DESIGN OF A SAFETY WARNING SYSTEM PROTOTYPE FOR THE GULF FREEWAY

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ABSTRACT

This report discusses the development of a safety warning system for urban freeways. The system is designed to alert motorists of freeway stoppages which occur downstream of overpasses. The design features of a prototype system installed on the Gulf Freeway are discussed.

KEY WORDS: Freeway surveillance and control, traffic control devices, safety, freeway operations, motorist information.

DISCLAIMER

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SUMMARY

Freeway ramp control has resulted in significant improvements in peak period operation and reduction of accidents. Certain safety and operational problems continue to exist because of geometric features and environmental phenomena which restrict driver sight distances. For example, the grade line and alignment of several freeways are such that sufficient sight distance is not always available for the motorist to confirm his expectations of traffic flow downstream. Problems arise due to unexpected traffic stoppages resulting from accidents, stalled vehicles, etc., or from stoppage waves generated during peak period flow. This report is concerned with the development of a safety warning system for urban freeways to warn motorists approaching crest type vertical curves of stoppage waves downstream of the crest.

Several candidate systems were proposed and evaluated. The recommended design concept is a traffic-actuated safety warning device which would be located upstream of the overpass crest and which would be activated when conditions warrant. Detectors installed on each lane and located strategically on both sides of the overpass transmit traffic information to an IBM 1800 digital computer located in the control system. The computer activates and deactivates the warning device according to preestablished criteria. Manual override features would be built into the system so that all controls could be accomplished manually if desired.

Three critical overpass sites were selected for a pilot installation on the Gulf Freeway. Double-loop detectors are positioned on each lane of the inbound freeway both upstream and downstream of the three overpasses. Each warning device is located upstream of the crest adjacent to the wingwall and consists of a 6' x 12' sign panel containing 10" black letters with the message CAUTION SLOW TRAFFIC WHEN FLASHING displayed on a yellow non-reflectorized panel. A 12" flashing beacon is attached on the right and left sides of the panel. An additional 12" flashing beacon is mounted at the crest on a post adjacent to the right side guardrail. Each sign is equipped with external flourescent lighting and with photoelectric cells for intensity control. The external lights are illuminated only when the sign is activated.

Implementation

The pilot safety warning system described in this report has been implemented on the Gulf Freeway for test and evaluation. Operation of the pilot system was initiated on March 13, 1972.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

General

The operation and control strategy of a freeway corridor surveillance and control system depends primarily on the traffic conditions of the freeway main lanes since the freeway serves as the principal traffic facility for the entire corridor. Operation on the Gulf Freeway is typical of many urban freeways that have been suffering severe congestion and high accident rates. Significant improvements in operation and reduction of accidents have been realized on the inbound portion of the freeway since the installation of a ramp control system (1, 2, 3). Freeway ramp control, however, is not a panacea for all of the safety and operational problems which exist on urban freeways. Certain safety problems continue to exist because of geometric features and environmental phenomena which restrict driver sight distances during the peak and off-peak periods. For example, the grade line and alignment on several freeways are such that sufficient sight distance is not always available for the motorist to confirm his expectations of traffic flow downstream (4). Problems arise due to unexpected traffic stoppages resulting from accidents, stalled vehicles, etc., or from stoppage waves generated during peak period flow. Conditions such as fog, rain, snow, and sleet create additional problems relative to sight distance requirements.

In addition to safety, certain operational problems continue to exist. The freeway in many cases is overtaxed during the peak periods while unused capacity on the frontage roads and parallel streets in the freeway corridor exist but are not fully exploited. In addition, available capacity on the parallel streets goes virtually unused when an emergency condition such as an accident occurs.

The results of a systems analysis of the inbound Gulf Freeway operations have shown that there is a need to reduce the congestion and improve the safety and level of service when freeway incidents occur (5). The study also indicates that a real-time traffic information system which provides accurate, reliable, and meaningful freeway traffic information would be a feasible alternative toward reducing congestion and improving safety and level of service. This report discusses one phase of such a system being developed on the Gulf Freeway.

Problem Identification

Recent studies by Messer, et al. (5) have shown that significant congestion and delay frequently occur on the inbound Gulf Freeway due to the reduction of capacity caused by the occurrence of incidents on the main lanes. On the average, approximately 13 incidents per week occur on the inbound section within the ramp control area. Approximately 80 percent of the incidents reduce the capacity of the inbound freeway by one-half or more.

Not all incidents result in significant delay; however, each creates queueing on the main lanes of the freeway which is a serious traffic hazard to uninformed motorists. For example, one-fourth of all incidents which occur on the inbound Gulf Freeway during the peak hours and most incidents which occur during the off-peak hours result in minimum delay but do create a safety hazard.

Messer, et al. also found that, although the entire inbound section of the Gulf Freeway study area was susceptible to incidents, a higher frequency of incidents occurred in the vicinity of the major overpasses. These results are consistent with earlier studies on Texas freeways by Mullins and Keese (6) who found that accident rates on vertical curves were more than double those on tangent sections. The high concentration of accidents on vertical curves was attributed to inadequate sight distance. Sight distance restrictions are compounded during the peak periods because of additional sight restrictions created by traffic in conjunction with the vertical alignment.

Studies by Drew and Dudek (7) on the Gulf Freeway disclosed high values of acceleration noise on crest curves. Acceleration noise is a measure of the uniformity of speed; high acceleration noise is indicative of rapid patterns of speed changes. The high acceleration noise on the overpasses can be ascribed to rapid decelerations and is indicative of accident potential locations.

The restricted sight distances created by the overpasses in many instances do not allow ample warning time when an incident occurs downstream and thus create unexpected situations for the approaching motorists. In many cases, the unexpectancy of the situation does not allow sufficient opportunity to adjust to the conditions, and rear-end collisions or near misses are prevalent.

The ability of a motorist to respond appropriately to a vehicle ahead which is stopped or is braking will depend primarily on his perception-reaction time, his speed, the coefficient of friction between the tires and pavement, and the spacing between the two vehicles. Perception-reaction time is the time necessary for perceiving the situation plus the brake reaction time. It is a complex phenomenon which is highly variable and is dependent on the driver's psychological and physiological make-up, as well as the condition to be perceived. This may explain the lack of research to measure perception-reaction values in actual highway driving situations.

Laboratory studies conducted over a period of about 30 years show that brake reaction time for most drivers is from 0.5 to 0.7 second (8). In most laboratory experiments, the driver is required to respond to one known stimulus, such as flashing light. Actual traffic situations are often complex. The driver must perceive a number of events happening at the same time and select the one or ones that require a response on his part. In many complex traffic situations, perception and reaction time may be as high as 3 to 4 seconds (9). These times may increase as a result of modifying factors such as fatigue, alcohol, conditional response, etc.

The high frequency of accidents on the crest-type curves on the Gulf Freeway suggests that the perception-reaction times associated with the car-following situations along these sections appear to be much higher than desirable. This may in part be attributed to driver expectancies.

The driver continually searches the environment for visual cues which provide him with the necessary information to drive safely and efficiently (10). He not only relies upon other vehicles in his lane for situational information but also reacts to visual cues transmitted from vehicles in adjacent lanes. He may elect to drive with a short headway because of his expectations of operations ahead and the availability of visual cues from his environment. When he notices brake lights in adjacent lanes, he has some expectation of slowing in his own lane, and thus reaction time to stoppages may be reduced. If his view of adjacent lanes is restricted, he must rely basically on the information received from vehicles ahead. Consequently, if a stoppage wave propagates rapidly in his lane without any fast reaction on the adjacent lanes, he may be vulnerable to a collision or near miss.

Studies by Malo, et al. (11) and May (12) have shown that at least one percent of the freeway motorists drive with time headways of 0.5 second or less regardless of volume. These short headways suggest that many motorists are apparently taking a high risk because of their expectations of downstream flow.

From the foregoing discussion, it appears that the visual cues available to the motorist may be somewhat reduced on the vertical curves. It also appears that if a mechanism could be devised which would increase the motorist's attention toward conditions of downstream flow, his reaction time to a stopped or a stopping vehicle might be reduced. A proposed system is a freeway warning system hereafter referred to as a safety warning system.

THE SYSTEM

Purpose

The safety warning system is an experimental system which will inform freeway drivers approaching crest type vertical curves of stoppage waves which are beyond their sight distance. The purpose of the system is to provide the driver with information which will structure his expectations about downstream traffic flow. The anticipated benefit is improved efficiency which will result in fewer accidents; reduced travel time, driver anxiety, and discomfort; and improvement in the level of service.

System Mission

The mission of the system is to provide the motorist with advisory information which improves his ability to respond to degradations of freeway flow downstream of a vertical crest. The driver retains all responsibilities he would ordinarily have in driving. The system, however, assists the driver in formulating his expectations of traffic operations.

System Requirements

The purpose of developing candidate systems is to provide for a logical approach in determining the system(s) which best satisfies the requirements and fulfills established goals. To evaluate the alternatives effectively, a set of criteria must be established. These criteria for the proposed system are as follows:

1. The system must be capable of immediate implementation.
2. The system must be capable of communicating with all the motorists approaching a crest curve.
3. The system must be capable of responding to stoppage waves.
4. The equipment must be reliable.
5. The system must be compatible with existing hardware associated with the freeway control system.
6. The operation of the system must be stable.
7. The amount of computer storage required should be minimized.
8. It must be acceptable to the motorists (i.e., message must be valid).
9. The overall system must be cost-effective.

Synthesis

Several candidate systems were proposed by staff members of the Urban Transportation Systems Program, Texas Transportation Institute. Each proposal was evaluated with respect to the objectives and system requirements. Based on this analysis, a system design concept was formulated.

The recommended system is a traffic-actuated safety warning device which would be located upstream of the overpass crest, and which would be activated when traffic conditions warrant. Detectors installed on each lane and located strategically on both sides of the overpass transmit traffic information to an IBM 1800 digital computer located in the control center. This surveillance system is integrated with the existing detection which is currently linked with the computer. The computer then activates the safety warning device when the traffic conditions on the freeway warrant activation according to preestablished criteria. The devices are also deactivated by the computer when the conditions no longer warrant its use. Manual override features are built into the system so that all controls can be accomplished manually if desired. A schematic diagram of the design concept is shown in Figure 1.

Four candidate systems were selected. The configuration of each system was essentially the same (i.e., detection, data transmission, controller, etc.) with the exception of the physical design of the safety warning device. The following alternatives were proposed:

1. Flashing beacons.
2. A sign with flashing beacons.
3. A blank-out type sign.
4. A blank-out type sign in combination with flashing beacons.

Analysis of Alternatives

Tables 1 and 2 summarize the costs, advantages, and disadvantages of the alternative designs. The alternative with flashing beacons is the least expensive. One disadvantage is that the motorist may not be aware of his required action.

A combination of a static sign and flashing beacons would provide the alert factor plus the information to the motorist concerning his

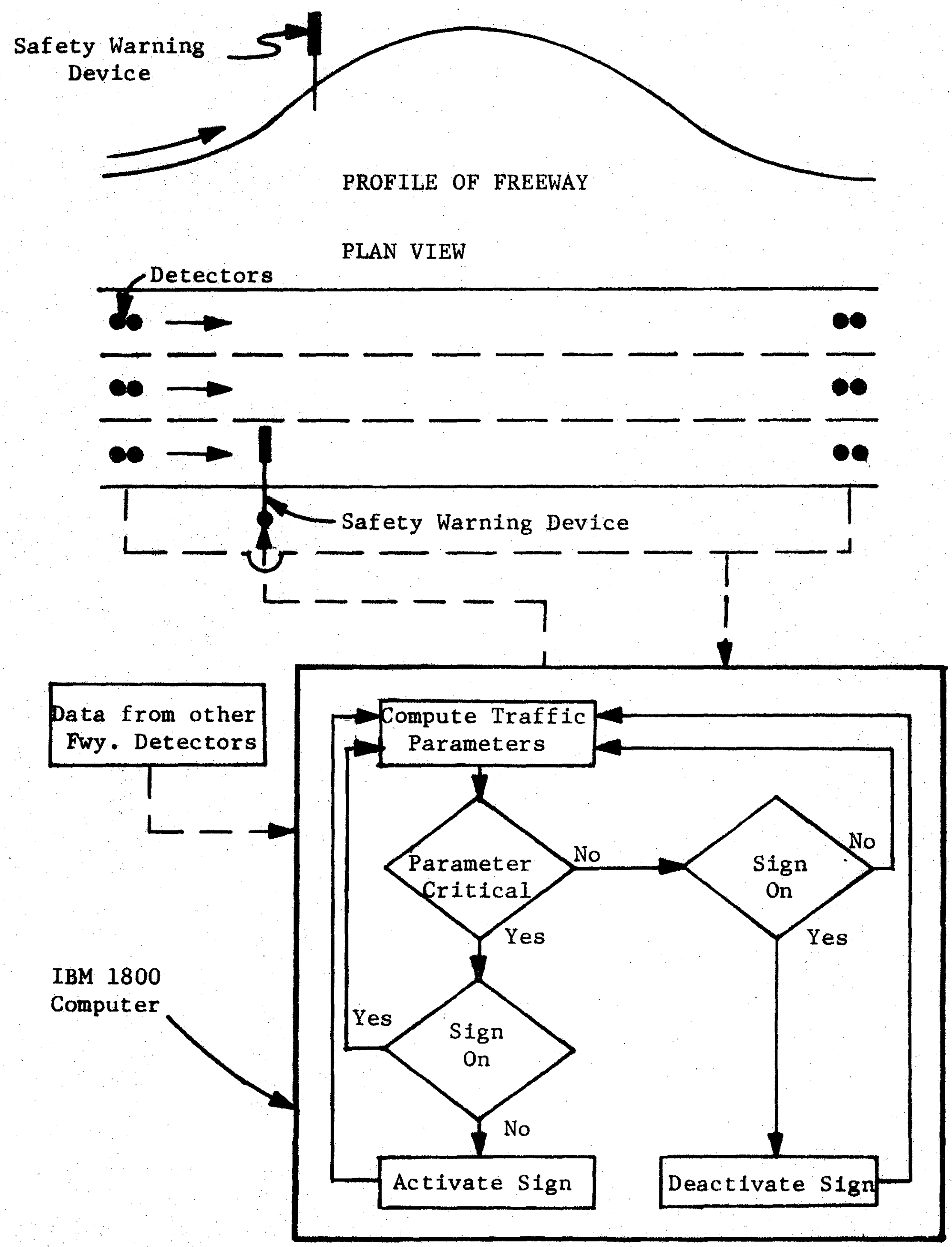


Figure 1 - Design Concept

TABLE 1

ALTERNATIVE SYSTEM COSTS

	Design Alternative	Estimated Cost* Per Unit
I	Flashing Beacons	$13,500
II	Sign in Combination With Flashing Beacons	14,700
III	Blank-Out Sign	17,300
IV	Blank-Out Sign in Combination With Flashing Beacons	17,400

*Includes $10,000 for 12 detectors in place. Does not include transmission or computer costs.

TABLE 2

DESIGN ALTERNATIVES FOR THE SAFETY WARNING DEVICE

Design Alternatives	Advantages	Disadvantages
I. Flashing Beacons	1. Relatively inexpensive. 2. Minimum maintenance required. 3. Can be assembled from standard components used by the Texas Highway Department.	1. Action required by the motorist may not be clear.
II. Sign in Combination With Flashing Beacons	1. Relatively inexpensive. 2. Minimum maintenance required. 3. Simplicity in fabrication. 4. Can be fabricated by the Texas Highway Department.	1. More expensive than alternative I. 2. Message is visible at all times and therefore would require additional wording to indicate when the message applies. 3. External lighting is required for night visibility. 4. Greater structural support required than alternative I.

TABLE 2 (CONTINUED)

Design Alternatives	Advantages	Disadvantages
III. Blank-Out Sign	1. Message is visible only when sign is illuminated. 2. No external lighting is necessary for night visibility.	1. More expensive than alternative II. 2. Must be fabricated by an outside organization. 3. Relatively high maintenance costs.
IV. Blank-Out Sign in Combination with Flashing Beacons	1. Message is visible only when sign is illuminated. 2. No external lighting is necessary for night visibility.	1. More expensive than alternative III. 2. Must be fabricated by an outside organization. 3. Relatively high maintenance costs.

response. One distinct disadvantage is that the message would be visible at all times. However, it is assumed that the ability to read the message might be advantageous for an experimental unit. Since the safety warning device constitutes a new application to freeway drivers, the continuous message may provide a period of learning.

A review of the table also suggests that a blank-out type sign has the distinct advantage of displaying the message only at times when the dynamically changing freeway conditions warrant. The larger cost of having this feature is evident.

After careful evaluation of the alternative designs, the decision was made to accept the design containing the static sign with flashing beacons for a pilot study. Further analysis of the design concept resulted in the decision to include an additional flasher unit which would be mounted on the bridge railing at the crest of the curve. The purpose of this unit is to alert motorists who are between the warning sign and the crest when the sign is initially activated.

Selection of Message

Perhaps one of the most complex problems encountered in the design of the safety warning device was the selection of a message display. Approximately 20 candidate messages were first considered by TTI, and after an evaluation of these, the list was reduced to the following five alternatives:

1. PREPARE TO BRAKE WHEN FLASHING
2. REDUCE SPEED WHEN FLASHING

3. SLOW TRAFFIC AHEAD WHEN FLASHING

4. CAUTION SLOW TRAFFIC WHEN FLASHING

5. BE ALERT

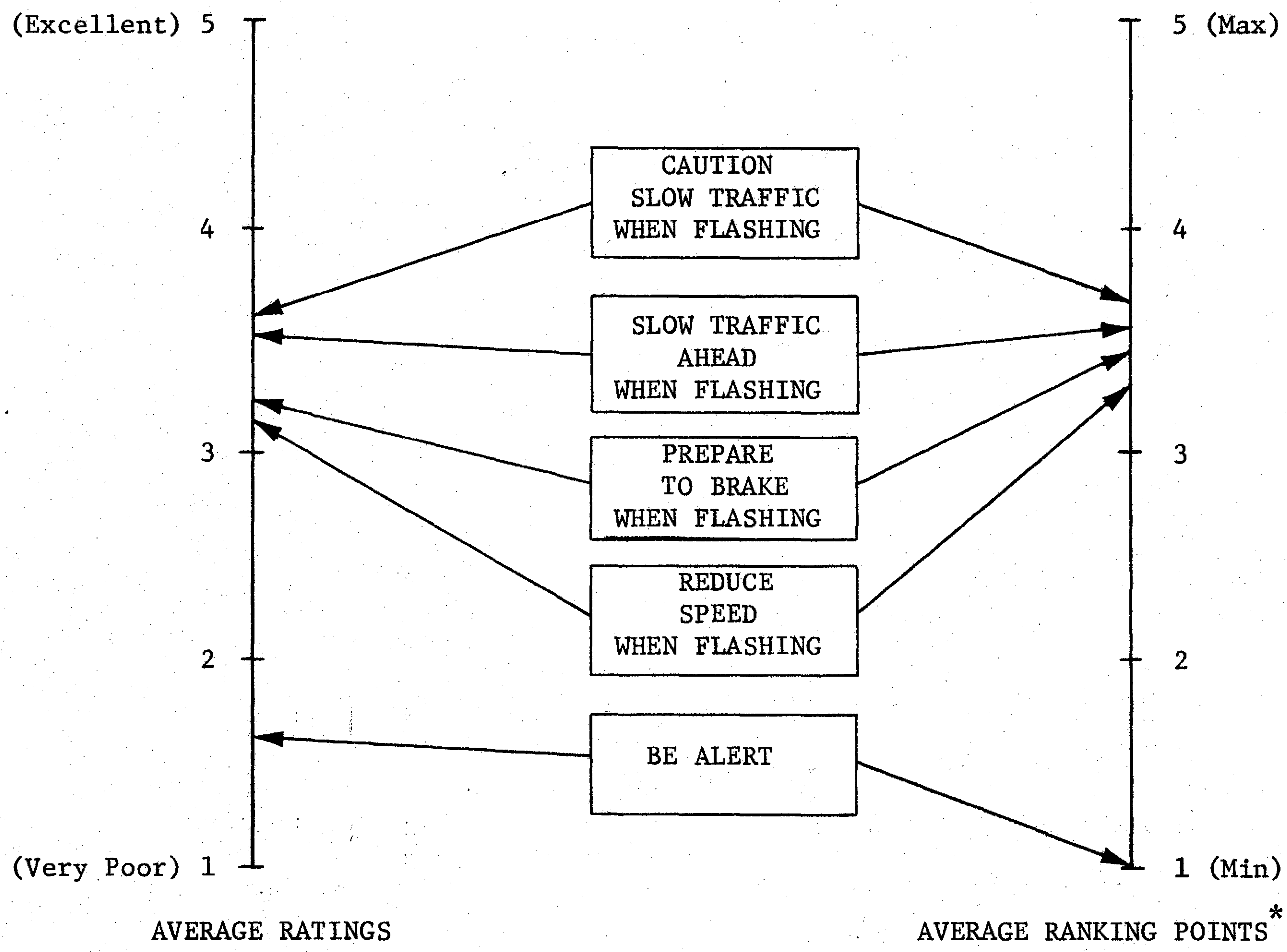
Message panels containing the above messages were fabricated. The panels were yellow with black lettering. Two 8' x 12' yellow sign panels were erected on an overhead sign truss located at the Texas Transportation Institute Research Annex in Bryan, Texas. The message panels were nailed to the larger panels when specific messages were desired. Flashing beacons were also installed to duplicate the proposed system as closely as possible.

Eighteen persons from the Texas Highway Department, Federal Highway Administration, and the Texas Transportation Institute with expertise in traffic operations and driver communications were invited to the Research Annex to evaluate the candidate messages as well as other design considerations. Each message was individually displayed each time the evaluators approached and passed under the sign truss in automobiles. They were asked to rate each message as to how well it would accomplish the desired results. Later, they were given a list of the candidate messages and were requested to rank them in order of preference.

Although no one message received unanimous first place rankings, the message BE ALERT was consistently considered to be least preferred. A statistical analysis of the remaining four messages revealed that there was not a discernible pattern regarding the rankings of the remaining four messages. However, the decision was made to use the message CAUTION SLOW TRAFFIC WHEN FLASHING. The order of selection based on average rank values was as follows:

1. CAUTION SLOW TRAFFIC WHEN FLASHING
2. SLOW TRAFFIC AHEAD WHEN FLASHING
3. PREPARE TO BRAKE WHEN FLASHING
4. REDUCE SPEED WHEN FLASHING
5. BE ALERT

Comparative average ratings and rankings are presented in Figure 2.



*Based on assigning 5 points to each first choice, 4 points to each second choice, 3 points to each third choice, 2 points to each fourth choice, and 1 point to each fifth choice.

Figure 2 - Ratings and Rankings of Sign Message Alternatives

PILOT SYSTEM INSTALLATION

Site Selection

An analysis of the grade line on the inbound Gulf Freeway in addition to accident experience during previous years (5) suggested that the following three overpasses appeared to be the most critical: Griggs, Lombardy, and Calhoun. These locations were, therefore, selected as the sites for pilot installations to study the effectiveness of the safety warning system and to further evaluate the design concepts.

System Description

Double-loop detectors were positioned on each lane of the inbound freeway both upstream and downstream of the above overpasses to form three subsystems. Additional detectors were installed at other locations where stoppage problems were anticipated relative to the three overpasses. Data from the detectors are transmitted to the IBM 1800 digital computer over direct line or via telemetry equipment depending upon the detector location within the system. The locations of the three subsystems and their associated detectors are illustrated in Figures 3 and 4.

The warning sign panels selected for the pilot installation are 6' x 12' and contain 10" black letters on a yellow non-reflectorized background. Twelve-inch flashing beacons with 150-watt bulbs are mounted on two sides of the sign panel. The assemblies are mounted

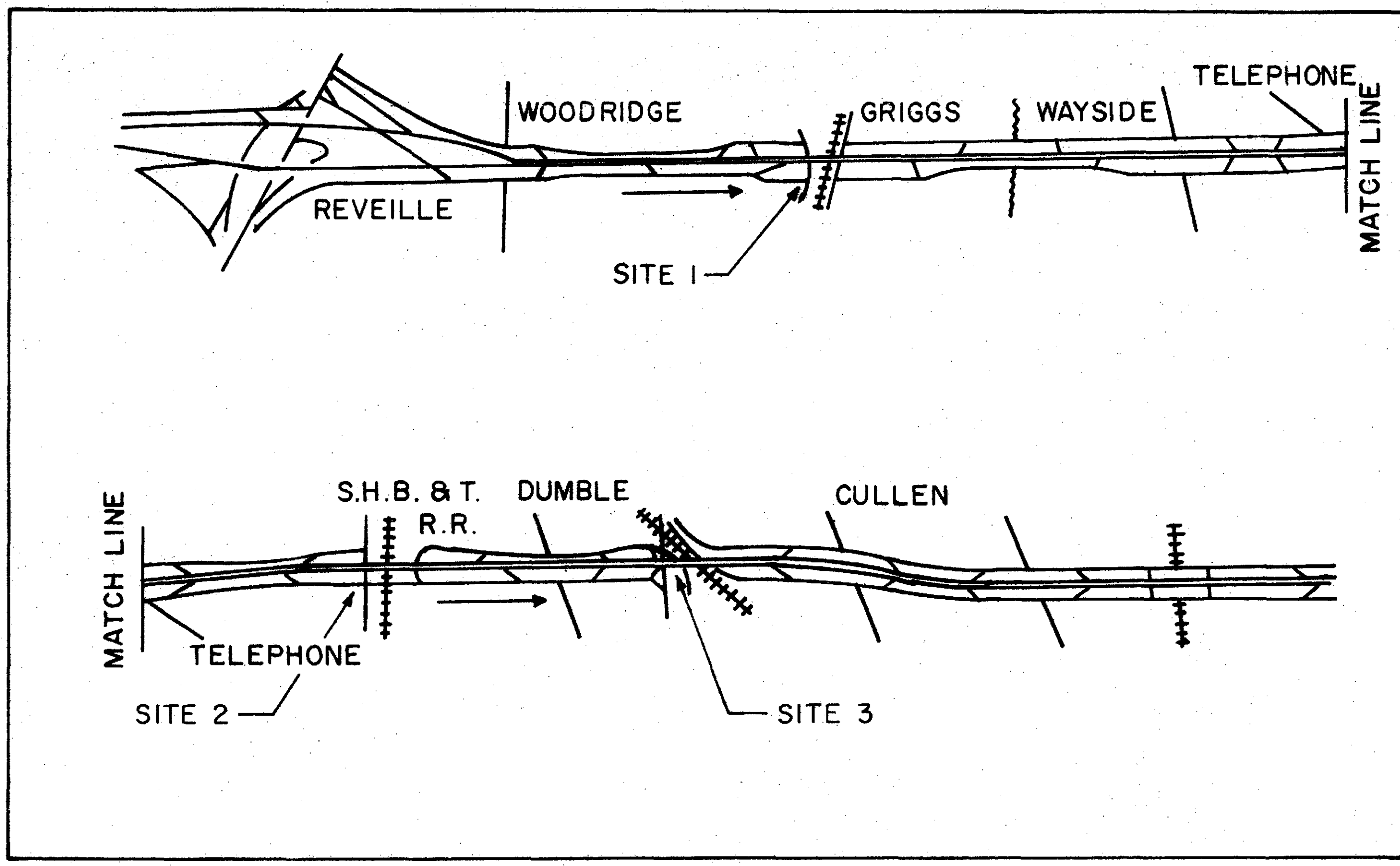


Figure 3 - Installation Sites for the Warning Devices

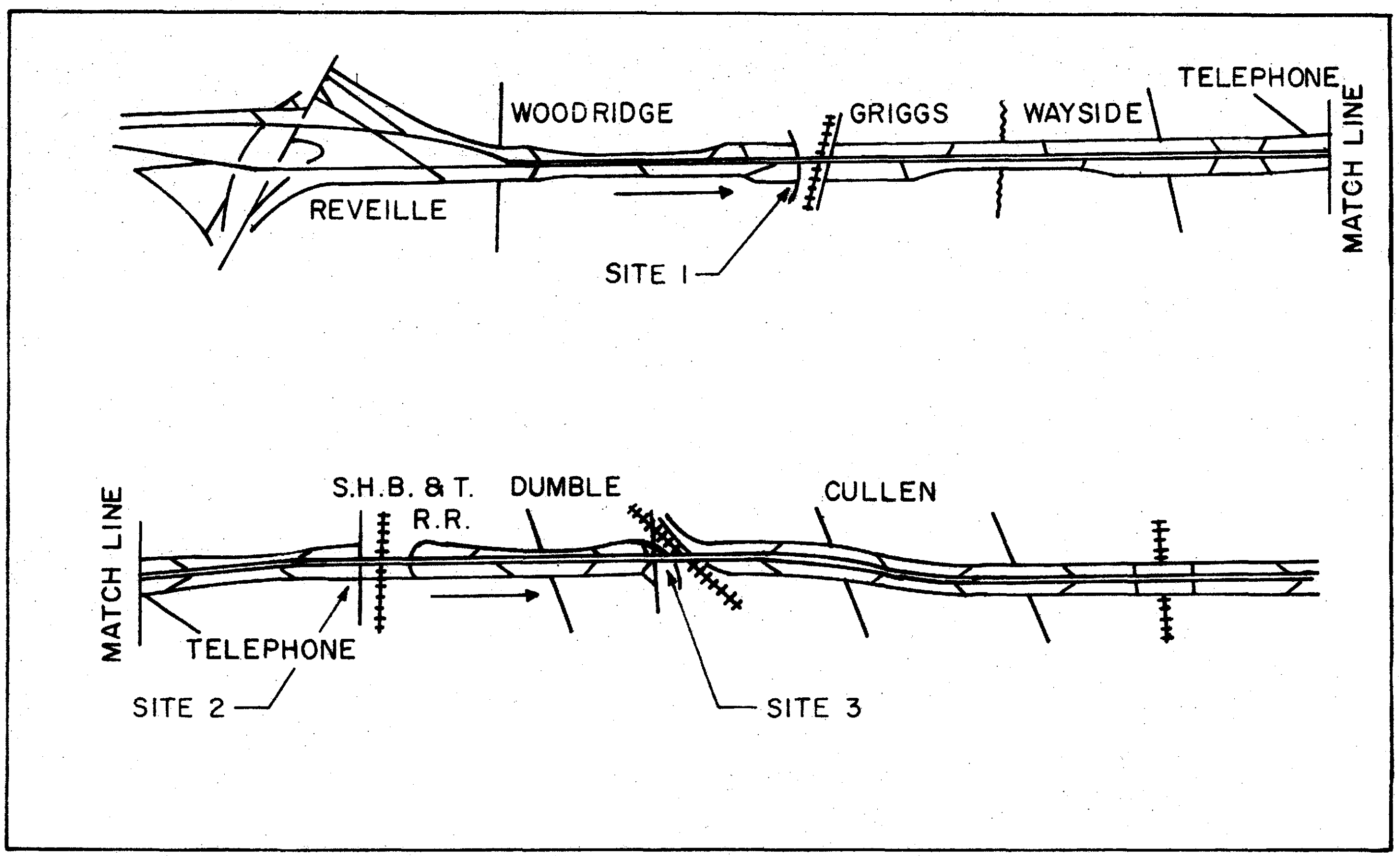


Figure 3 - Installation Sites for the Warning Devices

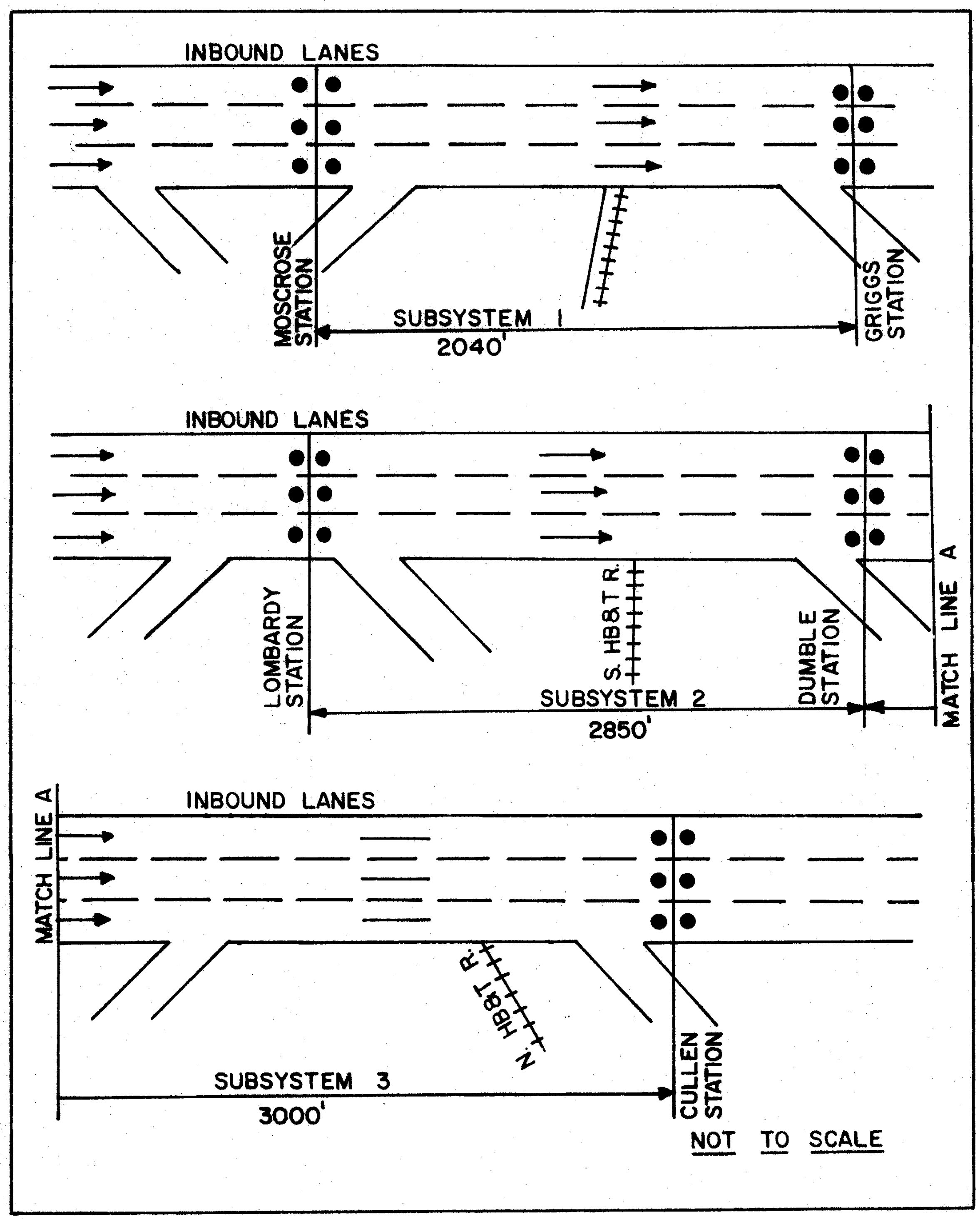


Figure 4 - Detector Locations

on salvaged T-structures. Details of the sign are presented in Figure 5.

Each warning sign is located on the upstream side of the respective overpass structure adjacent to the wingwall. An additional 12" flashing beacon is mounted on a post adjacent to the right side guardrail. A drawing of a typical installation is shown in Figure 6. Figures 7 and 8 are photographs of a typical field installation.

The system is designed such that the warning devices can be controlled automatically by the computer. Manual override features are incorporated to assure operation of the system in case of computer downtime. The manual control console consists of three-position center off switches (one for each sign) and confirmation status lights. The switches can be positioned in either an AUTOMATIC, OFF, or MANUAL mode. With the switch in the AUTOMATIC mode, the computer has complete control of the warning devices. The warning device will remain off when the switch is in the OFF mode regardless of the computer logic decisions, and will activate when the switch is placed in the MANUAL mode. The lights mounted in the console confirm the status of the warning signs regardless of whether the signs are operated manually or automatically.

A small inexpensive display (Figure 9) was also built to indicate the status of each sign as established by the computer logic. An alarm is sounded each time one of the warning devices is actuated by the computer. The display provides the opportunity to evaluate computer logic, to aid the observer in making decisions during periods when the

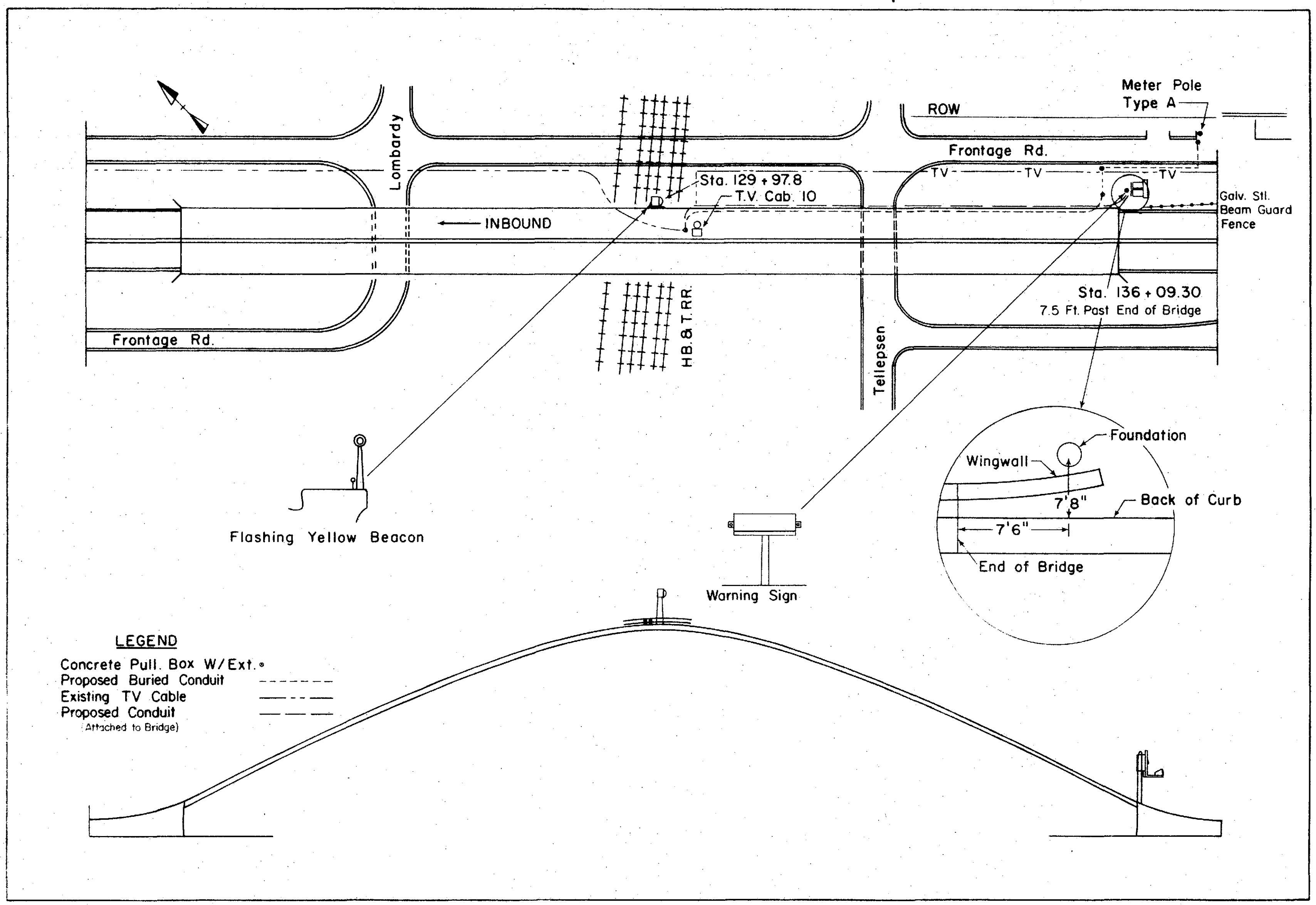


Figure 5 - Typical Field Installation

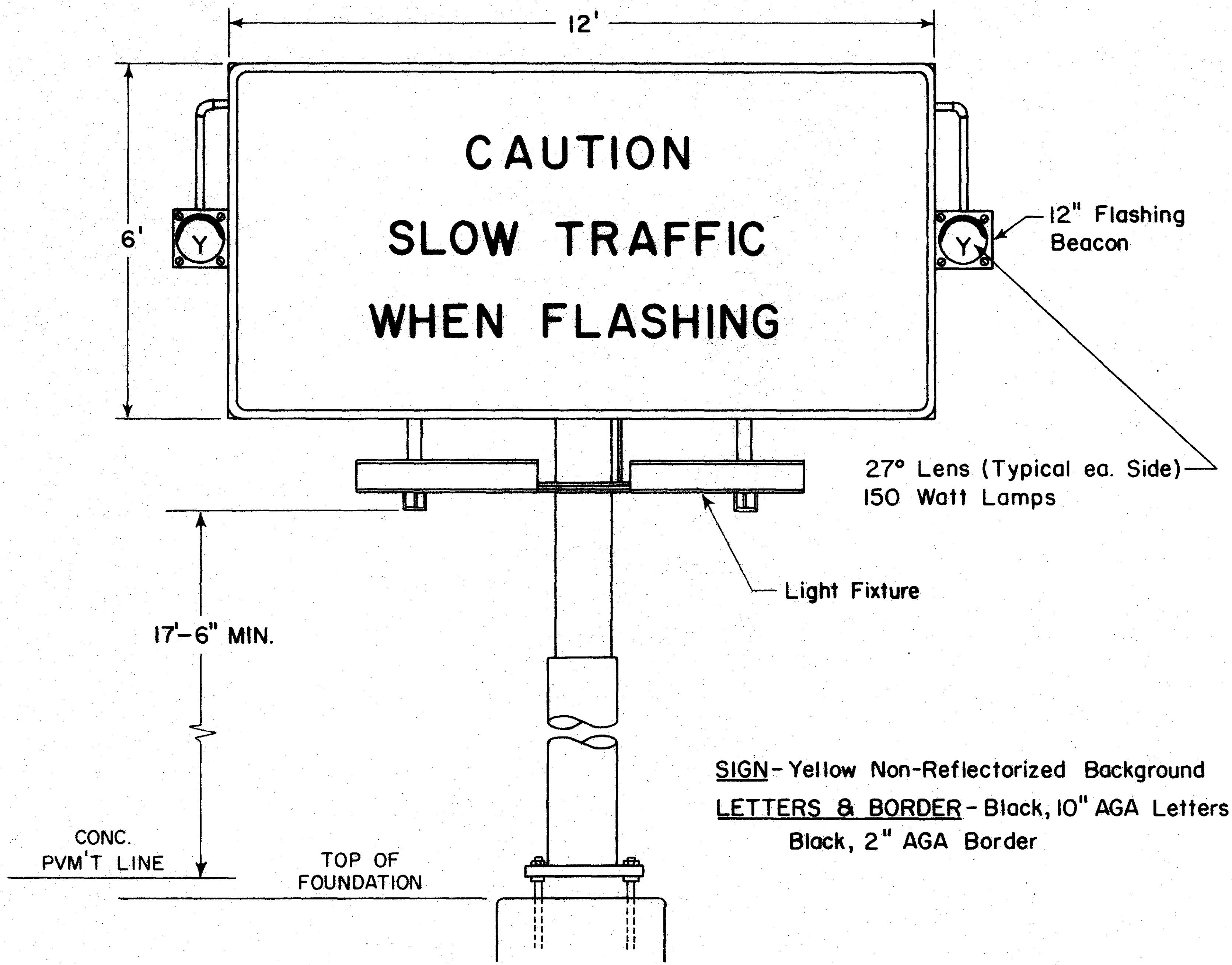


Figure 6 - Warning Sign Details

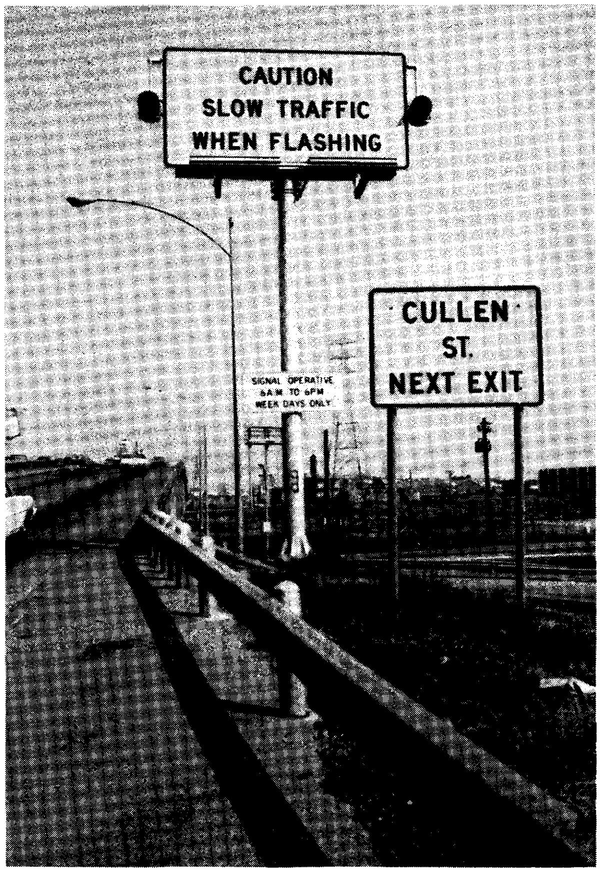


Figure 7 - Warning Sign with Flashers

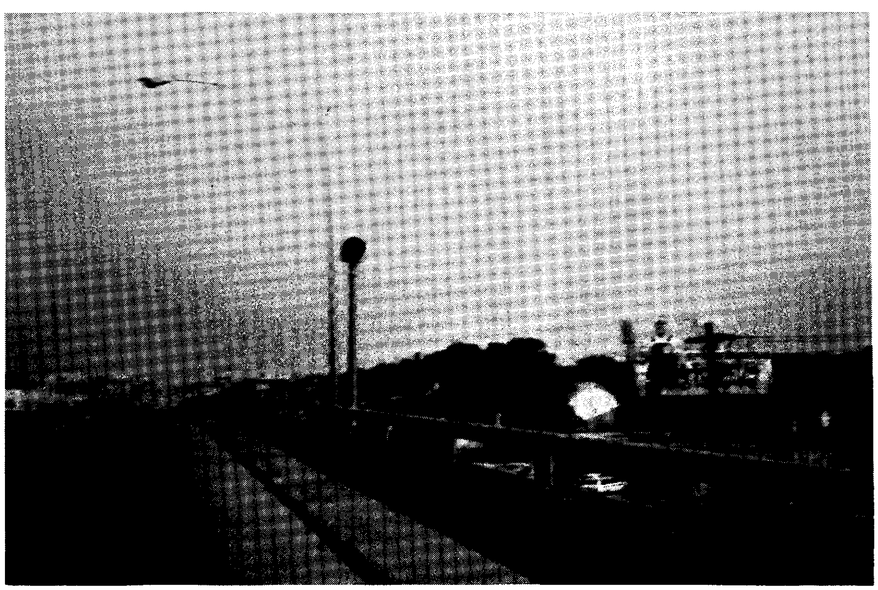


Figure 8 - Flasher Unit at Crest of Overpass

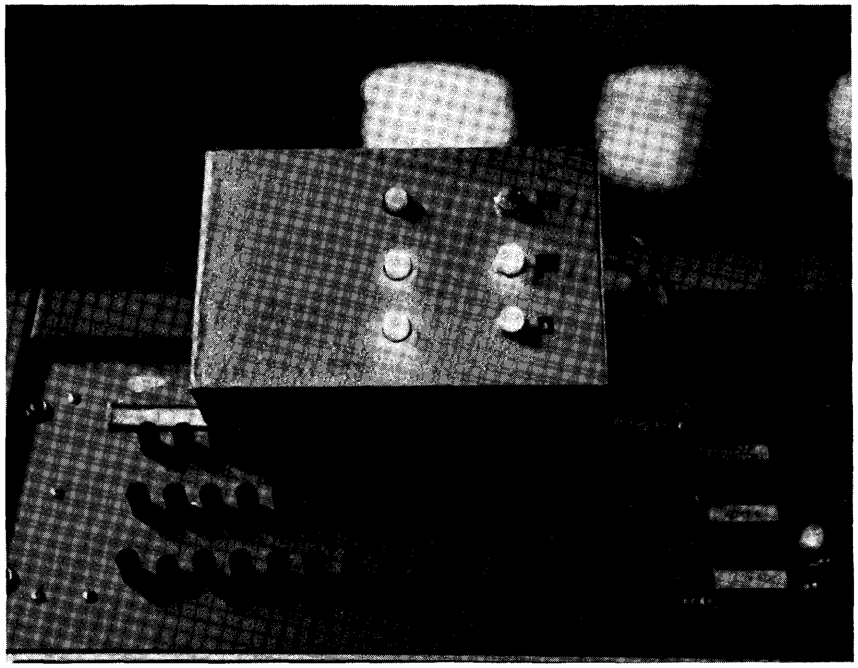


Figure 9 - Display for Computer Operation

system is operated manually, and to assist the observer in evaluating when manual control is necessary due to detector failures.

Each sign is equipped with external fluorescent lighting for night operation. These lights are illuminated only when the warning device is activated. In addition, photoelectric cells are used at each location to reduce the intensity of the flashers during operations at night. The wiring diagram for the sign control system is presented in Figure 10.

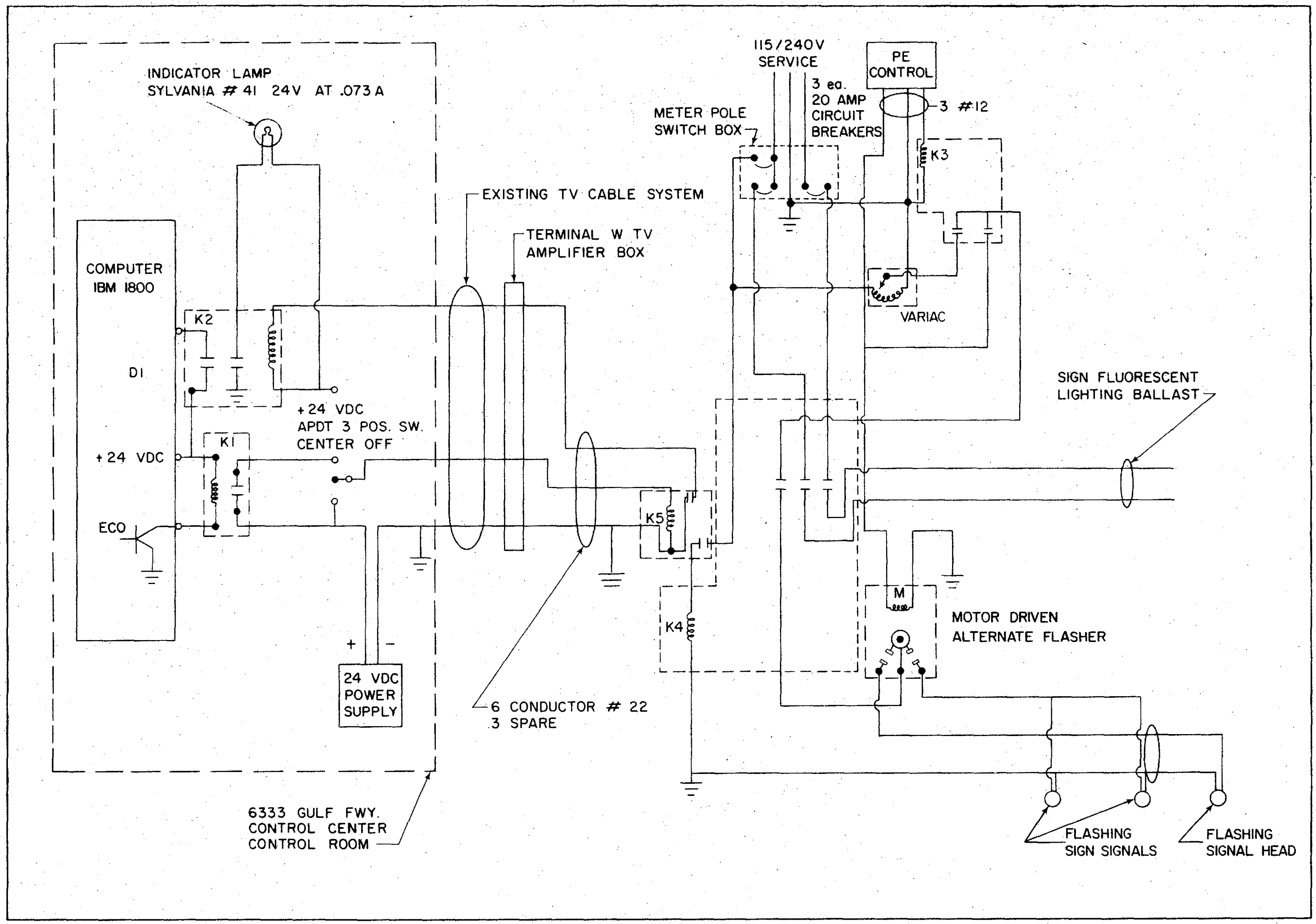


Figure 10 - Wiring Diagram

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