Davis

U.S. DEPARTMENT OF TRANSPORTATION

FEDERAL HIGHWAY ADMINISTRATION

SUBJECT	FHWA TECHNICAL ADVISORY
PIER PROTECTION AND WARNING SYSTEMS FOR BRIDGES SUBJECT TO SHIP COLLISIONS	T 5140.19 February 11, 1983

1. PURPOSE. To provide guidance to the Federal Highway Administration's field offices and to project applicants involved with bridges subject to ship collisions.

2. APPLICABILITY. This material, which is not regulatory, summarizes existing guidance and information on the state-of-the-art of addressing potential hazards to bridges from ship collisions. The increase in the occurrence of ship-bridge collisions during the past 10 years warrants additional emphasis at this time.

David K. Phillips

David K. Phillips
Director, Office of Engineering

Attachment

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H-E(BR/EC/FO)-3;H-E(SH)-4

OPI: HNG-31

Pier Protection and Warning Systems for Bridges Subject to Ship Collisions

Background

The increase in the occurrence of ship-bridge collisions during the past 10 years warrants additional emphasis on the need to consider protection for bridge piers as well as the installation of warning systems to alert motorists in the event of a span collapse. The purpose of this directive is to provide guidance on these subjects to the Federal Highway Administration's (FHWA) field offices and to State and local agencies involved with Federal-aid highway projects which cross navigable waters. This material is not regulatory, but has been developed to provide additional support and emphasis for developing appropriate protective and warning systems.

Project Development Procedures

The consideration of the potential for ship-bridge collisions should be addressed in the early stages of project development so that cost-effective means can be developed for addressing such hazards. Information from the Coast Guard and the waterway users regarding (1) the type and frequency of shipping on the waterway, and (2) special navigational needs or problems concerning the channel in the vicinity of the bridge, can be most helpful in assessing possible hazards during the location and design of the bridge piers, and the evaluation of the need for motorist warning systems.

The warrants for such systems should be based on an assessment of the risks and consequences of a ship-bridge collision, taking into consideration: (1) the type and frequency of shipping on the waterway; (2) the location and arrangement of the bridge piers in relation to the navigable channel and the resulting vulnerability of the piers to ship collisions; (3) other factors (fog, channel geometrics, wind, river currents, etc.) which may create navigational problems in the vicinity of the bridge; and (4) volume of highway traffic using the bridge.

Motorist Warning Systems

Several bridge failures involving the collapse of a bridge span have occurred in the recent past as a result of the collision of a ship with the bridge. In the immediate aftermath of such an accident, the potential exists for drivers to be unaware of the danger and to drive off the damaged bridge before warning devices and barricades can be erected. This hazard is compounded by the fact that such accidents are likely to occur at night or in periods of poor visibility.

The Department of Transportation has been evaluating the various factors involved in ship-bridge collisions in an effort to find ways to reduce the severity and occurrence of such accidents. While this type of catastrophic failure is not common, enough accidents do occur to warrant consideration of the need for motorist warning systems on bridges subject to ship collisions.

At this time, the most practical warning device is an electrical conductor attached to or a part of the bridge which will activate warning systems and/or gates when the continuity is disrupted (span collapse).

While the use of such a system is simple in concept, there are a number of design considerations (sources of power, need for gates, signals, lights, signs, etc.) to be taken into account. The design and location of warning mechanisms becomes more complex for bridges susceptible to collision over a considerable number of spans. Thus, the warning system must be designed to fit the type of structure, the approaches, and other specific conditions existing at each bridge site.

Appendix A, Alternate Surveillance and Warning Systems for the Sunshine Skyway Bridge Across Tampa Bay, was prepared for the Florida Department of Transportation and contains an excellent comprehensive overview of various factors which should be considered while assessing the need for a motorist warning system. Design Category II, Detection, lists a number of laser, radar, radio and television early warning systems to alert motorists of an impending collision. In general, these systems are still experimental and have not as yet been proven to be reliable for the purpose of providing an early warning to motorists. Accordingly, it is recommended that requests for such systems be submitted to Washington Headquarters for review.

Figure 8 of Appendix A has been modified by the addition of a schematic electrical circuit (Appendix B) in order to illustrate how an electrical conductor can be installed for purposes of detecting a span collapse. The continuity circuit (a pair of conductor wires) and the switch circuits are normally energized.

In the event of a span collapse, the switch circuits are de-energized, causing the activation of warning signs, alarms or gates by the local power source.

A source of local power must be available at each end of the bridge in order to activate the respective warning systems, and of course, the switches and warning devices should be located beyond the point where damage to the bridge is expected.

Under some circumstances, it is possible that a ship-bridge collision could cause severe displacement of a portion of the bridge without a span collapse so that the conductor would stretch but not break. For this reason, consideration should be given to designing the conductor with a circuit interrupter (mercury switch, bayonet-type plug, etc.) located at periodic intervals along the bridge so that a severe impact would interrupt the circuit and activate the warning devices (Appendix B).

Pier Protection

Because of the tremendous momentum achieved by modern ocean-going vessels even while traveling at low speeds in inland channels, it may be extremely difficult to retrofit some existing bridge piers with protective systems which can successfully withstand the anticipated impact loadings. For this reason, it becomes particularly important to recognize the potential hazards from ship collisions and to locate and design piers on new bridges in such a way that the risks of collision are reduced to an acceptable level.

At this time, FHWA is exploring with the American Association of State Highway and Transportation Officials the feasibility of developing standards for the location and protection of bridge piers in navigable waterways. As a result of a research study commissioned by the Coast Guard, a computer program to analyze impact loadings on piers and protection systems has been developed and is fully operational. This program provides a structural evaluation of the effectiveness of bridge pier protective systems for any selected vessel size, speed and angle of attack. Details of this computer program and further guidance of pier protective systems can be obtained from the Bridge Division.

References

1. Pier Protection System for Sunshine Skyway Bridge (Interstate 275 and U.S. Highway 19) Hillsborough, Manatee and Pinellas Counties Florida, U.S. Department of Transportation (Federal Highway Administration and U.S. Coast Guard) and the Florida Department of Transportation, December 10, 1982.

2. Motorist Warning System on Bridges Subject to Ship Collisions - Federal Highway Administration Washington Headquarters memorandum from Mr. Stanley Gordon, Chief, Bridge Division to Regional Federal Highway Administrators dated December 8, 1980.

3. USCG/FHWA Procedures for Handling Projects which Require a USCG Bridge Permit - FHWA Washington Headquarters memorandum from Mr. David K. Phillips, Director, Office of Engineering and Mr. Leon N. Larson, Director, Office of Environmental Policy to Regional Federal Highway Administrator dated October 25, 1982.

ALTERNATIVE SURVEILLANCE AND WARNING SYSTEMS FOR THE SUNSHINE SKYWAY BRIDGE ACROSS TAMPA BAY

STATE TRAFFIC OPERATIONS OFFICE
FLORIDA DEPARTMENT OF TRANSPORTATION
DECEMBER, 1980

REVISED 1/27/81

INTRODUCTION

The occurrence of a catastrophy such as the one that took place when the ship Summit Venture collided with the Sunshine Skyway Bridge on May 9, 1980, is very difficult, if not impossible, to predict. In most cases the possibility of such an occurrence is so remote that it is not considered in the design of structures such as the Sunshine Skyway Bridge. However, when such an accident does occur, attention is sharply focused on the prevention of accidents of this nature.

The purpose of this report is to document the results of a study conducted to identify alternative systems which could be installed on the Sunshine Skyway Bridge to provide detection of catastrophic failures of the bridge and warning motorists of such events. Systems which warn motorists of inclement weather conditions on the bridge such as fog or high winds were also included in this study.

SURVEILLANCE AND WARNING SYSTEMS - SYSTEM ELEMENTS

Three basic categories for design were selected prior to the development of alternative surveillance and warning systems. System elements were identified for each category. Listed below are the three design categories and the system elements contained in each. Short descriptive paragraphs and advantages and disadvantages follow each system element.

I. DESIGN CATEGORY - PREVENTION

A. System Element - Pier Markings

Amber lights are installed on each pier which supports the structural steel elements of the bridge. The amber lights outline the path of the channel beneath the bridge and identify the most critical piers closest to the channel. See Figure 1.

Advantages

- Provide positive guidance

Disadvantages

- Energy consumption
- Maintenance
- Limited visibility conditions hamper effectiveness

B. System Element - Subsurface Attenuation Devices

Subsurface attenuation devices such as dredge material, junked vehicles, etc., are placed parallel to the edge of the channel at a depth so as not to interfere with non-channel restricted waterway traffic. Off course ships are slowed or stopped when they impact the subsurface attenuation device. See Figure 2.

Advantages

- Low probability of impact
- Reduces damage when impacted
- Not affected by environmental conditions

Disadvantages

- Cost
- Environmental constraints
- Maintenance

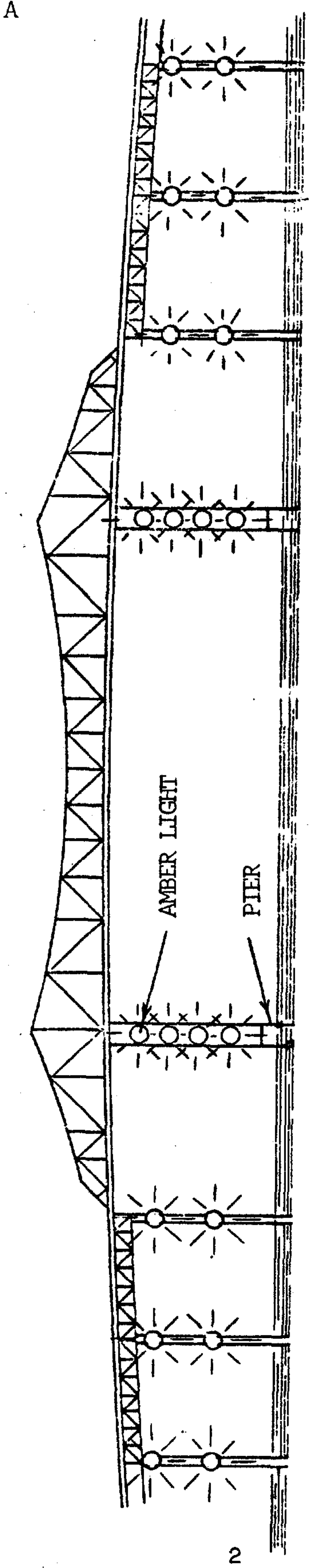

FIGURE 1. PIER MARKINGS FOR SUNSHINE SKYWAY BRIDGE

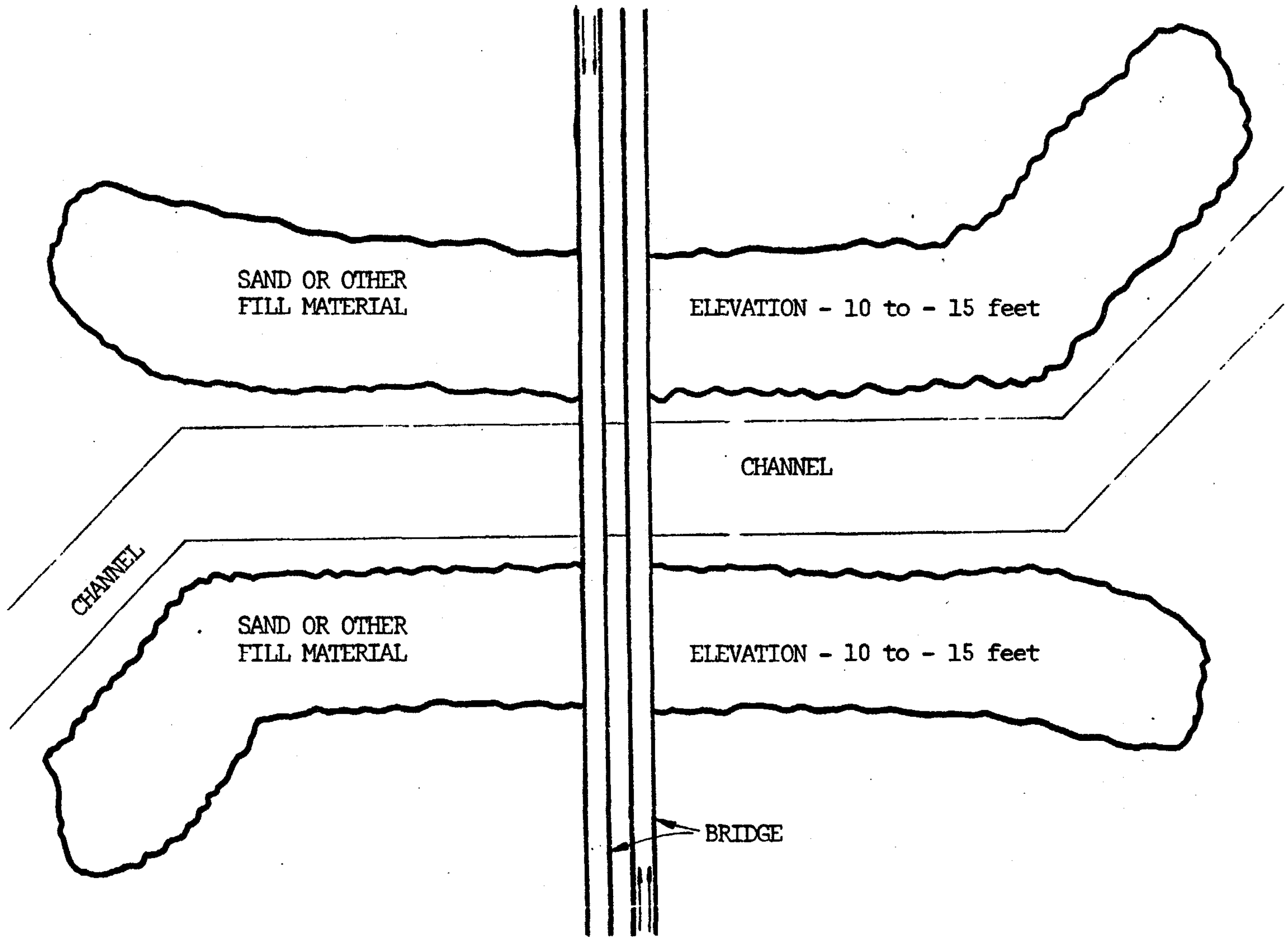

FIGURE 2. SUBSURFACE ATTENUATION DEVICES FOR SUNSHINE SKYWAY BRIDGE

C. System Element - Fender System

An extensive fender system is constructed along each side of the channel. The fender system outlines the path of the channel beneath the bridge and slows or stops off course ships. See Figure 3.

Advantages

- Positive guidance
- Reduces damage when impacted
- Not affected by environmental conditions

Disadvantages

- Maintenance
- Environmental constraints
- Cost

II. DESIGN CATEGORY - DETECTION

Probabilistic Determination

A. System Element - Ship Channel Surveillance (Laser)

A laser beam is projected along the edge of the ship channel at a height so as to be affected by larger vessels only. When the laser beam is disrupted, an off course ship and possible collision with the bridge is indicated. See Figure 4.

Advantages

- Early warning of erratic ship manuevers
- Operator not required

Disadvantages

- Cost
- Maintenance
- Environmental constraints
- Verification
- False detections

B. System Element - Radar System

A ground level radar system similar to those used in airports is installed near the bridge. An operator is able to track ships and verify their position relative to the channel and bridge. See Figure 5.

Advantages

- Complete tracking of ships
- Self-verification
- Reliability
- Not affected by environmental conditions
- Early warning of erratic ship manuevers

Disadvantages

- Cost
- Maintenance
- Operator required

C. System Element - Closed Circuit Television

Closed circuit television cameras are located on the bridge and provide visual surveillance of the ship channel. The operator and

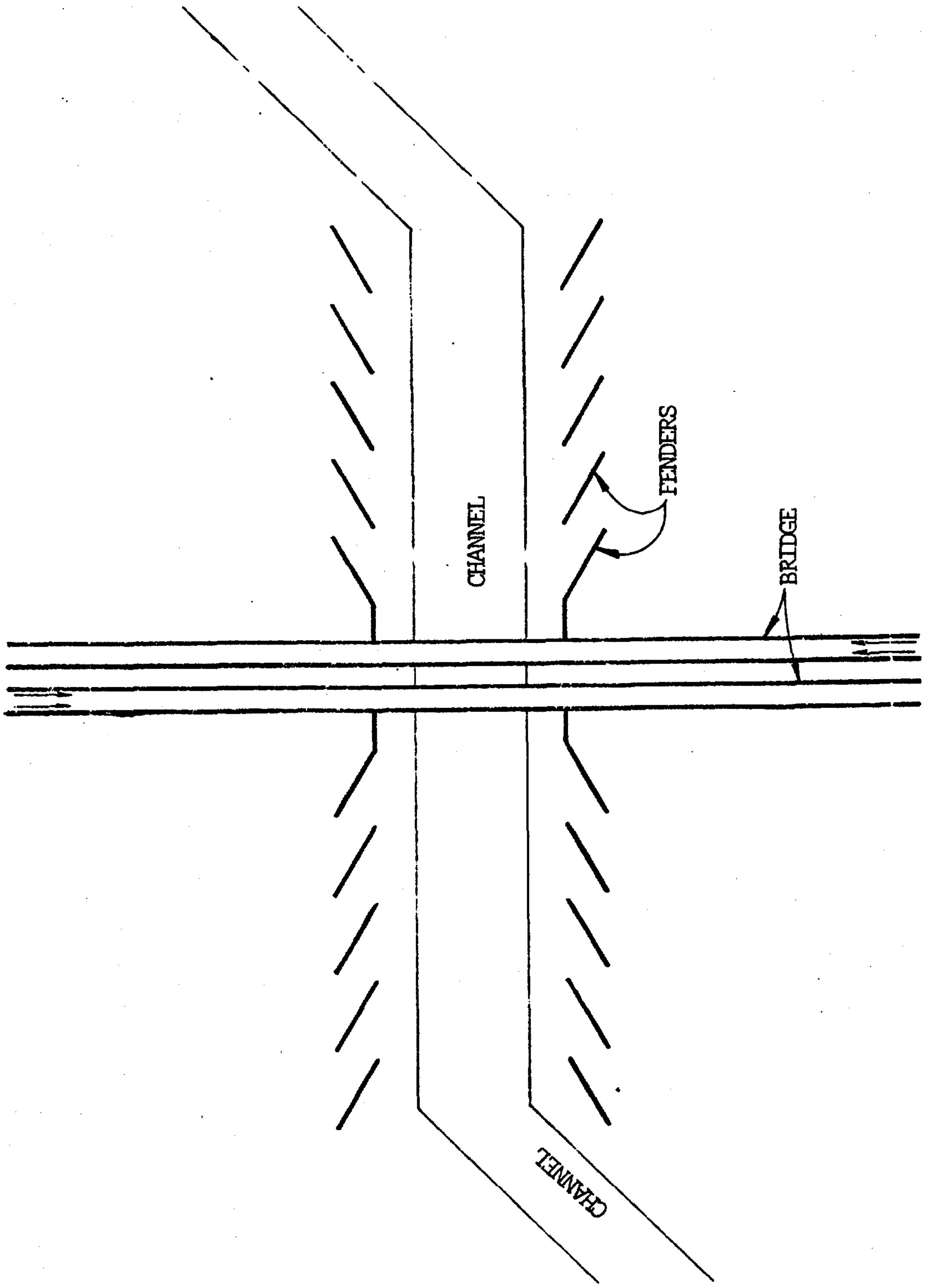

FIGURE 3. FENDER SYSTEM FOR SUNSHINE SKYWAY BRIDGE

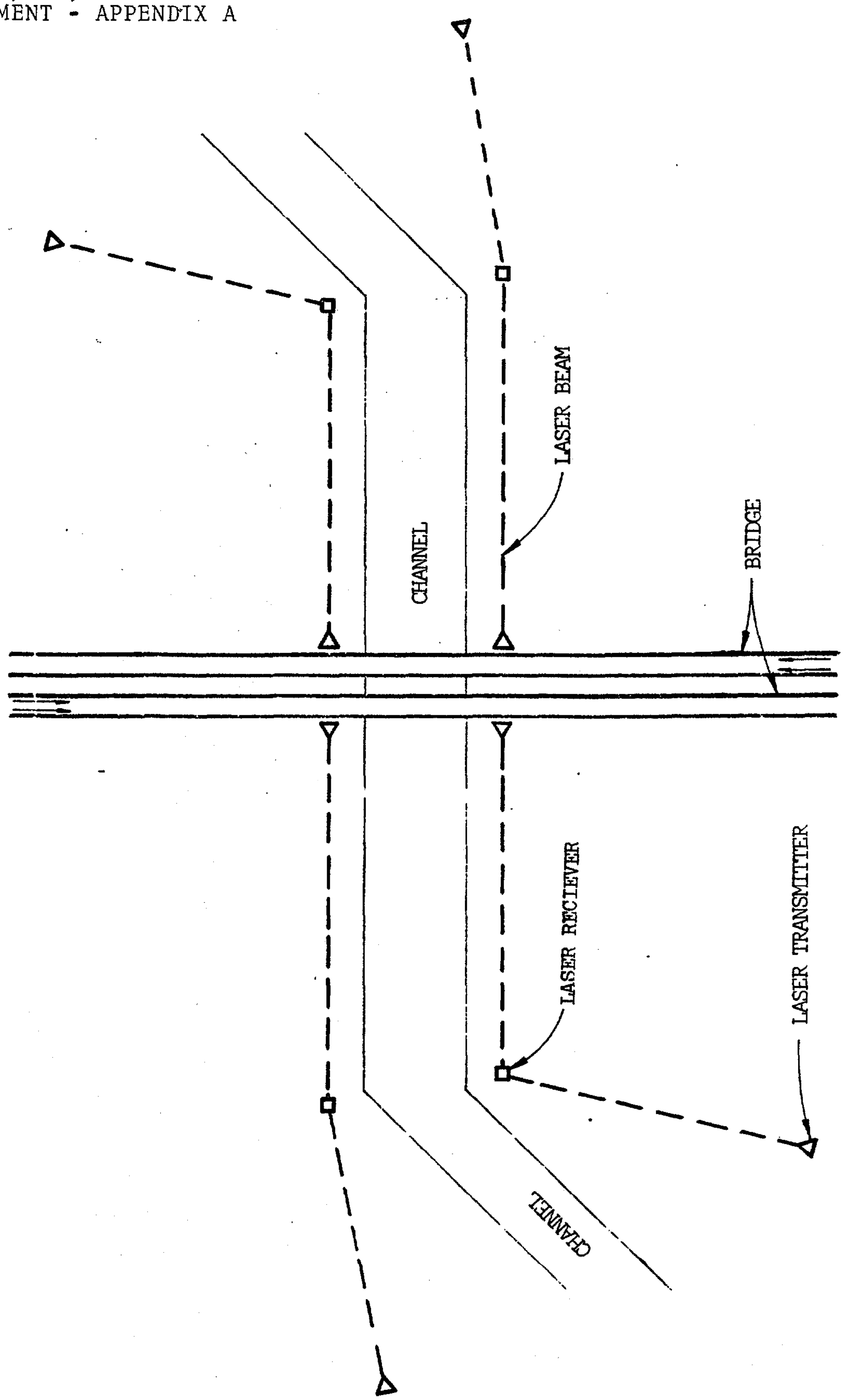

FIGURE 4. LASER SHIP CHANNEL SURVEILLANCE FOR SUNSHINE SKYWAY BRIDGE

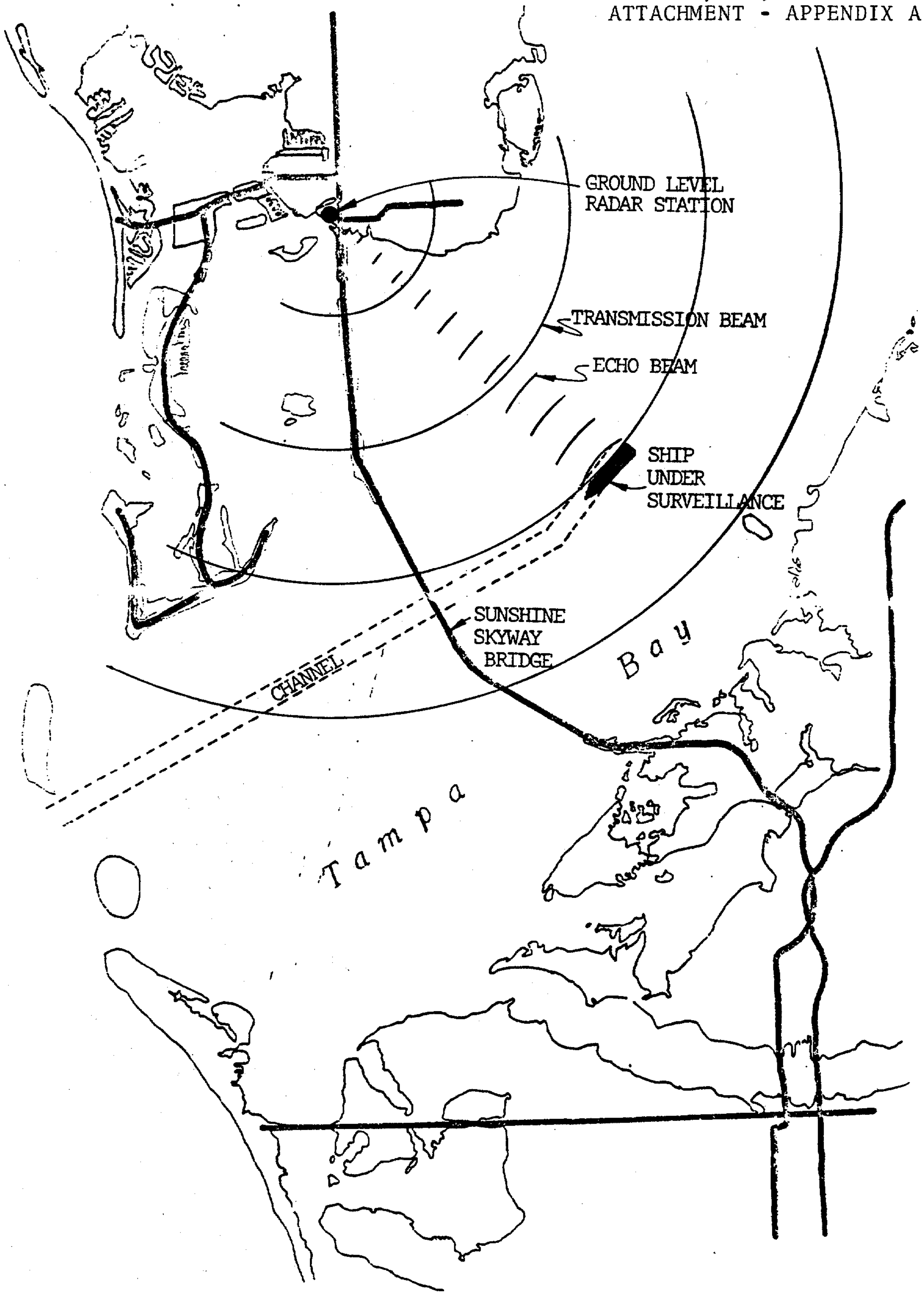

FIGURE 5. RADAR SYSTEM FOR SUNSHINE SKYWAY BRIDGE

television monitors are located at one of the toll facilities for the bridge. See Figure 6.

Advantages	Disadvantages
• Early implementation • Self-verification • Early warning of erratic ship manuevers • Roadway incident detection	• Part-time operator required • Limited visibility conditions hamper effectiveness

D. System Element - Radio Beam Guidance System

Directional radio beam transmitters are installed on the bridge and aimed toward the center of the channel. A portable radio beam receiver is carried on board by the pilot and the system provides the pilot with information on the ship's position relative to the center of the channel and distance from the bridge. See Figure 7.

Advantages	Disadvantages
• Early warning of erratic ship manuevers	• Cost • Maintenance • Environmental constraints • False detections

Impact Occurrence

E. System Element - Bridge Continuity

A conduit containing a pair of conductors is attached to the bridge structure. The pair of conductors are connected to a sensor which monitors electrical continuity of the conductors. A catastrophic failure of the bridge structure would break the continuity of the conductors and the sensor would detect this occurrence. See Figure 8.

Advantages	Disadvantages
• Low cost • Reliability • Not affected by environmental constraints • Low maintenance • No operator required • Early implementation	• Does not provide time to warn 100% of motorists • Malfunction of system creates severe impact on motorist behavior

F. System Element - Pier Vibration

A vibration sensor is placed on each pier which supports the structural steel elements of the bridge. Pier vibration above a threshold value which would be created by the impact of a ship is detected by the sensor. See Figure 9.

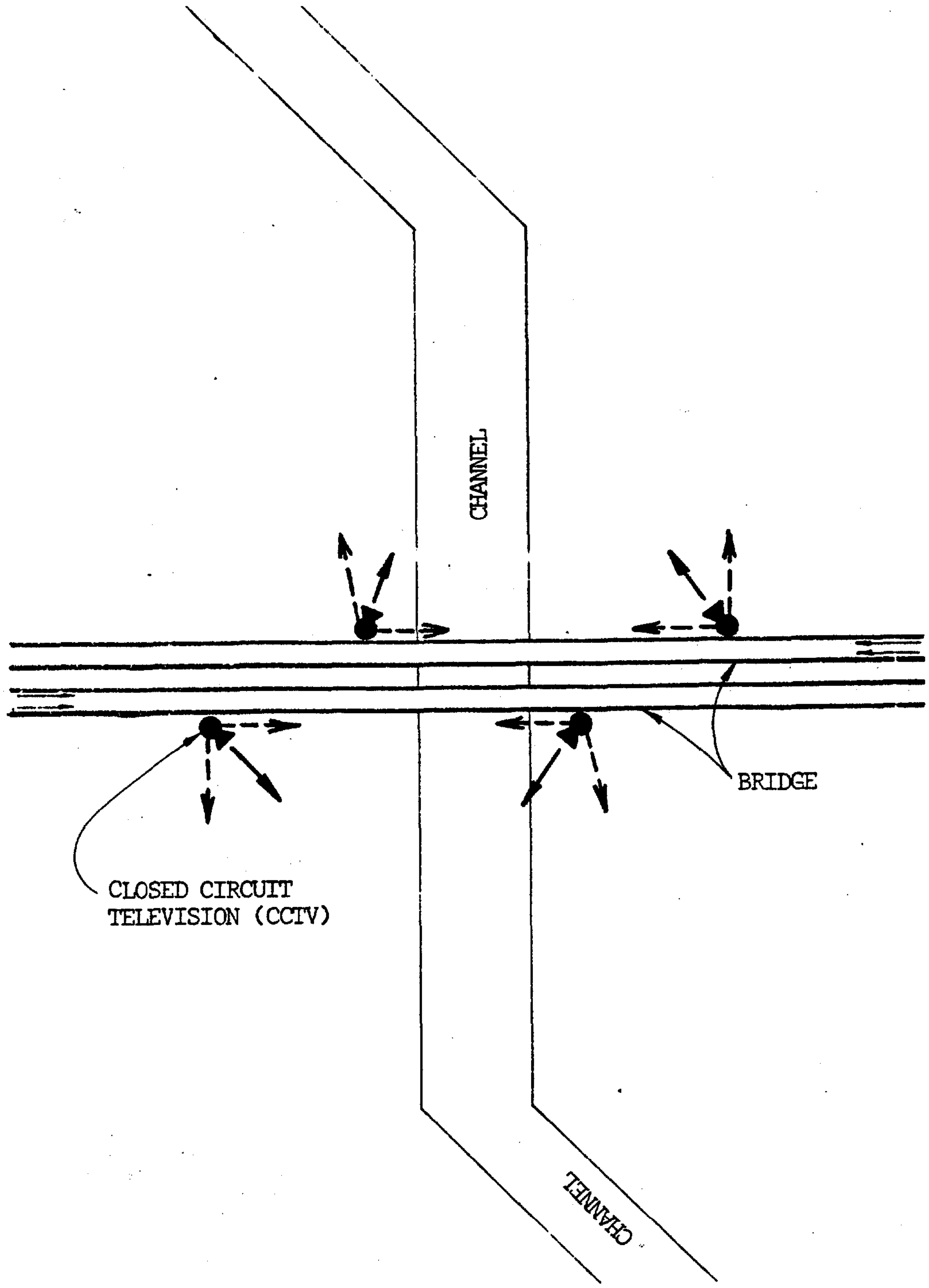

FIGURE 6. CLOSED CIRCUIT TELEVISION SYSTEM FOR SUNSHINE SKYWAY BRIDGE

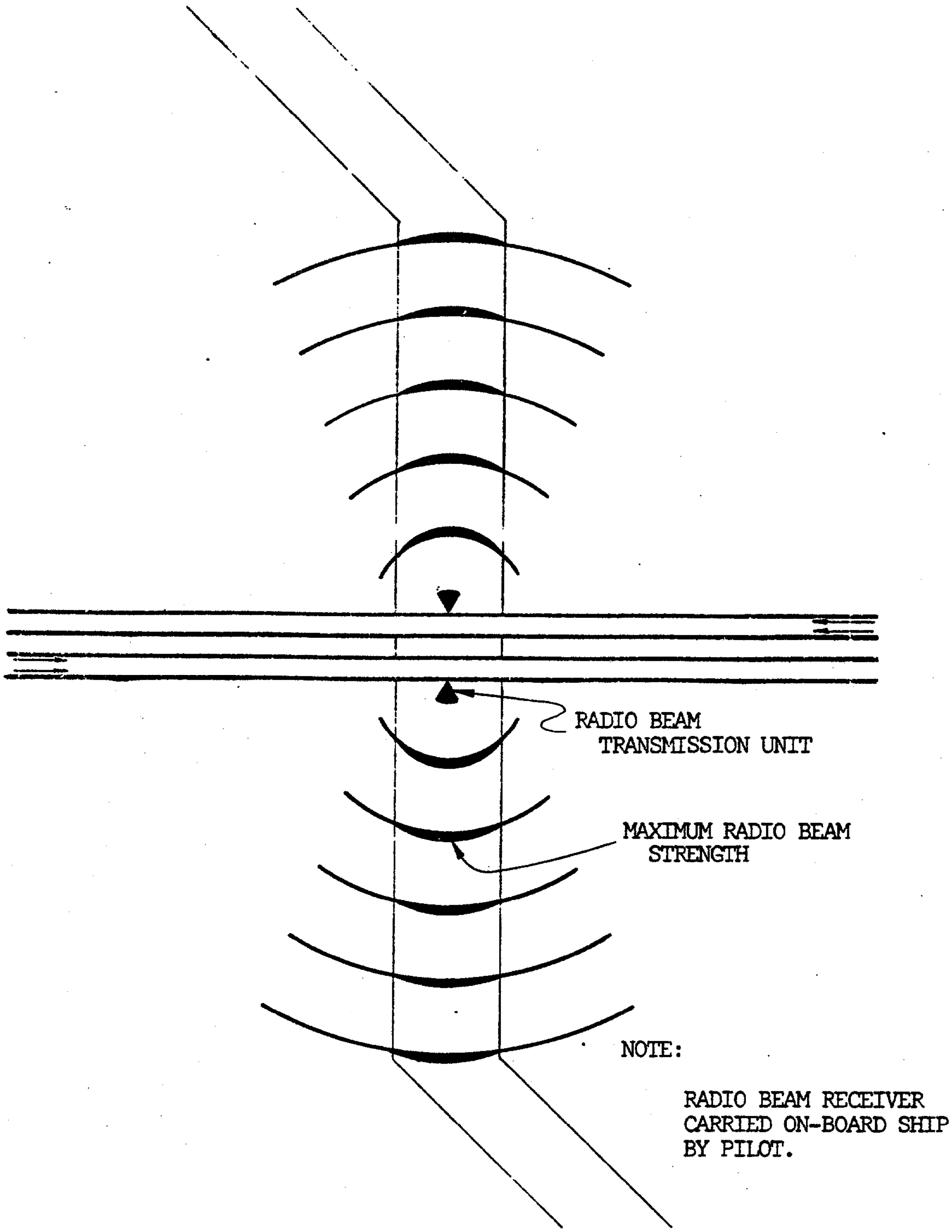

FIGURE 7. RADIO BEAM GUIDANCE SYSTEM FOR SUNSHINE SKYWAY BRIDGE

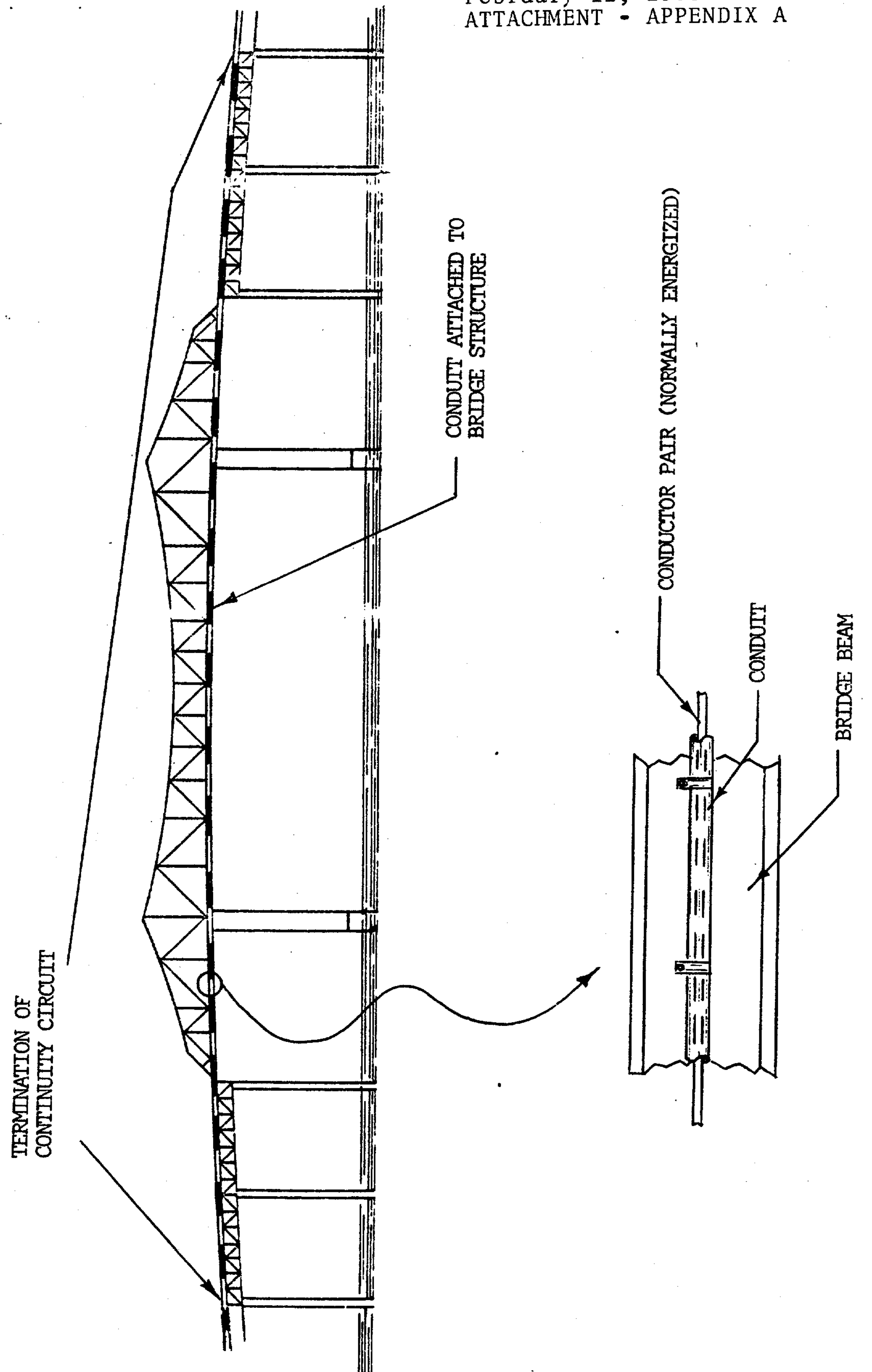

FIGURE 8. BRIDGE CONTINUITY SYSTEM FOR SUNSHINE SKYWAY BRIDGE

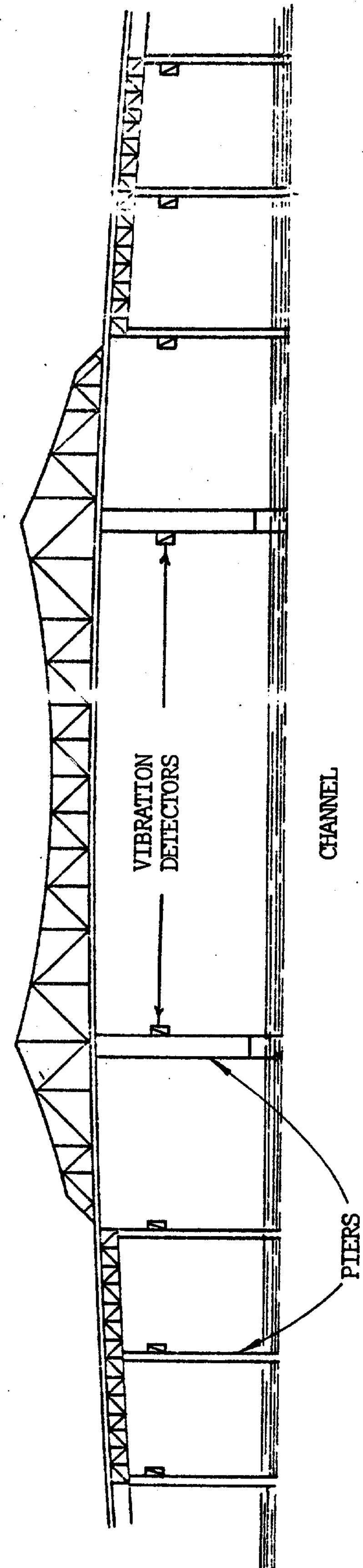

FIGURE 9. PIER VIBRATION SYSTEM FOR SUNSHINE SKYWAY BRIDGE

Advantages

- Low cost
- Early implementation
- No operator required
- Not affected by environmental conditions
- Detection of non-catastrophic damage

Disadvantages

- Does not provide time to warn 100% of motorists
- Maintenance
- False detections

G. System Element - Roadway Delineation (Reflectors)

Reflective button markers are attached to the hand rails at a close, uniform spacing. The presence of these markers at night would indicate a continuous structure, their absence would indicate a section of the bridge is missing.

Advantages

- Low cost
- Early implementation
- No operator required
- Low maintenance

Disadvantages

- Low effectiveness
- Limited visibility conditions hamper effectiveness
- Verification
- Notification
- Does not provide time to warn 100% of motorists

H. System Element - Roadway Delineation (Rail Lighting)

Rail lights, which are continuous longitudinal sections of lights for roadway illumination, are attached to the bridge hand rails. The presence of these lights at night would indicate a continuous structure, their absence would indicate a section of the bridge is missing.

Advantages

- Early implementation
- No operator required
- Improves nighttime traffic operations

Disadvantages

- Does not provide time to warn 100% of motorists
- Limited visibility conditions hamper effectiveness
- Limited effectiveness
- Maintenance
- Driver education

III. DESIGN CATEGORY - WARNING

A. System Element - Passive Signing with Flashers

Passive signs with static messages are installed on the bridge at regular intervals. Both environmental and operational messages are displayed on the signs. These messages are in effect when the flasher is activated. See Figure 10.

Advantages

- No operator required

Disadvantages

- Malfunction of system creates severe impact on motorist behavior

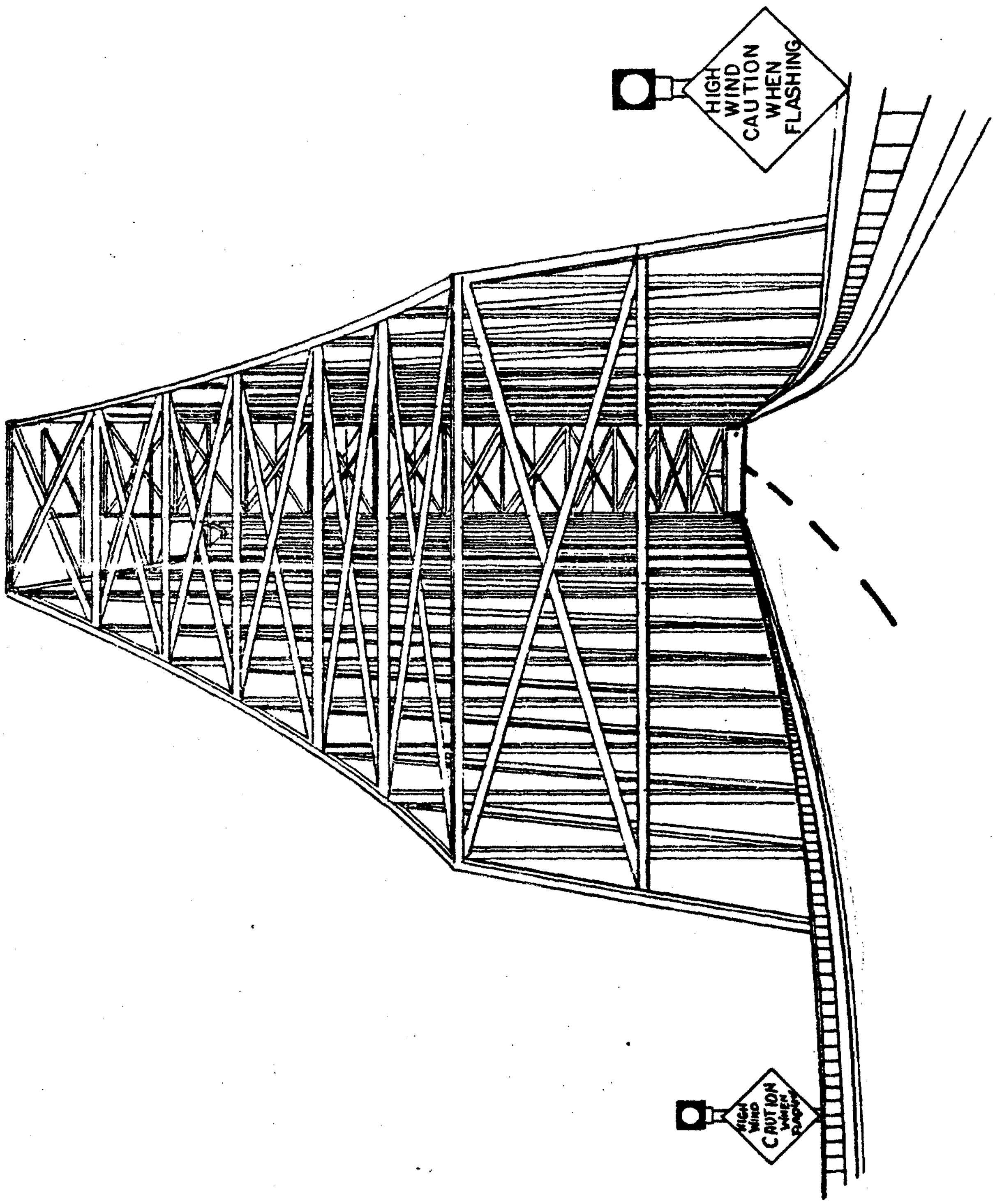

FIGURE 10. PASSIVE SIGNING WITH FLASHER FOR SUNSHINE SKYWAY BRIDGE

- Low cost
- Low maintenance
- Early implementation

- Not positive control
- Limited visibility conditions hamper effectiveness
- Psychological effects on motorists
- Does not provide time to warn 100% of motorists
- Message not observed by all motorists

B. System Element - Dynamic Signing

Variable message signs are located over the roadway at regular intervals across the bridge. Both environmental and operational messages are displayed on the signs in response to operator commands or detection systems. See Figure 11.

Advantages

- Can be used for other applications
- Good target value
- Early implementation

Disadvantages

- Cost
- Message not observed by all motorists
- Not positive control
- Does not provide time to warn 100% of motorists

C. System Element - Signals and Gates

Drawbridge type signals and gates are located on the bridge at several locations prior to the main span structure. Signals and gates are activated by detection systems. See Figure 12.

Advantages

- Positive control
- No operator required
- Early implementation

Disadvantages

- Psychological effects on motorists
- Maintenance

D. System Element - Lane Control Signs

Lane control signs are located over each roadway lane at one quarter mile spacings across the high rise section of the bridge. Roadway lanes are closed by changing the lane control sign message from a green arrow to a red "X" on command from a system operator. See Figure 13.

Advantages

- Can be used for other applications

Disadvantages

- Not positive control
- Maintenance
- Message not observed by all motorists
- Does not provide time to warn 100% of motorists

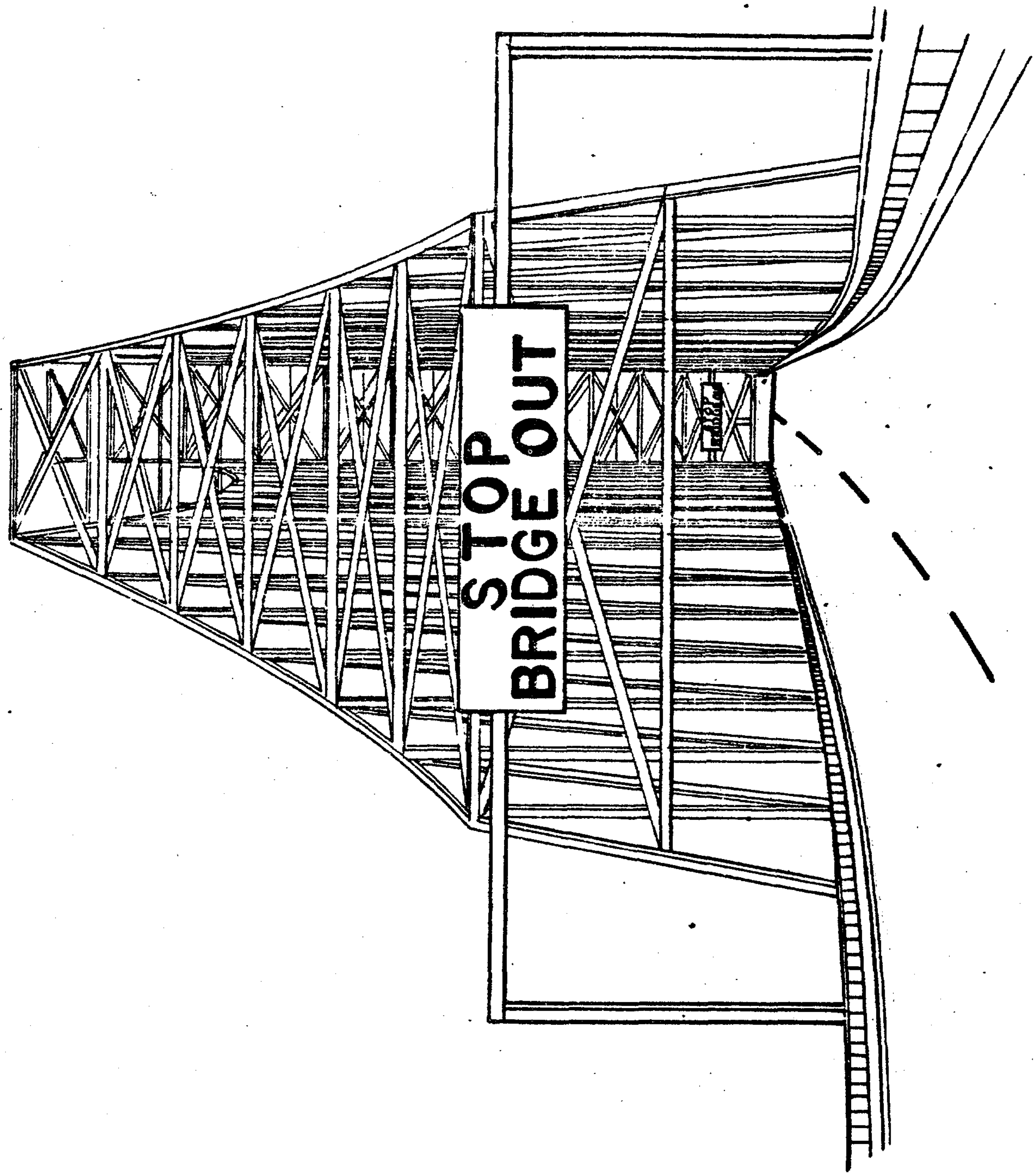

FIGURE 11. DYNAMIC SIGNING FOR SUNSHINE SKYWAY BRIDGE

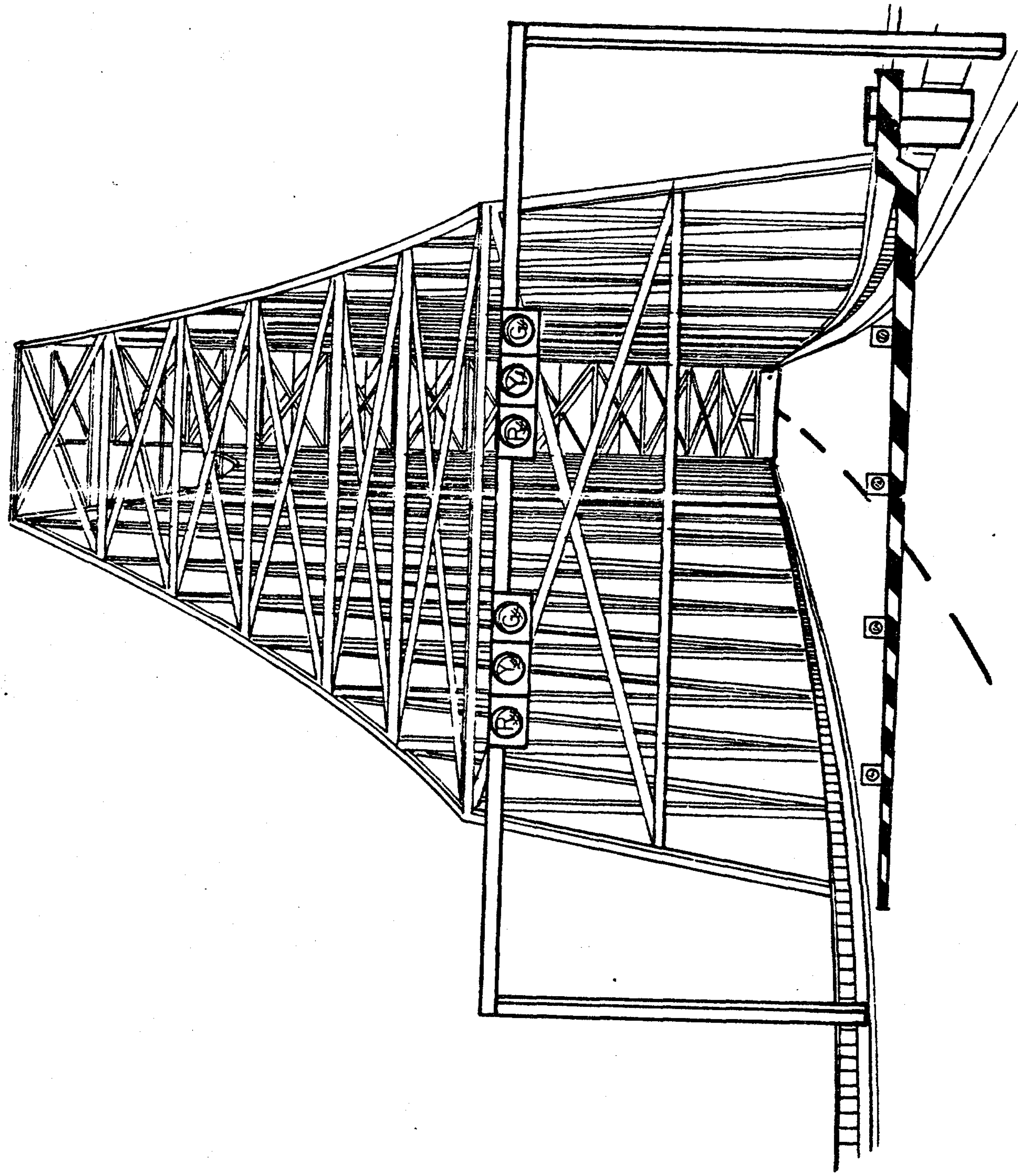

FIGURE 12. SIGNALS AND GATES FOR SUNSHINE SKYWAY BRIDGE

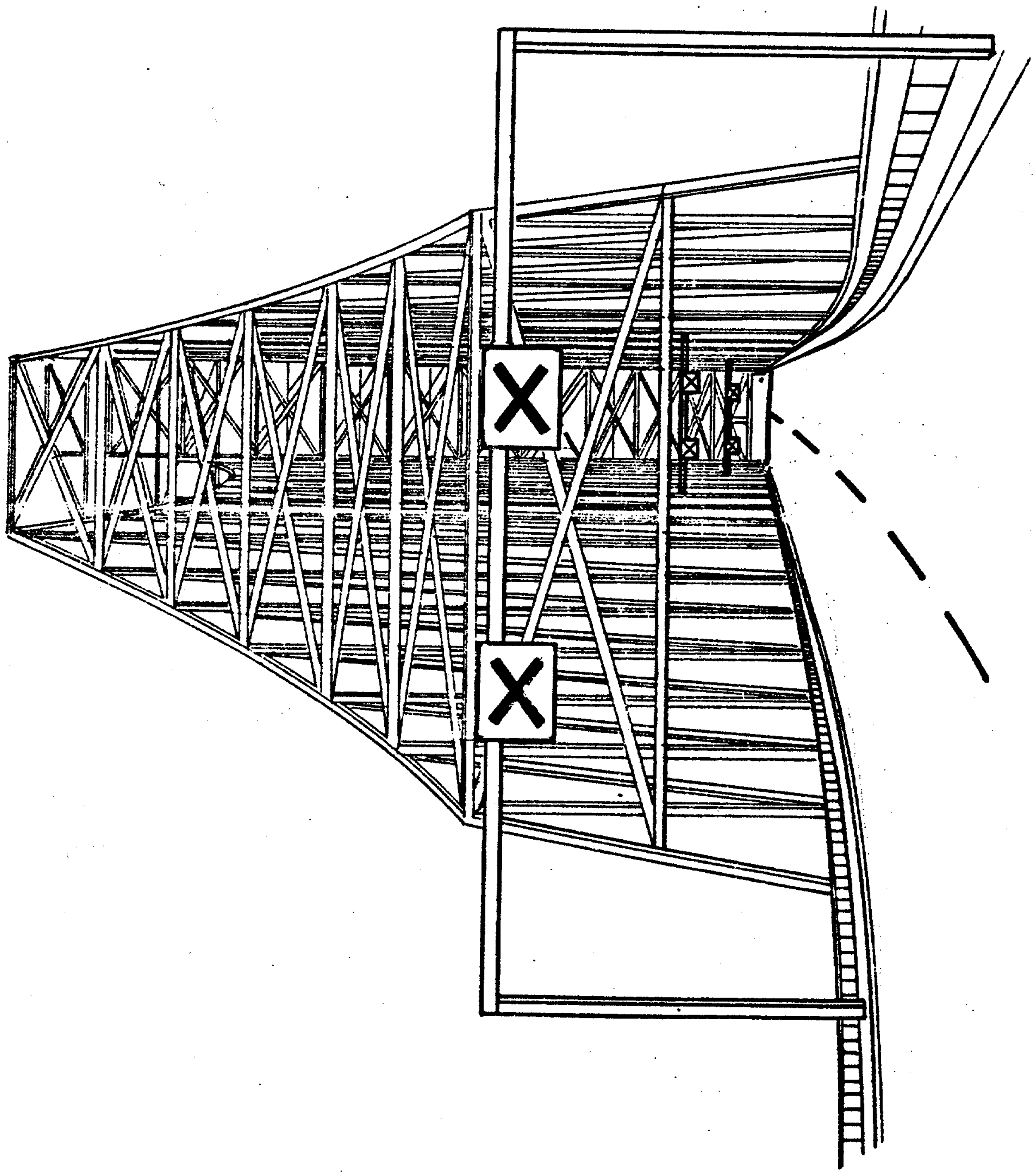

FIGURE 13. LANE CONTROL SIGNS ON SUNSHINE SKYWAY BRIDGE

E. System Element - Audible Alarm and Signs

Audible alarms are installed integral to the operation of the passive signs with flashers (Figure 10) or dynamic signs (Figure 11). See Figure 14.

Advantages	Disadvantages
• Low cost • Early implementation • No operator required	• Malfunction of system creates severe impace on motorist behavior • Message not observed by all motorists

F. System Element - Citizen Band Radio

A citizen band radio base station is located in the toll facility. An operator reports condition on the bridge over CB channel 9. See Figure 15.

Advantages	Disadvantages
• Low cost • Greater coverage area	• False calls • Message not observed by all motorists • Not reliable • Does not provide time to warn 100% of motorists

G. System Element - Traffic Signals

Pedestal mounted traffic signals (red and amber sections only) are located on both sides of the roadway at one quarter mile spacings across the high rise section of the bridge. Warnings (flashing amber) or bridge closure (steady red) are indicated on the traffic signal by operator command or input from detection systems. See Figure 16.

Advantages	Disadvantages
• Recognized roadway control • Early implementation	• Energy • Not positive control • Maintenance

ALTERNATIVE SURVEILLANCE AND WARNING SYSTEMS - DEVELOPMENT AND SELECTION

By combining various prevention, detection and warning devices presented in preceding sections of this report, ten alternative surveillance systems were developed. Each system element in the alternatives is listed in Table 1. The overall system cost and complexity increases as the alternative number increases. To achieve adequate system effectiveness; however, the surveillance system must be moderately complex, and the system cost is therefore relatively high.

Listed in Table 2 are eight surveillance system goals and numerical goal weights developed to quantitatively evaluate the alternative surveillance systems. The technique used involved the appraisal of intangible system benefits by numerically weighting goal achievements. For example, alternative system nine employs the use of a fender system which is considered to be an excellent positive guidance system for ships; therefore, a value of twenty-four out of a possible twenty-five was assigned to the first system goal for system nine. Performance values assigned to each goal were then totalled. Alternative systems six, seven, eight and nine had total goal achievement values of 64 or higher. The prevention, detection and warning techniques used in these four surveillance systems are considered to be the best choice for implementation on the Sunshine Skyway Bridge.

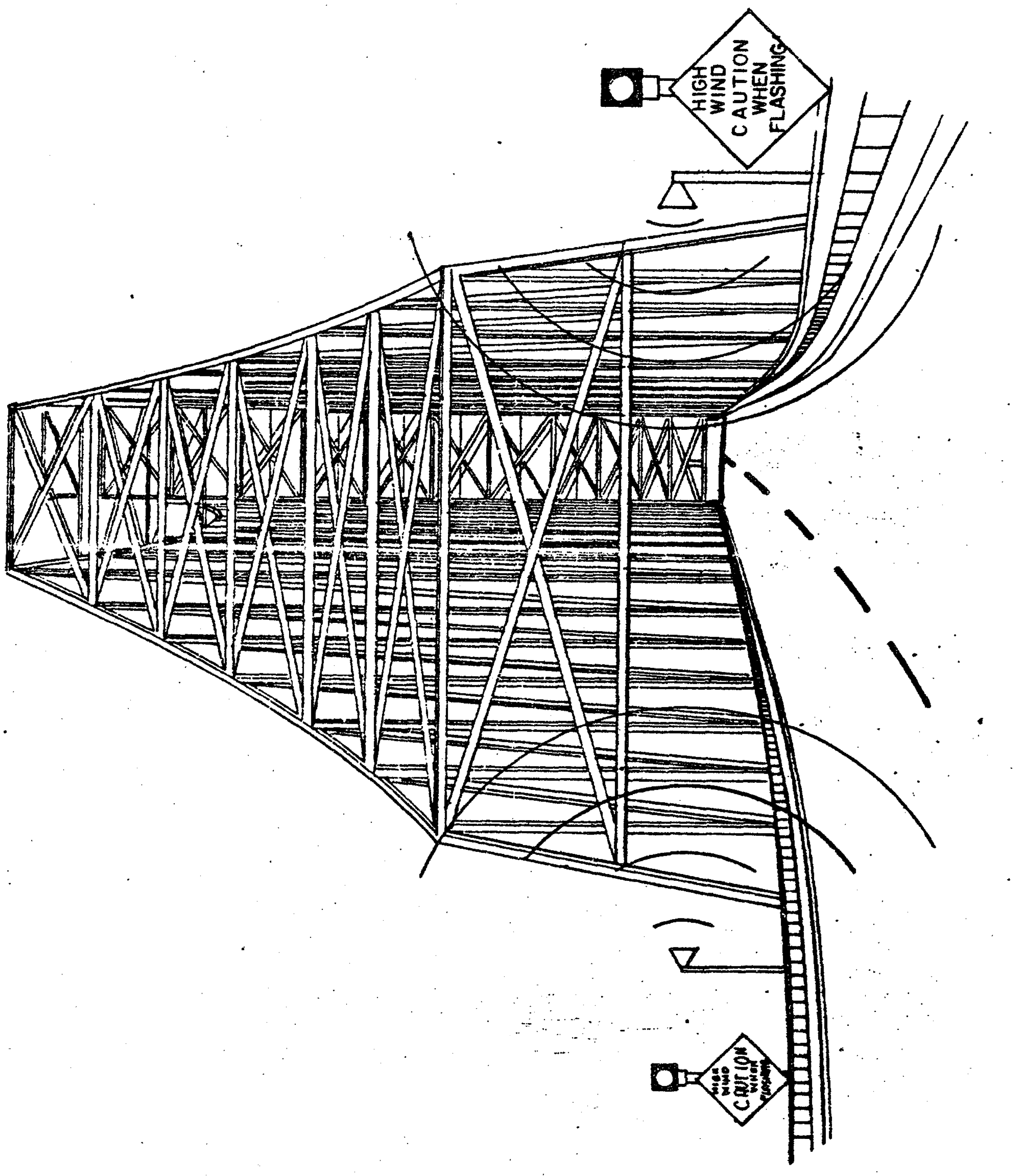

FIGURE 14. AUDIBLE ALARM AND PASSIVE SIGNS WITH FLASHERS FOR SUNSHINE SKYWAY BRIDGE

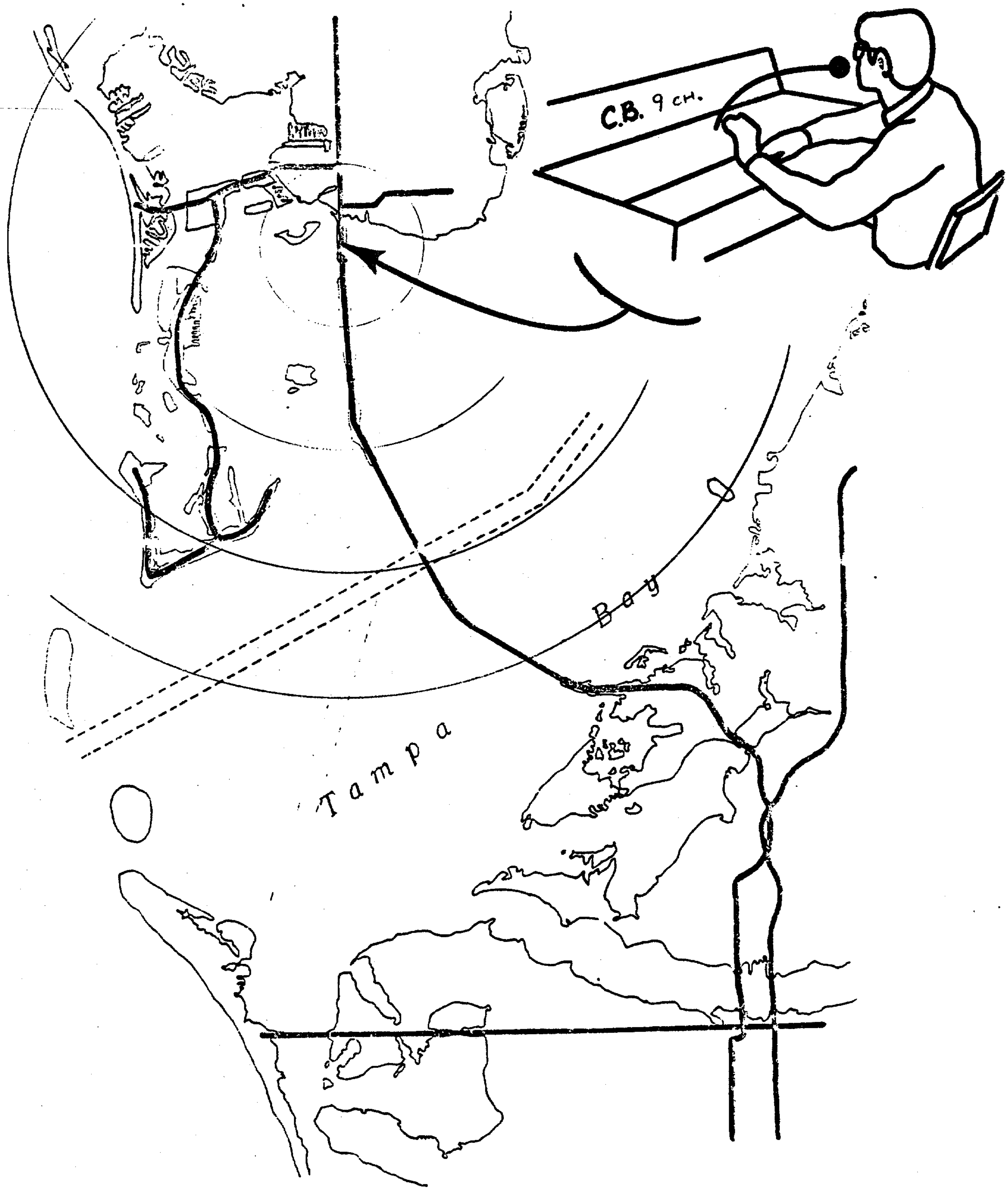

FIGURE 15. CITIZEN BAND RADIO FOR SUNSHINE SKYWAY BRIDGE

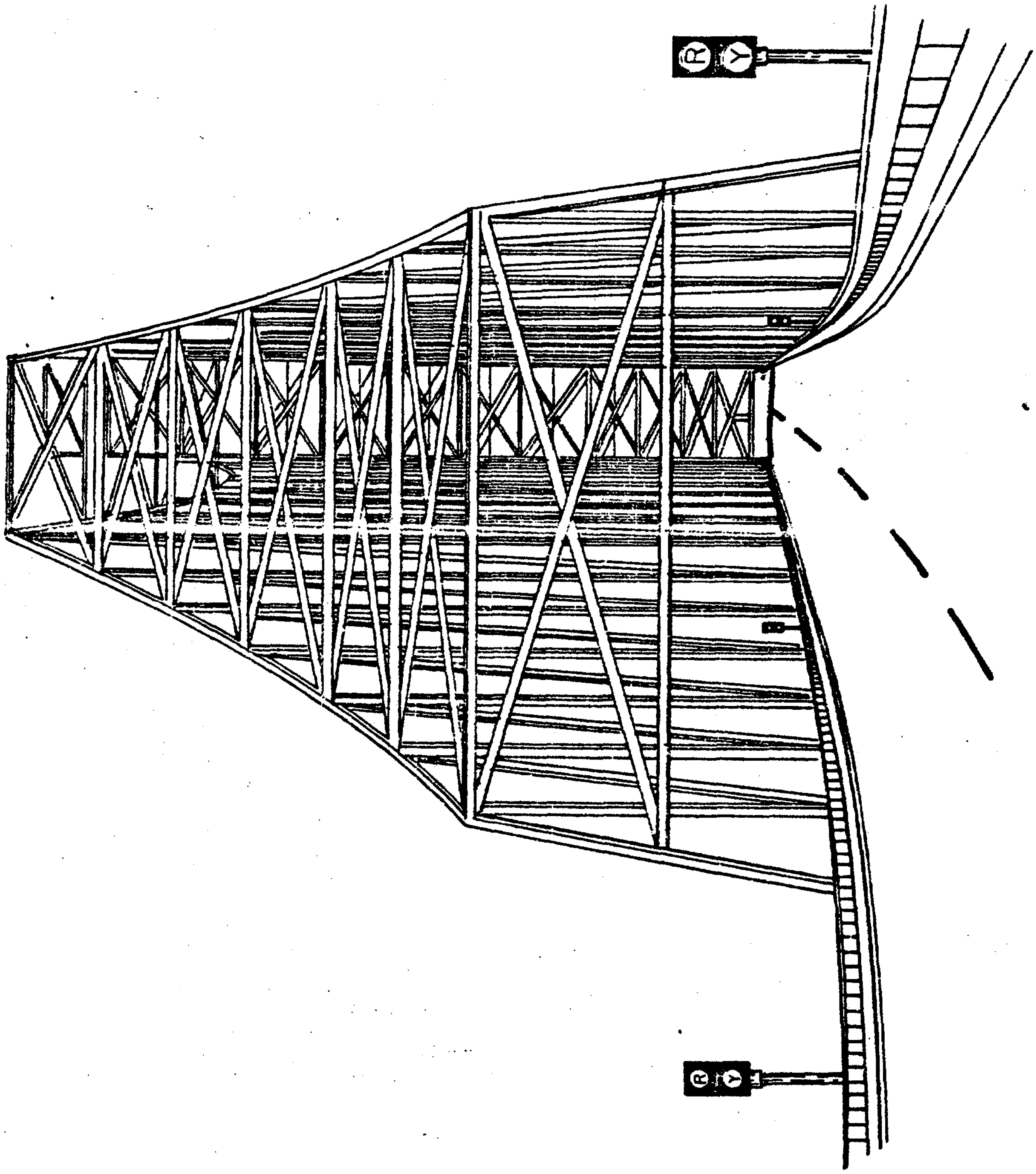

FIGURE 16. TRAFFIC SIGNALS ON SUNSHINE SKYWAY BRIDGE

	ALTERNATIVE 1	ALTERNATIVE 2	ALTERNATIVE 3	ALTERNATIVE 4	ALTERNATIVE 5	ALTERNATIVE 6	ALTERNATIVE 7	ALTERNATIVE 8	ALTERNATIVE 9	ALTERNATIVE 10
PREVENTION										
Pier Markings	X	X	X	X	X	X	X	X		
Attenuators										X
Fender System									X	
DETECTION (PROBABILISTIC)										
Laser System					X	X	X	X	X	
Radar System										
CCTV								X	X	
Radio Beam						X	X	X	X	
Weather Instruments	X	X	X	X	X	X	X	X	X	X
DETECTION (IMPACT OCCURRENCE)										
Bridge Continuity	X		X							
Pier Vibration		X	X	X	X	X	X	X		
Delineation (Reflectors)	X	X	X		X					
Delineation(Offset-Spot Rail Lighting)				X		X	X	X		
WARNING										
Passive Signing & Flashers	X	X								
Dynamic Signing			X	X	X	X	X	X	X	X
Gates						X	X	X	X	
Lane Control Signs						X				
Audible Alarm & Signs										
C.B. Radio										
Traffic Signals					X		X	X	X	

TABLE 1
ALTERNATIVE SYSTEMS DEVELOPMENT
SURVEILLANCE AND WARNING SYSTEM
FOR SUNSHINE SKYWAY BRIDGE

SYSTEM GOALS	GOAL WEIGHT	ALTERNATIVE SYSTEM 1	ALTERNATIVE SYSTEM 2	ALTERNATIVE SYSTEM 3	ALTERNATIVE SYSTEM 4	ALTERNATIVE SYSTEM 5	ALTERNATIVE SYSTEM 6	ALTERNATIVE SYSTEM 7	ALTERNATIVE SYSTEM 8	ALTERNATIVE SYSTEM 9	ALTERNATIVE SYSTEM 10
1. POSITIVE GUIDANCE TO SHIPS	25	5	5	5	5	10	22	22	22	24	0
2. POSITIVE BRIDGE PROTECTION	20	0	0	0	0	0	0	0	0	10	18
3. SYSTEM RELIABILITY	15	1	2	5	5	6	10	10	14	14	14
4. WARNING CONVEYED TO 100% OF MOTORISTS	15	0	0	0	0	12	14	14	14	14	14
5. POSITIVE VEHICLE TRAFFIC CONTROL	10	2	2	4	4	6	9	9	9	9	4
6. POSITIVE GUIDANCE TO MOTORISTS	5	2	2	2	4	2	4	4	4	0	0
7. MINIMAL MAINTENANCE & OPERATION COSTS	5	4	4	4	3	2	1	1	0	0	4
8. IMPROVEMENTS IN ROADWAY OPERATIONS	5	1	1	3	4	3	5	4	4	3	3
TOTAL	100	15	16	23	25	41	65	64	67	74	57

TABLE 2
ALTERNATIVE SYSTEMS
GOAL ACHIEVEMENT CHART

CONCLUSIONS AND RECOMMENDATIONS

Based on the results of this study, it is recommended that Alternative Systems 6, 7, 8 and 9 be evaluated in detail to determine which system would be the most cost effective for installation on the Sunshine Skyway Bridge. System 6 is estimated to be the least costly system and System 8 is the most expensive.

Functionally, Systems 6, 7, and 8 are basically the same, with the differences being in the maintenance, operation and initial costs of these systems.

Installation of a surveillance and warning system could take place during reconstruction of the Skyway Bridge. However, with the present two-way traffic conditions on the remaining bridge, consideration should be given to early implementation of the system on this existing section.

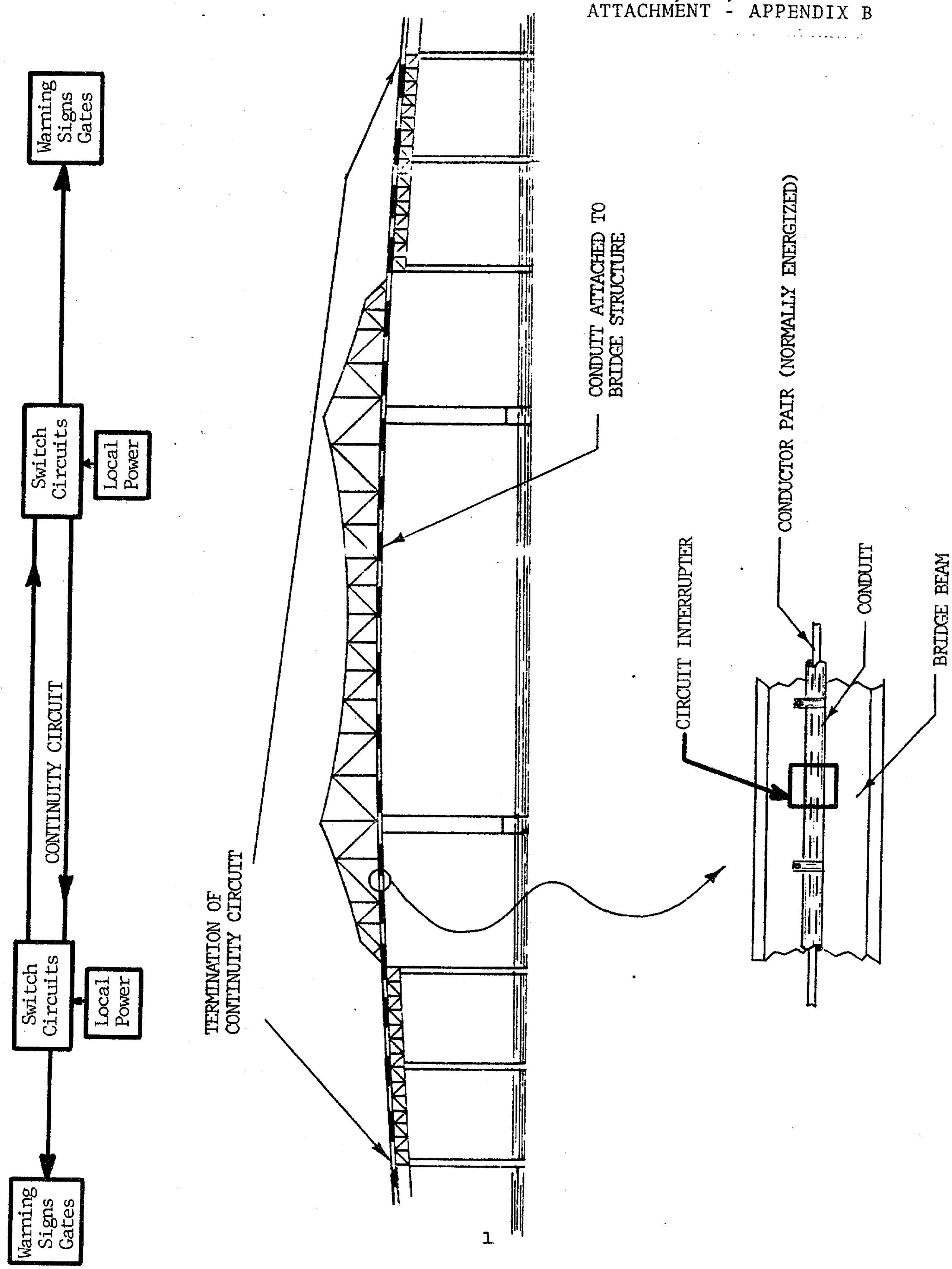

FIGURE 8. BRIDGE CONTINUITY SYSTEM FOR SUNSHINE SKYWAY BRIDGE