device should be used to stop the operation of the plant if the exhaust gas temperature exceeds this value. The temperature should be considerably less if the veil of aggregate inside the dryer or drum mixer is correct.
- The relationship between the gradation of the mix produced in the batch or drum mix plant should be compared with the gradation used in the mix design process. The amount of change in gradation will depend on whether a wet-scrubber system is used or whether the baghouse fines are returned to the plant or wasted.

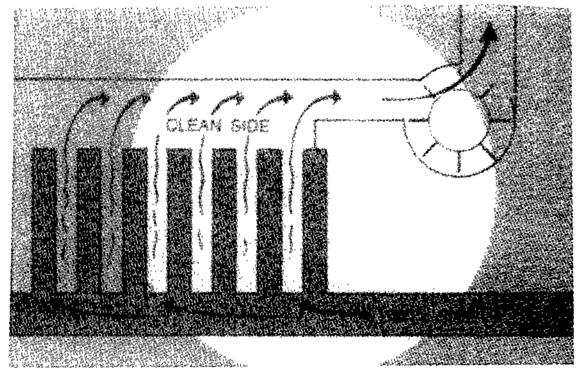


Figure 2-77. Clean air-dirty air sides in baghouse *(Barber-Greene)*.

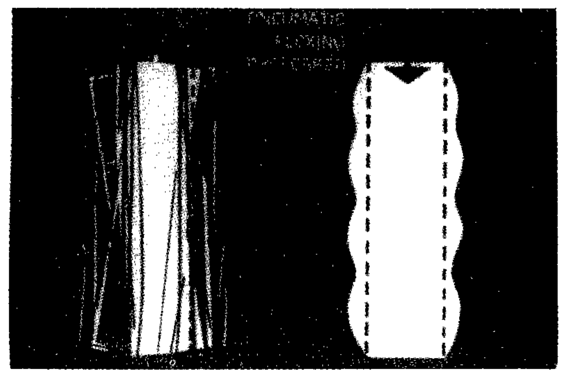


Figure 2-78. Cleaning by flexing or shaking bags *(Barber-Greene)*.

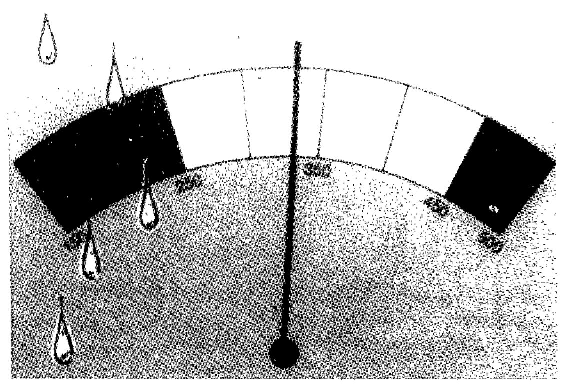


Figure 2-79. Bag blinding dew point *(Barber-Greene)*.

SECTION SEVEN
BATCH PLANT

INTRODUCTION

Discussed in this section are the major components of a batch plant: the cold-feed system, asphalt cement supply system, aggregate dryer, and mixing tower, as shown in Figure 2-80. In most cases, the cold-feed system for a batch plant is similar to the equipment used for a drum mix plant. The asphalt cement feed system operates, for the vast majority of the batch plants, on a weight basis instead of a volume basis. The aggregate dryer operates on a counter flow basis in contrast to most drum mixers, which use a parallel-flow type of system. The heating and drying of the aggregate through the dryer is reviewed.

The batch plant tower is made up of several key components: hot elevator, screen deck, hot bins, weigh hopper, and pugmill. These components are shown in Figures 2-80 and 2-81 and are discussed in depth. The screening of the aggregate is discussed, as is the delivery of the aggregate to the pugmill. The required dry mix and wet mix times for the blending of the aggregate and the asphalt cement are given. The introduction of RAP into the process is also presented.

AGGREGATE HANDLING

Aggregate Stockpiles

The stockpiling techniques used for handling aggregate in a batch plant mixing operation are no different from the procedures used for handling aggregate when producing a mix in a drum mix plant. Care needs to be taken to keep the various aggregate sizes separate and to prevent segregation of each size of aggregate in the stockpile.

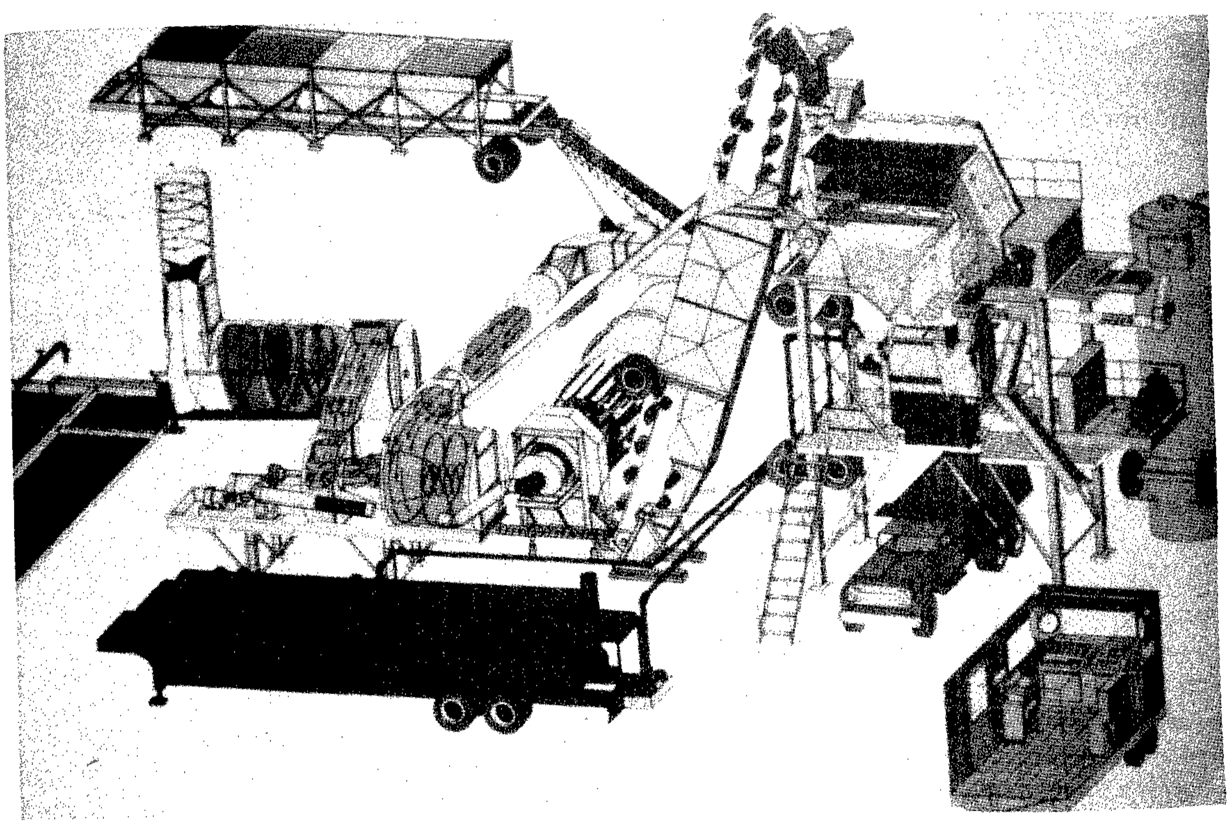


Figure 2-80. Batch plant layout *(Cedarapids)*.

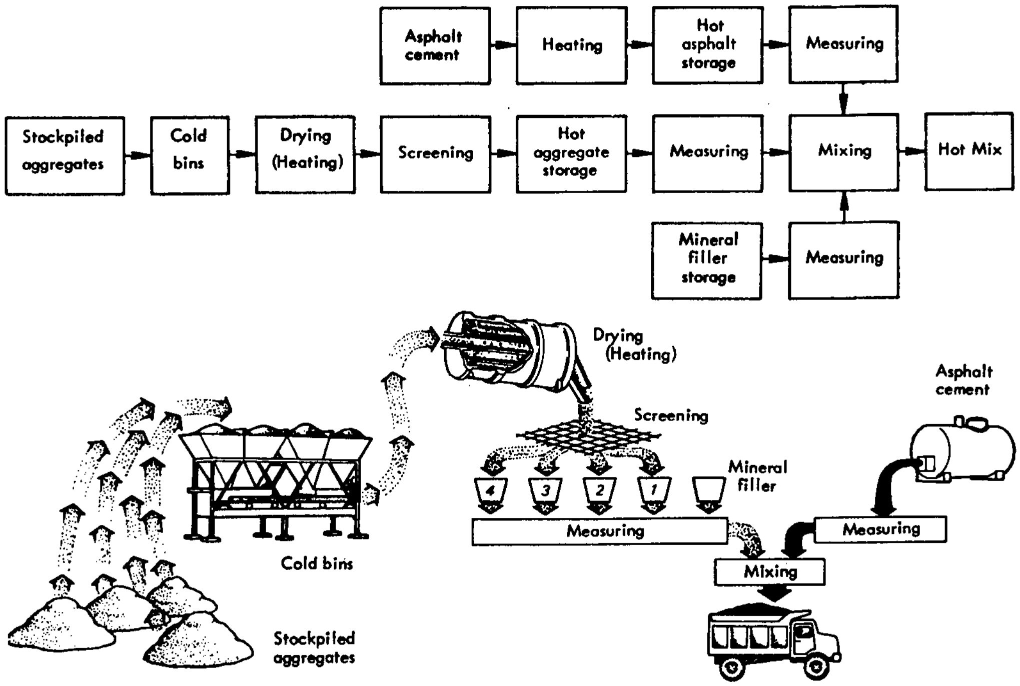


Figure 2-81. Batch plant flow chart *(Asphalt Institute).*

It is sometimes assumed that the screens in the batch plant tower will overcome any problems with variations in the gradation of the incoming new aggregate. If the proper proportion of each size of aggregate is not delivered from the cold-feed bins, however, the amount of aggregate in the hot bins will be out of balance. One or more of the hot bins may be starved for material or one of the hot bins may be overflowing if the aggregate feed at the cold-feed bins is not correct because of lack of separation between the aggregate stockpiles or segregation of the aggregate in one or more stockpiles. Proper stockpiling techniques are as important for batch plant operations as they are for drum mix plant operations.

Cold-Feed Systems for New Aggregates

Some batch plant cold-feed bins are equipped with a constant-speed feeder belt under each bin. The amount of aggregate withdrawn from each bin is controlled by the size of the gate opening at the bottom of the bin. Most plants, however, have cold-feed bins that are equipped with a variable-speed feeder belt beneath each bin. The amount of aggregate withdrawn from each bin is regulated by the size of the gate opening and the speed of the conveyor belt. The aggregate is discharged from each feeder belt onto the gathering conveyor, which runs underneath all of the bins and delivers the aggregate to a scalping screen, if one is used. After the aggregate passes through the scalping screen, it is deposited onto the charging conveyor for delivery to the dryer. If no scalping screen is included in the system (which is normally the case, because the screens at the top of the plant tower are used to remove oversize material) the aggregate is transferred directly from the gathering conveyor to the charging conveyor.

Cold-Feed Systems for RAP

Reclaimed asphalt pavement is usually held in a separate, steep-sided cold-feed bin that is equipped with either a variable-speed or constant-speed feeder belt. The material from the bin is deposited on the feeder conveyor and/or onto a gathering conveyor for transport to a scalping screen. After passing through the scalping screen, the RAP is deposited on a charging conveyor for delivery to the plant. An alternative to the use of the scalping screen at the transfer point between the gathering conveyor and the charging conveyor is to place the scalping screen or grizzly on top of the cold-feed bin so that the RAP passes through the screen as it is being placed in the bin.

The RAP cannot be heated in the dryer because it will generate visible hydrocarbon emissions when exposed to the high-temperature exhaust gases from the burner. Thus, the feed of the RAP must be separated from the feed of the new aggregate. The RAP can enter into the plant at one of three primary locations downstream of the dryer: the bottom of the hot elevator, one of the hot bins at the top of the tower, or the weigh hopper. The last location is the preferred one.

ADDITION OF HYDRATED LIME

Hydrated lime can be added to the aggregate in a batch plant mixing operation in one of two places. The additive can be placed on the aggregate, either in dry or slurry form, similar to the method of addition for a drum mix plant. It can also be added in dry form to the aggregate similar to a mineral filler.

ASPHALT CEMENT SUPPLY SYSTEM

Storage Tanks

The storage tank used for the asphalt cement for a batch plant operation is the same as that used for a drum mix plant. The material is stored at temperatures generally between 300°F and 350°F, depending on the grade and viscosity of the asphalt cement needed to mix properly with the aggregate in the pugmill.

Pump System

The asphalt content of the mix is determined by weight, not volume. Thus, no meter is used to proportion the amount of asphalt cement needed in the mix. The pump, which runs continuously, pulls the asphalt cement from the storage tank and either delivers it to the weigh bucket or recirculates it to the tank, depending on the opening of the control valve at the weigh bucket.

ADDITION OF LIQUID ANTISTRIP ADDITIVES

Liquid antistrip additives are added to the asphalt cement in the batch plant in a manner similar to that for a drum mixer. The additive can be in-line blended with the asphalt cement as that material is pumped out of the delivery vehicle or as it is pumped from the storage tank to the weigh bucket. In addition, it can be blended with the asphalt cement in the storage tank by circulating the two materials together for a period of time before the treated material is pumped to the asphalt cement weigh bucket.

AGGREGATE HEATING AND DRYING

In contrast to the parallel-flow operation of a drum mixer, the dryer on the batch plant operates on a counter flow principle. The aggregate is charged into the dryer at the upper end of the drum and flows through the dryer by the action of the rotating flights and gravity. The burner is located at the lower or discharge end of the dryer. The exhaust gases move toward the upper end of the dryer, in the opposite direction to the flow of the aggregate--the counter flow system. This process is shown in Figure 2-82.

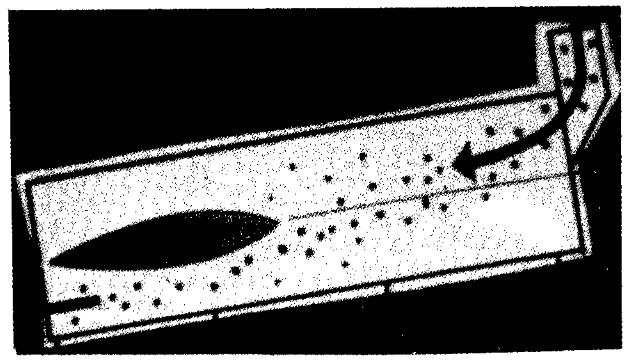


Figure 2-82. Counter flow dryer *(Barber-Greene)*.

The dryer is a rotating drum that is generally 5 to 10 ft in diameter and 20 to 40 ft long. The length of the drum is normally proportional to the diameter at a ratio of 4:1. Thus, a dryer with a diameter of 8 ft would typically be 32 ft in length. The function of the dryer is to remove the moisture from the aggregate and to heat that material to the desired discharge temperature, generally in the range of 290°F to 325°F. The moisture content of the aggregate should be less than 0.5 percent upon exiting the dryer and ideally less than 0.2 percent.

The aggregate is fed into the dryer from the charging conveyor either by means of a charging chute at the top of the dryer or, occasionally, by a slinger conveyor at the bottom of the dryer. The flights inside the dryer, shown in Figure 2-83, are used to lift and tumble the material in a veil across the cross-sectional area of the dryer. As the aggregate flows down the dryer, it is heated by the exhaust gases and the moisture is driven off. The burner flame, which generally has a much longer, thinner shape than the short, bushy flame used with the burner on a drum mix plant, extends into the dryer to penetrate the aggregate veil. The exhaust gases from the burner heat and dry the aggregate by conduction, convection, and radiation. Because of the higher efficiency of the counter flow system, a batch plant dryer typically uses less fuel to heat and dry a given amount of aggregate than does the parallel-flow system used in a

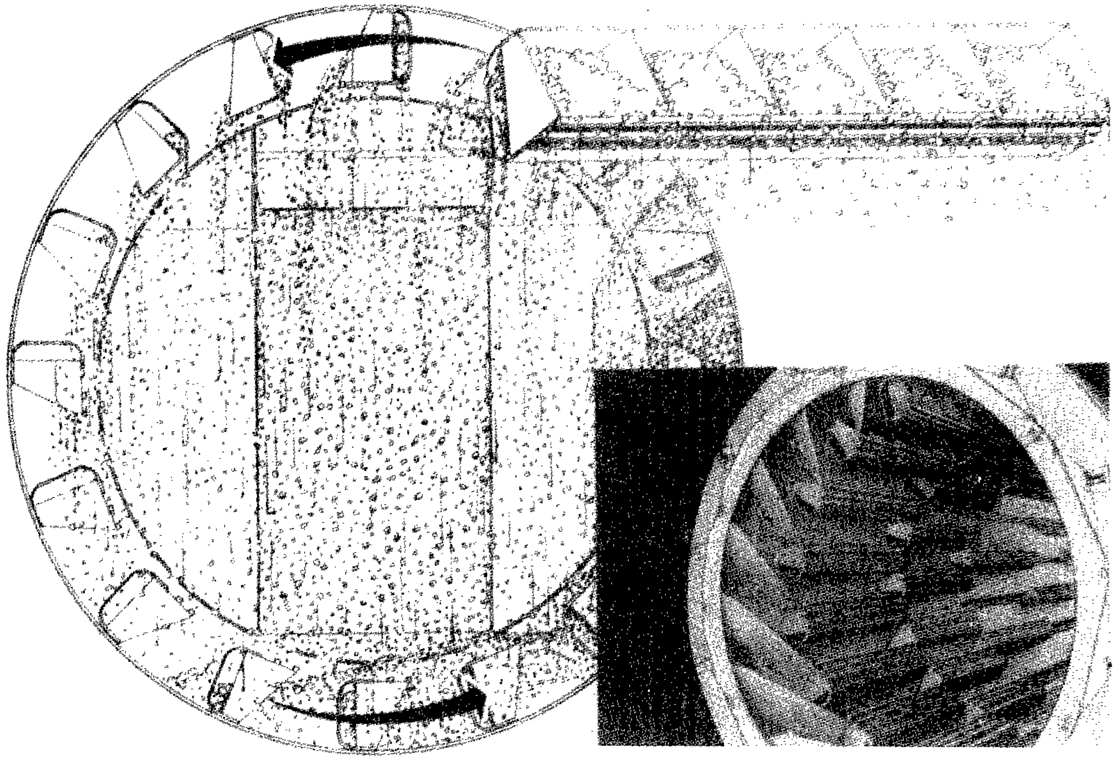


Figure 2-83. Flights inside dryer *(Cedarapids)*.

drum mixer.

The dwell or residence time of the aggregate inside the dryer is a function of the length of the drum, the design of the flights, the number of flights, the speed of rotation, and the slope of the dryer (typically between 2 1/2 degrees and 6 degrees or 5/16 in./ft and 3/4 in./ft, respectively). If moisture greater than 0.5 percent remains in the aggregate upon discharge from the dryer, the density of the veil of aggregate inside the drum must be increased, typically by lowering the slope of the dryer, or by changing the number and/or type of flights used in the dryer. Either of these will increase the dwell time of the aggregate inside the dryer.

Because the aggregate typically makes up between 92 and 96 percent of the weight of the mix, it governs the temperature of the asphalt mix produced in the pugmill. Excessive heating of the aggregate may cause excessive hardening of the asphalt cement in the mixing process. If a recycled mix is to be produced, however, the new aggregate must be superheated in the dryer in order to accomplish the necessary heat exchange in the pugmill. In this case, the temperature of the new aggregate is dependent on the amount and the moisture content of the RAP, as discussed later in this section.

SCREENING AND STORAGE OF HOT AGGREGATE

Hot Elevator

New Aggregate

The heated and dried aggregate is discharged from the dryer through a chute into the bottom of the hot-bucket elevator. The material is transported by the continuously moving buckets up to the top of the batch plant tower as illustrated in Figure 2-84.

Reclaimed Material

It is not recommended to add the RAP into the plant at the bottom of the hot elevator, particularly when the amount of RAP exceeds approximately 10 percent in the mix; however, small amounts of reclaimed asphalt material can be introduced there. The RAP should be fed, if possible, into the new aggregate discharge chute from the dryer so that it is on top of the new aggregate and directed into the center of the buckets. If that is not feasible, the reclaimed material should be deposited into a separate steep-sided chute located above the new aggregate entry at the bottom of the hot elevator. The RAP must be placed in the buckets after the new aggregate to prevent the asphalt-coated material from sticking to the buckets as it is heated by contact with the super-

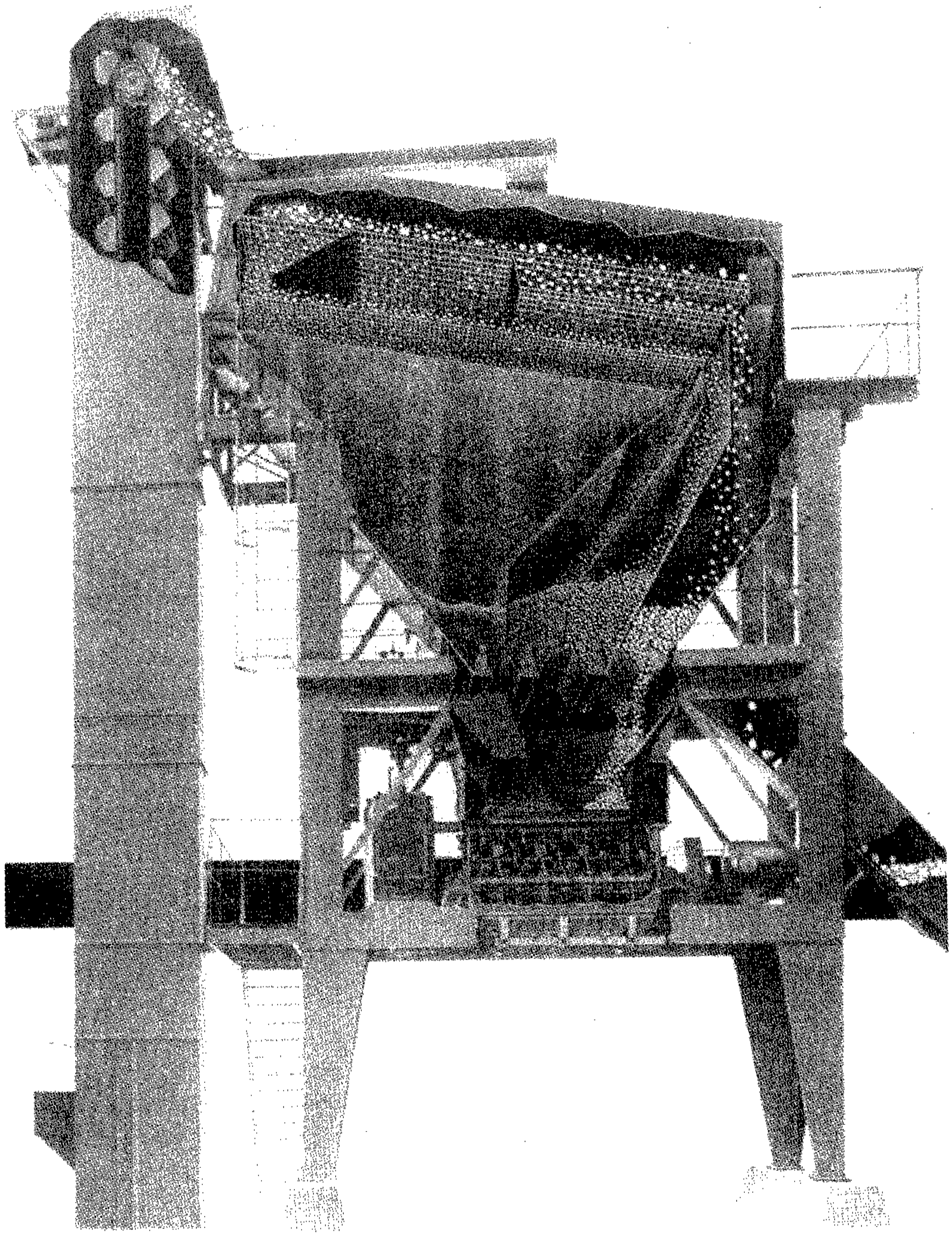


Figure 2-84. Hot-bucket elevator and batch plant tower *(Portec)*.

heated new aggregate.

There is a limit to the amount of RAP that can be fed into the bottom of the hot elevator and it is related to the heating process as the material travels to the top of the tower. Depending on the percentage of RAP used in the mix, the moisture content of the RAP, and environmental conditions, the reclaimed material can be heated enough while in the hot-bucket elevator to stick to the screen instead of passing through the screens. This may clog (blind) the screens and eventually cause shutdown of the plant. Thus, the screens may be removed or bypassed when the RAP is added at the bottom of the hot-bucket elevator if this becomes a problem.

Screen Deck

The aggregate is discharged from the hot-elevator buckets onto a set of vibrating screens that are used to separate the material into different sizes. Four screen decks typically are used, arranged as shown in Figures 2-84 and 2-85. The top screen is generally a scalping screen to remove any oversized material from the aggregate flow and reject it to a bypass/overflow chute. The remaining three screen decks divide the aggregate into four different fractions. The amount of material in each fraction is dependent on the size and shape of the openings in the screens. Each screen deck may have several different screen sizes in order to improve screening efficiency and to protect the smaller screens from oversize aggregate.

The screens can have square, rectangular, or slotted openings, with square openings being most common. For example, for a typical batch plant that would manufacture base, binder, and surface course mixes, the size of the openings in a square screen might be 1 1/4 in. for the top deck, 9/16 in. for the second deck, 5/16 in. for the third deck, and 5/32 in. for the bottom deck. The sand-sized aggregate, smaller than 5/32 in. in diameter, would pass directly through all of the screens and be deposited into the No. 1 hot bin. Aggregate that was larger than 5/32 in., but no greater than 5/16 in., would be carried over the first screen and then dropped into the No. 2 hot bin. For any particular mix, the proper screens need to be used in the screen deck in order to produce the required gradation in the asphalt mix. If mix gradations change significantly, it may be necessary to change the screen sizes used at the top of the mixing tower. Different-size screens than those in the example above may be used for different combinations of aggregate for different agency specifications.

In addition, many screen decks will use a split-screen setup in which screens with two different-size openings are placed at the same level (in the same deck). For example, the top screen deck might employ a screen with an opening of 5/16 in. for the half of the deck nearest to the hot elevator and a screen with an opening of 1 1/4 in. for the half of the deck over the No. 3 and No. 4 hot bins. This arrangement is done to improve the efficiency of the screening operation.

Not all of the material that should be in a particular bin always ends up in that bin. The amount of aggregate that is sand-sized and that should pass through all of the screens and end up in the No. 1 bin but instead is deposited into the No. 2 hot bin is called carryover. A small amount of carryover, generally less than 10 percent, from one bin to the adjacent bin is often found. The carryover is caused by the flow of aggregate moving across and through the screens. It is increased as the openings in the screens become clogged or blinded with aggregate and as the amount of aggregate being delivered by the hot elevator is increased. The primary

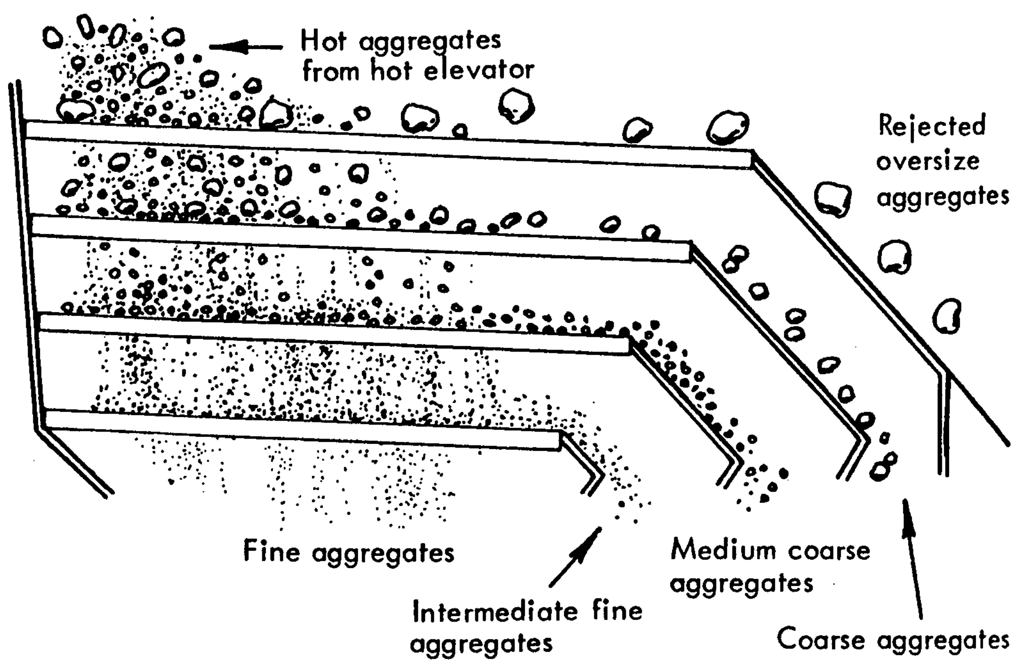


Figure 2-85. Screen deck *(Asphalt Institute)*.

problem is when the amount of carryover is variable from one time to another, causing the gradation of the aggregate found in each of the hot bins to change. This is often caused by continued variation in the rate of feed of the aggregate from the cold-feed bins.

If the screen develops tears or holes, some of the aggregate that should be deposited in another bin will pass through the screen and end up in a bin with smaller-sized material. The screens at the top of the tower should be checked regularly to ensure that there are no holes and that the screens are not clogged with aggregate and blinded.

In some locations, batch plants are routinely operated without screens; the screen deck is removed or a screen bypass chute is used. All of the aggregate that is transported up the hot elevator is deposited directly into the No. 1 bin. Without screens, the batch plant will be operated in essentially the same manner as a drum mix plant and will depend on the consistency of the gradation of the aggregate in the cold-feed bins to determine the final gradation of the mix. Because no screening is done to separate the aggregate into sizes, the various gradations that were proportioned out of the cold-feed bins (unless only one aggregate blend is used to make the mix) will be deposited directly into the No. 1 hot bin upon discharge from the hot elevator. All of the aggregate used in the mix will then be drawn from this one hot bin into the weigh hopper and then into the pugmill.

Hot Bins

New Aggregate

The total capacity of the hot bins is usually proportional to the size of the pugmill. The capacity of each of the hot bins, however, is not the same. The greatest capacity is in the No. 1 (sand) bin, as seen in Figure 2-84. Generally about 40 percent by weight of the aggregate delivered by the hot elevator passes through the screens and into this bin. The typical capacity (the percent of the total hot-bin capacity) of each of the remaining three bins is 30 percent for bin No. 2, 20 percent for bin No. 3, and 10 percent for bin No. 4.

Some segregation of the aggregate occurs in each hot bin, and particularly in the No. 1 sand bin, as shown in Figure 2-86. This is caused by the finer material in each size fraction passing through the screens more directly than the coarser material of the same aggregate size. Thus, the aggregate on the side of each hot bin that is the closest to the hot elevator will generally be finer in gradation than will be the aggregate on the opposite side of the same hot bin.

The partitions between each hot bin should be checked regularly to ensure that no holes have developed and that aggregate in one bin is not flowing into the adjacent bin. The overflow pipes at the top of each bin should be open. Fines sometimes build up in the corners of the No. 1 bin. When the level of aggregate in the bin is low, the collected fines can break loose and a slug of the material can enter the weigh hopper. If this is a continuing problem with a particular plant, fillets can be welded in the corners of the No. 1 bin to reduce the buildup of the fine material, or a plate can be used at the top of the No. 1 bin to deflect the fines into the center of the bin.

Even though the screens on the batch plant are used to regrade the aggregate that is fed into the plant from the cold-feed bins, the proportion of material delivered from each cold-feed bin must be correct or one of the hot bins will either run out of material or overflow. Because all the aggregate that is discharged from the cold-feed bins will end up in the mix, it is very important that the aggregate placed in the cold-feed bins is graded consistently. The screens should not be used to attempt to overcome a problem with a variable incoming aggregate gradation.

RAP

Although not a recommended practice, RAP has been deposited directly into one of the hot bins on the plant. A separate charging conveyor or bucket elevator is used to carry the reclaimed material to the top of the plant. The RAP is deposited through a screen bypass

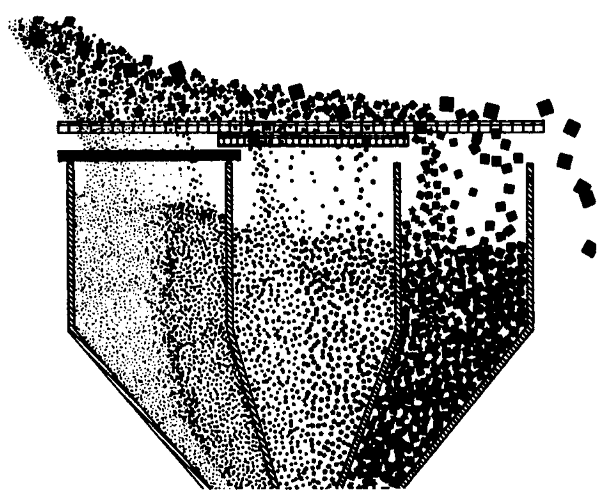


Figure 2-86. Hot-bin segregation *(Asphalt Institute)*.

directly into the No. 1 hot bin with the sand or into the No. 4 hot bin if no other aggregate is in that bin--when a surface course mix is being produced and no large aggregate is needed. Further, if the RAP is placed in the No. 1 hot bin, the heat-transfer process can begin between the superheated sand and the ambient-temperature RAP while both are together in the hot bin. If the asphalt-coated material is placed in the No. 4 bin, no such heat advantage is realized because of a lack of heated new aggregate in that bin.

The disadvantage of placing the RAP in either the No. 1 or the No. 4 bin is that some of the asphalt-coated particles will stick to the walls of the bin. This can be a major problem, particularly if the amount of reclaimed material used in the mix and the moisture content of that material are both high. If superheated new aggregate is in the bin adjacent to the RAP, a significant amount of the RAP will stick to the partition between the two bins.

WEIGH HOPPER

New Aggregate

If a base course mix is being produced, all four of the hot bins may be filled with aggregate. If a binder or surface course mix is manufactured, only two or three of the hot bins will normally be needed. The aggregate in the hot bins can be discharged into the weigh hopper in any order, and typically the coarse aggregate is discharged into the weigh hopper before the fine aggregate is deposited. Normally the gate at the bottom of the No. 3 hot bin is opened and the aggregate is discharged into the weigh hopper until the correct weight is reached. The gate on the No. 3 bin is then shut and the gate on the No. 2 hot bin opened and the weigh hopper filled with that material until the correct cumulative weight (combined weight of the No. 3 bin and the No. 2 bin material) is reached. The aggregate in each of the last two hot bins (the No. 1 and No. 4 bins) is added to the weigh hopper in the same manner. The weighing of each aggregate is accomplished in about 5 sec. It is important that the aggregate delivered from each hot bin be deposited as near the center of the weigh hopper as possible so that the hopper is not unbalanced on the scale and spillage of the aggregate does not occur.

If mineral filler is needed in the mix, it is normally added to the aggregate already in the weigh hopper. The filler is delivered pneumatically or mechanically from a storage silo to a small holding hopper typically located on the plant tower just above the weigh hopper. It is then added to the weigh hopper by means of a horizontal screw conveyor. On some batch plants, the filler is weighed separately from the other aggregate and then augered into the main aggregate weigh hopper after the aggregate from the hot bins has been weighed. On other plants, the filler is weighed as a fifth aggregate as it is added to the material already in the hopper.

Reclaimed Material

The best location to add RAP to a batch plant is into the weigh hopper. Once the aggregate from the hot bins has been deposited in the hopper and weighed, the reclaimed material is usually fed into the hopper as a fifth aggregate (or as the sixth aggregate, if mineral filler is used in the mix), although it can actually be added to the weigh hopper in any order except first. The charging conveyor used to deliver the RAP to the weigh hopper, shown in Figure 2-87, must be oversized in this case because it does not run continuously. The RAP should be deposited into the weigh hopper in approximately 5 sec.

The RAP must be discharged from the charging conveyor into a steeply angled chute (in order to prevent it from "hanging up" in the chute) and then into the center of the weigh hopper, as shown in Figure 2-88. If this material is deposited on one side of the weigh hopper to the point that the hopper is unbalanced, an accurate weight will not be determined. The charging chute should be equipped with a flop gate to prevent the escape of fugitive dust from the weigh hopper area when the aggregate is emptied into the pugmill.

PUGMILL

Capacity

The aggregate and the asphalt cement are blended together in a twin-shaft pugmill. Mixing paddles, shown in Figure 2-89, are attached to two horizontal shafts that rotate in opposite directions. The aggregate is first discharged from the weigh hopper into the pugmill and is mixed for a very brief time (dry mix time) before the asphalt cement is introduced into the pugmill and the wet mix time begins. When the mixing is completed, the asphalt mix is discharged from the pugmill directly into a haul truck or into the conveying device for transport to the silo.

The size of the batch produced depends on the size of the pugmill. Some batch plants have a pugmill

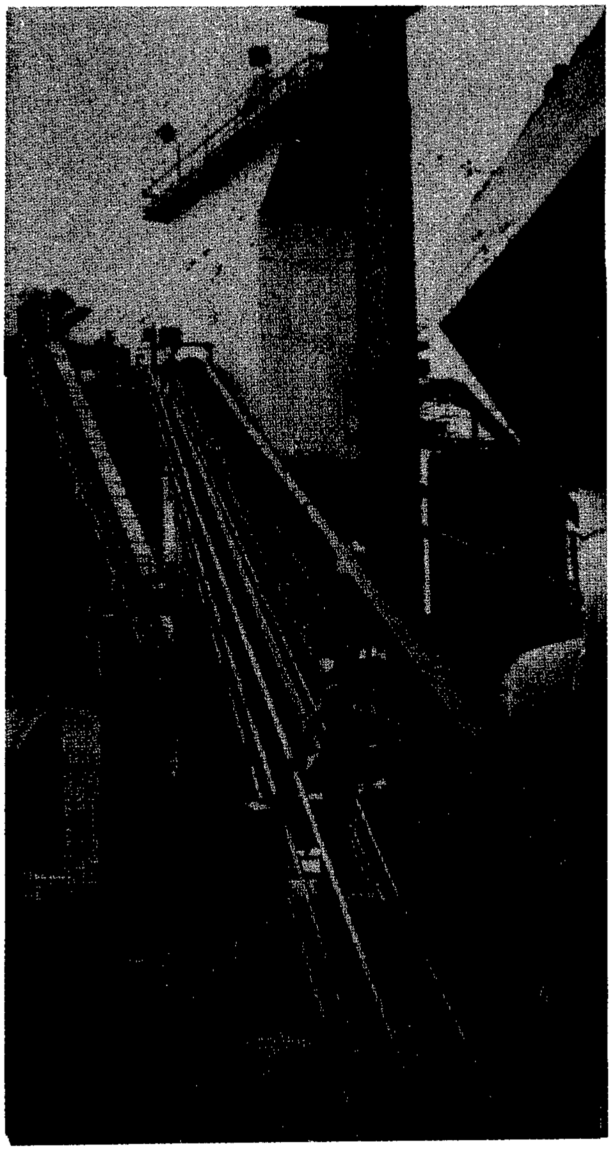


Figure 2-87. RAP conveyor to batch plant weigh hopper *(J. Scherocman)*.

capacity as little as 1 ton. Most batch plants, however, are equipped with pugmills that have capacities between 2 and 5 tons. One of the largest batch plant pugmills made has the capability to mix 11.5 tons (23,000 lb) of mix in a single batch. The total mixing time for all of the different batch sizes is the same--typically as short 35 sec/batch. The only difference is the size of each batch, not the time needed to produce it.

Nominal pugmill capacity is determined by the dimensions of the live zone, as shown in Figure 2-90. If too much aggregate is placed in the pugmill, the material above the paddle tips will tend to stay on top and not be mixed with the other aggregate. If too little aggregate is deposited into the pugmill, the material will be thrown around by the paddles instead of mixed. These two conditions are illustrated in Figures 2-91 and 2-92.

Batch size should not be varied from batch to batch. Consistent mix is obtained by selecting a batch size at or slightly less than the nominal capacity of the pugmill and producing all batches at that tonnage. If the plant is equipped with a 3-ton pugmill and the average haul truck being used can hold 14 tons of mix, the batch size selected should be 2.8 tons (14 tons per truck divided by five batches). The plant operator should not attempt to produce four batches of 3 tons each and a fifth batch of only 2 tons. Consistent batch size is one of the keys to a consistent mix.

Mixing Time

Dry Mix Time

Dry mix time is defined as the time between when the aggregate starts to be charged and when asphalt injection starts. Dry mix time should be minimal; normally no more than 1 or 2 sec. Although the aggregate in the weigh hopper is layered, the different-size aggregates can be blended adequately during the wet mix cycle and do not need to be premixed during the dry mix cycle. The main purpose of the dry mix time is to allow some aggregate to enter the pugmill before the asphalt cement is discharged so that it does not run out of the gates at the bottom of the pugmill.

There is no evidence that a longer dry mix time improves the quality of the asphalt concrete mix. Dry mix times of various lengths, from 1 to 20 sec, have been used and gradation tests conducted on the mix produced from the batch plant. No difference was found in the uniformity of the aggregate gradation regardless of the length of the dry mix time. Thus, increasing dry mix time decreases the plant production rate without benefiting the mix, and causes additional wear on pugmill paddles and liners.

Wet Mix Time

While the aggregate is still being discharged from the weigh hopper into the pugmill, the addition of the asphalt cement commences. This material is fed into the pugmill by gravity flow or pressure spray and is added through one pipe in the center of the pugmill or through

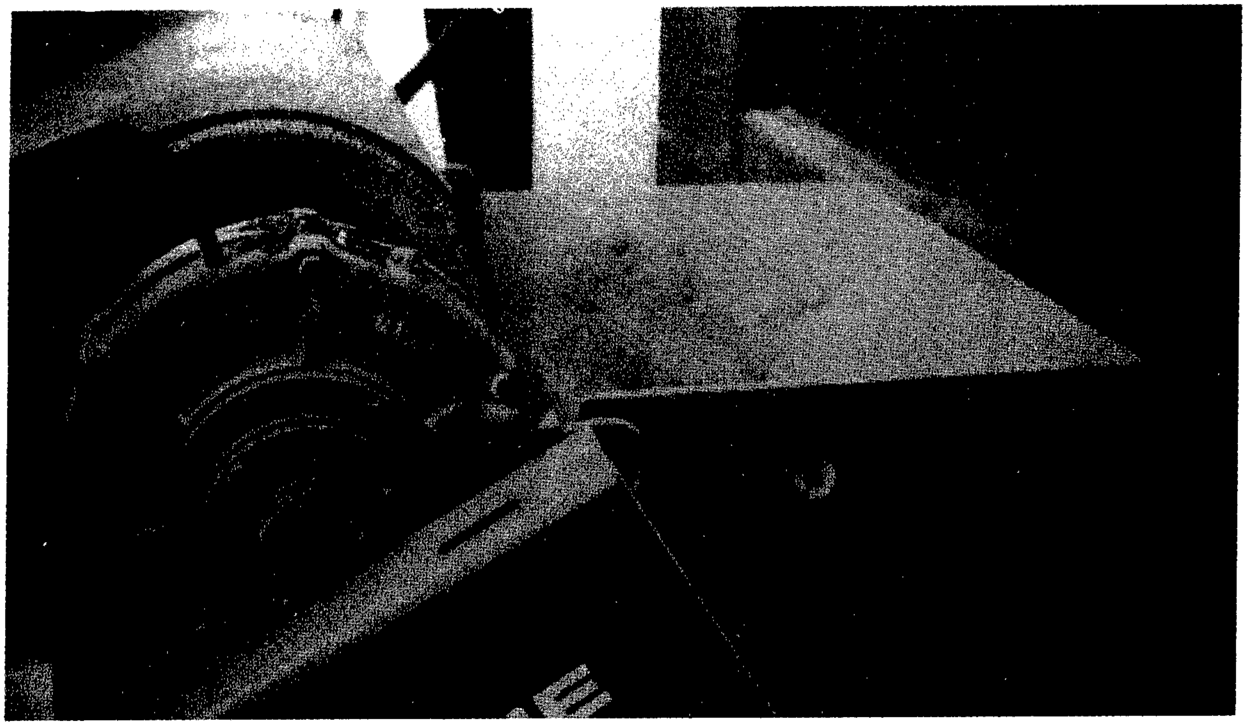


Figure 2-88. Reclaimed material chute to weigh hopper *(J. Scherocman)*.

two pipes, one over each of the two mixing shafts, as seen in Figure 2-93. The wet mix time starts when the asphalt enters the pugmill. Typically it takes from 5 to 10 sec for all the asphalt cement to be discharged from the weigh bucket. Pressure injection systems can be used to reduce the time to introduce the asphalt cement

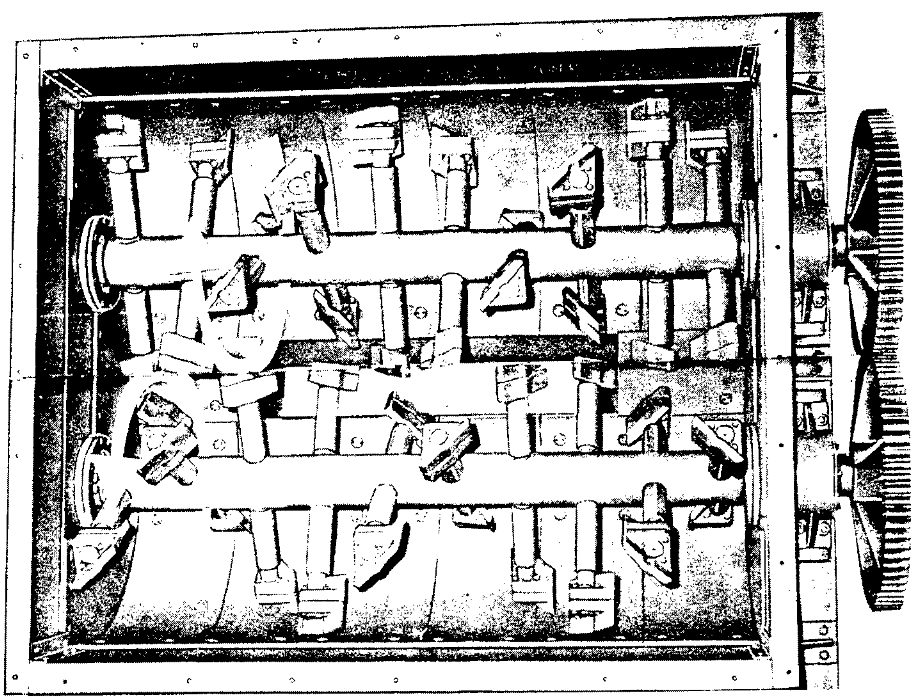


Figure 2-89. Twin-shaft pugmill *(Cedarapids)*.

into the pugmill.

Wet mix time should be no longer than it takes to coat the aggregate with asphalt cement. If the paddle tips and pugmill liners are in good condition and the pugmill is full, the wet mix time can be as short as 27 sec. If the paddle tips are worn, the wet mix time will be extended slightly but typically should not be more than 33 sec. Because they affect the amount of wet mix time, the condition of the paddle tips should be checked regularly and the tips should be changed when necessary. As a general rule, a 30-sec wet mix time is very adequate to distribute the asphalt cement and coat the aggregate.

The mixing time should be as short as possible to avoid excessive hardening of the asphalt cement when it is exposed to high temperatures in a thin film around the aggregate particles. The required wet mix time can be established using the Ross Count procedure to determine the degree of particle coating of the coarse aggregate in the mix as given in ASTM D 2489. Once the asphalt cement is properly distributed, additional wet mix time does not improve the coating but only oxidizes (hardens) the asphalt cement.

Coating of the aggregate in a pugmill occurs first with the smallest-size aggregate particles. If wet mixing was only done for 10 sec and the material discharged from the pugmill at the end of that time, only the smaller fine aggregate (the material finer than the No. 30 or No. 40 (600 μm or 425 μm) sieve) would typically be coated with the asphalt cement; the coarser aggregate particles, however, would only be partially coated with asphalt. If wet mixing time was extended to 20 sec and the material discharged from the pugmill at the end of that time, only the aggregate of No. 4 (4.75 mm) sieve size and smaller would typically be coated with asphalt cement; the coarser aggregate particle would still remain uncoated. Complete coating of all the coarse aggregate in the mix usually takes about 26 to 28 sec of wet mixing time in a pugmill with paddle tips and lining in good condition. Thus the Ross Count procedure, which looks only at the degree of asphalt coating on the coarse aggregate particles (larger than the No. 4 sieve), is an effective way to determine the minimum amount of wet mix time needed to properly distribute the asphalt cement throughout the aggregate.

Total Mix Time

Mixing time also has a direct effect on the production capacity of a plant. If a 1-sec dry mix time and a 27-sec wet mix time are used, proper mixing of the two materials can be accomplished in 28 sec. Given approximately 7 sec more to open the gates at the bottom of the pugmill, discharge the mix, and close the gates, the total cycle time to produce a batch of asphalt concrete mix is 35 sec. This time is the same whether the batch size is 2 tons or 5 tons. Theoretically, if a plant having a pugmill capacity of 5 tons is run continuously for 1 hr, 514 tons of asphalt mix can be manufactured.

If a 5-sec dry mix time and a 35-sec wet mix time were required by specification, the total cycle time to

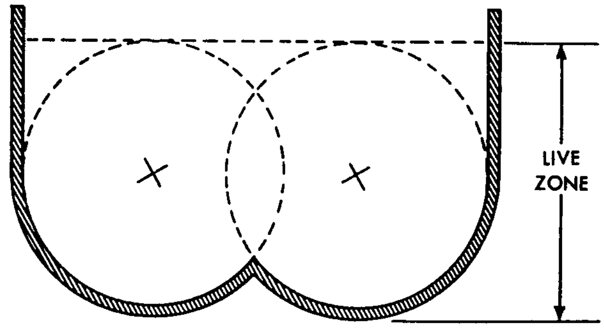


Figure 2-90. Pugmill live zone *(Asphalt Institute)*.

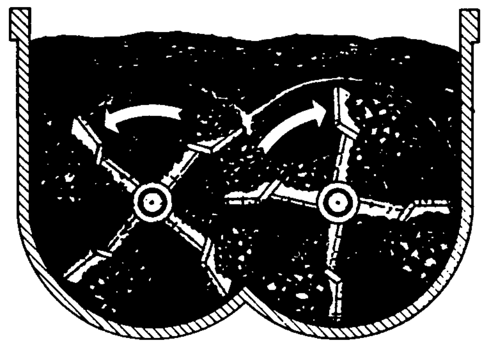


Figure 2-91. Too much aggregate *(Asphalt Institute)*.

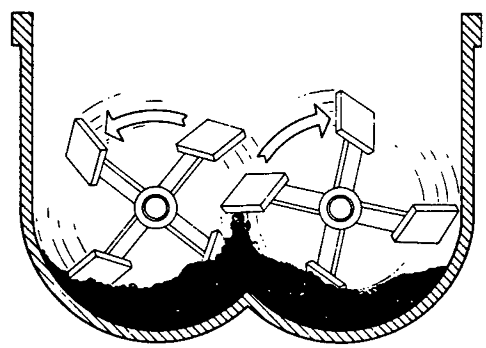


Figure 2-92. Too little aggregate *(Asphalt Institute)*.

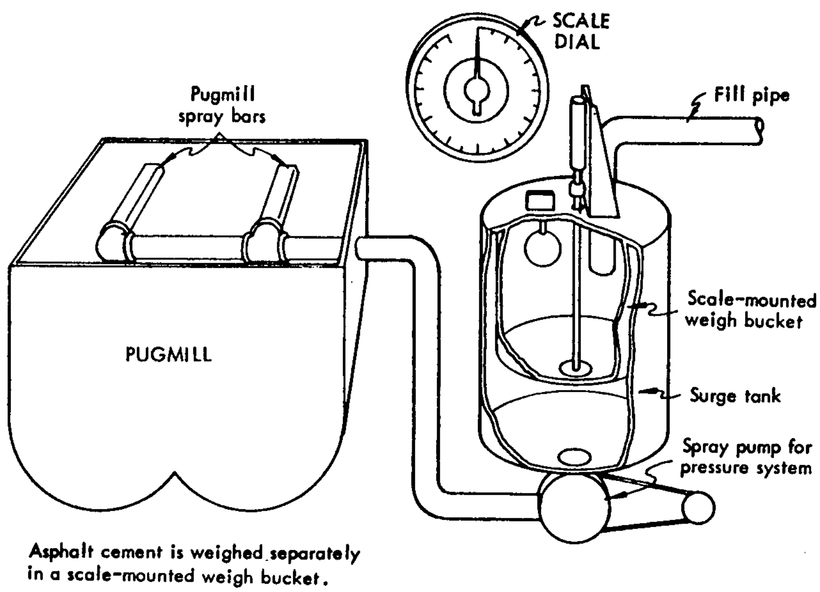


Figure 2-93. AC flow to pug mill *(Asphalt Institute)*.

produce the mix would be 47 sec (assuming a 7-sec gate opening/closing and mix discharge time). This increased cycle time (47 sec compared with 35 sec) would decrease the amount of mix produced in a 5-ton-capacity pugmill from 514 tons to 383 tons/hr. If a 60-sec total cycle time were used, the production rate for the same plant would be reduced to only 300 tons/hr. As expected, the dry and wet mix times have a significant effect on the amount of mix produced by a given plant.

If the plant is not equipped with a silo, there will be times when the plant production may have to be interrupted because of a lack of available haul trucks. This problem must be monitored by the plant operator. In no case should the plant mixing time be extended during the wet mix cycle. If the asphalt cement has been added to the aggregate and the wet mixing time is extended to 40 or 50 sec or longer, excessive hardening of the asphalt cement will occur. This extended wet mix time can be very detrimental to the long-term performance of the mix on the roadway.

If trucks are not available, the plant should be idled with no material in the pugmill; the paddles should be "mixing air." The second choice, but not nearly as good as the first choice, is to let the plant wait during the dry mix time; the aggregate is in the pugmill but the asphalt cement has not been added. Depending on the length of the extended dry mix time, some degradation of the aggregate may occur, but the effect on the long-term performance of the mix will be less than when the wet mix time is lengthened. Again, the plant should not be idled during the wet mix time.

When the incoming aggregate has a high moisture content, the dryer may not have enough capacity to remove all of the moisture efficiently. In some cases, the capacity of the screens is not great enough to handle all of the aggregate being delivered, particularly if the screens are clogged or blinded. The production rate of the plant will be reduced (total cycle time increased) while waiting for dry material in the hot bins. If this problem occurs, the plant operator must not increase the total cycle time by arbitrarily increasing the wet mix time. The total cycle time should be increased by delaying the discharge of the aggregate from the weigh hopper into the pugmill and thus "mixing air" instead of aggregate (increased dry mix time) or instead of asphalt mix (increased wet mix time).

PRODUCING RECYCLED MIX

Recycling Variables

The temperature of the new aggregate governs the amount of reclaimed material that can be introduced into a recycled mix produced in a batch plant. For the heat transfer to take place from the heated new aggregate to the ambient-temperature RAP, the new aggregate must be superheated--heated to a temperature above that needed to produce a conventional asphalt concrete mixture. This heat transfer can take place in the hot elevator, in the hot bins, in the weigh hopper, or in the pugmill, depending on where the RAP is introduced into the plant. For most dryers, in order not to reduce the life of the dryer and to keep from driving off internal (hygroscopic) moisture in the aggregate, the maximum new aggregate temperature upon discharge from the dryer should be about 500°F.

The three primary variables that determine the temperature to which the new aggregate has to be heated to accomplish the necessary heat transfer are the moisture content of the reclaimed material, the discharge temperature of the final recycled mix, and the amount of reclaimed material used. Depending on the values for these variables, up to 50 percent RAP can be blended with new aggregate to manufacture a recycled asphalt concrete mix.

Moisture Content

As the moisture content of the reclaimed material increases, the required new aggregate temperature increases significantly. This is illustrated in Figure 2-94. If 20 percent RAP is used in the mix, the moisture content of that material is 1 percent, and the required mix discharge temperature is 260°F, the temperature to which the new aggregate would need to be heated would be 350°F, as seen in Section B of this table. If the same RAP had a moisture content of 4 percent, however, the new aggregate temperature would need to be increased to 390°F for the same amount of reclaimed material and the same mix discharge temperature.

Mix Discharge Temperature

Using Section C of Figure 2-94 as an illustration, the amount of RAP incorporated into the mix is 30 percent. If the moisture content of this material is 3 percent as it is delivered to the plant, the new aggregate temperature would need to be at least 385°F when the mix discharge temperature is only 220°F. If the discharge temperature was 280°F, the temperature of the new aggregate would need to be increased to 475°F, however. Thus, a higher mix discharge temperature for the recycled mix from the pugmill requires an increase in the new aggregate temperature from the dryer.

Amount of Reclaimed Material

As the amount of RAP in the recycled mix increases, the new aggregate temperature also must increase. If only 20 percent reclaimed material is used and if the moisture content of that material is 4 percent for a mix discharge temperature of 280°F, the new aggregate discharge temperature would need to be 415°F, as determined from Section B of Figure 2-94. Increasing the amount of RAP to 50 percent, using Section E of the same table and for the same value of moisture content (4 percent) and mix discharge temperature (280°F), the new aggregate temperature must be raised to 760°F to accomplish the heat-transfer process. This latter temperature significantly exceeds the recommended maximum new aggregate temperature of 500°F.

Dryer Operation

If the temperature of the new aggregate exiting the dryer exceeds approximately 500°F, the cost of operating and maintaining the dryer can increase significantly. Because of extremely high aggregate temperatures and the reduced volume of aggregate in the dryer when a large percentage of RAP is used in the recycled mix compared with a normal mix, the veil of aggregate inside the dryer will typically not be adequate. This lack of veil will increase the temperature of the dryer shell and may require increased maintenance on the inside of the dryer, especially on the discharge flights.

If the mix production is stopped for a long period of time because of a lack of haul trucks or because of mechanical problems, the superheated new aggregate will lie in the bottom portion of the dryer. If the temperature of this material is greater than about 500°F, warping of the drum shell can occur and the dryer will be out of round. Further, at the end of each production cycle, the dryer should be allowed to run empty with the exhaust fan operating for a reasonable cooling down period after aggregate feed shutdown. This cooling procedure will protect against possible warping of the dryer shell and the flights.

Visible Emissions

When the RAP is deposited on top of the superheated new aggregate in the weigh hopper and when the two materials are mixed together in the pugmill, emissions of both moisture and dust can occur. These emissions are caused by the escape of the moisture, in the form of steam, from the RAP. The amount of moisture vapor, as well as blue smoke, released can be quite large. For a mix containing 50 percent reclaimed material in a 3-ton batch of recycled mix, with a mois-

Required Aggregate Temperatures

A. Ratio: 10% RAP/90% Aggregate

Reclaimed Material Moisture Content %	Recycled Mix Discharge Temperature, °F 220° F 104° C	240° F 116° C	260° F 127° C	280° F 138° C
0	250	280	305	325
1	260	290	310	335
2	270	295	315	340
3	280	300	325	345
4	285	305	330	350
5	290	315	335	360

B. Ratio: 20% RAP/80% Aggregate

0	280	310	335	360
1	295	320	350	375
2	310	335	360	385
3	325	350	375	400
4	340	365	390	415
5	355	380	405	430

C. Ratio: 30% RAP/70% Aggregate

0	315	340	375	405
1	335	365	395	425
2	360	390	420	450
3	385	415	445	475
4	410	440	470	[illegible]
5	435	465	495	[illegible]

D. Ratio: 40% RAP/60% Aggregate

0	355	390	425	460
1	390	425	460	495
2	425	460	495	[illegible]
3	470	[illegible]	[illegible]	[illegible]
4	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	[illegible]	[illegible]	[illegible]

E. Ratio: 50% RAP/50% Aggregate

0	410	455	495	[illegible]
1	465	[illegible]	[illegible]	[illegible]
2	[illegible]	[illegible]	[illegible]	[illegible]
3	[illegible]	[illegible]	[illegible]	[illegible]
4	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	[illegible]	[illegible]	[illegible]

NOTE: 20°F loss between dryer and pugmill assumed in these calculations

Figure 2-94. Moisture RAP temperature capacity chart *(NAPA)*.

ture content of 3 percent, approximately 14,900 ft^3 of water vapor will be released in about 5 sec. This release of vapor usually causes carryout of dust particles from the weigh hopper and the pugmill.

One way to control the particulate emissions is to reduce the amount of moisture and/or reduce the amount of RAP used in the recycled mix. The moisture content of the reclaimed material can be kept low by not crushing this material until just before it is needed and by preventing rain from falling on the RAP by keeping it under a roof. Another approach, required in some areas, is to adequately vent the weigh hopper and pugmill into the emission-control system on the plant.

LOADING THE TRUCK OR SILO

If the mix discharged from the pugmill is loaded directly into the haul truck, each batch should be deposited into a different location on the truck. The first batch should be placed in the front of the bed. The driver should move the truck forward so that the second batch is placed into the rear of the truck bed, adjacent to the tailgate. The remaining batches should be discharged into the center of the bed, with the position of the truck under the pugmill changing for each batch. This procedure will minimize the distance the coarse aggregate particles can roll in the bed and, thus, reduce the possibility for segregation of the mix.

If the mix is to be stored in a silo temporarily, it should be discharged into the center of a hopper and then into a conveying device, which can be a drag slat conveyor, a belt conveyor, or a bucket elevator. The silo should be operated in a manner similar to the silo used with a drum mix plant.

EMISSION-CONTROL EQUIPMENT

Because the asphalt cement is not added to the aggregate inside the dryer, the amount of dust carryout from a batch plant dryer is generally greater than from a drum mixer. The operation of the emission-control equipment--wet-scrubber system or baghouse (fabric filter)--is the same, however, regardless of the type of plant used.

If the baghouse fines are fed back into the mix, the fines should be fed into a filler-metering system before being introduced into the weigh hopper on the tower. This procedure will assure that the baghouse fines are delivered uniformly into the mix. On some plants, the fines are transported to the bottom of the hot elevator and deposited on top of the new aggregate that is discharged from the dryer. As long as the fines are delivered consistently, this method of fines return is acceptable, particularly if the aggregate will pass through the screen deck. If screens are not used, however, small lumps of fines can be deposited into the No. 1 hot bin and possibly end up in the mix. Thus, returning the baghouse fines to the hot elevator is probably not as good as placing the fines directly in the weigh hopper.

If the plant is equipped with a baghouse and a recycled asphalt mix is being produced with a high percentage of reclaimed material, the temperature of the exhaust gases from the dryer to the baghouse should be monitored continuously to assure that the bags in the emission-control device are not damaged by excessive heat. The higher the temperature to which the new aggregates must be heated, the greater the chance for problems with the baghouse operation.

CALIBRATION

The calibration procedure for a batch plant involves checking the accuracy of the scales, both for the aggregate weigh hopper and for the asphalt cement weigh bucket. This is usually accomplished by adding a known amount of weight to each scale and reading the weight shown on the scale dial. For this purpose, a set of 10 50-lb weights is normally used.

The aggregate scale is unloaded and set to a zero reading. The 10 50-lb weights are hung from the scale and the reading on the dial recorded. The weights are removed and 500 lb of aggregate are then added to the weigh hopper. The 10 weights are again hung from the scale and the next reading on the dial (1000 lb) is recorded. The weights are removed once again and an additional 500 lb of material is added. The weights are placed on the scale and the next dial reading recorded (1500 lb). This process continues (adding the weights, recording the dial reading, removing the weights, adding 500 lb of aggregate to the weigh hopper, and then repeating the sequence) until the capacity of the aggregate scale is reached.

For the asphalt cement weigh bucket, the same process is employed, except that only one 50-lb weight typically is used. First the weigh bucket is unloaded and the scale set to a zero reading. Next one 50-lb weight is hung from the scale and the dial reading recorded. Fifty lb of asphalt cement is then introduced into the weigh bucket. The 50-lb weight is placed back on the scale again and the dial reading recorded. Fifty lb of asphalt cement is added to the weigh bucket (for a total of 100 lb). The procedure continues (adding the weight, recording the dial reading, removing the weight, adding 50 lb of asphalt cement, and then repeating the sequence) until the capacity of the asphalt cement weigh bucket scale is reached.

For both scales, a comparison is made of the actual dial reading after each set of weights is added to the scale and the "theoretical" scale reading. If the two readings are the same (within 0.5 percent), the scale is in calibration. If the two readings differ by more than that amount, the scale must be adjusted. Adjustments must be accomplished using the procedures provided by the scale manufacturer.

SUMMARY OF PLANT OPERATING TECHNIQUES

The following factors should be considered when monitoring the operation of a batch plant:

- The moisture content of the aggregate when discharged from the dryer should be less than 0.5 percent.
- The amount of carryover of the aggregate from one hot bin to the next bin should be relatively constant and generally less than 10 percent.
- The screens should be checked regularly for holes and blinding.
- The pugmill should be operated at nominal capacity. Both overloading and underloading of the pugmill with aggregate will decrease the efficiency of the mixing process significantly. Batch size should be consistent from batch to batch. The paddle tips and the pugmill lining should be checked periodically to assure that they are in good condition.
- The dry mix time for the aggregate in the pugmill should be minimal--usually no more than 1 or 2 sec.
- The wet mix time for blending the asphalt cement and the aggregate should be no longer than needed to properly coat the aggregate and can be as short as 27 sec.
- The plant operator must not idle the plant during the wet mix cycle and should not do so during the dry mix time. When the plant is waiting for trucks, there should be no material in the pugmill.
- The total mix cycle time to produce a batch of mix, regardless of the size of the pugmill, could be as short as 35 sec.
- If reclaimed material is introduced into the plant at the bottom of the hot elevator, it should be placed on top of the superheated new material in the buckets.
- If reclaimed material is charged into the weigh hopper, it should be placed into the center of the hopper so that the weigh hopper is not unbalanced and an accurate weight can be determined.
- The temperature to which the new aggregate must be heated to obtain adequate heat transfer to the reclaimed material is a function of the amount of RAP used in the recycled mix, the amount of moisture in the RAP, and the mix discharge temperature. The new aggregate generally should not be heated to a temperature greater than 500°F to prevent potential damage to the dryer. If the temperature of the new aggregate, as found in Figure 2-94, is greater than this value for the amount of RAP and the moisture content of the RAP, it will be necessary to reduce the percentage of RAP added to the recycled mix.

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Part Three

LAYDOWN AND COMPACTION

PART THREE
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SECTION ONE
MIX DELIVERY

TYPES OF TRUCKS

The purpose of the haul vehicle is to transport the asphalt mixture from the asphalt plant to the laydown machine. This must be done without delay and without any change in the characteristics of the mix during the delivery process. Three primary types of trucks are usually employed to transport the mix: end dump, bottom or belly dump, and live bottom (conveyor) trucks. All of these trucks are loaded in the same manner, either directly from the pugmill at a batch plant or from the surge silo at a batch or drum mix plant. The three types of vehicles differ in how each unloads the mix at the paver.

End Dump Trucks

An end dump truck delivers the mix directly into the hopper of the paver. The mix is unloaded by raising the truck bed and allowing the mix to slide down the bed into the hopper. When the bed is raised, it should not be in contact with the hopper and should not press down on or ride on the paver. For the smaller-capacity dump trucks, contact with the paver is not normally a problem. Contact between the truck bed and the paver can be a problem, however, when large semitractor trailer units are used as haul vehicles, particularly when the truck bed is extended to its highest point. When the weight of the truck is being carried by the paver, the laydown machine may lose its ability to operate properly. Typical end dump trucks are shown in Figures 3-1 and 3-2.

Bottom Dump Trucks

A bottom or belly dump truck delivers its load to the roadway in front of the paver. The mix is deposited from underneath the truck bed into a windrow, as seen in Figure 3-3. For this method of mix delivery, it is important that the correct amount of mix be placed in the windrow to assure that the paver hopper does not run out of mix or become overloaded with too much mix. Continuous operation of the paver, which must be equipped with a pickup machine (windrow elevator), can only be accomplished if a continuous and consistent supply of mix is available to it.

The windrow can be formed in one of two ways. A

Figure 3-1. End dump truck *(J. Scherocman)*.

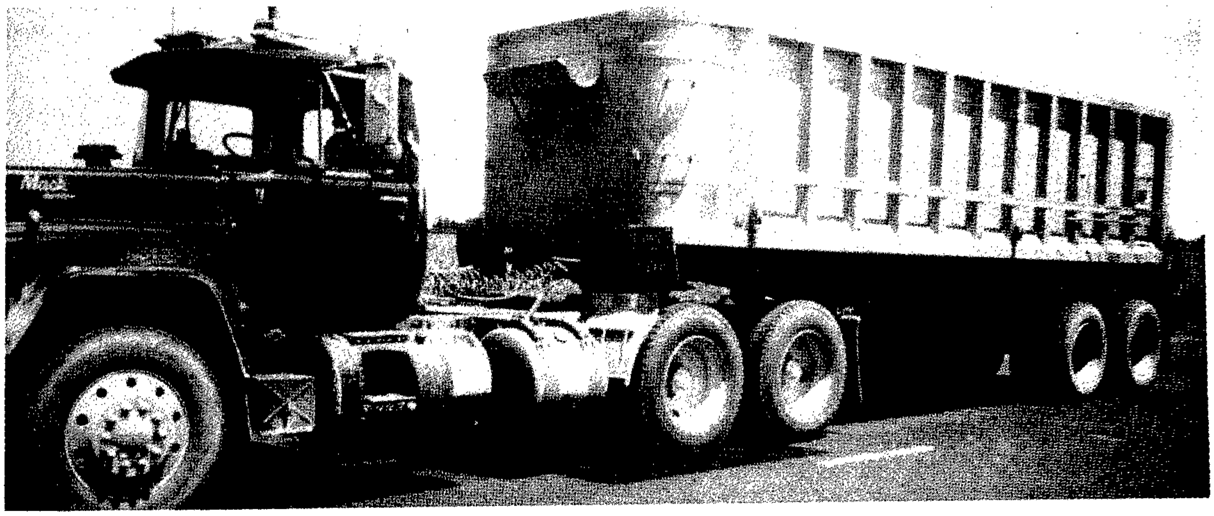


Figure 3-2. End dump truck *(J. Scherocman)*.

spreader box (windrow sizer) can be employed. In this case, the mix is deposited into the box and is uniformly metered out onto the roadway as the truck moves forward. The amount of mix placed in the windrow is determined by the setting of the discharge opening in the box. This procedure provides the most accurate means of keeping a constant supply of mix in front of the paver.

The second, and more common, method is to control the amount of mix discharged by the width of the gate opening under the truck and the speed of the truck. Although this procedure is quicker than the use of a windrow sizer, the amount of mix deposited at any time is highly dependent on the skill of the person controlling the discharge gates and on the attention of the truck driver in operating the truck at the required speed. Manual control of the discharge requires constant attention of the "dump person" to assure that neither too little mix nor too much is being fed in to the paver hopper. For both of these methods, the amount of mix delivered is dependent on the width and the thickness of the layer being placed. Thus, a different gate opening in the windrow sizer or the truck bed is needed for each set of project conditions and truck speed.

Once the amount of mix being delivered to the paver gets out of balance with the quantity of mix needed by

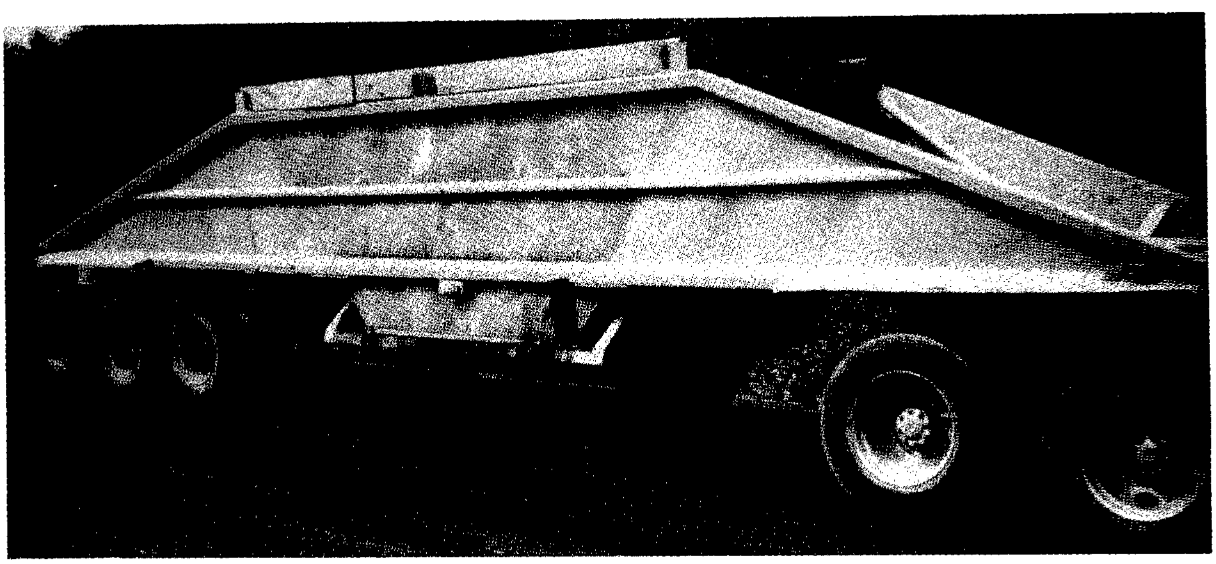


Figure 3-3. Bottom dump truck *(J. Scherocman)*.

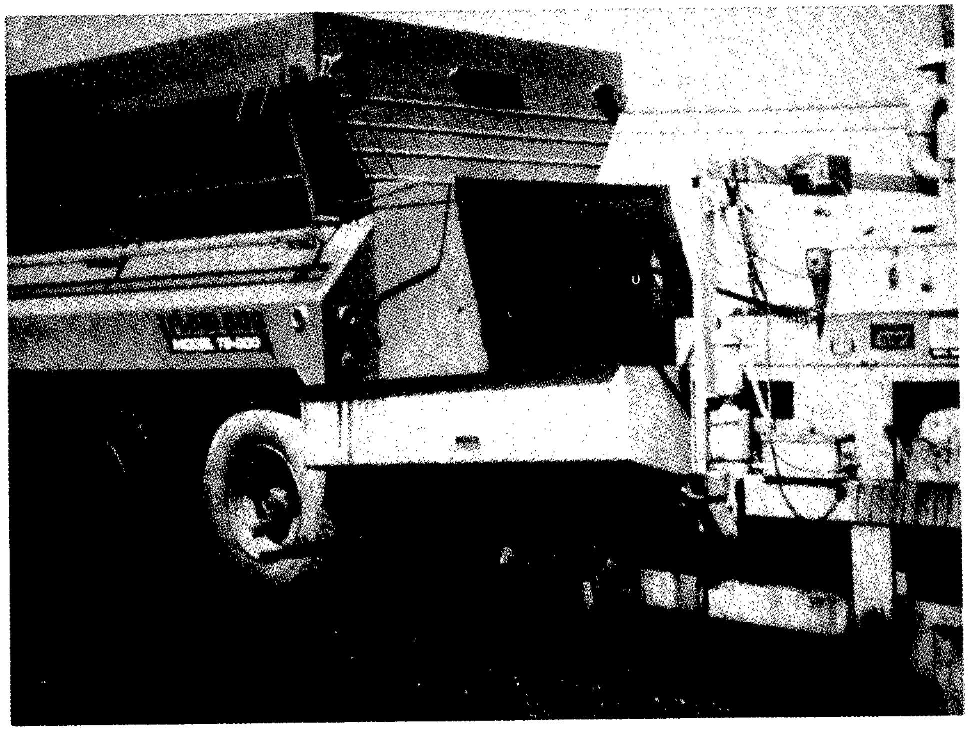


Figure 3-4. Live bottom (flow boy) unit *(J. Scherocman)*.

the paver, an adjustment must be made in the discharge operation of the bottom dump trucks. If the problem is noticed before the paver is underloaded or overloaded, the amount of mix deposited on the roadway can easily be altered by changing the width of the gate opening on the truck and/or by the speed of the truck during discharge. When there is no mix in the hopper of the paver, however, mix must be deposited in the hopper without the paver moving forward. Depending on the equipment available to the contractor, this can be very difficult. When the hopper is overloaded with mix, some of the material in the windrow in front of the paver must be removed so that the paver can move forward without additional mix being picked up. When the mix in the hopper reaches its desired level (the hopper should be half full), the paver again needs to start picking up additional mix from the windrow.

Because of the difficulty in adjusting the quantity of mix needed by the paver when the hopper is either underloaded or overloaded, it is very important that the windrow of mix produced by the bottom or belly dump truck be as consistent as possible. The ability of the paver to place a smooth layer of mix will be affected by the uniformity of the windrow available for use by the paver. Keeping the size of the windrow constant is easier than correcting the problem of too little or too much mix in the paver hopper.

Live Bottom Trucks

A live bottom truck is one that employs a conveyor belt or slat conveyor in the bottom of the truck bed to discharge the mix without the need to raise the bed. This type of truck, often generically called a flow boy truck, deposits the mix directly into the hopper of the paver as does an end dump truck. Because the bed of this type of truck is not raised, there is no potential problem with the bed pressing on the paver hopper. A live bottom truck is illustrated in Figure 3-4.

Material Transfer Vehicle

As shown in Figure 3-5, an additional method used to deliver mix to the paver is a material transfer vehicle. This piece of equipment is basically a surge bin on wheels. Asphalt mix is deposited into the hopper on the front of the vehicle. The device is equipped with twin remixing augers. The mix is transported from the hopper through the augers and to a conveyor, which delivers the mix to the extended hopper on the paver. The purpose of the auger system is to reblend the coarse and fine particles of the mix and reduce the amount of segregation that might occur in the mix because of the operation of the surge/storage silo or the truck-loading

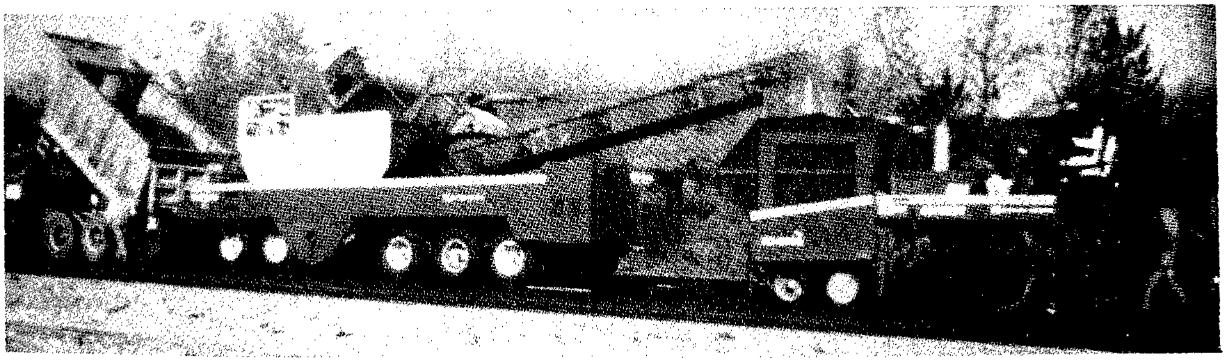


Figure 3-5. Material transfer vehicle *(J. Scherocman)*.

procedures.

The material transfer vehicle also allows the paver to be operated almost continuously (without stopping between truckloads of mix) if a continuous supply of mix is available from the asphalt plant. This provides for a smoother mat behind the paver screed by permitting the paver operator to keep the head of material in front of the screed constant by supplying a continuous flow of mix back to the screed. The equipment also eliminates the problem of the haul trucks bumping the paver and truck drivers holding the brakes on the truck when being pushed by the paver.

The material transfer vehicle can be operated directly in front of the paver or off to one side, as shown in Figures 3-6 and 3-7. Because of the weight of this piece of equipment when it is full of mix, it must be determined ahead of time that the pavement over which this machinery will be running can support the weight of the device without being overstressed and damaged.

HAULING PROCEDURES

Cleaning and Oiling the Bed

The bed of the haul truck, whether an end dump, bottom dump, or live bottom truck, should be free of all deleterious materials before mix is placed in it. Any debris in the bed from previous use of the truck should

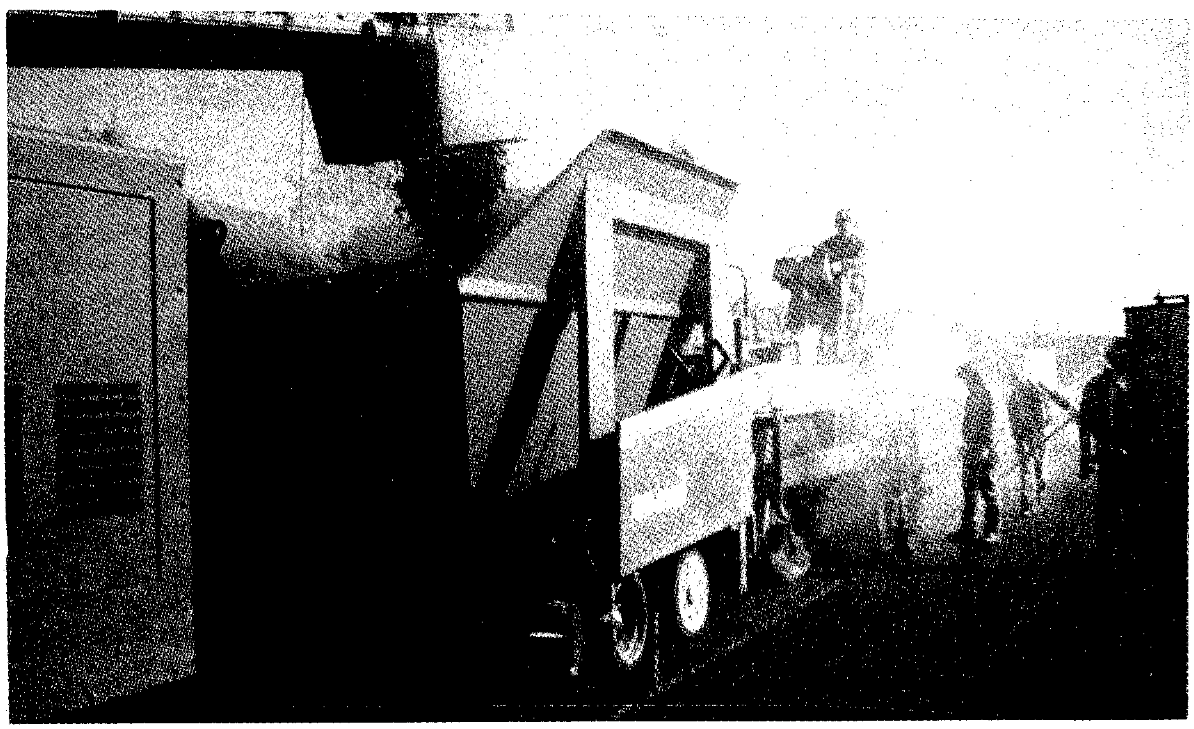


Figure 3-6. Material transfer vehicle directly in front of paver *(J. Scherocman)*.

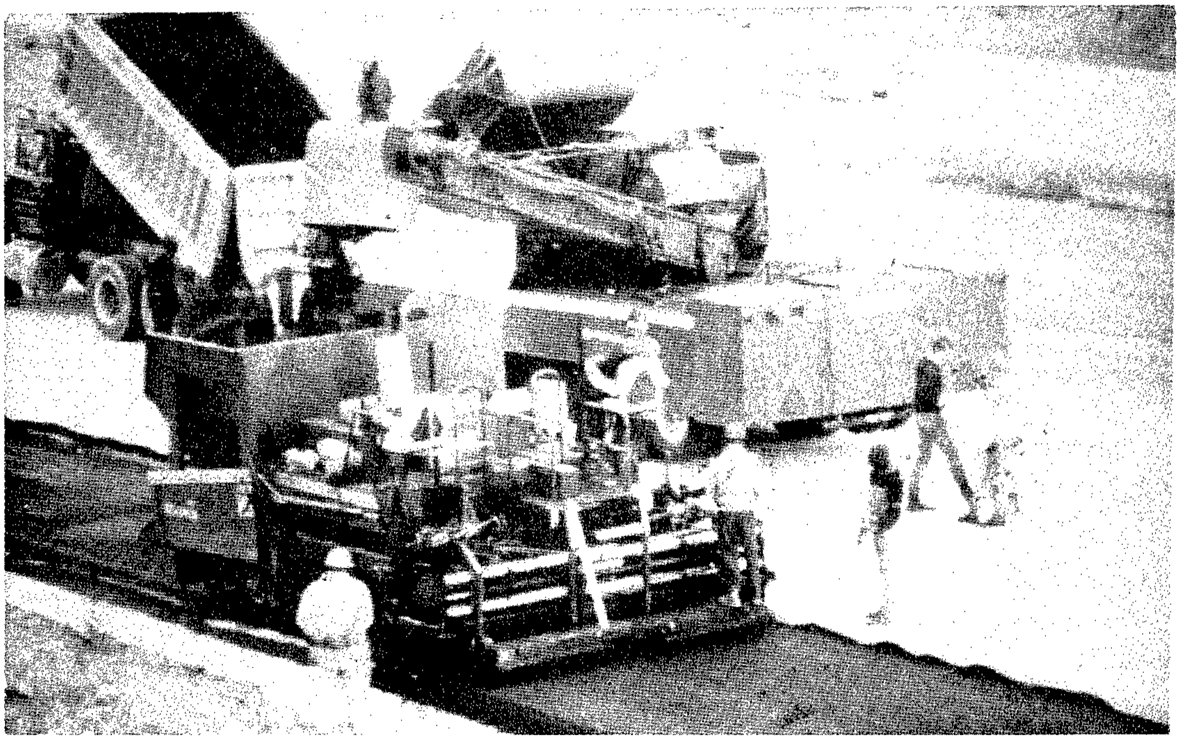


Figure 3-7. Material transfer vehicle on lane adjacent to paver *(Barber-Greene)*.

be removed. The bed should be reasonably smooth and free from any major indentations or depressions where the truck bed release agent and the HMA can accumulate.

Once the bed is clean, it should be coated with a release agent, as shown in Figure 3-8, to prevent the HMA from sticking to the bed. Nonpetroleum-based materials, such as lime water or one of a variety of commercial products, should be used for release agents. The lubricant or release agent should be sprayed uni-

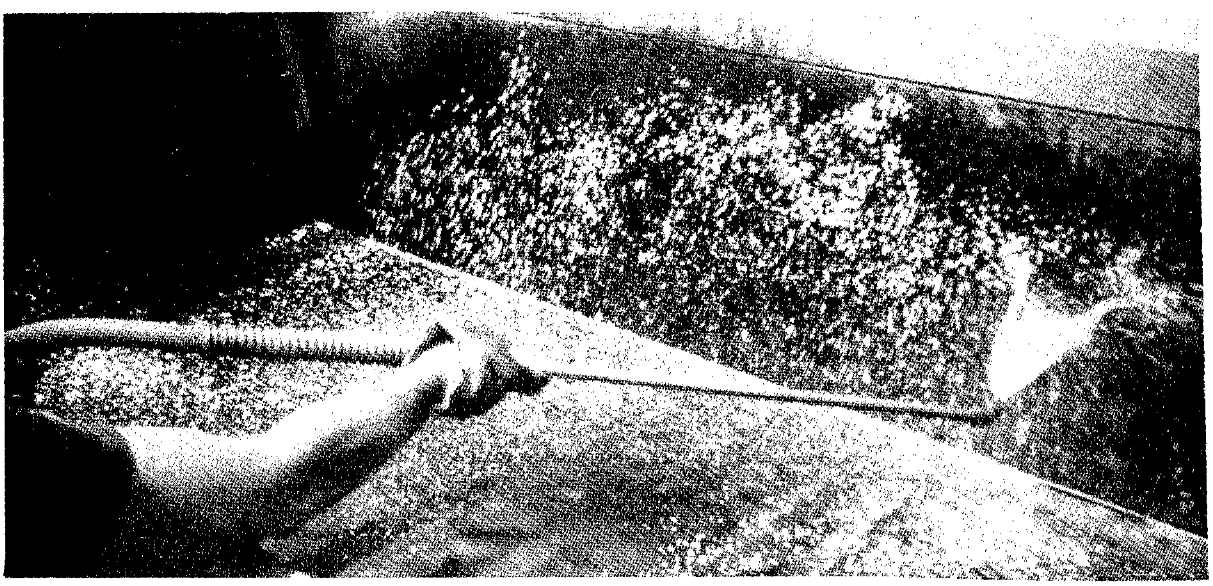


Figure 3-8. Spraying lime water solution as a truck bed release agent *(J. Scherocman)*.

formly over the sides and bottom of the truck bed and should be used in the minimum quantity necessary to cover the surface area of the bed without runoff. Any excess lubricant that is used should be drained from the truck bed before the truck is loaded with mix.

Diesel fuel should not be used as a lubricant for the truck bed. If an excessive amount of diesel fuel is used and if it accumulates in depressions in the bed of the truck, the material can cause changes in the properties of the binder material with which it comes in contact. In addition, use of diesel fuel can contribute to environmental problems as it evaporates or if it soaks into the ground. Thus, although often convenient and economical to use, diesel fuel should not be used as a release agent in the bed of a haul truck.

Insulation

If environmental conditions warrant it, the sides and bottoms of the truck bed should be insulated. The insulation should be tight against the body of the bed; there should not be any gaps between the side of the truck and the insulation through which wind could enter. The insulation material should be protected on its outside face with plywood or similar cover, as shown in Figure 3-9. Missing or torn insulation should be replaced.

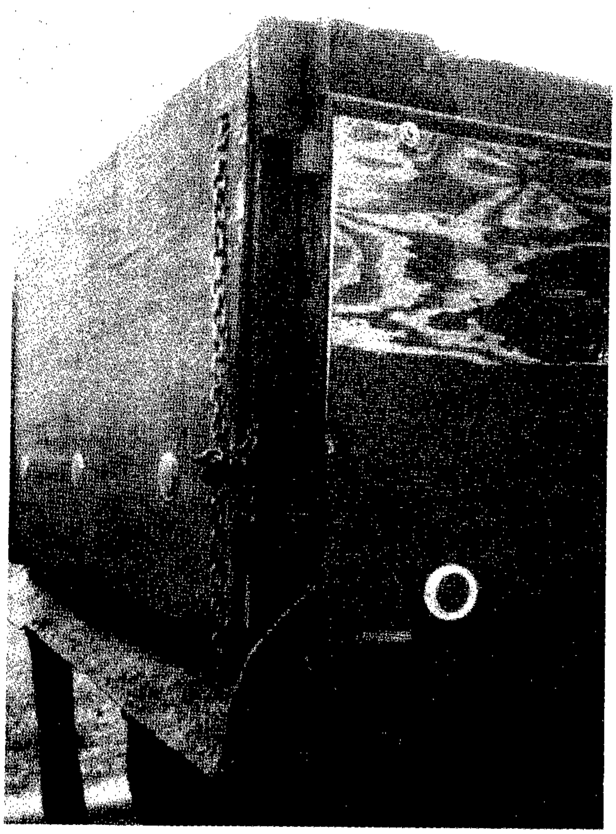


Figure 3-9. Plywood cover over insulation on haul truck *(J. Scherocman)*.

Loading

One objective of the truck-loading operation is to get the vehicle filled with mix and on its way to the paver as quickly as possible. This objective must be balanced, however, with the need to minimize segregation of the mix that occurs during the loading process. Proper loading procedure, discussed in Section 5 of Part 2, requires that multiple drops of mix be made into the truck instead of a single discharge of mix into the bed. This is necessary to minimize the distance that the coarse aggregate particles in the mix can roll and to keep the mix consistent in gradation throughout the load of material.

From the Pugmill

The haul truck, regardless of its type and length, should be loaded in multiple drops of mix in several different locations in the bed. If loaded directly from the pugmill of a batch plant, the criteria for multiple drops of mix into the bed will necessarily be accomplished. The truck should be moved, however, between each delivery of mix from the pugmill. If it takes three batches of mix to reach the capacity of the haul truck, one pugmill batch should be loaded into the front of the truck bed. The truck should then be moved forward and the second batch of mix should be discharged into the rear of the truck, just in front of the tailgate. The third batch of material should be delivered into the center of the bed, between the first and second batches of mix. This procedure is illustrated in Figure 2-67 from the section on surge and storage silos in Part 2.

If the capacity of the pugmill and the truck are such that five batches of mix are needed to fill the truck bed, the first batch of mix should be emptied into the front of the truck and the second batch into the rear of the truck at the tailgate. The next batch of material should then be deposited into the center of the truck bed. The fourth batch should be placed between the front and middle batches, whereas the fifth and last batch should be delivered into the bed between the back (second) and the middle (third) batches.

For other numbers of batches, multiple drops of mix should also be used, with the first batch delivered to the front of the truck bed, the second batch deposited at the tailgate end of the bed, and the remaining drops of mix placed evenly in between the first two. Such a loading sequence will minimize the distance the coarse aggregate particles can roll and thus minimize the amount of segregation that is produced in the mix.

From the Silo

Segregation of the mix can occur when mix discharged from the surge silo is deposited into the haul truck in a single drop. If the mix is loaded in only one drop from the silo, the material will form a cone-shaped pile in the truck bed. The coarser aggregate particles will tend to separate from the mass of mix and roll to the front and rear of the bed, collecting at both ends. Some rolling of the coarser material may also occur along the sides of the bed. This segregation problem can be minimized by loading the truck in multiple drops of mix from the silo, similar to the procedure used for loading from the batch plant pugmill.

The number of drops used depends on the length and capacity of the truck. Even on the smallest trucks, at least three drops should be used: the first at the front of the bed, the second at the rear of the bed, and the last in the middle of the first two. When a semitractor trailer truck is to be loaded, at least five and probably seven different discharges of mix should be made before the truck capacity is reached. In every case, the mix should first be deposited at the front of the bed and then at the tailgate of the truck. The space in between the first two drops should be filled in with small, separate piles of mix placed between the initial "batches" of mix. The use of multiple drops of mix is slower than loading the truck in a single discharge of material from the silo. It is necessary, however, in order to reduce the amount of segregation that occurs during the loading process for mixes that have a tendency to segregate.

One procedure that should never be used when a truck is loaded from the silo is to move the truck slowly forward while the mix is being discharged from the surge bin. If this is done, all the coarse aggregate particles in the mix will continually run down the cone that is formed and will be pushed toward the tailgate of the truck, where they will accumulate. This will significantly increase the amount of truckload-to-truckload segregation that is seen behind the paver. Thus, proper loading procedures require that the truck driver move the vehicle backward and forward several times in between delivery of loads of mix. Although this increases the time needed to load the truck and send it to the paver, it is necessary that it be done to minimize segregation.

There is a tendency for the plant operator to fill the truck to its legal capacity to reduce haul costs, particularly if the truck is sitting on a scale under the silo. Although this is good economic practice, it should not be accomplished by dribbling mix in to the truck from the silo after the majority of the mix is already in the truck. Only a limited number of trucks typically are used by a contractor during a paving project. The plant operator should be able to judge the time needed to place each drop of mix into each individual truck bed and be able to come close to the legal capacity of each truck without resorting to the use of a number of additional small dribbles of mix at the end to finish the loading process. The discharge of small amounts of mix from the silo greatly increases the chance for segregation of the mix as the coarse aggregate particles roll down the sides of the piles of mix already in the bed.

Tarpaulins

Every haul truck should be equipped with a tarpaulin, which can be employed as needed to protect the mix in case of inclement weather. The tarp should be made of a water repellent material, should be of sufficient weight and strength to resist tearing, should be in good condition, and should not have any holes or tears in it. Most important, the tarp should be large enough to cover the top of the load and to extend down over the sides and the tailgate of the truck. The requirement for the overlap of the tarp over the sides of the truck is to assure that the mix is protected adequately from wind and water. The tarps should have enough tie-down points to secure the tarp properly and prevent it from flapping in the wind during delivery of the mix to the paver.

Some trucks are equipped with tarps that run from the front of the truck to the back in a rail on the top of the side boards of the truck. The rail keeps the tarp stretched across the top of the load of mix and covers the mix without the tarp extending over the sides of the truck bed. As long as the tarp is tight, this type of tarp can provide adequate cover for the mix. For safety reasons, it is desirable to use tarps that can be extended by mechanical means over the bed of the truck without the driver having to climb up on the sides of the vehicle to unroll the tarp.

A tarp that does not cover the load during transport is worse than not having a tarp on the load at all. Unless the tarp extends over the sides of the truck, air will flow under the tarp during movement of the truck and increase the rate of cooling of the mix. In addition, during rainy weather, any water that falls on the tarp will run into the truck bed instead of off the side of the vehicle. Further, even if the tarp covers the bed, if there is any water on the tarp when the truck is ready to discharge mix into the paver hopper, the water should first be removed from the tarp by raising the bed of the truck and letting the water run off before the truck backs into the hopper.

Tarps are not normally necessary in warm weather and with relatively short haul distances between the plant and the paver. If a tarp is used, however, it should be removed from the top of the bed before the truck is unloaded into the laydown machine. This allows the mix to be inspected visually for defective material before it is discharged into the paver.

Crusting of the Mix

There is no set limit as to how far a load of HMA can be transported. There are many variables that affect the maximum haul distance, but the key factors are the workability of the mix while it is passing through the paver and the ability to get the mix compacted once it has been placed by the paver. Both of these factors are highly dependent on the temperature of the mix.

Hot-mix asphalt in a mass, such as when the mix is confined in a truck bed, will maintain a reasonable temperature for as long as 2 or 3 hr. The rate of cooling of the mix depends on such variables as the temperature of the mix at the time of production, the ambient air temperature, the velocity and the temperature of the wind that passes over the mix, and the efficiency of the insulation on the sides of the truck. When it is hauled long distances without being covered by a tarp, the mix will develop a crust on the top and cool and begin to harden. The formation of the crust provides an insulating layer for the rest of the mix in the truck bed and reduces the rate of cooling for the remainder of the mass of material. Thus, within limits, the formation of the crust on the outside of the mass of mix is beneficial to maintaining the internal temperature of the rest of the mix in the truck bed.

If the load of mix is properly tarped, the amount of crust buildup will be minimized because the wind will have significantly less effect on the rate of cooling of the mix. The slight crust thickness that does form during transport should be able to be broken up completely as the mix is discharged from the haul vehicle into the paver, is carried by the slat conveyors back to the augers, and is passed under the paver screed. As long as chunks of asphalt mix do not affect the quality of the mat behind the paver, the crust that forms on top of the mix during delivery will not be detrimental to the long-term performance of the mix. If chunks of mix can be seen behind the screed, however, changes need to be made in the mix production temperature, the amount of insulation, the covering of the load with the tarp, or with the paving schedule (waiting for warmer ambient temperatures).

Rain

These same variables are also present when rain occurs at the paving site and mix is still in the trucks waiting to be unloaded. Judgment is needed. One alternative is to stop paving and return any mix in the trucks to the plant to be recycled at a later date. If the rain is relatively light and appears to be going to continue for some time, and if the pavement surface has been tacked and does not contain puddled water, the trucks can be unloaded as quickly as possible and the rollers brought up directly behind the paver to compact the mix before it cools completely. If the rain appears to be of short duration--a passing shower--the mix should be held in the haul truck instead of being dumped into the paver hopper and laid after the surface has dried. Again, because of the mass of mix in the truck bed, the mix will lose temperature slowly if the load is properly tarped and the sides of the truck are insulated. Once the rain has stopped and any puddles of water have been swept from the roadway surface, the mix can be unloaded from the waiting trucks into the paver and laid down. As long as chunks of mix do not appear behind the screed and the rollers can densify the mix adequately, little harm is done in holding the mix in the haul trucks for even 2 or 3 hr, depending on environmental conditions.

Bumping the Paver

When an end dump or a live bottom truck is used to deliver mix to the paver, the truck driver should back the truck up to the laydown machine but stop just short of the push rollers on the front of the paver. Once the truck has come to a halt and the driver has released the brakes on the vehicle, the paver operator should start the machine moving forward, picking up the stopped truck. The key to this process is that the paver picks up the truck instead of the truck backing into and bumping the paver. Use of the proper procedure will reduce the incidence of screed marks and roughness in the mat.

Unloading

If an end dump truck is used and if the mix being delivered to the paver has a tendency to segregate, the bed of the truck should be raised a short distance in order to allow the mix in the bed to slide against the tailgate before the tailgate is opened. Once the tailgate is opened, this procedure will allow the mix to be discharged from the truck in a mass and to flood the hopper of the paver, reducing the possibility of segregation behind the paver screed.

The same procedure should be employed, if possible, when a live bottom truck is used to transport the mix. The belt or slat conveyor should be started for a few seconds before the end gate on the truck is opened. This action will create a mass of material that can be delivered to the hopper instead of allowing any coarse aggregate particles that have rolled to the end gate to exit into the hopper first.

For bottom dump trucks, a windrow-sizing box should be used to control the dimensions of the windrow. If this is done, the gates on the bottom of the truck bed can be opened wide to allow a mass of mix to be discharged instead of only some of the mix dribbled out. If manual methods are used to control the truck discharge, the gates should still be opened widely so that a mass of mix is deposited on the roadway. The size of the windrow should then be controlled by the forward speed of the haul truck.

SUMMARY OF MIX DELIVERY TECHNIQUES

Several primary factors should be observed when the truck loading, hauling, and unloading operation is monitored. They are:

- The truck bed should be free of all contaminants. The bed should be lightly and uniformly coated with a nonpetroleum release agent. Diesel fuel should not be used.
- If required, the insulation around the truck bed should be tight to the sides and bottom of the truck.
- The truck should be loaded in multiple drops of mix from either the pugmill or surge silo. The first delivery of mix should be at the front of the truck bed. After the truck moves forward, the second drop of mix should be at the rear of the truck near the tailgate. Additional drops of mix should be placed in the middle portion of the truck as necessary to minimize the distance that any coarse aggregate particles can roll in order to prevent segregation. (This procedure is discussed in detail in the section on surge and storage silos.)
- The plant operator should not continually open the silo gates and dribble in small amounts of mix in order to "top off" the load of mix in the haul truck.
- The truck should be equipped with a tarpaulin that is in good condition: without tears and holes. The tarp should be large enough to cover the bed and to wrap over the sides and end of the truck bed. The tarp should have enough fasteners to allow it to be tied down completely and to prevent it from flapping in the wind. If side rails are used to hold the tarp in place, the tarp should be stretched tightly over the load of mix.
- End dump and live bottom trucks should stop short of the paver and allow that machine to pick up the truck instead of the truck bumping into the stopped paver.
- The bed on an end dump truck should be raised a short distance and the mix in the truck allowed to slide against the tailgate before the tailgate is opened to discharge mix into the paver hopper. The belt or slat conveyor on a live bottom truck should be started a few seconds before the end gate is opened in order to discharge a mass of asphalt mix into the hopper instead of just a dribble of coarse aggregate particles.
- The load carried in a bottom dump truck should be deposited uniformly on the roadway in front of the paver so that the amount of mix picked up by the windrow elevator allows the paver operator to maintain a uniform head of material in front of the paver screed.
- End dump trucks should not be allowed to contact or transfer any weight to the paver hopper.

SECTION TWO
SURFACE PREPARATION

INTRODUCTION

The performance of a hot-mix asphalt pavement under traffic is directly related to the condition of the surface on which the pavement layers are placed. For a full-depth asphalt pavement, if the condition of the subgrade soil is poor (particularly if it is wet and rutted under the haul trucks) the ultimate durability of the roadway may be reduced. For HMA layers placed on top of a new, untreated granular base course, that base material should be stable and the surface should be dry and should not be distorted by the trucks carrying mix to the paver. For mix laid on top of existing asphalt layers, the present surface should be free of potholes and major distress, reasonably smooth, and clean.

PREPARATION OF EXISTING SURFACE

HMA over HMA

If an HMA overlay is to be placed on top of an existing asphalt pavement, the existing surface must be prepared properly before any mix is laid. The degree of preparation needed depends on the condition of that surface. At a minimum, the failed areas should be removed and replaced, the potholes properly patched, the cracks cleaned out and sealed, and the ruts filled in or, preferably, removed by cold milling.

Pavement Replacement and Patching

To attempt to bridge failed areas with the new overlay material is usually foolish unless a very thick overlay is to be constructed. Removal and replacement should be carried out on all pavement areas on which severe load-related distress has occurred. All of the asphalt concrete mix and granular base materials that have failed should be excavated or cold milled and either recycled or wasted. Subgrade distortion should be repaired by undercutting and replacement with suitable backfill material. Proper subsurface drainage should be installed as necessary. New granular base course material, stabilized base course layers, and/or asphalt mix should be placed in order to bring the strength of the pavement structure in the failed area to the same level as the surrounding good pavement layers. If asphalt concrete mix is used to patch a large area, the mix should be placed with a paver.

Localized failed areas should be patched properly. Each failed area should be cut back to sound pavement and squared up with the sides as vertical as possible, the loose material and water in the hole removed, a tack coat applied to the sides and bottom of the pothole, and the mix placed in the hole. If the pothole is deeper than 4 in., the mix should be placed in layers and each layer compacted properly.

Crack Filling

Badly cracked pavement sections, especially those with pattern cracking (e.g., map or alligator), are normally patched or replaced. The benefits of filling other cracks in the existing surface depend, in part, on the width of the cracks. If the cracks are narrow (less than 3/8 in. in width), it is doubtful that the crack sealing material will actually enter the crack instead of pooling on the pavement surface. These cracks can be widened, if desired, with a mechanical router before sealing is attempted. If wider cracks are present, they should be cleaned of debris. The crack sealing material should be inserted when the cracks are clean and dry. The level of the crack filling material should be slightly lower than that of the surrounding pavement surface.

The amount of reflective cracking that occurs in an overlay sometimes may be reduced by the use of a surface treatment on the existing pavement, depending on the cause of the cracking. If that pavement structure contains a great number of cracks, consideration should be given to the application of a surface treatment instead of an individual crack filling operation. The cracks should be cleaned, if feasible, by being blown out with air. The surface treatment should be applied when the pavement surface is clean and dry and should consist of a single application of asphalt binder material (asphalt cement, cutback asphalt, or asphalt emulsion) and cover aggregate. Alternatively, a slurry seal consisting of a slow-setting emulsion, fine aggregate, and water may be used. Such a crack filler operation may be more economical than a standard crack sealing process, depending on the extent of the cracking.

Leveling Courses

Common practice in the past has been to place a leveling course on the existing pavement surface in order to improve the rideability of the pavement structure. This leveling course, sometimes also called a wedge and level course or a scratch course, was designed to fill in the low spots on the pavement surface. This leveling action was accomplished through the principle of the floating screed on the paver. The thicker mix, however, typically compacts more than the mix in thinner locations. This problem, called differential compaction, requires that multiple courses be constructed over a pavement surface that is badly out of shape before a smooth surface can be obtained. The mix, as it passes from under the paver screed, is in loose condition. After compaction by the rollers, the thickness of the layer will be reduced. The rule of thumb is that conventional mixes will compact approximately 1/4 in. per 1 in. of compacted thickness. Thus, for a 1-in.-thick (compacted) course, about 1 1/4 in. of mix would have to be placed by the paver. Similarly, 3 3/4 in. of mix would need to pass from under the paver screed in order to construct a layer with a compacted thickness of 3 in.

When a leveling course is placed, the mix laid in the low areas (in the wheelpaths if the pavement is rutted) will be thicker than the mix placed over the high points in the surface (between the wheelpaths). The thicker mix will compact more under the rollers, particularly if a pneumatic tire roller is used, than will the mix that is thinner. Thus, although some smoothing is accomplished with a single leveling course of mix, low spots will still exist in the wheelpaths where the mix has been compacted to a different degree than the mix between the wheelpaths. Multiple layers of mix are usually needed to eliminate the roughness in the existing pavement surface completely. This potential problem can sometimes be addressed by using a motor grader to place mix in the low spots ahead of the normal paving operation, if traffic conditions permit.

Milling

Milling, also called cold planing, can be used in lieu of placing a leveling course (filling in the low spots) to remove the high points in the existing surface. Milling can be accomplished in any width necessary, from 6 in. to more than 13 ft. Figures 3-10 and 3-11 illustrate two different types of milling machines. Equipped with automatic grade and slope controls similar to those used on an asphalt paver, the milling machine is capable of producing a level surface in one pass over the present roadway. The RAP produced by the milling process can be hauled back to the asphalt plant for future recycling. In addition, the texture of the milled surface enhances tack and bond and may reduce the possibility of slippage of an overlay over the existing surface.

A pavement surface that has been milled typically is very dusty and dirty. Once the pavement has dried, multiple sweepings with a mechanical broom are usually needed to remove all of the residual grit from the milled surface. In some cases, it may be necessary to dampen the milled surface before sweeping or to air blow and/or flush the milled surface with water in order to remove dust and very fine material completely. Any dust and dirt left on the milled surface will greatly affect the bond between that course and the new asphalt overlay. Because of the increased surface area of the milled pavement (from the grooves left by the cutting teeth on the milling machine), an additional quantity of tack coat material may be required in order to assure adequate bond between those layers. That increased quantity is a function of the type, number, condition, and spacing of the teeth used on the cutting mandrel of the milling machine.

Hot-Mix Asphalt over Portland Cement Concrete

When HMA is placed over a PCC pavement, the PCC surface should be prepared properly. The following is a general overview of PCC surface preparation. Any severely distressed areas in the PCC slabs should be cut out, removed, and replaced using full-depth slab-repair techniques with PCC or HMA. Corrective work should also be completed on the underlying subbase or subgrade material, if necessary. Any severely spalled areas at joints should be repaired using partial-depth slab-replacement methods. Portland cement concrete should be used for partial-depth repairs. Rocking slabs must be stabilized. Depending on the condition of the PCC pavement, procedures such as crack and seat, break and seat, or rubblizing can be used before the overlay is placed. Further, consideration can be given to the use of a crack-relief layer between the existing PCC pavement and the new overlay.

Joints that are poorly sealed should have the old seal material removed and then the joints should be cleaned. The joints, when dry, should be resealed with appropriate joint seal material. Care should be taken not to overfill the joints, particularly in cool weather when the joints are open wide. Once the patching and resealing has been accomplished, the surface of the PCC pavement should be cleaned completely using mechanical brooms and air blowing and/or water flushing where needed.

Base Preparation

Subgrade Soil

If the asphalt pavement is to be placed directly on the subgrade soil, that subgrade material should meet all applicable requirements for moisture content, density,

Figure 3-10. Rear-loading milling machine *(Caterpillar)*.

and smoothness. After the subgrade soil has been determined to be ready for paving, and before paving is allowed to commence, the subgrade should be checked to be certain that it will be able to support the weight of the haul traffic. The subgrade must provide a firm foundation before the asphalt paving commences. If distortion of the subgrade soil occurs during the paving operation, the placement of the mix should be stopped until the condition of the soil can be corrected.

There is generally no need for a prime coat of

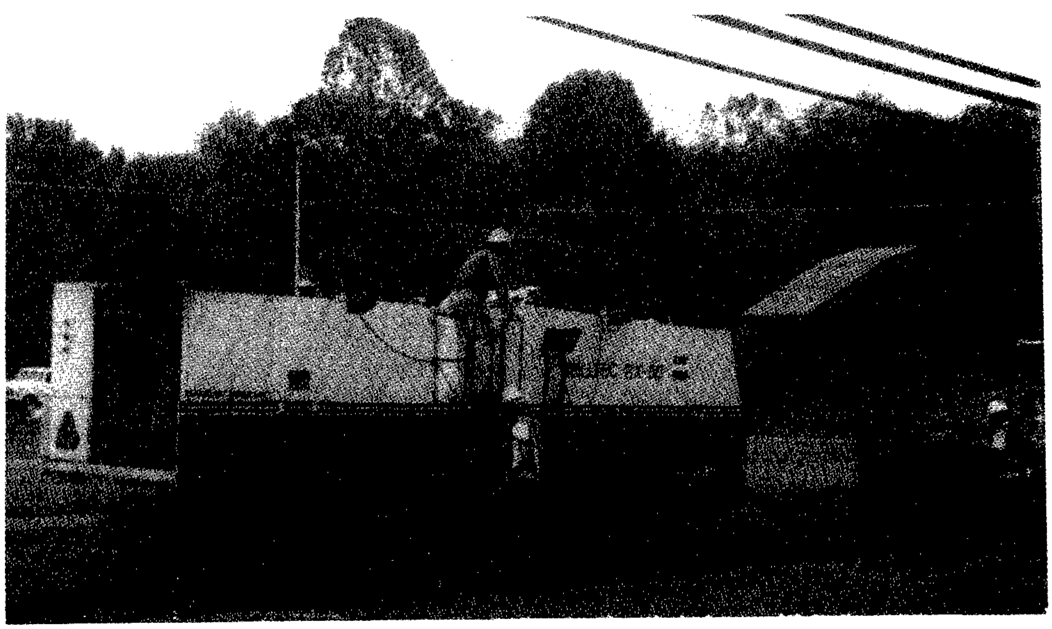


Figure 3-11. Front-loading milling machine *(Barber-Greene)*.

asphalt emulsion or cutback asphalt to be placed on the subgrade soil. This is especially true when that soil is a silty clay or clay material because the prime coat material cannot be absorbed into the subgrade material. The use of a prime coat on sandy subgrade soils is also questionable. If the sandy material displaces excessively under the wheels of the haul trucks, that material should probably be stabilized with some type of binder material before paving. The application of a prime coat in that case will generally not be enough to hold the sandy soil in place during the paving operations. A prime coat should not be used as a substitute for proper preparation of the subgrade soil.

Granular Base Course

If the asphalt layer is to be constructed directly on a new or existing untreated granular base layer, that material should meet all the requirements for moisture content, density, and smoothness. Proof rolling should be done, however, on top of the granular base material and the amount of deflection of the base and the amount of indentation of the truck wheels into the granular base course material noted. If the base material is stable and dry and does not deflect and indent significantly under the wheels of a loaded tandem axle truck, placement of the prime coat and/or the new asphalt mix should be permitted to start. If the condition of the granular material is not satisfactory, the base course should be reworked or stabilized to put it into the proper condition for overlay.

There is a considerable difference of opinion as to the benefits of a prime coat of asphalt material on a granular base course layer. Advocates of the use of a prime coat feel that the material acts as a temporary waterproofing layer that protects the base course and prevents it from absorbing excess moisture during rain before paving, allows the base course to be used for light traffic, binds together any dust on the surface of the granular base layer, promotes the bond between the base course material and the new asphalt overlay, and prevents slipping of thin pavement layers. In many cases, however, a prime coat is not needed on a granular base course layer. A prime coat does not add anything to the structural capacity of the pavement layers, and, if the granular base course yields under the wheels of a loaded truck, the application of the prime coat material generally will not improve the condition of that base course material enough to allow paving to be done on top of the base layer. As pointed out under "Subgrade Soil," the use of a prime coat is not a substitute for proper preparation of the granular base course material.

If the specifications require the application of a prime coat to a new or existing granular base course layer, the prime coat material should be applied with a pressure distributor to the base course at least 48 hr before paving is to begin. Typically a cutback asphalt (MC-30 or MC-70) is used as the prime coat material, if available. An asphalt emulsion is not normally used because it will not penetrate very far into the granular material, although some inverted emulsions (emulsion containing limited amounts of cutter material) have been applied successfully. The application rate should be varied with the openness (porosity) of the base course material. Typical application rates range from 0.15 gal/yd^2 for a tight surface to 0.40 gal/yd^2 for an open surface. No more prime should be applied than can be absorbed completely by the granular base course in 24 hr. If not absorbed, the excess should be blotted with sand and removed.

TACK COAT

The purpose of a tack coat is to ensure a bond between the existing pavement surface and the new asphalt overlay. The tack coat should not be used in lieu of cleaning the present pavement surface: removing accumulated dust and dirt by mechanical brooming or by flushing with air and/or water. If a good bond is not formed between the existing surface and the new overlay, a slippage or sliding-type failure can easily occur. The new overlay can be shoved in a longitudinal direction by traffic, particularly at locations where the traffic accelerates or where the vehicle brakes are applied. Thus, the pavement surface must be completely clean before the tack coat is applied.

The tack coat material should be applied by a pressure distributor, as shown in Figure 3-12. All nozzles on the distributor should be open and functioning. All nozzles should be turned at the same angle to the spray bar; approximately 30°, depending on the manufacturer of the distributor. In addition, the spray bar should be at the proper height above the pavement surface to provide for a double or triple lap of the liquid asphalt material. This will provide the proper amount of overlap between the nozzles and a uniform application of the tack coat material to the road surface. The tack coat material, which is normally asphalt emulsion but can also be asphalt cement or cut back asphalt, should be heated to the proper temperature so that it is fluid enough to be sprayed from the nozzles instead of coming out in strings.

Uniformity of application and use of the proper application rate is the key to the success of the tack coat

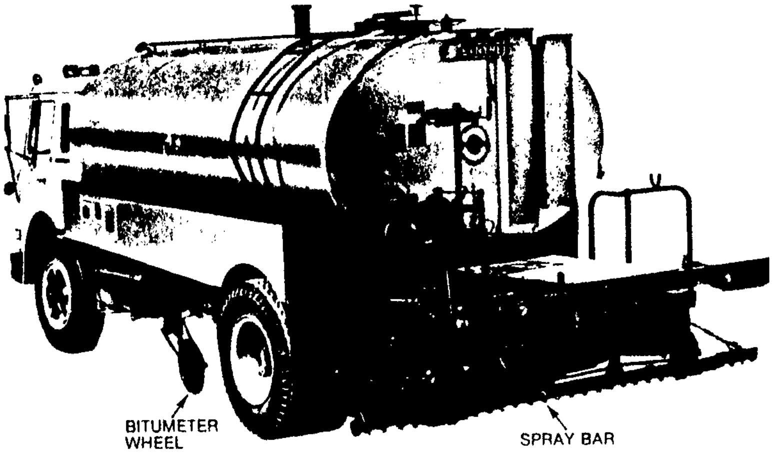


Figure 3-12. Asphalt distributor *(Asphalt Institute)*.

process. Figure 3-13 illustrates a tack coat application that is too light--not enough tack coat has been sprayed on the road surface. Figure 3-14 shows the opposite problem--too much tack coat material on the existing pavement. If the correct amount of tack coat is sprayed on the surface, some of the existing surface will still be visible through the tack coat--not all of the existing pavement surface will be covered with the tack coat. Use of a diluted asphalt emulsion tack coat (slow-setting asphalt emulsion diluted 1:1 with water) will result in complete coverage of an extremely thin residual asphalt film.

The proper tack coat application will leave a residual asphalt cement content of approximately 0.04 to 0.06 gal/yd^2 on the roadway. The amount of tack coat used will depend on the condition of the pavement surface; an open-textured surface requires more tack coat than a surface that is tight or one that is "fat" or flushed. In addition, more tack coat material may be needed on a milled surface because of the increased surface area. In the last case, the application rate could be as great as 0.08 gal/yd^2 of residual asphalt cement.

The amount of water in an asphalt emulsion and the amount of diluent material in a cutback asphalt must be taken into account when determining the proper application rate to be sprayed from the distributor. Too little tack coat will not provide sufficient bond between the old and the new pavement layers. Too much tack coat may contribute to the sliding of the overlay on the existing pavement surface and bleeding of the tack coat material through a thin overlay.

If an asphalt cement is used as the tack coat material, it will cool to ambient temperatures very quickly. Further, because there is no carrier material to evaporate, paving may follow the asphalt cement tack coat application immediately. If a cutback asphalt is employed as a tack coat, sufficient time must be allotted between the application of the tack coat and the start of paving to permit the diluent in the cutback material to evaporate. The rate of evaporation will depend on the type and grade of the cutback asphalt used and on environmental conditions. If an asphalt emulsion is used for the tack coat, a delay must also occur between the emulsion application and the placement of the overlay.

Figure 3-13. Too little tack coat *(J. Scherocman)*.

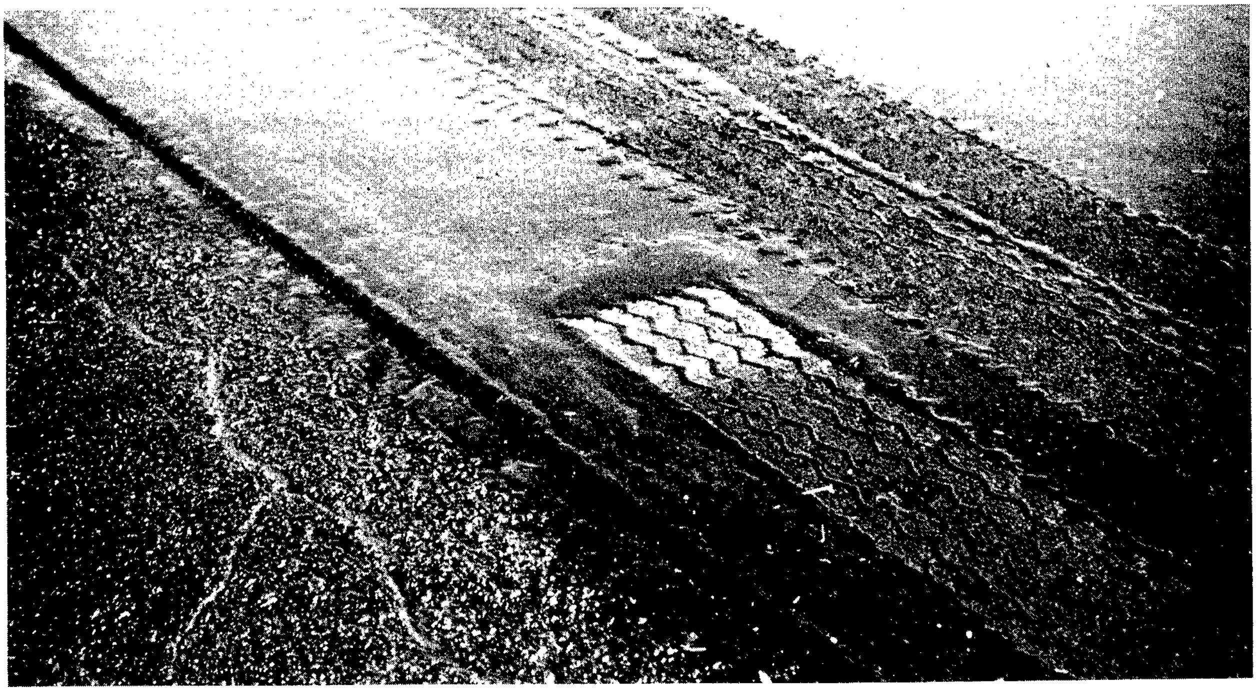


Figure 3-14. Excessive tack coat *(J. Scherocman).*

The emulsion must break (change color from brown to black) and the water must evaporate from the emulsion before the new mix can be placed over the tack coat material.

If the overlay is to be constructed under traffic, the tack coat is normally placed only a short distance in front of the paver; within the lane closure and far enough ahead for the tack to cure properly before the mix is laid on top of it. Traffic is kept off of the tack coat at all times. If the roadway being paved is closed to traffic, the tack coat can be placed as early as 24 hr ahead of the laydown operation. This will assure that the tack coat will be well cured before the mix is placed on top of it. Under unusual circumstances, if traffic must travel over the tack coat before the overlay is placed, a light layer of sand can be spread on top of the tack coat to prevent the pickup of the tack coat material by traffic. The application rate of the sand should be in the range of 4 to 8 lb/yd^2, depending on the application rate of the tack coat material and the gradation of the sand. Excess sand should be broomed from the pavement surface before the overlay is placed to assure the proper bond between the overlay and the existing surface.

The application of the tack coat material is essential when an overlay is being constructed on an existing pavement surface; either portland cement concrete, hot-mix asphalt, or surface treatment. A tack coat often is not needed, however, when a layer of new mix is being placed over another layer of asphalt pavement that has been laid within a few days. As long as the underlying new layer has not become dirty under traffic or from windblown dust, a tack coat may be deleted between lifts of mix placed within a period of several days.

SURFACE PREPARATION TECHNIQUES

Before an asphalt pavement course is placed over an existing surface (subgrade soil, aggregate base, asphalt stabilized material, or portland cement concrete) that surface must be prepared properly for the new layer. Some of the recommended preparation procedures include:

- Any failures in the existing surface must be removed and replaced or repaired by patching unless a very thick overlay is constructed.
- Cracks in an existing asphalt pavement surface generally should be sealed individually or some type of surface treatment should be applied to the whole roadway area. Joints in a PCC pavement that are poorly sealed should be routed out and resealed. Rocking PCC slabs should be stabilized.
- A rough, uneven asphalt surface should be leveled with asphalt mix (using a paver to place mix in large areas) to fill in the low spots in that surface or should be cold planed with a milling machine to remove the high spots.

- After the needed repairs are completed, the pavement surface should be cleaned of all dust, dirt, and other debris. This should be accomplished using multiple passes of a mechanical broom. If brooming does not remove all of the accumulated dirt, flushing with air and/or water may be required.
- A prime coat is generally not needed on subgrade soil. A difference of opinion exists on the benefits of the use of a prime coat on a granular base course, but in many cases a prime coat can be eliminated without detrimental effect on the performance of the pavement structure.
- The application of a tack coat must be accomplished before an overlay is constructed on an existing asphalt or PCC pavement surface. The distributor that is used should be checked to assure that all the nozzles are open and set at the correct angle and that the spray bar is at the proper height above the pavement surface.
- The application rate for the tack coat must be based on the residual amount of asphalt cement on the road surface, which should be between 0.04 and 0.06 gal/yd^2 for normal surfaces. Milled pavements may need a greater amount of residual tack coat. Too little tack coat will not provide the needed bond between the old and new layers. Too much tack coat may promote slippage of the new overlay on the old pavement or bleeding of the tack material through a thin overlay.

SECTION THREE
MIX PLACEMENT

INTRODUCTION

The purpose of the paver is to place the hot-mix asphalt to the desired width and thickness and to produce a satisfactory mat texture. The paver consists of two primary parts: the tractor unit and the screed unit. The tractor unit provides the motive power to the paver and transfers the asphalt mixture from the receiving hopper on the front of the machine to the spreading screws at the back of the paver. The second unit consists of the paver screed. This leveling device is attached to the tractor unit at only one point on each side of the paver and is able to "float" on the asphalt mix and provide initial texture and compaction to that material as it passes out from under the screed. The parts of the tractor unit and the screed unit are shown in Figure 3-15.

THE TRACTOR UNIT

The tractor unit fulfills all of the functions necessary to receive the asphalt mix from the haul trucks, carry that material back to the spreading screws, and distribute the mix across the width of the screed. The tractor unit is powered by its own engine and provides the required propulsion energy to move the machine forward, either on rubber tires or crawler tracks. It is composed of several major components including the truck push rollers, mix-receiving hopper, material flow gates, twin slat conveyors, and a pair of screw conveyors or augers.

Propulsion Systems

The paver is mounted on either crawler tracks or rubber tires. The crawler tracks could be all steel, steel equipped with rubber pads, or flexible bands with steel shoes and rubber pads. If the paver is used on top of a yielding surface, the crawler track system will provide an increased area over which to spread and support the weight of the paver. If the paver is moved regularly under its own power between paving locations, the rubber tire machine is normally used, because its travel speed is much greater than that of the crawler track paver. The type of propulsion system does not affect the basic functions of the paver.

Push Rollers

The push rollers, located on the front of the paver hopper, are used to maintain contact with the tires of the haul truck and to push that truck ahead of the paver. The rollers must be clean and free to rotate to allow smooth forward travel of the paver. If the push rollers are not cleaned periodically and do not rotate freely, the truck tires will slide on the rollers and increase the load on the paver. Moreover, if one roller rotates freely and the other does not, the paver may tend to change direction.

Many pavers are equipped with a truck hitch that is located underneath the push rollers on the front of the paver hopper. The purpose of the hitch is to keep the truck in contact with the paver and prevent the truck

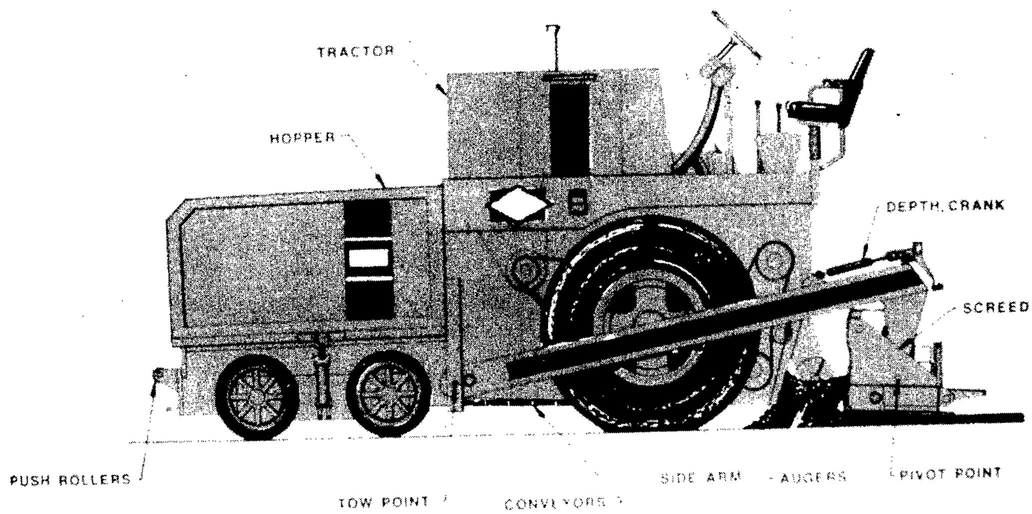


Figure 3-15. Components of an asphalt paver *(Blaw-Knox)*.

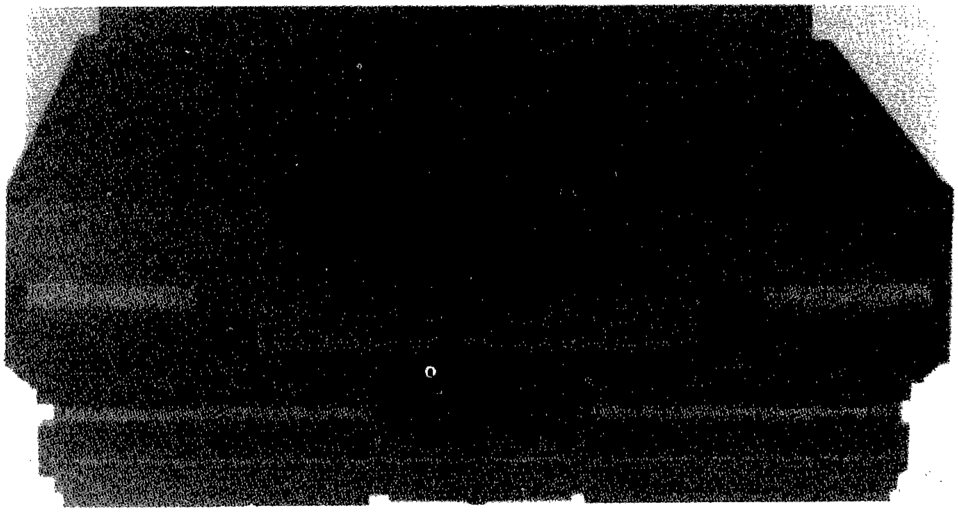


Figure 3-16. Paver hopper *(Barber-Greene)*.

driver from pulling away from the paver and inadvertently dumping mix on the pavement in front of the paver. The hitch, controlled by the paver operator, comes in contact with the rear wheels of the truck on each side of the truck. Once the truck bed has been emptied of mix, the truck hitch is withdrawn and the truck is able to pull away from the paver.

Paver Hopper

The paver hopper, shown in Figure 3-16, is used to receive and temporarily hold the asphalt mix from the haul vehicle or the pickup machine. The hopper must be wide enough to allow the body of the haul truck to fit inside of it. In addition, particularly for smaller pavers, the hopper must be low enough to permit the truck bed to be raised without the bed placing excessive weight on the front of the hopper. The front of the hopper must be designed in a way to minimize the spillage of mix out of the hopper during the dumping of the hopper wings. This is normally accomplished by using rubber belts or flaps attached to the wings.

If a windrow elevator (illustrated in Figure 3-17) is

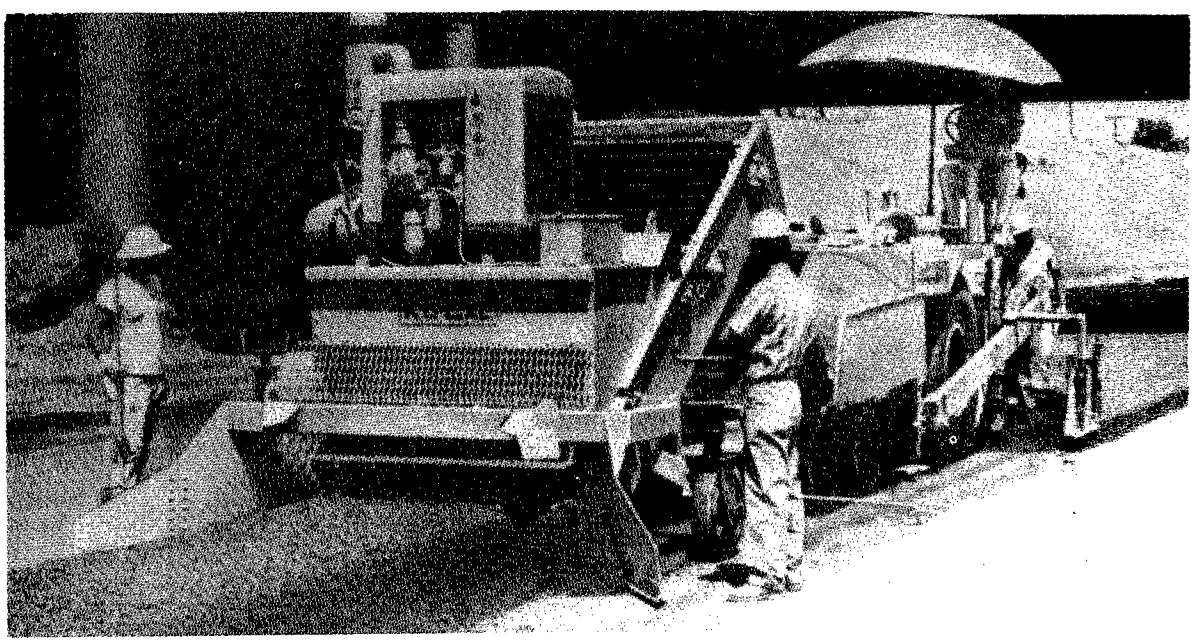


Figure 3-17. Windrow elevator attached to front of paver *(Ko-Cal; Koehring Co.)*.

Figure 3-18. Thin layer of asphalt concrete left on pavement surface under windrow elevator *(J. Scherocman)*.

used to feed mix to the paver, the hopper must be able to hold the proper volume of mix without unbalancing the paver. The blades on the slat conveyor of the windrow elevator must be set at the right level to pick up all of the mix that has been placed on the existing pavement. No mix should be left in the windrow; this thin layer of material (Figure 3-18) will cool quickly and may result in difficulties in compacting the mix. In addition, longitudinal streaks may occur in the mat behind the paver at the edges of the windrow, as shown in Figure 3-19.

As shown in Figure 3-20, the sides, or wings, of the hopper are movable. Mix, if left to stand for a long period of time in the corners of the hopper, will cool and may appear as chunks of mix back of the screed when it passes through the paver. Thus, the mix is periodically moved from the sides of the hopper into the middle of the hopper by folding the wings (sides) and allowing the mix to be deposited into the area of the slat conveyors.

Many paver operators dump (fold) the wings of the paver after each truckload of mix has been emptied into the hopper. Further, to prevent spillage of the mix out the front of the hopper, the operator often pulls the amount of mix left in the hopper down during discharge and after the truck has left the hopper by continuing to run the slat conveyors to feed mix back to the augers. This may result in the slat conveyor running completely empty. This practice can lead to increased mat prob-

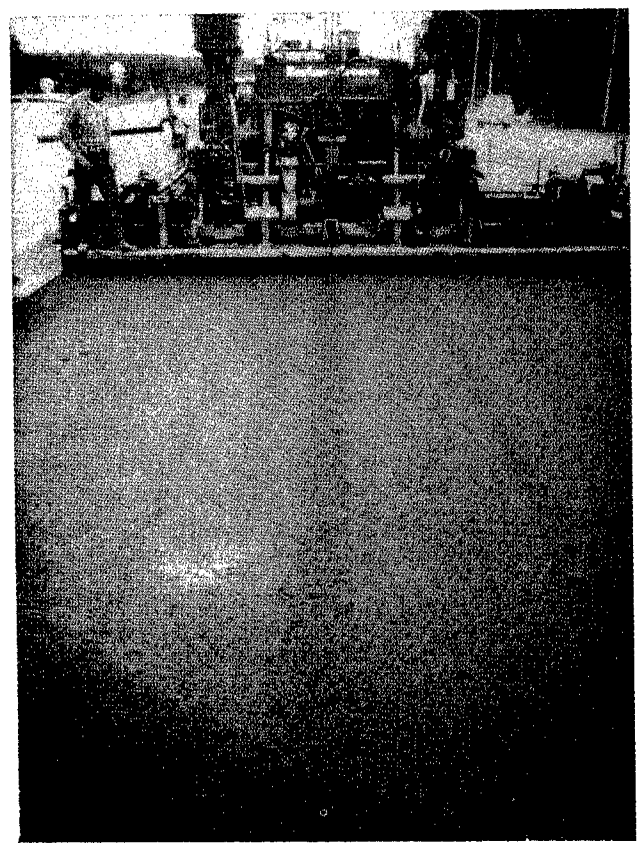


Figure 3-19. Parallel streaks same width as windrow behind paver screed *(J. Scherocman)*.

Figure 3-20. Folded wings on paver hopper *(Blaw-Knox)*.

lems if segregated mix is deposited on the conveyor slats, either from the paver wings or from the haul truck, and carried back to the augers and screed. It is not good practice to dump the paver wings after each truckload of mix has been delivered or to deposit the mix held in the wings into the empty paver hopper, because either procedure can decrease the quality of the finished mat.

To minimize segregation, the paver operator should fold the wings as seldom as possible. The frequency at which the wings are dumped depends on the rate of delivery of the mix to the paver, the temperature of the mix, and the environmental conditions. The wings should be emptied before the mix that collects in the corners of the hopper cools so much that chunks are formed that cannot be broken up as that mix moves through the paver to the augers and under the screed. On colder days, the hopper wings will need to be dumped more frequently than on warmer days.

In all cases, the paver hopper should be at least partially full at the time that the wings are dumped into the center of the hopper; the amount of mix in the hopper should be approximately at the level of the bottom of the flow gates at the back of the hopper. This will provide enough mix to heat the cooler material in the wings before it goes through the screed. The slat conveyors should not be visible at the time that the wings are raised. As discussed later, keeping the hopper relatively full between truckloads of mix keeps the head

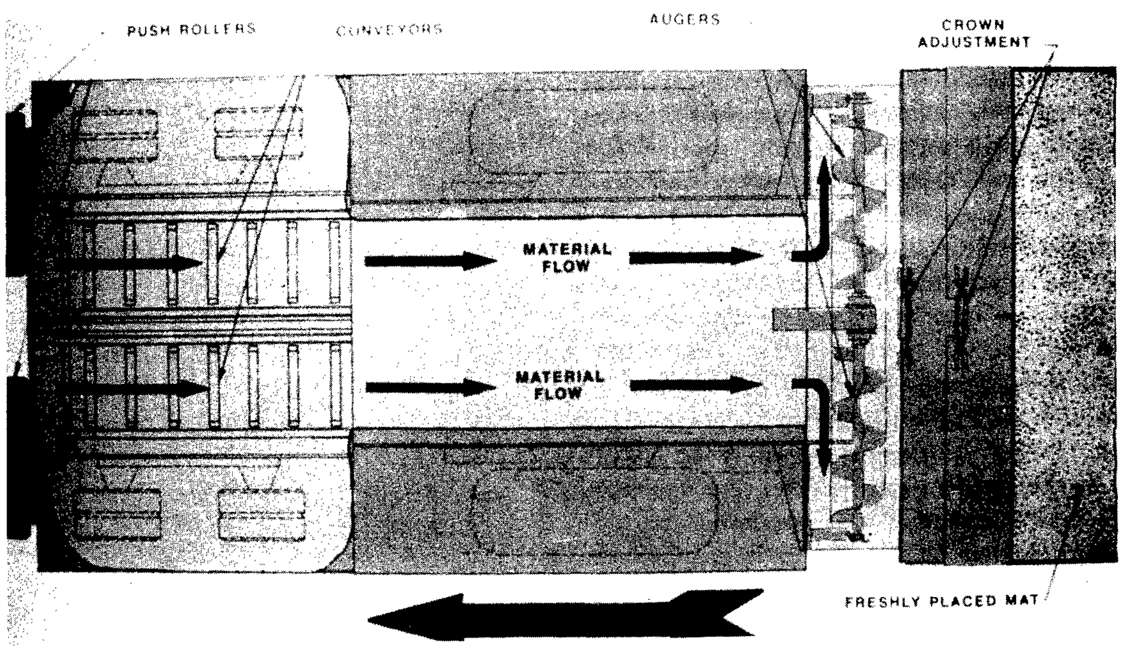


Figure 3-21. Slat conveyor at bottom of paver hopper *(Blaw-Knox)*.

of asphalt mix in front of the paver screed constant and also reduces any segregation that might be present in the mix. In addition, the wings should not be "banged" repeatedly as they are emptied.

Slat Conveyors

At the bottom of the paver hopper is a set of slat conveyors. As shown in Figure 3-21, these devices are used to carry the asphalt mix from the hopper through the tunnel on the paver and back to the spreading screws. The slat conveyor on one side of the paver operates independently from the movement of the slat conveyor on the other side of the machine. Thus, the amount of mix that can be carried back through the paver on one side can be different from the volume of material that is being delivered on the other side. This procedure allows the paver operator to feed more or less material to one side of the paver or the other in order to pave ramps, mail box turnouts, and tapers. The slat conveyors are a continuous system, with the slats being rotated back to the bottom of the hopper underneath the paver itself.

Flow Gates

At the back of the paver hopper is a set of flow gates. These gates, one over each of the two slat conveyors, are used to regulate the amount of mix that can be delivered by the conveyors to the augers. The gates move vertically, either by manual manipulation or mechanically. Depending on the vertical setting of the gates, more or less mix is permitted to enter the paver tunnel. The location of the flow gates is shown in Figure 3-22. The flow gates should be adjusted to provide a uniform head of material (at a level at or just above the center of the auger shaft) in front of the screed. Figure 3-23 shows three possible positions of the flow gates (too high, too low, and correct) in relation to the head of material in front of the paver screed.

Augers

The mix that is carried to the back of the tractor unit by the slat conveyors is deposited in front of the screw conveyors or augers (Figures 3-24 and 3-25). Just as the two slat conveyors operate independently of each other, the augers on each side of the paver are run separately from one another. The auger on one side of the paver, however, is run in conjunction with the slat conveyor on that same side of the paver. The mix placed in the auger chamber from the slat conveyors is distributed across the width of the paver screed by the movement of the augers. At the junction of the two augers in the center of the paver, adjacent to the auger gear box, there typically is a different-shaped auger (reverse auger or paddle) to tuck mix under the gear box and assure that the mix placement at this location is the same as that across the rest of the width of the mix being laid. This reverse auger (paddle) is shown at the upper left side of the main screw auger in Figure 3-26. It is important that the augers carry a consistent amount of mix across the front of the screed so that the pressure (head of material) on the screed is kept as constant as possible.

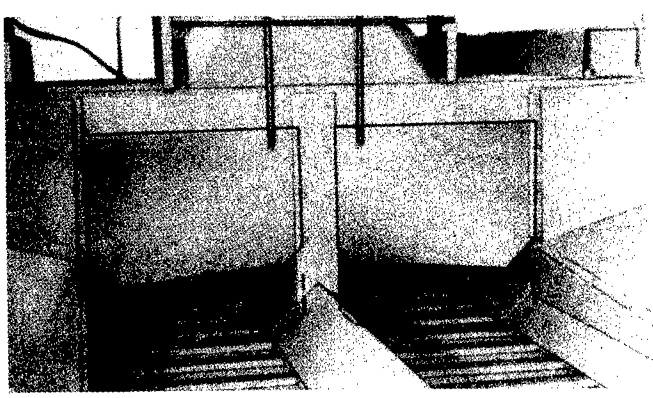


Figure 3-22. Flow gates at back of paver hopper *(Cedarapids)*.

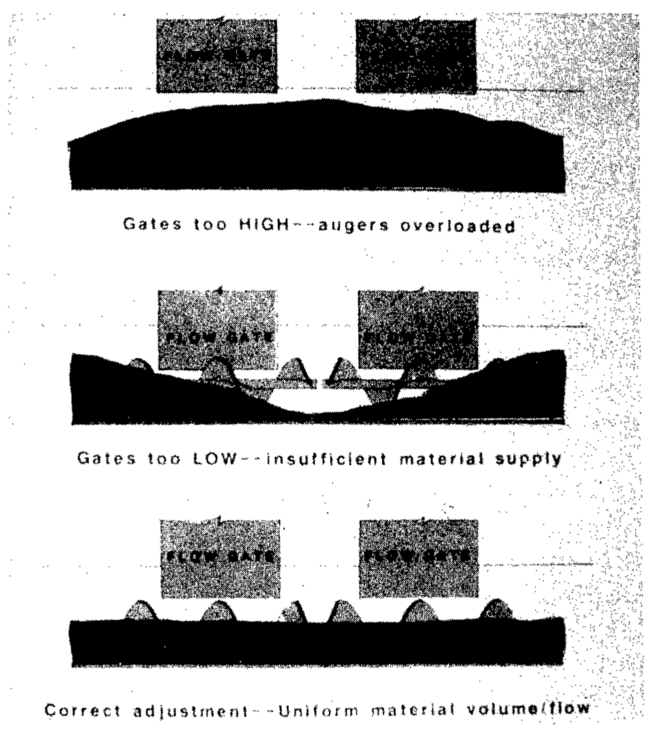


Figure 3-23. Position of flow gates *(Blaw-Knox)*.

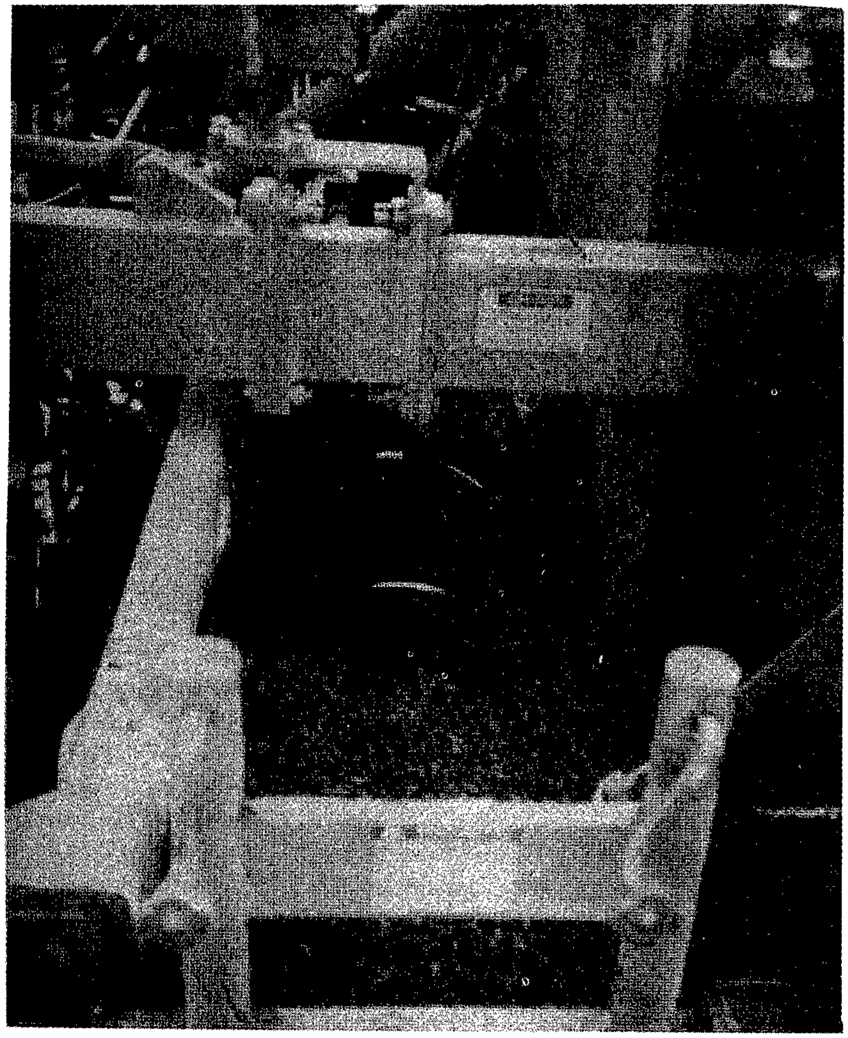


Figure 3-24. Paver auger *(J. Scherocman)*.

Material Feed System

Manual Control-Constant Speed

As shown in Figure 3-25, the slat conveyor and auger on one side of the paver act independently from the slat conveyor and auger on the other side of the paver. On older pavers, in the manual mode, the slat conveyor and the auger speed are constant. The paver operator can only control the amount of mix being carried back to the screed by adjusting the height of the flow gates. If the gates are set too high, the material feed system will provide a "slug" of asphalt mix to the augers whenever the slat conveyors and the augers are operated. This will significantly increase the head of material in front of the paver screed and cause increased pressure on the screed. This greater force will lift the screed and increase the thickness of the mat being placed. Because of this action, the angle of attack of the screed is reduced slightly as the screed pivots about the tow point.

If the gates are set too low, the material feed system will not be able to deliver enough material to the augers, thus reducing the head of mix in front of the screed and the force pushing on the screed. This action reduces the thickness of the mat being placed as the screed settles and increases the angle of attack of the screed as it pivots about the tow point. With the older paver system, in which the material feed system operates at a single speed on an off-on basis, the only way the operator can control the head of material in front of the screed is by proper setting of the flow gates at the back of the paver hopper. The flow gates and feeder on-off switches must be set at a position that requires the slat conveyors and augers on each side of the machine to run as close to 100 percent of the time as possible.

Manual Control-Variable Speed

Some pavers are designed so that in the manual mode the paver operator can select one of several speeds for the slat conveyor, each essentially a percentage of the maximum speed of the conveyor. Once the conveyor speed is selected, the speed of the spreading screw conveyor (auger) is proportioned to the speed of the slat conveyor. The operator is responsible for controlling the slat conveyor and augers in order to keep a constant level of asphalt mix in front of the paver screed. The flow of material to the screed essentially is regulated by the height of the hopper flow gates and by the starting and stopping of the slat conveyor and auger on each side of the paver. With this manual system, no changes occur in the head of material in front of the screed as the speed of the laydown machine changes unless the speed of the whole material delivery system is changed by the paver operator.

Automatic Control

Most pavers are equipped with an automatic feed system that supplies mix to the paver screed in proportion to the need for the material. For this system, a feed control sensor (a type of limit switch) is used to

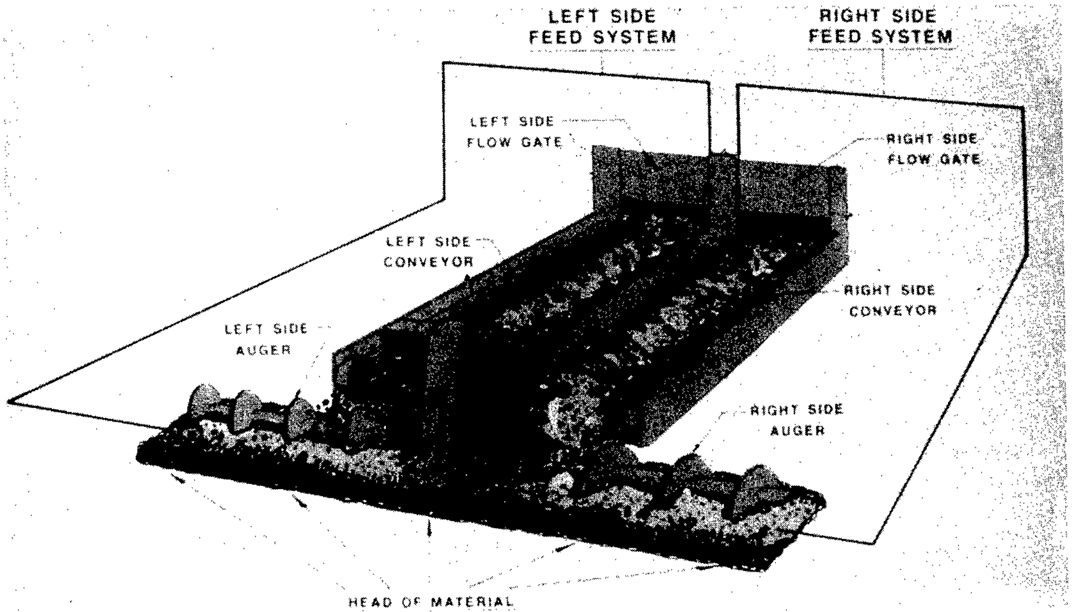


Figure 3-25. Dual-feed system (slat conveyor and auger) *(Blaw-Knox)*.

determine the amount of mix in the auger chamber, as shown in Figure 3-27. If the volume of mix available in front of the screed falls below the desired amount, the feed control sensor will move enough to engage the slat conveyor and auger system, pulling more mix back to the screed area. As the material is distributed in front of the screed, the feed control sensor will rise and disengage the feed system. This action will maintain the preselected head of material in front of the screed. This sequence repeats itself, continuously maintaining a consistent head of mix as long as material is available in the hopper. On some pavers, a variable-speed (potentiometer-type) feed system is used to control the amount of material in front of the screed. Instead of an on-off system, the speed of the delivery system is increased when more mix is needed and the speed of the slat conveyor and auger system (on each side of the paver) is decreased when the head of material in front of the screed is too great. This type of equipment is illustrated in Figure 3-28.

In addition to these limit switch-type and variable-speed systems, both ultrasound and infrared sensing devices can be used to determine the amount of mix in the auger chamber. These two types of systems operate on the same basis as the limit switch system; measuring the amount of mix in front of the screed and controlling

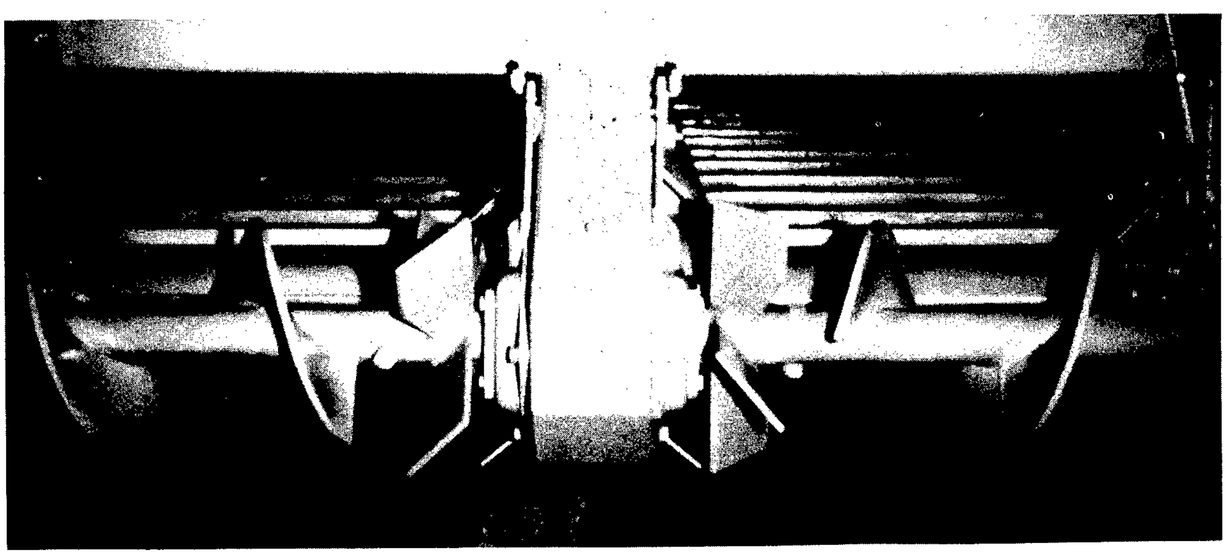


Figure 3-26. Reverse paddle on auger at gear box *(Cedarapids)*.

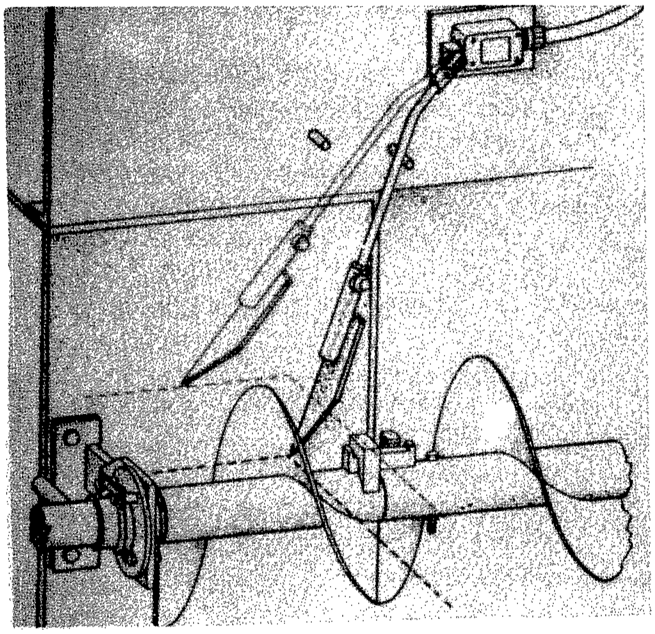


Figure 3-27. On and off automatic feed control system *(Barber-Greene)*.

the slat conveyor and auger feed system to maintain a constant head of mix at the screed.

For the automatic feed control system to function properly, the feed sensor control arm should be located as close to the outside end of the augers as possible. If rigid paver screed extensions are used, as discussed later, the control arm should be mounted beyond the end of the augers, just inside the end gate on the paver screed.

The amount of mix carried in the auger chamber should be as constant as possible. The proper depth of material on the augers should be at the center of the auger shaft (Figure 3-29). The level of material carried in front of the screed should not be so little as to expose the lower half of the screw conveyor flights. Further, the level of mix delivered to the screed should never be so great as to cover the upper portion of the auger, as shown in this same figure.

If the feed system is set and operating properly, the slat conveyor and augers on each side of the paver will rarely shut off. This continuous action of the conveyors and augers is accomplished by setting the proper position for the hopper flow gates and determining the correct speed setting for the slat and screw conveyors. *The primary key to the placement of a smooth pavement layer is the use of the material feed system to keep the head (level) of material in front of the screed constant, primarily by keeping the slat conveyor and augers running as close to 100 percent of the time as possible.* Intermittent operation of the slat conveyor and auger system could cause both auger shadows and ripples in the mat behind the screed, as discussed in the section on mat

Figure 3-28. Variable auger speed automatic feed control systems *(Blaw-Knox)*.

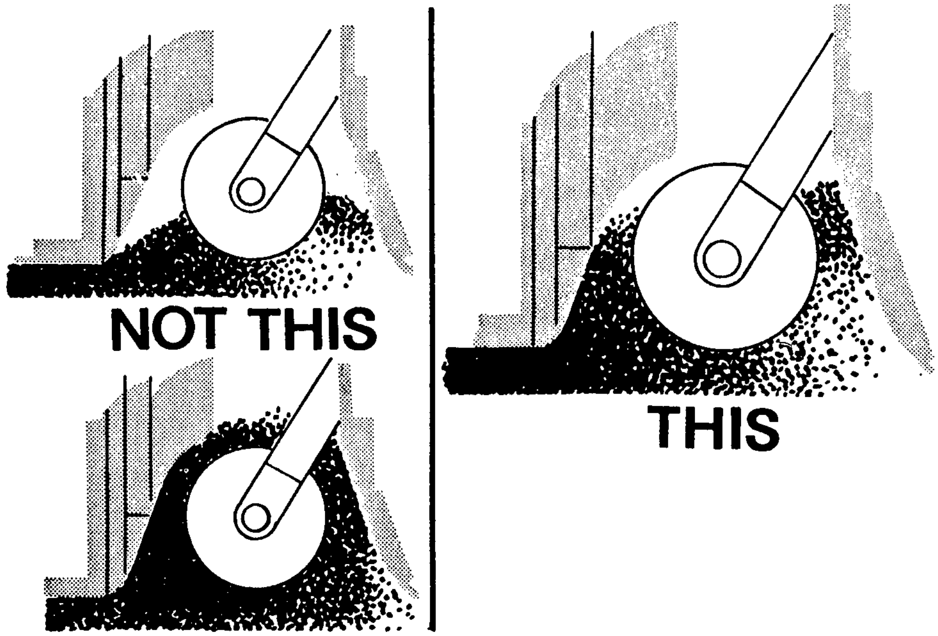


Figure 3-29. Correct and incorrect mix levels in the paver auger chamber *(Barber-Greene)*.

problems.

THE SCREED UNIT

The screed unit, which is towed by the tractor unit, establishes the thickness of the asphalt layer and provides the initial texture to the new surface. In addition, the screed imparts some level of density to the material being placed through the vibratory or combination tamping and vibratory action of the screed. A diagram showing the parts of the screed for one particular make and model of paver is shown in Figure 3-30.

The principle of the free-floating paver screed was developed in the early 1930s. That concept allows the paver screed, which is attached to the tractor unit at only one point on each side of the machine (the tow or pull point), to average out changes in grade that are experienced by the wheelbase (rubber tires or crawler tracks) of the tractor unit. The floating-screed principle is employed on all of the modern asphalt pavers in use today.

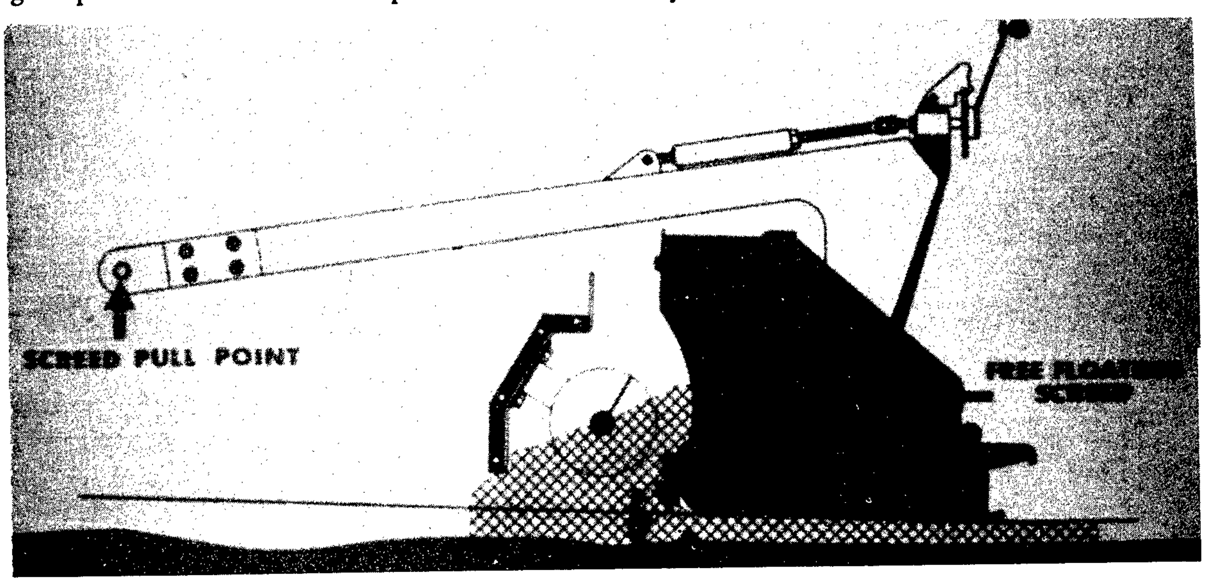


Figure 3-30. Screed unit *(Barber-Greene)*.

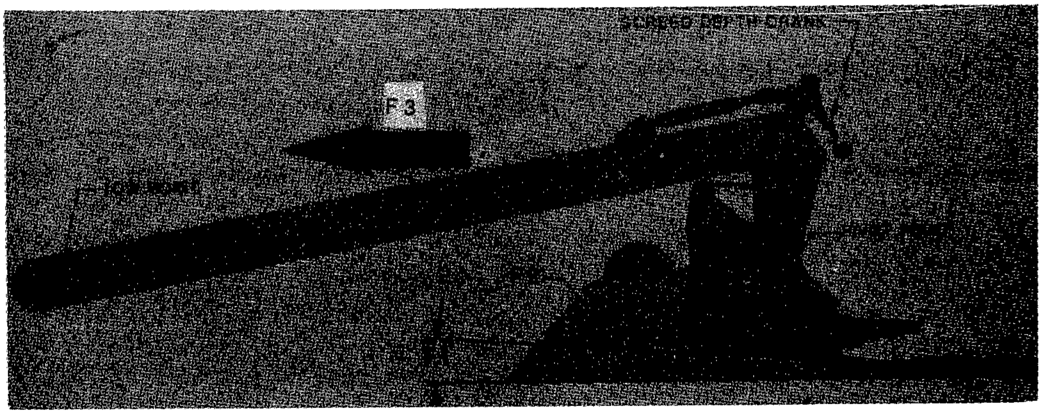


Figure 3-31. Screed tow point and tow arm forces acting on paver screed *(Blaw-Knox)*.

Tow (Pull) Point

The screed unit is attached to the tractor unit at only one point on each side of the paver. This point, shown in Figure 3-31, is called the tow point or the pull point by the different paver manufacturers. The tow point is really a pin-type connection that allows the leveling arms (also called side arms or pull arms) of the screed to rotate or pivot around that point. This pin connection reduces the transmission of movement between the tractor unit and the screed unit.

The concept of the pull point and the free-floating screed allows the tractor unit to provide the wheelbase for the screed unit. The screed then pivots around the pull or tow point and responds to the average grade being spanned by the tractor wheelbase. For the floating-screed principle to work properly, under manual control, it is important that the pull points on both sides of the tractor be at the same level above the ground. The position of the screed pull points can be altered by raising or lowering the rods on which the pull points are mounted. For most asphalt mixtures, the pull or tow point is positioned near the center of the rod. For some asphalt mixtures being placed, however, it may be advantageous to change the elevation of the pull points: raise or lower that elevation to improve the texture of the mat being placed. (If the paver is being operated under automatic grade and slope control, as discussed in the following section, the elevation of the pull point typically is centered when paving is started. The location then changes as necessary as paving proceeds in order to maintain the proper angle of attack of the screed.)

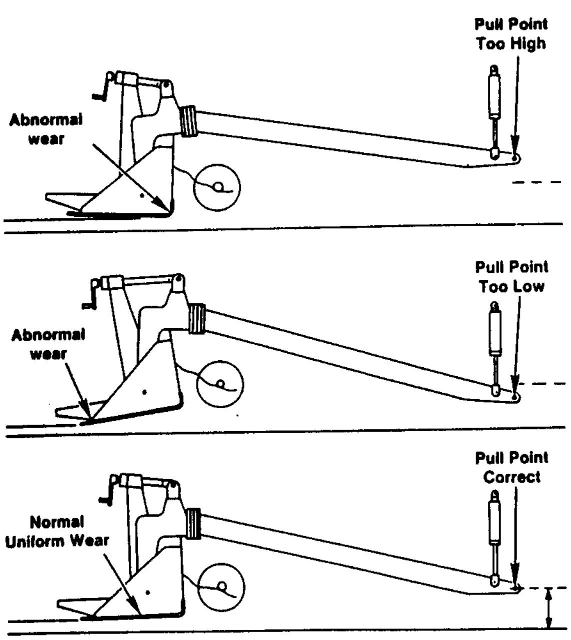


Figure 3-32. Effects of pull point height on screed wear *(Cedarapids)*.

On some pavers, under manual control, when the pull points are too high, the front of the screed is tilted down in order to maintain the proper angle of attack for proper mat thickness. Premature wear on the strike-off and the leading edge of the screed can be experienced (as shown in Figure 3-32), the smoothness of the mat can be reduced, and the degree of compaction imparted to the mix will be lessened. When the pull points are too low, on the other hand, the front of the screed is tilted up in order to maintain the correct thickness of the asphalt mix being placed. Additional wear can occur on the trailing edge of the screed.

For a paver not equipped with automatic screed controls, the relationship between a change in the elevation of the tow point on one end of the leveling arm and the movement of the screed on the opposite end of the leveling arm is shown in Figure 3-33. Typically an 8:1 ratio exists between the movement of the tow point

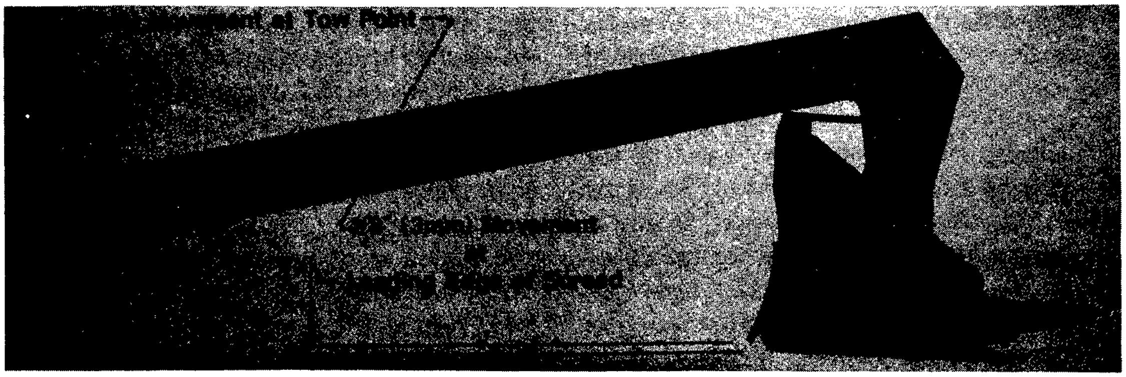


Figure 3-33. Ratio of tow point movement to mat thickness *(Blaw-Knox)*.

and the change in the angle of attack of the front edge of the paver screed. This means that if the tow point is moved vertically upward 1 in., the angle of attack of the screed will be increased by 1/8 in. As discussed in detail below, the paver must move forward approximately five lengths of the leveling arm before the screed will move up to the new level of the tow point and the forces on the screed will again be in equilibrium.

The combination of the screed pivot point at the end of the leveling arm attached to the tractor and the thickness-control device at the screed provides for adjustments to be made to the angle of attack of the screed unit. The angle of attack is shown in Figure 3-34. Because of the method by which the screed is attached to the tractor, the screed acts in a manner similar to that of a water skier being pulled by a speed boat.

Forces Acting on the Screed

The screed assembly, including the tow point, the leveling or towing arm, the screw conveyor or auger, the thickness-control crank, and the screed with its pivot point, is shown in Figure 3-31. There are two primary forces that constantly act on the paver screed as the paver places the mix. The first force acting on the screed is the towing force of the tractor, F3 as shown in this figure. This force varies as the speed of the tractor unit increases and decreases.

The second force on the screed is the head of material pushing against the screed, F2. As the amount of asphalt material in the auger chamber that pushes against the screed changes, the net force acting on the screed also changes. As the forces acting on the screed change, the screed must come to a new angle of attack in order to compensate for the change in force acting on it.

The forces on the screed must be in equilibrium (all forces equal) for the screed to remain at a constant angle of attack as it is towed by the tractor unit. When a change in one force occurs, the screed will rise or fall and will change the thickness of the mat being placed. This will also result in a change in the angle of attack of the screed. The screed will react to the change in the force against it until it reaches a new equilibrium elevation in which the forces are in balance.

Paver Speed

Because the speed of the paver has a major effect on the angle of attack of the paver screed, it is good paving practice to keep the speed of the paver as consistent as possible during laydown operations. Under manual

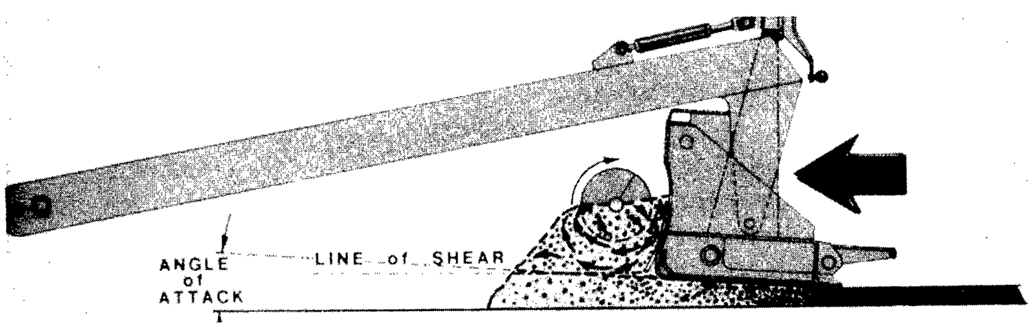


Figure 3-34. Screed angle attack position *(Blaw-Knox)*.

material flow control and screed control, if the forces on the screed remain constant except for the change in paver speed, an increase in the speed of the paver will cause the thickness of the asphalt layer being placed to decrease. Similarly, a decrease in the speed of the tractor unit will cause an increase of the thickness of the mat being laid. This will only occur, however, as long as no other changes are made in the system; the location of the pull points (tow points) of the screed remain at a constant level and the rate of feed of mix to the augers remains constant. As paver speed increases, if no additional mix is delivered by the slat conveyors to the augers, less mix is available to pass under the screed and the thickness of the layer would be reduced.

Under manual material flow control, the paver operator would have to increase the amount of mix transferred to the augers in order to maintain a constant head of material in front of the screed and a constant layer thickness. Under automatic material flow control, however, the volume of mix delivered to the augers would increase as the paver speed increased, maintaining a constant head of mix in front of the screed. In this latter case, the forces against the screed would remain balanced at the new speed and the thickness of the layer would be unchanged even as the paver speed was increased. Thus, through the use of automatic material-control devices on the paver, the head of material can be maintained at a constant level regardless of paver speed, and the layer thickness placed will remain constant. Under manual flow control, however, the paver operator must alter the amount of mix delivered to the augers and screed as the speed of the paver is changed. In addition, the paving speed should be selected to match the amount of mix being delivered from the plant.

When changing trucks, it would be best if the transfer could be done without slowing down or stopping the paver. At relatively slow paving speeds, it might be possible to make the truck exchange while keeping the head of material in front of the screed constant. This would require, however, that the level of mix in the hopper be kept at a level at least even with the bottom of the flow gates at all times. Use of a windrow elevator or a material transfer device eliminates this problem.

If the normal paving speed is fast enough or the truck exchange is slow enough that the proper amount of mix cannot be maintained in the hopper (on the slat conveyors and on the augers) between loads, it would be better to stop the paver when the transfer of trucks occurs. As soon as one truck is emptied, it should pull away from the paver. The paver should be brought from paving speed to a stop as quickly and smoothly as possible without jerking the machine. The next truck should then be backed toward the paver, stopping short of the paver; 1 or 2 ft away. For a dump truck, the bed should be raised in the air, without releasing the tailgate, so that some mix can slide against the tailgate. The paver should be started and brought back to the preselected paving speed as quickly and smoothly as possible. The tailgate on the truck should be released as soon as the push rollers on the paver make contact with the vehicle tires, and the mix should be delivered to the paver hopper before the level of mix in the hopper drops below the level of the bottom of the flow gates. This procedure of stopping and restarting the paver quickly will minimize the change in the forces acting on the screed and will allow a near-constant mat thickness to be placed.

Maintaining a constant paver speed is one of the primary advantages associated with the use of a pickup machine or material transfer device to deliver mix to the paver. By keeping the speed of the paver constant, a consistent head of material can be maintained by the slat conveyors and the augers and a constant layer thickness will be the result. If dump-type haul trucks are used, however, a smoother-riding pavement can be constructed by quickly reducing the speed of the paver and then stopping the paver when a truckload of mix is depleted instead of by keeping the paver creeping along until the next truck arrives at the hopper. Once the next truckload of mix is in the hopper, the paver operator should quickly increase the speed of the paver back to normal operating speed.

Head of Material

If the volume of mix in the auger chamber is increased, the force on the screed will also increase, causing the screed to rise. This action will then cause the angle of attack of the screed to decrease until a new equilibrium position is reached. If the amount of material being carried on the augers is decreased, the thickness of the mat will be reduced, all other factors being equal, as the screed falls. This results in an increase in the angle of attack of the screed until the forces on the screed are once again in equilibrium.

One of the primary factors that affects the head of material in the auger chamber is the action of the slat conveyor and auger on each side of the paver. When the slat conveyors and augers are operating, the mix is pulled from the paver hopper, through the tunnel, and is distributed across the front of the screed. As long as this flow of material is relatively constant, the head of material pushing against the screed will be relatively

Figure 3-35. Angle of attack *(Blaw-Knox)*.

constant and the mat being placed will be smooth and have a consistent texture.

If the head of material is allowed to vary, however, the screed will move up and down in relation and reaction to the forces acting on it. As the amount of mix being carried by the augers is decreased because the slat conveyor and auger system is shut off, the screed will move downward, reducing the thickness of the mat behind the screed. As the slat conveyor and auger system comes on, more mix is carried back to the augers and across the front of the screed. This increases the force on the screed and causes it to rise to a new elevation, resulting in a thicker mat. Thus, the elevation of the flow gates becomes very important in regulating the amount of mix in front of the screed.

There is a potential for the head of material to be affected each time the slat conveyors and augers are turned off and on. This is true particularly if the head of material is not properly set initially. For this reason, the use of a proportional automatic feed-control system is very important, because this device keeps the slat conveyors and augers running as much of the time as possible, provided the flow gates are properly set. This, in turn, keeps the head of material relatively constant and allows the screed to place a mat of consistent thickness. A constant head of material against the paver screed reduces the occurrence of ripples and auger shadows.

Another factor that affects the uniformity of the head of material in front of the screed is the temperature of the mix. If a cold load of material is deposited in the paver hopper and carried back to the screed by the slat conveyors and the augers, the colder, stiffer mix will increase the force acting on the screed and cause the screed to rise, increasing the thickness of the layer placed. If a hot load of mix, on the other hand, is delivered to the paver, the decrease in viscosity of the binder material will reduce the stiffness of the mix and reduce the force of the mix on the screed when the mix is deposited in front of it. This action may cause the screed to fall and reduce the layer thickness.

Thickness Control Cranks for Manual Operation

The screed is attached to the leveling or tow arms on each side of the paver through a hinge or pivot point, as illustrated in Figure 3-31. The thickness-control mechanism, usually either a crank or a handle, allows the screed to be moved or rotated around the pivot point. The key to the leveling action of the screed is its ability, by rotating around the pivot point and being attached to the tractor unit at only the tow point, to establish an equilibrium attitude based on the forces applied to the screed, as illustrated in Figure 3-35. As the mix passes under the screed plate, the screed floats on the mix, determining the mat thickness and the texture of the material as well as providing the initial compaction of the asphalt mix.

For a constant position of the tow point (the tractor unit running on a level surface and without automatic screed controls), altering the setting of the thickness-control devices changes the attitude (angle of attack) of the screed and changes the forces acting on the screed. This, in turn, causes the screed to move up to, or down to, a new elevation as the paver moves forward, and thus alters the thickness of the mat being placed. The reaction of the screed to changes in the position of the thickness-control settings, however, is not instantaneous. Rather, there is a lag in the reaction of the screed that allows the screed to average out variations in the input forces acting on it.

Reaction of the Screed

Figure 3-36 provides information on the reaction time of the screed when a change is made in the angle of attack of the screed either at the screed or at the location of the tow point. After the tow or pull point has been raised, as shown in this figure, it takes approximately five times the length of the leveling or tow arms on the paver screed for the screed to complete 99 percent of the change, up or down, to the desired new

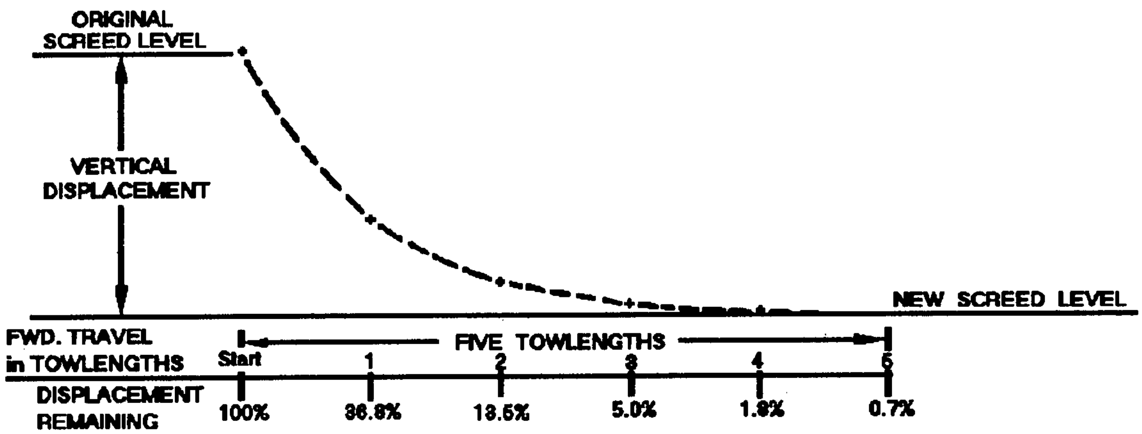


Figure 3-36. Screed reaction time *(Blaw-Knox)*.

elevation. This means that if the length of the leveling arm is 9 ft, the paver would have to move forward for a distance of at least 45 ft before the required input to the thickness-control device was completely carried out by the paver screed.

Changing Screed Pivot Point

As an example, assume that it is desired to increase the thickness of the mat being placed from 1 in. to 1 1/2 in. A change is made in the thickness-control crank, by turning it clockwise or counterclockwise depending on the make of the machine, to change the angle of attack of the screed. The movement of the thickness-control mechanism causes the screed to move around the hinge or pivot point and increase the angle compared with the road surface. The change in mat depth, however, is not immediate. The paver must move forward for some distance before the modification in mat thickness can be completed.

As shown in this figure, approximately 63 percent of the thickness change is accomplished after the paver has moved forward a distance equal to one leveling arm length, or 9 ft in this example. As the paver moves forward another 9 ft, about 87 percent of the desired thickness change has been completed. Approximately 95 percent of the elevation change is done by the time a distance of 27 ft has been traveled (three leveling arm lengths of 9 ft each). It is not until the paver has moved down the roadway a distance equal to at least five leveling arm lengths, however, that some 99+ percent of the thickness change has been completed.

The same exercise holds for a reduction in the thickness-control settings at the screed. A screed operator desiring to reduce the depth of the asphalt layer turns the thickness-control crank in the opposite direction and causes the screed to rotate around the hinge point. As the paver moves forward, the decreased angle of attack of the screed causes it to move downward, thereby reducing the amount of mix being fed under the screed. The screed will continue its downward movement until the forces acting on it are again in equilibrium. If the pavement layer depth were being changed from 1 1/2 in. to 1 in., it would still require the paver to move a distance of more than five lengths of the leveling arm before 99+ percent of the thickness change would be completed.

Changing Tow Point Elevation

The same principle applies to a change in the location of the tow point or pull point of the screed leveling

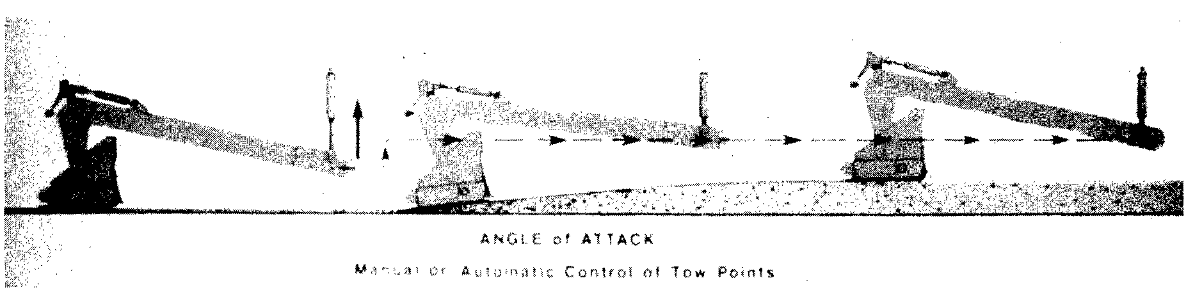


Figure 3-37. Angle of attack *(Blaw-Knox)*.

arm where it is attached to the tractor unit. If the tow point is displaced, as shown in Figure 3-37, the change in elevation of the tow point is translated to a change in the angle of attack of the paver screed. The paver must still move forward for a distance of approximately five times the length of the leveling arm on the machine for the screed to react to the change in the location of the tow point and move up to or down to the new elevation.

As a roadway is being paved without the use of automatic grade and slope controls, the tractor unit moves upward and downward in response to the grade of the underlying material. The vertical movement of the tractor translates into vertical movement of the tow point on the side of the paver. Each time the tractor goes over a hump or into a dip in the existing pavement surface, the elevation of the pull point changes. This, in turn, alters the angle of attack of the paver screed, causing the amount of material flowing under the screed to be decreased or increased. The fact that it takes five times the length of the leveling arm before the screed completely reacts to a change in the location of the tow point allows the screed to reduce the thickness of the asphalt mix being placed over the high places in the existing surface and to place more mix in the low spots on the present roadway. It is this averaging or leveling action that forms the basis for the floating screed principle of the asphalt paver.

When a paver is being operated manually, as in the above examples, it is very important for the screed operator to realize that the reaction to a change in the setting of the thickness-control crank is not immediate. The paver must move forward at least one leveling arm length before 63 percent of the thickness change is completed. If a second change is made in the setting of the thickness-control crank before the first change is accomplished, the first change will never be completed. It will still take an additional five times the length of the leveling arm for the second thickness change to be carried out. For this reason, continual changes in the setting of the thickness-control devices are usually detrimental to the development of a smooth mat.

The use of automatic paver controls, discussed in the next section, allows the paver to construct a smoother pavement by keeping the location of the screed pull or tow point constant relative to a predetermined reference as the tractor unit moves up and down vertically in response to small changes in the grade of the underlying pavement surface. By maintaining the tow point at a constant relationship to the predetermined reference while the tractor moves vertically, the force on the screed remains constant and the angle of attack of the screed is consistent in comparison to the reference. This allows the screed to carry out the leveling action needed over a longer reference length in order to reduce the roughness of the existing surface through the application of the new asphalt layer.

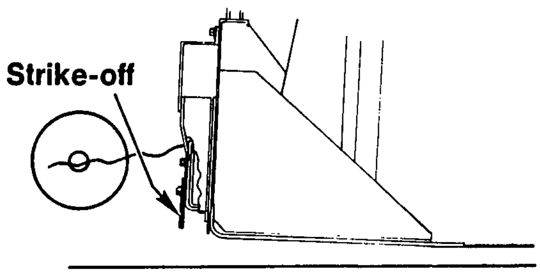
Screed Strike-offs

Depending on the make of the paver, the screed may be equipped with a device on its front edge that is called a strike-off by some manufacturers and a prestrike-off by others. The purpose of this device is to control the feed of the asphalt mix under the paver screed, thereby regulating the amount of mix that reaches the nose of the screed plate. Further, the strike-off or prestrike-off is used to reduce the wear on the leading edge of the screed. The location of the strike-off assembly is shown in Figure 3-38.

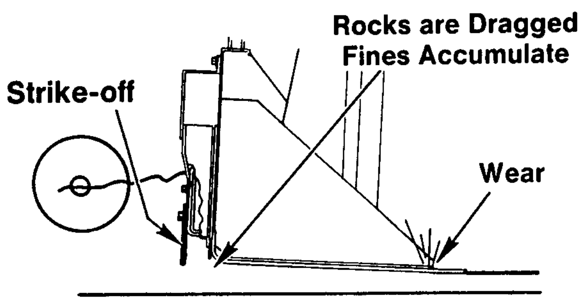
When the strike-off is attached to the front of the screed, its position becomes important relative to the ability of the screed to handle the asphalt mix properly. If the strike-off is set too high, as shown in this same figure, extra material will be fed under the screed. This action will cause the screed to rise. The resulting increase in the mat thickness will be overcome by manually reducing the angle of attack of the screed, using the thickness-control cranks. This, in turn, will cause the screed to pivot around its hinge point and ride on its nose. Rapid wear of the nose plate will result. In addition, the screed will settle when the paver is stopped between truckloads of mix because the weight of the screed is carried only on the front part of the screed.

When the strike-off is set too low, as shown in Figure 3-38, the thickness of the lift will be reduced because of the lack of mix being fed under the screed. In order to maintain the proper thickness, the angle of attack of the screed must be altered, causing the screed to ride on its tail. This increases the wear on the back of the screed and also causes the screed to settle whenever the paver is stopped because of the concentration of weight of the screed on a smaller surface area.

The exact location of the strike-off depends on the type of paver being used and on the depth of the layer being placed by the paver. For relatively thin layers of pavement (1 in. thick or less), the strike-off is usually placed lower than when thicker lifts of mix are being placed. Similarly, for thick lifts of asphalt pavement (greater than 2 in.), the strike-off assembly is usually raised slightly above the normal position. In general, the strike-off is located in the range of 3/16 in. to 1/2 in. above the bottom plane of the main screed plate. No compaction of the mix occurs under the strike-off.



Strike-off Positioned Properly



Strike-off Positioned Too Low

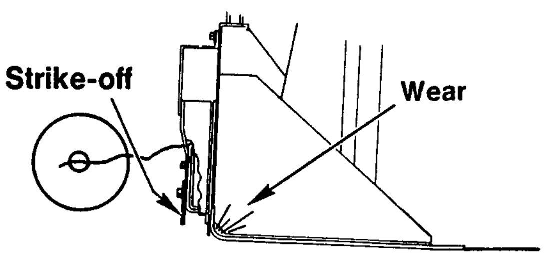


Figure 3-38. Strike-off position *(Cedarapids).*

Screed Heaters

The screed is equipped with heaters or burners, the primary purpose of which is to increase the temperature of a cold bottom screed plate to approximately 300°F. It is necessary for the screed to be at the same temperature as the asphalt material passing under it in order to assure that the mix does not stick to the screed plate and tear, providing a rough texture to the mat. A properly heated screed, particularly at the start of the day's paving operations or after any extended shutdown of the laydown process, provides for a more uniform mat surface texture.

To preheat the screed, the burners are normally operated for a period of 10 to 20 min before the commencement of the laydown operation. Care should be taken to avoid overheating, which can cause permanent warping of the screed. Usually within 10 min after paving begins, the temperature of the screed plate has increased to the point at which it can generally be maintained by the temperature of the mix passing under it. Thus, the burners are not needed and are shut off. The screed heaters cannot be used to increase the temperature of the mix being placed because the amount of time that the mix is actually under the screed is much too short to accomplish any temperature rise in the mix.

In cool weather, when the plant is cold, the haul trucks are cold, and the paver is cold, it is sometimes advantageous to place the second or third truckload of mix delivered to the paver first. This second or third load of mix is typically higher in temperature than is the first load and will serve to heat the paver more and reduce the amount of tearing that might occur under the screed. By placing the second or third truckload of mix first, two warm loads of mix are laid down instead of one cooler first load. This procedure can provide for a more uniform surface texture of the mix when paving must be accomplished in lower ambient temperatures.

Screed Crown Control

The screed on the paver can be angled at its center to provide for positive or negative crown. The amount of crown that can be introduced into the screed varies with the width of the basic screed and with the make and model of the equipment. The adjustment of the crown is typically done using a turnbuckle device to flex the bottom of the screed and impart the desired degree of crown. When rigid extensions are used in conjunction with the main or basic screed, the crown being placed in the pavement by the paver can usually also be altered at any of the points where the extensions are joined. If a hydraulically extendable screed is being used with the paver, the crown can be introduced not only in the center of the main screed but also at the points between the basic screed and the hydraulic extensions.

Most of the paver manufacturers recommend that the screed be warped slightly, from front to back in the center of the screed, to facilitate the passage of mix under the screed and to obtain a more uniform texture on the asphalt mat. This involves setting the lead crown on the screed slightly greater than the tail crown on the screed. In general, there should be more lead crown than tail crown, but the amount of difference depends on the make of paver and the type of screed on the machine. Normally the lead crown setting is 1/32 in. to 3/16 in. greater than the tail crown position, with 1/8 in. being the average difference in the crown settings.

Screed Vibrators

Early pavers were equipped with tamper bars that were located on the leading edge of the paver screed. These tamper bars were used to tuck the asphalt mix under the screed and to provide some degree of initial compaction to the mix as it passed under the screed. The tamper bar system was replaced by the more efficient vibratory screed system. A few of the most recent pavers (and many pavers used in other countries) are equipped with combination screeds--both tamper bars and a vibratory screed. The discussion below, however, is limited to pavers having vibratory screeds only.

The amount of compaction imparted to the asphalt mix is a function of many variables. The properties of the mix itself are very important; the stiffness of the mix, the temperature of the mix, and the amount of asphalt cement and moisture in the mix all affect the ability of the screed to densify the mix. Two factors within the screed itself also contribute to the degree of compaction. The first is the frequency of vibration and the second is the amplitude of the compactive effort.

The frequency of vibration is controlled by the rotary speed of the vibrator shaft. Increasing the revolutions per minute of the shaft will increase the frequency of the vibration. The applied amplitude is determined by the location of the eccentric weights that are located on the shaft. The position of the eccentric weights can be altered to increase or decrease the amount of compactive effort applied to the mix by the screed, as illustrated in Figures 3-39 and 3-40. In general, the vibrators should be used near the maximum possible frequency. On screeds where it is possible to change the amplitude of the applied vibrational force, the amplitude setting selected is related to the thickness of the mat being placed; lower amplitude for thinner lifts and higher amplitude for thicker lifts.

The amount of density obtained by the paver screed is also a function of the speed of the paver. The faster the paver moves, the less time the screed sits over any particular point in the new mat, and, thus, the amount of compactive effort applied by the screed decreases. For asphalt concrete mixes, it can be expected that approximately 70 to 80 percent of the theoretical maximum density of the mix will be realized in the mix when it passes out from under the paver screed.

Screed Extensions and End Plates

When the basic width of the paver screed (8 ft for small pavers and 10 ft for the larger machines) needs to be changed to accommodate increased paving widths, rigid screed extensions can be employed, as seen in Figures 3-41 and 3-42. These extensions come in several widths, usually 6-in., 1-ft, 2-ft, 3-ft, and 5-ft sections. In order to keep the paver in balance, the width of the rigid extensions added to the paver screed should be approximately equal on both sides of the machine, if possible.

It is important for the screed extension to be attached securely to the main screed. Further, it is very important that the extension be set at the same elevation

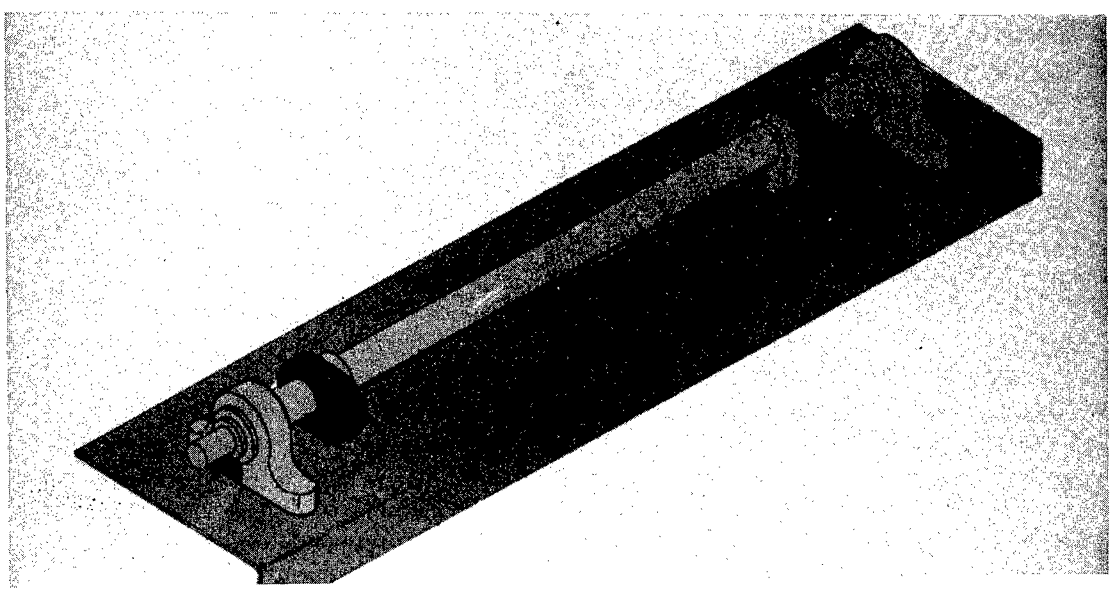


Figure 3-39. Screed vibrator shaft with weights *(Blaw-Knox)*.

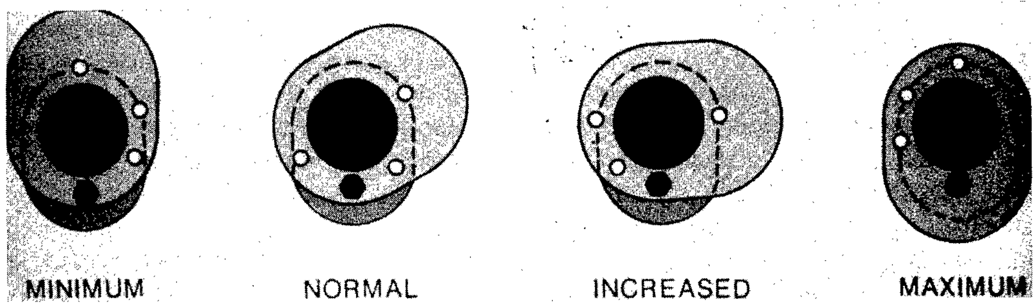


Figure 3-40. Eccentric-weight positions *(Blaw-Knox)*.

and angle as the basic screed to prevent the presence of a transition line or ridge at the intersection of the main screed and the extension or between different sections of extension. Alignment of the front edge of the extension is typically controlled independently of the alignment of the rear edge of the extension.

Whenever a rigid screed extension is employed on the basic paver screed, auger extensions and the accompanying auger tunnel extensions should also be added. The length of all the auger and tunnel extensions should, in general, be the same length as the added screed extensions to allow room between the end of the auger and the end plate of the screed. Typically the distance between the end of the auger extension and the end plate should be about 18 in. Further, whenever rigid screed extensions are employed, the strike-off or pre-strike-off assembly must also be added to the extension, and set at the same location as the strike-off on the main screed.

An end plate (or end gate or edger plate) is attached to the end of the screed to restrict the outward movement of the mix around the end of the screed, as shown in Figure 3-43. The vertical alignment of the end gate is adjustable so that mix can be bled out from under the gate if necessary. In typical operating mode, however, the end plate is positioned tight to the surface being paved to retain the mix and control the width of material being placed.

Cutoff shoes can be used, if necessary, to reduce the width of mix placed to a width that is less than the basic

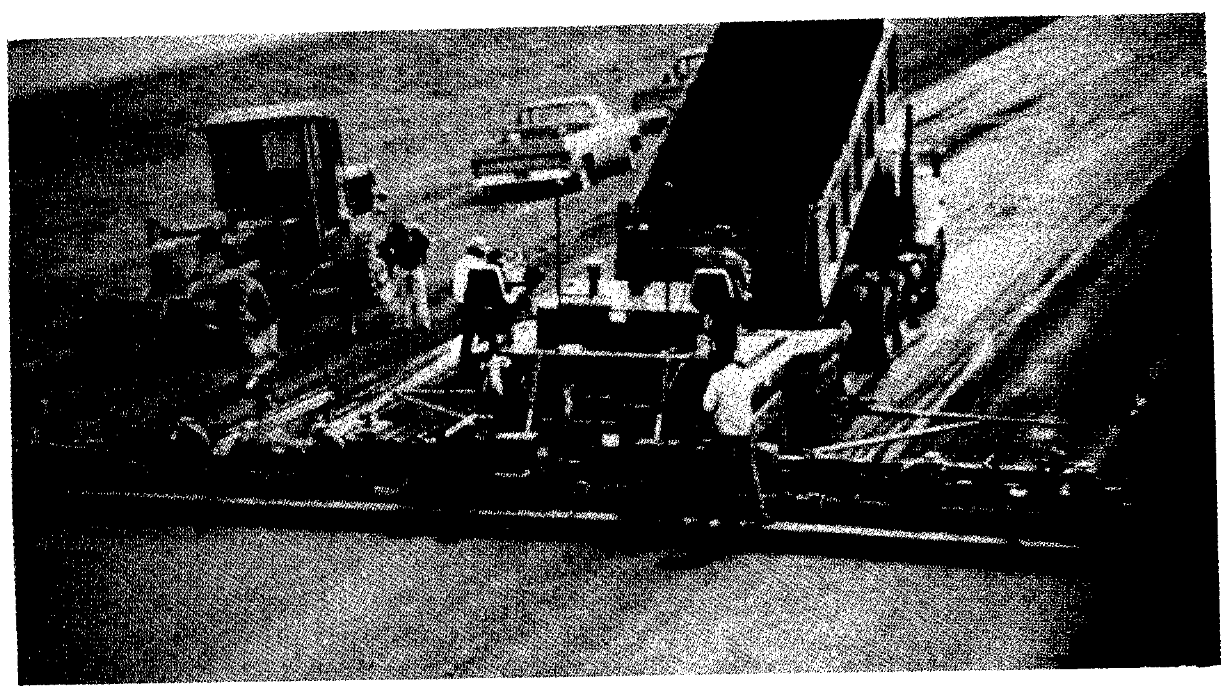


Figure 3-41. Rigid screed extensions *(J. Scherocman)*.

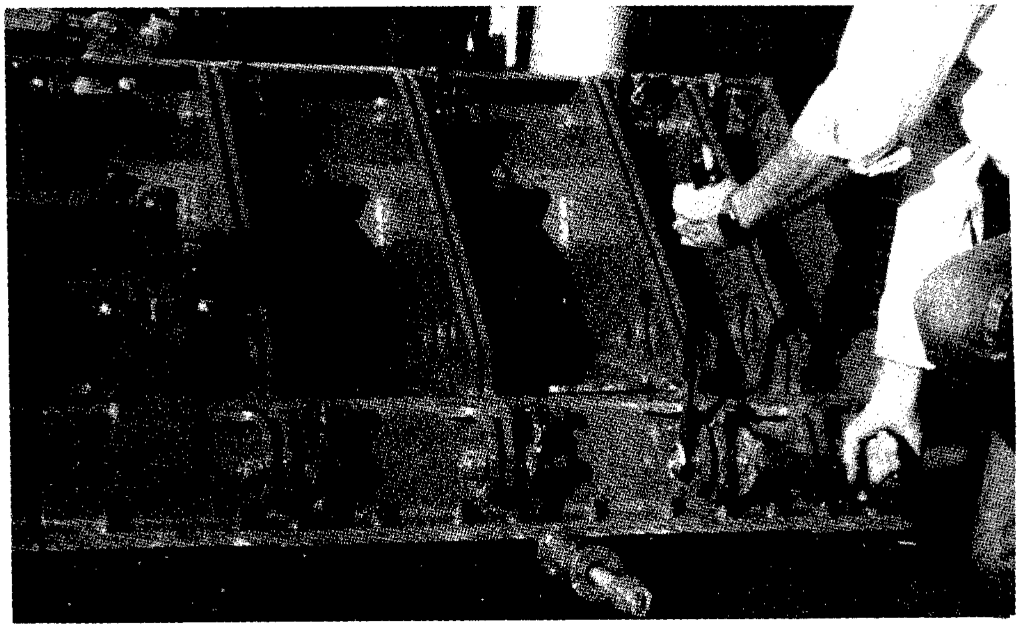


Figure 3-42. Rigid screed extensions *(Blaw-Knox)*.

main screed width. As illustrated in Figure 3-44, the standard cutoff shoes are attached to the paver end gate and are employed to restrict the width of mix being laid between the end plates. Typically the cutoff shoes come in widths of 1 ft or 2 ft, and are adjustable in increments of 1 1/2 in. or 3 in., depending on the manufacturer.

Hydraulically Extendable Screeds

Most paver manufacturers have developed hydraulically extendable paver screeds that trail the primary or basic screed on the paver. One make of pavers, however, is equipped with a power extendable screed that places the extendable portion of the screed in front of the main screed. An example of each type of extendable screed is shown in Figures 3-45 and 3-46.

For all hydraulically extendable screeds, it is very important that the angle of attack for the extendable screeds (one on each side of the main screed) is the same as the basic screed (see Figure 3-47). On some makes and models of pavers, it may be necessary for the trailing (rear) screeds to have a slightly positive attack angle compared with the main screed. In general, however, the forces that act on the extendable screed are similar to those that are present on the main paver screed. Further, if a strike-off assembly is used on the main screed, similar strike-off devices should be used on the extendable screed sections.

If the extensions on the extendable portion of the screed are not properly aligned with the main screed, a longitudinal mark or ridge will occur in the surface of the mix at the junction between the two screeds. This mark can easily be eliminated by adjusting the elevation of the extendable screed in relation to the main screed. In addition to the longitudinal mark, a mismatch in the elevation between the two screeds can also result in a possible difference in surface texture in the mix behind the extended screed and the main screed. Finally, the lack of proper alignment between the two screeds can cause a difference in the degree of compaction that is obtained in the mix under the extendable screed.

If a hydraulically extendable screed is to be used at a fixed extended width for a period of time, the paver should be equipped with auger extensions equal to the

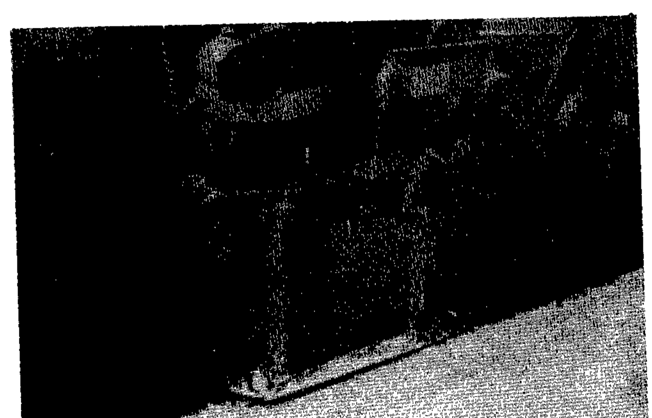


Figure 3-43. End plate *(Blaw-Knox)*.

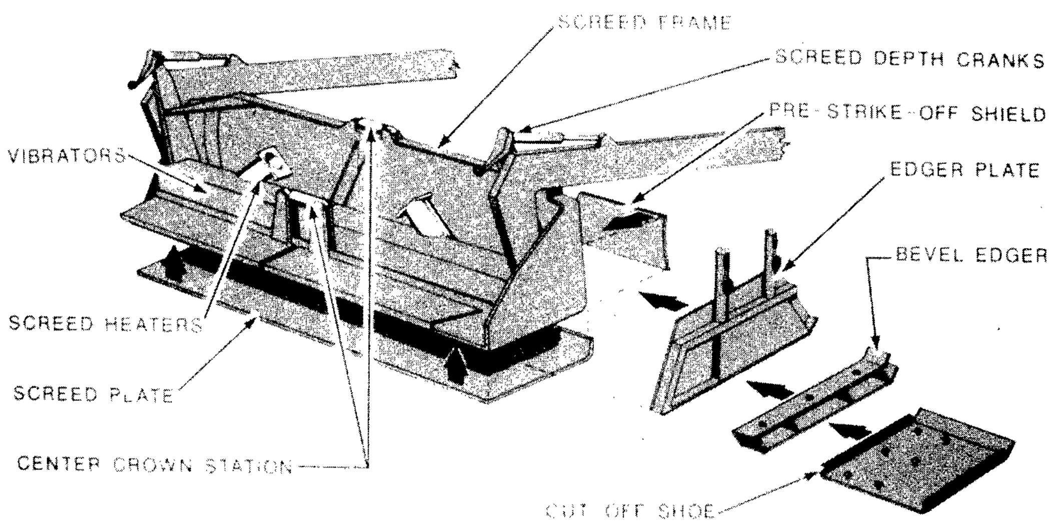


Figure 3-44. Screed components *(Blaw-Knox)*.

width of the extended screed (and ending approximately 18 in. from the end plate). The use of the auger extensions will enhance the distribution of the asphalt mix across the width being paved and help keep a constant head of material pushing on the whole width of the screed. Further, auger tunnel extensions should also be added to the paver.

If a hydraulically extendable screed is to be employed at variable widths with the width being paved changing frequently, some paver manufacturers recommend that the machinery be equipped with kick out paddles or augers at the end of the main auger. This particular device helps push the mix out to the end of the extendable screed and keeps the head of material in front of

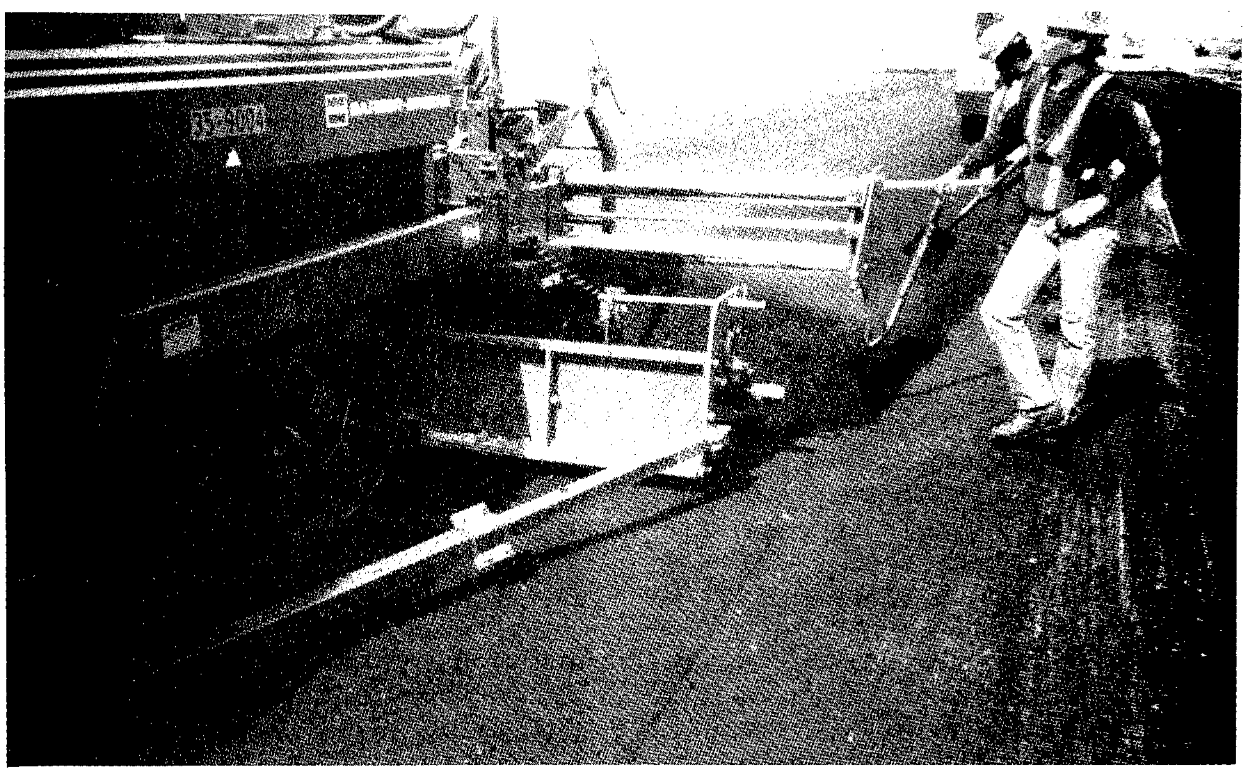


Figure 3-45. Rear-mounted extendable screed *(J. Scherocman)*.

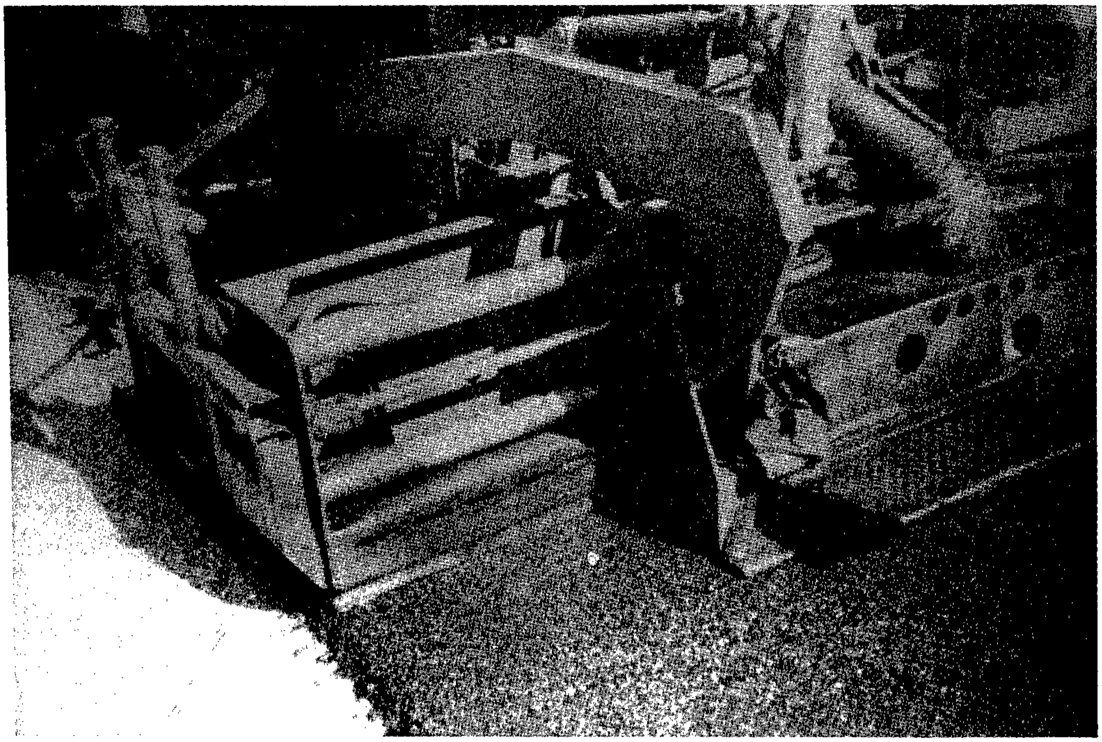


Figure 3-46. Front-mounted extendable screed *(J. Scherocman)*.

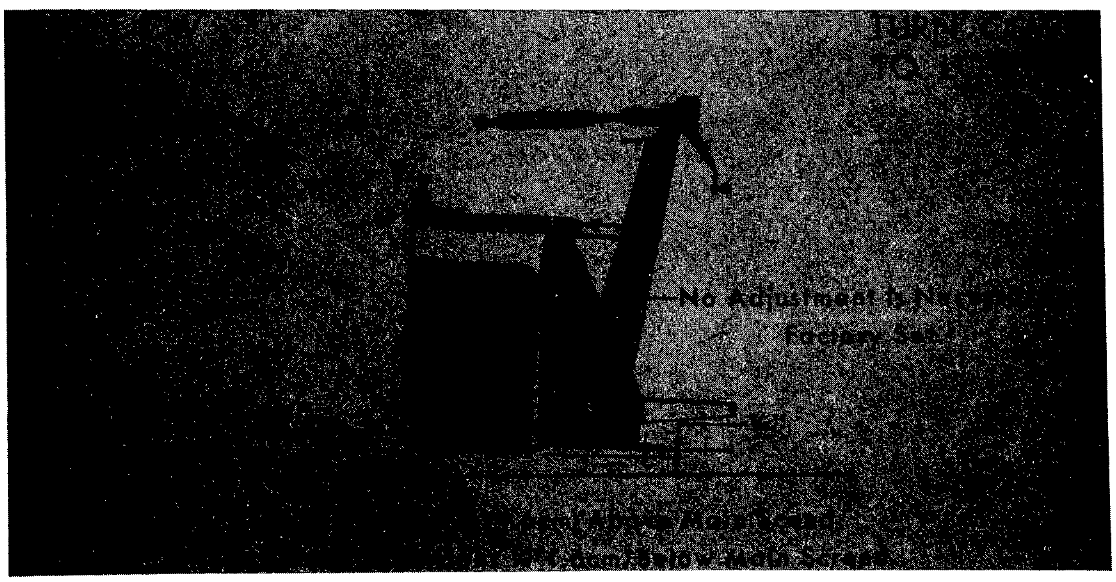


Figure 3-47. Angle of attack on extendable screed *(Blaw-Knox)*.

the screed as constant as possible. Some pavers may be equipped with augers that extend automatically as the screed is extended. For either of these procedures, the material feed sensors should be mounted on the end gate of the screed to assure that an adequate amount of material is delivered to the outside edge of the screed.

MIX PLACEMENT TECHNIQUES

When standing next to an asphalt paver, there are several key operating techniques that should be observed to determine whether the paver is operating properly. Those items are:

- If the mix is being delivered by a haul truck that dumps mix directly into the paver hopper, the truck should stop short of the paver. The paver should be moving forward when it comes in contact with the truck; the paver should pick up the truck instead of the truck backing into the paver. This procedure will eliminate indentations of the screed in the mix if the truck were to hit the paver.

- Before the tailgate on the haul truck is opened to deliver mix to the paver hopper, the truck bed should slowly be raised in the air until the mix in the truck bed begins to slide against the tailgate. This procedure will allow the mix to flood the paver hopper when the tailgate is opened and will reduce the amount of segregation that appears behind the screed. If the tailgate-opening lever cannot be reached when the truck bed is raised, it should be modified to allow for operation from ground level when the bed is raised.

- If a windrow elevator is used to gather mix from a windrow on the roadway and deliver the mix to the paver hopper, the slat conveyor should pick up all of the mix that is in the windrow without leaving any mix on the existing surface.

- The windrow should be sized so that the hopper on the paver is from 25 percent to 75 percent full. The paver hopper should contain enough mix so that the slat conveyors are not visible on the bottom of the hopper, and the hopper should not be so full that mix runs out the front of the hopper.

- When a truck has completed delivery of mix and pulls away from the paver, the paver should be stopped as quickly and smoothly as possible without jerking the paver. Enough mix should remain in the paver hopper to be at least at the level of the bottom of the flow gates. In no case should the hopper be emptied to the point that the slat conveyors at the bottom of the hopper are visible. The slat conveyors also should not be visible when a windrow elevator or a material transfer device is used to deliver mix to the paver hopper.

- When the paver is stopped to allow the next truckload of mix to move into position, the wings on the paver can be folded, but only when necessary to prevent buildup of cold mix in the hopper corners. The wings should not repeatedly be banged as they are emptied. The wings should be dumped into a relatively full paver hopper; the slat conveyors should not be visible at the time the wings are emptied. Dumping the wings into a relatively full hopper may result in some mix spilling out of the front of the hopper; rubber flaps should be used to contain as much mix as possible.

- Once the new truckload of mix has begun to be emptied into the half-full hopper, the paver should be brought up to paving speed as quickly as feasible and operated at a constant speed in proportion to the amount of mix being delivered from the plant. This will keep the head of material in front of the screed as constant as possible.

- The paver should not be operated at a slow speed while the truck exchange is being completed. When the paver continues to move forward while one truck is leaving and the second truck is moving into position, the amount of mix in the hopper will be drawn down, possibly to the point that the hopper is emptied. This procedure will cause the amount of mix at the augers to be reduced, in turn also causing the screed to fall and the thickness of the mat to decrease. The reduction in the speed of the paver, from normal paving speed to crawl speed between truckloads, will also change the forces acting on the screed, further altering the thickness of the asphalt layer. In addition, when the newly delivered mix is emptied into the hopper and is pulled back to the augers by the slat conveyors, the large amount of mix (head of material) against the screed will cause the screed to rise, increasing the thickness of the mat. Thus, slowing the paver between truckloads of mix while emptying the hopper causes significant changes in the forces acting on the screed and accompanying changes in the thickness of the layer being constructed.

- The flow gates on each side of the machine on the back of the paver hopper should be set at a height to permit the slat conveyor and corresponding auger to operate as close to 100 percent of the time as possible. The key to a smooth layer of mix is a constant head of material in front of the screed. The key to a constant head of material is a constant paver speed and continuous operation of the paver augers, with a good rule of thumb being that the amount of material in front of the screed should be located near the center of the auger shaft.

- If the paver is equipped with automatic flow-control devices, the flow-control equipment should be set at a location near the end plate in order to maintain a constant head of mix in front of the screed by causing the auger to run continuously. The location of the device is important to prevent too much or too little mix from being carried at the outside edge of the screed.

- If the paver screed is being operated under manual control, the screed operator should not change the angle of attack of the screed by turning the thickness-control cranks except to increase or decrease the thickness of layer being placed. After the controls are turned, it takes five times the length of the tow arm on the paver before the screed completes the input change in thickness. If the paver is being operated under automatic grade and slope control, the screed operator should not attempt to change the angle of attack of the screed by turning the thickness-control cranks. The automatic controls, if they are mounted in the proper position, will simply correct any changes made in the angle of attack of the screed by changing the position of the tow point where the screed is attached to the tractor in order to reestablish the original angle of the screed.

SECTION FOUR
AUTOMATIC SCREED CONTROLS

INTRODUCTION

The screed unit on the paver is attached to the tractor unit at only one point on each side of the paver: the pull or tow point. As the tractor follows the grade of the existing pavement surface with the rubber tires or crawler tracks, the length of the wheelbase of the paver becomes the reference for the screed. Because of the reaction time of the screed, as discussed in the previous section, the screed will react more slowly to changes in grade than will the tractor. Thus, under manual screed control, the screed will average out deviations in the roughness of the present pavement layer, placing more mix in the low spots and less mix over the high points in the underlying pavement.

Automatic screed controls are employed to keep the elevation of the tow points on the paver at a more constant elevation relative to the reference being used. Deviations in the pavement surface are averaged out over the length of the reference (either a preset string-line or a long mobile ski). As the tractor unit moves up and down over the existing grade, the elevation of the tow point moves over a smaller range of elevations than if the relatively short wheelbase of the tractor provided the reference. Keeping the elevation of the tow points constant permits the screed to maintain a more consistent angle of attack. This provides for a smoother mat behind the screed.

Many factors, however, affect the smoothness of the mix placed by the paver. The use of automatic screed controls by themselves will not necessarily assure that the mat constructed will always be smooth. Proper attention to the operation of the paver, as discussed in the previous section, is extremely important is obtaining a smooth-riding pavement layer.

If the paver always moved over a level grade, the forces on the screed would be constant as long as the paver was moving at a constant speed. The towing force on the screed would be stable and the head of material in front of the screed would be consistent as long as the feed-control system was set to operate as much of the time (close to 100 percent) as possible. Under these conditions, a very smooth asphalt mat could be obtained from behind the paver without a screed operator ever changing the setting of the thickness-control cranks on the back of the screed. Indeed, once the angle of attack of the screed is set when the paver starts up in the morning, no changes would ever need to be made to the setting of the thickness-control handles.

In the real world, however, the tractor unit operates on a grade that is variable. As the elevation of the existing surface moves up and down, the wheelbase of the tractor unit (either crawler or rubber tire) follows that grade. This vertical movement of the tractor as it moves forward causes the elevation of the tow or pull point on the tractor to change in direct relation to the movement of the tractor unit. As the location of the tow point is altered by the movement of the tractor, the angle of attack of the screed is changed.

If the elevation of the pull point is raised, the screed will be rotated upward at a ratio of 1:8 compared with the change in elevation of the tow point. As the paver moves forward a distance equal to at least five times the length of the leveling arm on the machine, the screed will float up to the new elevation and the asphalt mat will be thicker. If the tractor unit moves into a dip in the existing pavement surface, the elevation of the tow point will be lowered, reducing the angle of attack of the screed. If no other changes are made in the forces acting on the screed, the screed will move downward as the paver travels forward, lessening the thickness of the layer being placed.

The self-leveling action of the screed takes place continuously as the tractor unit travels over the roadway. The reaction of the screed to the location of the tow point, the speed of the tractor, and the head of material in the auger chamber determine the thickness of the mat being laid. This whole operation occurs without the thickness-control cranks on the screed ever being changed. The floating screed principle permits the paver to reduce the thickness of the mix placed on high points in the existing pavement surface and increase the depth of the material deposited in the low spots on the same surface.

If the thickness-control cranks or handles are turned by the screed operator, the screed will react to the change in setting (change its angle of attack) by rotating around the hinge or pivot point where it is attached to the leveling arm and thus to the tow point of the screed. As the paver moves forward, the screed will float up to or down to the new elevation. Similar to the change in elevation of the tow point on the leveling arm, however, the paver must travel forward a distance of at least five lengths of the leveling arm before the change in the depth of the mat is fully realized.

On many projects, particularly those involving the resurfacing of an existing pavement, the screed operator is forced by the job specifications to maintain a certain yield of asphalt mix per square yard or per station. It is not uncommon to watch a screed operator continually check the thickness of the mat being placed by the paver and then adjust the setting of the thickness-control cranks to increase or decrease the amount of mix being placed. This change in the setting of the thickness-control system is done without regard to the changes being made at the same time to the screed as the elevation of the tow point changes while the tractor unit moves forward over the variable grade.

Two inputs, then, are being introduced into the self-leveling system at the same time. The first input is the vertical movement of the tow point of the screed, which reacts to changes in the movement of the wheelbase of the paver. The second input is the manual changing of the thickness-control cranks by the screed operator. The input from the movement of the tow point and the input from the change in setting of the thickness-control device may be in the same direction as one another or they may be opposite to one another, even canceling each other out.

Under manual screed operation, the ability of the screed operator to produce a consistently smooth asphalt layer is dependent on a number of factors. The first is the frequency at which the operator feels the need to adjust the setting of the thickness-control cranks: The more the screed operator changes the angle of attack of the screed, the more uneven the resulting asphalt pavement will be. The second factor is the roughness of the existing pavement surface: The more the screed operator tries to assist the self-leveling action of the screed, the rougher the resulting pavement surface will be.

The third factor is the need to meet a certain maximum yield specification. It is usually not possible, particularly for thin courses, to produce a smooth pavement layer and stay within a certain volume of material usage at the same time. This is particularly true if a minimum overlay thickness is specified at the same time as the yield criteria are to be met. This problem is discussed later in this section.

The fourth factor is related to the need of the screed operator to match the elevation of the longitudinal joint in the adjacent lane. As paving speeds have increased because of greater plant production rates, it has become more difficult manually to maintain the level of the new mat relative to the adjacent mat.

Finally, when it is desired to produce a constant cross-slope across the width of the lane being paved, automatic grade and slope devices can be employed to control the elevation of the tow points of the screed on both sides of the paver at the same time. This is very difficult to do manually, even with two very experienced screed operators. Grade control can be used on both sides of the machine, or, more commonly, on one side of the paver, with slope control used on the other side.

AUTOMATIC SCREED CONTROLS

The primary purpose of automatic screed controls is to produce a smoother asphalt pavement layer; smoother than the paver can accomplish by itself and smoother than a screed operator can accomplish by continually changing the setting of the thickness-control cranks.

The automatic screed control functions by maintaining the elevation of the screed tow points in relation to a reference other than that of the wheelbase of the paver itself. Figure 3-48 illustrates the automatic grade and slope control system for one particular make of paver.

The elevation of the tow point is kept at a constant elevation in relation to a given grade reference. The automatic system does not permit the relative position of the tow or pull point to change even though the tractor unit is moving up and down vertically in response to the roughness of the surface over which it is traveling. Thus, by maintaining the tow point at a constant elevation, the angle of attack of the screed is also maintained at a constant setting. This allows the screed to ride at a consistent angle, permitting the screed to do an even better job of reducing the quantity of mix placed over the high spots in the existing pavement surface and increasing the amount of mix laid in the low spots. The principles of the automatic screed control system are shown in Figure 3-49.

Before the automatic screed control is engaged, the screed should be nulled (angle of attack set in flat position) before paving starts and the proper angle of attack should be set for the screed.

If automatic controls are being used on the paver, the screed operator should not try to change the angle of attack of the screed manually by turning the thickness-control cranks. If this is done while the machine is moving, the automatic grade and slope controls will attempt to compensate for the manual input by changing the elevation of the tow point. Manual input will be needed, however, if the tow point actuator has reached the limit of its travel--the tow point hydraulic ram is at its upper or lower limit. In this case the paver should be

HOW THE SYSTEM WORKS
The grade control unit sensor follows an erected stringline. mobile reference, adjacent mat or other suitable reference and controls the edge of the screed on the side of the paver on which it is operating. The other side of the machine can be controlled manually through the thickness control screws, by another grade controller sensing to a reference or by a slope controller.

Since the system is "nulled out" or "zeroed in" before startup, the desired relationship is maintained by the hydraulic cylinder at the tow point on the grade controller side. As corrections are required to keep the screed on grade, the tow point is automatically adjusted to compensate for variations.

Once properly set, the slope controller accurately maintains slope automatically across the full width of the screed (± ⅛" [3.18 mm] in 24' [7.32 m]). Any deviation from slope is sensed by the controller and the appropriate correction is made at the tow point. Like the grade controller, the slope control is a proportional unit. A remote set dial allows the screed operator to change slope while the machine is paving as required by job specifications.

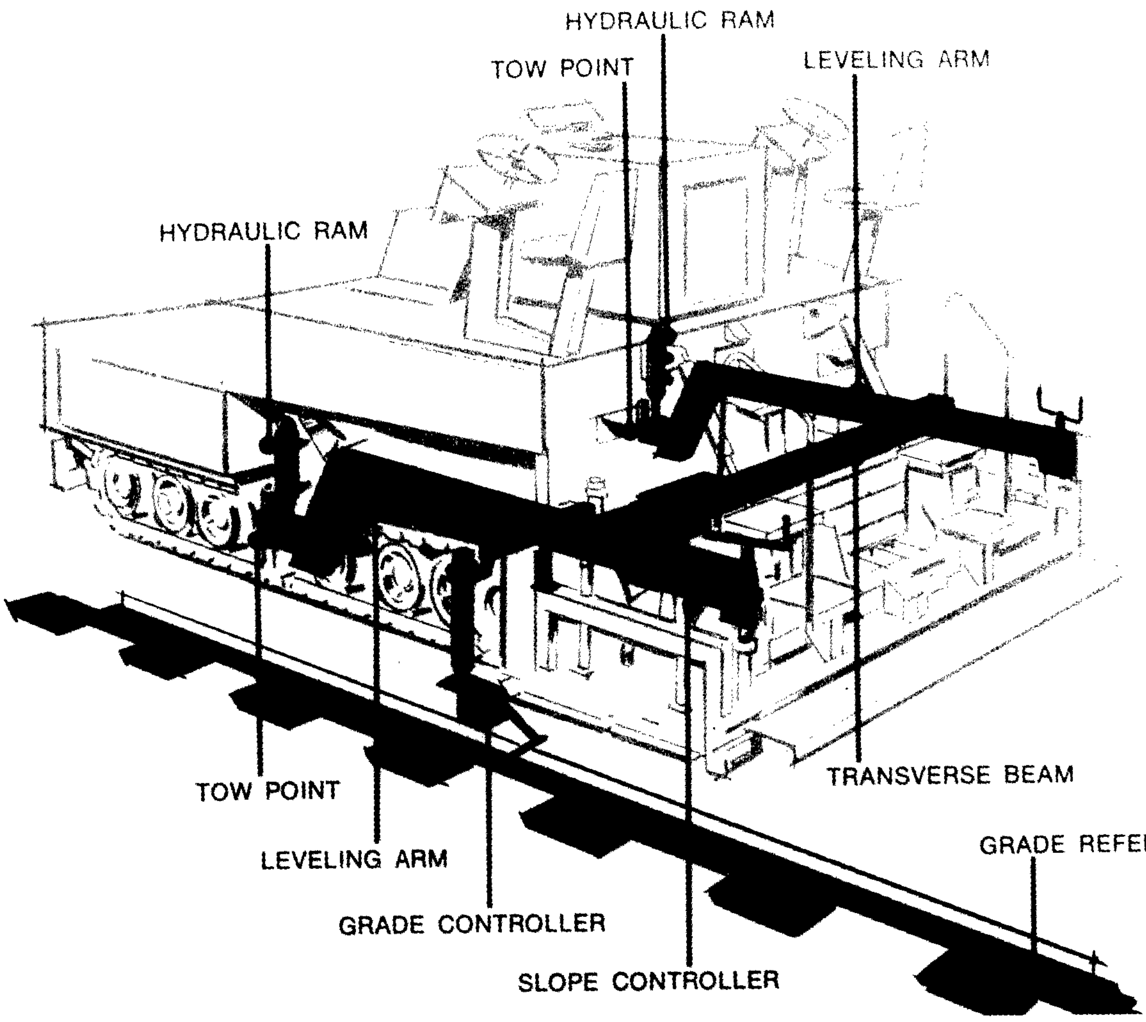


Figure 3-48. Automatic grade and slope control *(Barber-Greene)*.

stopped and the tow arm reset at the centerpoint of its travel. The screed should be nulled, the proper angle of attack input to the screed, and paving restarted again.

In addition, when a superelevated curve is being paved that requires a change from the existing cross-slope, it is necessary to run the grade sensor on one side of the paver automatically and the slope sensor on the other side of the paver manually. This process will permit changes to be made in the amount of superelevation and provide the required degree of cross-slope.

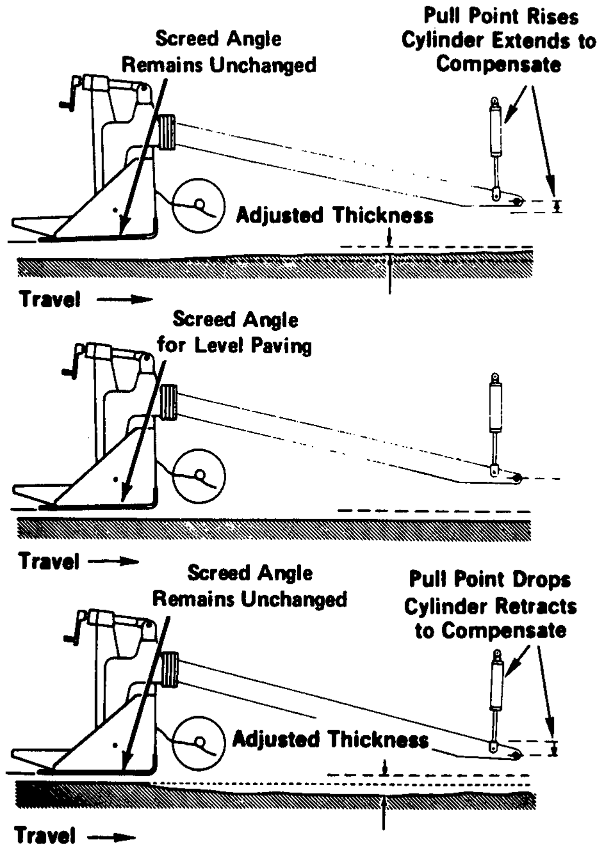


Figure 3-49. Principle of automatic screed control *(Cedarapids)*.

GRADE CONTROL

Types of Grade References

Grade sensors are used to monitor the elevation of the existing pavement surface in a longitudinal direction. There are three basic types of grade references that can be employed to maintain the elevation of the screed tow point: (a) the erected stringline, (b) the mobile reference, and (c) the joint matching shoe.

Each type of grade control can be used alone on either side of the paver. Grade sensors can also be employed on both sides of the paver at the same time. This use of the references will average out the variations in the grade of the existing pavement surface on both sides of the lane being paved. The same type of grade reference can be used on both sides of the machine or a different type of grade reference can be mounted on each side of the paver; a preset stringline on one side and a mobile reference on the other side, for example. Use of double grade references generally will not produce a uniform cross-slope for the new asphalt layer except if a preset stringline is used on both sides of the laydown machine. When a grade reference is used in conjunction with a slope-control device, the grade sensor is typically positioned on the centerline side of the paver, with the slope controller determining the depth of the mat on the outside edge of the pavement.

Erected Stringline

Theoretically, the use of an erected stringline, shown in Figure 3-50, should allow for the smoothest possible asphalt mat behind the paver screed. This method of supplying an elevation input provides the most consistent reference for the paver tow point. Thus, its principal advantage is that a predetermined grade can be matched very accurately if the controls are used properly.

Laser technology has been used successfully on a number of paving projects. Additional care must be exercised when using this equipment.

Practically, however, the use of the erected stringline has a number of drawbacks that may offset the theoretical increase in smoothness obtained by its use. The elevation of the erected stringline must be set by a

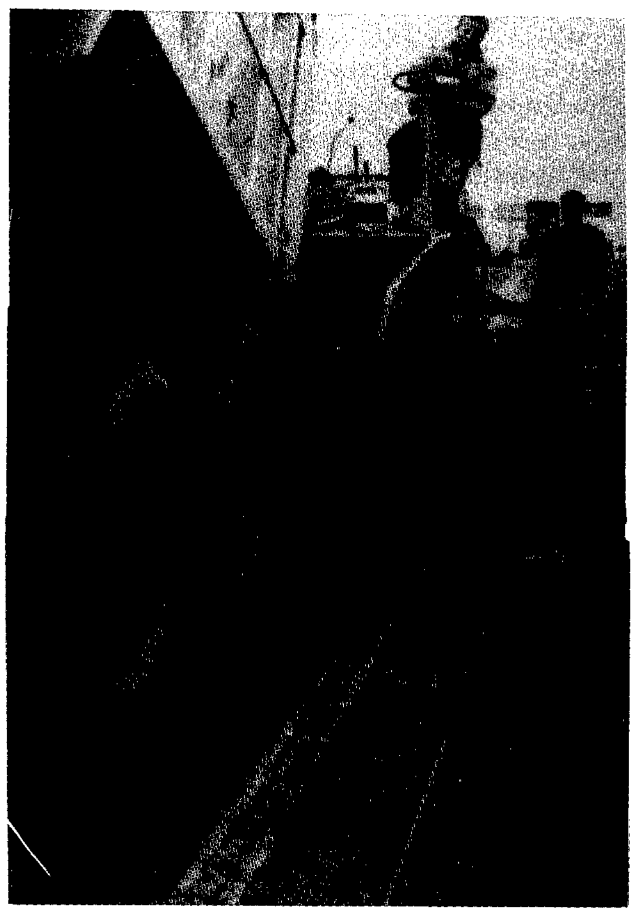


Figure 3-50. Erected stringline reference *(Barber-Greene)*.

surveying crew. The accuracy of the elevation of the line and resulting pavement smoothness is directly dependent on the care taken in its erection. If the grade set by the surveyors is incorrect in any way, the paver screed will duplicate that error in the pavement surface. On horizontal curves, it is very difficult to use an erected stringline to control the grade of the new pavement layer. The string cannot be set in a curve, and therefore a series of chords must be used around the radius of the curve. This, in turn, requires the positioning of a large number of support posts and rods, usually at 5-to-20-ft intervals, around the curve. The surveying done to set the stringline must be accurate in order to prevent a misalignment of string and the setting of the wrong grade reference for the paver.

The stringline must be very taut when it is set. Typically, the string is supported at 25-ft intervals on metal posts and rods. The string is anchored at one end of its length and then pulled tight and anchored at its other end. It is extremely important that the string be stretched very taut, without any dips or sags in the line between the support rods. If the string is not stretched tightly, the sensor wand on the paver, which can run either on the top or below the stringline, will react to the sags in the line and duplicate those sags in the new pavement surface. Even when high-strength line (greater than 100 lb tensile strength) is used, it is not always possible to keep the line tight enough to prevent some small sags from occurring between the support posts.

Another disadvantage of the erected stringline is the fact that the haul trucks and all paving personnel must keep away from the line and not disturb it in any way. Once the line is set at the proper elevation, it is imperative that the line remain untouched both before and after the paver sensor passes over the line. Any change in the elevation of the line caused by someone hitting the line or a truck backing into the line will result in a change in the input to the grade sensor and movement of the pull point on the paver leveling arm.

With a properly set and maintained stringline, the mat placed by a paver equipped with automatic screed controls can be very smooth and at the correct elevation. This is primarily because of the extended length of the reference being used compared to the more limited length of a mobile reference. Unless smoothness, or compliance with a predetermined grade reference, is an extremely important criterion on a paving project, however, it is questionable that the added price of erecting and maintaining the stringline is cost-effective for the typical hot-mix asphalt highway-paving job. Thus, for the vast majority of the highway-paving projects, an erected stringline is not used. For airport runway paving, however, the use of a stringline may be cost-effective in providing a smooth-riding pavement, proper lateral drainage, and the correct elevation of the overlay in relation to abutting pavement structures.

Mobile References

Different paver manufacturers use different types of mobile reference devices to extend the relative wheelbase for the automatic screed-control system. The operation of these reference systems, however, is essentially the same. The purpose of the mobile reference is to average the deviations in the existing pavement surface out over a distance that is greater than the wheelbase of the tractor unit itself.

One paver manufacturer offers two different versions of a mobile reference or ski. They both employ a semirigid tubular grade reference (pipe) that is 20, 30, or 40 ft in length, as seen in Figure 3-51. For one version, the pipe or tube rides directly on the existing pavement surface. A spring-loaded wire is stretched between the quarter points of the ski, on top of the pipe. The grade sensor that inputs the electrical signal to the paver tow point rides on top of the wire. As the pipe moves up and down (and flexes) over the existing grade, the stretched wire on the ski is used to average out the differences in elevation that occur under the mobile reference.

The second variation employs the same semi-rigid tubular grade reference pipe with the spring-loaded wire, but it is equipped with numerous spring-loaded wheel assemblies attached to the pipe at 2 1/2-ft intervals. This version is similar to a floating beam.

Another paver manufacturer provides a different type of mobile reference, termed a floating beam. A series of feet or shoes are attached to the bottom of the floating beam, as shown in Figure 3-52. The purpose of the shoes is to allow one or more of the feet to pass over a singular high or low point in the existing pavement surface without altering the slope of the whole beam. The feet are spring loaded (see Figure 3-53) to allow them to be deflected by a large stone on the pavement surface, for example, without pushing the whole beam upward. The grade sensor usually rides directly on the beam at its midpoint. As with the other types of mobile references, this floating-beam system averages out the variation of the existing grade over a 30- or 40-ft distance.

A third paver distributor also supplies a floating-beam type of mobile reference system. The beam is normally 30 or 40 ft in length. Instead of multiple feet

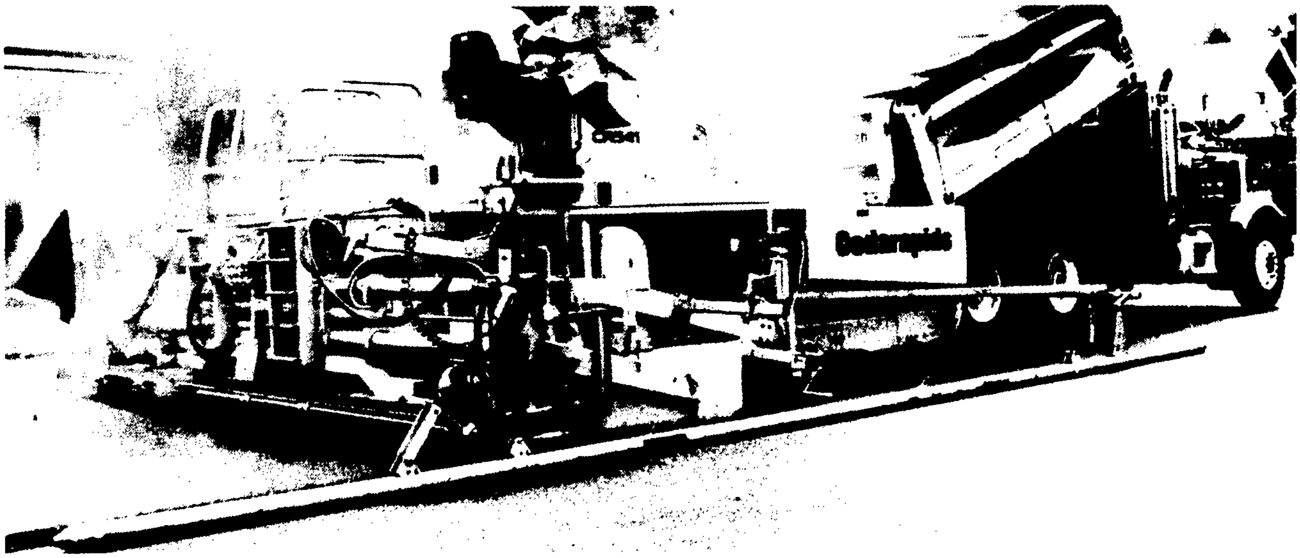


Figure 3-51. Tubular grade reference *(Cedarapids)*.

spread out along the length of the beam, however, a series of shoes is placed at each end of the beam (Figure 3-54). These shoes are allowed to rotate and can be individually displaced by isolated disruptions in the existing pavement surface without changing the height of the whole beam. This allows the beam to average the grade of that surface over the length of the reference without being influenced by the presence of a single high point or dip in that surface. As for the other mobile reference systems, the grade sensor is located in the center of the length of the beam.

Of the three types of mobile reference devices described above, the floating-beam type reference that uses multiple feet or shoes typically results in a smoother pavement compared with the mat placed with the rigid tubular grade-control device. The beam will typically provide a reference for the paver that will ignore isolated deviations in grade (a rock on the roadway) and provide a smoother layer behind the paver. Further, the longer the grade reference used, within reason, the better the paver will average out variations in the elevation of the existing pavement surface. A mobile

Figure 3-52. Floating-beam grade reference *(J. Scherocman)*.

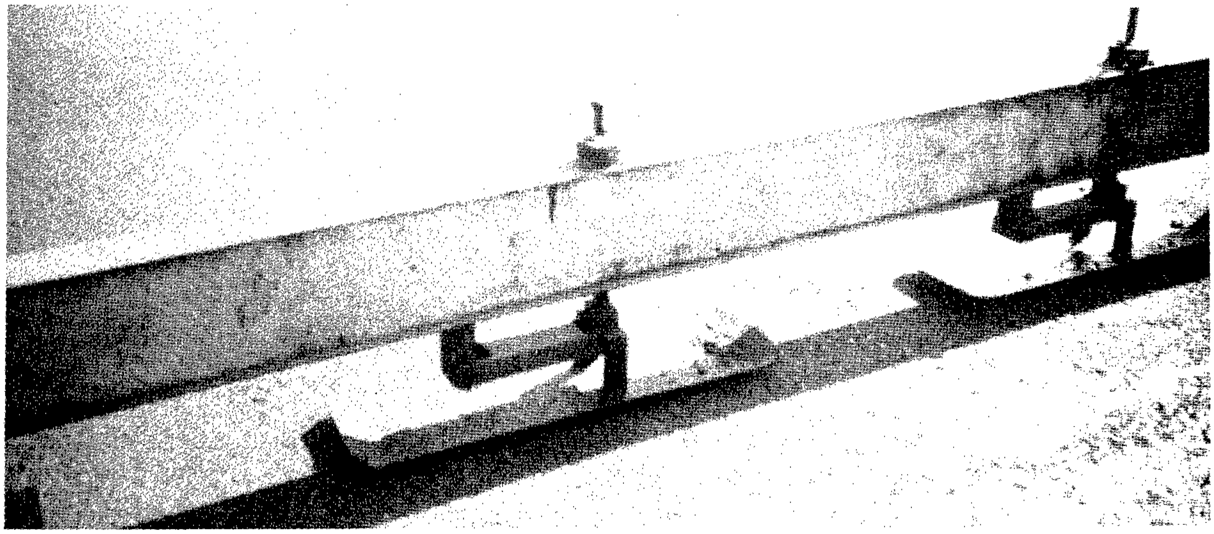


Figure 3-53. Spring-loaded shoe on mobile grade reference *(J. Scherocman)*.

reference will not, however, assure that the mix being placed will be at the proper elevation; the elevation is controlled by the elevation of the underlying pavement surface.

As shown in Figure 3-55, one paver manufacturer has produced a mobile reference ski that is 55 ft in length from front to back. Part of the reference beam is located in front of the paver screed. This is basically a floating-beam-type system, equipped with a series of spring-loaded shoes. This portion of the reference system senses the grade of the existing pavement surface. To the rear of the screed, riding on a series of spring-loaded wheels, is another floating beam that is used to reference the grade of the newly placed asphalt mix. A set of intermediate bridge beams, which go up and over the screed, are used to join the two parts of the floating beam together. The grade sensor rides on one of the intermediate bridge beams and transmits the average grade of the front and back beam to the paver tow point to control its elevation. This device may not be practi-

Figure 3-54. Different make of mobile grade reference *(J. Scherocman)*.

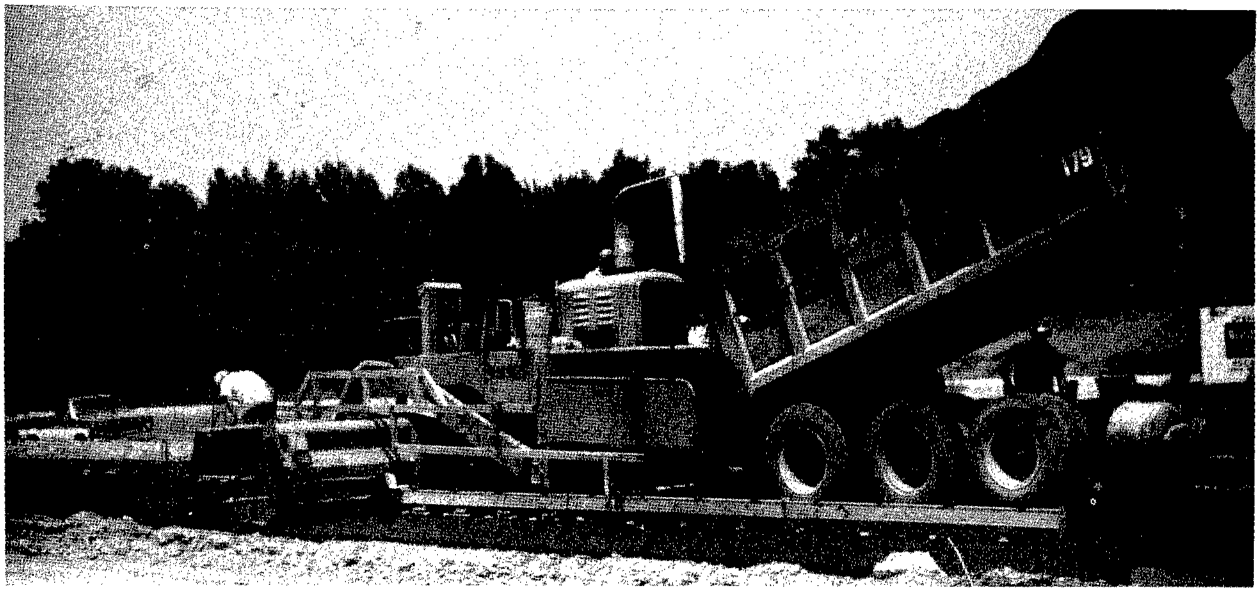


Figure 3-55. Over the screed mobile grade reference *(J. Scherocman)*.

cal, however, in hilly terrain or on a pavement that has a great number of vertical curves.

Joint Matching Shoe

The third type of reference is the joint matching shoe, which is shown in Figure 3-56. This device consists of a short (approximately 1-ft-long) shoe or ski that is used to reference the grade of an adjacent piece of pavement or curb. This type of mobile reference is used only when the grade being sensed is relatively smooth. The shoe rotates around its own pivot point and supplies an input signal to the paver tow point when the shoe or ski is displaced (see Figure 3-57). The shoe should be checked to assure that it is free to rotate properly.

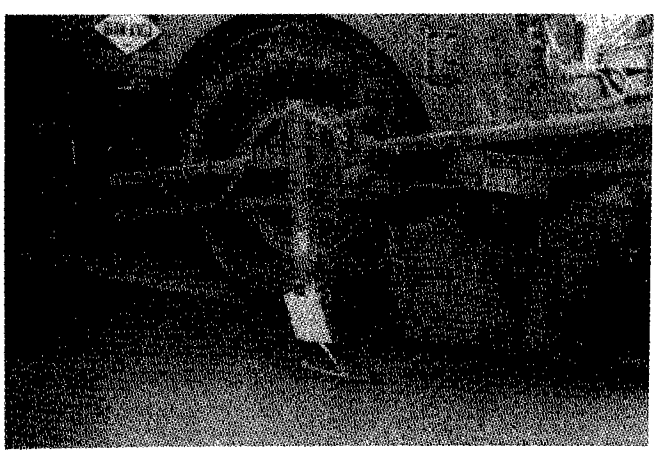


Figure 3-56. Joint matching shoe grade reference *(Blaw-Knox)*.

Because of its short length, the joint matching shoe will not remove any major variations that occur in the pavement surface. Indeed, the purpose of the shoe is to duplicate the grade of the adjacent surface. This grade-control device should be used with caution because pebbles, rocks, and other obstructions over which the shoe might ride will input grade changes into the screed tow point. When placing the second lane of a base course or a binder course layer, it may be better to use a longer mobile reference (a 30-ft-long ski) instead of the joint matching shoe. The mobile reference will provide the input needed to construct a smoother pavement surface than will the joint matching shoe. For the surface course layer, however, the joint matching shoe may be used to assure that the elevation of the mix on both sides of the longitudinal joint is the same, although the use of a longer mobile reference is still better paving practice.

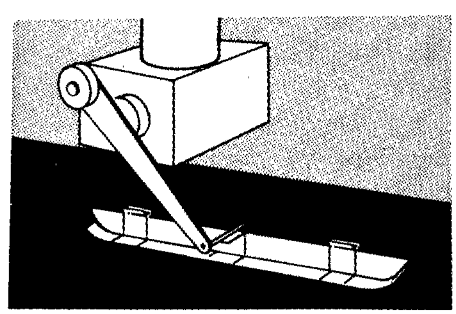


Figure 3-57. Joint matching shoe *(Barber-Greene)*.

Location of the Grade Reference

Different paver manufacturers have different recommendations for the placement of the grade reference-control sensors. Occasionally the grade sensor will be mounted adjacent to the tow point on the paver (Position 1), as seen in Figure 3-58. As also shown in this figure, the grade sensor is sometimes located at various positions (Positions 2 and 3) on the leveling arm. This side-mounting position typically is recommended when it is desired to correct long vertical deviations in the present pavement surface. When located on the leveling arm, the reaction time to changes in grade is short and the angle of attack of the screed is altered quickly. On some occasions, and particularly for wide-width paving, the grade sensor is mounted near or on the paver screed (Position 4). To function properly, the grade sensor must be located in front of the pivot or hinge point of the screed.

The location of the grade sensor makes a difference in the reaction of the tow point and the screed to the grade being sensed. There is no set rule that can be followed, however, as to the proper location to place the grade sensor. It is recommended, therefore, that the paver manufacturer's suggestions be followed for the particular make and model of paver being used. If no information is available about the suggested location for the sensor for a particular paving operation, it is recommended that the sensor be hung on the leveling arm, at a point between one-third and two-thirds of the length of the arm between the tow point and the screed.

The operation of the grade-control sensor should be checked regularly. The sensor wand should be lifted 1/32 in. when the machine is stopped and the movement of the tow point observed. Input to the sensor should result in a corresponding movement of the tow point. When the paver is moving, the up and down lights on the grade sensor should either blink occasionally or blink constantly but change in intensity, both top and bottom, to indicate that a signal is being sent to the tow point actuator. If the grade sensor uses a meter instead of lights, the reading on the meter should change when the sensor wand is moved as well as when the paver is placing mix on the roadway. In addition, the elevation of the tow point should change occasionally, depending on the amount of roughness of the existing pavement surface, in order for the angle of attack of the screed to remain constant as the tractor unit follows the underlying pavement grade. The change in elevation, however, should be smooth; the screed should not be moving up and down rapidly and constantly.

SLOPE CONTROL

In most cases, paving that is done with automatic screed controls is accomplished with a combination of grade control on one side of the paver and slope control to determine the grade on the other side of the machine. The slope control operates through a slope sensor that is located on a cross-beam between the two side arms of the screed. One side of the paver screed is controlled by the grade sensor. The other side of the screed is controlled by the slope controller, as shown in Figure 3-48.

When slope control is used, the thickness of the mat on the side of the machine (usually the outside edge of the roadway) that is controlled by the slope sensor could be variable in depth, depending on the condition of the existing pavement surface. The desired degree of cross-slope, shown in Figure 3-59, is dialed in to the slope controller, seen in Figure 3-60. This cross-slope is then regulated by a pendulum-type device that is part of the slope-control system. Without regard to the grade of the existing pavement, the slope controller maintains a constant cross-slope regardless of the resulting thickness of the asphalt layer placed. If there is a high point in the present pavement surface, the slope controller will place less material over that location. If there is a low point in the existing pavement, the slope controller will allow the screed to deposit more mix in that location.

For a wide pavement, such as an airport runway, it is good practice to check the slope of the outside edge of the mix being placed after two passes of the paver in the longitudinal direction. If the slope is not set properly or the slope sensor setting is changed accidentally, it is possible to compound the error in the slope setting all the way across the pavement. This can result in a very thick or a very thin layer of mix on the edge of the runway, unless proper monitoring is completed regularly during the paving operation. Thus, the use of one or more stringlines across a wide pavement may be beneficial in providing the proper cross-slope.

YIELD, MINIMUM THICKNESS, AND SCREED CONTROLS

The paving specifications for hot-mix asphalt overlay projects are written in a variety of ways. In some cases, the specifications call for a minimum thickness of mix to be placed. For this type of requirement, in order for the minimum thickness specification to be met at all points in the pavement layer, it is usually necessary for the paver to place a mat thickness that is greater than the minimum depth required in the contract. The amount

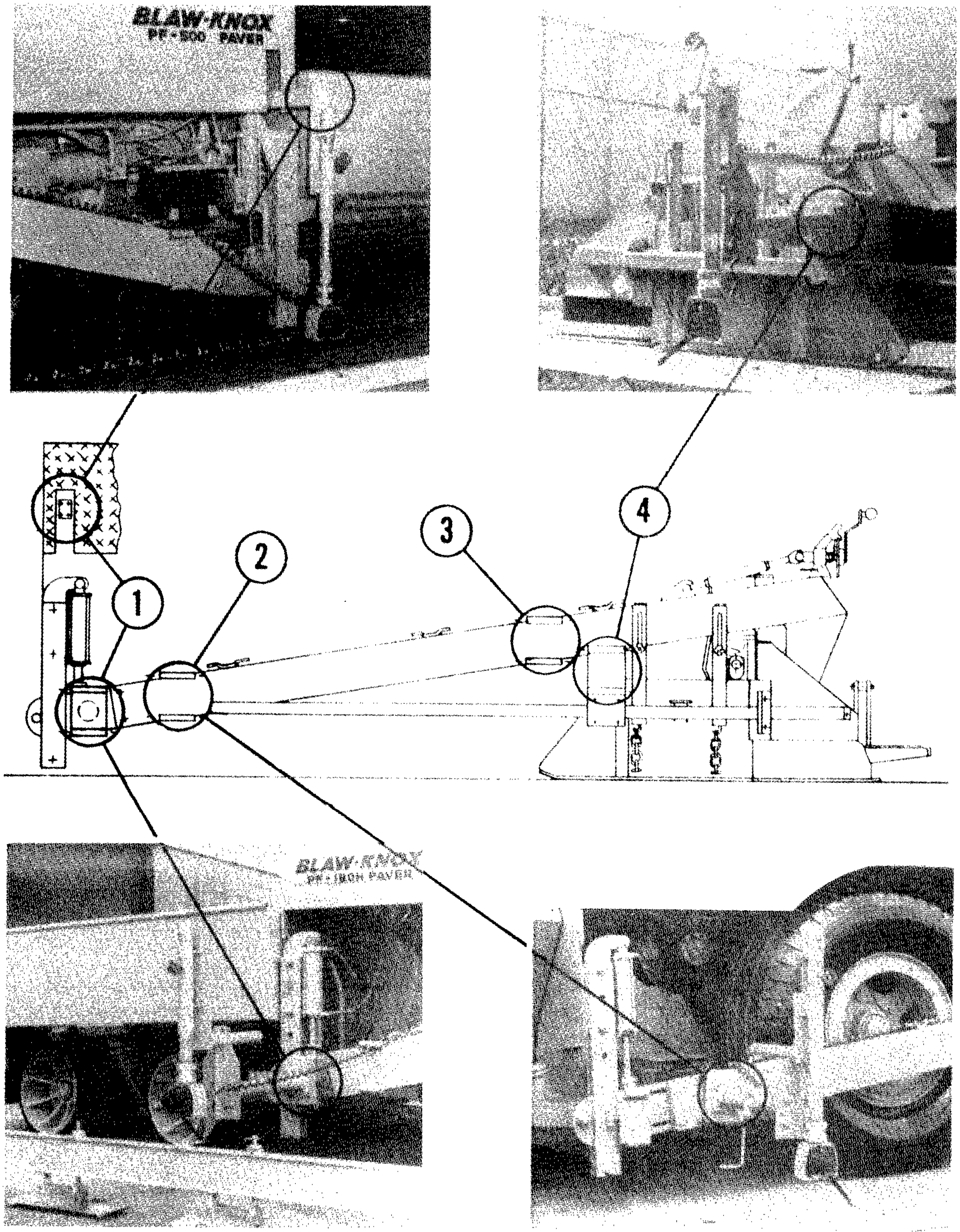


Figure 3-58. Mounting position for grade sensor *(Blaw-Knox)*.

Percent Slope	Inches Per Foot		Inches Per 10′	Inches Per 11′	Inches Per 12′	Inches Per 13′	Inches Per 14′	Inches Per 15′	Inches Per 16′	Inches Per 17′	Inches Per 18′	Inches Per 19′	Inches Per 20′
	Actual Decimal	Approx. Fraction											
0.10%	.012	1/64	1/8	1/8	5/32	5/32	5/32	3/16	3/16	7/32	7/32	7/32	1/4
0.13%	.015	1/64	5/32	5/32	3/16	3/16	7/32	7/32	1/4	1/4	9/32	9/32	5/16
0.20%	.024	1/32	1/4	1/4	9/32	5/16	11/32	3/8	3/8	13/32	7/16	15/32	15/32
0.26%	.031	1/32	5/16	11/32	3/8	13/32	7/16	15/32	1/2	17/32	9/16	19/32	5/8
0.30%	.036	3/64	3/8	13/32	7/16	15/32	1/2	17/32	9/16	5/8	21/32	11/16	23/32
0.40%	.048	3/64	1/2	17/32	9/16	5/8	11/16	23/32	25/32	13/16	7/8	29/32	31/32
0.50%	.060	1/16	19/32	21/32	23/32	25/32	27/32	29/32	31/32	1 1/32	1 3/32	1 1/8	1 3/16
0.52%	.062	1/16	5/8	11/16	3/4	13/16	7/8	15/16	1	1 1/16	1 1/8	1 5/32	1 1/4
0.60%	.072	5/64	23/32	25/32	7/8	15/16	1	1 3/32	1 5/32	1 7/32	1 9/32	1 3/8	1 7/16
0.78%	.093	3/32	15/16	1 1/32	1 1/8	1 7/32	1 5/16	1 13/32	1 1/2	1 19/32	1 11/16	1 25/32	1 7/8
0.80%	.096	3/32	31/32	1 1/16	1 5/32	1 1/4	1 11/32	1 7/16	1 17/32	1 5/8	1 23/32	1 13/16	1 29/32
1.0%	.120	1/8	1 3/16	1 5/16	1 7/16	1 9/16	1 11/16	1 13/16	1 29/32	2 1/32	2 5/32	2 9/32	2 13/32
1.5%	.180	3/16	1 13/16	1 31/32	2 5/32	2 11/32	2 17/32	2 11/16	2 7/8	3 1/16	3 1/4	3 13/32	3 19/32
2%	.240	1/4	2 7/16	2 5/8	2 7/8	3 1/8	3 3/8	3 19/32	3 27/32	4 3/32	4 5/16	4 9/16	4 13/16
3%	.360	3/8	3 5/8	3 31/32	4 5/16	4 11/16	5 1/32	5 13/32	5 3/4	6 1/8	6 15/32	6 27/32	7 3/16
4%	.480	15/32	4 13/16	5 9/32	5 3/4	6 1/4	6 23/32	7 3/16	7 11/16	8 5/32	8 5/8	9 1/8	9 19/32
5%	.600	19/32	6	6 19/32	7 3/16	7 13/16	8 13/32	9	9 19/32	10 3/16	10 13/16	11 13/32	12
6%	.720	23/32	7 3/16	7 29/32	8 5/8	9 3/8	10 3/32	10 13/16	11 17/32	12 1/4	12 31/32	13 11/16	14 13/32
7%	.840	27/32	8 13/32	9 1/4	10 3/32	10 29/32	11 3/4	12 19/32	13 7/16	14 9/32	15 1/8	15 31/32	16 13/16
8%	.960	31/32	9 19/32	10 9/16	11 17/32	12 15/32	13 7/16	14 13/32	15 3/8	16 5/16	17 9/32	18 1/4	19 3/16
9%	1.08	1 3/32	10 13/16	11 7/8	12 31/32	14 1/32	15 1/8	16 3/16	17 9/32	18 3/8	19 7/16	20 17/32	21 19/32
10%	1.20	1 3/16	12	13 3/16	14 13/32	15 19/32	16 13/16	18	19 3/16	20 13/32	21 19/32	22 13/16	24
11%	1.32	1 5/16	13 3/16	14 17/32	15 27/32	17 5/32	18 15/32	19 13/16	21 1/8	22 7/16	23 3/4	25 3/32	26 13/32
12%	1.44	1 7/16	14 13/32	15 27/32	17 9/32	18 23/32	20 5/32	21 19/32	23 1/32	24 15/32	25 29/32	27 3/8	28 13/16

Percent Slope	Inches Per Foot		Inches Per 21′	Inches Per 22′	Inches Per 23′	Inches Per 24′	Inches Per 25′	Inches Per 26′	Inches Per 27′	Inches Per 28′	Inches Per 29′	Inches Per 30′
	Actual Decimal	Approx. Fraction										
0.10%	.012	1/64	1/4	1/4	9/32	9/32	5/16	5/16	5/16	11/32	11/32	3/8
0.13%	.015	1/64	5/16	11/32	11/32	3/8	3/8	13/32	13/32	7/16	7/16	15/32
0.20%	.024	1/32	1/2	17/32	9/16	9/16	19/32	5/8	21/32	11/16	11/16	23/32
0.26%	.031	1/32	21/32	11/16	23/32	3/4	25/32	13/16	27/32	7/8	29/32	15/16
0.30%	.036	3/64	3/4	25/32	13/16	7/8	29/32	15/16	31/32	1	1 1/32	1 1/16
0.40%	.048	3/64	1 1/32	1 1/16	1 3/32	1 5/32	1 3/16	1 1/4	1 9/32	1 11/32	1 13/32	1 7/16
0.50%	.060	1/16	1 1/4	1 5/16	1 3/8	1 7/16	1 1/2	1 9/16	1 5/8	1 11/16	1 3/4	1 13/16
0.52%	.062	1/16	1 5/16	1 3/8	1 7/16	1 1/2	1 9/16	1 5/8	1 11/16	1 3/4	1 13/16	1 7/8
0.60%	.072	5/64	1 1/2	1 19/32	1 21/32	1 23/32	1 13/16	1 7/8	1 15/16	2 1/32	2 3/32	2 5/32
0.78%	.093	3/32	1 31/32	2 1/16	2 5/32	2 1/4	2 11/32	2 7/16	2 17/32	2 5/8	2 23/32	2 13/16
0.80%	.096	3/32	2 1/32	2 1/8	2 7/32	2 5/16	2 13/32	2 1/2	2 19/32	2 11/16	2 25/32	2 7/8
1.0%	.120	1/8	2 17/32	2 5/8	2 3/4	2 7/8	3	3 1/8	3 1/4	3 3/8	3 1/2	3 5/8
1.5%	.180	3/16	3 25/32	3 31/32	4 1/8	4 5/16	4 1/2	4 11/16	4 7/8	5 1/32	5 7/32	5 13/32
2%	.240	1/4	5 1/32	5 9/32	5 17/32	5 3/4	6	6 1/4	6 15/32	6 23/32	6 31/32	7 3/16
3%	.360	3/8	7 9/16	7 15/16	8 9/32	8 5/8	9	9 3/8	9 23/32	10 3/32	10 7/16	10 13/16
4%	.480	1/2	10 3/32	10 9/16	11 1/32	11 17/32	12	12 1/2	12 31/32	13 7/16	13 15/16	14 13/32
5%	.600	19/32	12 19/32	13 3/16	13 13/16	14 13/32	15	15 19/32	16 3/16	16 13/16	17 13/32	18
6%	.720	23/32	15 1/8	15 27/32	16 9/16	17 9/32	18	18 23/32	19 7/16	20 5/32	20 7/8	21 19/32
7%	.840	27/32	17 5/8	18 15/32	19 5/16	20 5/32	21	21 27/32	22 11/16	23 17/32	24 3/8	25 3/16
8%	.960	31/32	20 5/32	21 1/8	22 3/32	23 1/32	24	24 31/32	25 29/32	26 7/8	27 27/32	28 13/16
9%	1.08	1 3/32	22 11/16	23 3/4	24 27/32	25 29/32	27	28 3/32	29 5/32	30 1/4	31 5/16	32 13/32
10%	1.20	1 3/16	25 3/16	26 13/32	27 19/32	28 13/16	30	31 3/16	32 13/32	33 19/32	34 13/16	36
11%	1.32	1 5/16	27 23/32	29 1/32	30 3/8	31 11/16	33	34 5/16	35 5/8	36 31/32	38 9/32	39 19/32
12%	1.44	1 7/16	30 1/4	31 11/16	33 1/8	34 9/16	36	37 7/16	38 7/8	40 5/16	41 3/4	43 3/16

All figures shown in feet are measured horizontally.

All figures shown in inches are measured vertically and are accurate to within 1/32 inch.

Figure 3-59. Slope conversion table *(Cedarapids)*.

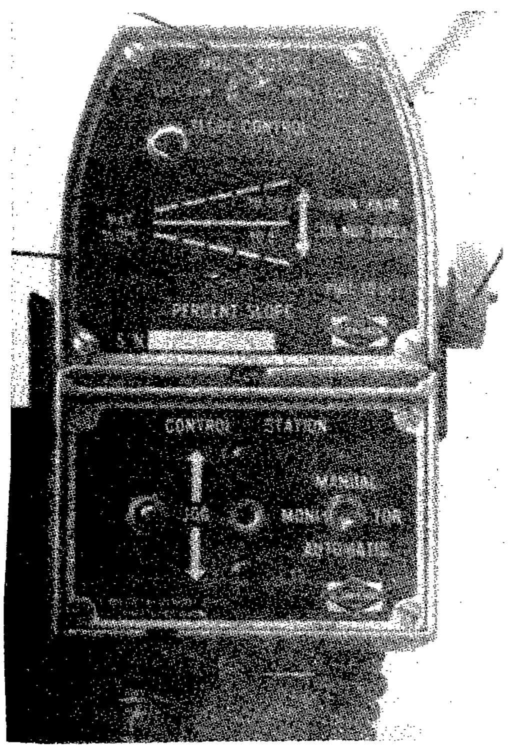


Figure 3-60. Slope-control device *(Blaw-Knox)*.

of extra thickness depends on the roughness of the existing pavement: The more uneven the pavement being paved, the greater will be the volume of mix needed to assure compliance with the minimum thickness requirement.

As an example of this type of specification, if the existing pavement is relatively uneven, and if a minimum asphalt concrete overlay thickness of 1 in. is required, the paver thickness-control system would need to be set so as to place an average depth of uncompacted layer of asphalt concrete of approximately 1 1/2 in. This means that the angle of attack of the screed would have to be positioned so that the average thickness placed would assure that the minimum depth of mix was laid over all the high spots in the pavement surface.

The second type of specification calls for the placement of a given amount of mix, in terms of pounds of mix per square yard, over the pavement surface area. In this case, the thickness requirement is an average depth, not a minimum depth. If the specifications for a project called for the placement of 110 lb of mix/yd^2 (approximately 1 in. of compacted thickness for an asphalt concrete mixture), the angle of attack of the paver screed would not have to be set at as great an angle in order to place the mix an average depth of 1 in. (compacted) compared with a minimum specification thickness of 1 in.

The paver screed, left to operate without human intervention on the thickness-control cranks and run either with or without automatic controls, will typically overyield mix. This means that the paver will require more material than generally expected in order to react to variations in the grade of the existing pavement and to shave off the high spots and fill in the low spots in that surface. In order to meet the yield requirement, therefore, it is usually necessary to reduce the thickness of the mat being placed slightly in order to comply with the yield requirement. An additional problem with a yield-type specification is the longitudinal distance used to determine the yield value. In some cases, yield is checked after every truckload of mix. This frequency of checking often leads to continual changes in the thickness-control cranks on the paver. Yield should only be checked periodically: the tons of mix placed over a distance of 1000 ft or more than an hour's duration of paving.

The third type of specification is one that requires a certain degree of smoothness for the finished pavement surface. Many different smoothness specifications exist. Most are related to the amount of deviation permitted from a straightedge of a given length or to a certain maximum number of inches of roughness per unit of length, typically a mile or some part of a mile. Although it is normally possible to meet such smoothness specifications through the use of automatic screed controls, the ultimate success in making the requirements depends on the amount of mix available to be placed, the condition of the existing pavement, and the number of layers of mix to be laid. The amount of mix necessary to meet a smoothness requirement will usually be greater than the amount needed to meet a given yield requirement.

The problem comes when it is desired to meet some specified yield requirement *and* to meet a minimum thickness or smoothness requirement at the same time. Because of the principle of the floating screed, it generally is not possible to accomplish both of the specifications at the same time on the same project, depending on the smoothness of the pavement being overlaid. Particularly for thin overlays, the paver is normally not capable of meeting a minimum thickness and/or a smoothness specification at the same time as a yield type requirement. The governing criteria (yield, minimum thickness, or smoothness) should be determined at the time the job is designed and verified to the contractor before paving commences (during the preconstruction meeting).

AUTOMATIC SCREED-CONTROL OPERATING TECHNIQUES

When automatic screed controls are used on a paver to control the grade and/or the slope of the pavement layer being constructed, there are several key operating techniques that should be observed to determine whether the automatic controls are being used properly. Those items are:

- The screed operator should not attempt to make manual changes in the angle of attack of the screed by turning the thickness-control cranks, because the automatic controls will attempt to change the elevation of the pull point to compensate for the manual input to the screed.
- The grade sensor should be checked to assure that it is working. If the wand (which rides on the stringline or mobile reference device) is raised 1/32 in., there should be a corresponding movement of the actuator at the tow point on the paver. If the wand is raised (or lowered) and the actuator does not move, either the system is not turned on or the sensitivity of the sensor is set too wide--with too great a dead band or sensitivity setting.
- When the sensor is set on the grade reference and the paver is moving forward, the up and down lights on the sensor should blink occasionally or the constantly blinking lights should change intensity occasionally, both top and bottom, to indicate that a signal is being sent from the sensor to the tow point cylinder. On grade sensors that use a meter, the meter should indicate a change in reading as the paver travels down the roadway. Further, the movement of the tow point actuator should be smooth, without constant up and down movement.
- If a stringline is used as the grade reference, the line should be very taut. There should not be any sags in the line, particularly between the vertical support locations. This can be checked by sighting down the line. The grade sensor wand should ride easily over the stringline and not be displaced in a vertical direction when it passes over a support arm. Every effort should be made to keep all personnel and equipment from coming in contact with the stringline and disturbing it, either longitudinally or vertically.
- If a mobile reference is used for the grade control, the sensor should ride on the reference at the midpoint of its length. This allows the input to the paver to be made equally over the length of the mobile reference. If the mobile reference is equipped with multiple feet or shoes, each of the devices should be checked to assure that each is clean and free to move or rotate around its own hinge or spring point. The length of the mobile reference should be as long as practical to provide for the greatest averaging out of variations in the elevation of the existing roadway surface.
- If a joint matching shoe is employed for grade control, the shoe should be checked to assure that it is free to move or rotate around its own hinge or spring point.
- If the automatic-control system includes grade control on one side of the paver and slope control on the other side of the paver, the cross-slope of the layer placed should be checked regularly to assure that the proper cross-slope is being built in to the pavement layer by the paver. This is particularly important on very wide pavements, such as an airport runway.
- For most paving situations, the grade-control sensor should be hung on the leveling (tow) arm of the paver, typically between one-third and two-thirds of the way between the tow point and the screed. For some paving jobs, the sensor can be placed just in front of the screed and but never behind the pivot point of the screed. The sensor, except in conjunction with the use of a joint matching shoe, should generally not be located at the tow point.

SECTION FIVE
JOINT CONSTRUCTION

INTRODUCTION

During the construction of hot-mix asphalt pavements, two types of joints are encountered. The first type of joint is a transverse joint. This joint occurs whenever the paving operation is interrupted for a period of time--from an hour or so to overnight. The second type of joint is the longitudinal joint. This kind of joint occurs when one lane of asphalt mix is constructed adjacent to a previously placed lane of mix. The techniques for constructing each type of joint are discussed in this section.

TRANSVERSE JOINTS

End of Paving

When the placement of the asphalt mix is to be suspended for a period of time, it is necessary to construct a transverse joint across the pavement being placed. This is accomplished in one of several ways, depending primarily on whether traffic is to travel over the asphalt mix between the time the paving is stopped and it is started again.

If traffic is not going to pass over the end of the paving, a vertical butt joint can be constructed. If traffic will be permitted to travel over the transverse joint, a tapered joint will be necessary. In either case, the operation of the paver is essentially the same. The actual construction of the joint itself, however, is different.

It is very important that the paver be run in normal fashion right up to the point at which the transverse joint is constructed. This means that the head of material carried in front of the screed should be as consistent as possible at the location of the joint. This requirement permits the forces acting on the screed to be constant and maintains the angle of attack for the paver screed. The result of such a paving operation is a uniform mat thickness at the joint, the same thickness as for the previously placed mix.

It is a common but incorrect practice, however, to empty out the paver hopper whenever a transverse joint is to be built. The paver operator normally anticipates the location of the joint by drawing down the mix in the paver hopper. In most instances, the hopper is emptied and the amount of mix carried on the augers is minimal. This process reduces the head of material in front of the paver screed, causing the screed to fall, thereby decreasing the thickness of the mat at the joint. It is a much better practice to locate the transverse joint at the point where the amount of material in front of the screed is normal than it is to run the hopper and the auger chamber empty and then construct the transverse joint at the point the paver runs out of mix.

Butt Joints

For a butt joint, a vertical face is constructed by hand methods across the width being paved. This operation consists of raking, shoveling, and then removing the mix that is located downstream of the selected joint location, as shown in Figure 3-61. The asphalt mix that is in place upstream of the joint is not touched in any manner. The mix that is removed from the downstream side of the joint is then recycled or discarded.

Compaction of the mix on the upstream side of the joint is accomplished in normal fashion. It is necessary, however, for the rollers to compact the mix immediately adjacent to the joint. For this to be done properly, runoff boards must be placed next to the joint. The thickness of the boards should be approximately equal to the compacted thickness of the layer being placed. In addition, the boards must be wide enough and long enough to support the full length of a roller. The

Figure 3-61. Construction of transverse butt joint *(J. Scherocman).*

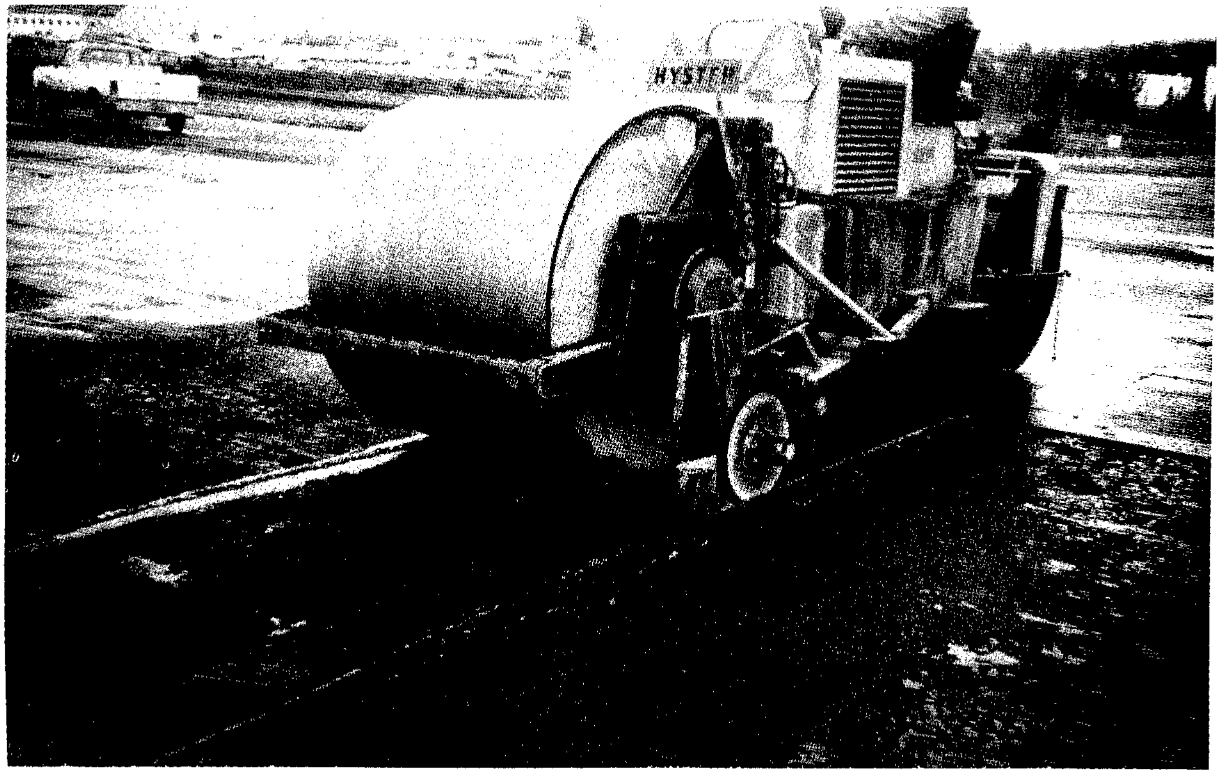


Figure 3-62. Constructing transverse butt joint with cutting wheel *(J. Scherocman)*.

compaction equipment passes over the mix at the joint and onto the boards before the rolling direction is reversed. This assures that the transverse joint receives the same degree of densification as the rest of the mix in the pavement layer.

Runoff boards should be used; when they are not used, the front wheel of the compaction equipment is normally run up to the transverse joint, stopping just short of the joint. The roller direction is then reversed and the rest of the mat is compacted. Occasionally, one wheel or roll of the roller will be driven over the end of the course, over the vertical face of the joint. Passing the rollers over the edge of the transverse joint, without having any boards beyond the edge to support the weight of the rollers, will cause rounding of the edge of the joint. The degree of rounding that will occur will depend on the number of times the roller runs off of the joint and the thickness of the layer being constructed.

This latter type of joint construction results in two problems. First, the rounding of the edge of the butt joint prevents the construction of a proper vertical joint when paving is restarted. Second, the amount of compactive effort applied to the asphalt mix adjacent to the joint is typically not adequate. The lack of proper compaction results in a high air void content in the mix upstream of the joint and a weak spot and bump in the pavement structure. The use of runoff boards for the rolling equipment is thus necessary to assure the correct construction of a butt-type transverse joint. This problem is eliminated by cutting the mix back to a point of constant thickness and density, as illustrated in Figures 3-62 and 3-63.

Tapered Joints

If traffic is to be carried over the transverse joint, it is necessary to build a tapered joint. For this type of joint, as for the butt joint, it is proper for the paver operator to keep the head of material in front of the paver screed as consistent as possible up to the point that the joint is to be built. This process assures that the thickness of the mix being placed is uniform up to the joint. There is more opportunity for this to be done in practice with tapered joint construction than with butt joint construction because the mix left in the paver hopper can be used to build the taper.

At the point of the transverse joint, the asphalt mix downstream of the joint is temporarily pushed aside, away from the joint. A vertical edge is formed at the upstream face of the mix. If the tapered joint is to be only temporary, treated paper or other similar material

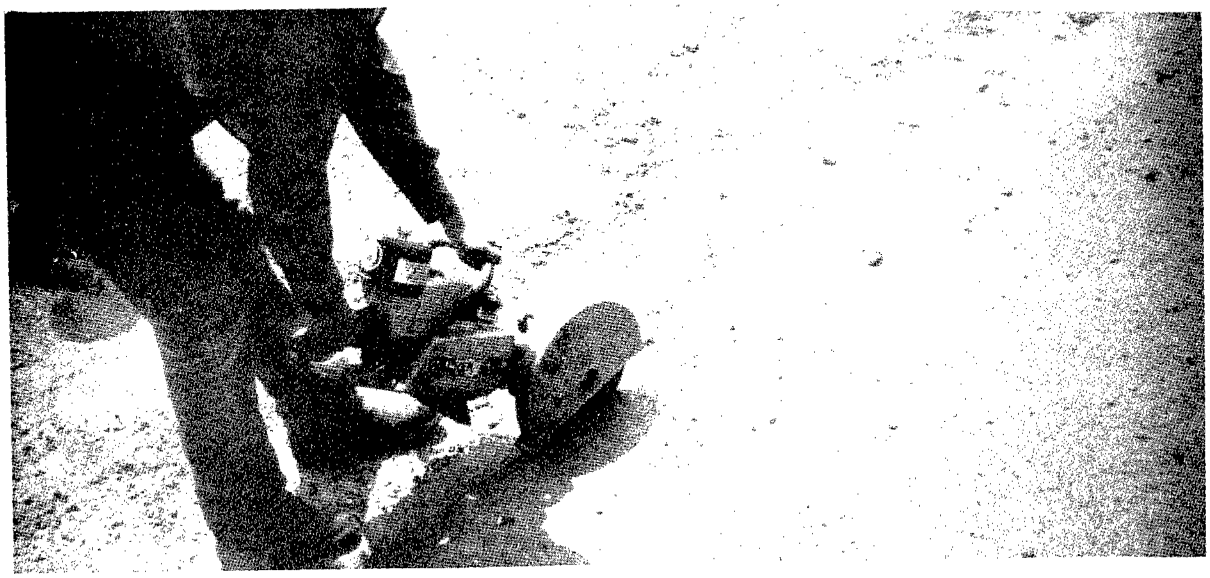


Figure 3-63. Constructing transverse butt joint by sawing *(J. Scherocman)*.

is then placed downstream of the joint directly on the existing pavement surface (Figures 3-64 and 3-65). This paper is used because the asphalt mix will not stick to it. The length of the paper is dependent on the thickness of the course just placed but is typically about 3 or 4 ft long and the width of the lane being paved. If the length of the paper used is too short, the roller might tend to shove the mix, causing rounding of the joint at the upstream side of the paper.

Once the paper is in place, the asphalt mix is shov-

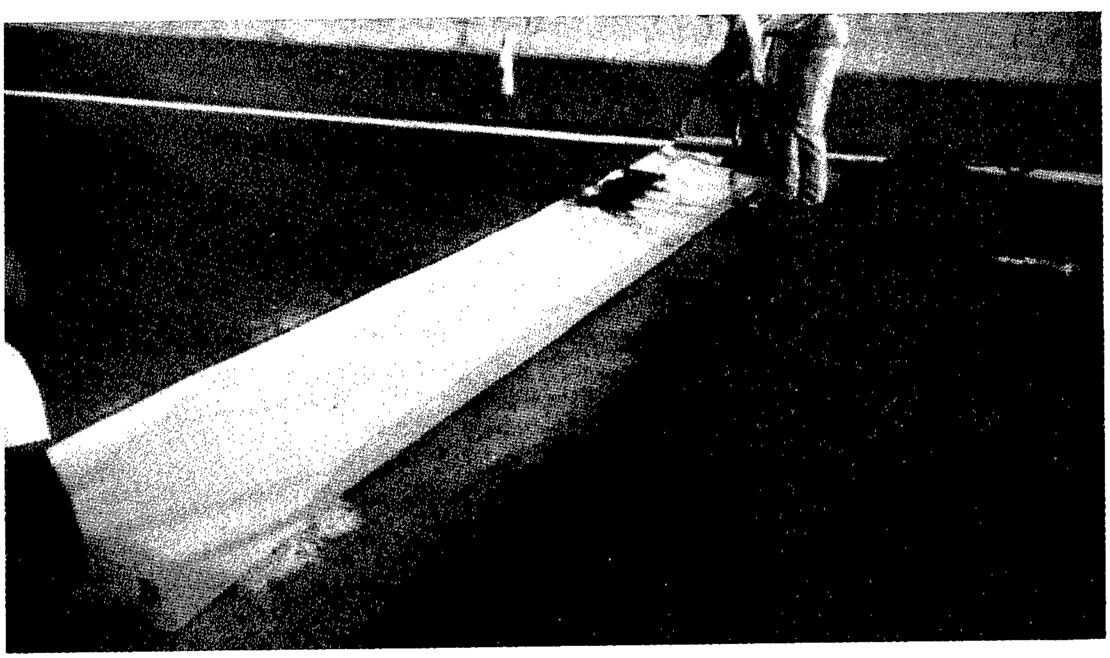


Figure 3-64. Placing treated paper for tapered joint *(J. Scherocman)*.

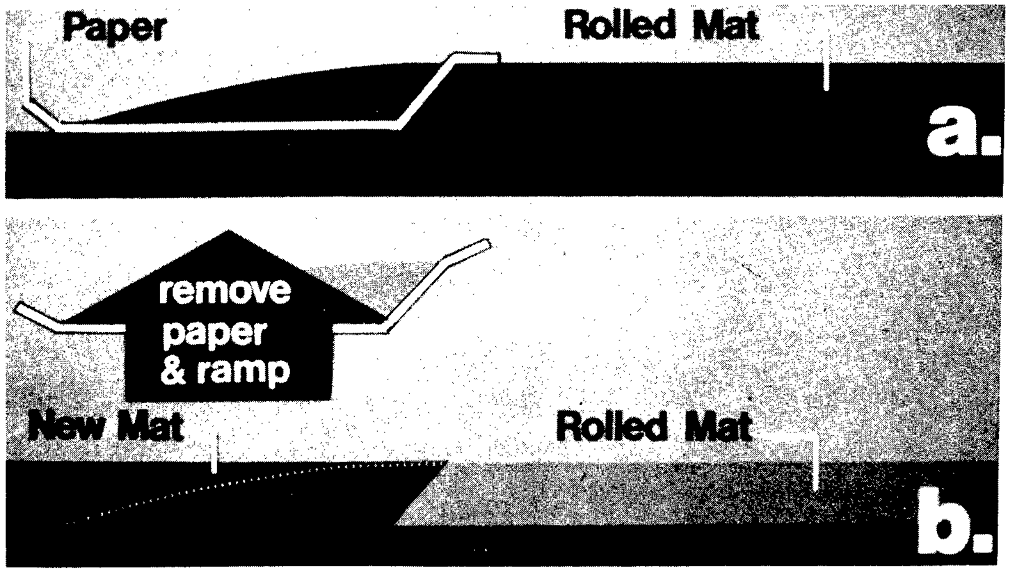


Figure 3-65. Paper transfer joint *(NAPA)*.

eled back over the paper and a ramp is formed in this mix with a lute or rake. Any asphalt mix that is not used to construct the ramp or taper is discarded. If the joint is to be left in place permanently, the taper is constructed in the same manner except that the treated paper is not used.

Instead of treated paper, sand or dirt from the edge of the roadway is sometimes spread on the road surface, as shown in Figure 3-66. This is not good practice. Although the sand or dirt does prevent the asphalt material in the taper from sticking to the underlying pavement surface, it is also very difficult to remove the sand or dirt completely from the surface once the mix in the taper has been removed. Typically some of the bond-breaking material remains on the existing surface even after that surface has been swept with a hand broom. This dirty surface will provide a slip plane for the new asphalt mix, and a shoving failure can occur at that point when the new pavement is subjected to traffic. This is true even if a tack coat is applied on top of the dirty surface to "improve" the bond of the new mix to the existing pavement. Indeed, in many cases an extra amount of tack coat material is applied near the joint to compensate for the dirt at that location. The extra tack coat material, particularly if it is not cured before the new mix is placed on it, can increase the chances for slippage to occur at that point. Constructing a temporary tapered transverse joint using sand or dirt as the bond-breaking medium is not an acceptable paving practice.

As shown in Figures 3-67 and 3-68, an alternative way to form the transverse joint is to use a board that is the same thickness as the compacted pavement layer. The paver passes over the joint location and the mix is

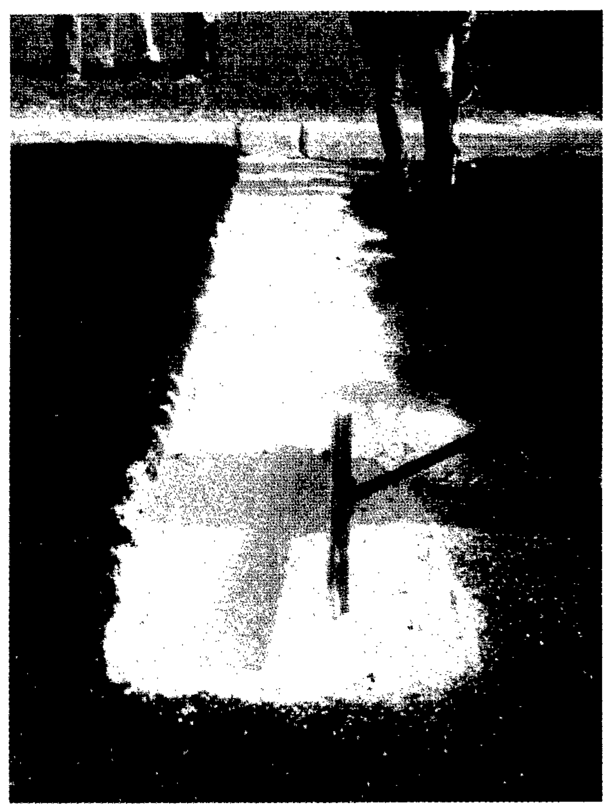


Figure 3-66. Placing sand for tapered joint *(J. Scherocman)*.

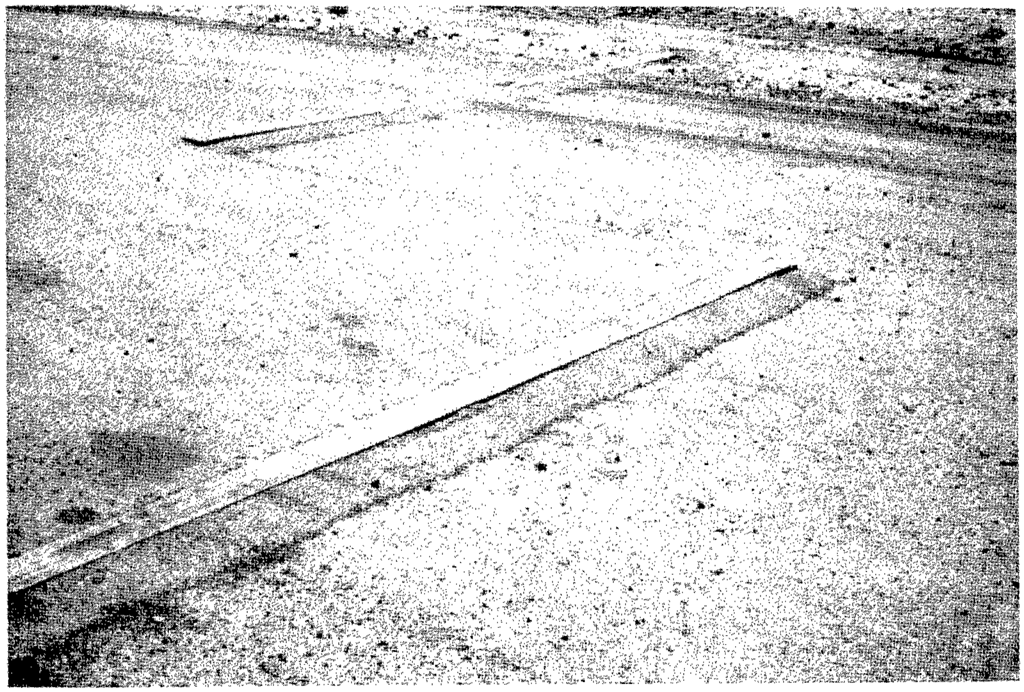


Figure 3-67. Transverse joint with boards *(J. Scherocman)*.

shoveled away from the joint. A vertical face is formed in the upstream side of the joint, but the mix adjacent to the joint on that side is not disturbed. Once the vertical face is formed, the board is set in place, immediately downstream of the vertical face and against it. The mix that had been removed from the joint is then shoveled back against the board and a taper formed from the edge of the board to the existing pavement surface. Traffic runs over the edge of the joint, over the board, and down the taper. To prevent dislodgement of the board by traffic, the board must be the same thickness as the layer being constructed and must be straight and not bowed upward where the wheels of the vehicle can hit it and jar it loose. In practice, this type of transverse joint is rarely constructed because of movement of the boards under traffic.

A third type of tapered joint is the nonformed, sawed joint. For this type of joint, the paver operator keeps

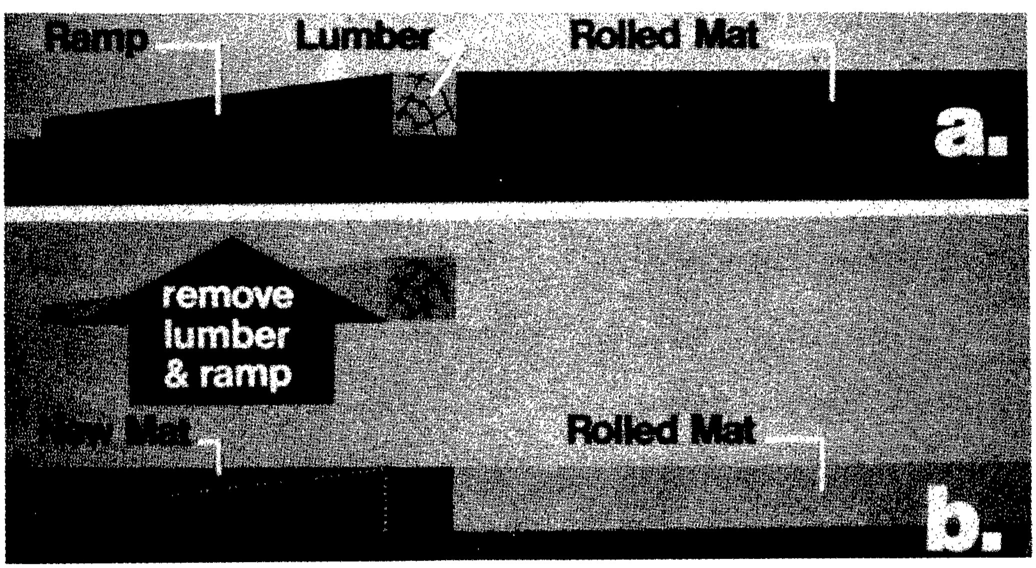


Figure 3-68. Use of boards for transverse joints *(NAPA)*.

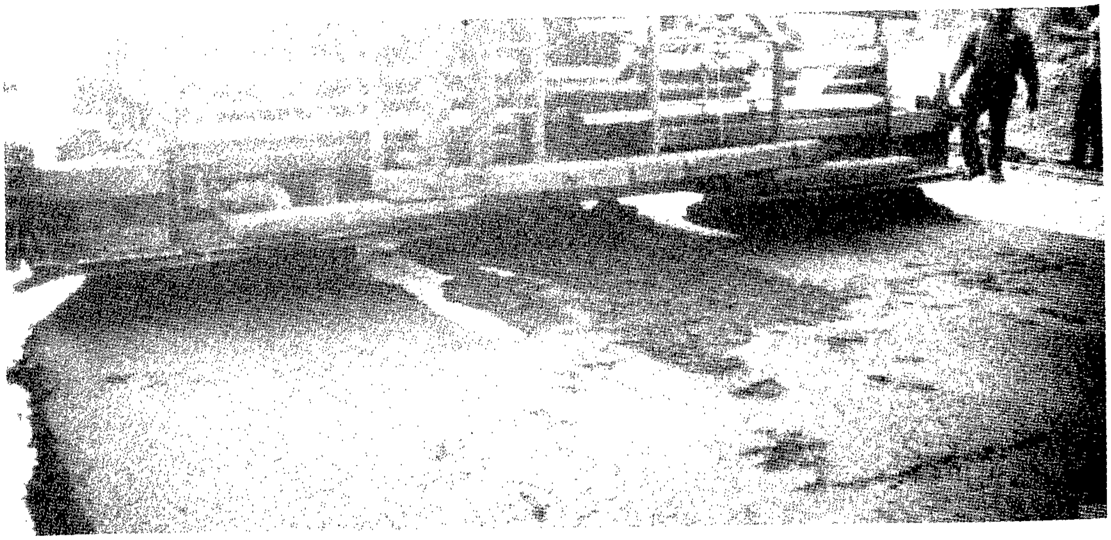


Figure 3-69. Tapered joint completed by running out of mix in paver hopper *(J. Scherocman)*.

the paver operating normally until there is no more mix in the hopper or in the auger chamber (Figure 3-69). At the point where the mix becomes nonuniform across the width of the lane being paved, a ramp is constructed with the "left-over" mix. No vertical face is formed, and the mix is merely tapered from the proper layer thickness to the level of the adjacent existing pavement. Any mix not needed to make the ramp is removed and wasted. Figure 3-70 illustrates the compaction of such a tapered transverse joint.

One advantage of the tapered joint is the fact that the compaction equipment can run over the edge of the transverse joint and down the ramp without rounding the joint. Because the rollers can pass over the end of the mat easily, the compaction of the mix upstream of the joint is usually superior to the mix adjacent to the

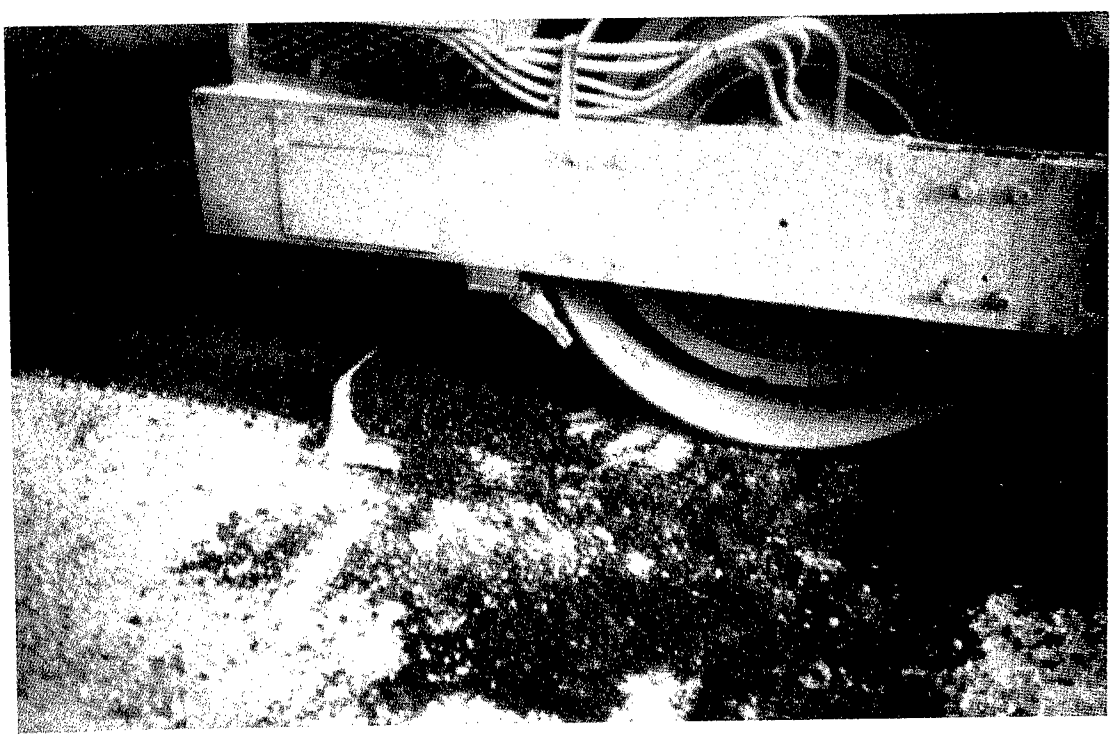


Figure 3-70. Compacting tapered joint *(J. Scherocman)*.

butt-type joint. A second advantage is that there generally is less mix to shovel from the joint, because some of the extra mix is used to make the ramp or taper. The disadvantage of this kind of joint is that this mix must eventually be removed before paving commences downstream of the transverse joint.

Handmade Joints

In areas where the new hot-mix asphalt layer abuts an existing structure, such as a bridge deck, it is often necessary to place the mix adjacent to the joint by hand. The mix that is needed to complete the joint is deposited in the area to be paved either by the paver or by being dumped from a haul truck. In order to avoid overworking the mix and possibly causing segregation, the mix should be placed as close as feasible to its final location. The mix is then spread by hand methods, normally using rakes or lutes.

In addition, the mix must be "left high" in order to allow for the compression of the material by the compaction equipment. Because the mix is being placed by hand, it will not be as dense as it would be if it were laid by the paver. Thus the 1/4 in./1 in. rule of thumb usually used will not be valid for hand-spread mix. To permit proper compaction of the mix and have the mix end up at the proper elevation to match the adjacent structure, the level of the mix should be approximately 3/8 in. higher than the surrounding pavement for each 1 in. of compacted layer thickness.

The hand work area must be rolled by the compaction equipment as soon as possible after the mix is in the proper location. Because of the time necessary to place the mix, rolling will be delayed and the mix will be cooling during the placement process. In order to achieve the required density, extra rolling may be needed.

Start of Paving

Removal of the Taper

If a tapered joint has been constructed at the transverse joint, the mix in the ramp or taper must be removed before the paving can be started. For a taper built with treated paper, there is no bond between the mix in the ramp and the underlying pavement. The paper and mix are readily removed and returned for recycling. A vertical face is left at the upstream edge of the joint.

For a taper constructed with the board and a ramp of asphalt mix, the material downstream of the board will be partially bonded to the existing pavement surface. A front-end loader typically is used to pry up the mix in the taper. This can be very difficult to do, depending on the amount of traffic that has passed over the transverse joint and the environmental conditions at the site. Once the mix has been removed, the board is then removed, exposing the vertical face of the joint.

If a nonformed tapered transverse joint is used, it is necessary first to saw a transverse joint in the asphalt mat. The advantage of this type of joint is that the saw cut can be made at any longitudinal point in the asphalt layer (Figure 3-63). It can be placed far enough back from the taper to assure that the thickness of the layer is constant. Once the joint is cut completely through the asphalt mat, a front-end loader is used to pry up the mix that is downstream of the saw cut. As with the tapered joint that uses the board, one disadvantage of this type of joint is that it is often very difficult to remove the mix downstream of the saw cut from the existing roadway. As an alternative, a cold-milling machine can be used both to form the vertical edge of the transverse joint and to remove the mix in the taper.

A straightedge should be used to determine the condition of the transverse joint before paving begins. If the mix upstream of the joint is level, the location of the transverse joint is fine. If the straightedge indicates that the previously placed mix is not level, the location of the transverse joint should be moved to a point where the proper thickness and smoothness of the pavement layer exists. The mix downstream of the new joint location should be removed and recycled.

Use of Starting Blocks

The asphalt mix that passes out the back of the paver screed still must be compacted. As a rule of thumb, an asphalt concrete is expected to densify approximately 20 percent under the action of the compaction equipment. This means that the mix must be placed about 1 1/4 in. thick in order to produce a compacted mix that is 1 in. thick. This rule must be applied when the paver is used to place mix at a transverse joint.

If the layer being placed is to be 2 in. thick, the mix passing out from under the screed should be approximately 2 1/2 in. in depth to allow for compaction. It is therefore improper and very poor practice to set the paver screed directly on the old mat upstream of the transverse joint and start the placement of the new mix by dragging the screed off of the previously placed material. If this is done, not enough mix will be placed on the downstream side of the joint, and a dip in the compacted pavement surface will result. Proper paving practice requires that the paver screed be placed on a set of starting blocks on the upstream side of the transverse joint. The thickness of the blocks, or strips of wood, should allow the additional thickness of the layer to be placed, which will be compacted to the required asphalt thickness.

The starting blocks should be placed completely under the length of the screed, front to back, as illustrated in Figures 3-71 and 3-72. At least three strips of wood should be used for a standard screed up to 16 ft

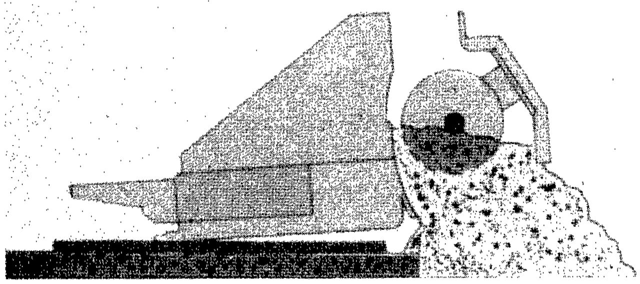


Figure 3-71. Starting blocks under paver screed at transverse joint on asphalt overlay (schematic) *(Blaw-Knox)*.

wide equipped with rigid extensions. If the width of the screed with rigid extensions is greater than 16 ft, at least four blocks should be placed under the screed. For a screed equipped with hydraulic extensions, at least three blocks should be set under the main screed and two additional blocks placed under each extension.

If the paver is starting out at a new location where there is no old mat on which to set the starting blocks and screed, the thickness of the starting blocks must be increased to compensate for the lack of mix on the upstream side of the joint (Figure 3-73). In this case, if a 2-in. (compacted) layer of mix is being constructed, the blocks should be about 2 1/2 in. thick in order to allow for the compaction of the mix by the rollers. For a 3-in.-thick compacted mat, the depth of the starting wood strips should be approximately 3 3/4 in.

Nulling the Screed and Setting the Angle of Attack

Once the paver screed has been set on starting blocks of the proper thickness, the screed should be nulled. This means that the angle of attack of the screed should be set in the neutral or flat position. The thickness-control cranks should be able to be turned slightly in both directions when the screed is in the nulled position without any pressure being put on the screed and without the angle of attack of the screed being altered.

An angle of attack should then be set into the screed. This is accomplished by turning the thickness-control cranks approximately one full turn (depending on the make of the paver) and introducing an up angle to the front of the screed. Both thickness-control cranks or handles (one on each side of the machine) must be

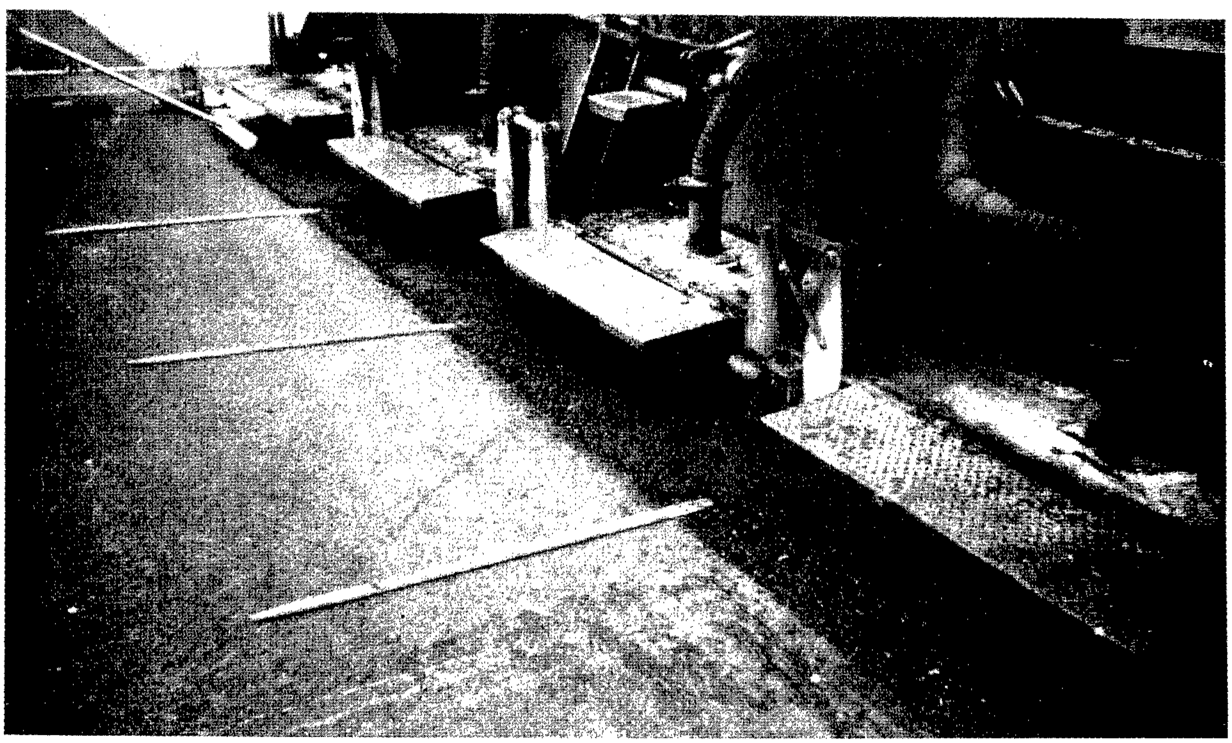


Figure 3-72. Starting blocks under paver screed at transverse joint on asphalt overlay *(J. Scherocman)*.

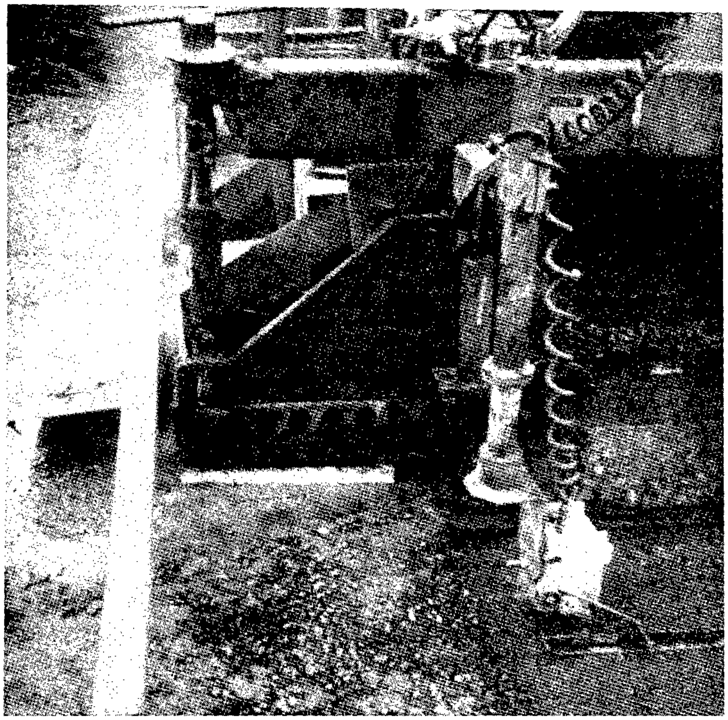


Figure 3-73. Use of starting blocks on new construction *(J. Scherocman)*.

adjusted in order for the screed to be set properly.

Before the paver pulls off of the starting blocks, the material feed system on the machine is activated and mix is deposited in the auger chamber in front of the screed. The amount of mix delivered should be enough to cover the augers up to the center of the auger shaft. This will provide the proper head of material against the screed. Once the auger chamber is properly filled, the paver is started, the screed is pulled off of the starting blocks (Figure 3-74), and the paver is brought up to the desired laydown speed as quickly as feasible. The angle of attack of the screed is adjusted, as needed, as the paver moves down the roadway, in order to provide the proper thickness of the asphalt mat. If the paver screed is nulled and the angle of attack set correctly while the screed is on the starting blocks, the amount of adjustment necessary to the screed should be minimal.

Raking the Joint

If the transverse joint is constructed properly up to this point, the amount of raking that needs to be done also is minimal, as shown in Figure 3-75. If the paver screed starts out on blocks and if the head of material against the screed is constant, the thickness of the mat downstream of the joint will be correct. Very little mix, if any, will need to be brushed back from the joint. There is never any reason to rake a transverse joint excessively (Figure 3-76).

When a joint is raked, there is a tendency for the raker to reduce the thickness of the new, uncompacted mat to match the elevation of the compacted pavement on the upstream side of the transverse joint. This is accomplished by pushing the mix at the joint down-

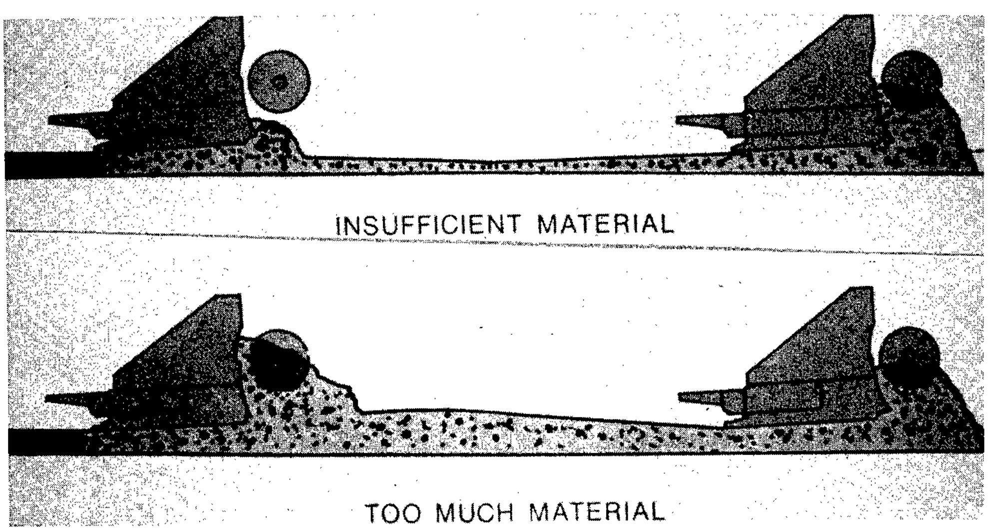


Figure 3-74. Head of material of transverse joint *(Blaw-Knox)*.

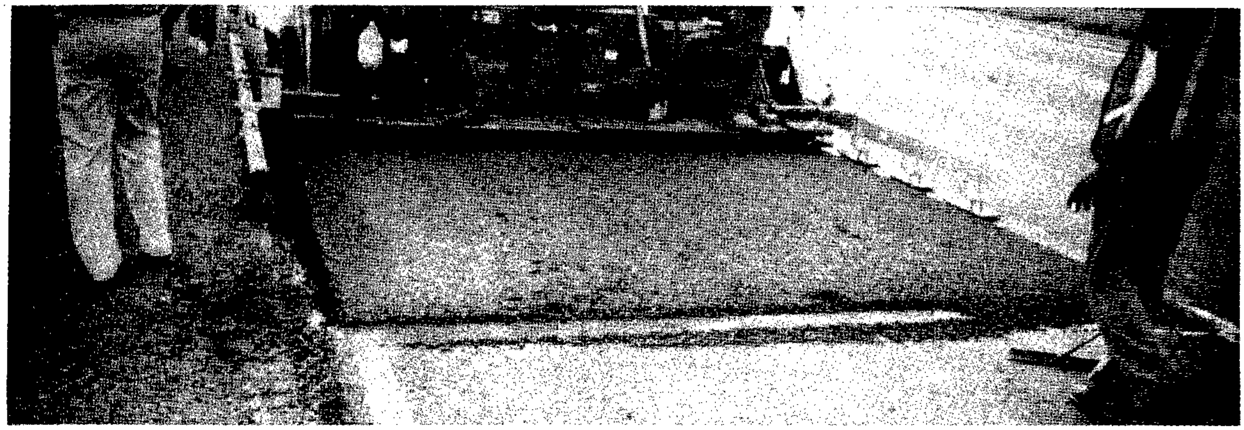


Figure 3-75. Proper raking of transverse joint *(J. Scherocman)*.

stream farther onto the new mat. When the level of the new, uncompacted mat is the same as the old, compacted mat, the final elevation of the newly placed material, after compaction by the rollers, will be lower than the mix on the upstream side of the joint. Thus, only minimal raking should be done.

Before the material on the downstream side of the joint is compacted, it should be determined if the joint is smooth by running a straightedge across the joint, as seen in Figure 3-77. The straightedge should rest on the uncompacted mat and extend over the already compacted mix. The distance between the bottom of the straightedge and the top of the compacted mat should be equal to the amount of rolldown that will occur during the compaction process, approximately 1/4 in./in. of compacted mat thickness. The straightedge should be

Figure 3-76. Excessive raking *(J. Scherocman)*.

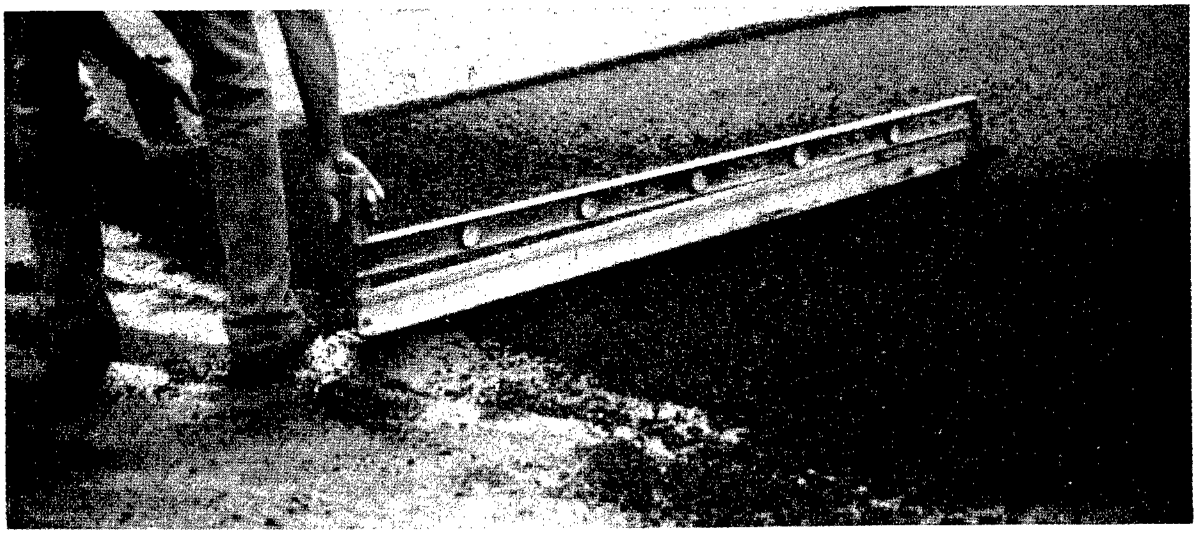


Figure 3-77. Checking transverse joint elevation *(J. Scherocman)*.

used again to check the level of the joint once the compaction process has been completed.

Compacting the Joint

As shown in Figure 3-78, ideally, a transverse joint should be compacted transversely. This means that the equipment that is used to roll the joint should operate across the width of the lane instead of longitudinally down the mat. If the rolling is done transversely, wood boards must be used to support the roller as it moves beyond the longitudinal edge of the pavement. The roller should operate in a manner so that the whole width of the joint receives equal compactive effort. This is very difficult to accomplish unless the wood boards placed on each side of the lane are long enough to allow the roller to move completely off the mix on both sides of the pavement.

If the roller cannot compact the joint in the transverse direction because of site restrictions (adjacent guardrail or steep side slope, for example) or traffic in the next lane, the transverse joint will have to be rolled in the longitudinal direction (Figure 3-79), similar to rolling of the mix at other locations. The initial (breakdown) rolling should be accomplished, however, as

Figure 3-78. Compacting transverse joint *(J. Scherocman)*.

Figure 3-79. Compacting transverse joint in longitudinal direction *(J. Scherocman)*.

quickly as possible after the paver has moved off of the joint. The roller should pass slowly and completely over the joint before the machine is reversed. If the joint has been constructed properly, the compaction process is no different from the application of ordinary compactive effort on any other part of the asphalt mixture.

LONGITUDINAL JOINTS

Cutting Back the Joint

In some cases, before the longitudinal joint between two adjacent lanes of pavement is constructed, the longitudinal edge of the previously placed mix is cut back for a distance of 1 to 2 in. This is accomplished with a saw or with a cutting wheel attached to a grader or front-end loader. The purpose of this operation is to remove that portion of the mix at the longitudinal joint that may have a lower density than the main portion of the mat because of the lack of confinement of the mix during the compaction process. If this is done, a tack coat should be placed on the newly exposed face of the longitudinal joint.

Further, a vertical face is formed at the longitudinal joint instead of the normal inclined face (typically about a 60-degree angle). This generally permits an increase in density to be obtained in the newly placed mat adjacent to the cut joint. Adequate joint density, however, can typically be obtained without cutting back the longitudinal joint: by properly overlapping, raking, and compacting the joint. If the joint is not cut back and the mix along the joint is clean, a tack coat is not normally needed.

Overlapping the Joint

The key to the construction of a good longitudinal joint between lanes of asphalt mix is the amount of overlap between the new mat and the previously placed mat. The end gate on the paver should extend over the top surface of the adjacent mix a distance of not more than 1 to 1 1/2 in., as shown in Figure 3-80. This amount of overlap provides just enough material on top of the joint to allow for proper compaction without having extra mix, which must be pushed back from the joint by a raker. The height of the new mix above the compacted mix should be 1/4 in. for each 1 in. of compacted mix.

One major problem with longitudinal joint construction is an excessive amount of overlap of the paver screed over the previously placed mat. (This may be caused, in part, by a ragged or wavy longitudinal edge on the first paver pass. Use of a string to guide the paver operator as the first lane is placed will usually reduce this problem greatly.) Because this extra asphalt

Figure 3-80. Overlap of new mix at longitudinal joint *(J. Scherocman)*.

mix cannot be pushed into the compacted mat, the material is raked or luted onto the new mat. If the longitudinal edge of the first lane is straight and if the correct amount of overlap is used, the amount of raking that must be done will be minimal.

Raking the Joint

If the amount of overlap of the new mix on the old lane is 1 to 1 1/2 in., any raking that is done should be used merely to "bump" the joint, pushing the mix off of the old lane and onto the new mat directly over the joint, as shown in Figure 3-81. This will leave the mix a little high at the joint and will create a slight amount of extra mix to be compacted by the roller. If the adjacent lane is overlapped too far and too much mix is deposited on the old mat, the excess material should be pulled away from the new mat instead of being pushed onto the new mix. The mix should not be broadcast across the new lane. The excess mix should be picked up and recycled, as shown in Figures 3-81 and 3-82.

Poor longitudinal joint construction is often related to "over-raking" the joint. Instead of any excess mix being pulled away from the joint, most often the extra material is brushed back onto the new mix, as shown in Figure 3-83. During the raking process, there is a tendency for too much material to be pushed off of the joint, leaving the level of the mix adjacent to the longitudinal joint at the same elevation on both sides of that joint. In some cases, so much mix is raked off the joint that a dip occurs at the longitudinal joint even before compaction of the mix is done. When either of these two problems occurs, it becomes impossible to obtain the required density at the joint.

Mix that is pushed off the longitudinal joint is deposited on the new asphalt mat. This material changes the surface texture of a portion of the mat where the mix is deposited. Depending on the gradation of the mix being placed, the extra mix raked onto the new mat can make a significant difference in the texture of the mat from one side of the lane to the other. Excessive raking of the longitudinal joint is detrimental to the long-term performance of that joint.

Excellent longitudinal joints can be constructed without raking the joint at all. If the proper amount of overlap of the new mix on the previously placed mat has been done, raking of the longitudinal joint can be eliminated, as shown in Figure 3-84. It is recommended that raking of this joint be deleted if proper overlap and compaction can be obtained.

Compacting the Longitudinal Joint

If the level of the new, uncompacted mix is even with or below the level of the compacted mix in the adjacent lane, the compaction equipment will not be able to densify the mix along the joint properly. Whether the first pass of the roller is on the cold side of the joint or on the hot side of the joint (Figure 3-85), part of the weight of the roller will be supported on the previously compacted mat. This means that the compaction equipment will bridge the mix in the joint, leaving it essentially uncompacted or only partially compacted. (Use of an intermediate pneumatic tire roller instead of a steel wheel roller--static or vibratory--will reduce this problem.) Thus, the level of the mix at the longitudinal joint must be above the elevation of the compacted mix, by an amount equal to approximately 1/4 in. for each 1 in. of compacted pavement, if proper compaction of the mix at the joint is to be accomplished.

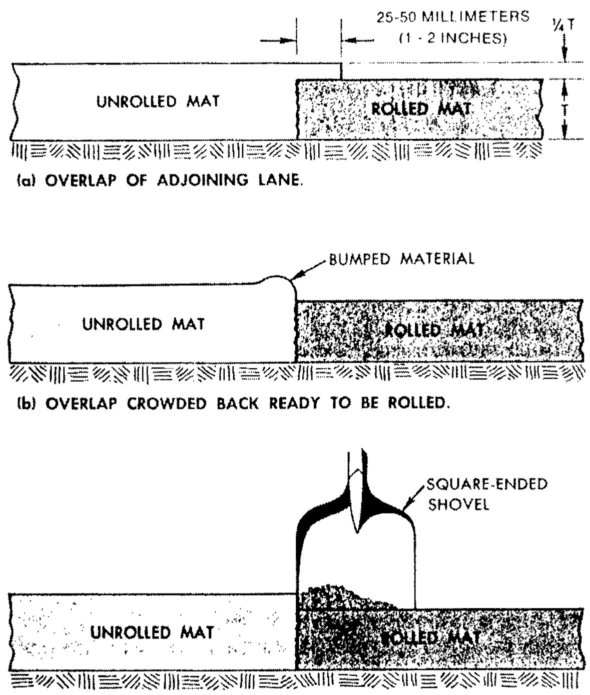


Figure 3-81. Constructing longitudinal joints *(NAPA)*.

Rolling from the Hot Side

The most efficient way to compact the longitudinal joint is to put the roller on the hot mat and overlap the joint by a distance of approximately 6 in. over the cold mat, as shown in Figure 3-86. This places the majority of the weight of the compaction equipment where it is needed. The mix at the joint is still pushed into the joint area by the roller as long as the elevation of the new mix at the joint is proper. The longitudinal joint

Figure 3-83. Excess raking of longitudinal joint *(J. Scherocman)*.

Figure 3-82. Removing excess mix from longitudinal joint.

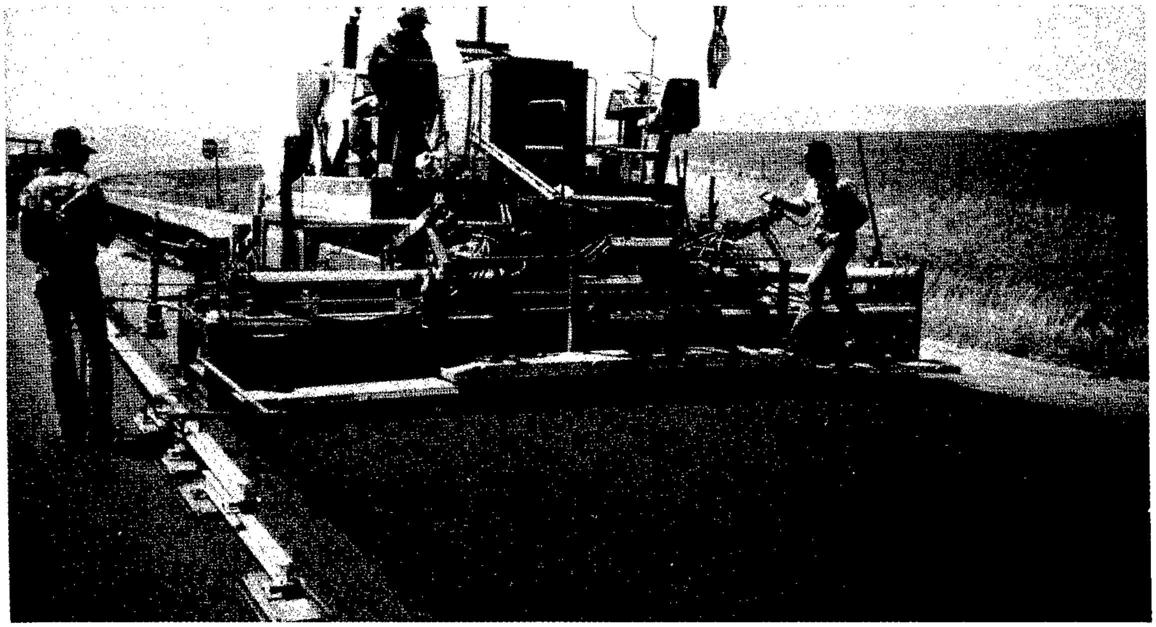


Figure 3-84. Longitudinal joint not raked *(J. Scherocman)*.

can be compacted effectively by keeping the roller on the new mix instead of on the already compacted mix. Any type of roller used for the breakdown rolling of the mix can be employed to compact the longitudinal joint as long as the elevation of the mix at the joint is above the level of the cold mat and the mix is still hot.

Sometimes the first pass of the roller is completed with the edge of the machine about 6 in. inside of the longitudinal joint. The theory behind this method of compaction is that the mix will be shoved toward the joint by the roller, and better compaction will be obtained. If the mix being placed is stable enough, the roller should not be able to move the material laterally

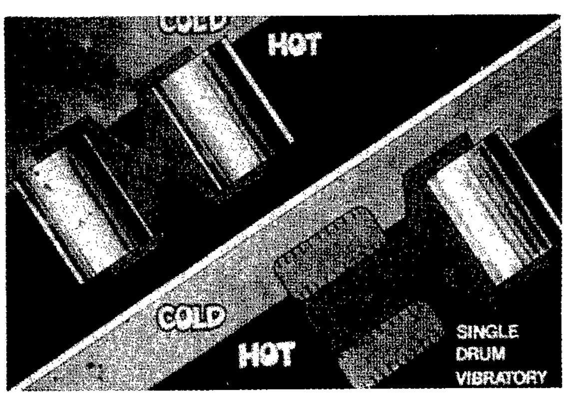


Figure 3-85. Compacting longitudinal joint *(Dynapac)*.

to any significant degree. If the mix design is proper, this method of compacting the joint does not provide any advantage over moving the first pass of the roller outward 1 ft (from 6 in. inside the joint to 6 in. outside the joint). Rolling the mat by lapping the roller over the adjacent old pavement typically is the more efficient way to provide roller coverage for the whole pavement width.

Rolling from the Cold Side

It has been common practice in the past to do the initial rolling of the longitudinal joint from the cold (previously placed mat) side of the joint, as seen in Figure 3-87. The major portion of the weight of the roller was supported by the cold, compacted mat. Only 6 in. or so of the width of the roller hung over the fresh mat, compressing the mix along the joint. The majority of the compactive effort was wasted because the roller essentially was applying its compactive effort to an already-compacted asphalt material.

During the time that the roller was operating on the cold side of the longitudinal joint, the mix on the hot side of the joint, and the rest of the mix in the course being laid, was cooling. Depending on the environmental conditions and the thickness of the mix being placed, the process of compacting the joint from the cold side often proves to be detrimental to the ability to obtain

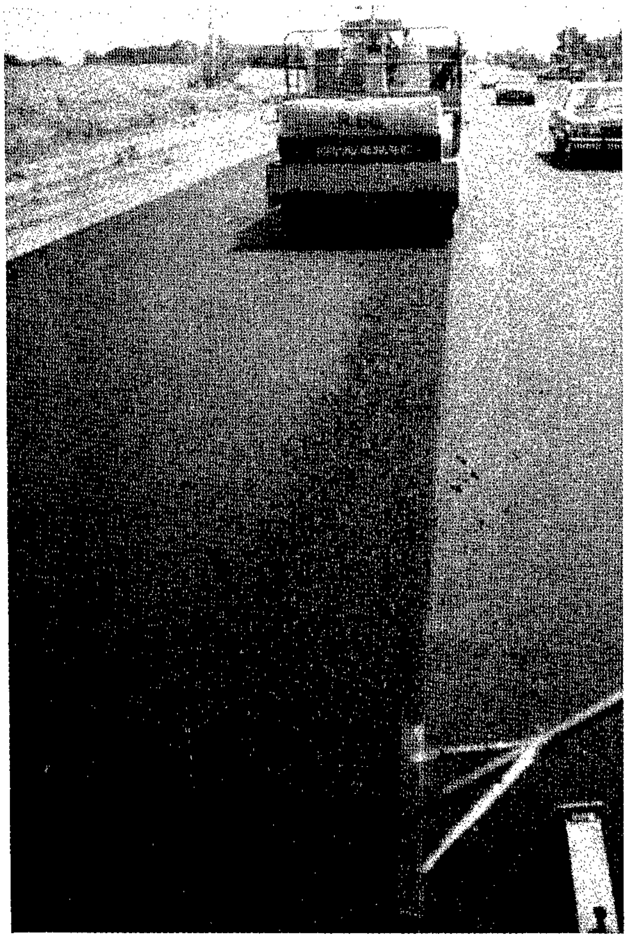


Figure 3-86. Compacting longitudinal joint from hot side *(J. Scherocman)*.

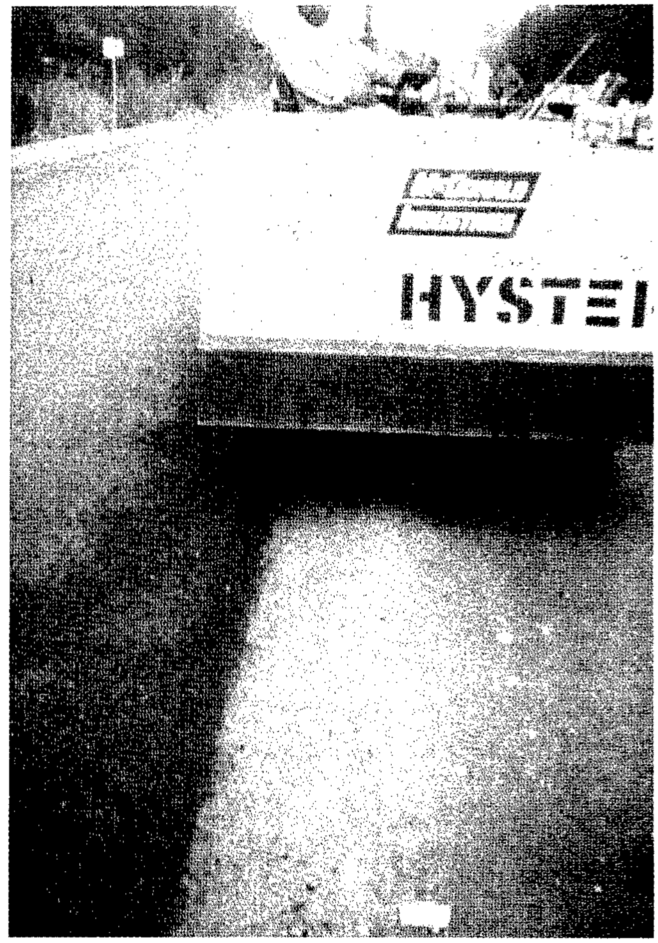


Figure 3-87. Compacting longitudinal joint from cold side *(J. Scherocman)*.

density on the whole pavement layer.

The reason often given for rolling the joint from the cold side of the joint was that this compaction method allowed the rollers to "pinch" the joint and obtain a higher degree of density. There is no evidence that this is true. Indeed, regardless of the method used to compact the longitudinal joint, the level of density obtained at that location is typically 1 to 2 percent below the average density that can be produced in the main part of the mat. This is primarily because of the fact that the first placed lane has an unsupported edge that is always more difficult to compact. It is the lack of density in this original part of the longitudinal joint that affects the level of density that can be obtained when the new mix is placed along the joint.

Echelon Paving

If echelon paving (two pavers running next to each other) is used, the construction of the longitudinal joint is essentially similar to the building of a joint against a cold, compacted pavement layer. In this case, however, the amount of overlap between the first and second lanes is very important. The distance that the screed and end gate of the trailing paver should extend over the uncompacted mat behind the first paver should be limited to no more than 1 in. The end gate of the second paver must be set at the same level as the bottom of the screed plate of the first paver. This will prevent the end gate of the screed of the second paver from dragging on the mix placed by the first or leading paver.

No raking of the joint need be accomplished. The compaction process is modified to require the rollers densifying the mix behind the lead paver to stay about 6 in. away from the free edge of the mat on the side toward the second paver. Once the mix from the second or trailing paver is placed against the uncompacted edge of the mix from the first paver, the rollers compacting the second lane are employed to densify the mix on both sides of the joint. Properly lapped and properly compacted, it is usually difficult to see the longitudinal joint produced by the echelon paving process. In addition, use of this technique will normally result in the density of the longitudinal joint being equal to the density of the adjacent mat.

JOINT CONSTRUCTION OPERATING TECHNIQUES

Several key techniques should be observed when viewing the construction of both transverse and longitudinal joints in an asphalt pavement. They are:

- If a transverse butt joint is to be built, the paver operator should maintain a constant head of material in front of the screed to a point downstream of the location where the joint is to be made. In order to prevent a decrease in the layer thickness upstream of the transverse joint, the operator should not be allowed to run the hopper, slat conveyors, and augers empty of mix before the joint location is reached.
- For the construction of a transverse butt joint, either treated paper or a wooden board should be used just downstream of the actual butt joint location. Provision must be made to compact the mix adjacent to the butt joint to the same degree as the previously placed mix.
- For the construction of a tapered transverse joint, the thickness of the layer should be maintained to a point downstream of the location where the vertical face of the joint will eventually be constructed. Treated paper, not sand or dirt, should be used as a bond-breaker material under the taper.
- When paving is restarted, the asphalt mix downstream of the transverse joint should be removed and recycled. A vertical face should be present at the selected joint location. A tack coat should be applied to the existing pavement surface adjacent to the joint location.
- The screed of the paver must be set on "starting blocks" on the cold side of the transverse joint. The thickness of the starting blocks should be 1/4 in. for each 1 in. of compacted layer thickness when the blocks and paver screed are set on another pavement layer. If the paver is starting to pave at a new location, the thickness of the starting blocks should be the thickness of the compacted new layer plus 1/4 in./in. of compacted thickness. It is impossible to construct a proper transverse joint if the blocks are not used to bring the screed to the proper elevation on the cold side of the joint before paving is started.
- The mix on the downstream side of the transverse joint must be higher than the mix on the compacted side of the joint. This is necessary to allow for adequate compaction of the freshly placed mix.
- Minimal raking needs to be done at a properly constructed transverse joint. The rakers should never be allowed to disturb the paver-placed mix at the joint except to clear away any new mix that has been dribbled or overlapped onto the upstream or previously compacted side of the joint.
- Ideally, the transverse joint should be compacted in a transverse direction with the rollers. On a practical basis, the transverse joint can be compacted properly with the roller running in a longitudinal direction as long as the initial elevation of the new mix is above that of the old mix on the cold side of the joint.
- During the construction of a longitudinal joint, the end plate or end gate of the paver should overlap the previously placed lane by no more than 1 1/2 in. Any increase in the amount of overlap beyond this distance will provide excess material that will need to be raked off of the joint. The thickness of the new mix should be 1/4 in./in. higher than the compacted mix.
- Minimal or no raking of the longitudinal joint should be necessary if the amount of overlay of the paver screed on the adjacent lane is 1 1/2 in. or less. If raking is done, the raker should not broadcast the mix across the newly placed mix. The excess material should only be pushed 1 in. or 2 toward the longitudinal joint location and be deposited just on the uncompacted side of the joint.
- Compaction of the longitudinal joint should be accomplished by rolling from the hot side of the layer with the roller wheels lapping approximately 6 in. over on the cold mat.

SECTION SIX COMPACTION

INTRODUCTION

Compaction is the single most important factor that affects the ultimate performance of a hot-mix asphalt pavement. Adequate compaction of the mix increases the fatigue life, decreases permanent deformation (rutting), reduces oxidation or aging, decreases moisture damage, increases strength and stability, and decreases low-temperature cracking. An asphalt mixture that has all the desirable mix design characteristics will perform poorly under traffic if that mix is not compacted to the proper density level. A properly compacted mix with marginal properties will often outperform a mix with desirable properties if that mix that is inadequately compacted.

DEFINITIONS

The terms density and compaction are often used interchangeably to describe the process of compressing asphalt mix and increasing its unit weight. The two terms, however, have different definitions.

The density of a material is simply the weight of the material that occupies a certain volume of space. For example, an asphalt concrete mixture containing limestone aggregate might have a compacted density of 147 lb/ft^3. This density, or unit weight, is an indication of the degree of compaction of the mixture. Different paving materials made with different aggregates can have significantly different densities. An asphalt concrete mixture manufactured with lightweight aggregate, for example, might have a compacted density of only 85 lb/ft^3 of volume.

Compaction is the process through which the asphalt mix is compressed and reduced in volume. Compaction permits the unit weight or density of the mix to be increased by placing more materials in a given volume of space or by taking a given amount of material and compressing it into a smaller space or volume. As a result of the compaction process, the asphalt-coated aggregates in the mix are forced closer together, which increases aggregate interlock and interparticle friction and reduces the air void content in the mix.

It is possible, under controlled laboratory conditions, to compact an asphalt concrete mixture to a certain maximum value. At this point, called the maximum theoretical density, no further compaction would be possible and no air voids would remain in the mix (a voidless condition). The maximum theoretical density of a mix can be calculated from the percentages and the specific gravities of each component in the mix. It can also be determined from a laboratory test (the Rice procedure, ASTM Test Method D 2041), which is the recommended procedure.

Because it is impossible on the roadway to compact a well-designed mix to a level of a voidless condition, all asphalt mixes will contain some void spaces or air voids when the compaction process is completed by the rollers. The air void content of the mix is simply the volume of the space between the asphalt-coated particles. Because the volume of those air voids is impossible to measure directly, a ratio of actual unit weight to the theoretical maximum density is used. The air void content is expressed as the ratio of the difference between the maximum theoretical density and the actual density of the mix, as shown by the formula percent air voids = 100[1-(bulk specific gravity/maximum theoretical specific gravity)] and in ASTM Test Method D 3203. Thus, if the compacted density of an asphalt concrete mix is 147.0 lb/ft^3 and the maximum theoretical density of the same mix is 154.0 lb/ft^3, the air void content of the mix would be the difference in the two values (154.0 - 147.0 = 7.0) divided by the value of the maximum theoretical density (154.0), or 4.5 percent.

FACTORS AFFECTING COMPACTION

Four primary factors affect the ability of the compaction equipment to densify an asphalt mixture: the properties of the materials in the asphalt mixture, environmental variables, conditions at the laydown site, and the type of compaction equipment used. Each of these factors is discussed below.

Properties of the Materials

Aggregates

Three properties of the coarse aggregate particles used in an asphalt mixture that can affect the ability to obtain the proper level of density are the particle shape of the aggregate, the number of fractured faces, and the surface texture. As the crushed content of the coarse aggregate increases, as the nominal maximum size of the aggregate increases, and as the hardness of the aggregate (granite compared with limestone, for example) increases, the compactive effort needed to obtain a specific level of density also increases. Angular particles offer more resistance to manipulation than do rounded aggregate particles. This angularity increases the resistance to the applied compactive effort. The surface texture of the individual aggregate particles is also important, with aggregates that have a rough surface texture being harder to compact than aggregates with a smooth surface texture. The compactive effort is also affected by the shape of the aggregate, with a cubical or block-shaped aggregate needing a greater degree of manipulation than a rounded particle shape before achieving a given density level.

A continuously graded (dense-graded) aggregate, from coarse to fine, may be easier to compact than a mixture with any other aggregate gradation. A harsh mix typically requires a significant increase in compactive effort to obtain the desired level of density. An oversanded or finely graded mix, on the other hand, tends to be extremely workable. It still might be difficult to achieve density on such a mix, however, because of the inherent tender nature of such an oversanded mix. Mixes that contain an excess of midsize fine aggregate [between the No. 30 and No. 50 (600 μm and 300 μm) sieves or between the No. 40 and No. 80 (425 μm and 180 μm) sieves] also are difficult to compact because of their lack of internal cohesion; they tend to displace laterally rather than compress vertically. The dust content [amount of aggregate passing the No. 200 (75 μm) sieve] affects the compactive effort needed. A mix designed with a high dust content will generally be more difficult to compact than a mix designed with a lower dust content.

All of the properties of an aggregate that are beneficial in terms of improving the characteristics of the mix in regard to resistance to fatigue and permanent deformation typically increase the difficulty in obtaining a required level of density with a given compactive effort. Thus, the compactive effort needs to be increased to achieve the density level needed in the mix.

Asphalt Cement

The grade and amount of asphalt cement used in the mix affects the ability to densify the mix. An asphalt cement that is higher in viscosity or lower in penetration will generally provide for a stiffer mix at a given mix temperature and therefore require a greater compactive effort. Thus, a mix produced with an AC-20 viscosity-graded asphalt will typically be stiffer, at any particular temperature, than a similar mix that contains an AC-10 asphalt cement. The stiffer the mix, the more compactive effort needed to reach a given density level. This stiffness trend, however, is affected by the temperature viscosity relationship for each particular binder material.

The degree of hardening that occurs in the asphalt cement during the manufacture of the mix affects the compactibility of that material. Different asphalts harden differently during the mixing process, and that hardening is related, in part, to the chemical properties of each asphalt cement and its temperature susceptibility. The degree of hardening is also a function of the type and operating characteristics of the plant; more hardening will typically occur when a drum mix plant is operating at partial capacity compared with when it is producing mix at full capacity. Further, hardening is a function of the mixing temperature at the plant, with higher manufacturing temperatures typically producing stiffer mixes.

The asphalt cement content of the mix influences its compactability. In general, a mix with too little asphalt cement may be stiff and require an increase in compactive effort, whereas a mix with too much asphalt cement may shove under the rollers.

Mix Properties

A mix that is placed at a higher temperature will be easier to compact than will a mix that is lower in temperature when it is laid. If the initial mix temperature is too high, however, the mix may be tender and difficult to compact until the mix temperature decreases and the viscosity of the asphalt cement increases. If the mix temperature is too low, an increased amount of compactive effort will be needed to obtain the required density, and, if the temperature is too low, required density may never be achieved.

The workability of the mix is affected by the temperature susceptibility of the asphalt cement. For a highly temperature-susceptible asphalt binder material, less time will be available for compaction because the mix will change stiffness more quickly with a change in temperature than will a mix containing a less temperature-susceptible asphalt.

The fluids content of the mix, not just the asphalt content, affects the compactive effort needed. Fluids content is the sum of the asphalt cement content and the moisture content of the mix. If the amount of moisture in the mix from the plant is high, the extra fluids content may make the mix unstable and difficult to compact. Thus, the moisture content of the mix should be less than 0.5 percent, by weight of mix, when the mix is discharged from the plant.

Environmental Variables

Research work completed in the early 1970s determined the time available for compaction of various asphalt concrete mixes. The time available for compaction was defined as the time, in minutes, it took for a mix to cool from laydown temperature to a minimum compaction temperature. Laydown temperature is the mix temperature when the paver screed passes over the mix. Minimum compaction temperature for this study was set at 175°F. Below this temperature, it was found that the internal friction and cohesion of the mix increases to the point that little density gain is achieved with the application of additional compactive effort. Any additional rolling with steel wheel rollers, except to remove roller marks, may result in fracture of the aggregate in the mix and in a decrease in density. (It is emphasized, however, that rolling should occur at as high a temperature as possible, given the properties of the asphalt mix, in order to achieve the required level of density with minimum compactive effort. At temperatures near 175°F, the probability of significantly increasing density or reducing air voids is very low except for unusual mix behavior or with the use of special rolling techniques such as heavy vibratory rollers or pneumatic tire rollers with very high tire pressures.)

Six variables were found to have an effect on the rate of cooling (and, therefore, on the possibility of obtaining a required level of density) of a layer of asphalt placed on top of another existing layer of the same type of material. Those variables are: layer thickness, air temperature, base temperature, mix temperature, wind velocity, and solar flux.

A series of "cooling curves" for asphalt concrete mixtures, which are shown in Figures 3-88 and 3-89, illustrate the amount of time available for compaction under different combinations of variables. For these two figures, it is assumed that the material being compacted is a dense-graded asphalt concrete mix. Ambient air temperature is assumed to be equal to the surface temperature of the base. A constant wind velocity of 10 knots (about 11.1 miles/hr) and a constant degree of solar radiation (solar flux of 50 BTU/ft^2/hr) is also used to generate the graphs. The curves then provide the time, in minutes, for the mix to cool from the laydown temperature to the minimum compaction temperature (175°F) for different compacted layer thicknesses.

To use the graphs it is necessary to determine the value of three different variables: initial mix laydown temperature, base surface temperature (which is often assumed to be equal to the ambient air temperature), and compacted layer thickness. Figure 3-88 is to be used for mix laydown temperatures of both 250°F and 300°F. Figure 3-89 is to be used when the mix laydown temperature is 225°F or 275°F. The range of base temperatures for each set of curves is from 10°F to 60°F. The range of mix layer thicknesses is from 1/2 in. to 6 in.

Layer Thickness

Layer thickness is probably the single most important variable in the rate of cooling of asphalt mixtures, especially for thin lifts. In many places, for early spring and late fall paving, layers of mix less than 2 in. in compacted thickness are very susceptible to premature failure because of the inability of the compaction equipment to densify the mix adequately before it cools below the minimum compaction temperature. It is very difficult to obtain the desired density on thin lifts of mix in cool weather because of the rapid loss in temperature in the mix.

As the thickness of the layer being placed increases, the time available for compaction also increases. For example, in Figure 3-88, for a mix laydown temperature of 250°F and a base of 40°F, a 1-in.-thick mat will cool from that 250°F temperature to the 175°F compaction cutoff point in less than 4 min. For a 2-in.-thick layer, under the same mix and base temperature conditions, it will take about 10 min for the material to cool to 175°F. Doubling the lift thickness from 1 to 2 in. increases the time available for compaction from 4 to 10 min. If the layer depth is 4 in., the time to cool changes to about 29 min, a significant increase in available compaction time under similar temperature conditions.

Using the same figure, the relative effect of pavement lift thickness is the same for a mix laydown temperature of 300°F and a base temperature of 40°F. As the course depth is decreased from 4 in. to 2 in. to 1 in., the time available for the mix to cool from 300°F to 175°F decreases from more than 40 min to 16 min to only 6 min, respectively. From these data, it is apparent that the time available to compact a thin layer of asphalt is extremely limited in cold weather.

Air and Base Temperature

A portion of the heat in the asphalt layer is lost to the air. All other factors being equal, an increase in the ambient air temperature decreases the rate of cooling of the mix. This increase in air temperature allows more time for the compaction equipment to achieve the desired density level in the mix.

Heat in the mix is also lost to the layer on which the new material is placed. There usually is more rapid

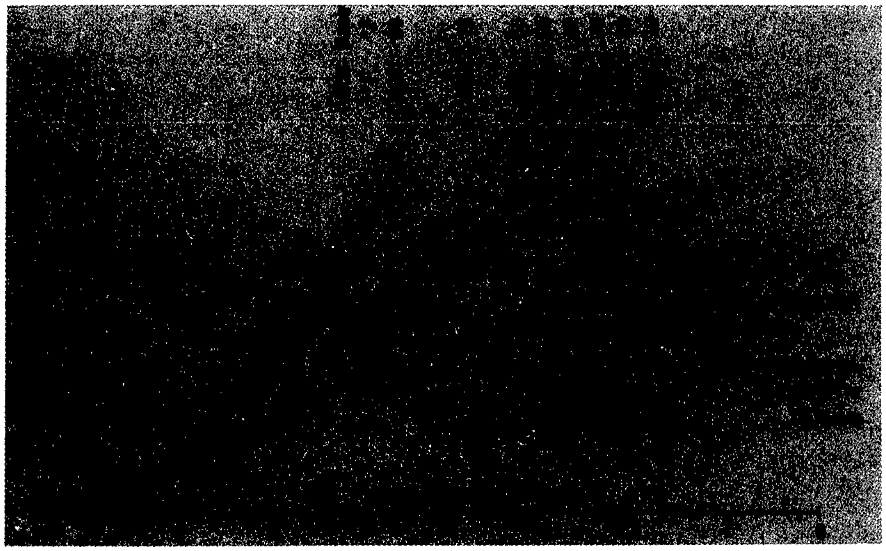


Figure 3-88. Time for mat to cool to 175°F vs. mat thickness for lines of constant mix and base temperatures (250°F or 300°F behind paver) *(Dickson and Corlew; AAPT 1970)*.

cooling of the mix downward to the base than upward into the air. Base temperature is actually more important than air temperature in determining the time available for compaction. Most specifications, however, specify a minimum air temperature for paving and compaction operations.

It is often assumed that air and base temperature are the same. This is not necessarily true, particularly in cool weather. In early spring, the base temperature (surface temperature of an existing pavement layer) will be less than the ambient air temperature early in the morning. The air temperature may be "40°F and rising," but the base might be 5°F or 10°F below the air temperature. This low base temperature will cause the newly placed course to cool quickly, reducing significantly the time available to achieve adequate density. Base temperatures are often higher in the late fall than in the early spring for the same overnight air temperature. Thus, less heat is lost to the base and it is easier to compact a given thickness of material in the fall com-

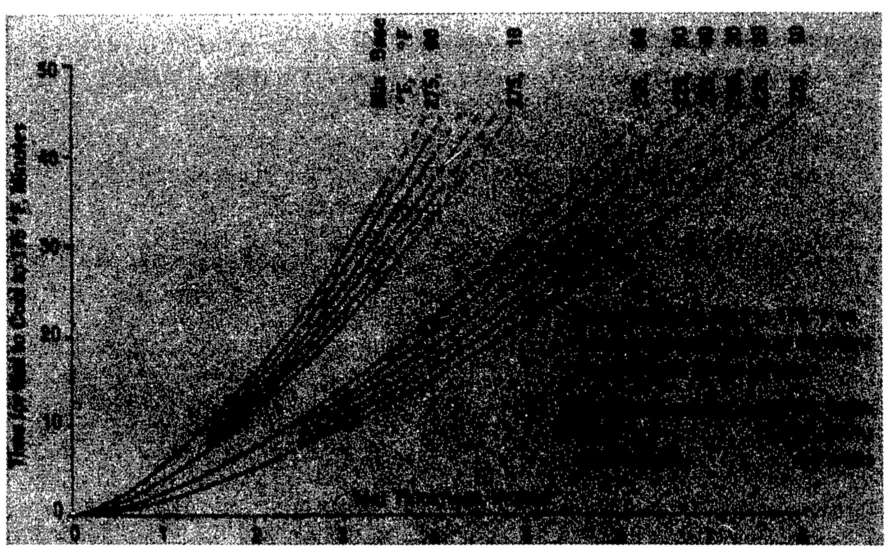


Figure 3-89. Time for mat to cool to 175°F vs. mat thickness for lines of constant mix and base temperatures (225°F or 275°F behind paver) *(Dickson and Corlew; AAPT 1970)*.

pared with the spring.

A moist base layer significantly increases the cooling rate of the new overlying asphalt layer. Heat is lost from the mix to the moisture, turning water into steam and increasing the rate of heat transfer. Paving on a wet surface is detrimental to the ability to gain proper density in the mix. The presence of the moisture may cause the mix to cool quickly and reduce the time available for compaction.

As the temperature of the ambient air and existing pavement surface increases, the time for the mix to cool from the laydown temperature to 175°F also increases. In Figure 3-89, for a mix of 275°F and a lift thickness of 3 in., it takes only 22 min for the mix to cool when the base and air temperatures are both 20°F. The time available is extended to 25 min for a base/air temperature of 40°F and to 30 min for a 60°F base/air temperature.

For a 2-in. lift thickness, using the same mix laydown temperature of 275°F in Figure 3-89, the time to cool to 175°F increases from 11 min, to 13 min, and to 15 min for a base/air temperature of 20°F, 40°F, and 60°F, respectively. The temperature of the ambient air and base surface are important, but not nearly so crucial as mat lift thickness in determining the time available for compaction.

Mix Laydown Temperature

Asphalt mixes are usually produced at temperatures between 270°F and 325°F. Depending on environmental conditions and the length of haul, the mixture can lose between 5°F and 25°F from the plant to the paver. It is not the plant mixing temperature that is important in determining the time available for compaction but the temperature at which the mix comes out from under the paver screed. As the initial mix laydown temperature is increased, the time available for compaction also increases. Within limits, the mixing temperature should be determined by the laydown and compaction temperature requirements.

As the temperature of the hot-mix asphalt being placed is increased, the time available for compaction is greater. This is seen in Figure 3-88 for laydown temperatures of both 250°F and 300°F. For a lift thickness of 2 in. and a base/air temperature of 40°F, the time to cool to 175°F increases from 9 min to 16 min as the placement temperature increases from 250°F to 300°F. For a 4-in. course thickness and a 60°F base/air temperature, a change in laydown temperature from 300°F to 250°F reduces the time available for compaction from 36 min to 21 min.

The effect of mat laydown temperature is more significant at lesser mat thicknesses and lower base temperatures. As the time to cool to 175°F becomes shorter, an increase in the mix laydown temperature extends the compaction time significantly in most cases.

Wind Velocity

A thin layer of mix will cool more quickly in a strong wind than when there is little or no wind. Wind has a greater effect at the surface of the mix than within the mix, and can cause the surface to cool so rapidly that a crust will form. This crust must be broken down by the rollers before the actual compaction process can begin. The velocity of the wind must be considered more for thin layers of mix placed in cool weather than for thicker layers laid in warmer temperatures.

Solar Flux

The amount of radiant energy available from the sun (solar flux) is a function of many variables, including the position of the sun above the horizon, the distance above sea level of the paving project, the amount of turbidity in the air, and the degree of cloud cover. A mix will cool more slowly on a sunny day compared with a cloudy one. The amount of solar flux is more important in its effect on base temperature than its effect on mix temperature. The base temperature will be higher on a sunny day, for a particular ambient air temperature, than it will be on a day with heavy cloud cover. This higher base temperature will reduce the rate of cooling of the mix and increase the time available for compaction.

Obtaining Proper Density under Varying Environmental Conditions

Compaction of the mix requires common sense. If the lift thickness decreases, if the air and base surface temperatures are both reduced, if the laydown temperature is less, if the amount of solar flux is decreased, and/or the wind velocity is increased, then the time available to properly obtain the required level of density before the mix cools to 175°F also decreases. A significant change in any one of the above factors can make the difference between constructing a durable pavement structure or building one that would be subject to an early pavement failure.

If possible, the best solution to a potential compaction problem is to increase the thickness of the material being placed. One-in.-thick layers cool so quickly, even in good environmental conditions, that proper density is almost impossible to obtain. The minimum course thickness that should be specified under the best of circumstances should be 1 1/2 in. For early spring or late fall paving projects, at least 2 in. of compacted asphalt mix should be placed in a single lift, if possible.

The easiest solution to a potential time-availability problem is to increase the discharge temperature of the asphalt mix at the plant, if this procedure does not cause other problems with the mixture. This will permit an increase in the laydown temperature of the mix behind the paver screed, thereby allowing more time for the mix to cool to 175°F, all other factors being constant. Increasing the mix temperature may not be enough, however, to provide adequate time for compaction under adverse environmental conditions and for thin layers of material. If the mix temperature is increased too much, the mix may be tender under the compaction equipment. The mix must then be allowed to cool before the compaction process can be commenced. Thus, there is an upper limit to the amount of temperature increase to which the mix can be subjected.

Compaction effort can be increased by simply using more rollers to compact the pavement layer. In addition, rollers that are wider and/or heavier can be substituted for narrower and/or lighter compaction equipment. A double-drum vibratory roller, for example, that is 7 ft wide can be employed in place of a static steel wheel tandem roller that is only 4 1/2 ft wide.

Another means to achieve proper compaction levels is to use the compaction equipment more effectively. Depending on the width being paved and the width of the rollers, the rollers can be placed almost "side by side" instead of end to end. Two rollers running in echelon can cover a given area much more quickly than two rollers operating in conventional fashion. The level of density obtained will be increased because more compactive effort may be applied before the asphalt mat cools to 175°F. In essence, this method provides for two breakdown rollers instead of one breakdown roller and one intermediate roller. To obtain the required density levels, however, use of an intermediate roller or rollers may still be necessary.

If two different types and/or sizes of rollers (such as a vibratory roller and a pneumatic tire roller) are used for echelon rolling, it is important that each roller cover all of the mix surface. This may mean that the rollers have to cross back and forth and run different roller patterns and numbers of passes. In addition, if one of the rollers is compacting a longitudinal joint, consideration of this fact must be made in setting the rolling pattern for each piece of compaction equipment. It is very important that both rollers are able to keep up with the speed of the paver and that the density obtained is measured to assure that the required level of compaction is achieved uniformly across the width of the mat.

One procedure that should *not* be done in an attempt to increase the level of density in the mix is to increase the asphalt cement content of the mix arbitrarily. Although the additional asphalt cement may be beneficial in increasing the workability of the mix, it defeats the purpose of mix design and may create long-term performance problems for the mix under traffic, such as rutting and shoving. Thus, the required level of density should be obtained by changing the compaction operations instead of increasing the asphalt content of the mix.

Laydown Site Conditions

A number of factors at the laydown site directly affect the ability of the compaction equipment to gain the required level of pavement density. The most important of these is the thickness of the layer being placed. As discussed previously, the thicker the lift, the more slowly the mix will cool down and the more time will be available for compaction. The retained heat of the thicker courses makes it easier to obtain the desired air void content.

The relationship between lift thickness and nominal maximum aggregate size in the mix is another variable that affects the amount of density that can be obtained. If the course depth is at least twice the nominal maximum aggregate size, adequate density can be achieved with normal compactive effort. When the lift thickness is less than two times the dimensions of the largest aggregate pieces, a rough surface texture may result when the large aggregate pieces are dragged by the paver screed. The voids created in the mix from the dragged aggregate negate any efforts to obtain the proper level of density in the mix.

The uniformity of the lift thickness is another factor to be considered. It is much easier to obtain a required level of density in an asphalt layer that has a constant thickness compared with a course that varies in depth. Asphalt leveling courses that, by their very nature and purpose, are nonuniform in thickness, are often difficult to densify to a given air void content uniformly, especially when placed over a rutted or wavy road.

Depending on the width and the depth of the rut, static steel wheel rollers tend to bridge over the rut, particularly if the rut is relatively deep and narrow. Vibratory rollers also tend to be supported by the high points in the surface, but the vibratory action has some beneficial effect in compacting the mix in the rut. Thus,

Figure 3-90. Static 3-wheel roller *(J. Scherocman)*.

adequate density is usually not obtained throughout the mix, particularly in the rutted areas where it is needed the most. Use of a pneumatic tire roller may be helpful in achieving density in the low spots (ruts) as well as in the high spots on the pavement surface if proper tire inflation pressure and wheel load are used.

Compaction Equipment

The type of equipment used to compact the asphalt mix obviously has a significant effect on the degree of density that can be obtained in a given number of passes of a particular roller. Three types of self-propelled compaction equipment are currently being used: static

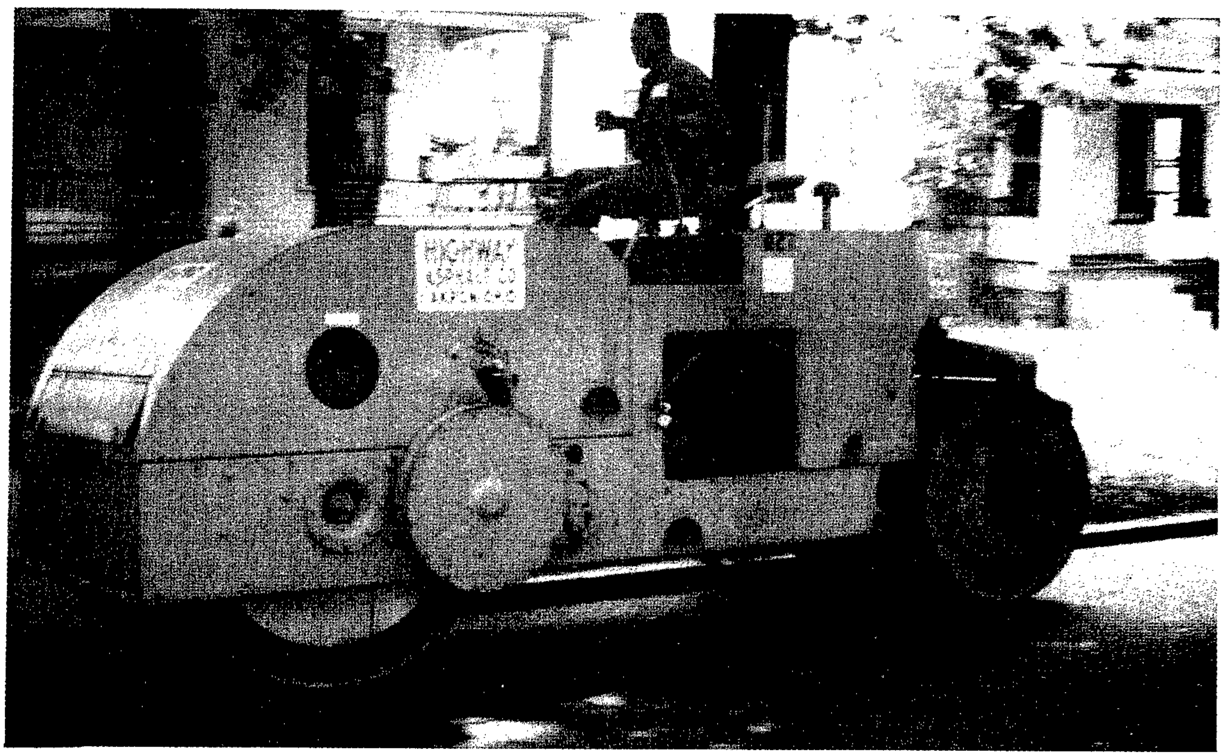


Figure 3-91. Static tandem roller *(J. Scherocman)*.

steel wheel rollers, pneumatic tire rollers, and vibratory rollers.

Static Steel Wheel Rollers

Static steel wheel rollers, shown in Figures 3-90 and 3-91, normally range in weight from 3 to 14 tons and have compression drums or rolls that vary in diameter from approximately 40 in. to more than 60 in. The gross weight of the roller can usually be altered by adding ballast to the roller, but this adjustment cannot be made while the roller is operating, and is not normally changed during the term of a paving project. For this type of roller, the gross weight of the machine and the contact area of the rolls with the mix are both important in determining the compactive effort applied by the roller.

Effective weight or contact pressure, in terms of pounds per square inch of contact area, is the key variable for this type of equipment and is dependent on the depth of the penetration of the rolls into the mix. The greater the depth of penetration, the greater the contact area and thus the less the contact pressure. This means that on the first pass of the roller, when the indentation of the rolls into the mix is the greatest, the roller exerts less compactive effort on the mix. On subsequent passes of the roller over the same mix and as the mix gets more dense, the rolls on the roller penetrate the mix to a lesser degree and the compactive effort obtained by the roller is increased.

Drawbar pull is defined as the horizontal force required to move the roller forward. The most efficient roller is the machine with the smallest drawbar pull. Rollers with large-diameter rolls have lower drawbar pull (rolling resistance) because they do not tend to penetrate as far into the mix as does a roller with smaller-diameter rolls.

Once the size and weight of a static steel wheel roller is selected, the variables under the control of the roller operator are the speed of the roller, the position of the roller on the mat in relation to the paver, operation with the drive wheel toward the paver, and the number of passes made with the roller.

Pneumatic Tire Rollers

Most pneumatic rollers are operated in the intermediate roller position, behind a vibratory or static steel wheel breakdown roller and in front of a static steel wheel finish roller. These rollers are sometimes used, however, for initial rolling of the mix as well as occasionally for finish rolling.

For this type of roller, shown in Figure 3-92, the compactive effort applied to the mix is a function of the wheel load of the machine, the tire pressure, the tire design (tire size and ply rating), and the depth of penetration of the tires into the mix. All of the tires on the roller should be the same size, ply, and tire pressure. The area of each tire footprint and the wheel load of the roller are the primary factors in judging the effectiveness of a rubber tire roller. The greater the contact pressure between the tire and the mix, the greater the compactive effort applied by the roller. To be effective when used in the breakdown roller position, larger tire size rollers should be used. Rollers that are equipped with tires that are 7.50 x 15 or less are not normally effective as a breakdown roller; pneumatic tire rollers with larger-size tires should be employed. If these rollers are used as intermediate rollers, the minimum tire ply rating should be 10 ply and the tire pressure should be 60 psi or greater.

The tire pressure used depends in part on the number of plies used in the tires. In general, a 6-ply tire is limited to a tire pressure of 60 psi, whereas a 10-ply tire can carry a pressure up to 90 psi. A 12-ply tire, normally used on most large pneumatic tire rollers, can be inflated up to 120 psi to compact asphalt mixes. The minimum weight of the pneumatic tire roller should be 15 tons.

If the mix is tender, a lower tire pressure will displace the mix less than will a higher pressure in the tires. For a stiff mix, a higher tire pressure can be used, because the mix will be stable enough to support the weight of the roller without the mix shoving laterally under the tires. Tire pressure is normally kept constant for a particular project, but the level selected should be dependent on the properties of the mix being compacted and the position of the roller on the mat. The tire pressure should not necessarily be the same if the pneumatic tire roller is used in the breakdown position compared with the intermediate position in the roller train.

Some pneumatic tire rollers have the capability of changing tire pressure during the compaction process; the "air on the run" or centralized tire inflation-control system. In theory, this feature allows the roller operator to change tire pressures as the mix becomes more dense; that is, a low tire pressure is used for the initial passes of the roller and a higher tire pressure is used as the mix stiffness is increased (as the density of the mix becomes greater). In practice, however, this process seldom is used because the operator cannot develop a consistent rolling pattern and is not able to adjust the tire pressure continually as the mix and environmental variables change throughout the day.

The tires on the pneumatic roller will often pick up the mix when an oversanded surface course mix or a mix with some particular additives is being compacted. Many times attempts are made to eliminate this pickup problem by spraying water or a release agent on the tires during the rolling process. This does not always solve the problem. A better solution is to allow the tires on the roller to reach the same temperature as the mix being compacted without adding water or release agent to the tires. When the pneumatic tires and the mix are at the same temperature, the amount of pickup will be minimized or eliminated. Skirts, consisting of pieces of plywood or rubber sheeting, are sometimes hung down from the sides of the roller around the tires for the purpose of shielding the tires from the wind and keeping them hotter. The benefits of such a practice are not well documented.

If this type of roller is to be used as the breakdown roller in the roller train at the start of paving in the morning, it is suggested that, in order to minimize pickup, the roller should be run back and forth for 10 min or so, before the paver begins to lay mix, in order to start heating up the tires. Once paving commences, the rubber tire roller should be operated in the intermediate position, behind a static steel wheel roller or a vibratory roller, for another 10 min while the temperature of the tires increases to the same level as the mix. During the heating process, some pickup of the mix may occur with the tires. Once the tires have reached the same temperature as the mix, however, the pneumatic tire roller can be moved into the breakdown position and should be able to operate successfully without pick-up of the mix. If the paving process is interrupted for any significant length of time, this heating start-up procedure will have to be repeated. In no case should the pneumatic tire roller, or any other roller, park on the hot mat while waiting for the paving operation to start again.

Once the size of the pneumatic tire roller and the tire pressure to be used are selected, the only variables that can be controlled easily by the operator are the rolling speed, the location of the roller with respect to the paver, and the number of roller passes over each point in the pavement surface. If the compactive effort applied by the pneumatic tire roller is not adequate, the operator should alter the wheel load on the tires and/or change the inflation pressure in the tires.

Figure 3-92. Pneumatic roller *(J. Scherocman)*.

Vibratory Rollers

Vibratory rollers come in a variety of configurations. Single-drum vibratory rollers, illustrated in Figure 3-93, are manufactured with both a rigid frame and an articulated frame. Double-drum vibratory rollers, shown in Figures 3-94 and 3-95, come in rigid-frame, single-articulated-frame, and double-articulated-frame models. These rollers can be operated in any one of three modes: static (with the vibrators off), with one drum

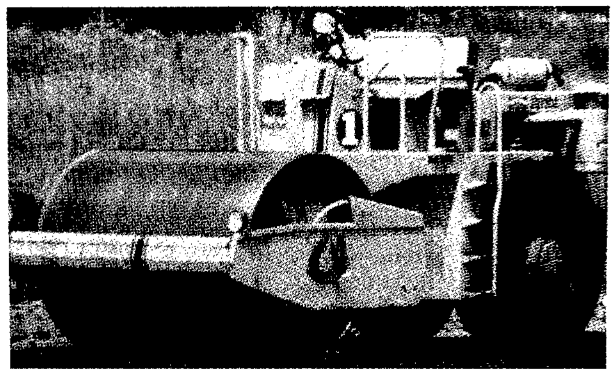


Figure 3-93. Single-drum vibratory roller *(J. Scherocman)*.

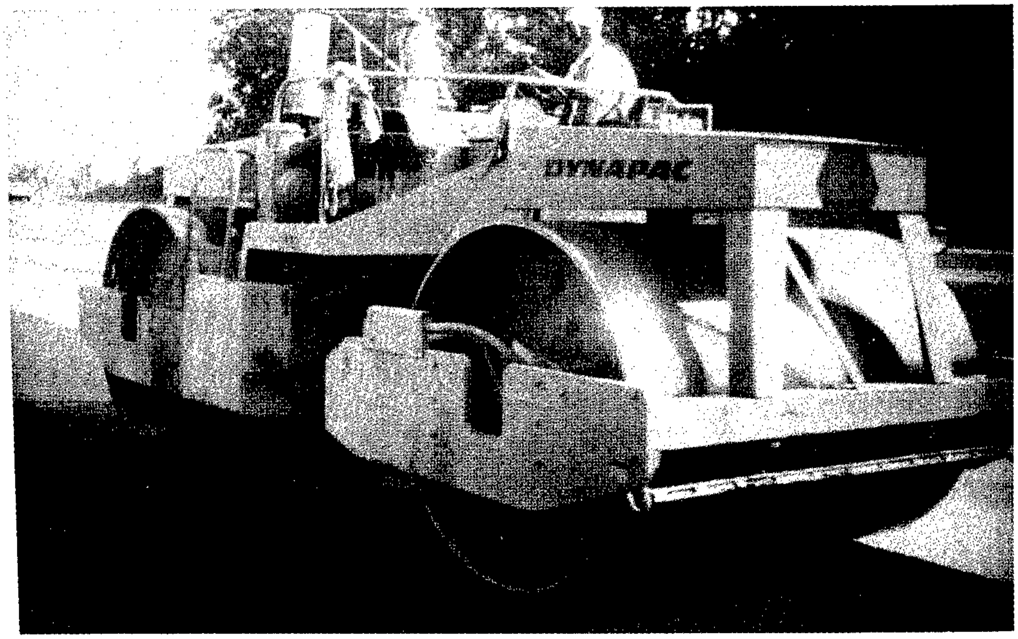


Figure 3-94. Double-drum vibratory roller *(J. Scherocman)*.

vibrating and one drum static, and with both drums vibrating.

These rollers thus have two types of compactive force that is applied to the hot-mix asphalt: static weight and dynamic (impact) force. The compactive effort derived from the static weight of the roller is caused by the weight of the rolls and frame. The compactive effort derived from the impact force is produced by a rotating eccentric weight located inside the drum (or drums). As the eccentric weight rotates about the shaft inside the drum, a dynamic force is produced. This force is proportional to the eccentric moment of the rotating weights and the square of the rotational velocity, as shown in Figure 3-96. Changing the eccentric moment

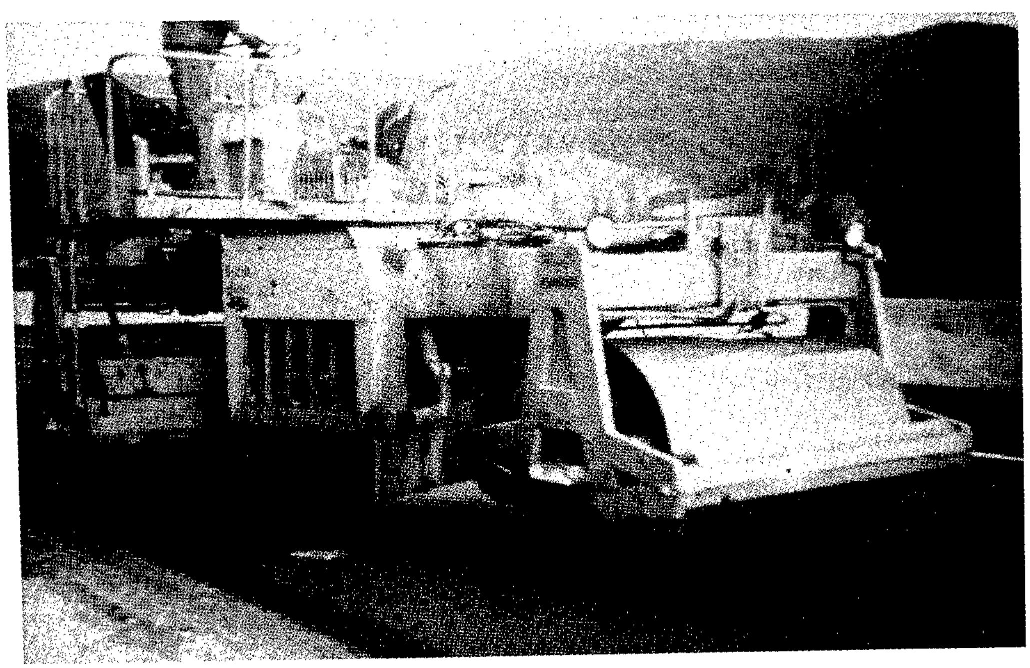


Figure 3-95. Articulated double-drum vibrator roller *(J. Scherocman)*.

arm or adjusting the eccentric mass has a directly proportional effect on the dynamic force.

Although it is possible to combine the static and the dynamic forces to determine a total applied force, this procedure is not recommended for comparing vibratory rollers of the same or different classes. Each component of the total applied force should be evaluated separately. The elements of comparison for the dynamic component of a vibratory roller are the magnitude of the centrifugal force, its vibrating frequency, the nominal amplitude, and the ratio of the vibrating and nonvibrating masses acting on the drum. The nominal amplitude is defined as equal to the weight of the drum divided by the eccentric moment of the rotating weight and is a function of the weight of the drum and the location of the eccentrics.

Normal values of nominal amplitude range from 0.01 to 0.04 in. Some rollers can operate at only one fixed amplitude. Other rollers have "high" and "low" amplitude positions. For these rollers, the "low" nominal setting is typically 50 percent of the "high" nominal amplitude setting. The actual amplitude differs from the nominal amplitude because of the variation in damping effect of different materials at different states of compaction. An increase in the applied nominal amplitude of vibration increases the compactive effort applied to the asphalt mixture. For a given frequency, changing the amplitude setting has a proportional effect on the dynamic force. For a given amplitude, changing the frequency influences the dynamic force to the second power.

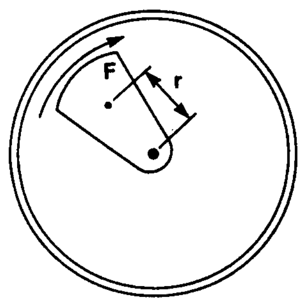
The effectiveness of an increase in the amplitude value, however, is sometimes dependent on the thickness of the layer being densified. For relatively thin layers of mix, generally less than approximately 1 1/4 in. in compacted thickness, the vibratory roller should typically be operated in the static mode--without vibration. This is because the roller will bounce after a few passes (and possibly decompact instead of compact the mix) on such thin layers of mix because of the variable stiffness of the underlying pavement courses. In general, for layers 1 1/4 in. thick or greater, a "low" amplitude setting should be used on the vibratory roller. As the layer thickness increases, it is often advantageous to increase the nominal amplitude applied to the asphalt mix. Unless "high" amplitude is needed to achieve a particular density level, the vibratory roller should be operated in "low" amplitude.

The frequency of vibration is the number of complete cycles that the eccentrics rotate per minute. The faster the rotation of the eccentrics, the greater the frequency of vibration. Some vibratory rollers can operate at only one frequency or have a very limited selection of frequencies. Other vibratory rollers can alter the frequency of the applied load between 1600 and 3000 vibrations/min. Frequencies below 2000 vibrations/min are not normally acceptable to compact asphalt mixtures.

The spacing of the impacts of the applied force is a function of the frequency of the vibration and the travel speed of the roller. A decrease in the frequency of vibration and an increase in the roller speed both serve to increase the distance between impacts on the surface of the mix. Conversely, an increase in the vibratory frequency and a decrease in the roller speed both cause the number of impacts per foot of distance to increase, thereby increasing the compactive effort applied by the roller. A smaller impact spacing (a greater number of impacts per foot) is thus usually preferred. It must be realized, however, that the productivity of the roller can be decreased as the roller speed is reduced.

It has been suggested by several roller manufacturers that the ideal impact spacing is in the range of 8 to 10 impacts/ft in order to provide a balance between roller productivity and layer smoothness. This spacing can be determined by dividing the roller speed by the frequency of vibration: Impact spacing = roller speed in feet per minute divided by the frequency in vibrations per minute. Eight impacts/ft = 1.5 in. between impacts, whereas 10 impacts/ft = 1.2 in. between impacts. At a vibratory frequency of 2400 vibrations/min, a roller speed of 3.4 miles/hr would provide an impact spacing of 8 impacts/ft, and a roller speed of 2.7 miles/hr would result in an impact spacing of 10 impacts/ft. If the vibratory frequency was 3000 vibrations/min, the corresponding roller speeds would be 4.1 and 3.3 miles/hr for an impact spacing of 8 and 10 impacts/ft, respectively.

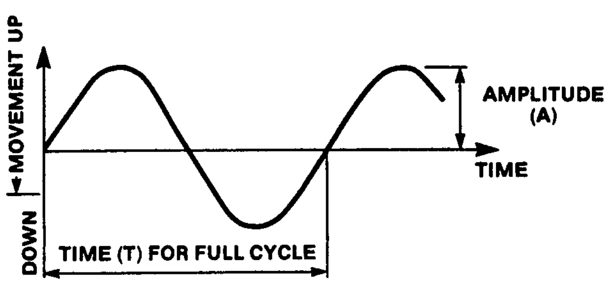
In general, the vibratory roller should be operated at as high a frequency as possible. A roller capable of running from 2000 to 2400 vibrations/min should be operated at the upper end of this frequency range. Similarly, a roller that can be run at 3000 vibrations/min should be run at or near that maximum frequency instead of some lower frequency. The use of the highest possible frequency of vibration increases the number of impacts per foot at a given roller speed. Most rollers are designed so that the highest frequency can be employed at the highest amplitude setting. For some rollers, however, it is necessary to operate at a somewhat lower frequency when the roller is used in the highest amplitude setting. In any case, the most appropriate impact spacing varies with the lift thickness and the properties of the asphalt mixture. The selected impact



Centrifugal force, N (lb) = $\frac{(4\pi^2 f^2 Fr)}{g}$

where:
- F = weight of eccentric, N (1 lb)
- r = eccentricity, m (ft)
- Fr = eccentric moment, Nm (1 lb · ft)
- f = frequency, Hz (cycles/s)
- g = acceleration due to gravity, 9.81 m/s^2 (32.17 ft/s^2)

Centrifugal force.



Frequency, f = the number of hertz (cycles/s) -- a single cycle is one full rotation of the eccentric weight. Frequency = $\frac{1}{T}$

Amplitude, A = the maximum deviation from position at rest -- one-half of the total movement.

Frequency and amplitude.

Figure 3-96. Basic formulas for vibratory compaction effort *(Asphalt Institute)*.

spacing (and corresponding roller speed and vibratory frequency) should optimize the amount of compaction obtained per pass of the roller and the smoothness of the pavement.

The roller operator is in control of more variables when using a vibratory roller and thus should be well educated in the proper selection and interaction of the variables. In addition to roller speed, location on the layer being compacted, and number of passes made, both the nominal amplitude and the frequency of the vibratory impact can be varied. Roller speed and vibratory frequency are combined to determine the impact spacing. Further, for double-drum vibratory rollers, the operator can vibrate either one or both rolls. This allows the operator to control the compactive effort applied to the mix to a greater degree and makes the vibratory roller more versatile than either the static steel wheel or the pneumatic tire rollers. Construction of a roller test strip is needed, however, to determine the optimum combination of rollers, roller speed, and vibratory amplitude for each particular set of project conditions. If the required compactive effort cannot be achieved, the speed of the roller should typically be decreased and the nominal amplitude setting being used should be changed.

Care should be taken when operating a vibratory roller in areas where buildings are nearby. (A safe distance from buildings would be about 3 ft for each ton of roller weight.) In addition, the use of vibration on the roller when underground utilities and drainage structures are directly under the pavement layer being compacted needs to be considered carefully.

COMPACTION VARIABLES

The primary compaction variables for all types of rollers that can be controlled during the rolling process are: (a) roller speed, (b) number of roller passes, (c) rolling zone, and (d) roller pattern. In addition, for vibratory rollers, vibration frequency, vibration amplitude, and direction of travel are also under the control of the operator. Each of these factors has an effect on the level of density achieved under the compactive effort applied to the mix.

Roller Speed

The faster a roller passes over a particular point in the new asphalt surface, the less time the weight of the roller "dwells" on that point. This in turn means that less compactive effort is applied to the mixture. As roller speed increases, the density achieved with each roller pass decreases. The roller speed selected is dependent on a combination of factors: productivity, layer thickness, and the position of the equipment in the roller "train."

Static steel wheel rollers can normally operate at a speed between 2 and 5 miles/hr (176 and 440 ft/min). Pneumatic tire rollers typically run between 2 and 7 miles/hr (176 and 616 ft/min), whereas vibratory rollers can operate at speeds between 2 and 3 1/2 miles/hr (176 and 308 ft/min). In the breakdown position, the roller used should be operated at the lower end of its speed range. In the intermediate position, the speed of the roller can be increased somewhat, typically into the middle of the speed range. In the finish rolling position, the maximum speed of each type of roller can be near the upper end of its range of compaction speeds. The following table provides an indication of the range of roller speed for three different types of rollers and three different operating positions:

TYPE OF ROLLER	TYPICAL RANGE OF ROLLER SPEEDS, IN MILES PER HOUR		
	Breakdown	Intermediate	Finish
Static steel wheel	2 - 3½	2½ - 4	3 - 5
Pneumatic	2 - 3½	2½ - 4	4 - 7
Vibratory	2 - 3	2½ - 3½	----

Rollers can move faster or slower than these speeds, but compaction varies directly with roller speed. Compactive effort is significantly improved at slower roller speeds. Roller speed will also be governed by the lateral displacement or tenderness of the asphalt mix. If the mixture moves excessively under the rollers, the speed of the compaction equipment should be reduced. In addition, for vibratory compactors, roller speed also affects the impact spacing as shown in Figures 3-97 and 3-98. As discussed above, this spacing is important for controlling the amount of dynamic compaction energy applied to the mix and also for obtaining the proper surface smoothness.

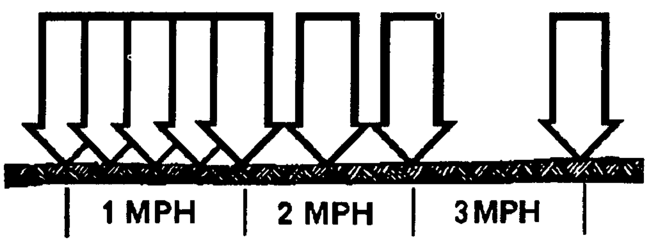


Figure 3-97. Effect of roller speed on impact spacing *(Asphalt Institute)*.

Roller speed is usually established by the speed of the paver; if the paver pulls away from the rollers, the roller speed is increased in order to catch up. This only causes the density developed in the asphalt mixture to decrease for the same number of roller passes. If the paver continually pulls ahead of the rollers, several courses of action can be taken. First, paver speed can be reduced to match both plant production and roller production. Too often, the paver is operated on a "hurry and wait" basis between truckloads. If plant production capacity necessitates higher paver speeds, additional rollers will be required to achieve adequate density. Wider rollers can be employed; a 7-ft-wide vibratory roller can be used in place of a 4 1/2-ft-wide tandem roller, for example. The type of roller used can also be changed; a double-drum vibratory roller employed in lieu of a single-drum vibratory roller.

Varying the speed of the compaction equipment merely causes variations in density. Too often roller operators hustle along to catch up with the paver, park on the hot mat, and sit and talk to the rest of the paving crew. "Slow and steady" is the key to proper compaction.

Number of Roller Passes

To obtain the target air void content and uniform density in an asphalt mixture, it is necessary to roll over each point in the pavement mat a certain number of times. The actual number of passes depends on many variables. The type of compaction equipment is one very important consideration. Three-wheel steel rollers have different compaction capabilities than tandem steel wheel rollers, than pneumatic tire rollers, and than single- or double-drum vibratory rollers.

Frequency (cycles per minute)	Roller Speed Miles per hour (ft/minute)				
	1.5 (132)	2.0 (176)	2.5 (220)	3.0 (264)	3.5 (305)
1000	7.6	5.7	4.5	3.8	3.2
1200	9.1	6.8	5.5	4.6	3.9
1400	10.6	8.0	6.4	5.3	4.5
1600	12.1	9.1	7.3	6.1	5.2
1800	13.6	10.2	8.2	6.8	5.8
2000	15.2	11.4	9.1	7.6	6.5
2200	16.7	12.5	10.0	8.3	7.1
2400	18.2	13.6	10.9	9.1	7.8
2600	19.7	14.8	11.8	9.8	8.4
2800	21.2	15.9	12.7	10.6	9.1
3000	22.7	17.0	13.6	11.4	9.7

Figure 3-98. Impacts per linear foot *(Utah DOT)*.

The capabilities of each type of roller vary, however, with mat thickness, mix temperature, mix design (asphalt content and aggregate characteristics) and environmental conditions. In addition, the number of passes required depends on the position of the rollers in the roller train. To determine the minimum number of roller passes needed to achieve proper density levels, a test strip should be constructed at the start of any major paving project. A number of different combinations of rollers and roller patterns should be tried to determine the "optimum" combination of compactive efforts to achieve the required density level as efficiently as possible. Rarely will the first combination of rollers, roller passes, and rolling zones tried provide the most economical rolling sequence unless the mix is one with which the contractor is thoroughly familiar.

Roller passes must be distributed uniformly over the width and length of the mat. All too often, the center of the paver lane (the area between wheelpaths of a single-lane pavement) receives adequate roller coverage whereas the edges of the mat receive considerably less compactive effort. As discussed further under the section on roller patterns, the uniformity of roller passes is just as important as the number of passes.

A nuclear density gauge can be employed to determine the optimum number of roller passes necessary to obtain the required density level. If this piece of equipment is used, however, a proper correlation to the actual density of the asphalt pavement layer, measured by cores, must be completed to assure that the density measured by the nuclear gauge is equal to or greater than the specifications requirements. Nuclear gauges typically measure relative density of the mix, not actual density as determined by the specific gravity of pavement cores.

Rolling Zone

Compaction must be achieved while the viscosity of the asphalt cement in the mix and the stiffness of the mix is low enough to allow for reorientation of the aggregate particles under the action of the rollers. In other words, the mat must still be hot for effective compaction. The rule of thumb commonly used is that the proper level of air voids should be obtained before the mix cools from laydown temperature to 175°F. Many variables affect the rate of cooling of the mixture, as discussed previously, and the mix compaction cutoff temperature is a function of all of those variables. Harsh mixes, for example, may require a higher cutoff temperature, whereas a tender mix may be able to be compacted adequately at a much lower temperature than 175°F.

To reach the required density level the quickest, initial compaction should occur directly behind the laydown machine. If the stability of the asphalt mixture is high enough, breakdown rolling can be carried out very close to the paver, while the mat temperature is still high. More density is obtained with one pass when the mix temperature is 250°F than with a similar pass when the mat is at 220°F. Thus, the rolling zone (the distance the breakdown roller operates behind the paver) should be as short as possible.

Sometimes when a tender mix is placed, the initial rolling is delayed (the rolling zone is lengthened) to avoid excessive shoving or checking of the mix by the rollers. Depending on the characteristics of the mix, it is still often possible to obtain the required level of density of the mix as long as the proper combination of rollers and compactive effort is applied to the mix. In some cases, however, the mix is so tender that rolling must be delayed to the point that the desired density level cannot be achieved. In this case, other solutions need to be tried. When a tender mix is encountered, the cause of the tenderness must be determined and changes made in the mix production and paving operation to assure adequate density of the asphalt mix. A discussion of causes for checking and shoving in the mix is given in the following section on mat problems.

Roller Patterns

Rollers are "busy" most of the time on a paving project. The question is whether they operate correctly and effectively. Generally, compaction is applied, but not necessarily in the right place. Numerous compaction studies have shown that the middle of the width of the paver pass typically receives more compactive effort than the edges of the pavement. This is unfortunate, because traffic uses the wheelpath areas and travels near the edge of the pavement more often than in the center of a lane.

On an actual asphalt concrete-paving project of an Interstate roadway, the mixture was placed in a trench section, 12 ft wide, in two 3-in. compacted lifts. Initial or breakdown rolling on the first layer was accomplished by the contractor using a 7-ft-wide vibratory roller. For the 12-ft-wide paver pass, two passes of the vibratory roller could cover the whole mat width, with a 2-ft overlap in the center. To gain adequate density, the breakdown roller operator had to keep the vibratory roller tight to each side of the trench. In order to cover the complete width of the lane, the operator needed to make each roller pass, on each side of the lane, directly

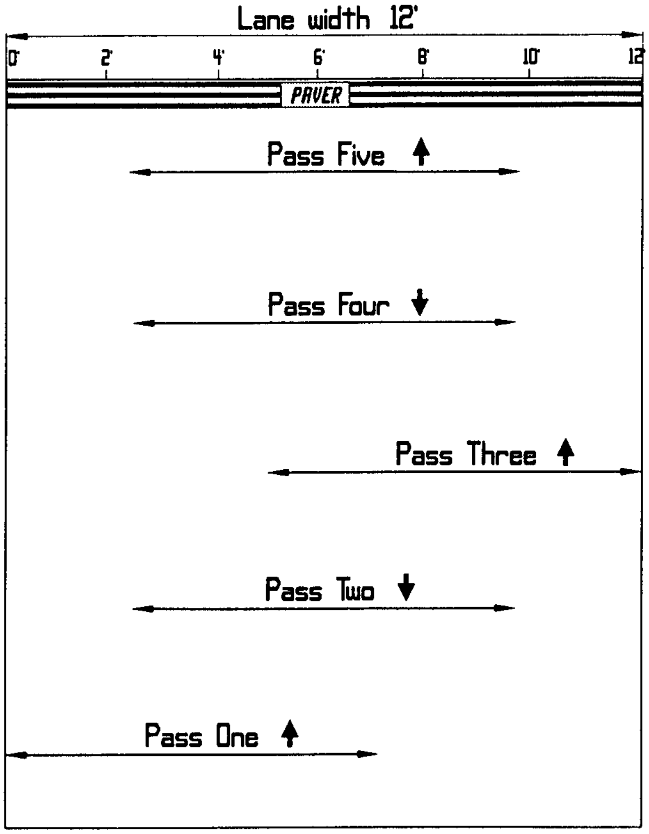


Figure 3-99. Improper roller pattern *(J. Scherocman).*

toward and away from the paver without ever making an attempt to roll the center of the lane.

On the job, however, the roller operator made his first pass, 7 ft wide, up the left-hand side of the mat (Figure 3-99). Upon reaching the back of the paver, the roller operator reversed direction, changed lateral direction slightly, and moved away from the paver by traveling down the center of the mat, with 2 1/2 ft of free area on both sides of the vibratory roller. The third pass, again toward the paver, was along the right-hand edge of the driving lane The fourth pass (away from the paver) was once more down the center, similar to pass number two. The final roller pass, to catch up to the paver, was a reversal of pass four--up the center of the lane. The roller operator continued to repeat this five-pass pattern as the paver moved down the roadway.

Five passes of this breakdown roller were applied to the center of the 12-ft area, a place where no traffic runs. Only one pass each was provided over each wheelpath and the edge of the lift. The roller was simply not being used properly because no rolling pattern had been set up and followed. A future failure was built because proper density was not obtained in the wheelpaths, where it was needed. If an adequate number of roller passes are provided on each edge of the lane being compacted, the density level in the center of the lane will always be more than enough to meet specifications. Thus, roller patterns should be designed to assure proper compaction of the whole lane width.

For each roller employed on a project, the mat width can be divided by the width of the compaction rolls to determine the number of passes needed to cover each transverse point in the surface. A pass is defined as one trip of the roller in one direction over any one spot. Multiple passes are needed to completely compact the transverse width of the lane being paved as well as over each point in the pavement surface to assure attainment of the required level of density.

If the width of the roller drums (or tires) is 84 in. (7 ft), only two passes of the roller are needed to cover the 12-ft-wide lane, including a 6-in.-wide overhang at each edge of pavement. This is shown in Figure 3-100. The two passes of the 84-in.-wide roller overlap for a distance of 12 in. in the center of the lane. If allowance is made for the fact that the roller operator may not always be able to maintain a 6-in. overhang on the edge of the pavement, the 12-in.-wide overlap in the center of the lane is still sufficient to permit the whole pavement width to be compacted in two passes of the 84-in.-wide roller with a minimum of a 6-in.-wide overlap needed between roller passes.

A roller that is 72 in. (6 ft) wide cannot cover the complete 12-ft lane width in only two passes, as shown on the second line of Figure 3-100. Two passes do not allow for any overhang at the edge of the lane or any overlap at the center. Thus, three passes of the 72-in.-wide roller would be necessary to properly compact the lane, as shown in the third line of the figure.

If the roller had drums or tires that were 60 in. (5 ft) in width, three passes of the roller would be required, similar to the roller with the 72-in.-wide drums. This is illustrated on the fourth line of Figure 3-100. If 6 in. is allowed for edge-of-lane overhang, the amount of overlap between roller passes is 12 in. This allows for ample steering variation by the roller operator and will permit the 12-ft lane width to be covered with three passes of the 60-in.-wide roller.

A roller with drums that are 54 in. would need to make four passes across the width of a 12-ft lane in order to completely cover the lane width. As shown in the fifth line of Figure 3-100, if this roller overhangs each edge of the pavement by 6 in. and only three passes across the lane width are made, the roller drums would only overlap 3 in. between the first and second passes and 3 in. between the second and third passes

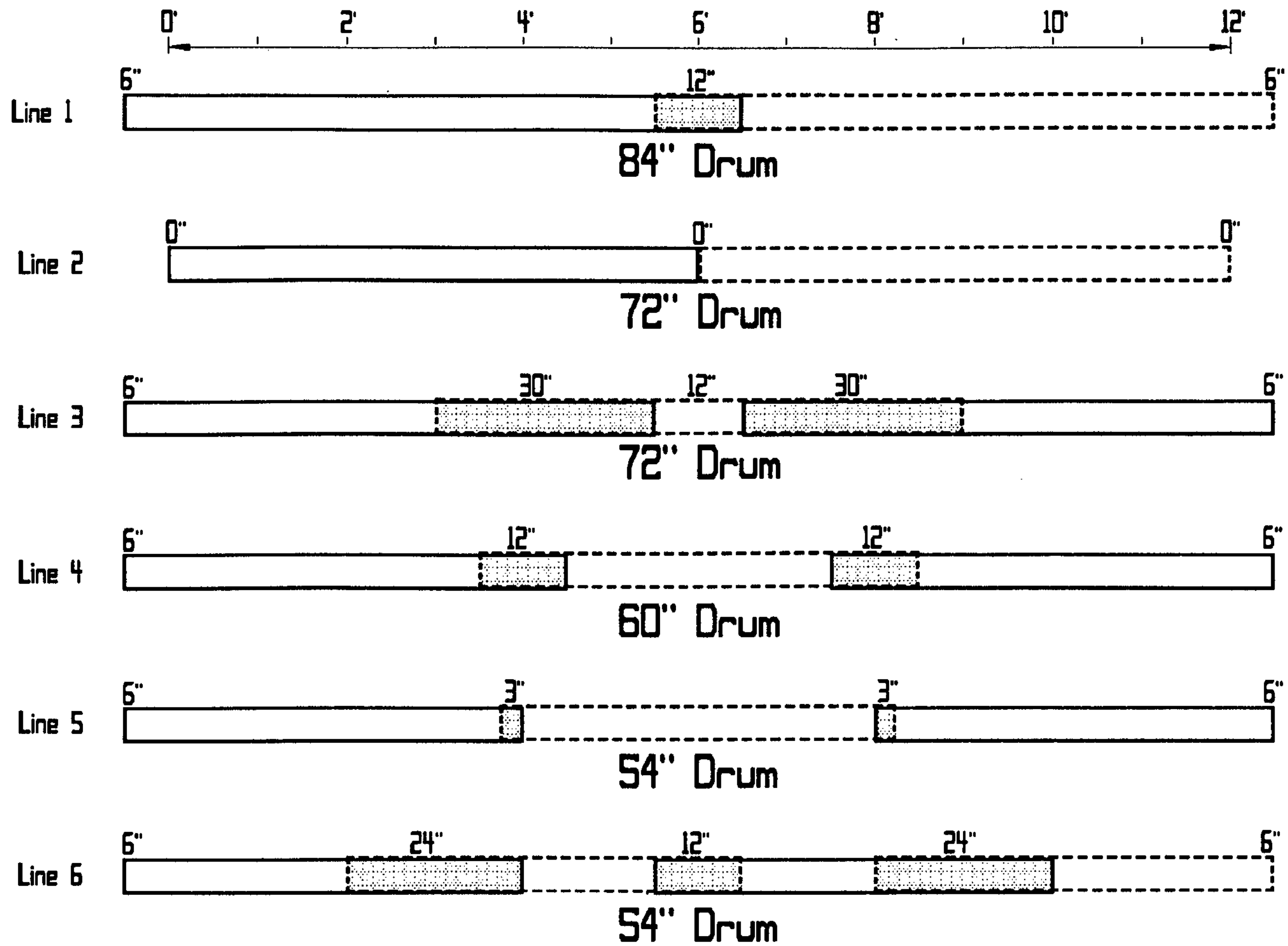


Figure 3-100. Lane width versus roller width *(J. Scherocman).*

across the width. This amount of overlap between passes would not be adequate and four passes of the 54-in.-wide roller would be necessary to properly compact a paving lane that is 12 ft wide, as shown in the last line of Figure 3-100.

In a longitudinal direction, the rollers should not stop at the same transverse end point with each pass of the roller. The reversal points should be staggered to prevent shoving of the mix. A slight change in direction, or curl, is beneficial at each reversal spot to further reduce the tendency of the mix to shove under the compactor and to eliminate the possibility of a bump at the point where the roller reversal occurs. The roller should not sit and wait while parked on the hot mat. A long delay, caused by lack of haul trucks at the paver or filling the compactor with water, allows the roller to indent the new mat. It is generally impossible to roll out these marks once the mat has cooled.

Many old compaction specifications require the compaction process to start at the low side of the pavement lane and proceed toward the high or upper side of the lane on subsequent passes of the rollers. With modern compaction equipment and more stable asphalt mixes, this requirement usually is not necessary but may be advisable for superelevations and lifts that are thick in relation to maximum particle size. In addition, some of these same specifications stated that the rollers had to overlap the width of the previous pass by at least half the width of the roller. This procedure leads to very nonuniform compaction across the width of the pavement lane. It is thus recommended that each subsequent pass of a roller overlap the previous pass by a minimum of 6 in.

Direction of Travel and Mode of Operation for Vibratory Rollers

When using a single-drum vibratory roller, the compression drum should normally be operated toward the paver. This assures that the maximum compactive effort of the compression drum is placed on the mat before the lesser compactive effort of the steering drum. In addition, it provides a denser layer to better resist displacement of the mix caused by the continual movement of the tiller drum during the steering action. A single-drum articulated-frame roller should also be operated with the driven drum toward the laydown machine. Again, this assures that the maximum compactive effort is applied to the mix as quickly as possible.

When only one drum is operated in vibration, double-drum rollers are often operated with the vibrated drum toward the laydown machine and with the static drum trailing. A double-drum articulated-frame roller that has two driven drums (a vibratory tandem roller) operates the same in either direction; thus, the direction of travel is not a consideration for this type of roller.

For harsh or stiff mixtures, breakdown rolling is normally accomplished with both drums vibrating. Subsequent compaction passes are also made in the full vibratory mode. For mixtures with normal stability, breakdown rolling with a vibratory roller should be accomplished in the full vibratory mode or in a combination mode (with one drum vibrating and the other drum static). The full vibratory mode is typically more efficient in terms of compactive effort, however, than is the combination mode. For tender mixtures, breakdown is usually accomplished in the static mode. Subsequent passes are usually made in the combination mode if mixture displacement is not too significant. When in the combination mode for tender mixtures, the trailing drum instead of the front drum is usually vibrated.

DETERMINATION OF THE ROLLING PATTERN

Choice of Compaction Equipment

Different mixes may require considerably different levels of compactive effort and thus different compaction equipment and rolling procedures. An asphalt mix containing large aggregate, for example, may need different types of rollers to achieve a required level of density than an asphalt concrete mix made with smaller-size coarse aggregate.

The actual rolling pattern to be used to compact the mix on a paving project should be determined at the start of the project through the construction of a roller test strip. This strip should be located at a convenient point where the pavement layer placed will remain as part of the final pavement structure. The mix should be representative of the material to be produced for the project; generally the plant should produce mix for a short period of time before mix is made for the compaction test section. The thickness of the layer compacted should be the same as that to be used for the rest of that particular layer, and the length of the test strip should be at least 300 ft. The condition of the underlying layers should be representative of that on the rest of the project.

Due consideration should be given to the selection of rollers that are to be employed to densify the pavement layer. The combination of rollers used on a previous project might not be the most cost-efficient or effective for the variables involved in the present job. Although vibratory rollers are usually used for breakdown rolling and pneumatic tire rollers for intermediate rolling, a greater degree of density with a lesser number of total roller passes might be obtained on some mixes (e.g., when a large pneumatic tire roller is used in the breakdown position with the vibratory roller following in the intermediate position). Determination of the "optimum" combination of rollers and roller patterns might require the construction of two or more test sections.

If a large pneumatic tire roller is used in the breakdown position, it is generally difficult to determine the degree of density obtained in the mat through the use of a nuclear gauge because of the rough texture of the mat after the first several passes of the pneumatic tires. Nuclear readings must be taken after the mix has been smoothed out with the intermediate roller. A compaction test strip should be conducted to determine the most effective sequence of rollers to achieve the required degree of compaction, the smoothness of the mat, and economical production.

Desired density levels are easier to obtain when the asphalt mix is hot. Instead of using the rollers in the traditional roller "train" concept, consideration should be given to using two breakdown rollers (of the same type) instead of a breakdown roller followed by an intermediate roller. This will be particularly beneficial on thin layers of mix under unfavorable environmental conditions.

Rolling Patterns

The first calculation needed concerns the amount of mix to be produced by the plant, the width of the pavement lane, and the depth of the mix. Once the typical speed of the paver is known, the maximum speed of the rollers should be selected. The actual speed selected for each roller will depend on the type of roller and its width as well as its position in the rolling sequence. It will also depend on the ability of the roller to achieve a balance between achieving density, smoothness, and an unblemished pavement surface.

The next calculation that must be made concerns a comparison of the width of the layer being placed and the width of the rollers to be used in order to determine the number of transverse roller lanes needed to cover the whole width of the pavement. (A pass is defined as one trip of the roller in one direction over any point on the pavement surface.) With the paver speed, the roller speed, and the number of transverse lanes needed to obtain full-width coverage of the roadway surface, the number of passes that each roller can place over each point in the pavement and still keep up with the paver can be determined. The number of passes, however, must be matched to the plant production rate and to the speed of the paver.

The number of roller passes needed over each point on the pavement surface is a function of a large number of variables. One of the most important variables is the level of density required in the pavement layer. If a method-type specification is being used, the required number of passes can simply be counted. What is not known, however, is what degree of density (air void content) will be obtained in the mix after the specified number of passes is completed. If a certain percentage of laboratory density or theoretical maximum density is needed, the higher the required percentage, the more compactive effort that will have to be applied to the pavement layer.

The type of breakdown roller used also will be very important. Under some conditions, one vibratory roller may be all that is needed to achieve density, depending on the properties of the mix. In other cases, if checking in the mix occurs, several passes of a pneumatic tire roller may be necessary to reach the density level needed. One or more passes of a static steel wheel roller is normally needed to remove roller marks, particularly if a pneumatic tire roller has been used. Because of the number of variables involved, it is impossible to generalize about the "best" combination of rollers and roller pattern to use.

The most common method for monitoring changes in density with roller passes is through the use of a nuclear density gauge. Density is estimated by transmitting gamma rays into the mix and measuring the amount of radiation reflected back to the device in a given amount of time. The count data that are obtained can be related to the relative density of the layer. Nuclear gauge readings should be taken after each pass of each roller, and the rate of increase in density after each pass determined. When no appreciable increase in density is obtained with the application of additional roller passes, the maximum relative density for that mix has been obtained. When a pneumatic tire roller is used in the compaction process, particularly in the breakdown mode, it is often very difficult to obtain an accurate density reading with a nuclear gauge. One or more passes with a steel wheel roller may be necessary before a valid nuclear gauge reading can be obtained.

The density value determined with the nuclear gauge is relative and is generally not the same as the density value obtained from cores cut from the pavement. The gauge reading indicates the density that can be obtained at one given time, under one set of environmental conditions, with one combination of rollers. Thus a correlation must be developed between the nuclear density reading and the actual unit weight of the pavement. The correlation is determined from cores that are cut from the test section after the rolling process is complete. That unit weight must be compared to the maximum theoretical unit weight of the mix in order to calculate the actual in-place air void content of the layer.

If the proposed test section rolling pattern does not achieve the required density, as measured by the cores, changes to the pattern should be made. An initial adjustment might be to reduce the speed of the rollers. The frequency of vibration and the applied nominal amplitude from a vibratory roller might be increased. The air pressure in the tires of a pneumatic tire roller might be increased and/or the weight on the roller could be increased. The first two rollers might be run in echelon instead of end to end, as in a normal roller train. If none of these changes can increase the density of the mix enough and still permit the rollers to keep up with the production requirements of the paver, additional rollers may be needed to obtain the required density levels.

ROLLER OPERATING TECHNIQUES

To compact an asphalt layer properly, the rollers should be used efficiently while the mix is still above the minimum compaction temperature. The factors that should be observed when monitoring the compaction process follow. The techniques noted in Section Five for joint construction should also be observed.

- The time available for compaction is primarily related to the thickness of the layer being placed. An increase in lift thickness can substantially increase the time available for the roller to densify the mix.

- An increase in the laydown temperature of the mix behind the paver can increase the amount of time available for compaction significantly. The feasibility of this approach, however, depends on the properties of the asphalt concrete mix at the elevated temperature and the tenderness of the mix under the compaction equipment.

- A decrease in the speed of the rollers will increase the compactive effort applied to the mix.
- The breakdown roller and intermediate roller should be operated as close to the paver as possible in order to obtain density before the mix cools to a minimum temperature of 175°F.
- If the mix cannot support the weight of the compaction equipment, the mix should be redesigned or the compaction procedures should be changed.
- The roller pattern should be monitored to assure that the compaction equipment is applying the same amount of compactive effort at all points transversely across the lane being paved.
- The speed of the compaction equipment will depend on the type of roller being used and its position in the compaction process. For static steel wheel and pneumatic tire rollers in the breakdown position, the maximum speed should not exceed 2 1/2 miles/hr. For a vibratory roller in the same position, the maximum speed should not exceed 3 1/2 miles/hr.
- A vibratory roller should be operated at the maximum possible vibratory frequency in order to increase the number of impacts per foot. At least 8 to 10 impacts/ft are needed to obtain adequate density and layer smoothness.
- The nominal amplitude setting on the vibratory roller should be determined by the characteristics of the mix and by the thickness of the layer being compacted. In general, vibratory rollers should be operated in the static mode when the compacted lift thickness is less than about 1 1/4 in. For greater lift thicknesses, the roller should normally be operated at low nominal amplitude. If density cannot be obtained, the nominal amplitude may be increased to determine if additional compactive effort will be beneficial in achieving the required density level. In general, the nominal amplitude setting can be increased in proportion to the increase in compacted thickness of the layer.
- The optimum combination of rollers and roller patterns for a past project may not be the same optimum combination for a current project or even for a different type or layer of mix on the same project. Test sections should be constructed to determine the most efficient and most effective combination of compaction equipment and roller patterns to use for each combination of job variables.
- Two similar rollers run side by side (in echelon) will typically produce a greater level of density in the mix, with the same number of roller passes, than will the same two rollers operated end to end as a breakdown and an intermediate roller.
- If the rollers cannot keep up with the speed of the paver, more rollers should be used or the paver should be slowed down.

SECTION SEVEN
EQUIPMENT AND MAT PROBLEMS

INTRODUCTION

Equipment and mat problems can be defined as defects that occur in the asphalt mixture during or soon after the laydown and compaction operations. These problems can be divided into two primary categories: (a) equipment-related problems and (b) mixture-related problems. Several different types of mat deficiencies are discussed, with emphasis on the description of the problem, the cause of the problem (equipment- or mix-related), the solution, and the effect on pavement performance.

Figure 3-101 summarizes the various kinds of problems that can occur in an asphalt concrete layer during construction. Problems in other types of mixes are not listed, but many problems are common to all mixes. Listed in the first column is a description of various mat defects. Marked in the remaining columns are several possible causes for each particular mat problem. The check marks indicate equipment-related causes, and the X marks indicate mix-related causes. Mix-related causes should generally be corrected by changes in the mix design. Because of the interaction of various equipment-related and mix-related causes, no attempt has been made to prioritize the causal items.

SURFACE WAVES

Description

An asphalt surface can have two types of waves: short waves and long waves. Short waves are generally 1 to 3 ft apart, with 1 1/2 to 2 ft being the most common distance. Long waves are considerably further apart and may correspond to the distance between truckloads of mix. Long waves may also be associated with the reversal points of the compaction equipment, particularly on thick-lift construction.

An additional type of defect in the pavement surface is a roughness or washboard effect caused by improper operation of the vibratory roller. The distance between this type of wave is generally very small, typically less than 3 or 4 in.

Cause

A major cause of short waves is a fluctuating head of material in front of the paver screed. This variation in the amount of mix being carried back to the augers by the slat conveyors and deposited in front of the screed causes the screed to rise and fall as the force pushing against it changes. Too much mix (at the top of the augers) and then too little mix (at the bottom of the augers) being carried in the auger chamber in front of the screed causes the wavy surface as the screed reacts to the variable forces on it.

Another cause of short waves can be a screed that is in poor mechanical condition; one that has excessive play in the screed-control connections. Short waves can also be formed in the mat by improper mounting or sensitivity of the automatic grade control on the paver or by use of an inadequate grade reference device. The problem might also be related to a mobile reference (floating beam) that is bouncing or to the truck driver holding the brakes while the truck is being pushed by the paver.

Short waves can also be a function of the mix design, particularly in regard to a mix that varies in stiffness caused by changes in mix temperature or mix composition. As the stiffness of the mix varies, the forces of the mix pushing on the screed also vary, causing the screed to rise and fall and place a mat with short waves. Finally, if the mix design is improper in aggregate gradation, asphalt content, mix temperature, and/or moisture content, the rollers may shove and displace the mix during the compaction process. Normally, however, the short waves are placed in the mat by the paver either because of its operation or because of changes in mix stiffness rather than by the compaction equipment.

Long waves are caused by some of the same variables that cause short waves. A fluctuation in the amount of material in front of the screed and mix stiffness variation causes the screed to react to the change in the pressure on it. If the distance between the wave peaks, however, corresponds to the length of pavement between truckloads of mix, the waves may have been caused by incorrectly set hopper flow gates on the paver or by the paver hopper and slat conveyor being emptied between loads of mix. Poor mechanical condition and improper operation of the screed (continually changing the manual thickness-control cranks, for example) as well as incorrectly mounted automatic grade controls can cause a long-wave type of surface problem. If a stringline is being used as a grade reference, a sag in that line between support posts can be a cause of long waves. Delivery of the mix to the paver can also be a factor in

CAUSES

Causes related to the paver (checks):

PROBLEM	Fluctuating Head of Material	Feeder Screws Overloaded	Finisher Speed Too Fast	Too Much Lead Crown in Screed	Too Little Lead Crown in Screed	Overcorrecting Thickness Control Screws	Excessive Play in Screed Mechanical Connection	Screed Riding on Lift Cylinders	Screed Plates Worn Out or Warped	Screed Plates Not Tight	Cold Screed	Moldboard on Strikeoff Too Low	Running Hopper Empty Between Loads	Feeder Gates Set Incorrectly	Kicker Screws Worn Out or Mounted Incorrectly	Incorrect Nulling of Screed	Screed Starting Blocks Too Short	Screed Extensions Installed Incorrectly	Vibrators Running Too Slow	Grade Control Mounted Incorrectly	Grade Control Hunting (Sensitivity Too High)	Grade Control Wand Bouncing on Reference	Grade Reference Inadequate	Sitting Long Period Between Loads	Improper Joint Overlap
Wavy Surface — Short Waves (Ripples)	✓	✓	✓				✓	✓		✓										✓	✓	✓	✓		
Wavy Surface — Long Waves	✓	✓				✓	✓	✓					✓	✓						✓			✓	✓	
Tearing of Mat — Full Width			✓						✓		✓														
Tearing of Mat — Center Streak					✓				✓		✓			✓	✓										
Tearing of Mat — Outside Streaks				✓					✓		✓	✓		✓				✓							
Mat Texture — Nonuniform	✓	✓	✓					✓	✓	✓	✓		✓					✓	✓					✓	
Screed Marks							✓																		
Screed Not Responding to Correction			✓				✓	✓		✓										✓					
Auger Shadows		✓																							
Poor Precompaction			✓					✓											✓						
Poor Longitudinal Joint	✓	✓				✓		✓												✓	✓	✓			✓
Poor Transverse Joint		✓					✓	✓		✓						✓	✓								
Transverse Cracking (Checking)																									
Mat Shoving Under Roller																									
Bleeding or Fat Spots in Mat																									
Roller Marks																									
Poor Mix Compaction																									

Other problems to be investigated (X's):

PROBLEM	Improper Mat Thickness for Max. Agg. Size	Trucks Bumping Finisher	Truck Holding Brakes	Improper Base Preparation	Improper Rolling Operation	Reversing or Turning Too Fast of Rollers	Parking Roller on Hot Mat	Improper Mix Design (Aggregate)	Improper Mix Design (Asphalt)	Mix Segregation	Moisture in Mix	Variation of Mix Temperature	Cold Mix Temperature
Wavy Surface — Short Waves (Ripples)				X	X			X	X	X		X	
Wavy Surface — Long Waves		X	X	X		X	X			X		X	
Tearing of Mat — Full Width	X							X	X	X	X	X	X
Tearing of Mat — Center Streak													X
Tearing of Mat — Outside Streaks													X
Mat Texture — Nonuniform	X			X				X	X	X		X	X
Screed Marks		X	X										
Screed Not Responding to Correction	X											X	X
Auger Shadows								X	X	X			
Poor Precompaction	X			X									X
Poor Longitudinal Joint					X								X
Poor Transverse Joint					X								X
Transverse Cracking (Checking)				X	X			X	X		X	X	
Mat Shoving Under Roller				X	X	X		X	X		X	X	
Bleeding or Fat Spots in Mat								X	X		X	X	
Roller Marks				X	X	X	X					X	
Poor Mix Compaction				X	X	X	X	X	X		X	X	X

1. Find problem above.
2. Checks indicate causes related to the pavor. X's indicate other problems to be investigated.

NOTE: Many times a problem can be caused by more than one item, therefore, it is important that each cause listed is eliminated to assure solving the problem.

Figure 101. Mat problem troubleshooting guide *(Barber-Greene)*.

long-wave roughness, particularly if the haul truck bumps into the paver or if the truck driver holds the brakes while the truck is being pushed by the paver. One final factor can be the condition of the underlying surface; the long waves may be a reflection of the waves in that base material.

Long waves can also be found at the points where the compaction equipment reverses direction. This problem will be most prevalent when the asphalt layer being placed is greater than about 4 in. thick. The problem may be enhanced when the maximum-size coarse aggregate used in the mix is relatively small compared with the lift thickness. The waves are caused by the bow wave that forms in front of the roller.

In terms of mix design, long waves can be caused by truckload-to-truckload segregation of the mix and by changes in mix temperature. Both of these deficiencies cause the forces on the screed to vary, causing, in turn, a wavy surface. Compaction equipment can also create a wavy mat if the roller operator turns or reverses the machine too abruptly.

Roughness or washboarding is normally caused by improper operation of the vibratory roller. This type of equipment should be operated at as high a frequency as possible and at an amplitude related to the thickness of the layer being compacted; usually a greater amplitude setting for a thicker layer of mix and a lower amplitude setting for thinner lifts of material. Further, the washboard effect can be worse if the roller is operated at a high speed, particularly if the frequency setting is less than 2400 vibrations/min.

Solution

Short waves can be cured only by preventing their formation. The most important factor for short waves is to keep the amount of mix (head of material) in front of the screed as consistent as possible. In addition, the stiffness of the mix that is related to both its temperature and its composition should be maintained as constant as feasible. The amount of mix is controlled by the proper setting of the hopper flow gates and by keeping the slat conveyors and augers operating as much of the time as possible (close to 100 percent) while the machine is moving forward. Mix stiffness is controlled at the asphalt plant by keeping the mix temperature, aggregate gradation, and fluids content (asphalt content plus moisture content) within normal specification limits. Any factors that cause either the volume or the stiffness of the mix at the screed to change can cause short waves in the asphalt concrete mat.

Surface waves caused by automatic grade-control problems can be detected by shutting off the grade controls and determining whether or not the long or short waves continue to be formed. If the grade controls are at fault, the operation and maintenance manual supplied with the controls should be consulted to determine the proper corrective action to take. Sags in a stringline reference can be found by sighting down the line as the grade sensor wand passes along the string. Short or long waves caused by the mechanical condition or operation of the paver screed can usually be detected by careful observation of the paver during mix laydown. The long waves formed by incorrect haul truck operation and/or incorrect compaction equipment operation can also be detected easily by spending a few minutes watching each of these processes.

If washboarding is caused by the incorrect operation of the vibratory roller, a change should be made in the vibratory amplitude setting, the vibratory frequency, and/or the speed of the roller. This problem is discussed in detail in the section on compaction techniques.

Performance

Long-term pavement performance is affected by surface waves, both short and long, in two primary ways. First, the waves reduce the smoothness of the pavement, which lowers the pavement condition rating or present serviceability index of the roadway. Structural performance of the pavement may be changed, however, only if the waves are severe enough to increase the dynamic or impact loading of the pavement under heavy truck traffic. Second, short waves and the factors that cause the short waves can affect pavement density levels. A tender mix is generally more difficult to compact properly than is a stable mix. This may result in a decrease in density and a corresponding increase in air void content.

Washboarding is basically roughness built into the pavement surface during the compaction operation. As it affects the degree of density obtained during the compaction process, this type of defect can reduce the long-term durability of the pavement layer. In addition, it contributes to a rough ride for the vehicles using the pavement.

TEARING

Description

There are three types of mat tearing or pulling of the asphalt mix under the screed of the paver. Each of the types is described by the location of the tear marks in the mat: (a) in the center of the lane, (b) on the outside edges of the lane, and (c) full width. Tearing of the mat is usually caused by improper paver condition or operation, by a cold mix temperature, or by a compacted mat thickness that is less than twice the maximum size of the aggregate used in the mix.

Cause

The screed on the paver should be adjusted to provide the correct degree of crown. The appearance of streaks behind the screed is primarily caused by an improper relationship between the crown at the leading (front) and trailing (back) edge of the screed. A tearing or open texture of the mat several feet wide in the center of the mat may be caused by a lack of lead crown in the paver screed. Conversely, a tearing or open texture along both outside edges of the asphalt mixture is normally caused by an excess of lead crown in the screed. For most mixes, the lead crown of the screed should be set slightly greater than the tail crown. The proper relationship between lead and tail crown results in a uniform texture of the mat across its full width.

Center streaks, 6 to 8 in. wide, can be caused by a lack of asphalt material being tucked under the auger gearbox area at the center of the auger chamber. This could be the result of improper flow gate settings: not enough mix being fed back to the screed. It is more likely to be caused by missing, worn, or improperly set reverse augers or paddles on the augers that are used to force mix underneath the gearbox. Edge streaks can be formed by improper flow gate settings or by incorrect installation of the screed extensions.

Full-width tearing of the mat can be attributed to a number of different factors. Tearing can occur because of warped or worn-out screed plates. If the forward speed of the paver is too great for a particular mix, tearing can occur. The use of a mixture with aggregate that is large compared with the mat thickness being paved can be responsible for tearing of the mat. Cold mix temperatures, particularly when combined with a cold paver screed, can significantly affect the amount of tearing that will occur. In addition, if the thickness of the layer being placed is less than twice the size of the maximum aggregate used in the mix, full-width tearing can occur.

Solution

Constant center or outside edge mat tearing usually can be eliminated by adjusting the relationship between the lead and tail crown on the paver screed. If this change does not solve the problem, the setting of the paver flow gates should be modified. Full-width tearing, which is normally caused by a cold screed, cold mix temperature, worn screed plates, or a compacted mat thickness that is less than twice the depth of the maximum aggregate, can be cured by preheating the screed properly before paving commences, increasing the mix temperature, replacing the warped or worn-out screed plates, or increasing the lift thickness, respectively.

Performance

Tearing of the mat affects the long-term pavement performance by causing changes in mixture density in areas where the tearing has occurred. Torn areas may appear segregated and are usually deficient in mix quantity. Depending on the severity of the tearing, pavement performance will be reduced in relation to the degree to which the tearing reduces the density and increases the air void content of the mat. In addition, the torn areas will be more susceptible to raveling and also to the effects of moisture (stripping) in those areas.

NONUNIFORM TEXTURE

Description

Nonuniform mat texture (Figure 3-102) can be described as differences in the appearance of the mix, both transversely and longitudinally, as the mix is placed and compacted. Normally, minor differences in surface texture will be apparent because of differences in the alignment of the larger coarse aggregate particles as the mix passes out from beneath the paver screed. Additionally, a mix with a higher fine aggregate (sand) content will have a more uniform surface texture than a mix containing a larger percentage of coarse aggregate.

Cause

Many factors concerning the operation of the asphalt paver affect the uniformity of the surface texture of the mix. A variable amount of mix against the screed, caused by overloaded augers or running the hopper empty between truckloads, can cause variations in the amount of mix tucked under the screed and thus produces a nonuniform texture. Improper screed maintenance, including worn or loose screed plates, screed extensions incorrectly installed, or low screed vibratory frequency, may alter the mat texture significantly and cause nonuniformity. A low mix temperature, caused either by plant problems or by the paver sitting too long between truckloads of mix, can also be a factor in obtaining uneven mat texture, especially if the paver screed is also cold.

When the compacted layer thickness is less than two times the dimension of the largest aggregate particles, tearing of the mat and nonuniform surface texture result. A good rule of thumb for the relationship

Figure 3-102. Nonuniform mat texture *(J. Scherocman)*.

between maximum aggregate size used in the mix and the minimum compacted course thickness is that the depth of the compacted layer should be at least twice the largest coarse aggregate particle size. Thus a mix containing a 3/4-in. top-size aggregate should be placed at least 1 1/2 in. thick.

A soft or yielding base under the course being constructed may cause a variable surface texture for the new layer. Obviously, segregation of the mix caused by poor mix design or improper handling of the mix during the mixing, loading, hauling, unloading, or placing operations can contribute to a nonuniform surface texture. The variability of the texture will also be affected by any factors that cause nonuniformity in the mix, such as deviations in aggregate gradation, asphalt content, or mix temperature.

Solution

The causes of nonuniform surface texture are many, and thus the solutions to the problems are many. Paver operation, particularly in regard to the need for a constant head of material in front of the screed, should be monitored closely. The paver and screed should both be well maintained and in good operating condition. The compacted thickness of the mat being placed should be designed so that it is at least twice the size of the largest coarse aggregate piece used in the mix. Finally, a mix that is tender, variable in aggregate gradation or asphalt content, or easily segregated should be modified to improve its characteristics before it is delivered to the paver for laydown.

Performance

Nonuniform surface texture usually goes together with nonuniform density. Areas in which the coarse aggregate has been dragged by the paver screed or in which segregation of the mix has occurred will generally have a lower density after the application of the same compactive effort by the rollers. As density decreases and air void content increases, the durability and serviceability of the asphalt concrete mat decrease markedly.

SCREED MARKS

Description

Screed marks are transverse indentations in the asphalt mat. They occur when the paver stops between truckloads of mix (Figure 3-103). Depending on the mixture being placed, some screed marks are barely noticeable, whereas some can be very deep. Screed marks can also occur in the longitudinal direction when rigid or hydraulic extensions are used (Figure 3-104).

Cause

There are several causes of transverse screed marks. One is excessive play in the mechanical connections on the screed. If this is the problem, the screed marks will be visible each time the paver stops. A second cause of screed marks is when the screed is set up incorrectly and rides heavily on its rear edge. Another cause is the haul truck bumping into the paver when preparing to discharge the mix, and/or the truck driver holding the brakes on the truck when the paver starts to push the truck. In this case, the screed marks will appear only when the truck-paver interchange is improper. An asphalt mix that is very tender will be indented by the paver screed, particularly if the screed is heavy, such as a screed with hydraulic extensions or with several rigid extensions.

Longitudinal screed marks are caused by improper setting of the screed extensions relative to the main screed. When extensions are used, the vertical position of the extension and the angle of attack of the extension must be the same as that of the primary paver screed. If rigid extensions are set at the wrong elevation, a longitudinal mark will occur at the point where the

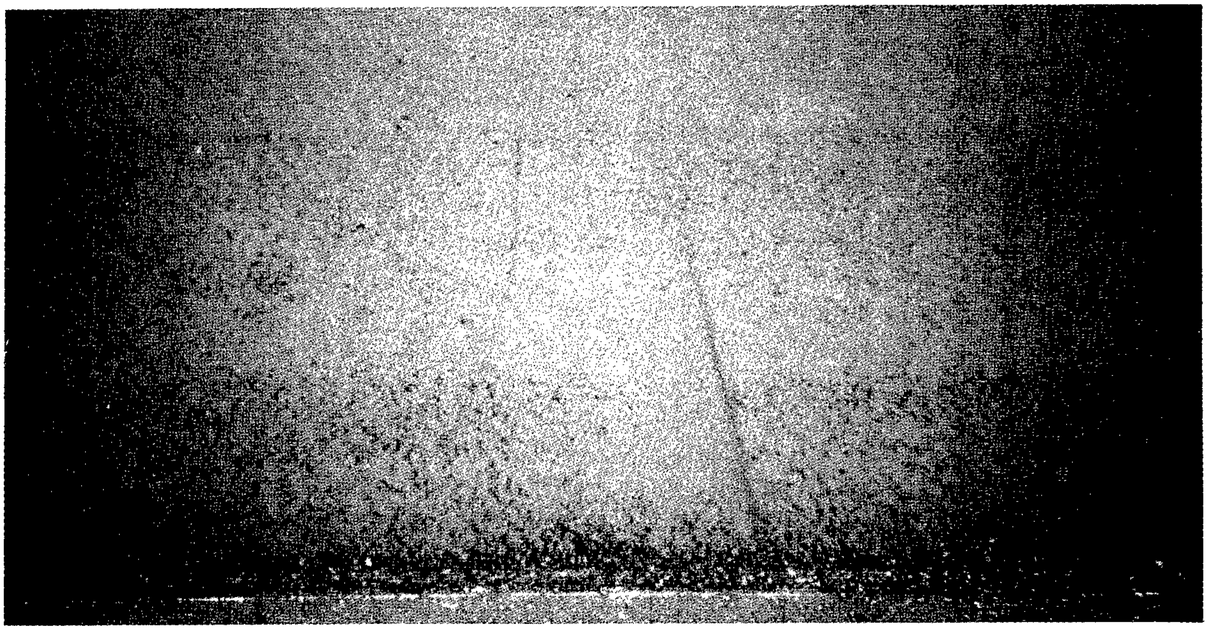


Figure 3-103. Transverse screed marks on one side of an extendable screed *(J. Scherocman)*.

screeds are joined. If hydraulic extensions are used, two longitudinal marks may occur--one at the end of the main screed and/or one at the inside edge of the extension on each side of the machine.

Solution

If the transverse screed marks are a result of the mechanical condition of the paver screed or improper setup of the screed, the screed should be repaired. If the screed marks are caused by the truck bumping into the paver, the laydown operation should be altered so that the paver picks up the haul truck instead of the truck backing into the paver. In addition, once the paver establishes contact with the truck, the truck drivers should apply only enough pressure to the brakes to keep the truck in contact with the paver.

The development of screed marks, particularly if the mix is very tender, can be eliminated by not stopping the paver between truckloads of mix. This can be accomplished by using a windrow elevator or material transfer vehicle to deliver mix to the paver hopper. If dump trucks are used to haul the mix, however, it generally is better paving practice to stop the paver between truckloads of material (stopping and restarting the paver as quickly as practical) instead of allowing the opportunity for the paver operator to run the paver hopper dry, reduce the head of mix in front of the paver screed, and increase the opportunity for truckload-to-truckload segregation.

Longitudinal screed marks caused by improper setting of the elevation of the extensions can be eliminated by correcting the position of each extension relative to the main screed. Adjustments to both the vertical position and the angle of attack of the extensions may be needed.

Performance

Transverse screed marks generally are not detrimental to the durability of the mat. They may, however, affect the ride, creating a bump whenever the marks cannot be rolled out completely by the compaction equipment. In many cases, the screed marks affect the overall performance of the mix less than does the slowdown and startup of the paver when the operator attempts to keep the paver moving as the empty truck pulls away from the paver and the loaded truck backs into the hopper.

Longitudinal screed marks indicate that the level of the mix under the extension is different from the level of mix under the main screed. If the screed marks are severe, differential compaction may occur across the "joint," with the compaction equipment initially riding on the higher mat. If not able to be completely rolled out, the longitudinal screed marks can leave a ridge in the mix.

Figure 3-104. Longitudinal screed marks between main and extendable screed *(J. Scherocman)*.

SCREED RESPONSIVENESS

Description

As the thickness-control cranks on the screed are changed, the angle of attack of the screed is increased or decreased. As the paver moves forward to place the mix, the screed moves up to or down to the new equilibrium point for the new mat thickness. When the screed fails to respond to changes in the thickness-control cranks, the operator is unable to alter the depth of the layer being placed. The paver also loses its inherent ability, through the principle of the floating screed, to provide the self-leveling action needed to place a smooth asphalt mat.

Cause

An extremely fast paver speed (more than 80 ft/min for thin lifts or more than 50 ft/min for layers more than 2 1/2 in. in depth) may cause a lack of responsiveness of the screed. The mechanical condition of the screed affects the screed reaction. The screed riding on the screea lift cylinders or loose connections on the thickness-control cranks will cause the screed to be unresponsive. If automatic grade controls are used, an incorrect sensor location will cause the screed to be unable to react to input signals from the grade sensors. If the maximum aggregate size used in the mix is too great compared with the depth of mix being placed, the screed will ride on or drag the largest aggregate pieces. The screed, therefore, cannot change angle and is thus unresponsive to changes in the thickness-control settings. Variations in mix temperature also cause the screed to be unresponsive to angle-of-attack changes, because the mix stiffness variations themselves are causing the screed to continually seek new equilibrium levels for the forces acting on it.

Solution

The paver and screed must be in good operating condition. The sensor for the automatic grade controls must not be located at either the tow point or behind the pivot point of the screed; the sensor should be placed in the area between one-third and two-thirds of the length of the leveling arm. If the mix texture is uniform (indicating a proper relationship between course thickness and maximum aggregate size), the screed will be able to respond to changes in the settings on the thickness controls.

Performance

An unresponsive screed causes a rough asphalt mat. The screed is unable to react to manual changes in the thickness settings and also loses its ability to self-level an existing pavement surface by being unable to reduce the amount of mix placed over the high points in that surface and increase the volume of material placed in the low areas. Thus, the rideability of the course being placed can be affected significantly by the unresponsiveness of the paver screed.

SURFACE SHADOWS

Description

Surface shadows are dark areas (Figure 3-105) that appear in the surface of an asphalt concrete mix. In most cases, the surface shadows cannot be seen until sometime after the asphalt concrete mix has been used by traffic and some of the asphalt cement film has been worn off the exposed aggregate particles by the vehicle tires. Auger shadows are seen most easily under certain sunlight conditions--when the sun is low on the horizon and the pavement is viewed when looking into the sun. In severe cases, however, they may be visible immediate-

Figure 3-105. Surface shadows *(J. Scherocman).*

ly behind the screed during the laydown operation. Even in this latter case, the shadows will "disappear" when the mix is being compacted by the rollers. The auger shadows may be completely across the lane width being placed or they may be only partway across the width.

Cause

Surface shadows are caused primarily by overloading the augers on the paver. If the head of material in the auger chamber is so great as to "bury" the augers, the screed will react to the variable forces acting on it. The spacing between the shadows will normally correspond to the starting of the augers when those augers are operated in a stop-start manner. Whenever the amount of mix in front of the screed is at or above the top of the auger, the shadows will be formed and ultimately be seen in the asphalt concrete mix.

On most pavers it is possible to adjust the distance between the screed and the tractor unit. This is accomplished by unbolting a connection on the leveling or tow arm of the paver and moving the tractor forward (or backward) with the screed sitting stationary on the mix. Depending on the make and model of the paver, there is typically a 4-in. length of slide for the screed connection. The severity of the surface shadows may be increased with the screed in the back position--when more mix is being carried in the auger chamber and the augers are being overloaded.

The dark areas, or shadows, are thought to be the result of a slight increase in mix density caused by the startup of the augers and the forcing of additional mix under the screed at the time the augers begin turning again after being stopped. There is no difference in surface texture associated with the location of the surface shadows. They can only be seen from an angle; when viewed from directly overhead, the shadows usually cannot be seen. The intensity of the shadows is often increased when a tender mix is being laid.

Solution

The asphalt concrete mixture carried in the auger chamber should be maintained at a level near the center of the auger shaft. This means that the flow gates should be set so that the augers operate as close to 100 percent of the time as possible and the stopping and starting of the augers is minimized. In no case should the top of the augers be completely covered with mix. Further, the location of the screed should be set as far forward as possible so that the amount of material in the auger chamber is reduced and the head of material in front of the screed is kept to a minimum.

Performance

Surface shadows are not necessarily detrimental to the mix except as they may affect rideability in a minor way. The difference in density of the mix in areas where the shadows are present and between the shadows is generally not enough to be determined accurately. The main concern with surface shadows is the visual appearance of the mix to the vehicle driver.

PRECOMPACTION LEVELS

Description

A modern asphalt paver normally is equipped with a vibratory screed. This type of screed allows the mix to be compacted partially as it passes beneath the screed. Depending on such variables as forward paver speed, layer thickness, mix temperature, and ambient environmental conditions, the density of the asphalt concrete mixture measured behind the paver screed before roller compaction is usually in the range of 70 percent to 80 percent of the theoretical maximum density (a voidless mix).

Some pavers are equipped with combination screeds: screeds that have both tamper bars and vibratory mechanisms. At slow paver speeds, the degree of compaction achieved in the mix by the combination screed is typically greater than that obtained by the vibratory screed alone. At paver speeds greater than 25 ft/min, however, the increased effectiveness of the tamper bar compactive

Figure 3-106. Excessive raking of transverse joint *(J. Scherocman)*.

effort is lost and the degree of compaction obtained by the combination screed is similar to that achieved with a normal vibratory screed.

Cause

The amount of precompaction obtained by the paver screed decreases as the paver speed increases. It increases somewhat as the frequency of the screed vibration increases. Precompaction will decrease significantly, however, if the paver screed is riding on the screed lift cylinders, thereby limiting the available compactive effort. The level of precompaction obtained will be further limited if the mat is too thin for the maximum aggregate size used in the mix, if the mix being placed is too cold, or if the base on which the new layer is being laid is soft and yielding.

Solution

Decreasing the paver speed and increasing the frequency of vibration of the paver screed should increase, within limits, the level of precompaction achieved during the laydown operation. It is also possible on some pavers to increase the amplitude of the vibration in order to increase the impact force of the screed on the mix. Proper maintenance of the screed also helps obtain a uniform compactive effort from the screed.

Performance

As long as the required density level is obtained using conventional rollers behind the paver, the absolute level of precompaction accomplished by the screed will not affect the long-term performance of the asphalt concrete layer. It may be possible, however, to reduce the number of roller passes needed to meet the density and air void content criteria if the amount of precompaction obtained by the screed is higher. In addition, increased precompaction density can reduce the amount of differential compaction that will occur in low spots and rutted areas.

JOINT PROBLEMS

Description

Poor transverse joints (Figure 3-106) are associated either with a bump at the joint, a dip in the pavement surface several feet beyond the joint, or both. Poor longitudinal joints (Figure 3-107) between passes of the paver are usually characterized by a difference in elevation between the two lanes, by a raveling of the asphalt at the joint, or both. The area adjacent to the longitudinal joint is usually depressed below the level of the surrounding pavement surface.

Cause and Solution

As discussed in Section 5 on joint construction, the key to a good transverse joint is to start the paver with the screed sitting on blocks on the cold side of the joint. The thickness of the blocks is related to the depth of the course being laid. The second factor is to do only the amount of raking necessary to form the joint properly. Finally, the joint should be compacted by rolling it in a transverse direction, if possible. The key to a good longitudinal joint is the amount of overlap of the new mat over the adjacent cold material. If the overlap is not greater than 1 to 1 1/2 in., minimal raking is necessary, and the compaction equipment will be able to densify the mix at the joint properly.

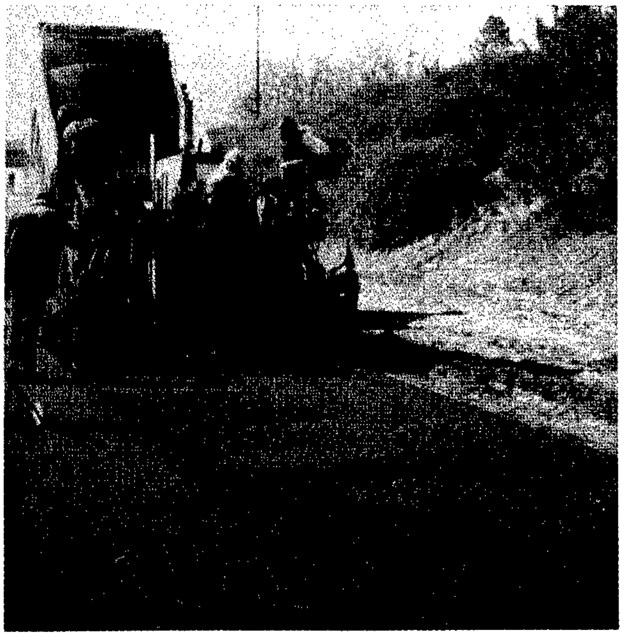


Figure 3-107. Excessive raking of longitudinal joint *(J. Scherocman)*.

Performance

A poor transverse joint will not affect pavement performance to any significant degree if proper density levels are obtained by the compaction equipment. A poor ride will usually be the only negative result. An improperly constructed longitudinal joint, however, can seriously decrease the serviceability of the pavement structure. A poorly placed and compacted joint will ravel and cause one side of the joint to be lower than the other side. If the density level is too low, it is possible for the whole pavement layer thickness at the longitudinal joint to wear away under the action of traffic. A poor joint will also be porous, allowing water to enter the underlying pavement courses.

CHECKING

Description

Checking can be defined as short transverse cracks, usually 1 to 4 in. in length and 1 to 3 in. apart, which occur in the asphalt concrete mat (Figure 3-108). These surface cracks, or checks, are not visible when the paver places the material. The cracks may occur after the second or third pass of the compaction equipment over the mix or after several passes of the roller when the mix is approaching the design density level, particularly when a static steel wheel roller is employed for the breakdown rolling. Rarely does the checking appear after only one pass of the breakdown roller. Checking typically does not occur when a pneumatic tire roller is used for breakdown rolling. If a pneumatic tire roller is followed by any type of static steel wheel roller when the mat temperature is too high, however, that steel wheel roller may introduce the check marks into the mix if the mix is tender. Checking is not normally caused by "over-rolling" of the mix by the compaction equipment. The checks typically do not extend completely through the course but normally are only 1/2 to 3/8 in. in depth.

Cause

Checking can be caused by two primary factors: (a) excessive deflection of the pavement structure under the compaction equipment and (b) a deficiency in the asphalt concrete mix design. In the former case, the pavement on which the new asphalt concrete layer is being placed is weak. The weight of the rollers causes the pavement layers to bend excessively, placing the new mix in tension at the surface. The check marks are then formed when the surface of the new mixture is pulled apart as the pavement deflects during the rolling operation.

A more prevalent cause of checking is a deficiency in the asphalt concrete mixture: (a) an excess of fluids in the mix: too much asphalt cement or too much moisture in the mix, or both; (b) a nonuniform sand gradation: too much middle-size sand [No. 16 and No. 30 (1.18 mm and 600 μm) sieve size material] and too little fine size sand [No. 50 and No. 100 (300 μm and 150 μm) sieve size material]; and (c) a lack of room in the aggregate gradation for the asphalt cement (low voids in mineral aggregate--VMA). The excess of fluids makes the mix tender and allows it to be displaced easily by the compaction equipment. The hump in the fine aggregate gradation curve also causes the mix to be tender. Mixes that are low in voids in mineral aggregate content will generally be tender and move easily under the force of a vibratory or static steel wheel roller. Further, the various characteristics of the aggregate such as surface texture, crushed content, and amount of dust coating can play a role in the amount of checking that occurs.

The mix tends to be shoved by the roller instead of being tucked under the drums or tires of the compaction equipment. The potential for checking is characterized by a bow wave that occurs in front of the drums on a steel wheel roller. The mix deficiency is compounded, and the amount of checking that occurs is increased, when the mix temperature is too high for the particular asphalt cement grade being used in the mix. As the mix temperature increases, the viscosity of the asphalt cement decreases, causing the mixture to be more tender. An additional factor that can affect the degree

Figure 3-108. Checking of the mix *(J. Scherocman)*.

of checking that occurs is the temperature susceptibility of the asphalt cement itself.

Occasionally, checking can be caused by temperature differentials within a layer of asphalt concrete mix (heat checking). On a cool day and under windy conditions, it is possible for the mix that is in contact with the existing pavement surface to decrease in temperature quickly. In addition, the top surface of the mix will also cool quickly. The temperature of the mix in the middle of the layer, however, is still high. This temperature differential can sometimes cause the mix to check under the compactive effort of the rollers.

There are also a number of secondary causes of checking. Included are a mix whose temperature is too high; the mix overheated in the plant. In addition, improper rolling techniques can cause checking: rolling too fast, stopping too quickly, making sharp turns on the hot mat, or making an excessive number of passes with the finish roller or finish rolling with the mat still at an elevated temperature. Finally, checking may be enhanced by a poor bond between the new mat and the underlying surface because of a dirty surface or the lack of a tack coat.

Solution

Because checking is generally a mix-design-related problem, the proper long-term solution is to change the mix properties. Quick mix changes might include reducing the asphalt content or reducing the moisture content by drying the aggregates properly. In addition, the temperature of the mix at the plant can be reduced, but this might increase the amount of moisture left in the mix. Other changes, however, might be time-consuming and expensive, such as altering the fine aggregate gradation to remove the hump from that portion of the grading curve or changing the gradation of the aggregate to increase the amount of VMA in the mix. Care should be taken, however, in making arbitrary adjustments to the mix design without determining how the mix design changes affect the long-term mechanical properties and performance of that mixture.

In the short term, if checking develops under the compaction equipment, changes in both the rolling zone and in the type of rollers used to densify the mix can be made to reduce the amount of checking obtained. If the mix is tender because of excess fluids, a problem with the fine aggregate gradation, or lack of VMA, it may be possible to densify the mix at an elevated temperature without causing the checking. By delaying compaction, the mix has a chance to cool and the viscosity of the asphalt cement increases. This, in turn, stiffens the mix and decreases its displacement by the rollers. The delay in rolling, however, may reduce the opportunity, for some mixtures, to obtain the required level of density in the mix. Thus the problem concerns how to obtain the proper compaction in the mix while the mix is moving under the compaction equipment. With a tender mix, it may not be possible to accomplish both objectives (no checking and adequate density) at the same time.

Depending on the cause of the mix tenderness, some mixes can be adequately compacted at lower than normal mix temperatures. In some cases, because of the properties of the aggregate and the asphalt cement in the mix, the effective compaction temperature range may shift downward by as much as 50°F and adequate density can be obtained even at relatively low compaction temperatures. This means that the rolling zone (the distance between the paver and the breakdown roller) is increased and the mix is permitted to cool more before the initial compactive effort is applied. The feasibility of this solution to the checking problem is determined by two factors: whether checking is eliminated or significantly reduced during the delayed rolling procedure and whether an adequate level of density is obtained. A roller combination test strip should be constructed to determine the proper rolling zone to be used. The density level obtained should be checked with both a nuclear density gauge and with cores cut from the roadway. If the density level achieved is proper and if the amount of checking obtained is significantly reduced, the delayed rolling procedure can be used to overcome the problem.

Another solution is to change the roller type and pattern being used to compact the mix. If a static steel wheel roller is being used in the breakdown position, it should be removed and either a pneumatic tire roller or a vibratory roller used as the initial compaction machine. On some very tender mixes, even when a pneumatic tire roller or a vibratory roller is used in the breakdown position, checking may still occur if a steel wheel roller is used as the intermediate roller. Some benefit, in terms of "healing" the cracks, may also be obtained by using the pneumatic tire roller in the intermediate or in the finish rolling position. In general, however, it is often more effective and efficient to use the pneumatic tire roller in the breakdown position because checking rarely occurs under this piece of compaction equipment. The level of density obtained with the change in roller type and pattern must be checked through the use of a roller compaction test strip together with nuclear density gauge readings and core density determinations.

If the mix delivered to the paver is too hot, the mix should be allowed to cool to normal laydown temperature before the compaction process is started. Improper rolling techniques should be corrected. The surface of the underlying pavement surface should be clean and properly tack coated before placement of the new mix commences.

None of the solutions to the checking problem will always work. Each mix will have its own compaction characteristics. For some very tender mixes, checking may occur at a wide range of temperatures, even as low as 150°F. For other mixes, checking may occur only at more elevated temperatures. In general, mixes that lack internal stability will check under the steel wheel rollers and should not be used--the mix should be redesigned.

Performance

Although the cracks or checks extend only a short distance down from the surface, they are detrimental to long-term performance, because the tender mix characteristics affect the level of density obtained. If the rollers are kept back from the paver to attempt to decrease the amount of checking that occurs, and if the level of density obtained by the compaction equipment is thus reduced, checking can decrease the ultimate pavement life significantly, because the air void content of the asphalt concrete mat is increased. A mix that contains check marks is one that has significant potential to have reduced pavement life under traffic.

SHOVING

Description

Shoving of an asphalt concrete layer is the displacement of the mixture in a longitudinal direction. It can take place during the compaction operation or can occur later under traffic. In most cases, shoving is accompanied by a large bow wave in front of the breakdown roller, particularly if that roller is a static steel wheel machine. Shoving may also occur in conjunction with mix checking if the mix is tender enough because of the aggregate gradation or excess fluids (asphalt cement and/or moisture) content deficiencies. Finally, mat or mix shoving can happen at the reversal point of the rollers, especially at the location closest to the paver.

Cause

Shoving is caused primarily by an unstable or tender mix. This instability can be caused by the same variables that cause checking: an excess of fluids (asphalt cement and/or moisture) in the mix, a hump in the fine aggregate grading curve, the properties of the aggregates and the asphalt cement, or excessive mat temperature during rolling. A mix that has a high Marshall stability can still be a mix that will distort longitudinally under the compaction equipment and later under traffic. Shoving can be very prevalent when a sand mix is placed in a thick layer (more than 1 1/2 in.) at a high temperature (more than 280°F). Further, thicker lifts in proportion to the maximum-size aggregate used in the mix will tend to shove more than thinner lifts with the same aggregate grading.

Improper roller operation, particularly sudden reversal of the roller, can also be a contributing factor to the shoving of the mix during construction. If a vibratory roller is run at too great a speed and the impact spacing is too great, the mat may develop a washboard effect where the peak-to-peak distance is the impact spacing. Washboarding or shoving is more likely to occur at normal frequencies but at high speeds where the impact force is greater. If a pneumatic tire roller with high tire pressure is used for breakdown compaction, a tender mix may shove laterally under the tires. Shoving can occur under any roller if the roller is operated improperly.

Another possible cause of shoving is an excess of tack coat material that may be pulled into the mix. In a similar manner, excess asphalt from a bleeding underlying surface or from joint filler material can be pulled into the mix and increase its fluidity and tenderness. Shoving may also occur when the underlying surface is dusty or dirty--a slippage-type failure.

Solution

The cure for a mix that shoves under the compaction equipment is to increase the internal stability of the mixture. This can be accomplished by reducing the fluids content (either asphalt content or moisture content or both) of the mix, but only after determining the effect of a change in asphalt cement content on the mechanical properties of the mix. It can also be done by increasing the internal friction among the aggregate particles by changing the aggregate gradation or increasing the amount of angular (crushed) particles in the mix. Tender mixes should be placed at lower laydown temperatures, consistent, however, with the ability to obtain sufficient density under the rollers. Sand mixes, because of their inherent tender nature, should be placed in several thin layers instead of one thick layer when used as base or binder courses.

The compaction equipment should be operated properly so as to reduce the opportunity to displace the mix during the rolling operation. Further, if the underlying pavement surface is dirty, it should be cleaned and a proper tack coat applied.

Performance

Mats that tend to shove under the compaction equipment are basically unstable. These mixtures, under traffic, usually will continue to distort, both longitudinally and laterally. Shoving of the asphalt concrete mixture during construction is a strong indication that the pavement will not perform properly under traffic.

BLEEDING AND FAT SPOTS

Description

Fat spots in an asphalt mixture (Figure 3-109) are isolated areas where asphalt cement has come to the surface of the mix during the laydown and compaction operation. These spots can occur very erratically and irregularly, or they may be numerous and in a fairly regular pattern. Bleeding of an asphalt mixture (Figure 3-110) occurs when the asphalt cement flows to the top of the mix surface under the action of traffic. Bleeding is often seen as two flushed longitudinal streaks in the wheelpaths of the roadway.

Cause

Fat spots are caused primarily by excessive moisture in the mix. The problem is more prevalent with mix-

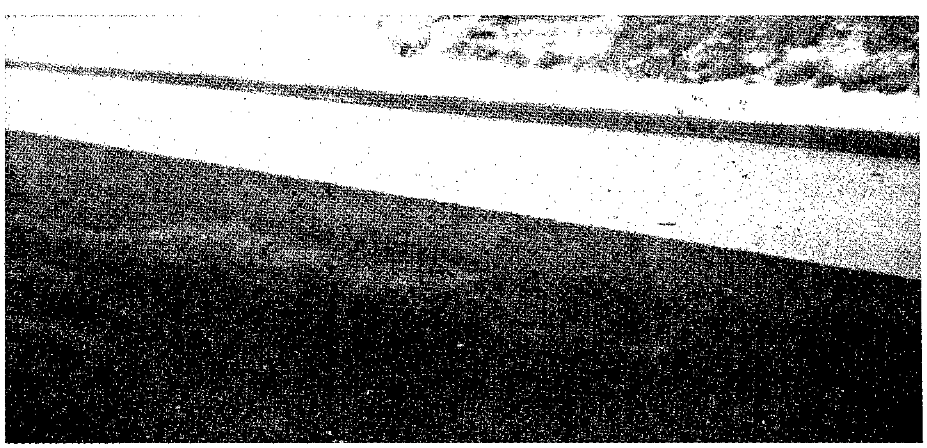


Figure 3-109. "Fat" spots in mix *(J. Scherocman)*.

Figure 3-110. Bleeding (and rutting) in the mix *(J. Scherocman)*.

tures that contain high percentages of fine aggregate (oversanded mixes) and on mixtures that contain aggregates that have a high porosity. If all the moisture in the coarse and fine aggregate is not removed during the drying and mixing operation at the asphalt plant, the moisture will pull asphalt cement to the surface of the mix behind the paver as the moisture escapes from the mix and evaporates. Fat spots occur more frequently when the aggregate stockpiles are wet or when the moisture content varies in different parts of those stockpiles. Fat spots can also be associated with segregated areas in the mix. If the mix deposited on the roadway by the paver is segregated, areas where excess asphalt cement is present in the mix can result in free binder material on the top of the layer being placed.

The cause of bleeding can normally be divided into two categories. The first cause is related to an excess of fluids in the asphalt mixture, either asphalt cement or moisture or both. Under traffic, the extra moisture and asphalt cement will be pulled to the surface by passage of the vehicle tires. This bleeding phenomenon usually occurs on new mix and during hot weather when the viscosity of the asphalt cement is at its lowest level. Typically the bleeding will occur shortly after traffic is allowed to travel over the fresh mix, while there is still some moisture in the mix and while the viscosity of the asphalt cement binder is still relatively low.

Bleeding can also be associated with a lack of adequate room in the mix for the asphalt cement. If the voids in mineral aggregate content and the air void content of the mix do not provide enough room for the binder material, bleeding can occur as the mix is densified by traffic, both shortly after construction and at later time periods. The traffic compaction process will decrease the air void content of the mix and may, in turn, squeeze some of the asphalt cement out of the mix. The "extra" asphalt will appear as a longitudinal streak or fat spot throughout the length of each wheelpath.

One additional possible cause of bleeding is the condition of the pavement layer on which the new mix is placed. If the underlying layer has excess asphalt on its surface or excess crack seal material in the cracks and joints, some of this material can be drawn up through a thin new mix layer. Further, if too much tack coat is applied to the original pavement layer, the excess material can be pulled up through a thin overlay and contribute to the bleeding problem.

Solution

A wide fluctuation in the asphalt mix temperature is an indication that the moisture content of that mix may also be variable. This latter phenomenon can contribute to both the generation of fat spots in the mix during construction and bleeding of the mix later under traffic. It is important, therefore, that the aggregate used in the mix be dry and that the moisture content of the mix, upon discharge from the asphalt plant, be as low as possible but not more than 0.5 percent. Extra care in drying needs to be exercised when producing mixtures that incorporate highly absorptive aggregate. Bleeding problems caused by excess asphalt cement in the mix can most easily be solved by reducing the asphalt content of mix consistent with other mixture properties such as air voids, voids in the mineral aggregate, and stability. Bleeding problems that occur in conjunction with pavement rutting may only be solved, however, by a complete redesign of the asphalt mixture with emphasis on the air void content and the voids in mineral aggregate criteria.

Performance

Fat spots in the mix, if there are only a few of them, should not affect the ultimate durability of the mixture to a significant degree. A great number of fat spots or bleeding in the wheelpaths does affect pavement performance because of variable asphalt and air void contents in different parts of the mix. In addition, other mix problems, such as shoving, rutting, and loss of skid resistance, can occur in a mix that contains many fat areas or bleeding in the wheelpaths. The design of the asphalt mixture, the operation of the asphalt plant (more complete removal of the moisture), or both should be checked to assure adequate pavement performance under vehicular loading.

ROLLER MARKS

Description

During the compaction process by the breakdown and intermediate rollers, whether static steel wheel, vibratory, or pneumatic tire, longitudinal creases are left in the surface of the mix. Once the mix has cooled to a temperature range of 160°F to 140°F, these marks are typically removed by the finish roller. Roller marks are the longitudinal indentations that remain in the surface of the mix after the final rolling has been completed (Figure 3-111).

Roller marks also exist in the asphalt surface when any roller is parked on the hot mat for a period of time or when a vibratory roller is vibrated in place. Particularly when used in the breakdown position, pneumatic tire rollers can leave visible longitudinal marks that can still be seen after the finish rolling has been completed. Vibratory washboard marks may be visible if that roller is operated at an improper vibratory amplitude or frequency setting.

Cause

Roller marks can be an indication that the proper number of roller passes have not been made on the mix. If the compaction process is halted before the required amount of rolling is completed or if the mix cools before the compaction process is completed, the longitudinal marks or creases made by the rolling process will still remain in the mix.

Roller marks left in an asphalt layer also can be an indication of a tender mix. The roller operator will normally be unable to remove all the marks left by the compaction equipment if the mix is tender or unstable. A tender mix normally will not support the weight of the roller until the mix has cooled sufficiently for the asphalt cement viscosity to increase enough to stiffen the mix. By the time the mix has decreased in temperature to this point, however, the required level of density can no

Figure 3-111. Roller marks *(J. Scherocman).*

longer be achieved because the mix has lost its workability. For this reason, the roller marks or indentations left during the breakdown and intermediate roller passes usually cannot be removed during the finish rolling process. All of the asphalt cement, aggregate, and mix properties that contribute to the cause of a tender mix also contribute to the inability of the finish roller to eliminate the roller marks.

Solution

If the cause of the roller marks is inadequate compaction, additional roller passes should be made with the breakdown, intermediate, and/or finish rollers to properly densify the mix. The cures for inadequate compaction related to mix design deficiencies are all concerned with improvements in the design of the mix components and with the production of the mix at the asphalt plant. Asphalt cement quality and content, aggregate properties and characteristics, and mix temperatures all play a significant role in the workability and stability of the asphalt material under the compaction equipment. Roller marks normally cannot be removed from a tender mix until the mix temperature has decreased to a relatively low level; usually less than 160°F.

Sometimes it is possible, depending on environmental conditions and the properties of the mix, to remove the roller marks left in the mix through the use of a pneumatic tire roller. If the surface of the mix is hot enough (140°F or more), several passes with the pneumatic tire roller can be made to "iron out" the surface of the pavement. Roughness or washboarding caused by incorrect operation of a vibratory roller should be eliminated by applying proper operating techniques with this piece of compaction equipment; this type of defect is virtually impossible to correct once it has been introduced into the pavement surface during the compaction process.

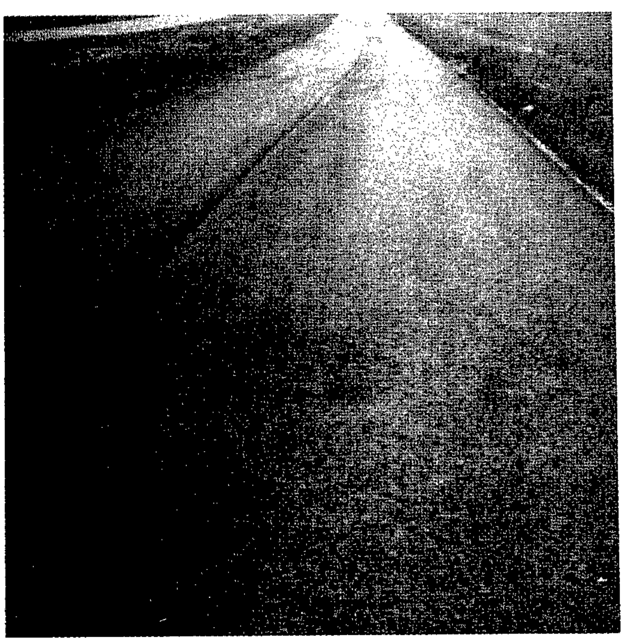


Figure 3-112. Transverse (truckload-to-truckload) segregation *(J. Scherocman)*.

Performance

Roller marks are an indication that the proper level of compaction has not been achieved. In terms of ultimate pavement durability, the air void content or density of the mix is the single most important characteristic that governs the performance of the asphalt mixture under traffic. If the air void content of a dense-graded mix is high, or too low, the pavement structure will generally not perform well under vehicular loading.

SEGREGATION

Description

Segregation is the separation of the coarse and fine aggregate particles in an asphalt mix. The segregation of the mix can occur at several locations during the mix production, hauling, and placing operation. Segregation can occur as the mix is delivered from the asphalt plant to a surge silo. It can take place as the mix is deposited into the haul truck from the silo. It can also occur when the mix is discharged from the truck to the paver hopper.

Segregation that is evident behind the paver screed can generally take one of three forms: It can consist of areas of coarse aggregate (rock pockets) that occur randomly across the length and width of the layer (Figure 3-112), it can occur as a longitudinal area along one side of the paver width (Figure 3-113), or it can be seen transversely across the lane "at the end of a truckload" of mix. Segregation was discussed at length in Section 1 of Part 3.

Cause

The cause of segregation behind the paver is directly related to the type of segregation that is present. Rock pockets are generally caused by improper handling of the aggregates in the stockpiles and cold-feed bins at the asphalt plant. They seldom occur when a batch plant is used to produce the mix (without a silo), because the screens and the hot bins in the plant recombine any segregated material before it is fed into the pugmill. Further, the pugmill blends all the aggregates together and eliminates any segregation that might have occurred previously. If a silo is employed on the batch plant, however, the mix may segregate for all the same reasons as a mix produced in a drum mix plant and passed through a surge or storage silo.

Rock pockets and random segregation can occasionally be found on the roadway when the mix is manufactured in a drum mix plant. If the loader operator places a bucketful of segregated aggregate in a cold-feed bin, that material can pass through the drum, surge silo, haul truck, and paver without being completely mixed in with the other aggregates. This is because the drum mix plant operates on a continuous-flow basis instead of on a batch basis. If the aggregate in the cold-feed bins is segregated, that material will show up on the roadway in a random pattern both transversely and longitudinally.

Some mixes are more prone to segregate than others. Asphalt mixes that have large top-size coarse aggregates (1 in. or greater), low asphalt cement contents, and are gap graded will tend to segregate more readily when handled than will a dense-graded mix containing optimum asphalt content and a smaller top-size coarse aggregate.

Segregation that occurs on one side of the paver (side-to-side segregation) when a batch plant without a silo is used to produce the mix is normally caused by improper loading of the haul truck from the pugmill. If the mix is not loaded in the center of the width of the truck bed, the coarse aggregate particles in the mix can roll to one side of the truck and accumulate along that side. When the mix is delivered to the paver hopper, the segregated mix will be placed on the roadway along the same side and the segregation will appear as a longitudinal streak on one side of the paver only.

Segregation that occurs on one side of the paver when a batch plant with a silo or a drum mix plant is used to produce the mix is typically caused by improper loading of the mix into the surge silo. As the mix is deposited into the silo from the conveying device (slat conveyor, belt conveyor, or bucket elevator), the mix is thrown to one side of the silo and the coarse aggregate particles are separated from the finer materials. When the silo is emptied, the coarse aggregate is deposited on only one side of the truck. This segregated material then passes through the paver and is seen on one side of the mix after laydown. Further, similar to the batch plant operation, if the truck is not loaded in the center of its width under the silo, rolling of the coarse aggregate particles can occur and longitudinal segregation will appear on one side of the new mat.

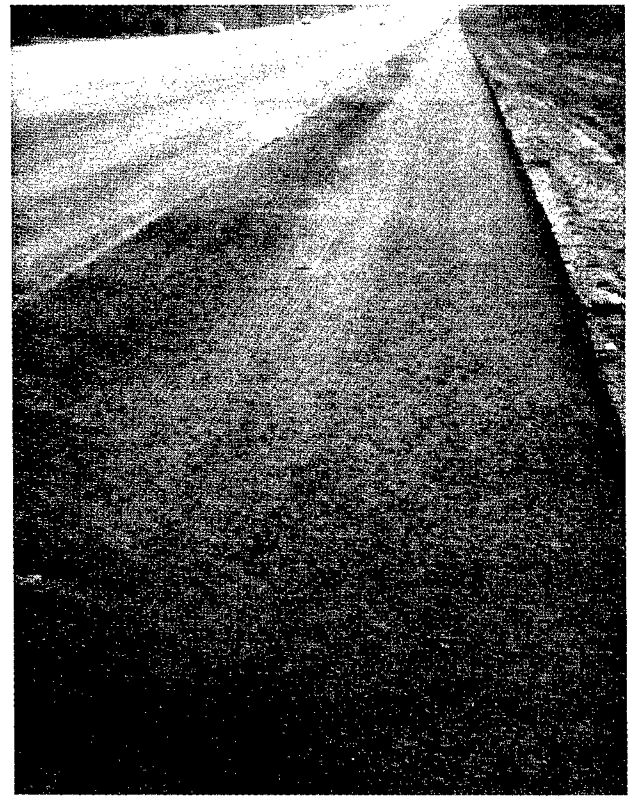


Figure 3-113. Longitudinal (side-to-side) segregation *(J. Scherocman)*.

Truckload-to-truckload segregation has many potential causes. The most prevalent cause is improper loading of the haul truck from the silo. If mix is placed in the truck bed in one drop from the silo, the coarse aggregate particles in the mix have a tendency to run to both the front of the bed and to the back tailgate. The rolling of the coarse aggregate is aggravated by the plant operator continuously opening and closing the silo gates near the end of the truck-loading procedure to assure that the full weight of mix is placed on the truck.

It has been stated that truckload-to-truckload segregation can also be caused by improper discharge of the mix into the silo. Mix that is dribbled into the silo from the conveying device is said to be susceptible to segregation inside the silo. Even if this occurs, the mix that is segregated in the silo would appear only as random rock pockets in the layer behind the paver instead of in a systematic manner between truckloads of mix delivered to the paver. Thus, it is doubtful that any segregation of the mix that occurs during the continuous process of loading the silo would appear on the roadway in a discontinuous pattern--only at the beginning and/or the end of a truckload of mix.

Solution

The solution to each type of segregation is related to its cause. For random rock pockets that appear intermittently in the mat, the method of stockpiling the coarse aggregates at the asphalt plant and the charging of those materials into the cold-feed bins by the front-end loader should be checked to assure proper aggregate-handling techniques are used. Further, all points in the mix-production system where coarse aggregate particles might accumulate should be inspected to determine if the flow of the coarse and fine aggregate pieces is uneven. A batcher should be used at the top of the silo to direct the mix into the center of that piece of equipment.

For longitudinal (side-to-side) segregation, the loading of the haul truck from the batch plant pugmill or from the silo at either the batch or drum mix plant should be monitored to assure that the mix is being delivered into the center of the width of the vehicle. When a drum mix plant is employed to manufacture the mix and the segregation always appears on one side of the paver, several trucks should be loaded at the silo while facing in the opposite direction to their normal loading procedure. When this mix is passed through the paver, the longitudinal segregation should change sides--go from one side of the paver lane to the other side. If the transverse position of the longitudinal segregation does change (and it should), the solution to the side-to-side segregation problem must take place at the top of the silo. The mix deposited into the silo from the conveying device must be placed into the center of the silo instead of to one side. The flow of mix entering the silo must be redirected into the middle of the silo so that the coarse aggregate particles in the mix are not thrown to only one side of the silo. This cure will require some changes in the configuration of the equipment at the top of the silo.

Most truckload-to-truckload segregation can be reduced significantly by using multiple drops of mix to load the haul trucks. If a tandem-axle truck is being loaded, at least three different drops of mix should be made: into the front of the truck, into the back of the truck, and into the center of the truck bed. If a larger truck is used, additional drops of mix should be made. One of the main solutions to the truckload-to-truckload segregation problem is to minimize the distance that the coarse aggregate particles can roll. This is accomplished by employing multiple drops of mix into the truck instead of a single loading of mix into the bed.

The plant operator should be prohibited from "topping off" the load of mix at the end of the loading process. Each time the silo gates are opened and a little bit of mix is dribbled into the truck, the coarse aggregate particles will have a definite tendency to separate from the finer material. This can only be eliminated by preventing its occurrence in the first place.

If segregation does take place during the loading of the truck and there is an accumulation of coarse aggregate particles both at the tailgate of the truck and at the front of the bed, the amount of segregation that appears on the roadway can be reduced by proper unloading of the haul truck at the paver. First, the truck bed should be raised a short distance, before the tailgate of the truck is opened, so that the mix can slide against the tailgate. This procedure surrounds any coarse particles that have rolled to the tailgate area in nonsegregated mix. Instead of only the coarse aggregates being deposited first into the paver hopper, a mass of mix is discharged once the truck tailgate is opened, flooding the hopper with mix.

The operation of the paver can also enhance or reduce the amount of segregation that appears behind the screed. If the paver hopper is emptied of mix, if the slat conveyors are visible, and if the wings of the hopper are dumped after each truckload of mix, any coarse aggregate particles that have collected at the tailgate of the new truckload of mix will be deposited into the bottom of the hopper and then carried directly back to the empty auger chamber in front of the screed. This segregated material will appear behind the screed as soon as the paver moves forward. This transverse segregation, therefore, does not really occur at the end of the truckload but rather occurs at the beginning of the next truckload of mix.

Segregation can be reduced by keeping the hopper full of mix between truckloads. The mass of mix that floods the hopper from the haul truck will be blended with the mix already in the paver hopper. Any segregated material will be further "lost" in the amount of mix that is pulled back to the augers by the slat conveyors and carried under the paver screed. The amount of truckload-to-truckload segregation can be decreased significantly, but not always eliminated completely, by good paver operating techniques. The problem of truckload-to-truckload segregation should be solved during the truck-loading procedure.

Performance

Segregation can affect pavement durability directly by increasing the air void content of the mix in the segregated areas and increasing the potential for moisture damage. Further, the segregated locations are susceptible to raveling and, if bad enough, to total disintegration under traffic. Segregation, in the form of rock pockets, longitudinal side-to-side segregation, or transverse truckload-to-truckload segregation, is detrimental to the long-term performance of the asphalt mixture.

OTHER PAVEMENT PROBLEMS

The discussion above is concerned only with those distresses that occur at the time of the asphalt mix production, laydown, and compaction. There are a number of other deficiencies that can occur on an asphalt pavement structure with time and traffic loading once construction has been completed. Some of those distresses include fatigue cracking, rutting, shoving, raveling, and disintegration. A discussion of these distresses is beyond the scope of this handbook.

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