NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM REPORT **118**

LOCATION, SELECTION, AND MAINTENANCE OF HIGHWAY TRAFFIC BARRIERS

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RESEARCH SPONSORED BY THE AMERICAN ASSOCIATION OF STATE HIGHWAY OFFICALS IN COOPERATION WITH THE FEDERAL HIGHWAY ADMINISTRATION

AREAS OF INTEREST:
- HIGHWAY DESIGN
- BRIDGE DESIGN
- HIGHWAY SAFETY
- TRAFFIC CONTROL AND OPERATIONS

HIGHWAY RESEARCH BOARD
DIVISION OF ENGINEERING NATIONAL RESEARCH COUNCIL
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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

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This report was prepared by the contracting research agency. It has been reviewed by the appropriate Advisory Panel for clarity, documentation, and fulfillment of the contract. It has been accepted by the Highway Research Board and published in the interest of effective dissemination of findings and their application in the formulation of policies, procedures, and practices in the subject problem area.

The opinions and conclusions expressed or implied in these reports are those of the research agencies that performed the research. They are not necessarily those of the Highway Research Board, the National Academy of Sciences, the Federal Highway Administration, the American Association of State Highway Officials, nor of the individual states participating in the Program.

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FOREWORD

By Staff

Highway Research Board

This report is recommended to highway design engineers, bridge engineers, safety engineers, maintenance engineers, and others concerned with highway safety hardware. It contains a compilation of the most advanced practices for locating, selecting, and maintaining highway traffic barrier systems as selected from a comprehensive literature review, a state-of-the-art survey, and the advice of a selected group of acknowledged experts. It is believed that this report, which is intended to supersede the widely distributed *NCHRP Report 54,* "Location, Selection and Maintenance of Highway Guardrails and Median Barriers," will contribute to the effort toward producing safer highways.

There is a pressing need on the part of design engineers for a choice of effective highway traffic barrier systems. Although the problem is one currently receiving extensive attention, it is recognized that considerable time will elapse before all work to identify or develop the effective systems will be completed. Many sources have been generating usable information that needed to be consolidated into an up-to-date, concise instructional manual that can provide immediate how-to-do-it guidance for engineers requiring knowledge of the various features of the commonly used, tried and proven barrier systems now in existence that should be recognized as interim standards until research has satisfied the ultimate needs in this area.

This report presents the results of the synthesis of existing information on warrants, service requirements, and performance criteria for all traffic barrier systems. For this purpose, "all traffic barrier systems" is defined to encompass guardrails, median barriers, bridge rails, and crash cushions. The result is a one-volume source of traffic barrier devices that are available to engineers to provide the highest level of highway safety capability available from the current technology.

Southwest Research Institute, in conducting this phase of NCHRP Project 15-1(2), "Guardrail Performance and Design," worked jointly with special NCHRP advisory groups consisting of John L. Beaton, California Division of Highways; Malcolm D. Graham, New York Department of Transportation; James D. Lacy, Federal Highway Administration; Paul C. Skeels, General Motors Proving Ground (retired); John N. Clary, Virginia Department of Highways; Robert M. Olson, Texas Transportation Institute; and F. J. Tamanini, Federal Highway Administration, that provided advice and counsel as to the contents of this report. Although the report originated with the research agency, each recommendation has the consensus endorsement of the advisory groups and NCHRP Advisory Panel C22-1, which had over-all advisory responsibility. Generally, where recommendations are founded on less than clear-cut evidence, the judgment of the advisory groups prevailed. It should be recognized that where no consensus of the advisory groups was evident, no recommendation is presented.

Inasmuch as this report is intended to be a design aid, references and supporting documentation have generally been limited in order to preserve a clear, straightforward presentation. It should also be noted that the selected designs included certainly will be refined and upgraded in the future, and a designer is obligated to periodically obtain the latest revisions from the issuing agency.

The reader should be aware that at the time this report was in preparation, Task Force 13 of the AASHO-ARBA Subcommittee on New Highway Materials was preparing a document entitled "A Guide to Standardized Highway Barrier Rail Hardware," issued in March 1971. The AASHO-ARBA Task Force 13 Guide shows standard components for many of the barrier systems included herein. It is obvious that the use of standard components will minimize the cost of traffic barrier systems and the designer is strongly urged to refer to "A Guide to Standardized Highway Barrier Rail Hardware," available from ARBA.

This report covers the first two tasks of the 18-month Phase II continuation of research under NCHRP Project 15-1(2). Previous publications from the research include *NCHRP Report 54,* "Location, Selection, and Maintenance of Highway Guardrails and Median Barriers," superseded by this report, and *NCHRP Report 115,* "Guardrail Performance and Design." Continuing work includes full-scale crash test evaluation of new concepts for end designs for guardrail. It is anticipated that the next report on this project will be issued in 1972.

CONTENTS

ACKNOWLEDGMENTS

The work reported herein was conducted at Southwest Research Institute by the Department of Structural Research. Jarvis D. Mickie, Group Leader, served as principal investigator. He was assisted by Maurice E. Bronstad, Senior Research Engineer.

To a large extent, this report reflects the in-depth traffic barrier experience of two special NCHRP advisory groups. The Task 1 *ad hoc* group, consisting of J. L. Beaton, California Division of Highways; M. D. Graham, New York Department of Transportation; J. D. Lacy, FHWA (Traffic Operations); and P. C. Skeels, General Motors Proving Ground (retired), extensively reviewed *NCHRP Report 54* and provided recommendations and information to update its content. The Task 2 *ad hoc* group, consisting of M. D. Graham; R. M. Olson, Texas Transportation Institute; P. C. Skeels; J. N. Clary, Virginia Department of Highways; and F. J. Tamanini and J. G. Viner, FHWA (Research), made recommendations as to content, supplied basic information, and reviewed preliminary drafts of this document. In the areas of crash cushions and bridge rails, J. G. Viner and R. M. Olson provided considerable documentation and assistance. HRB Committee A20A4 (chaired by E. F. Nordlin, California Division of Highways) and AASHO Design Committee (I. C. Jenkins, FHWA, survey coordinator) reviewed a preliminary draft of the updated version of *NCHRP Report 54* and made valuable comments. Finally, K. J. Boedecker, of U. S. Steel, and G. A. Alison, of the Aluminum Association, assisted NCHRP Advisory Panel C22-1 in the review of the final draft.

From Southwest Research Institute, the authors acknowledge the technical and administrative contributions of R. C. DeHart and L. U. Rastrelli.

LOCATION, SELECTION, AND MAINTENANCE OF HIGHWAY TRAFFIC BARRIERS

SUMMARY Judicious application of this current state-of-the-art information on traffic barriers should result in safer highways. Traffic barriers, as defined herein, consist of (1) *longitudinal* systems, such as guardrails, median barriers, and bridge rails; and (2) *crash cushion* systems, such as a nest of steel drums. The report is directed primarily for use by highway designers as a guide and by maintenance groups as an aid in upgrading existing installations. Because it is recognized that traffic barriers are hazards in themselves, emphasis is placed on reducing the number of such installations to only those that can be firmly justified.

No attempt is made to handle each of the infinite variety of roadside conditions. However, the more common highway-site conditions are treated in detail. With this background and with sound engineering judgment, these treatments can be extended to apply to the majority of roadside conditions.

Design procedures involve two basic steps—determination of the need and selection of the appropriate system. Specific warrants for an installation are determined from the roadway properties (such as shoulder embankment geometry) and the location and type of roadside obstacles. Traffic barrier systems evaluated by full-scale crash tests and satisfactory service performance are presented, together with a selection procedure.

CHAPTER ONE

INTRODUCTION

PURPOSE

The purpose of this document is to present to highway designers a concise state-of-the-art compilation of information on traffic barriers for (1) establishing need locations, (2) defining the functions and service requirements, and (3) delineating procedures for selecting a system. An objective of combining all traffic barrier system considerations into one document is to facilitate highway designs that will provide a consistent degree of protection and safety for the motorist. A second objective is to promote, where feasible, the integration of two or more separate installations, such as an approach guardrail and a bridge rail, into one continuous, effective system. *Use of the document as a design guide should obviously be supplemented with sound engineering judgment.* It is also recognized that traffic barrier technology is developing rapidly and the information presented herein may require continual upgrading.

This document supersedes *NCHRP Report 54* (*8*).*

* Denotes reference, Appendix H.

DEFINITIONS

Traffic barriers are highway appurtenances that provide a relative degree of protection to vehicle occupants from hazardous roadside features and from errant vehicles encroaching across a median. Traffic barriers are classified into two basic groups according to function: (1) longitudinal and (2) crash cushions (see Fig. 1). *Longitudinal* traffic barriers perform by redirecting errant vehicles away from the roadside hazard; examples of longitudinal barriers are guardrail, bridge rail, and median barrier installations. *Crash cushion* barriers function primarily by decelerating errant vehicles to a stop, thus greatly reducing severity of a head-on impact with fixed objects that exist in off-ramp gore areas. However, for glancing impacts along the barrier side, the crash cushion must also function as a longitudinal barrier. Examples of crash cushions are steel barrel configurations, entrapment nets, and an array of containers filled with sand or water.

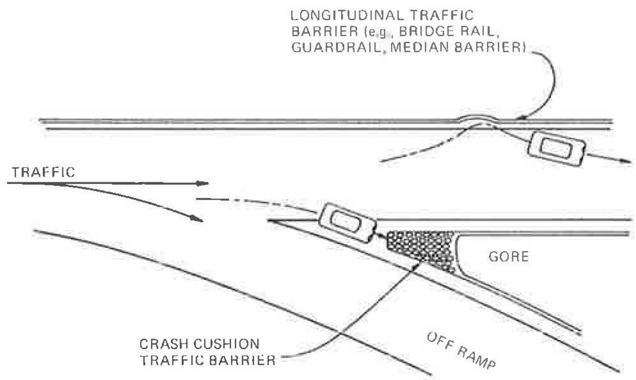

Figure 1. Traffic barrier definition.

CONTENT

The report content is organized with respect to major aspects of barrier technology. Chapter Two presents highway conditions that warrant a traffic barrier installation. The preferred barrier performance capabilities and service requirements are discussed in Chapter Three, and the performance criteria that translate service requirements into specific design quantities are discussed in Chapter Four. Barrier systems and procedures for selecting these systems are presented in Chapter Five. Aspects relating to maintenance and upgrading of existing barrier systems are discussed in Chapter Six.

CHAPTER TWO

WARRANTS

GENERAL APPROACH

Traffic barrier warrants are decision criteria that identify sites along highways needing traffic barrier installations. These warrants are delineated in terms of geometry and location of roadside features; for the special case of median barriers, traffic volume is also a use decision factor. Warranting criteria presented in this section have been developed from analysis of ran-off-the-road accident statistics and are applicable to highways in general. Accident experience records for a specific site normally supersede the traffic barrier warrants presented in this chapter.

The purpose of traffic barriers is to reduce accident fatalities and injuries by decreasing severity of crashes. Crash cushion barriers are designed for locations, such as off-ramp gores and bridge piers in the median, for which the primary problem is a head-on collision; generally, a crash cushion will decrease the severity of such direct-on impact. In contrast, the longitudinal barrier affords only a relative degree of protection to vehicle occupants, as a collision with this type of barrier can result in a severe accident; hence, longitudinal barriers are warranted only at highway locations where the severity of a collision with the roadside feature would be greater than that with the traffic barrier.

Installation of traffic barriers may increase the frequency of accidents by presenting a larger "target" located closer to the roadway than the hazard being shielded. For this reason, traffic barrier installations should be kept to a minimum. Highway designers should strive to eliminate *all* traffic barriers; and *where traffic barrier requirements are indicated by warrants, the roadway should be examined to determine the feasibility of adjusting site features so that the barrier will not be required (e.g., flattening an embankment slope, removing a tree, or eliminating a drainage headwall).*

DETERMINATION OF NEED

Highway features that may warrant traffic barrier installations are delineated in Table 1, together with indications as to whether the barrier system candidate may be a

TABLE 1

TRAFFIC BARRIER WARRANTING CONSIDERATIONS

	Refer to Chapter Section	Barrier Warranting Factor*	Barrier Candidate	
			Longitudinal	Crash Cushion
1. Lateral Dropoff				
a. Bridge†	2. B. 1. a	A	X	
b. Abrupt Embankment	2. B. 1. b	B, C	X	
c. Sloped Embankment	2. B. 1. c	D	X	
2. Roadside Obstacle				
a. Nontraversable Hazard				
(1) Rough rock cut	2. B. 2. a	B	X	
(2) Large boulders	2. B. 2. a	B	X	
(3) Water (permanent bodies)	2. B. 2. a	B, C	X	
(4) Line of trees	2. B. 2. a	B, E	X	
(5) Gores	2. B. 2. a	F		X
(6) Space between twin bridges	2. B. 2. a	G	X	X
b. Fixed Object				
(1) Bridge parapet; bridge rail end	2. B. 2. b	H	X	X
(2) Sign support	2. B. 2. b	B, E	X	X
(3) Bridge piers; abutments	2. B. 2. b	B	X	X
(4) Retaining walls, culvert headwalls	2. B. 2. b	B	X	X
(5) Trees	2. B. 2. b	B, E	X	X
(6) Wood poles, posts	2. B. 2. b	B, E	X	X
(7) Tower lighting structures	2. B. 2. b	B, E	X	X
3. Opposing Traffic	2. B. 3	I	X	

*A - all bridges
B - distance from pavement
C - depth of drop (water)
D - height and slope
E - size
F - elevated exit ramp
G - adverse accident experience
H - bridge width, traffic redirection
I - median width, traffic volume

†Bridge approach barrier and bridge rail should be an integrated barrier system.

longitudinal or a crash cushion design, or both. The three principal features are (1) lateral dropoff, (2) obstacle, and (3) opposing traffic. The highway features are discussed in more detail in the following.

Lateral Dropoff

Lateral dropoffs are further classified as (1) bridge structures, (2) abrupt embankments, and (3) sloped embankments, to facilitate warranting analysis.

Bridge Structure

All bridge structures warrant longitudinal barrier installations (e.g., bridge rail).

Abrupt Embankment

Shoulder dropoffs having a slope greater than 1:1, depth greater than 2 ft, and located within 30 ft of traveled way warrant a longitudinal barrier installation. Because an abrupt embankment may extend a considerable length along the roadway, the probability of an errant vehicle contacting the dropoff is greater than that of a vehicle hitting a roadside fixed object. For this reason, barrier installations may be needed at dropoffs located more than 30 ft from the traveled way to provide roadsides with a consistent degree of safety.

Ditches near roadways can be a severe hazard if their cross sections are such that they cannot be successfully traversed by errant vehicles. Although a barrier may be warranted on a relative severity basis, it is presumed that the cross section of a ditch can be altered to be less hazardous, or even safe, at less cost than installing a barrier. For this reason, ditches near a roadway will not alone justify the use of a traffic barrier; yet the improperly designed ditch is recognized as a highway hazard and should be corrected by other means. A preferred ditch profile is shown in Figure 2.

Sloped Embankments

Height and slope of roadway embankments are basic factors in determining traffic barrier needs. For low, flat embankments, out-of-control vehicles can "ride out" a slope with a hazard less than that associated with striking a longitudinal traffic barrier. For high, steep embankments, the hazard of being redirected by a guardrail is less than that of the vehicle being permitted access to the slope. A dividing line between these extremes is presented in Figure 3 as a plot of an equal severity curve developed from accident studies involving beam-type traffic barriers in California (*3*). This curve is independent of accident frequency, vehicle speed, and embankment slope material.*

Determination of warrants for barriers on sloped embankments is a straightforward procedure. If an intersection point falls below the equal severity curve of Figure 3, a traffic barrier is neither warranted nor desired for embankments with traversable (i.e., containing no large obstacles, such as trees or large sign posts) slopes. If the intersection point falls above the equal severity curve, use of traffic barrier is warranted. Obstacles on embankment slopes and hazards at the toe of the slope are discussed in the following sections. However, before the barrier is specified, the roadway design must be examined to determine the feasibility of removing and remedying the warranting feature.

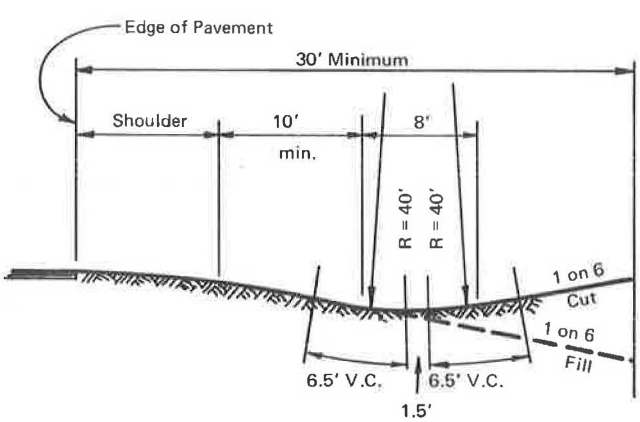

Figure 2. Preferred ditch section (12).

Roadside Obstacles

Nearly one-third of all highway fatalities occur when vehicles inadvertently leave the roadway and strike a roadside obstacle. Removal of these obstacles, thus providing traversable roadsides, would give drivers of errant vehicles the opportunity to regain control of their cars. Figure 4 shows a plot of 211 cases in which cars at General Motors Proving Ground left the pavement (*12*). Generally, the roadside is relatively flat (10:1 embankment slope) and clear of obstacles in the 100-ft zone adjacent to the pavement. Eighty percent of the errant vehicles did not travel more than 29 ft from the edge of the pavement. For warranting purposes, a 30-ft zone adjacent to the traveled way is recommended as the minimum for being clear of roadside obstacles; a zone of more than 30-ft width is desirable. If the 30-ft zone cannot be cleared of roadside obstacles such as bridge piers or permanent buildings, due to practical or economic reasons, a traffic barrier may be warranted.

The two major groups of roadside obstacles are nontraversable hazards and fixed objects.

Nontraversable Hazards

Examples of nontraversable hazards are (1) rough rock cuts, (2) large boulders, (3) permanent bodies of water with depths greater than 2 ft, and (4) lines of large (i.e.,

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* The curve was developed from the analysis of 331 accidents involving spring-mounted curved metal plate and W-beam guardrails and 999 accidents involving embankments. The Severity Index was computed using the ratio of 1:6:25 for property damage only, injury, and fatal accident, respectively; this ratio is based on direct cost of an accident and does not include loss of earnings. The curve is subject to future change to reflect (1) improved guardrail performance, (2) change in method of computing accidents costs, (3) variation in weights and dimensions of future automobiles, and (4) improvements to vehicle crashworthiness and "safety packaging" of occupants. Although recent accident data from New York seem to indicate improved traffic barrier performance, this information is considered insufficient to justify modification of the curve at this time.

greater than 6-in. diameter) trees. Nontraversable hazards located within 30 ft of the traveled way warrant a longitudinal traffic barrier. Because of the extended length of the hazard along the roadway, the probability of errant vehicles striking the nontraversable hazard is greater than that of a vehicle hitting a roadside object. For this reason, longitudinal traffic barriers may be needed at hazards located more than 30 ft from the traveled way to provide roadsides with a consistent degree of safety.

Off-ramp gores have been identified as locations of numerous ran-off-the-road type incidents; cause of this high frequency is conjectured to be either indecision or delayed decision of the errant driver to exit from the expressway. Many of these incidents are fatal when the gore areas are nontraversable and/or contain obstacles. Although substantiating accident data are unavailable, it is assumed that all elevated gores warrant crash cushion installations. The Federal Highway Administration recommends (*14*) that space be reserved on all new construction for potential crash cushion installations (see Table 2); however, these recommendations are currently under study and may be subject to change.

The narrow space between twin bridges is a roadside hazard that may warrant either remedial treatment or a traffic barrier. Adverse accident experience is the only warranting factor for this roadside feature. Safety options include, in order of preference, (1) a deck over the bridges' gap and (2) installation of a longitudinal or crash cushion barrier. It should be noted that traffic barriers will generally be warranted at a twin bridge location due to other features (e.g., bridge rail ends, embankment, etc.); hence, the installation layout should consider the two or more hazards as a single problem.

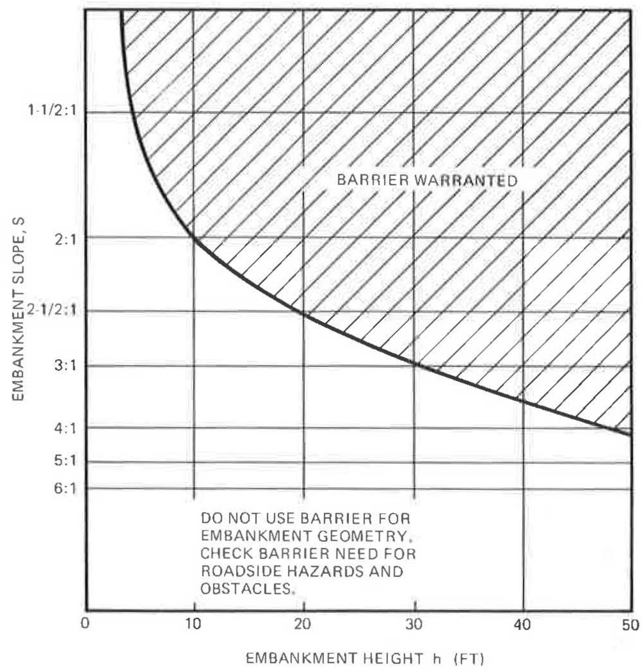


Figure 3. Barrier requirement for embankment geometry (3).

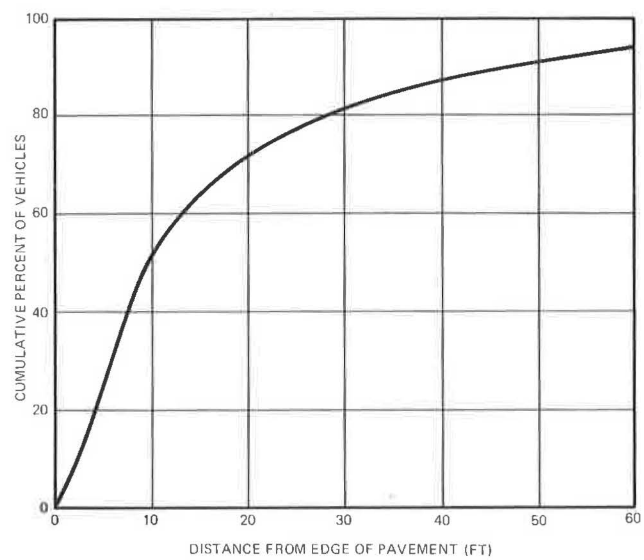


Figure 4. Distribution of 211 ran-off-the-road incidents, General Motors Proving Ground Study (12).

Fixed Objects

Specific determinations of longitudinal traffic barriers for bridge parapets and bridge rail ends are given in Figure 5. The width of the bridge and the direction of traffic are factors that affect barrier warrants; the warranting dimensions are derived from the 30-ft distance in Figure 4. Approach barrier systems must be compatible with bridge rail systems according to dynamic performance, and the two installations must be structurally integrated (Appendix C). To minimize the hazard of a bridge rail end, one state is currently extending the bridge rails off the bridge and flaring them away from the pavement edge.

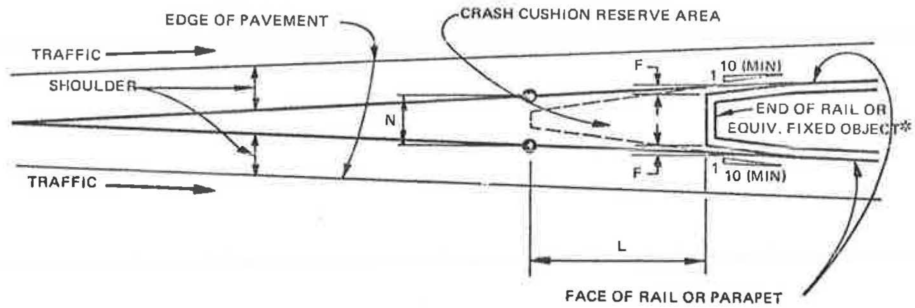
In Table 3, fixed-object warrant determinations are delineated for sign supports, lightpoles, bridge piers and abutments at underpasses, retaining walls, culvert headwalls, trees, and wood poles and posts. Where feasible, the fixed object that warrants the traffic barrier should be moved from the 30-ft-wide zone adjacent to the roadway or modified to make it a breakaway design.

Opposing Traffic

A longitudinal traffic barrier is used in narrow medians to prevent across-the-median, head-on collisions between automobiles in opposing traffic. Warrants for these barriers are determined by median width and traffic volume (*7*). With highway median width (e.g., distance between traveled ways) and the average daily traffic volume, the median barrier need can be determined as demonstrated in Figure 6. It is suggested that this daily traffic volume be based on a 2-year projection. Median barriers are not warranted if median width exceeds 50 ft, except on the basis of adverse accident experience. It is to be noted that although

TABLE 2

RESERVE AREA FOR OFF-RAMP GORES (*14*)



Design Speed on Mainline (m. p. h.)	Dimensions for Crash Cushion Reserve Area on New Construction (feet)								
	Minimum†						Preferred‡		
	Restricted Conditions			Unrestricted Conditions					
	N	L	F	N	L	F	N	L	F
30	6	8	2	8	11	3	12	17	4
50	6	17	2	8	25	3	12	33	4
70	6	28	2	8	45	3	12	55	4
80	6	35	2	8	55	3	12	70	4

NOTES:

*See Table 3 for fixed object definition.

†Minimum

Restricted Conditions - These dimensions approximately describe the space required for installation of the current generation of crash cushion devices without encroachment on shoulders and with the nose of the device offset slightly back of the parapet or shoulder line. However, there are designs already developed that would not fit in the space provided by these dimensions. These dimensions are absolute minimums and should only be considered where there are extremely tight geometric controls or where project plan development at the time of the issuance of this memorandum is so far advanced that revising plans to get greater space would be extremely disruptive to the highway program.

Unrestricted Conditions - These dimensions should be considered as the minimum for all projects where plan development is not far advanced except for those sites where it can be shown that the increased cost for accommodating these dimensions, as opposed to those for Restricted Conditions, will be unreasonable.

(For example, if the use of the greater dimensions would require the demolishing of an expensive building or a considerable increase in construction costs then the lesser dimensions might be considered.)

‡Preferred

These dimensions, which are considerably greater than required for the present generation of crash cushion devices, should also be considered optimum. There is no intention to imply that if space is provided in accordance with these dimensions that the space will be fully occupied by a crash cushion device. The reason for proposing these dimensions is so that if experience shows that devices should be designed for greater ranges of vehicle weights and/or for lower deceleration forces there will be space available for installation of such devices in the future. In the meantime, the unoccupied reserve crash cushion space will provide valuable additional recovery area.

TABLE 3

WARRANTS FOR TRAFFIC BARRIER PLACEMENT AT FIXED OBJECTS

Fixed Objects Within 30 ft. of Traveled Way	Traffic Barrier Required	
	Yes*	No
1. Sign support (ground mounted):		
(a) Post of breakaway design†		X
(b) Wood poles or posts with area greater than 50 sq. in.	X‡	
(c) Sign bridge supports	X	
(d) Metal shapes with moment of inertia greater than 3.0 in.^{4} for steel, 4.5 in.^{4} for aluminum	X	
(e) Concrete base extending 6 in. or more above ground	X	
2. Light poles and supports with breakaway linear impulse:		
(a) Less than 1,100 lb.-sec. (16)**		X
(b) Greater than 1,100 lb.-sec. (16)	X	
3. Bridge piers and abutments at underpasses	X	
4. Retaining walls and culvert headwalls	X	
5. Trees with diameter greater than 6 in.	X	
6. Wood poles or posts with area greater than 50 sq. in.	X‡	

NOTES:

* Traffic barrier recommended only if fixed object cannot be removed from 30-ft. zone, or where breakaway design is not feasible.
† Usually breakaway design should be used regardless of distance from travelled way.
‡ Cross-sectional area of large wood members can be reduced to below 50 sq. in. or less by boring holes at about 6 in. above grade. If this is not feasible, traffic barrier is recommended.
**Breakaway bases should always be used except where low-speed vehicular traffic or heavy pedestrian traffic is a consideration.

accident severity and fatalities decrease, accident frequency generally increases after a traffic barrier has been installed in a median; this is attributed to the decrease in maneuvering space for ran-off-the-road vehicles.

For all divided highways, regardless of median width and traffic volume, the median roadside must also be examined for other warranting factors, such as obstacles and lateral dropoff, as presented in the previous discussion.

Traffic Direction	W* (Ft.)	Barrier Required At†
North and South	60 or Less	A, B, C, D
North and South	Greater Than 60	A, D
South Only	All Widths	A, B
North Only	All Widths	C, D

*W denotes width between parapets. Dimensions arbitrarily based on 30-ft distance of Figure 4.
†Check roadway for other warranting features (e.g., use Fig. 3)

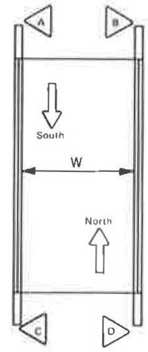


Figure 5. Barrier requirements for bridge parapets and bridge rail ends.

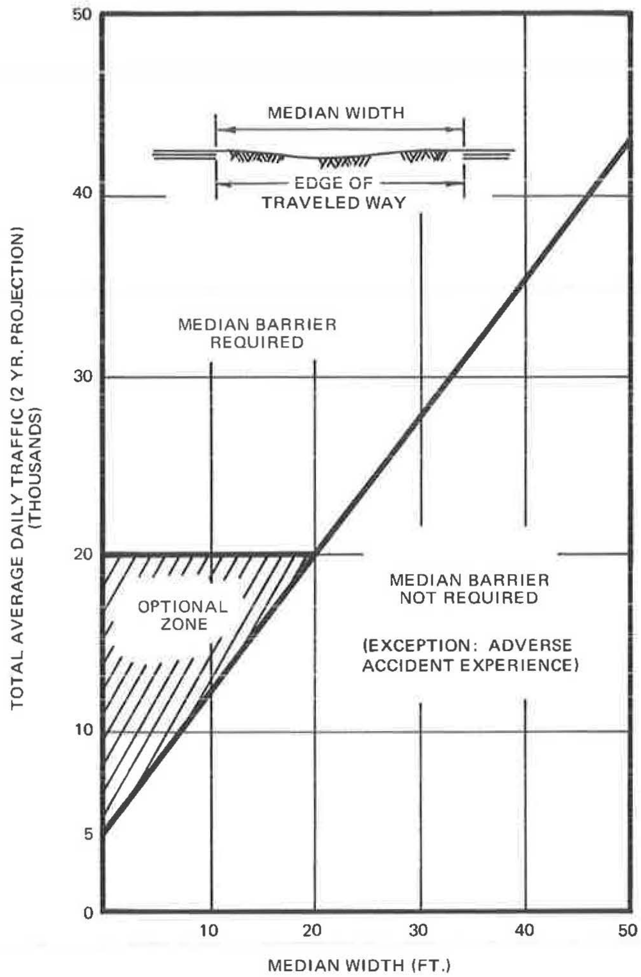


Figure 6. Median barrier requirements (7).

CHAPTER THREE

SERVICE REQUIREMENTS

The purpose of a traffic barrier is to reduce the number of highway fatalities and to minimize personal injuries. It accomplishes this objective by reducing the severity of ran-off-the-road, hit-other-object type of accidents. The design of traffic barriers is a complex task because of the sometimes conflicting performance requirements that necessitate compromise. To provide the designer with a complete and proper perspective from which to make consistent and quality judgments, service requirements are delineated and briefly discussed in this chapter. Although they have the same purpose, longitudinal barriers and crash cushions perform in a different manner, and their service requirements may vary; accordingly, requirements for the two types of barriers, when different, are presented separately.

The order of emphasis for service requirements is first to *safety,* second to *economics,* and third to *aesthetics* (*9, 39*).

DYNAMIC PERFORMANCE

1. A longitudinal barrier must restrain a selected vehicle. (The selected vehicle is one that is representative of a large majority of the vehicle population.) This implies that when a vehicle of specified weight, dimensions, velocity, and

approach angle strikes a barrier it will not climb over, break through, or wedge under the installation.

2. A crash cushion must decelerate a selected vehicle impacting direct-on in such a manner that occupants restrained by seat belts can survive with little or no injury.

3. A longitudinal or crash cushion barrier that is impacted by a selected vehicle along its length must either stop or redirect the vehicle in such a manner that passengers restrained by seat belts can survive, preferably uninjured.

4. A longitudinal or crash cushion barrier should redirect or stop the selected vehicle in such a manner as to minimize hazard to following or adjacent traffic. Ideally, the vehicle should remain close to the barrier installation and not be directed back into the traffic stream.

5. During impact, the longitudinal or crash cushion barrier must function in such a fashion that vehicle occupants and other traffic are not likely to be endangered by vehicle or barrier fragments or barrier elements that could intrude into the passenger compartment or be deposited on the traveled way.

COST CONSIDERATIONS

A longitudinal or crash cushion barrier should be economical in construction, installation, and maintenance; hence, in evaluating the relative merits of two or more systems, consideration should extend beyond the first cost to a least-annual-cost analysis. Design performance of traffic barriers should minimize damage to impacting vehicles; this consideration includes not only the high-speed, high-angle impacts, but also the more frequent minor "brush" accidents.

OTHER CONSIDERATIONS

To provide for maintenance crew safety, longitudinal and crash cushion barriers must be amenable to quick repair of crash damage; the design should not inhibit general maintenance operations at its location, particularly in narrow medians where high-speed traffic would be impeded and would endanger the crew.

A traffic barrier must remain functional in all weather conditions present at the highway site throughout its expected life. Also, it should exhibit weather durability (i.e., against moisture, snow and ice, salt, sunlight, and temperature excursions). A traffic barrier installation should be difficult to vandalize and should not be attractive to vandals.

A final consideration is for the traffic barrier to have a pleasing and functional appearance.

CHAPTER FOUR

PERFORMANCE CRITERIA

In conventional structural design, *structural strength* is the basic design criterion. Design loads are analytically imposed on a schematic of the structure, and the structural members are chosen so that the stresses will not exceed those allowable. A traffic barrier system could be designed in a similar manner if structural strength were the only design criterion. However, *safety* of the occupants of impacting vehicles and other traffic is also a primary service requirement, and these two factors (e.g., structural strength and occupant safety), being interdependent, must be considered simultaneously in system design in order to achieve optimum traffic barrier performance. For instance, it may be necessary to reduce the rigidity of a system in order to lessen the abruptness and severity of an impact, thereby improving safety.

Safety aspects of a barrier are evaluated according to (1) the probability of vehicle occupants surviving a traffic barrier collision with little or no injury and (2) the probability of the vehicle position after impact not causing a subsequent multicar collision with adjacent traffic. In the former, human tolerance to a hypothetical collision is projected on the basis of *vehicle* decelerations. For the latter, the vehicle postimpact trajectory is analyzed with respect to the roadway geometry. Unfortunately, these safety aspects cannot be theoretically determined with an acceptable degree of confidence and, therefore, must be determined by the more costly experimental methods.

Traffic barrier dynamic performance criteria are formulated for full-scale vehicular crash testing of candidate barrier systems whereby both strength and safety are simultaneously evaluated. These criteria are composed of (1) vehicle impact characteristics and (2) barrier response requirements, presented in the form of vehicle decelerations and trajectory. If the barrier system contains the moving vehicle (i.e., structural strength), the vehicle decelerations are judged to be within human tolerance levels, and the vehicle postimpact trajectory is acceptable, the candidate barrier is considered acceptable for in-service experimental use. After the system has been carefully monitored and evaluated in service and its effectiveness has been established, the system is judged to be operational.

VEHICLE IMPACT CHARACTERISTICS

Impact characteristics are presented in Table 4 for all traffic barrier systems. Although there are other vehicle properties that affect the dynamic performance of a barrier, vehicle weight, speed, approach angle, and point of impact are the most significant. The parametric values chosen represent a severe, rather than a typical, traffic barrier crash of standardweight and lightweight passenger vehicles.

Impact characteristics for longitudinal barriers are a 4,500-lb vehicle in collision with the candidate system at 60 mph at a 25-deg angle. Crash cushions are evaluated for a lightweight (2,000 lb) and a standardweight (4,500 lb) vehicle impacting the barrier direct-on. Also, for crash cushions that will be subjected to angle hits, two additional sets of test conditions are imposed: 15- and 25-deg angle hits. The 15-deg crash cushion test is evaluated according to performance criteria established for a longitudinal barrier, whereas the 25-deg crash cushion test is currently evaluated only for structural strength of the barrier.*

DYNAMIC PERFORMANCE CRITERIA

Structural Integrity

For the longitudinal barrier, the first dynamic performance requirement is to restrain the selected vehicle (Table 4); otherwise, it cannot effectively shield the warranting roadside feature (i.e., lateral drop-off, fixed object, etc.) A longitudinal barrier that does not prevent vehicle penetration (i.e., by vaulting, breaking through, or wedging under the rail) can be a greater hazard due to its relative length than the roadside feature being shielded. Hence, *only longitudinal barrier systems that successfully restrain the selected vehicle are acceptable for operational use.*

In redirecting or stopping the vehicle, the longitudinal or crash cushion barrier must deform or function in such a manner as to minimize the hazard of the passenger compartment being invaded by parts or elements of the system. For example, the installation design should minimize the chance of a beam rail spearing the vehicle, or the system fragmenting into lethal projectiles.

Vehicle Deceleration †

The objective of a highway traffic barrier is to reduce the number of fatalities and the severity of occupant injuries in ran-off-the-road-type accidents. Occupant injury and fatality are usually related to (1) accident severity (i.e., vehicle deceleration intensity and duration), (2) precrash physiological condition of passengers, (3) the passengers' degree of restraint, and (4) the crashworthiness of the vehicle. However, of these factors only accident severity is significantly affected by the dynamic performance of a traffic barrier. Accordingly, primary traffic barrier performance is evaluated on deceleration induced in the vehicle during a collision. In comparing performance of two or more traffic barrier systems, the one that induces the lowest level of deceleration to the colliding vehicle is generally preferred.

* It is desirable to have crash cushions that will perform in all respects at 60 mph and 25-deg angle; however, the present generation designs lack this capability. Hence, until this capability is developed, the 15-deg impact is considered as a minimum test criterion where redirectional performance is evaluated.

† Determined by full-scale crash test conducted in accord with the conditions in Table 4.

TABLE 4

VEHICLE IMPACT CHARACTERISTICS

Traffic Barrier Type	Vehicle Impact Characteristics: Weight (lb)	Speed (mph)	Angle (deg)	Barrier Impact Point*
Longitudinal	4,500	60	25	A
Crash Cushion	2,000	60	0	B
	4,500	60	0	B
	4,500	60	15	C
	4,500	60	25†	C

*A - midway between posts; B - barrier nose; C - along barrier side.
†For structural strength evaluation only.

Longitudinal Barriers

Guideline values for maximum vehicle decelerations (at center of mass) are presented in Table 5 (*10*) according to vehicle reference axes and three performance ratings. The procedure used to establish deceleration values given in Table 5 is not precisely described in the original reference. However, subsequent researchers (*1, 26*) have suggested the use of the highest 50-msec average deceleration occurring near the vehicle's center of mass during impact. The limits of deceleration given here are not nominal limits for "no injury," but rather are maximum limits beyond which disabling injury or fatality may be expected. The order of preference is Ratings A, B, and C. Barriers with full-scale crash test deceleration values within the limits of Table 5 are considered to have satisfied the deceleration requirements. Longitudinal barrier systems presented in Chapter Five are evaluated according to this rating system and the test results are presented in Appendix G.

Crash Cushion Barriers

For direct-on tests of crash cushions (i.e., where vehicle lateral deceleration is minimum), a maximum average permissible vehicle deceleration is 12 *g's*, as calculated from vehicle impact speed and stopping distance (see Eq. E-5a, Appendix E). At this level of deceleration, existing evidence indicates that injuries are to be expected in most collisions. Lesser deceleration levels are desirable, as these will reduce the severity and number of injury-producing accidents (*15*). For side impacts, the longitudinal barrier deceleration criterion (Table 5) is applicable.

Vehicle Postimpact Trajectory

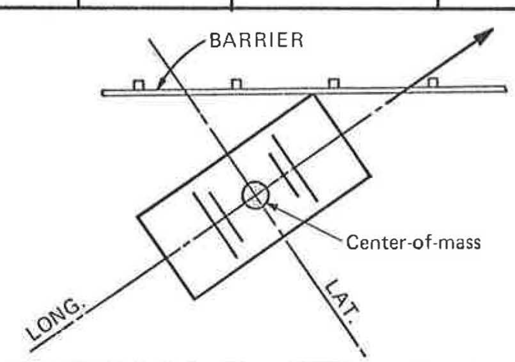
To minimize the possibility of involving other traffic, the third performance criterion is for vehicles impacting longitudinal barriers or the sides of crash cushions to be redirected in a trajectory nearly parallel to the pavement edge. For normal or angle hits on the nose of crash cushions, vehicle postimpact trajectory is judged satisfactory if the vehicle is not rebounded into the main traffic streams.

Accidents in which a vehicle is redirected into the traffic lane and becomes involved in a multicar collision seem to be few in number. Accordingly, postimpact trajectory is a performance consideration that is reserved in making a selection among systems that are comparable with regard to structural strength characteristics and decelerations produced during vehicle redirection.

TABLE 5

MAXIMUM VEHICLE DECELERATIONS (*10*)

Barrier Performance Rating†	Maximum Vehicle Decelerations (g's)*			
	Lateral	Longitudinal	Total	Remarks
A	3	5	6	Preferred Range
B	5	10	12	
C	15	25	25	



*Vehicle rigid body decelerations; maximum 500 g/sec onset rate; highest 50 msec average.

†A - limits for unrestrained passenger.
B - limits for passenger restrained by lap belt.
C - limits for passenger restrained by lap and shoulder belts.

CHAPTER FIVE

DESIGN AND SELECTION PROCEDURES

Present technology precludes the mathematical design of a traffic barrier with a predictable vehicle redirection or deceleration performance. Although the interaction between barrier and vehicle has been mathematically characterized, it has been discovered that small variations in designs or in construction details can have adverse effects on the safety performance of an otherwise sound and adequate barrier system. Consequently, barrier systems have evolved from a trial-and-error process in which emphasis is placed on full-scale crash testing of a developing prototype design.

Barrier systems shown in this report are classified according to their stage of development. An *R&D* (research and development) device is a design in the primary stage of research and test evaluation; test results and laboratory findings are considered inadequate to justify highway installation. An *experimental* device is a barrier that has performed satisfactorily (see "Dynamic Performance Criteria," Chapter Four) in full-scale crash tests and promises satisfactory service performance; the device can be installed on highways on a trial basis during which in-service performance is extensively monitored and documented. Finally, an experimental barrier system that demonstrates satisfactory in-service performance is reclassified as an *operational* device.

Several longitudinal and crash cushion barrier designs are presented in this document; there are other barrier systems, but adequate information is not available to permit their classification.

The characteristics of barrier designs, selection criteria, and design procedures of this chapter will aid the highway designer in choosing the best applicable system.

LONGITUDINAL BARRIERS

Characteristics of Systems

Summaries of basic characteristics of guardrail, median barrier, and bridge rail systems are presented in Tables 6, 7, and 8, respectively. Deflection, an important system characteristic, is the maximum lateral deflection that a system experiences during impact and redirection of a selected vehicle (see Table 4); deflections of systems vary from 0 to 12 ft for guardrail and median barriers and from 0 to 2 ft for bridge rails. Barrier performance is rated in terms of vehicle deceleration, test results, and the rating scale presented in Table 5. Other characteristics are (1) post type and spacing, (2) beam type and mounting detail, and (3) footing type or connection to bridge. Selected designs for operational longitudinal barrier systems are contained in Appendix D.

Selection Criteria

An appropriate longitudinal barrier system is selected by a straightforward procedure. The factors considered are relatively few in number. Principally, these factors are (1) the unobstructed space available for lateral deflection (i.e., for guardrail and median barriers) or maximum desired deflection for a bridge rail, (2) the roadway or bridge structure cross section, and (3) the installation and maintenance costs.

Deflection

The major factor in selecting a guardrail or median barrier system is matching dynamic lateral deflection characteristics of a system to the space available at the highway site. Because this lateral deflection varies with vehicular dynamics, a selected test (e.g., 4,000- to 4,500-lb vehicle, 60 to 65 mph, and 25-deg impact angle) was used in determining deflection (Tables 6, 7, and 8). For the systems to perform in a similar manner in actual service, minimum unobstructed distances behind guardrails and median barriers must be equal to or greater than this deflection. For example, if the roadside hazard is located 3 ft behind the proposed guardrail line, the guardrail system should be selected from those of Table 6 that indicate deflection of less than 3 ft. Similarly, if a barrier is to be placed in the center of a 10-ft median, the median barrier system should be selected from those of Table 7 that indicate a deflection of less than 5 ft (one-half the median width). For bridge rails, a maximum allowable dynamic lateral deflection of 2 ft beyond the outermost edge of the bridge deck is considered a reasonable performance criterion from the standpoint of preventing the vehicle from falling through the space between the edge of the bridge and the rail (*1*).

Roadway and Bridge Cross Section

Roadway and bridge cross section can significantly affect traffic barrier performance. Curbs, dikes, sloped shoulders, and stepped medians can cause errant vehicles to vault a barrier or to strike it so that the vehicle overturns. Optimum barrier system performance is provided by a level surface in front of the barrier. Preferably, curbs and dikes should be behind the barriers; if, however, curbs and dikes must be in front of the barrier, they should be of the low, mountable type. Where barriers are installed on superelevated sections of highway, the vertical axis of the barrier should be inclined in order to remain perpendicular to the pavement surface. This is particularly important for sloped-face concrete barriers.

Stepped * median sections affect selection of median barriers. Cable and box beam systems (Table 7) are limited to flat medians or stepped sections with slopes flatter than 2:1 or steps less than 6 in. high. Cable or rail heights must be adjusted so that proper contact is made with the vehicle (see Figs. C-10, C-11, C-12 of Appendix C). A median with a large step might use two guardrails (see Fig. C-9c of Appendix C). In a step median, the two sides of a rigid concrete barrier should be adjusted (see Fig. C-9d of Appendix C).

Installation and Maintenance Costs

Although cost of installation generally increases as system rigidity † increases, cost of repair and maintenance generally decreases. Because of wide variations in both installation and maintenance costs in different localities, representative unit prices cannot be established. Therefore, if two or more guardrail systems satisfy lateral deflection requirements, final system selection must be made on the basis of local (1) preference, (2) material availability and costs, (3) installation costs, and (4) maintenance and repair costs.

Design Procedure for a New Installation

For any new longitudinal barrier installation, the recommended design procedure is as follows:

1. Establish "point-of-need" or "length-of-need" by warranting procedures of Chapter Two.
2. Based on the unobstructed space available for system deflection, select a barrier system from Table 6, 7, or 8. For bridge rail selection, the system must be structurally compatible with the bridge.
3. Determine design particulars for the selected system, such as terminal treatments and adjustments for highway curvature.
4. Make installation layout drawings. Note that for guardrails and median barriers, installations should be extended a reasonable distance upstream beyond the warranted area to prevent vehicle access to a warranting feature. A method for establishing this necessary extension is presented in Appendix C. For highways with two-way traffic, the installation should also be extended downstream. For barriers placed on sloped shoulders, the rail height must be adjusted according to the method presented in Appendix C. Furthermore, terminal sections should occur outside the length-of-need so that within this length the protective system is at its typical design condition.

Bridge rails should be extended upstream (see Fig. 5) as approach guardrail, or the approach rail-bridge rail combination should be a structurally integrated system with consistent dynamic performance.

5. Make a field review, near the completion of highway construction, before setting the final installation limits. Short gaps between installations should be avoided.

CRASH CUSHION BARRIERS

Characteristics of Systems

A discussion of the mechanics of crash cushion behavior is presented in Appendix E. Several crash cushion systems are listed in Table 9 and grouped according to their current (March 1971) status. Unless otherwise noted, the experimental and operational systems have been evaluated by the design criteria (Chapter Four) and their dynamic performance judged acceptable. Characteristics such as developer, testing agency, and in-service experience are given for the systems in Appendix F.

Selection Criteria

An appropriate crash cushion is selected by a direct procedure. The factors to be considered are (1) the space available for the cushion and (2) the installation, maintenance, and damage repair costs.

Space

The crash cushion designs shown in Appendix F require specific width and length to decelerate the selected vehicle. If this space is available to the highway site, the current version of the designs can be used; however, if the space is restricted in either width or length, a change in crash cushion design may be necessary and may result in performance compromise (such as higher deceleration forces). The designs in Appendix F vary in their susceptibility to being adjusted to highway sites. Modifications to a proved system design must be made with extreme caution, as experience has shown that a change in a seemingly insignificant detail has produced catastrophic barrier performance.

Costs

In evaluating crash cushion costs, the three factors of installation, maintenance, and damage repair should be considered. As an example, a crash cushion design with high initial cost may require minimum maintenance and be amenable to quick and inexpensive repairs; consequently, it may be the more cost effective system.

Other accident costs, such as those related to vehicle damage, traffic delay time, hospital, and loss of earnings, are dependent on the crash cushion dynamic performance. At the present time, accident data that establish the relative performance among crash cushions are lacking. Consequently, the systems must be assumed to be equal in performance, and, hence, these cost elements are not presently a selection criterion.

Design Procedure for a New Installation

The recommended design procedure for a new crash cushion installation is as follows:

1. Establish the need by the warranting procedures of Chapter Two.

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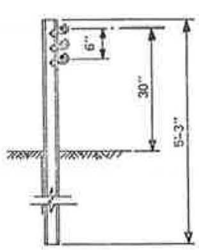
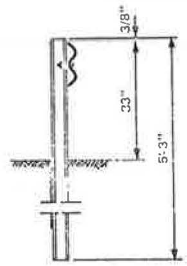
* The median between roadways of different elevations is referred to as a "stepped" median.

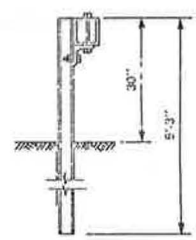
† A concrete barrier is the most rigid, a cable system most flexible, of the longitudinal barrier systems.

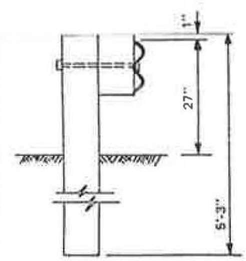
TABLE 6

SUMMARY OF GUARDRAIL CHARACTERISTICS

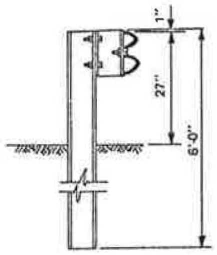


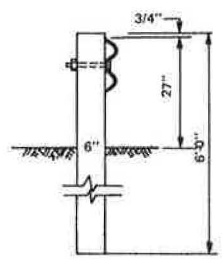


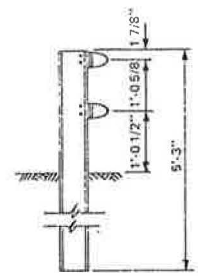


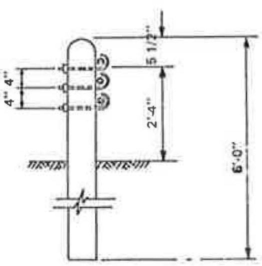


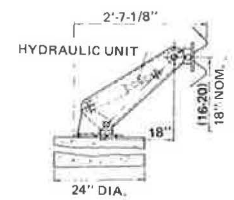
SYSTEM	G1 CABLE	G2 "W" BEAM (Steel Weak Post)	G3 BOX BEAM	G4W BLOCKED-OUT "W" BEAM (WOOD POST)
DEFLECTION	12 ft	8 ft	4 ft 2 ft	2 ft
DECELERATION RATING (See Table 5 and Appendix G)				
Vehicle Longitudinal		A	A -	A
Vehicle Lateral		B	C -	B
Test Results not Amenable to Rating System	*			
POST SPACING	16'-0"	12'-6" Nominal	6'-0" 4'-0"	6'-3"
POST	S3X5.7	S3X5.7	S3X5.7	8X8" Douglas Fir
BEAM	Three 3/4" Dia Steel Cables	Steel "W" Section	6X6X0.180" Steel Tube	Steel "W" Section
OFFSET BRACKETS	---	---	L5X3-1/2X1/4" Steel Angle 4-1/2" Lg	8X8X14" Douglas Fir Block
MOUNTINGS	5/16" Dia Steel Hook Bolts	5/16" Dia Steel Bolt	3/8" Dia Steel Bolt (beam to angle)	5/8" Carriage Bolts
FOOTINGS	1/4" Steel Plate Welded to Post	1/4" Steel Plate Welded to Post	1/4" Steel Plate Welded to Post	None
DEVELOPED BY	New York	New York	New York	California
REFERENCE	Appendices D and G	Appendices D and G	Appendices D and G	Appendices D and G
REMARKS	Revised 1971	Revised 1971	Increase height of rail from 30 to 33 in. on the outside of superelevated curve. Revised 1971	Southern yellow pine is acceptable alternate to Douglas fir.
STATUS	OPERATIONAL	OPERATIONAL	OPERATIONAL	OPERATIONAL







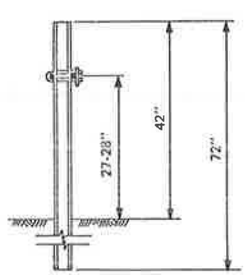


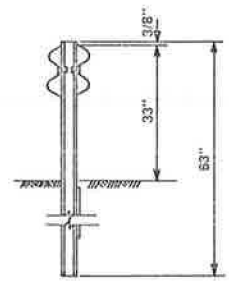


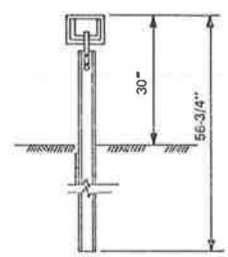
G4S BLOCKED-OUT "W" BEAM (STEEL POST)	XG-(a) "W" BEAM (Wood Weak Post)	YG-(b) ALUMINUM BALANCED BEAM	YG-(c) CABLE (WEAK POST)	YG-(d) "W" BEAM C & N POSTS
4 ft	7 ft	1.5 ft	7 ft	6 ft
A C	A B	 *	 *	A B
6'-3"	12'-6"	9'-4-1/2"	12'-6"	10'-0"
W6X8.5	5-1/2" Dia Southern Pine or 5x6 Southern Pine	5-1/2X7-1/4 H Section Aluminum	5-1/2" Nominal Dia Treated Wood	Fabricated steel with hydraulic energy absorber
Steel "W" Section	Steel "W" Beam	Two Standard Aluminum Extrusions (6061-T6)	Three 3/4" Dia Steel Cables	Steel "W" Section
W6X8.5	---	---	---	---
5/8" Dia Steel Bolt	1/4" Dia Steel Bolt with Pipe Insert	Standard Hardware	5/16" Dia Hook Bolts	Special sliding beam to post connection
None	None	None	None	Either 24" dia concrete footing or steel post driven to grade
	Ohio	Aluminum Association	Minnesota	Christiani and Nielsen, Ltd.
Appendices D and G	Appendix G	Appendix G	Appendix G	Appendix G
		Aluminum alloy selection is critical. Proper identification is essential.		This system developed and tested in England. Recently tested in U.S.A. as reported in Reference 46.
OPERATIONAL	EXPERIMENTAL	R & D	R & D	R & D

TABLE 7

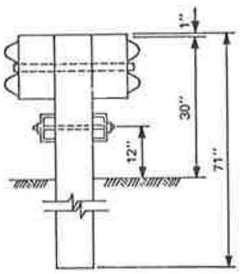
SUMMARY OF MEDIAN BARRIER CHARACTERISTICS

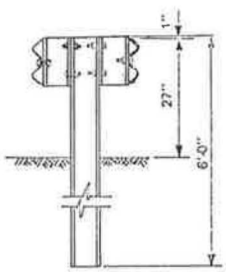


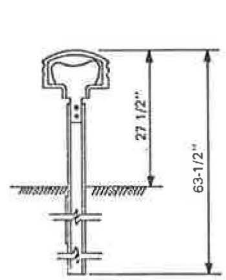


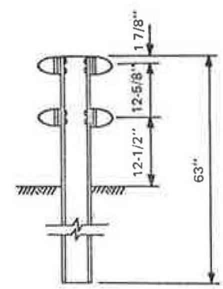


SYSTEM	MB1 CABLE	MB2 "W" BEAM	MB3 BOX BEAM
DEFLECTION	11 ft	7 ft	4 ft
DECELERATION RATING (See Table 5 and Appendix G)			
Vehicle Longitudinal	--	--	A
Vehicle Lateral	--	--	C
Test Results not Amenable to Rating System	*	*	
DEFLECTION	11 ft	7 ft	4 ft
POST SPACING	8'-0"	12'-6" Nominal	6'-0"
POST	H2-1/4X4.1	S3X5.7	S3X5.7
BEAM	Two 3/4" Dia Steel Cables	Two Steel "W" Sections	8X6X1/4" Steel Tube
OFFSET BRACKETS	---	---	---
MOUNTINGS	1/2" Dia Steel "U" Bolts	5/16" Dia Bolts	Steel Paddles (see details)
FOOTINGS	Details Vary With Application	1/4" Steel Plate Welded to Post	1/4" Steel Plate Welded to Post
DEVELOPED BY	California	New York	New York
REFERENCE	Appendix D and G	Appendix D and G	Appendix D and G
REMARKS	Use on flat medians or on saw-tooth sections with slope flatter than 3:1 or with step less than 6 inches in height.	For saw-tooth medians use two guardrail installations. Revised 1971	Use on flat medians or on saw-tooth sections with slope flatter than 3:1 or with step less than 6 inches in height. Revised 1971
STATUS	OPERATIONAL	OPERATIONAL	OPERATIONAL



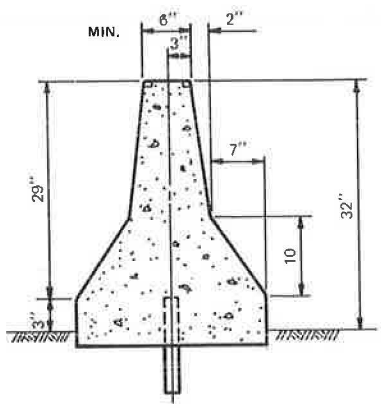
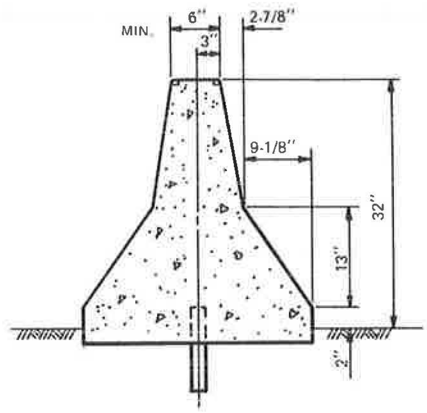






MB4W BLOCKED-OUT "W" BEAM (Wood Post)	MB4S BLOCKED-OUT "W" BEAM (Steel Post)	XMB-(a) ALUMINUM STRONG BEAM	XMB-(b) ALUMINUM BALANCED BEAM
2 ft	4 ft	7 ft	1.5 ft
-- -- *	-- -- *	A B	B C
2 ft	4 ft	7 ft	1.5 ft
6'-3"	6'-3"	6'-3"	12'-6"
8X8" Douglas Fir	W6X8.5	Aluminum I or Steel S3X5.7	5-1/2X7-1/4 H Section Aluminum
Two Steel "W" Sections Two C6X8.2 Steel Sections (rub rails)	Two Steel "W" Sections	Aluminum Extrusion (6351-T51)	Four Standard Aluminum Extrusions
Two 8X8X14" Douglas Fir Blocks	Two W6X8.5	---	---
5/8" Carriage Bolts	5/8" Dia Steel Bolts	Steel or Aluminum Paddles	Standard Hardware
None	None	8X3/16X24 Steel or Aluminum	None
California		Aluminum Association	Aluminum Association
Appendix D and G	Appendix D and G	Appendix G	Appendix G
Stagger beam heights when the saw-tooth step is over 6 inches high and/or the median slope is 3:1 or steeper. Southern yellow pine is acceptable alternate for Douglas fir. A "W" beam centered at 10 inches above grade is an acceptable alternate rub rail.	This system has been tested at 67 mph, 16 deg as reported in Reference 26. MB4S is considered operational based on test experience of G4S and considerable field experience.	Use on flat medians or on saw-tooth sections with slope flatter than 3:1 or with step less than 6 inches in height. Aluminum alloy selection is critical. Proper identification is essential.	Aluminum alloy selection is critical. Proper identification is essential.
OPERATIONAL	OPERATIONAL	EXPERIMENTAL	EXPERIMENTAL

TABLE 7 (Continued)

		
SYSTEM	MB5 CONCRETE BARRIER	MB6 CONCRETE BARRIER
DEFLECTION	0	0
DECELERATION RATING (See Table 5 and Appendix G) Vehicle Longitudinal Vehicle Lateral Test Results not Amenable to Rating System	*	*
DOWELS (into existing pavement)	1" Dia X 8" Long Steel Rod	1" Dia X 8" Long Steel Rod
DOWEL SPACING	4'-0"	4'-0"
CONCRETE	AASHO Class B	AASHO Class B
DEVELOPED BY	New Jersey	General Motors
REFERENCE	Appendices D and G	Appendices D and G
REMARKS	Use on narrow medians. Use of barrier profile is recommended at retaining walls, rock cuts, etc. (see Fig. C-8).	Use on narrow medians. Use of barrier profile is recommended at retaining walls, rock cuts, etc. (see Fig. C-8).
STATUS	OPERATIONAL (QUALIFIED)**	OPERATIONAL (QUALIFIED)**

**System is structurally adequate for 4,000-lb vehicle impacting at 60 mph and 25-deg angle; however, use of system should be restricted to locations where probability of impact angle is less than 15 deg for vehicle occupants' safety.

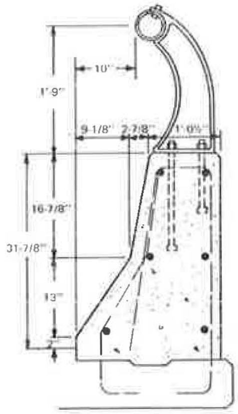
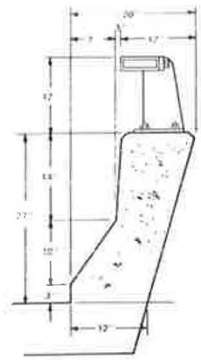
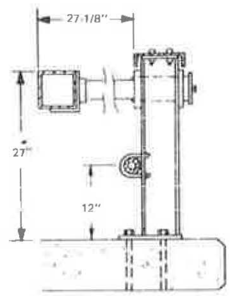
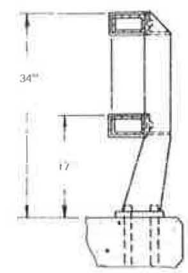
2. Based on space available at the site and costs, select an operational crash cushion type listed in Table 9 and further described in Appendix F.

3. Use the latest improved version of the selected barrier, as confirmed by testing—without modification, if possible.

4. Modify the basic design to suit the site according to procedures established by the crash cushion developer.

TABLE 8

SUMMARY OF BRIDGE RAIL CHARACTERISTICS

				
SYSTEM	BR-1	BR-2	XBR-(a)	YBR-(b)
DEFLECTION	0	0	1.75 ft	0
DECELERATION RATING (See Table 5 and Appendix G)				
Vehicle Longitudinal	--	C	B	--
Vehicle Lateral	--	C	C	--
Test Results not Amenable to Rating System	*			*
POST SPACING	Optional	10'-0"	8'-4"	10'-6"
POST	Optional	Fabricated Steel with Concrete Parapet	W6X25	Fabricated Steel*
BEAM	Optional	TS6X2 (12.02 lb/ft)	TS6X6X.1875 and C8X11.5 with 2-1/2" O.D. Rub Rail	TS5X3X0.25 (two)
OFFSET BRACKETS	--	---	Fragmenting Tube	---
DEVELOPED BY	General Motors	California	Southwest Research Institute	New York
REFERENCE	Appendices D and G	Appendices D and G	Appendix G	Appendix G
REMARKS	GM standard railing may be used, other rails are permissible.	California Highway Department bridge rail Type 20.	Fragmenting tube concept developed for Bureau of Public Roads	New York State standard steel bridge railing - two rail. *Six-inch curbe used on overpass structures.
STATUS	OPERATIONAL (QUALIFIED)**	OPERATIONAL (QUALIFIED)**	EXPERIMENTAL	R & D

**System is structurally adequate for 4,000-lb vehicle impacting at 60 mph and 25-deg angle; however, use of system should be restricted to locations where probability of impact angle is less than 15 deg for vehicle occupants' safety.

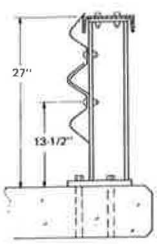
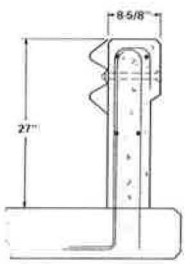
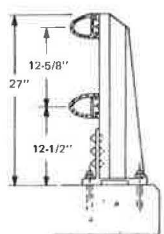
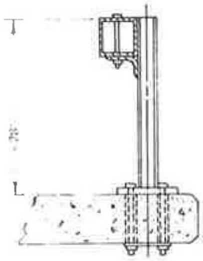
			
YBR-(c)	YBR-(d)	YBR-(e)	YBR-(f)
0	0	1.4 ft	1.5 ft
A C	-- --	-- --	A B *
8'-4"	---	6'-6"	4'-2"
	Continuous Concrete Parapet	Fabricated Aluminum	S3X5.7
Two W-Sections and C8X11.5	W-Section	Aluminum Extrusions (two)	TS6X6X0.1875
---	---	---	---
Texas Highway Department and Texas Transportation Institute	Texas Highway Department	Aluminum Association	New York
Appendix G	Appendix G	Appendix G	Appendix G
Texas Highway Department T-1 bridge rail with lower W-section added by TTI. This design is used with a "W" beam approach rail. A transition has been tested.	Texas Highway Department Standard T-2 This design permits the "W"beam approach rail to be continued across the structure	This system is similar to many state standards	This system is in development stage. A transition with System G3 has also been tested.
R & D	R & D	R & D	R & D

TABLE 9

CLASSIFICATION OF CRASH CUSHIONS

Status		Designation	Description
I	Operational	C-1 C-2 C-3 C-4	Steel Drums Water Cells Sand Containers Tor-Shok*
II	Experimental	XC-(a)	Entrapment Net
III	R&D	YC-(b) YC-(c) YC-(d) YC-(e) YC-(f)	Lightweight Cellular Concrete Timber Post Field Rigid Foams Frangible Post Field Yielding Beam

*Restricted for highways with posted speed of 50 mph or less.

CHAPTER SIX

MAINTENANCE AND UPGRADING OF EXISTING INSTALLATIONS

Traffic barrier maintenance and upgrading consists of examination and evaluation, classification of installation adequacy, and delineation of the action to be taken. The scope of each of these topics is introduced in the following paragraphs. Table 10 summarizes the classifications and servicing actions required for existing traffic barriers. Excluded from consideration are routine types of periodical maintenance (such as painting).

Examination and evaluation of existing traffic barrier installations may result from (1) routine or scheduled maintenance, (2) damage, or (3) administrative or technical conditions requiring evaluation of an installation's adequacy. On examination, an installation is evaluated with respect to its satisfying warrant and design standards, and, after evaluation, it is suggested that it be assigned one of the classifications which follow. This evaluation includes a review of original considerations used in warranting and designing the installation and an objective assessment of the installation in terms of current physical and traffic conditions at the installation site. When an existing traffic barrier installation is evaluated, possible installation removal should always be explored. Removal is permitted when the installation is shown to be unwarranted by the warranting criteria of Chapter Two or when the site features that dictate barrier needs have been altered. (For example, flattening an embankment slope may remove conditions requiring a shoulder guardrail installation.) Removal in this manner is always preferable to maintaining, replacing, or upgrading an installation.

Existing traffic barrier installations are classified as to (1) conforming, (2) nonconforming (inadequate layout), (3) nonconforming (unverified design), or (4) nonconforming (unwarranted). As shown in Table 10, classification is determined by considering three installation features—warrants, design, and layout. Servicing action is dictated by the classification; servicing actions for damaged and undamaged installations of various classifications are outlined in Table 10.

In servicing traffic barriers, actions outlined in Table 10 should be accomplished in as timely a manner as possible commensurate with the hazard presented and available funds.

TABLE 10

MAINTENANCE AND UPGRADING RECOMMENDATIONS

Classification	Evaluation: Warranted	Evaluation: Operational Design	Evaluation: Standard Layout	Recommended Action
I. CONFORMING				
An existing installation which is warranted, designed, and laid out in accordance with the criteria outlined in Chapters 2 and 5.	Yes	Yes	Yes	If the warrant cannot be removed by correcting the warranting feature, thereby permitting removal of the installation, a conforming installation should be serviced to assure an "as-built" condition in accordance with the design standards and specifications. This includes, for example, replacing damaged parts with new parts, and adjusting height and alignment.
II. NONCONFORMING				
An existing installation which fails to meet the warranting, design, or layout criteria of Chapters 2 and 5.				
A. Unwarranted				
An installation which is not required by the warranting criteria of Chapter 2 regardless of its design and layout.	No	Not Applicable	Not Applicable	UNWARRANTED INSTALLATIONS SHOULD BE REMOVED.
B. Unverified Design				
An installation which is both warranted and of an approved layout but neither (1) conforms with an operational design nor (2) has been experimentally verified by a full-scale crash test program and satisfactory service performance.	Yes	No	Yes	If the warrant cannot be removed by correcting the warranting feature, thereby permitting removal of the installation, undamaged installations of unverified design should be verified by a full-scale crash test program and satisfactory field performance or modified as soon as economically practical to conform to an operational design. If the warrant cannot be removed by correcting the warranting feature, thereby permitting removal of the installation, extensively damaged installations of unverified design should be replaced with an operational design. Replacement cannot await verification by a crash-test program and satisfactory field performance as in the case of undamaged installations. Barriers that have been extensively damaged should be replaced, at least in the damaged area, by an operational design. If transitions cannot be made at natural breaks (e.g., bridge piers), the replacement section should (1) be securely attached to the existing installation, (2) be anchored so both designs function effectively, and (3) not create sharp, hazardous transition sections.
C. Inadequate Layout				
An installation which is both warranted and of an approved design (Appendix D and E), but deviates from the recommended layout details (Appendix C)	Yes	Yes	No	If the warrant cannot be removed by correcting the warranting geature, thereby permitting removal of the installation, improper layout should be adjusted as soon as possible to conform to proper layout standards.

APPENDIX A

EXAMPLE WARRANT PROBLEMS

This appendix presents typical problems for barrier warrants. The appropriate solutions are determined from warranting criteria. Barrier needs determined by roadside shoulder features (embankment geometry, dropoff, water hazards, fixed objects) are examined, then techniques for investigating divided highways for barrier requirements are demonstrated.

SHOULDER BARRIERS

For illustrating the mechanics of the barrier warranting procedure, Figure A-1 shows the common roadside conditions affecting barrier placement. Each roadway section is analyzed as to specific barrier requirements.

Section A-A

Southbound Shoulder

Step 1: From Table 1, 1.a, barrier required on all bridges.

Solution: Install bridge rail and approach guardrail.

Northbound Shoulder

Step 1: From Table 1, 1.a, barrier required on all bridges.

Solution: Install bridge rail, check gore.

Off-Ramp—Southbound Shoulder

Step 1: From Table 1, 1.a, barrier required on all bridges.

Solution: Install bridge rail, check gore.

Off-Ramp—Northbound Shoulder

Step 1: From Table 1, 1.a, barrier required on all bridges.

Solution: Install bridge rail and approach guardrail.

Gore

Step 1: From Table 1, 2.a(5), elevated exit ramp; crash cushion is warranted.

Solution: Install crash cushion, pave gore to provide reserve area as shown in Table 2.

Section B-B

Southbound Shoulder

Step 1: Enter Figure 3 with $s = 3{:}1$ and $h = 13$ ft to determine if the basic embankment geometry warrants barrier. Barrier is not warranted.

Step 2: Check for roadside obstacles and hazards: none. Barrier is not warranted.

Solution: No barrier.

Northbound Shoulder

Step 1: Enter Figure 3 with $s = 2\frac{1}{2}{:}1$ and $h = 8$ ft. Barrier is not warranted.

Step 2: Check roadside obstacles and hazards. The sign supports are M8X6.5 structural steel sections; from Table 3, if the moment of inertia of steel shapes is greater than 3.0 in.^{4}, barrier is warranted.

Solution: Remove the sign from the 30-ft zone or replace the base with a breakaway design.

Alternative: If the above is impractical, barrier is warranted.

Section C-C

Southbound Shoulder

Step 1: Enter Figure 3 with $s = 3{:}1$ and $h = 4$ ft. Barrier is not warranted.

Step 2: Check roadside obstacles and hazards. From Table 1, rough rock cut is a nontraversable hazard. $L = 22$. Barrier is warranted.

Solution: Barrier placement at rough rock cut is warranted.

Northbound Shoulder

Step 1: Enter Figure 3 with $s = 2{:}1$ and $h = 20$ ft. Barrier is warranted.

Solution: Flatten the slope to traversable cross section.

Alternative: Barrier placement is warranted if the slope and the height of the embankment remain unchanged.

Section D-D

Southbound Shoulder

Step 1: Figure 3 is not applicable.

Step 2: Check roadside obstacles: none. Barrier is not warranted.

Step 3: A V-ditch is formed at the intersection of the shoulder and the backslope. This ditch should be "rounded" at the intersection of the slopes (40-ft radius is desirable; see Fig. 2).

Solution: Modify ditch; barrier is not warranted.

Northbound Shoulder

Step 1: Using Table 3, check the pond for water hazard. $L = 25$ ft; water depth is greater than 2 ft.

Solution: Barrier is warranted at the pond.

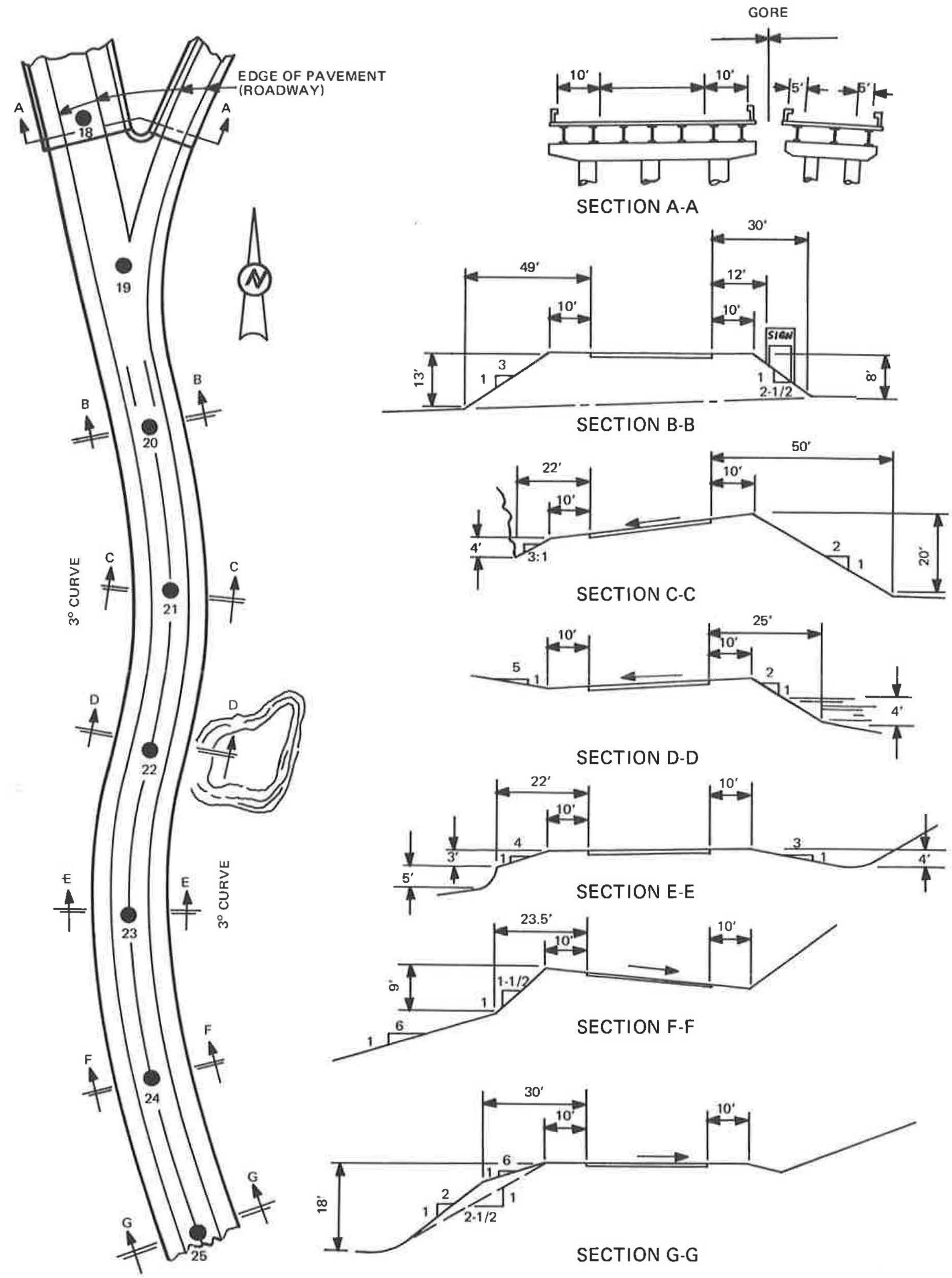


Figure A-1. Example roadway for determining warrants.

Section E-E

Southbound Shoulder

Step 1: Enter Figure 3 with $s = 4{:}1$ and $h = 3$ ft. Barrier is not warranted.

Step 2: Check hazards and roadside obstacles. $L = 22$ ft; dropoff depth is more than 2 ft. Barrier is warranted (Table 1).

Solution: Fill dropoff if practical.

Alternate: Barrier is warranted at dropoff, if left unchanged.

Northbound Shoulder

Step 1: Enter Figure 3 with $s = 3{:}1$ and $h = 4$ ft. Barrier is not warranted.

Step 2: The ditch cross section adjacent to the roadway has a curved transition.

Solution: Barrier is not warranted.

Section F-F

Southbound Shoulder

Step 1: Enter Figure 3 with $s = 1\frac{1}{2}{:}1$ and $h = 9$ ft. Barrier is warranted.

Solution: Flatten slope to tolerable dimensions.

Alternative: Place barrier if slope remains unchanged.

Northbound Shoulder

Step 1: Figure 3 is not applicable.

Step 2: The V-ditch formed by the shoulder and backslope intersection should be rounded (40-ft radius desirable).

Solution: Ditch should be rounded; barrier is not warranted.

Section G-G

Southbound Shoulder

Step 1: Enter Figure 3 with (average slope) $s = 2\frac{1}{2}{:}1$ and $h = 18$ ft. Barrier is not warranted.

Step 2: Check roadside obstacles and hazards: none. Barrier is not warranted.

Solution: Barrier is not warranted.

Northbound Shoulder

Solution: Provide a curved transition at the ditch. Barrier is not warranted.

To implement the results of the warranting procedure, a useful format for displaying these results is desirable. Figure A-2 shows a suggested format containing the warrant solutions for the example roadway. In this example format, embankment needs were checked at every station, and roadside obstacles and nontraversable hazards were checked as they occurred. Embankment and nontraversable hazard limits were arbitrarily terminated ½ station length on each side of the station where a barrier was warranted. Roadside obstacles, indicated in Figure A-2 by a "point of need," generally require shorter barrier installations.

It is extremely important to extend the barrier both upstream and downstream (two-way roadway) from the point of need so as to prevent vehicle access behind the installation. Short gaps between installations are undesirable.

MEDIAN BARRIERS

The warranting procedure for a divided highway is illustrated through application to the example roadway shown in Figure A-3. The treatment of the example sections points out that the outside shoulders of divided highways are always checked for embankment geometry, roadside obstacles, and hazards; inside shoulders (adjacent to the opposing roadway) are checked for barrier needs.

Section A-A

Westbound Roadway, Outside Shoulder

Step 1: Enter Figure 3 with $s = 2{:}1$ and $h = 26$ ft. Barrier is warranted.

Solution: Flatten slope to tolerable limits.

Alternative: Place barrier if slope remains unchanged.

Westbound Roadway, Inside Shoulder

Step 1: Check Figure 6 for barrier need. Median width is greater than 50 ft. Barrier is not warranted.

Step 2: Enter Figure 3 with $s = 7{:}1$ and $h = 3$ ft. Barrier is not warranted.

Step 3: Check for hazards and roadside obstacles. Drainage ditch should have rounded invert (40-ft radius is desirable). Barrier is not warranted.

Solution: Provide a smooth ditch invert. Barrier is not warranted.

Eastbound Roadway, Inside Shoulder

The median warrants have been checked previously; proceed to barrier warrants.

Step 1: Enter Figure 3 with $s = 2{:}1$ and $h = 18$ ft. Barrier is warranted.

Solution: Place barrier on shoulder (check for special treatment of System G4).

Eastbound Roadway, Outside Shoulder

The backfill and embankment slopes intersect to form a V-ditch. The embankment slope is relatively flat and a curved transition should be provided at the ditch. Barrier is not warranted.

Solution: Round the ditch invert. Barrier is not warranted.

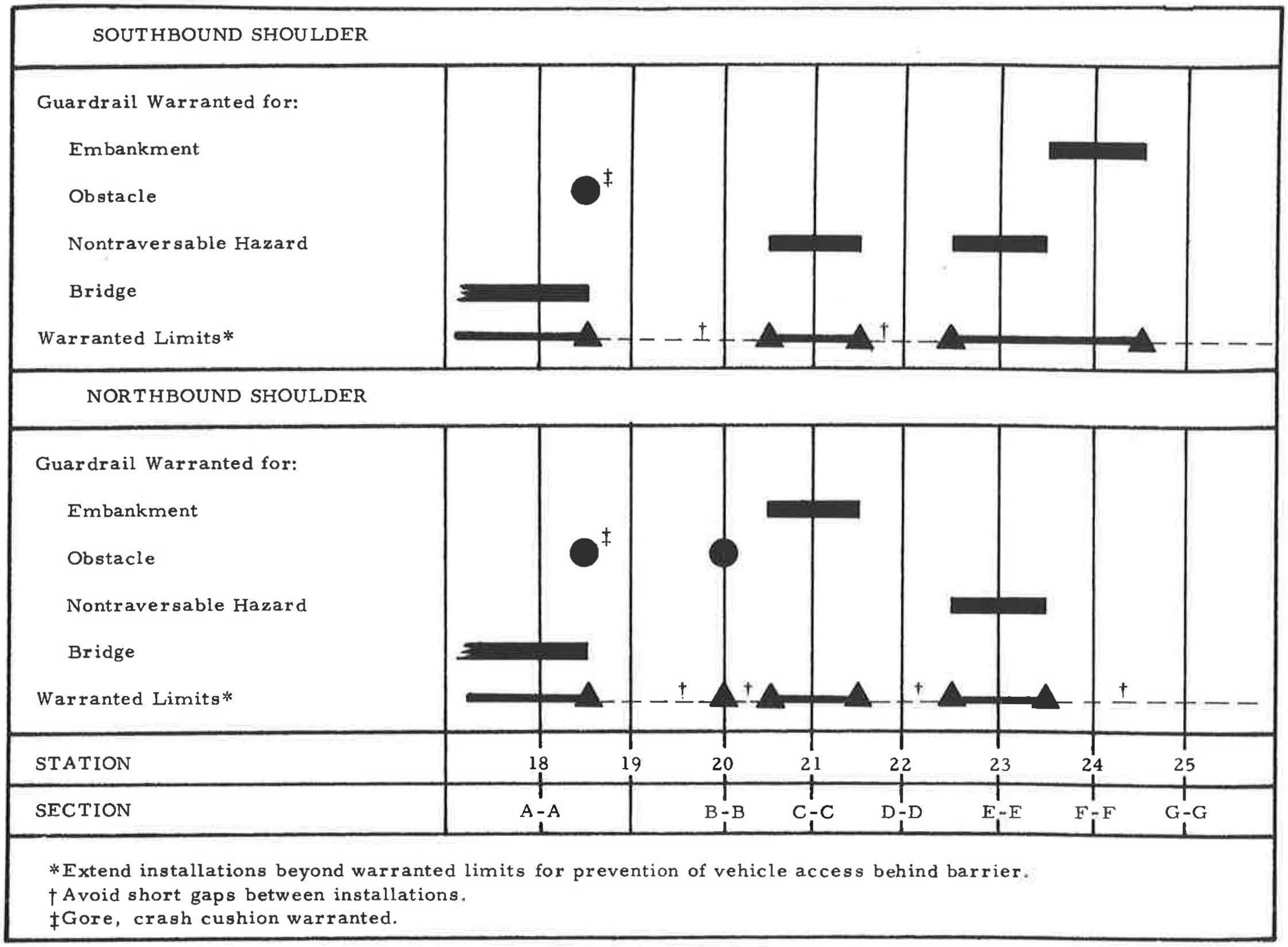


Figure A-2. Suggested format for summarizing results of warranting procedure.

Section B-B

Westbound Roadway, Outside Shoulder

Step 1: Enter Figure 3 with $s = 6{:}1$ and $h = 20$ ft. Barrier is not warranted.

Step 2: Check roadside obstacles and hazards: none. Barrier is not warranted.

Solution: Barrier is not warranted.

Westbound Roadway, Inside Shoulder

Step 1: Check barrier requirements (Fig. 6). Median width = 15 ft; ADT = 25,000. Barrier is warranted.

Solution: Install barrier.

Eastbound Roadway, Inside Shoulder

Solution: Barrier placement is previously warranted.

Eastbound Roadway, Outside Shoulder

The drainage ditch adjacent to this lane has a rounded invert.

Solution: Barrier is not warranted.

The warranted limits for barrier placements are indicated in Figure A-3. In this case the barrier installations in the median were extended beyond the lengths of need to form a continuous installation and thus eliminate a short gap.

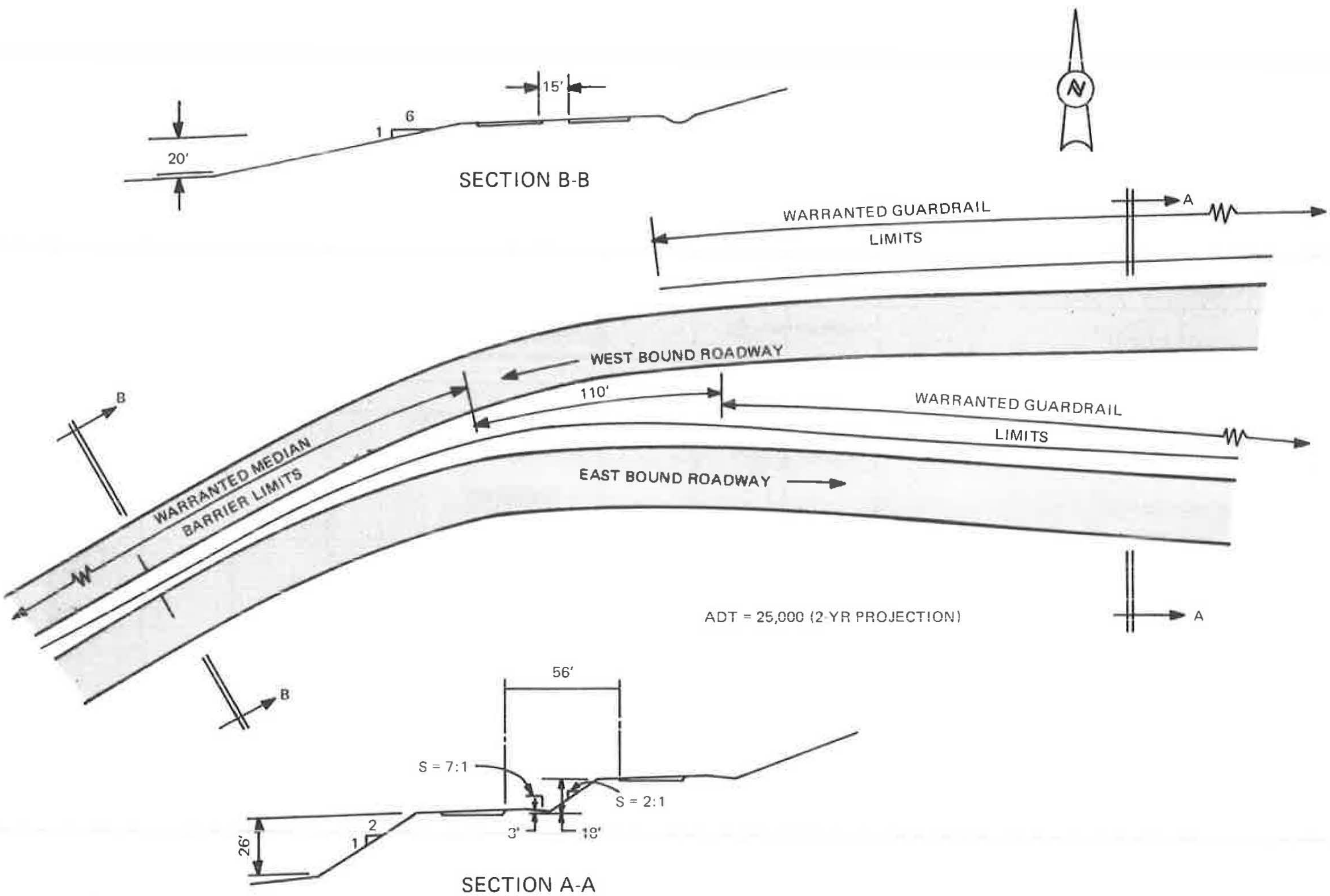


Figure A-3. Example divided highway for determining warrants.

APPENDIX B

TRAFFIC BARRIER INSTALLATION PRIORITY SEQUENCE

The embankment warranting procedure of Chapter Two determines where traffic barrier installations are required for the purpose of minimizing accident severity. The procedure is primarily applicable to new systems with high traffic volume.

Most existing highways require extensive funding and manpower to bring their barrier systems into conformance with the recommendations of this report. The enormity of the barrier upgrading task necessitates that the effort be performed on a priority basis. Obviously, those highway sites with adverse accident records or with the highest accident occurrence potential should be identified and upgraded first. The sequencing procedure of this appendix establishes a numerical rating index for each warranted embankment traffic barrier installation site—the larger the rating index, the greater the priority of barrier need. *This procedure does not apply to barriers warranted by roadside obstacles or hazards.*

Figure B-1 shows three basic need index curves having values of 50, 60, and 70. The "50" curve is identical to that of Figure 3. A basic need index, *N*, is determined by entering Figure B-1 with embankment height and slope, and interpolating between curves if necessary. For points below the "50" curve, no barrier is warranted for embankment conditions; thus, this procedure is not applicable. For $N \geqq 50$, the basic need index number is multiplied by a composite adjustment factor, A_T (which reflects accident frequency potential), to determine the priority number, R. That is,

$$R = N A_T \tag{B-1}$$

in which

R = the barrier site priority number;

N = the basic need index number; and

A_T = a composite adjustment factor based on ran-off-the-road accident frequency potential.

The value of A_T is determined by

$$A_T = A_1 A_2 A_3 A_4 A_5 \tag{B-2}$$

in which

A_1 = a factor based on shoulder width;

A_2 = a factor based on horizontal curvature;

A_3 = a factor based on downgrade or profile conditions;

A_4 = a factor based on climatic conditions; and

A_5 = a factor based on traffic volume.

Values for A_1 through A_5 are selected from Table B-1.

Scheduling of barrier installations is determined by engineering judgment based on rank order of all priority numbers for the highway, consistent with manpower funding, until all critical embankments ($N \geqq 50$) have been protected. Practical considerations will usually result in scheduling installations of reasonable proximity rather than blindly following the rank order.

NOTE: *Before any traffic barrier is installed, a site examination should verify that flattening the embankment slope is not feasible.*

The procedure is as follows:

Step 1: Examine the embankment geometry according to Chapter Two. This priority procedure is applicable only if embankment barrier is warranted.
Step 2: Determine the basic need index from Figure B-1.
Step 3: Select the appropriate accident frequency potential factors from Table B-1 and compute A_T by Eq. B-2.
Step 4: Compute the barrier site priority number, R, by Eq. B-1.
Step 5: Tabulate the priority numbers for the highway.
Step 6: Schedule embankment barrier installations according to the previous discussion.

ILLUSTRATIVE PROBLEM

Illustrative problem solutions based on the example roadway shown in Figure B-2 are as follows:

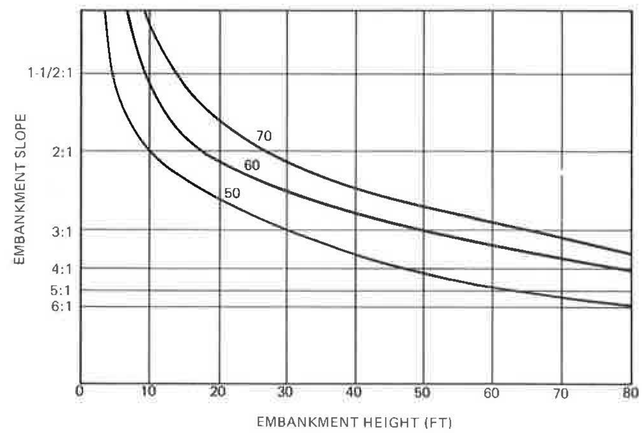


Figure B-1. Basic need index curves.

Section A-A

Southbound Shoulder

Step 1: Enter Figure 3 with $s = 2{:}1$ and $h = 13$ ft. Embankment barrier is warranted.
Step 2: Check for roadside hazards and obstacles (Chapter Two): none.
Step 3: Enter Figure B-1 with $s = 2{:}1$ and $h = 13$ ft. Basic need index, $N = 55$.
Step 4: Determine accident frequency potential factors and compute A_T from Table B-1.

Shoulder width = 10 ft	$A_1 = 1.05$
No curve	$A_2 = 1.00$
No grade	$A_3 = 1.00$
Severe freezing and thawing	$A_4 = 1.15$
Traffic volume: ADT = 4,000	$A_5 = 1.40$

$A_T = 1.05 \times 1.00 \times 1.00 \times 1.15 \times 1.40 = 1.69$

Step 5: Compute priority number, $R = N A_T = 55 \times 1.69 = 93$.

Northbound Shoulder

Step 1: Enter Figure 3 with $s = 2\frac{1}{2}{:}1$, and $h = 8$ ft. Embankment barrier is not warranted: Appendix B is not applicable.
Step 2: Check roadside obstacles, ditches, etc. Sign supports are W8 × 6.5 steel sections. Use Table 3.

Solution: Barrier is warranted. Remove sign from 30-ft zone or install breakaway base.

Alternative: If sign is not removed or modified, place barrier at sign.

Section B-B

Southbound Shoulder

Step 1: Figure 3 is not applicable.
Step 2: Check rough rock cut, Table 3. $L = 22$ ft.

Solution: Barrier is warranted at rough rock cut.

TABLE B-1

ACCIDENT FREQUENCY POTENTIAL FACTORS

Factor		Value
A_1	Shoulder width, overall (ft):	
	12 or more	1.00
	10	1.05
	8	1.10
	6 or less	1.15
A_2	Horizontal curvature:	
	Tangent or flat curve ($D < 1°$)	1.00
	Intermediate curve ($1° \leq D \leq 10°$)	1.05
	Isolated intermediate curve, or curves over 10°	1.10
A_3	Downgrade or profile conditions:	
	2% or less	1.00
	3% to 4%, or moderate crest V.C. in combination with horizontal curve	1.10
	5% or more, or extreme crest V.C. in combination with horizontal curve	1.20
A_4	Climatic conditions*:	
	Freezing and thawing:	
	Little to none	1.00
	Moderate	1.04
	Severe	1.15
	Fog prevalent	1.10
A_5	Traffic volume:	
	V = Average daily traffic	$1 + \frac{V}{10,000}$

*Use only one factor (either freezing and thawing or fog).

Northbound Shoulder

Step 1: Enter Figure 3 with $s = 2:1$ and $h = 20$ ft. Barrier is warranted.

Step 2: No obstacles or hazards present.

Step 3: Enter Figure B-1 with $s = 2:1$ and $h = 20$ ft. Basic need index, $N = 63$.

Step 4: Determine accident frequency potential factors and compute A_T from Table B-1.

Shoulder width = 10 ft	$A_1 = 1.05$
Outside curve, intermediate curve	$A_2 = 1.05$
No grade	$A_3 = 1.00$
Severe freezing and thawing	$A_4 = 1.15$
ADT = 4,000	$A_5 = 1.40$

$A_T = 1.05 \times 1.05 \times 1.00 \times 1.15 \times 1.4 = 1.77.$

Step 5: Compute barrier site priority number, $R = N\,A_T = 63 \times 1.77 = 112$.

Section C-C

Southbound Shoulder

Step 1: Enter Figure 3 with $s = 2:1$ and $h = 9$ ft. Barrier is not warranted.

Step 2: Check for roadside hazards and obstacles: none.

Solution: Barrier is not warranted.

Northbound Shoulder

Step 1: Figure 3 is not applicable, as water hazard is clearly present.

Step 2: From Table 1: $L = 25$ ft, depth of water greater than 2 ft.

Solution: Barrier is warranted at the pond.

Section D-D

Southbound Shoulder

Step 1: Enter Figure 3 with $s = 4:1$ and $h = 3$ ft. Barrier is not warranted.

Step 2: Check dropoff, Table 1. $L = 22$ ft, depth greater than 2 ft.

Solution: Fill dropoff if practical.

Alternative: Barrier is warranted at the dropoff.

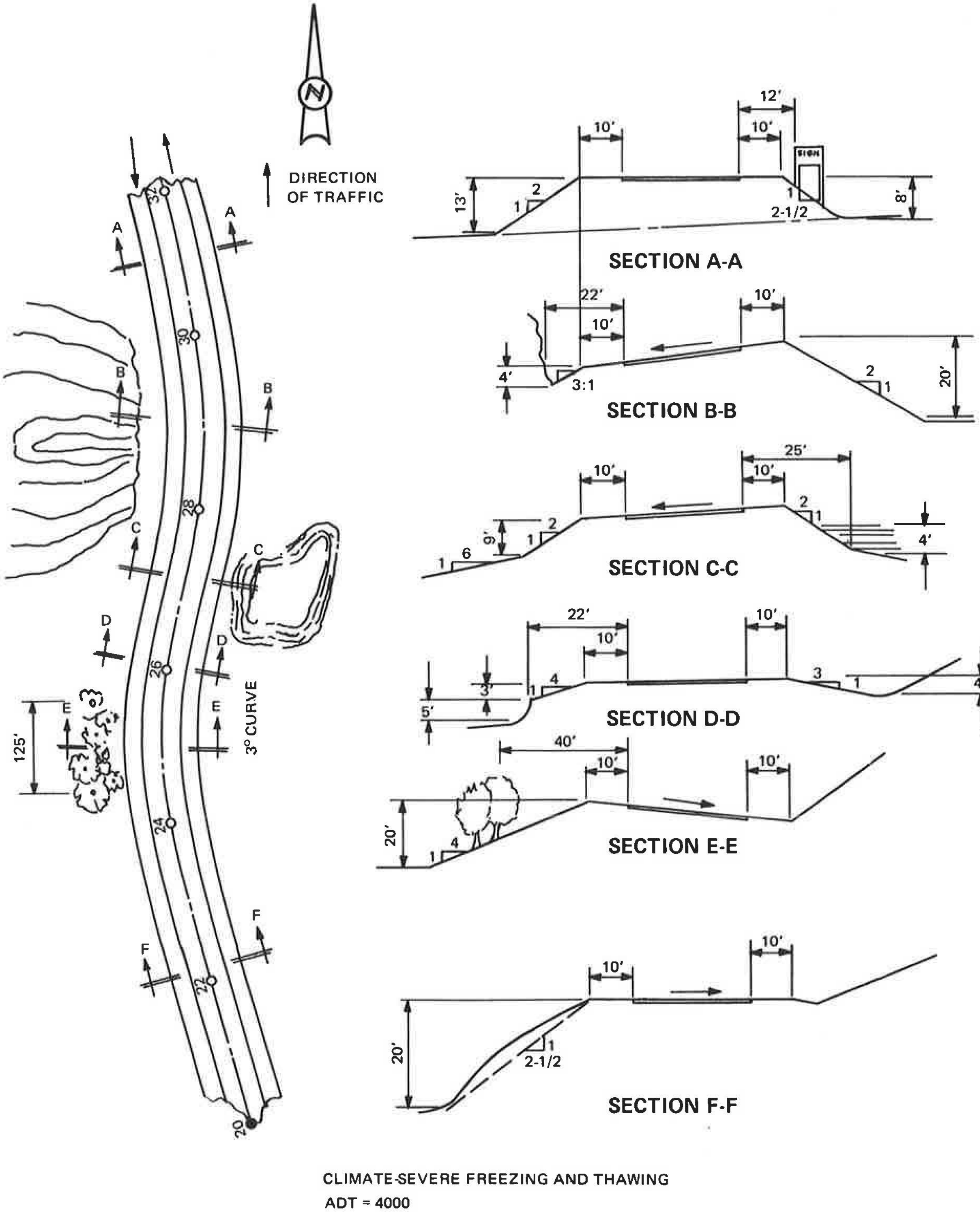


Figure B-2. Example roadway for determining installation priorities.

Northbound Shoulder

Step 1: Enter Figure 3 with $s = 3{:}1$ and $h = 4$ ft. Barrier is not warranted.

Step 2: No hazards or obstacles present. The slope transition is rounded as recommended.

Solution: Barrier is not warranted.

Section E-E

Southbound Shoulder

Step 1: Enter Figure 3 with $s = 4{:}1$ and $h = 20$ ft. Barrier is not warranted.

Step 2: Check line of trees, Table 3; $L = 40$ ft, tree diameter greater than 6 in. Although this line of trees is out of the established 30-ft zone of Table 1, the extent of this line of trees along the roadway is an example of how judgment should be exercised in determining needs. From Figure 4, it is noted that about 13 percent of the vehicles in this study would have reached this line of trees traveling on relatively level grade. The grade at this line of trees is 4:1.

Solution: Remove trees.

Alternative: Barrier may be installed at line of trees.

Northbound Shoulder

Step 1: Figure 3 is not applicable.
Step 2: The V-ditch formed by the shoulder and backslope intersection should be rounded.

Solution: Ditch should be rounded. Barrier is not warranted.

Section F-F

Southbound Shoulder

Step 1: Enter Figure 3 with $s = 2\frac{1}{2}:1$ and $h = 20$ ft. Barrier is warranted.

Step 2: No hazards or obstacles present.
Step 3: Enter Figure B-1 with $s = 2\frac{1}{2}:1$ and $h = 20$ ft; $N = 51$.
Step 4: Compute A_T from Table B-1:

Shoulder width = 10 ft	$A_1 = 1.05$
No curve	$A_2 = 1.00$
No grade	$A_3 = 1.00$
Severe freezing and thawing	$A_4 = 1.15$
ADT = 4,000	$A_5 = 1.40$

$A_T = 1.05 \times 1.00 \times 1.00 \times 1.15 \times 1.40 = 1.69$

Step 5: $R = N\,A_T = 51 \times 1.69 = 86.$

Northbound Shoulder

Solution: Provide curved transition at ditch. Barrier is not warranted.

The barrier need and the sequence of installation for the illustrative problem are summarized in Table B-2, establishing barrier placement limits. It should be remembered that Chapter Five calls for extension of each guardrail installation beyond the theoretical limits established by warrants.

TABLE B-2

BARRIER INSTALLATION SEQUENCE SUMMARY

Roadway* Section	Shoulder	Barrier Warranted	Priority Number	Installation Sequence†
A-A	Southbound	Yes	93	3
	Northbound	Yes	NA	1
B-B	Southbound	Yes	NA	1
	Northbound	Yes	112	2
C-C	Southbound	No		
	Northbound	Yes	NA	1
D-D	Southbound	No		
	Northbound	Yes	NA	1
E-E	Southbound	Yes	NA	1
	Northbound	No		
F-F	Southbound	Yes	86	4
	Northbound	No		

*See Figure B-2.
†Barrier warranted by roadside obstacles and nontraversable hazards installed first; barrier warranted by embankment installed according to sequence number.

APPENDIX C

INSTALLATION LAYOUT DETAILS FOR LONGITUDINAL BARRIERS

Layout details are presented in this appendix. They represent state-of-the-art engineering judgment and highway experience. This information supplements the design details of barrier systems contained in Appendix D.

UNIFORM CLEARANCE

As shown in Figure C-1, a desirable feature of highway design is its uniform clearance to all roadside elements (*4*). These basic elements—parapet, retaining wall, abutment, barrier—should be in line to prevent vehicle snagging. Shoulder width should be constant whether the highway is in cut, on fill, or on structure.

SHOULDER REQUIREMENTS

Barrier installations should be located a maximum distance from the pavement edge, with due consideration given to system deflection, shoulder terrain, and the aforementioned uniform clearance. For optimum performance, the surface in front of the barrier should be level; in special instances where a barrier must be located on an embankment downslope, the barrier height should be adjusted by the procedure presented under "Barriers in Stepped Medians." If the barrier installation is located near the embankment hinge point or the downslope, provisions should be made to compensate for loss of post embedment support (e.g., use longer posts or provide soil mound behind post).

Ideally, the preferred position of any curb is behind the installation. If the curb must be in front of the installation, it should be of the low mountable type.

INSTALLATION LENGTH

Installations should be extended upstream from the warranted limits to prevent vehicle access behind the protective system. It is not necessary to extend the installation downstream past the hazard on highways with one-way traffic. A method to establish the length-of-need of the installation is based on a 400-ft (*6*) encroachment distance; the length-of-need is calculated by

$$L = (1 - A/B)400 \qquad \text{(C-1)}$$

where the terms are defined in Figure C-2. As an example, for an installation to be located 12 ft from the pavement edge shielding a hazard that is 22 ft from the pavement edge, the length-of-need is $L = (1 - 12/22)400 = 180$ ft. Terminals' lengths are added to the length-of-need.

Short barrier installations should be avoided; they are often more hazardous than no section at all. To eliminate short lengths, flattening of critical portions of embankments should be considered (Fig. C-3). Short gaps between installations should be avoided.

GUARDRAIL LAYOUT ON FILL AND FILL-TO-CUT SECTIONS

The layout shown in Figure C-4A is inadequate because the barrier is too short and has improper end treatment. The recommended layout of a barrier on fill is shown in Figure C-4B.

The layout shown in Figure C-5A is inadequate because the barrier is too short and has improper end treatment. The recommended layout of a barrier on a fill-to-cut section is shown in Figure C-5B, an example of recommended end treatment of barrier.

END TREATMENTS

Both field performance and full-scale crash tests have demonstrated that end treatments of guardrails and median barriers represent the most hazardous part of an installation (*39*). End treatment designs presented in Appendix D develop structural strength of the barrier systems and prevent spearing of the car (a possible occurrence with the old unanchored blunt end). The ramped designs prevent this spearing tendency; however, vehicle impacts within these sections have resulted in rollover. Until improved terminal designs are developed, the highway engineer can minimize end treatment hazard by:

1. Terminating the installation at a natural roadside feature, such as a cut embankment (see Appendix D, Sheet 4, Guardrail in Cut detail).
2. Flaring the installation, including the length-of-need, so that the upstream terminal is away from the pavement edge (see Appendix D, Sheet 3, Type 7 Flare). This may require widening the highway shoulder to accommodate the flare.
3. Eliminating a barrier installation where the warranting feature (i.e., embankment slope, roadside fixed object, etc.) can be feasibly modified or removed.

GENERAL TREATMENT AT STRUCTURES

The installation must be attached to the guarded structure so that adequate strength of the system is developed. Recommended methods are shown in Appendix D. Any roadway narrowing transition should be gradual—15 to 20 ft longitudinally per foot of width reduction. To effect a smooth transition in rigidity, the post spacing should be graduated from the structure end, as shown in the barrier system details.

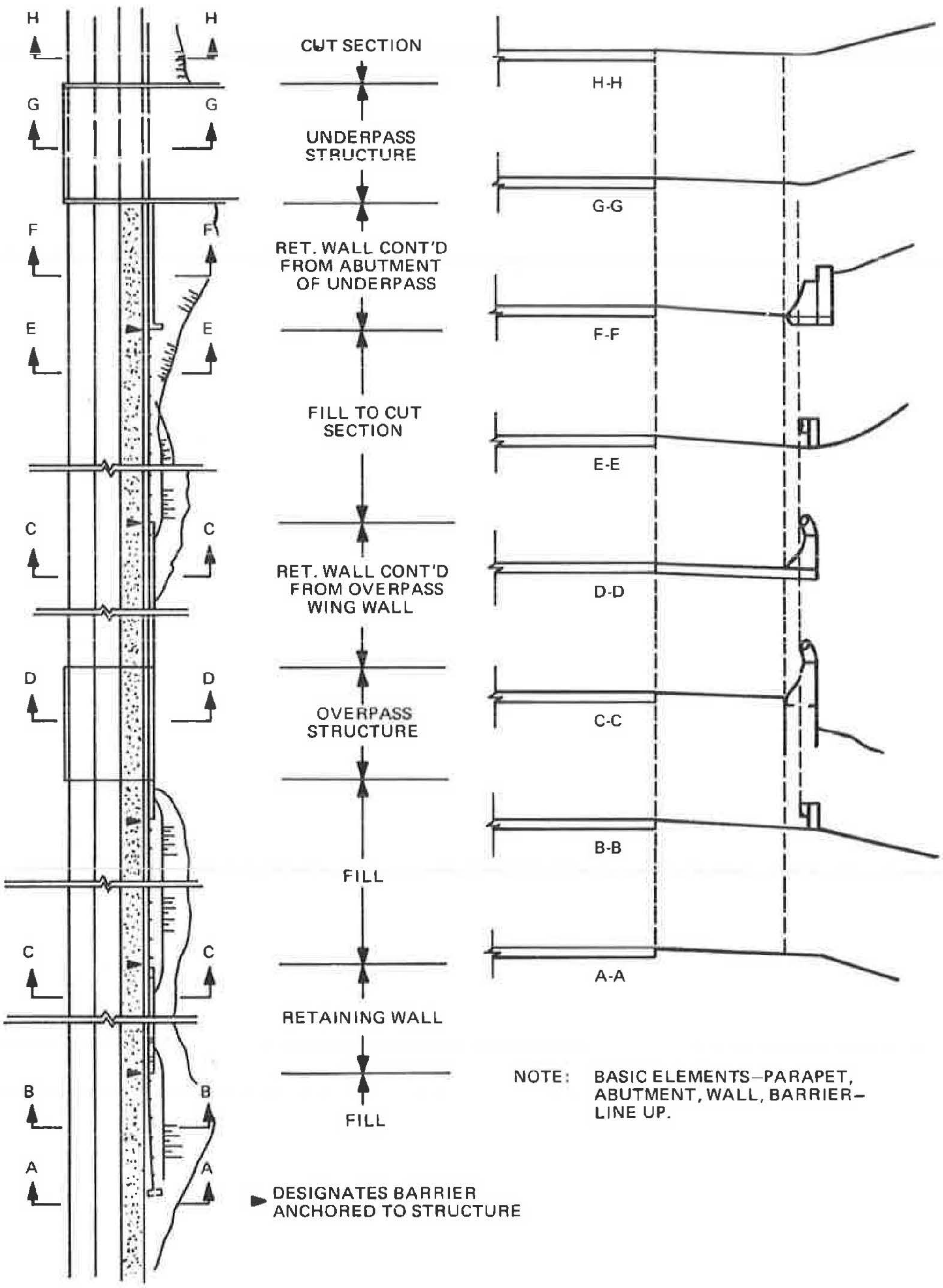


Figure C-1. Uniform shoulder treatment and uniform clearance to roadside elements.

CENTER TREATMENT AT OVERPASSES

Recommended treatments in the median at overpasses are illustrated in the barrier system details (Appendix D). Consideration should be given to widening the bridge decks to close the opening between twin bridges.

CENTER TREATMENT AT UNDERPASSES

Recommended treatments at underpasses are depicted in the barrier system details (Appendix D). A recommended treatment for concrete median barrier at underpass piers is shown in Figure C-6.

TREATMENT AT HIGHWAY APPURTENANCES

Short installations around light standards, signs, and gore areas, as shown in Figure C-7, are not recommended because they increase accident frequency, seldom decrease accident severity, and frequently cost more than modification or relocation of the appurtenance. Serious considera-

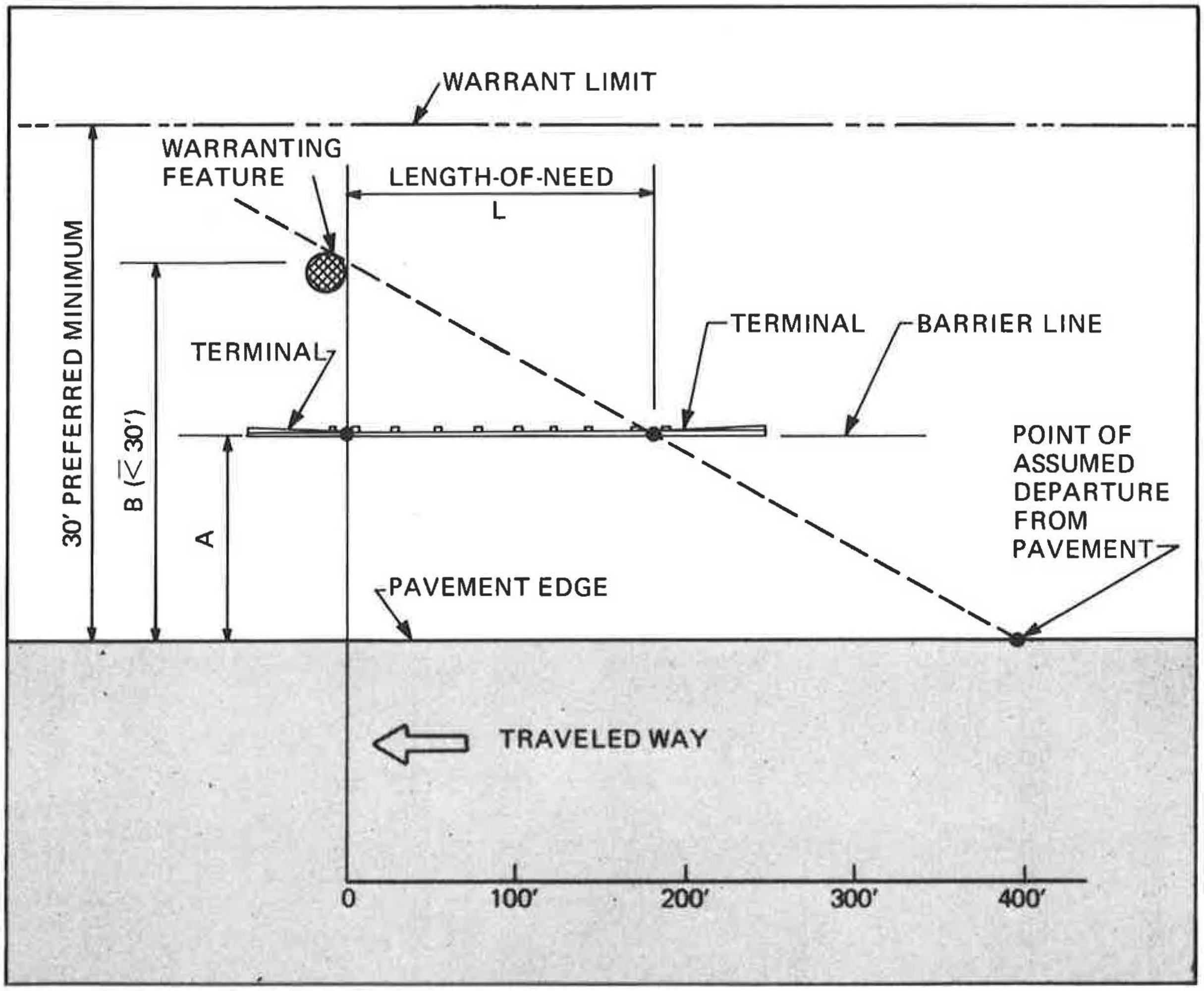


Figure C-2. Barrier length-of-need determination.

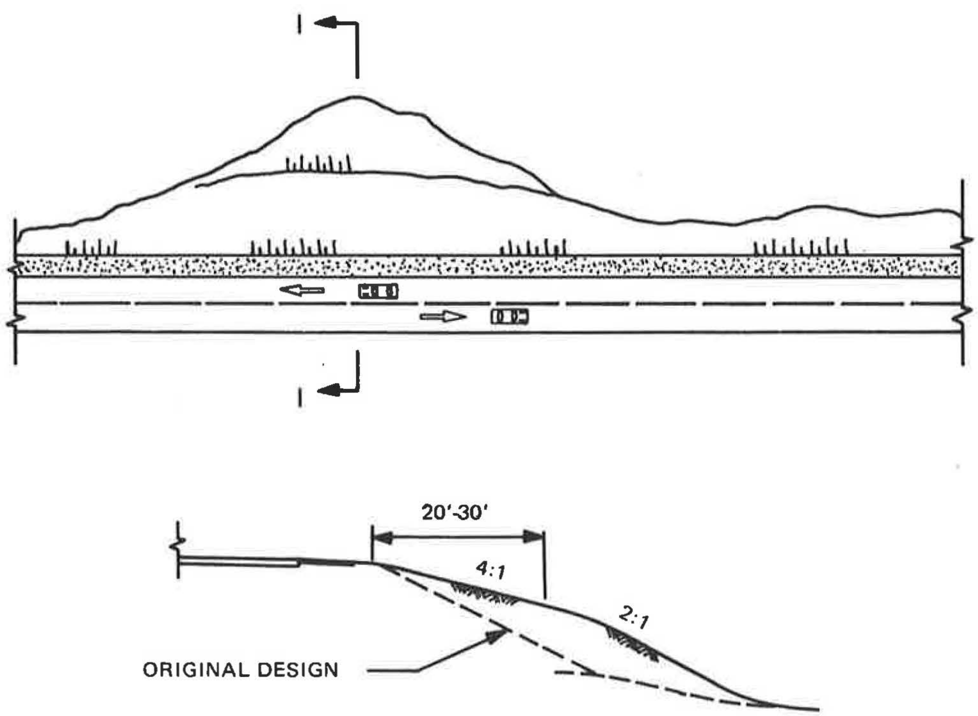


Figure C-3. Elimination of shoulder barrier by partial flattening of fill slope.

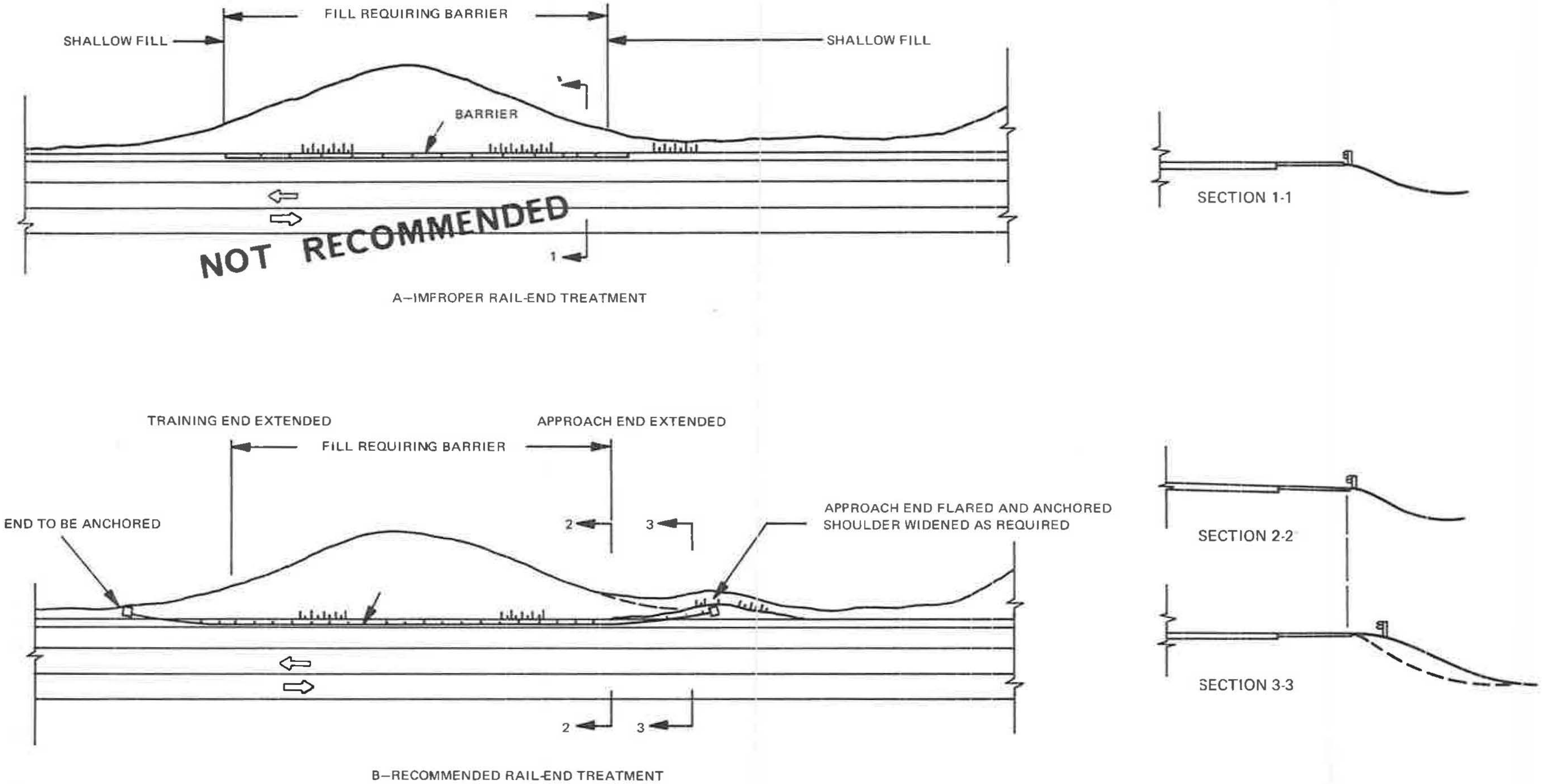


Figure C-4. Barrier terminal treatment for roadside fill condition.

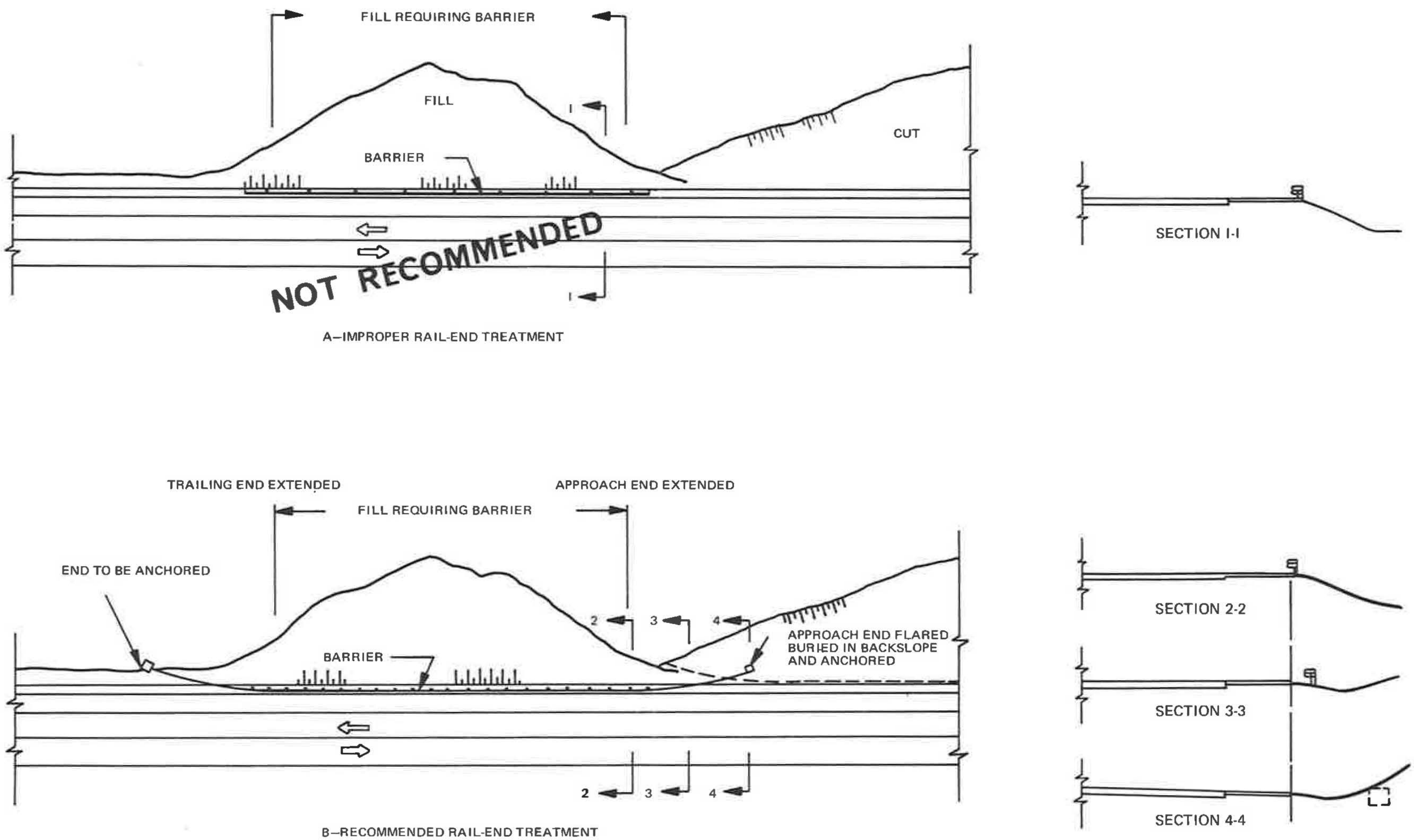


Figure C-5. Barrier terminal treatment for roadside fill-to-cut condition.

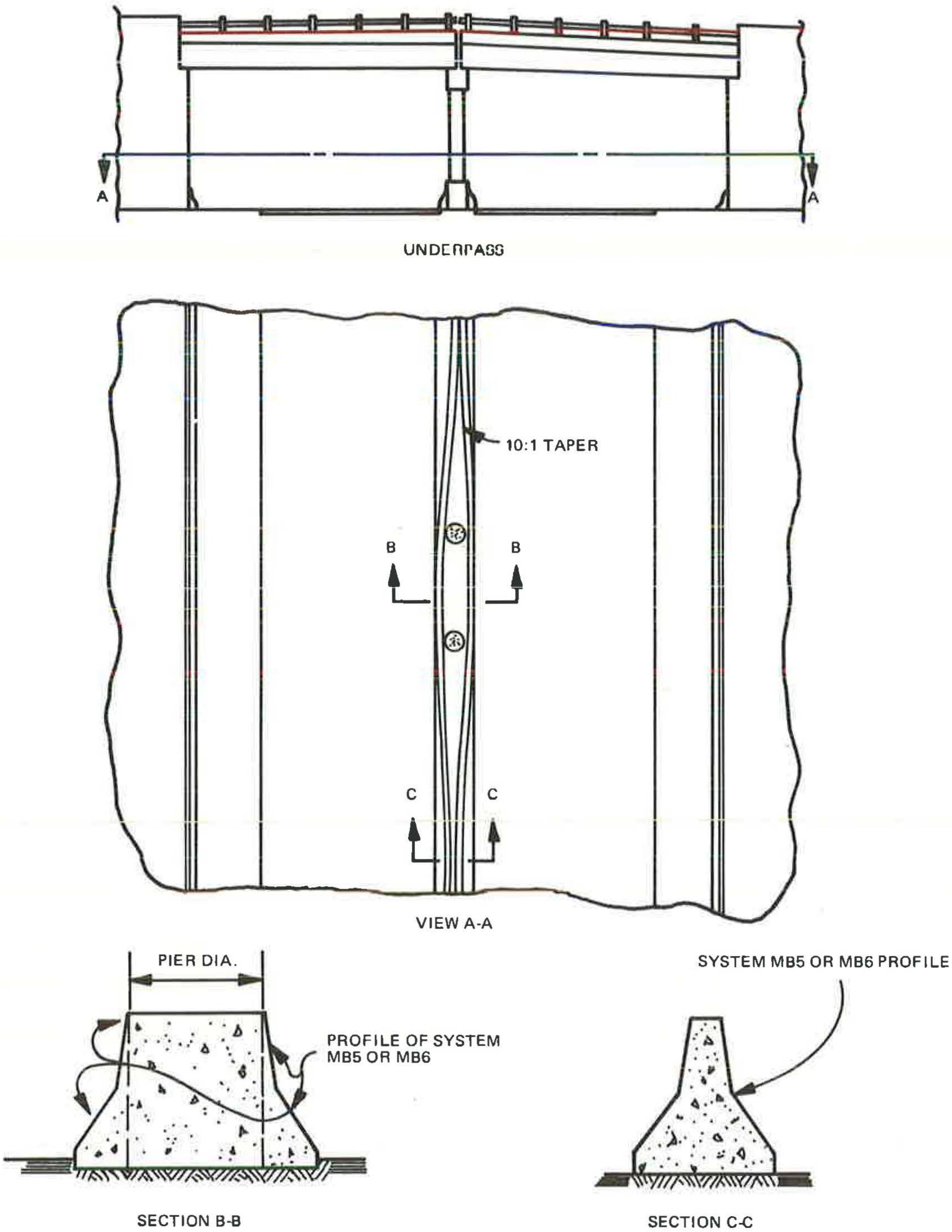


Figure C-6. Example of concrete median barrier treatment at underpass piers.

tion should be given to relocating the appurtenance or utilizing breakaway construction with no barrier. For large signs, bridge abutments, large trees, and other roadside obstacles, examples of barrier installations are shown in Appendix D.

Several techniques for using a concrete barrier profile are shown in Figure C-8. The profile can be incorporated in the base of a retaining wall or at a rough rock cut. A concrete parapet (with a MB5 or MB6 profile) providing a transition into a bridge rail is shown in Figure C-8(c).

TRANSITION BETWEEN SYSTEMS

The transition from one type to another should be smooth, with a graduated stiffness. Flexible systems should not be directly connected to rigid systems; a length of semirigid

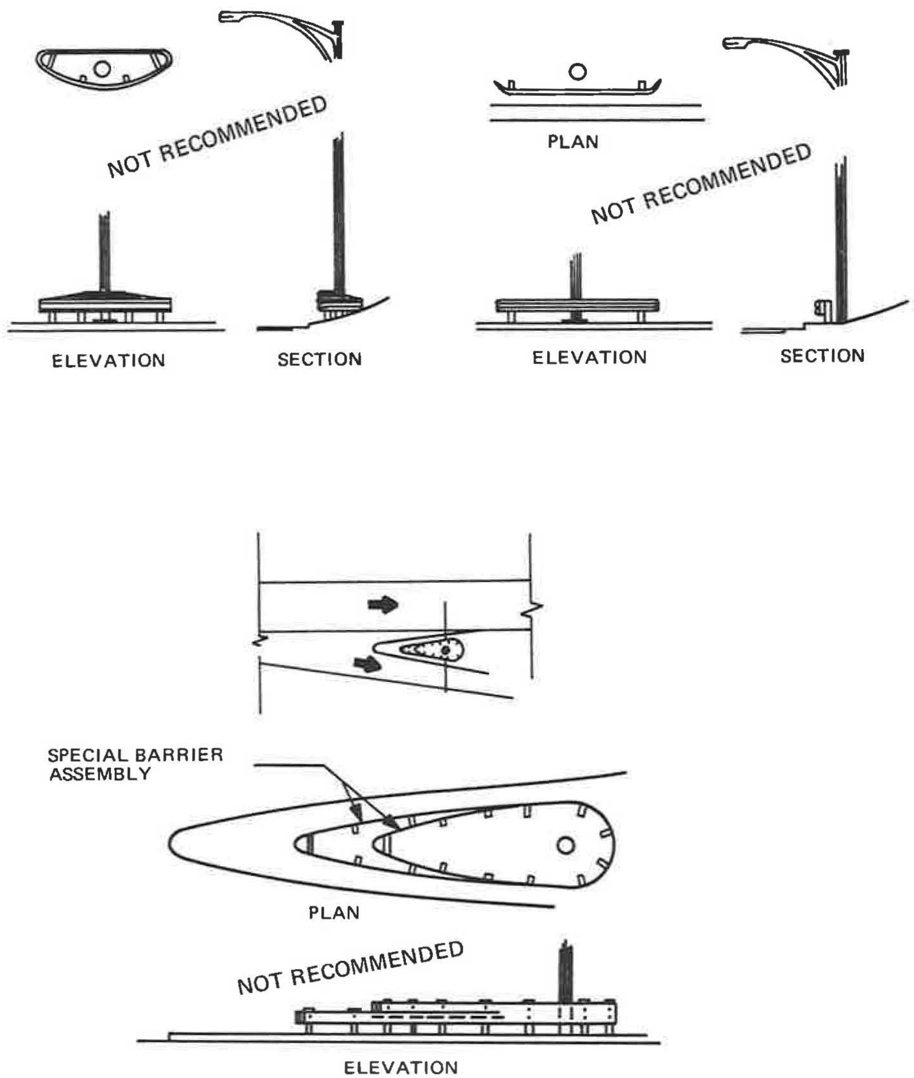


Figure C-7. Examples of poor practice.

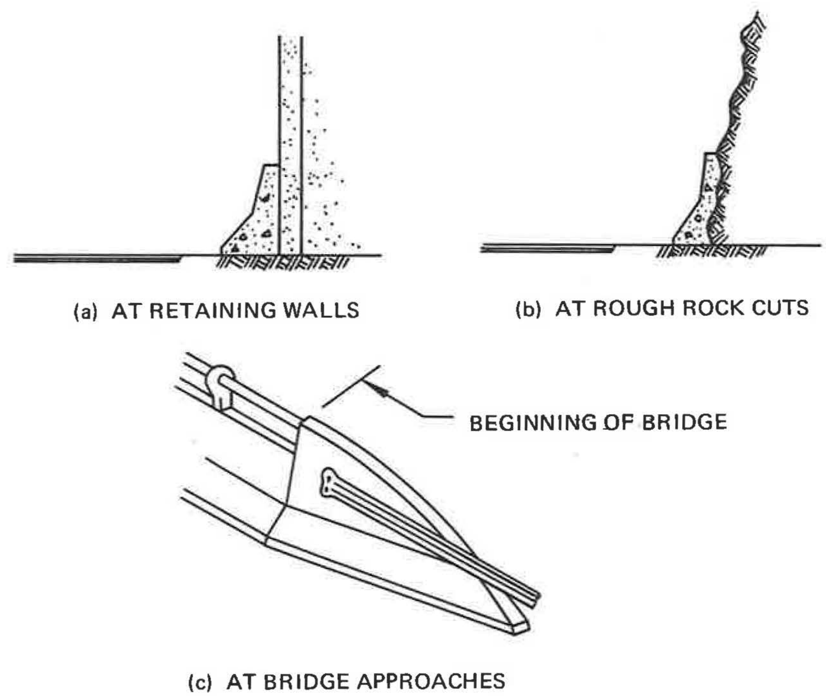
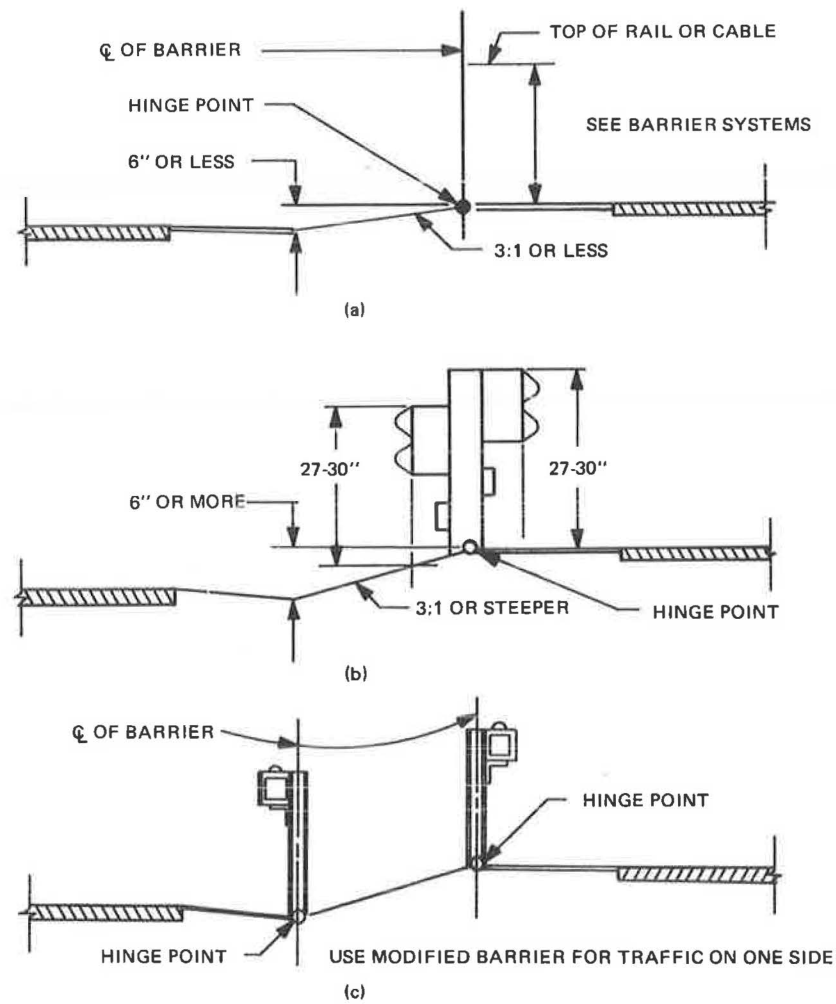


Figure C-8. Examples of concrete guardrail applications.



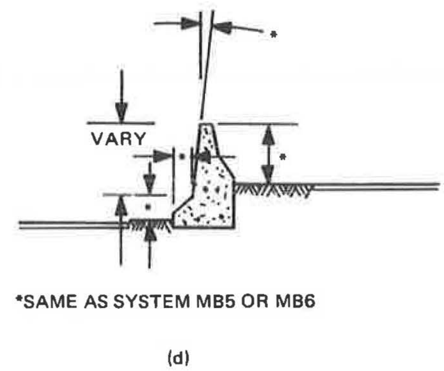


Figure C-9. Barriers for stepped medians.

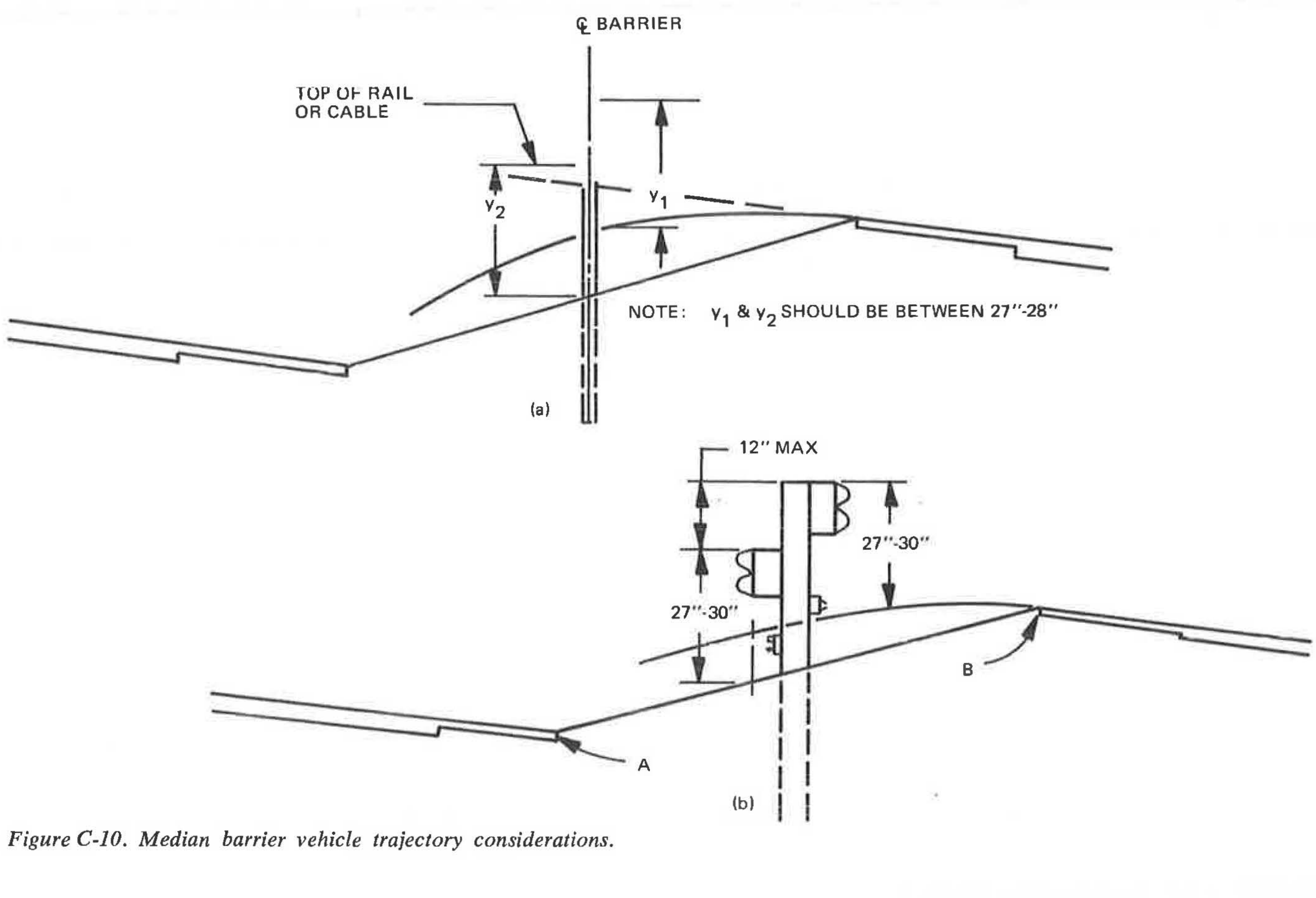


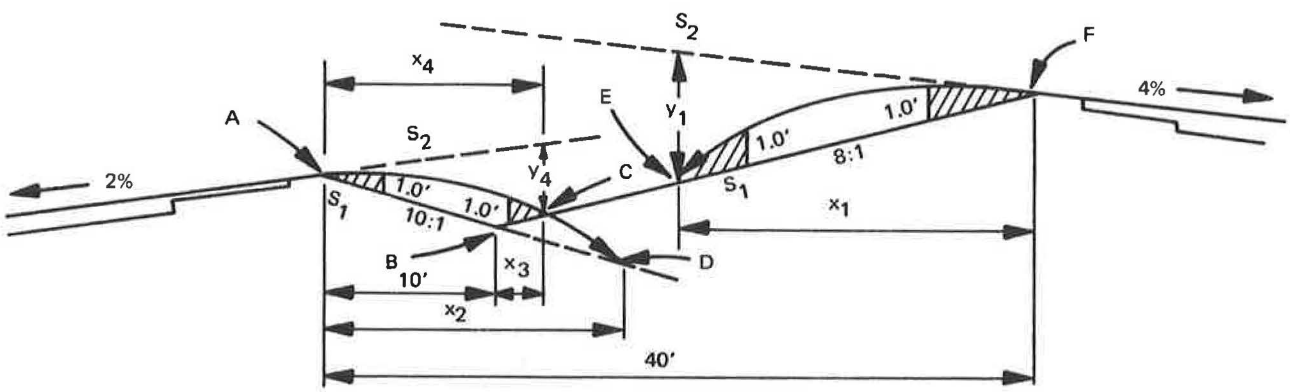
Figure C-10. Median barrier vehicle trajectory considerations.

section with graduated post spacing will produce an effective stiffness transition. Recommended transitions are shown in Appendix D.

BARRIERS IN STEPPED MEDIANS

Full-scale tests show that the height of the rail or cable is critical. The barrier type and its location in a stepped median are determined by considering vehicle trajectory. When a median slope is flatter than 3:1 and/or height is less than 6 in., as shown in Figure C-9(a), any barrier type satisfying the deflection criteria can be used if it is placed at the higher shoulder hinge point, as shown. If these slope or height conditions are exceeded, use the blocked-out W-beam barrier (System MB4) shown in Figure C-9(b) or a double row of guardrails at the hinge points as shown in Figure C-9(c). If a narrow median is stepped, a concrete median barrier can be used, as shown in Figure C-9(d). If a barrier location is desired other than at the upper shoulder hinge point, the barrier type and location are also determined by vehicle trajectory, as shown in Figures C-10 and C-11. Plotted vehicle trajectories are depicted in Figure C-12.

It should be emphasized that, ideally, the approaches to median barriers should be relatively level from both sides; however, it is recognized that situations occur (e.g., widening of existing roadways) for which a stepped median is unavoidable. The designer can use the work presented as a check for determining proper rail or cable height for these situations.



$y = 1/2at^2 = 16.1t^2$

$t = x/44$ ft/sec (based on 30° angle of attack at 60 mph)

Substituting,

$$y = 0.0083\,x^2 \quad \text{(Eq. A)}$$

Also,

$$y = x\,(S_1 - S_2) \quad \text{(Eq. B)}$$

Substituting, $x\,(S_1 - S_2) = 0.0083\,x^2$

Therefore,

$$x = (S_1 - S_2)/0.0083 \quad \text{(Eq. C)}$$

STEP 1. Determine where in the median the trajectory from the right roadway intercepts the ground.

Using Eq. C, $x_1 = [0.125 - (-0.04)]/0.0083$
$= 19.8$ ft.

(Barriers MB1, MB2, and MB3 cannot be installed between points E and F.)

STEP 2. Determine where in the median the trajectory from the left roadway intercepts the ground.

Using Eq. C, $x_2 = [0.02 - (-0.10)]/0.0083$
$= 14.5$ ft.

Because 14.5 ft is beyond point B (10 ft), an adjustment is necessary to determine the actual intercept with line BF.

Using Eq. A, $y_4 = 0.0083\,x_4^2$.

Also, from median geometry,

$y_4 = 0.10(10) - 0.125(x_3) + 0.02(x_4)$

and

$x_4 = 10 + x_3$

Substituting and simplifying, $0.0083\,x_4^2 + 0.105\,x_4 - 2.25 = 0$ and $x_4 = 11.2$ ft.

(Barriers MB1, MB2, and MB3 cannot be installed between points A and C.)

(Barriers MB1, MB2, and MB3 can be installed between points C and E only.)

STEP 3. If the trajectories overlap, MB1, MB2, and MB3 cannot be used. A blocked-out W-beam barrier (MB4) must be used.

STEP 4. If MB4 barrier is required, a staggered rail system as shown in Figure C-10 can be used in any area where both trajectories are no more than 1.0 ft above the ground (shaded area in above figure). The upper rail should be 27 to 30 in. above the trajectory at the rail, and the lower rail should be 30 in. above the ground at its rail. An alternative is to place a standard beam barrier at points A and F or between points C and E.

Figure C-11. Vehicle trajectory analysis procedure.

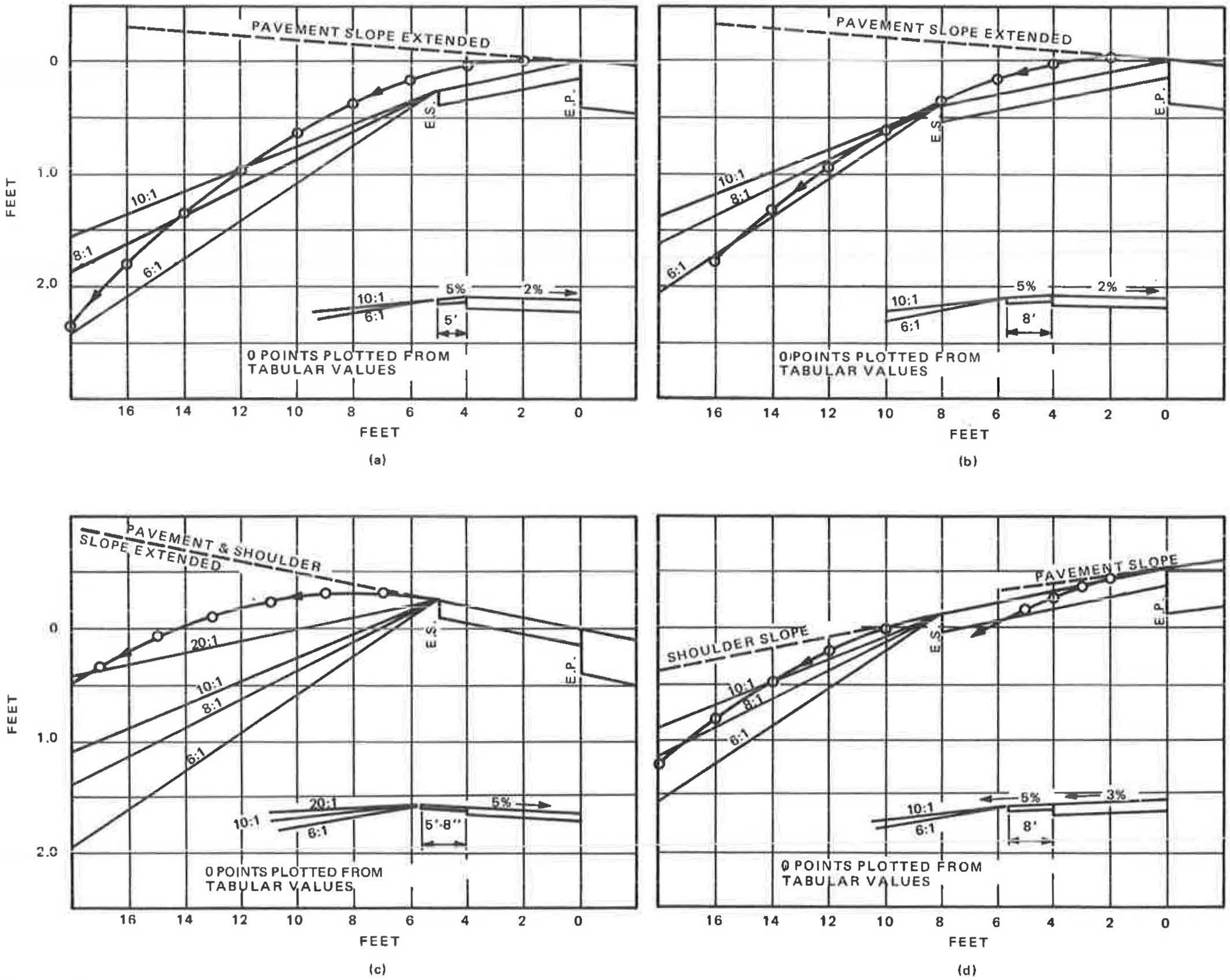


Figure C-12. Vehicle trajectory plots for stepped median.

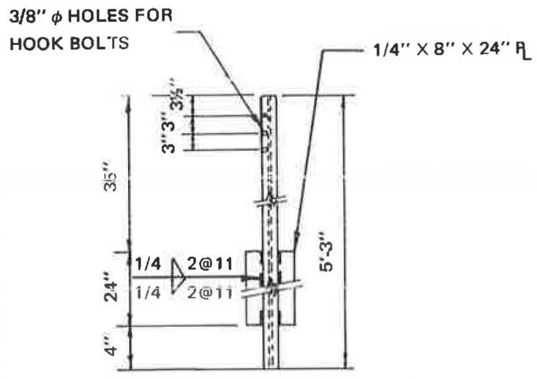
APPENDIX D

LONGITUDINAL BARRIER SYSTEMS

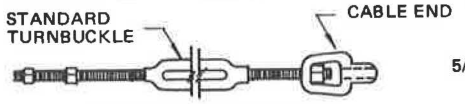
This appendix contains drawings of the operational systems as defined in Tables 6, 7, and 8 (Chapter Five).

No alterations should be made in these designs. Full-scale tests indicate that minor structural changes can affect barrier effectiveness.

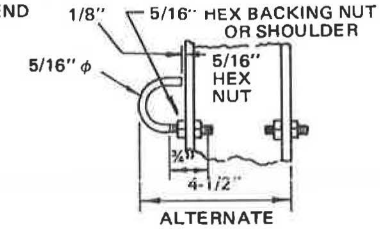
The following systems are included:



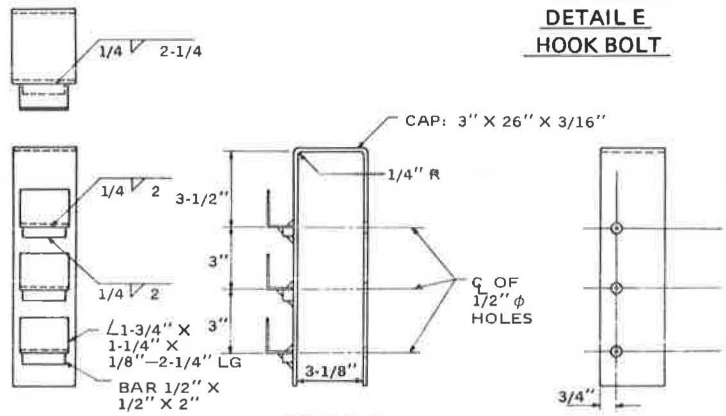
DETAIL A
INTERMEDIATE POST
S3 X 5.7



LOAD CAPACITY 25,000 LBS.
DETAIL D
STEEL TURNBUCKLE
CABLE END ASSEMBLY

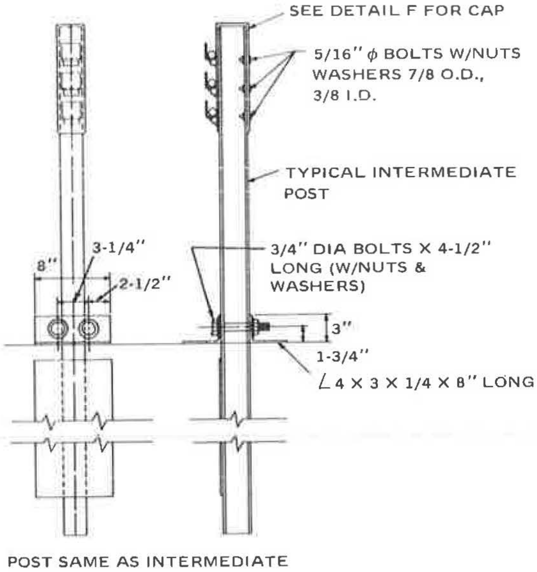


ALTERNATE
DETAIL E
HOOK BOLT



DETAIL F

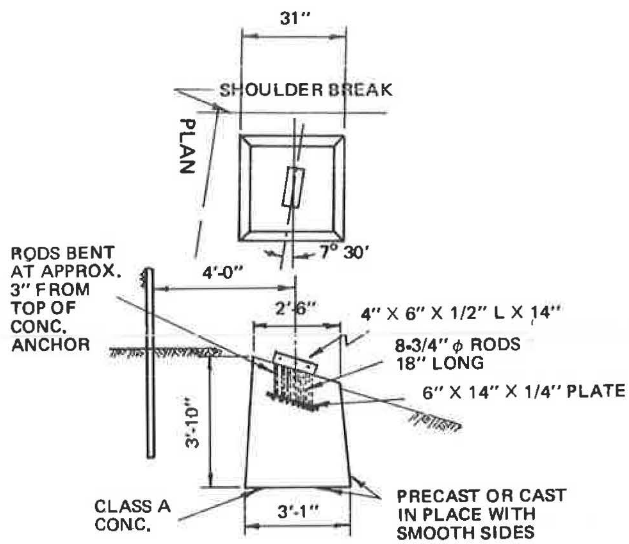
END POST CAP



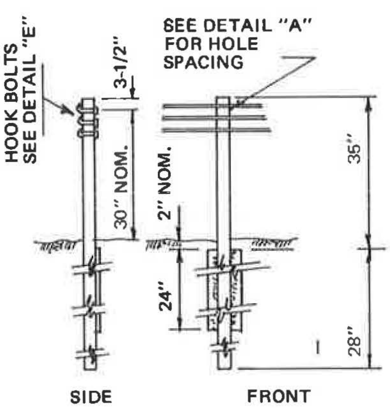
POST SAME AS INTERMEDIATE

DETAIL B

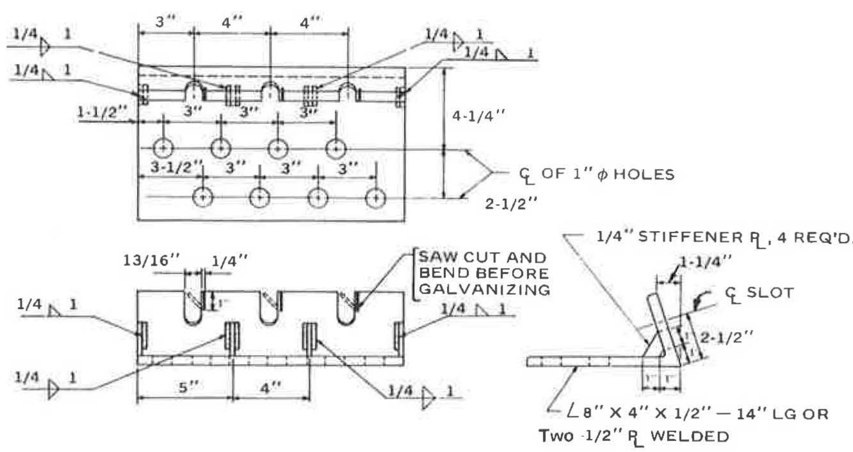
END POST



DETAIL G
CONCRETE ANCHOR

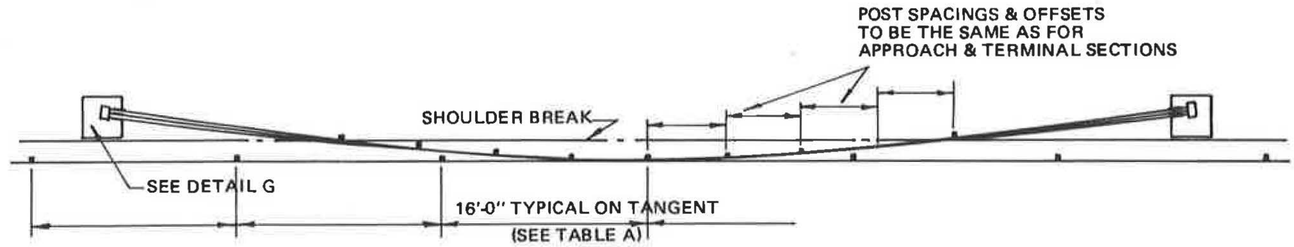


DETAIL C
INTERMEDIATE POST
S X 5.7

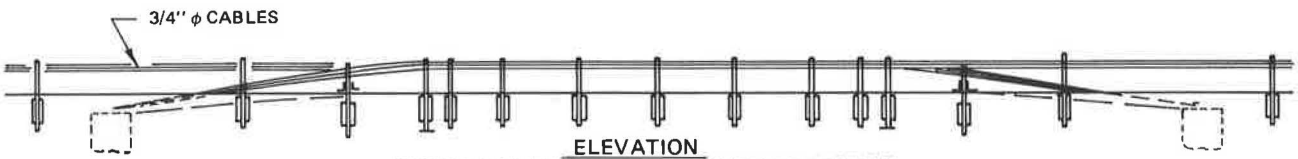


DETAIL H

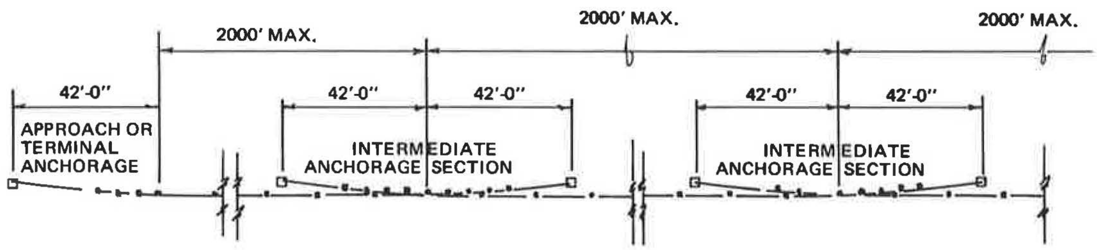
ANCHOR ANGLE



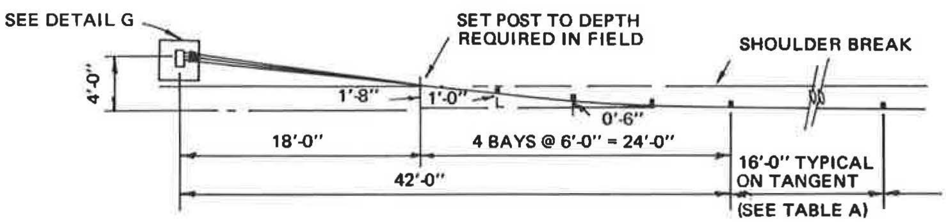
PLAN



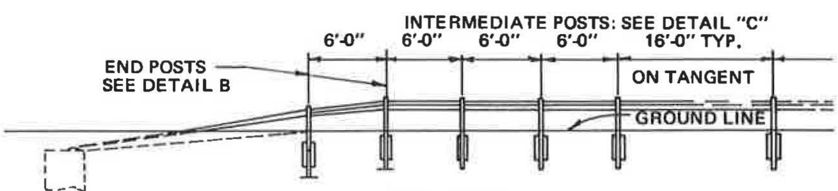
ELEVATION
TYPICAL INTERMEDIATE ANCHORAGE SECTION



TYPICAL LAYOUT
PLAN



PLAN



ELEVATION
TYPICAL APPROACH & TERMINAL SECTIONS

TABLE A

CURVATURE (DEGREE OR RADIUS)	POST SPACING
8° OR LESS	16'
8° TO 26° (220 FT. RADIUS)	12'
219 FT. TO 111 FT.	6'
110 FT. TO 76 FT.	4'
75 FT. TO 50 FT.	3'
LESS THAN 50 FT.	USE NOT RECOMMENDED

G 1 GENERAL NOTES

1. All fittings, cable splices, cable ends etc., shall be designed to develop the full strength of a single cable or cable assemblies as the case may be.

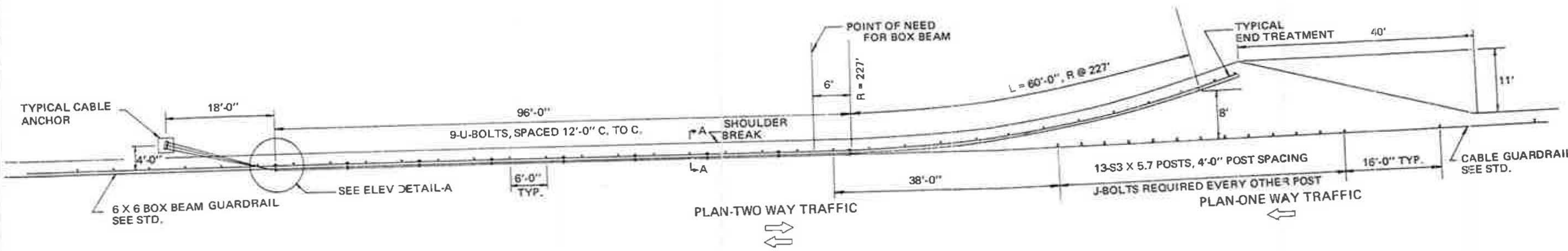
   Single cable assembly
   Min. tensile strength 25,000 lbs.

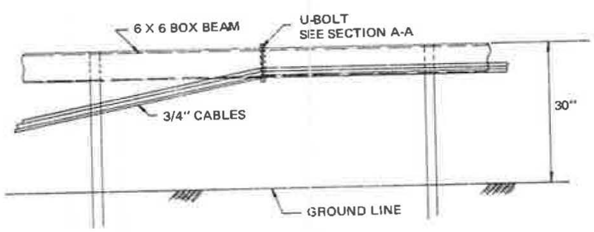
   Three cable anchor assembly
   Min. tensile strength 100,000 lbs.

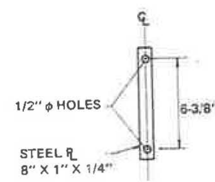
2. Hook bolts, as installed shall develop an ultimate pull open strength of between 500 lbs. and 1000 lbs. applied in a direction normal to the longitudinal axis of the post.

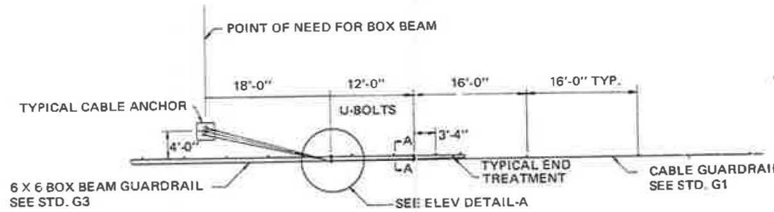
GUARDRAIL
SYSTEM G 1
CABLE

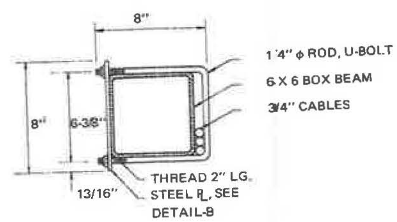
DATE June 1968 REV. 1971
DEVELOPED BY New York



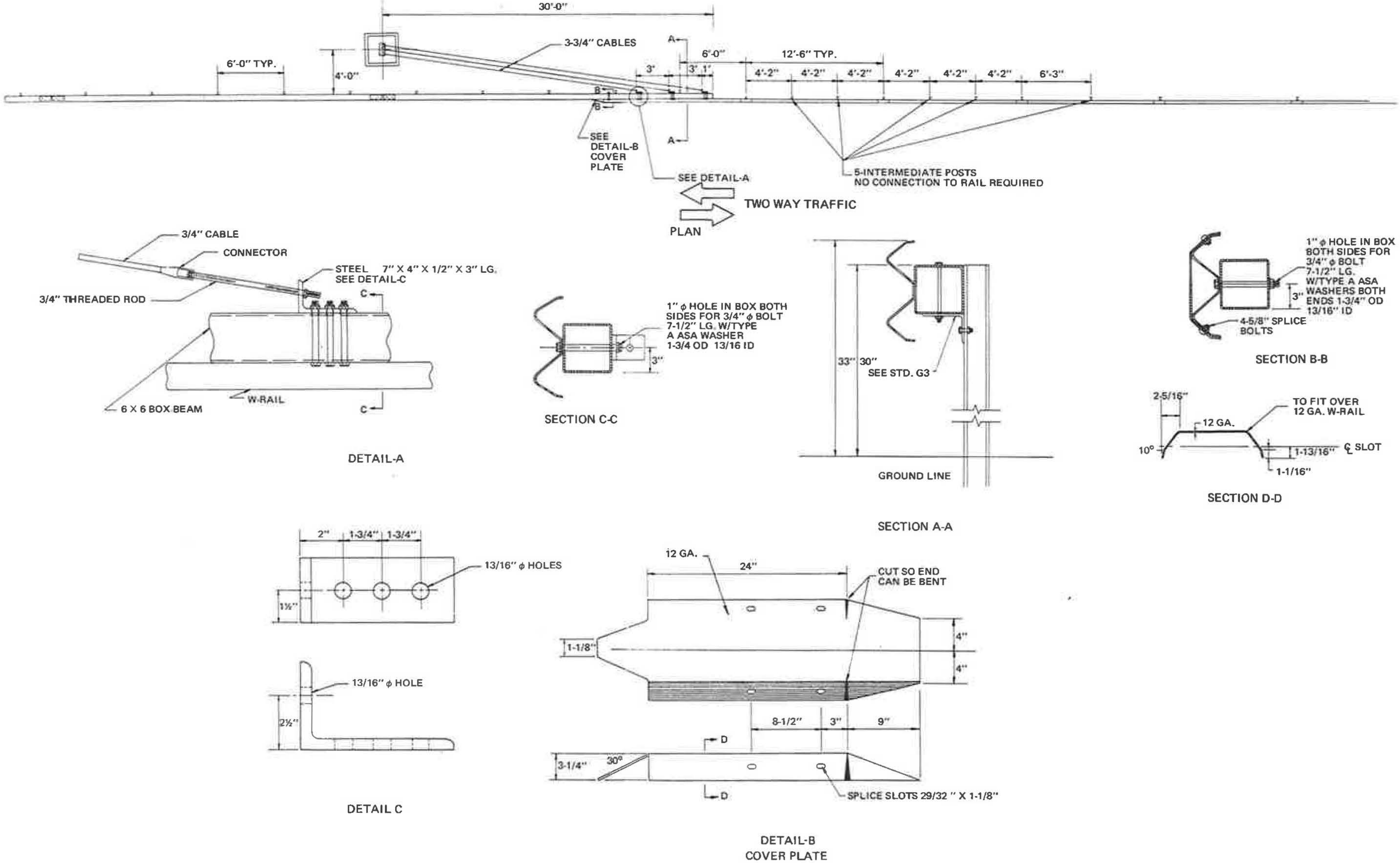








G1 TO G3 TRANSITION



G2 TO G3 TRANSITION

SHEET 1
TRANSITION DETAILS
G1, G2, G3
DATE 1971 REV
DEVELOPED BY NEW YORK

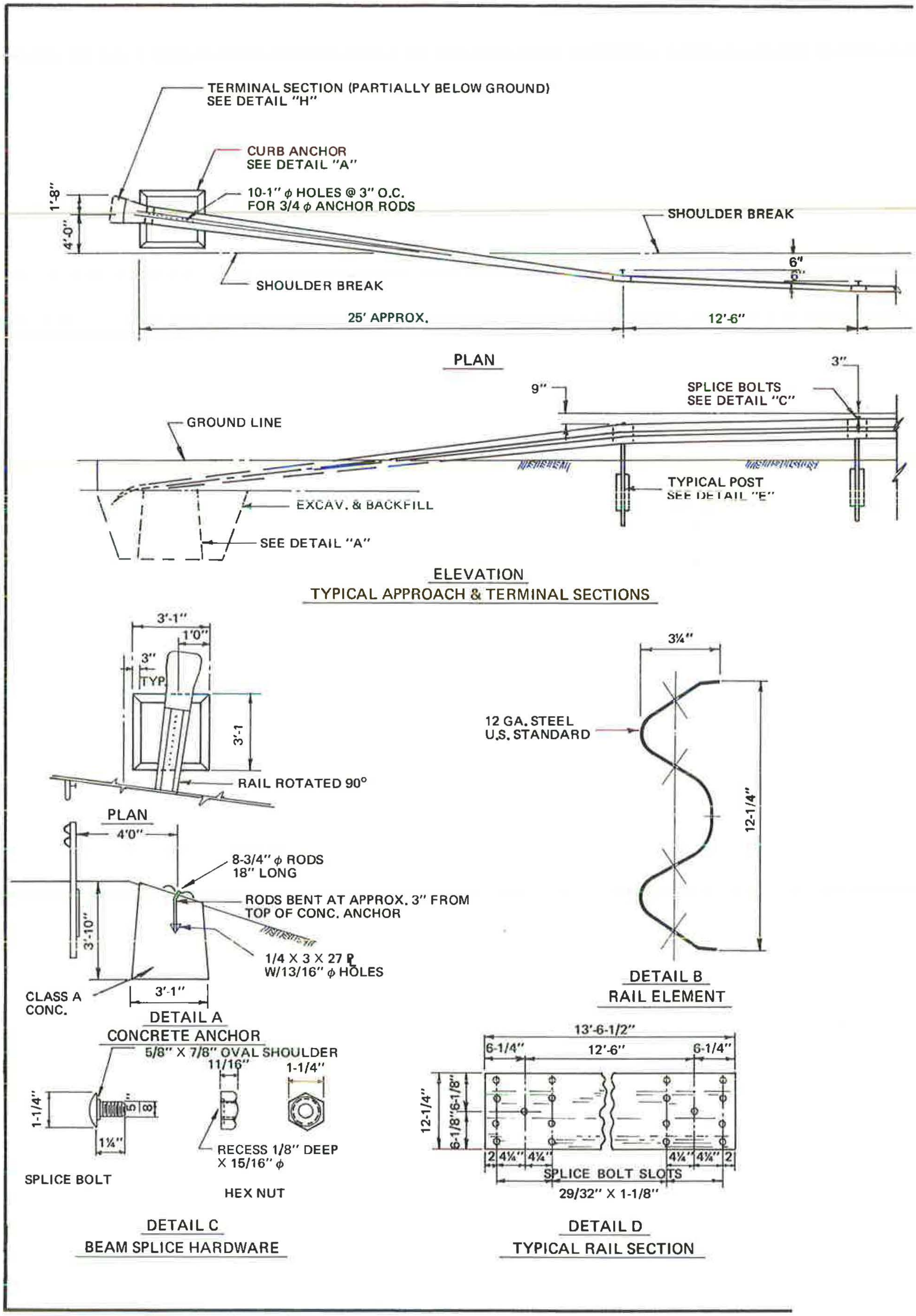
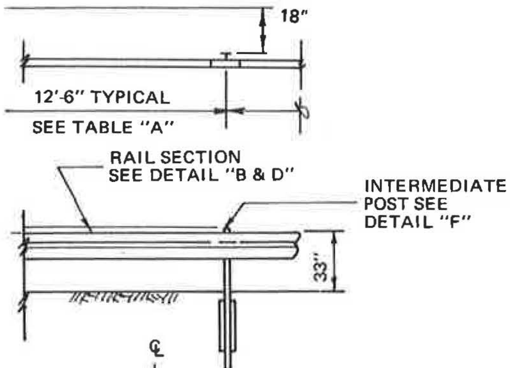
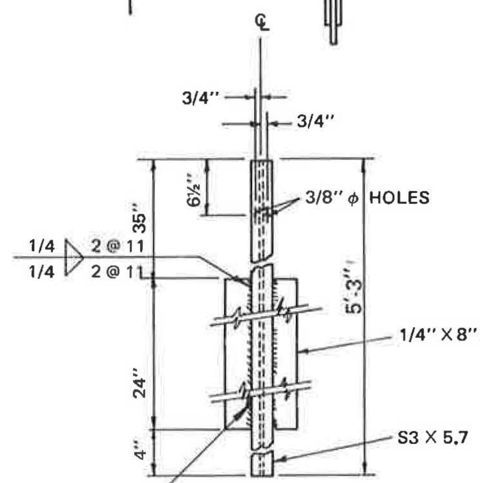

TERMINAL SECTION (PARTIALLY BELOW GROUND) SEE DETAIL "H"
CURB ANCHOR SEE DETAIL "A"
10-1" ϕ HOLES @ 3" O.C. FOR 3/4 ϕ ANCHOR RODS
SHOULDER BREAK
1'-8"
4'-0"
6"
SHOULDER BREAK
25' APPROX.
12'-6"
PLAN
3"
9"
SPLICE BOLTS SEE DETAIL "C"
GROUND LINE
TYPICAL POST SEE DETAIL "E"
EXCAV. & BACKFILL
SEE DETAIL "A"
ELEVATION
TYPICAL APPROACH & TERMINAL SECTIONS
3'-1"
1'0"
3" TYP.
3'-1
RAIL ROTATED 90°
PLAN
4'0"
8-3/4" ϕ RODS 18" LONG
RODS BENT AT APPROX. 3" FROM TOP OF CONC. ANCHOR
3'-10"
1/4 X 3 X 27 ℞ W/13/16" ϕ HOLES
CLASS A CONC.
3'-1"
DETAIL A
CONCRETE ANCHOR
3¼"
12 GA. STEEL U.S. STANDARD
12-1/4"
DETAIL B
RAIL ELEMENT
5/8" X 7/8" OVAL SHOULDER
11/16"
1-1/4"
1-1/4"
1¼"
RECESS 1/8" DEEP X 15/16" ϕ
SPLICE BOLT
HEX NUT
DETAIL C
BEAM SPLICE HARDWARE
13'-6-1/2"
6-1/4"
12'-6"
6-1/4"
12-1/4"
6-1/8"
6-1/8"
2
4¼"
4¼"
4¼"
4¼"
2
SPLICE BOLT SLOTS
29/32" X 1-1/8"
DETAIL D
TYPICAL RAIL SECTION

TABLE A

CURVATURE DEGREE OR RADIUS	POST SPACING
8° OR LESS	12'-6"
8° TO 26° (220 FT. RADIUS)	12'-6"
219 FT. TO 111 FT.	6'-3"
110 FT. TO 76 FT.	4'-2"
75 FT. TO 50 FT.	3'-1½"
LESS THAN 50 FT.	USE NOT RECOMMENDED

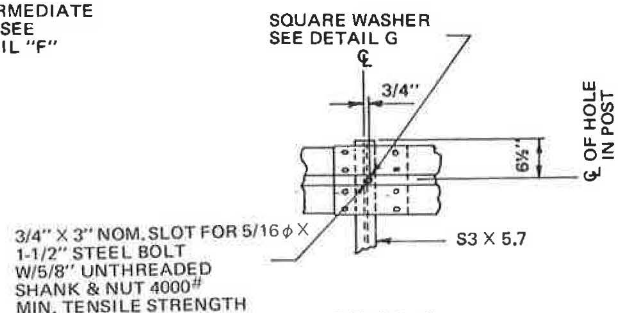




FRONT ELEVATION

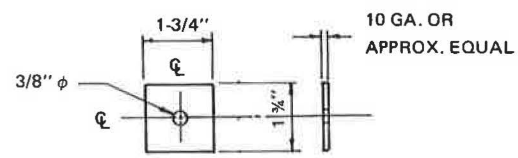
DETAIL E

INTERMEDIATE POST



DETAIL F

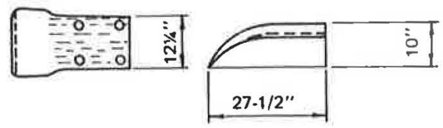
TYPICAL BEAM MOUNTING



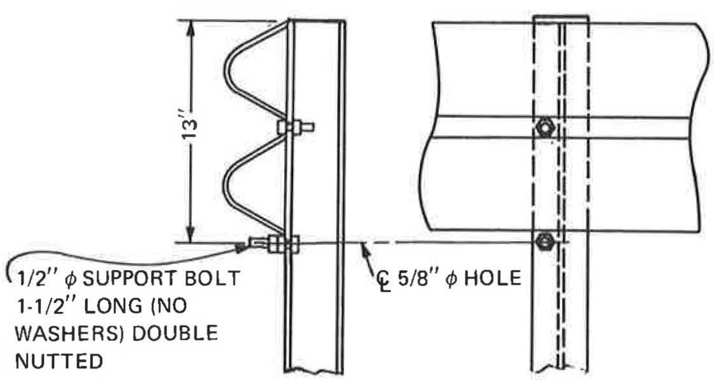
PLACE WASHER IN VALLEY OF BEAM WHEN MOUNTING BEAM TO INTERMEDIATE POST

DETAIL G

SQUARE WASHER



DETAIL H



DETAIL I

SUPPORT BOLT DETAIL

(Optional; for Areas of Heavy Snowfall)

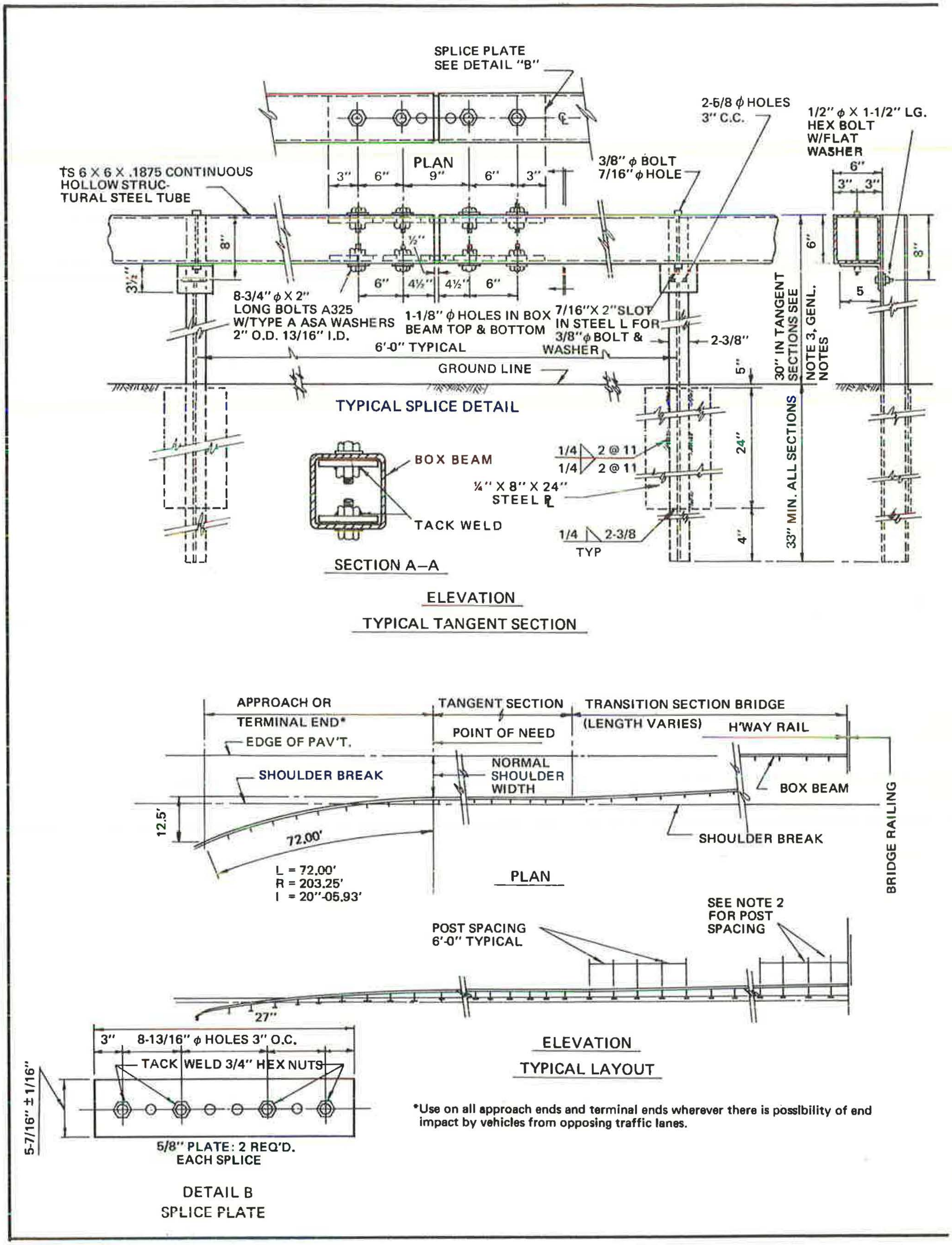
GUARDRAIL

SYSTEM G 2

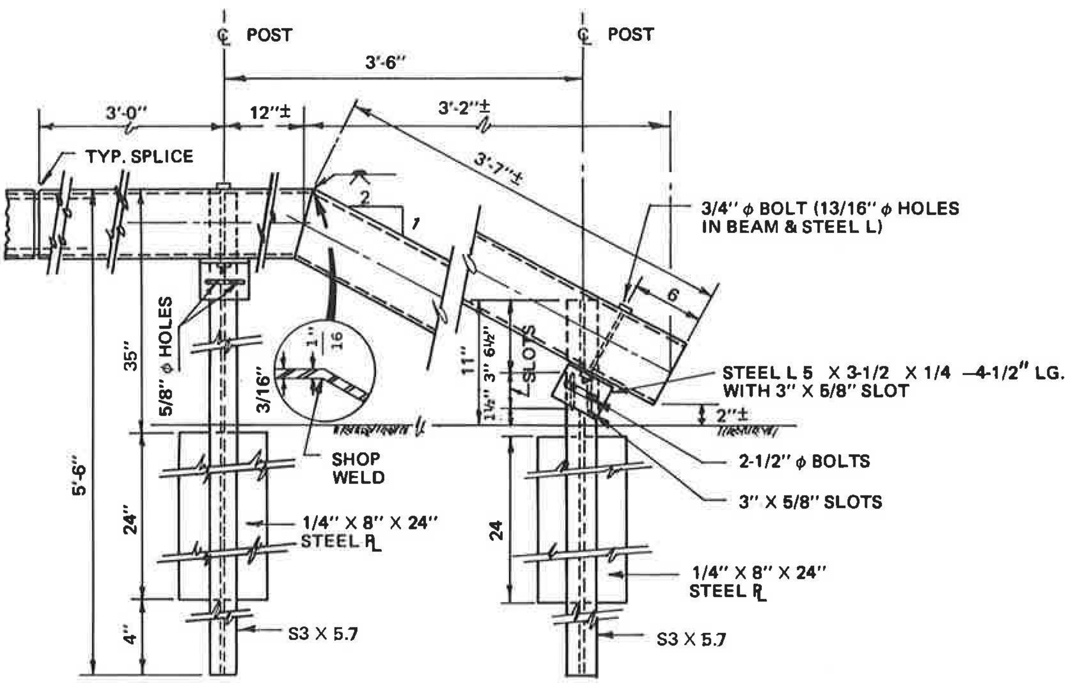
"W" BEAM

DATE June 1968 REV. 1971

DEVELOPED BY New York



SPLICE PLATE
SEE DETAIL "B"
PLAN
3" 6" 9" 6" 3"
TS 6 X 6 X .1875 CONTINUOUS HOLLOW STRUC-TURAL STEEL TUBE
2-5/8 ϕ HOLES 3" C.C.
1/2" ϕ X 1-1/2" LG. HEX BOLT W/FLAT WASHER
3/8" ϕ BOLT
7/16" ϕ HOLE
6" 3" 3"
6" 4½" 4½" 6"
8-3/4" ϕ X 2" LONG BOLTS A325 W/TYPE A ASA WASHERS 2" O.D. 13/16" I.D.
1-1/8" ϕ HOLES IN BOX BEAM TOP & BOTTOM
7/16"X 2"SLOT IN STEEL L FOR 3/8"ϕ BOLT & WASHER
6'-0" TYPICAL
2-3/8"
GROUND LINE
30" IN TANGENT SECTIONS SEE NOTE 3, GENL. NOTES
33" MIN. ALL SECTIONS
TYPICAL SPLICE DETAIL
BOX BEAM
TACK WELD
1/4 2 @ 11
1/4 2 @ 11
¼" X 8" X 24" STEEL PL
1/4 2-3/8
TYP
SECTION A–A
ELEVATION
TYPICAL TANGENT SECTION
APPROACH OR TERMINAL END*
EDGE OF PAV'T.
TANGENT SECTION
POINT OF NEED
TRANSITION SECTION BRIDGE (LENGTH VARIES)
H'WAY RAIL
SHOULDER BREAK
NORMAL SHOULDER WIDTH
BOX BEAM
BRIDGE RAILING
12.5'
72.00'
SHOULDER BREAK
L = 72.00'
R = 203.25'
I = 20"-05.93'
PLAN
POST SPACING 6'-0" TYPICAL
SEE NOTE 2 FOR POST SPACING
27"
ELEVATION
TYPICAL LAYOUT
3" 8-13/16" ϕ HOLES 3" O.C.
TACK WELD 3/4" HEX NUTS
5-7/16" ± 1/16"
5/8" PLATE: 2 REQ'D. EACH SPLICE
DETAIL B
SPLICE PLATE
*Use on all approach ends and terminal ends wherever there is possibility of end impact by vehicles from opposing traffic lanes.



ELEVATION
TYPICAL END TREATMENT AT FREE ENDS

G 3 GENERAL NOTES

1. Extend approach & terminal end transitions beyond point of need as shown in "typical layout."

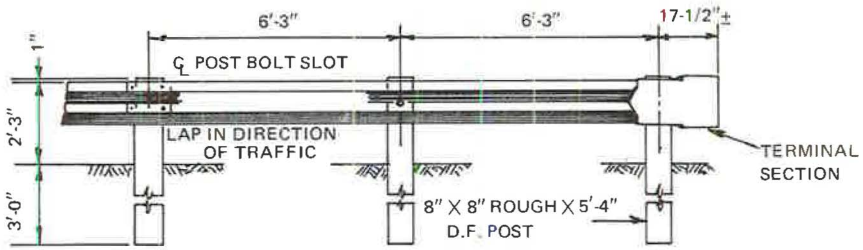
2. Post spacing shall be 6'-0" except in vicinity of the junction of the guardrail and the bridge approach. At bridge approaches, 12 post spaces @ 4'-0" is used for transition.

3. In approach and terminal end sections, post heights may average 24" to 30".

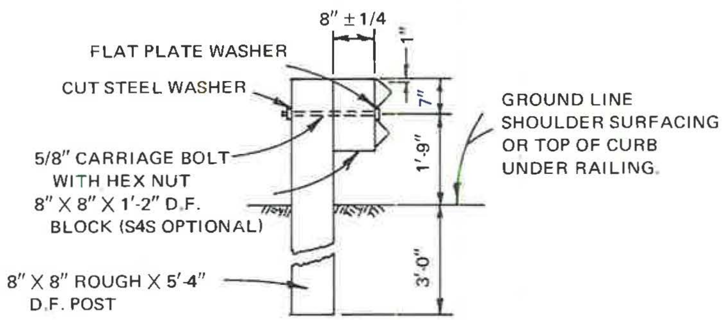
4. When the side clearance from the back face of the beam to the front face of a fixed object is less than 4 ft., reduce post spacing to 4 ft. and provide 24 ft. of beam leading and 24 ft. leaving the point of the fixed object at the 4 ft. post spacing, however, the back clearance at 4 ft. post spacing must be 2 ft. minimum.

5. For curves greater than 8° box beam shall be shop worked to the required curvature.

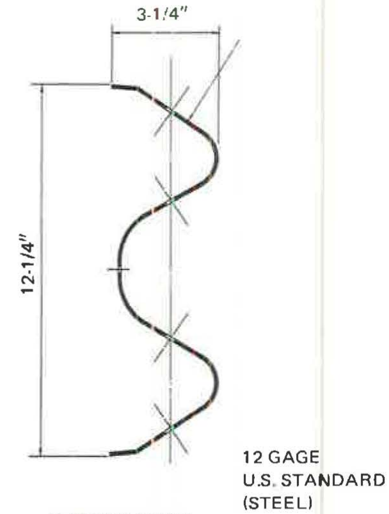
GUARDRAIL
SYSTEM G 3
BOX BEAM
DATE June 1968 REV. 1971
DEVELOPED BY New York



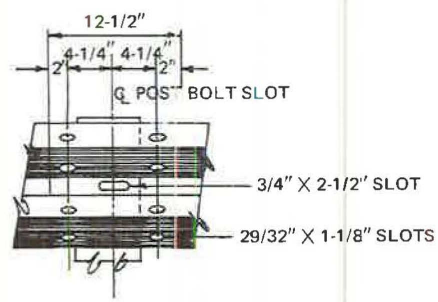
METAL BEAM GUARD RAILING



TYPICAL POST SPACING 6'-3" C. TO C.



SECTION THRU RAIL ELEMENT



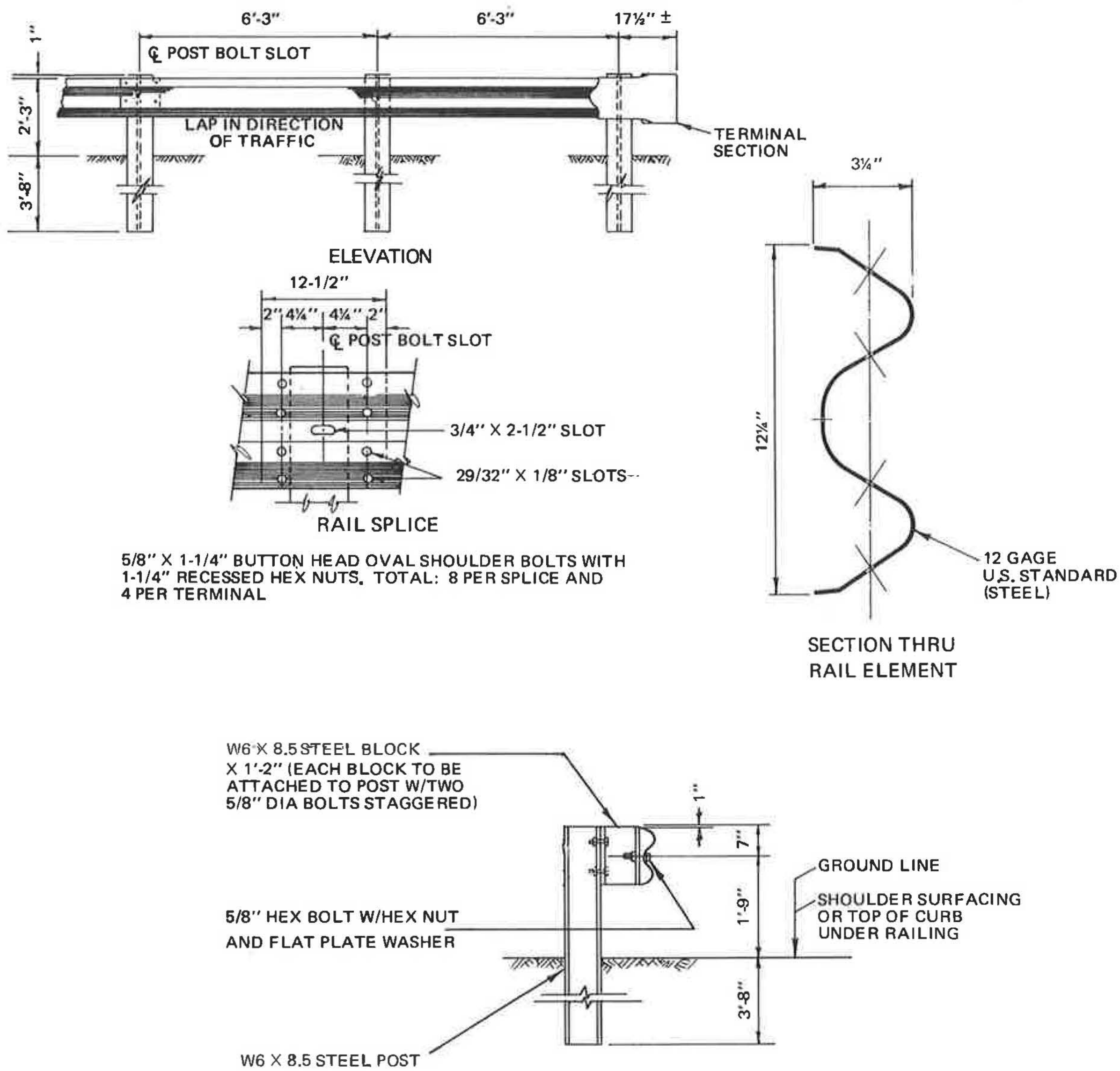
RAIL SPLICE

5/8" X 1-1/4" BUTTON HEAD OVAL SHOULDER BOLTS WITH 1-1/4" RECESSED HEX NUTS. TOTAL 8 PER SPLICE AND 4 PER TERMINAL SECTION.

GENERAL NOTES

1. Except where noted, cut washers are required at all bolt installations where nut would bear on wood.
2. See Sheet 2 for Anchorage Details.
3. See Sheets 3 and 4 for Flare Details.
4. See Sheet 5 for Connection Details.
5. Do not use S4S and rough blocks in the same installation.

GUARDRAIL
SYSTEM G 4 W
BLOCKED OUT "W" BEAM
TIMBER POST
DATE JUNE 68 REV 1971
DEVELOPED BY CALIFORNIA



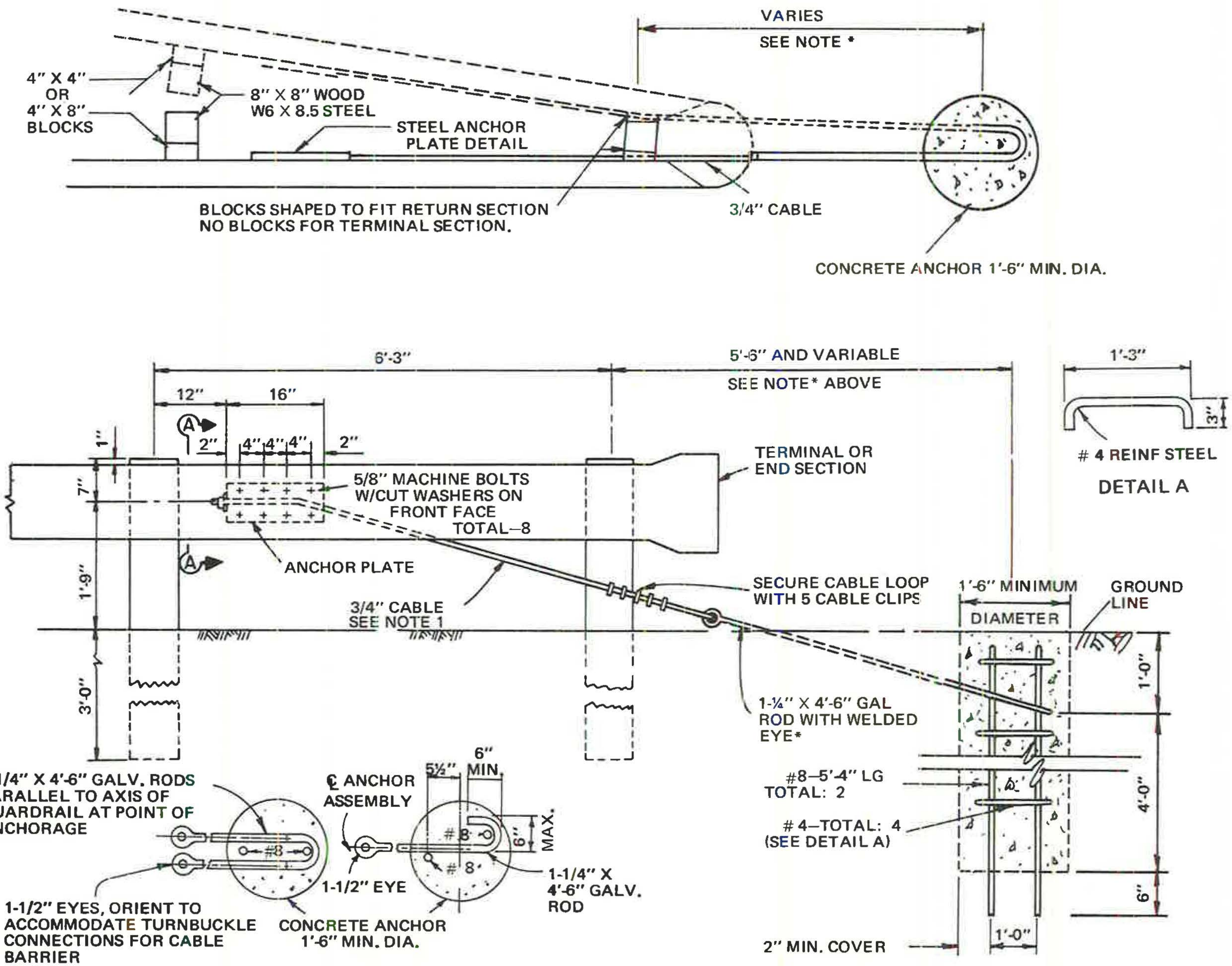
GENERAL NOTES

1. See Sheet 2 for Anchorage Details.

GUARDRAIL
SYSTEM G 4 S
BLOCKED OUT "W" BEAM
STEEL POST
DATE 1971 REV. ______

NOTE: CABLE TO BE PARALLEL TO GUARDRAIL FOR STRAIGHT RUNS OF RAIL. CABLE MAY HAVE ANGLE POINT AT ANCHOR PLATE IF GUARDRAIL IS CURVED.

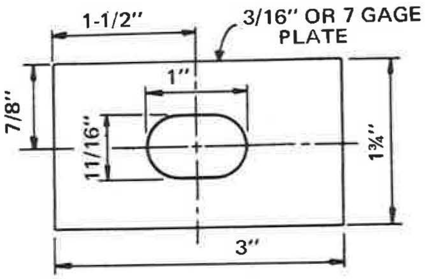
*NOTE: 5'-6" WITH TERMINAL SECTION. MAY BE LESS WITH RETURN SECTIONS IF SEPARATE RODS CONNECT TO CONCRETE ANCHOR. FOR TYPE 3 FLARE, ANCHORAGE IS ONLY REQUIRED FOR GUARDRAIL ON SIDE OF MEDIAN WHERE TRAFFIC IS APPROACHING BRIDGE.



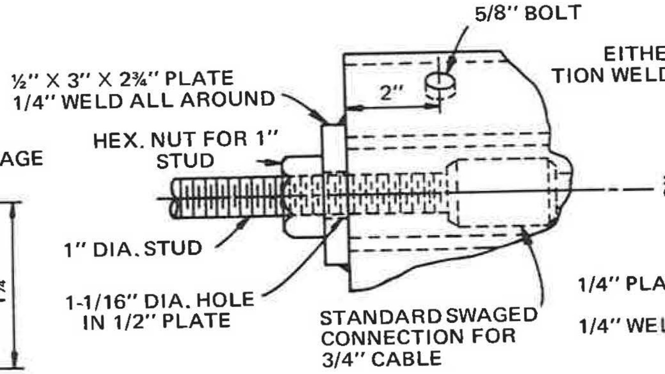
*20 MIL COAT OF COAL TAR ENAMEL OR EPOXY IS ALSO RECOMMENDED

CABLE BARRIER ANCHOR OR DOUBLE GUARDRAIL ANCHOR

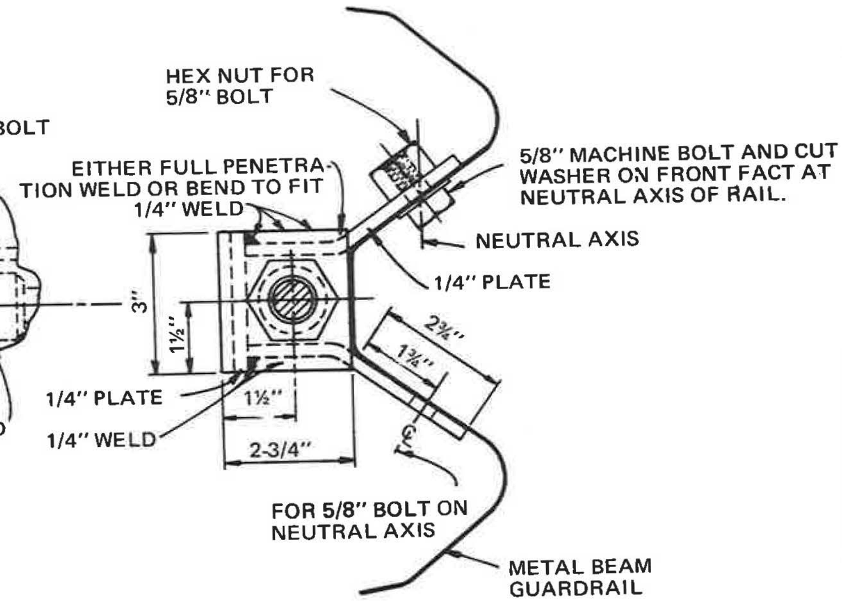
SINGLE GUARDRAIL ANCHOR



FLAT PLATE WASHER

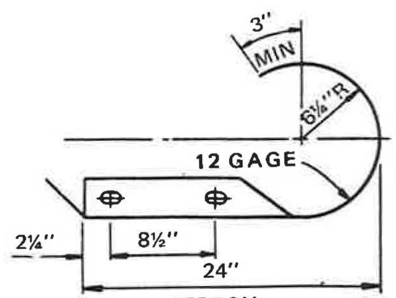


SEE NOTE 1

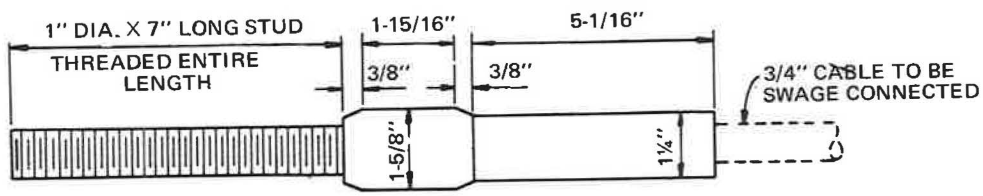


SECTION A–A

ANCHOR PLATE DETAILS

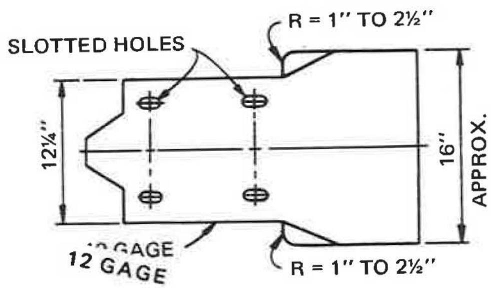


APPROX.



STANDARD SWAGED FITTING AND STUD

1. OTHER ANCHOR CABLE ASSEMBLIES MAY BE USED. MINIMUM BREAKING STRENGTH OF ASSEMBLY SHOULD BE 40,000 LBS.
2. USE WOOD BLOCKS WITH STEEL POSTS FOR G4S.

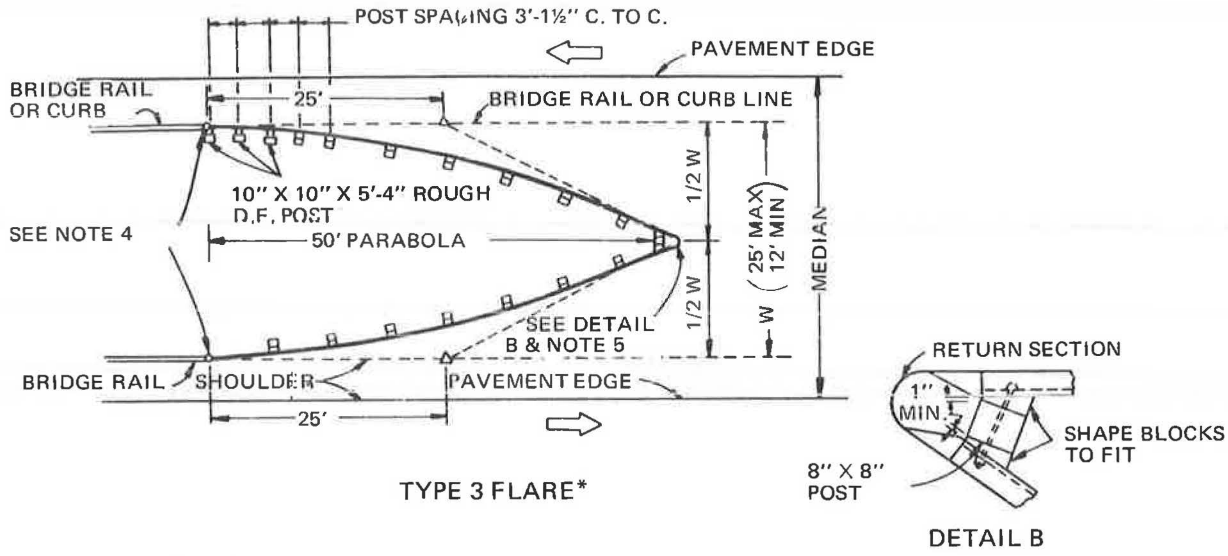


TERMINAL SECTION

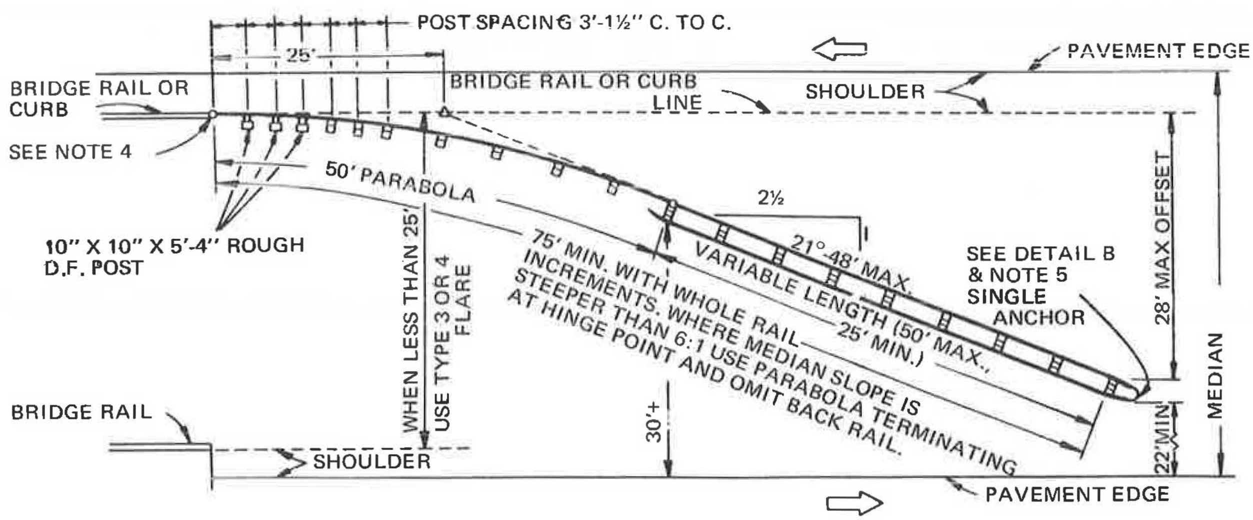
"U" BOLTS OF CLIP ON SHORT END OF CABLE

CABLE CLIP INSTALLATION

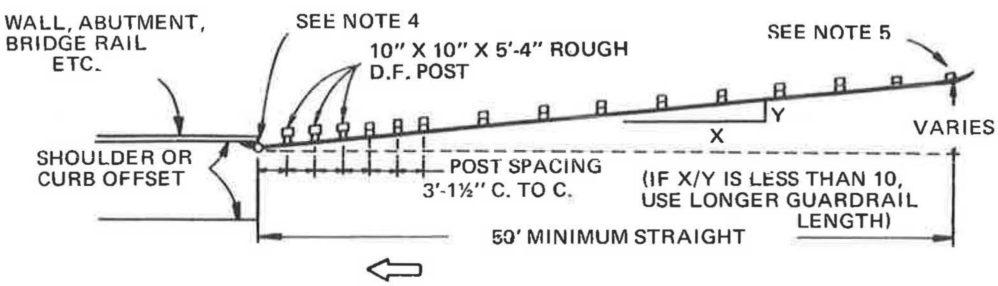
SHEET 2
END ANCHORAGE DETAILS
BLOCKED OUT "W" BEAM
DATE June 68 REV. 1971
DEVELOPED BY California



TYPE 3 FLARE*



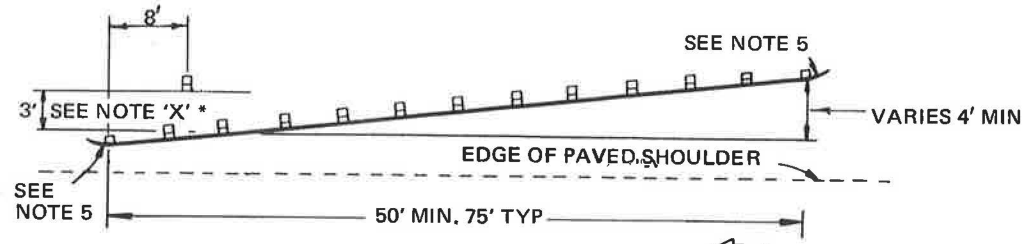
TYPE 2 FLARE*



TYPE 1 FLARE*

SHOULDER ENCROACHMENTS (RT. OR LT.)

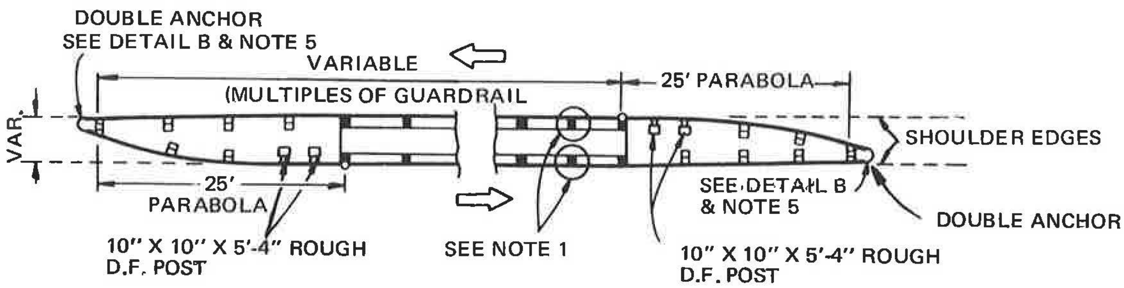
*See Note 2.



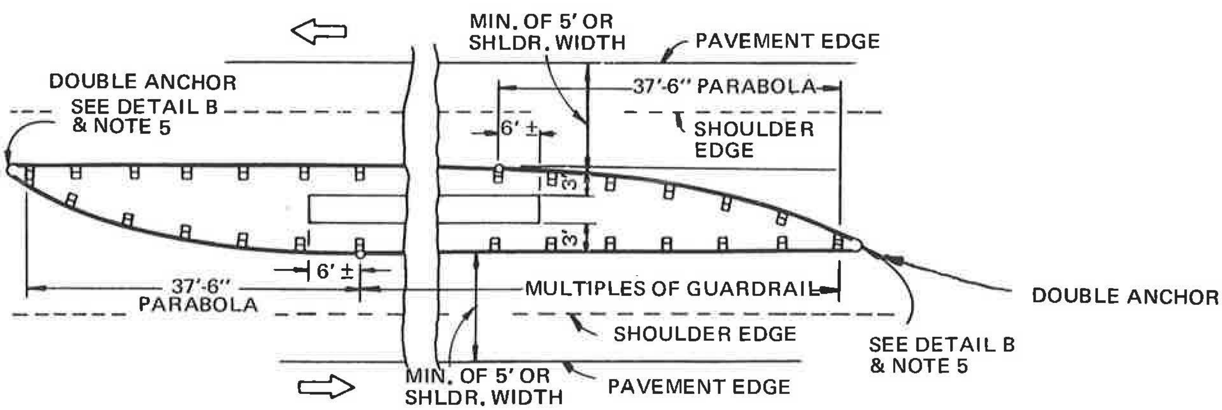
*NOTE 'X': WHEN 3' OFFSET CAUSES RAIL TO ENCROACH ON SHOULDER INSTALL GUARDRAIL AT EDGE OF SHOULDER

TYPE 7 FLARE*

SHOULDER INSTALLATION AT SIGN STANDARDS



TYPE 6 FLARE*



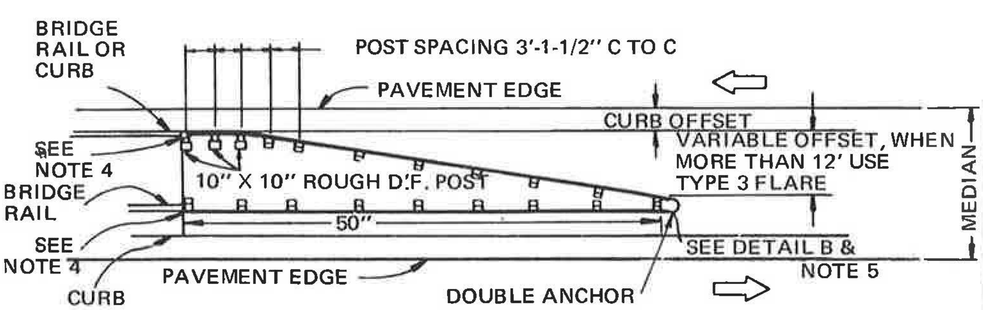
TYPE 5 FLARE*

MEDIAN INSTALLATION AT BRIDGE AND/OR SIGN STANDARDS

WHERE CLEARANCE SHOWN CANNOT BE OBTAINED USE TYPE 6 FLARE.

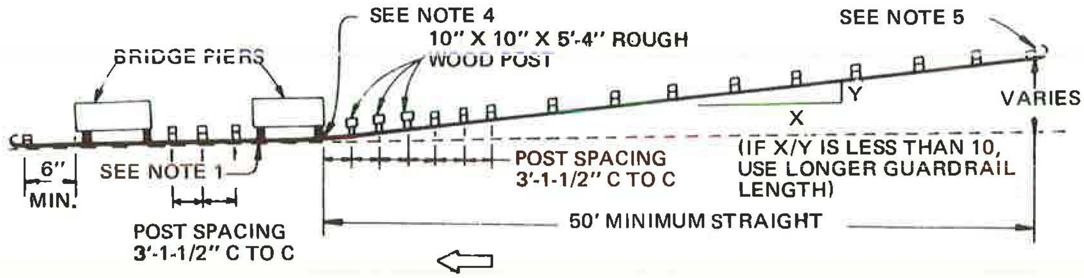
GENERAL NOTES

1. See Sheet 4 for applicable notes.
2. Crash cushions may be preferred treatment here.



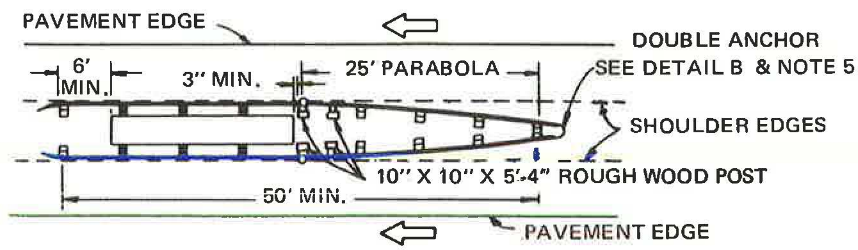
TYPE 4 FLARE*

SHEET 3
FLARE DETAILS
G4W AND MB4W
DATE June 68 REV. 1971
DEVELOPED BY California

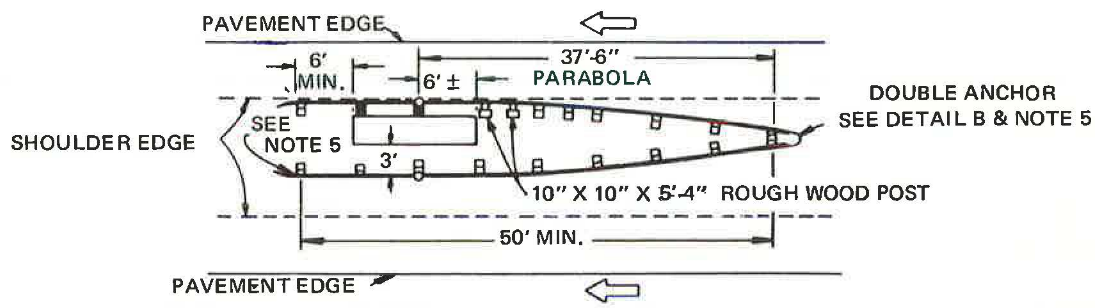


USE WHERE OBSTRUCTION IS LESS THAN 18' FROM EDGE OF PAVEMENT

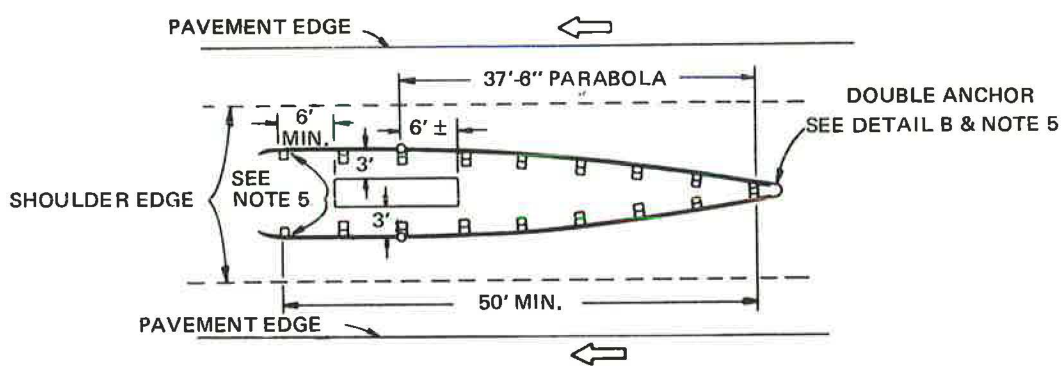
TYPE 11 FLARE*



TYPE 10 FLARE*

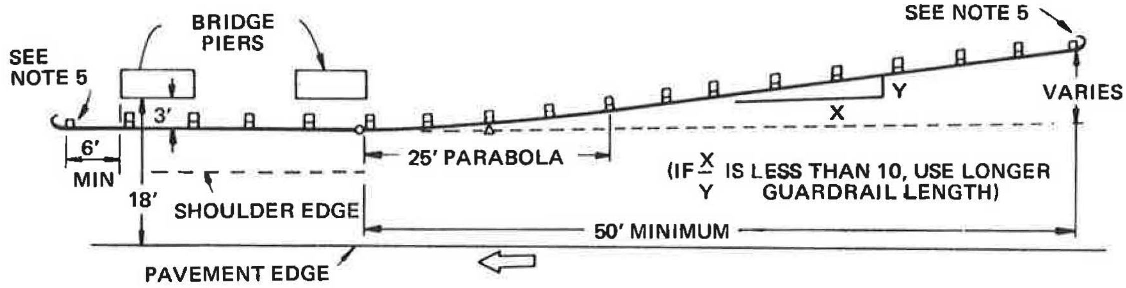


TYPE 9 FLARE*



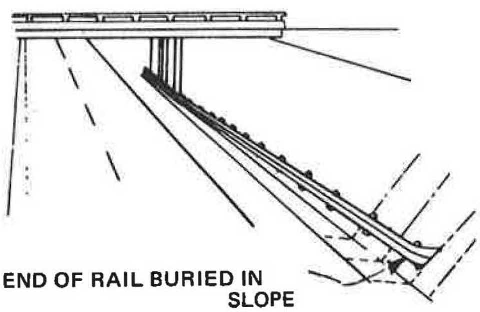
TYPE 8 FLARE*

*SEE NOTE 6

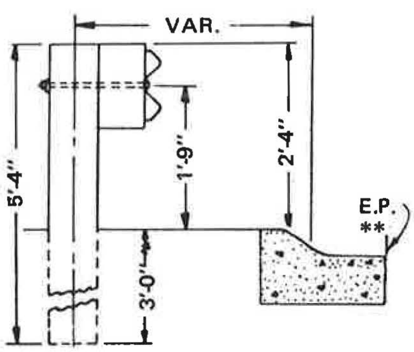


USE WHERE OBSTRUCTION IS AT LEAST 18' FROM EDGE OF PAVEMENT

TYPE 12 FLARE*

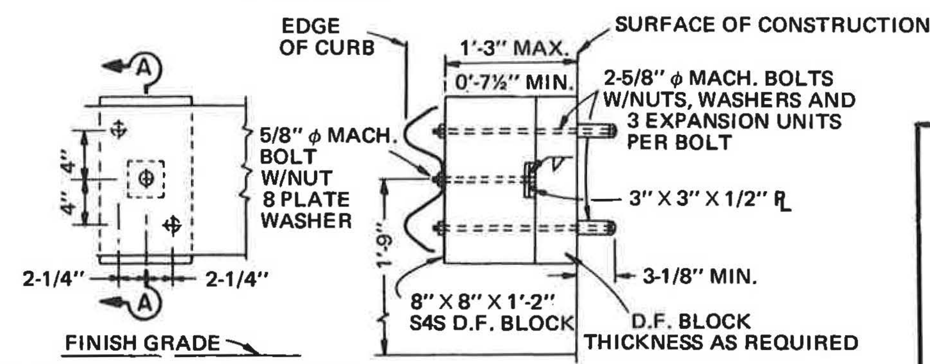


GUARDRAIL IN CUT



**CURBS NOT RECOMMENDED IN FRONT OF GUARDRAILS.

GUARDRAIL AT CURB



BLOCKOUT DETAIL—ELEVATION

SECTION A-A

METAL BEAM RAIL OBSTRUCTION DETAIL A

GENERAL NOTES

1. Use timber shims without posts where rail to pier clearance is less than 15″ (See Detail A, Sheet 4).

2. On median installations where pier footing is between 2′ and 3′ below surface, posts may be embedded a minimum of 2′. Use Detail A when footing is less than 2′ below surface.

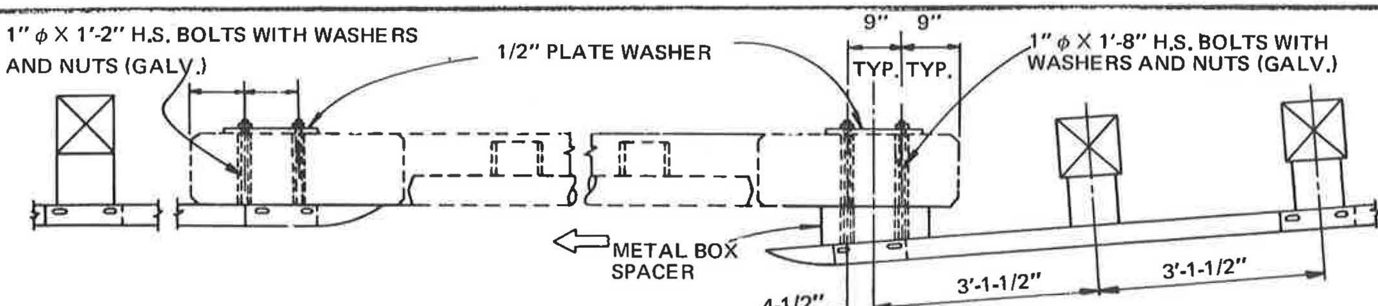
3. Direction of traffic is indicated by arrow.

4. For connection details see Sheet 5 Blocked-Out "W" Beam Details.

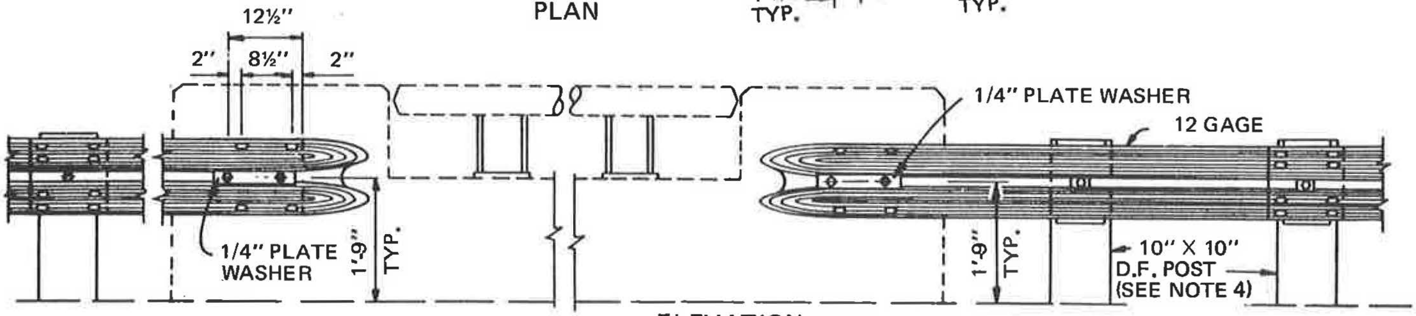
5. For cable anchor details see Sheet 2, Blocked-Out "W" beam Details.

6. Crash cushions may be better treatment.

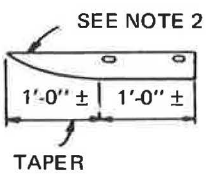
SHEET 4
FLARE DETAILS
G4W AND MB4W
DATE JUNE 68 REV 1971
DEVELOPED BY CALIFORNIA



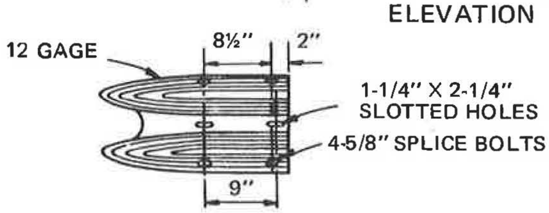
PLAN



ELEVATION

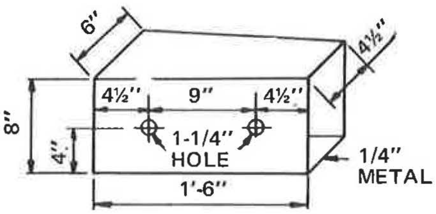


PLAN



ELEVATION

END SECTION DETAILS



METAL BOX SPACER
(SEE NOTE 5)

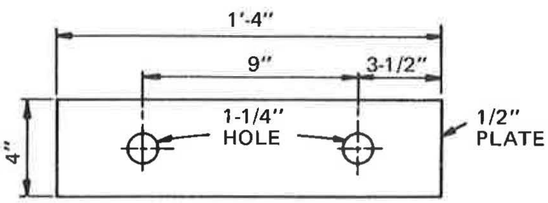


PLATE WASHER
FOR BACKSIDE OF PARAPET

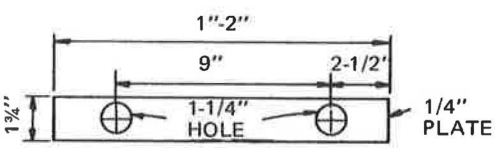
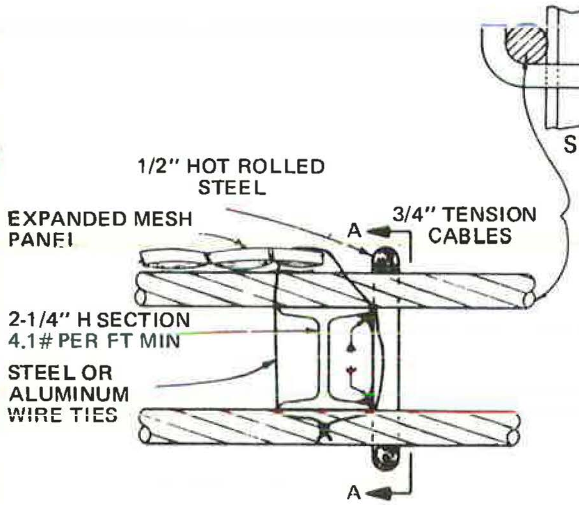


PLATE WASHER
FOR GUARDRAIL

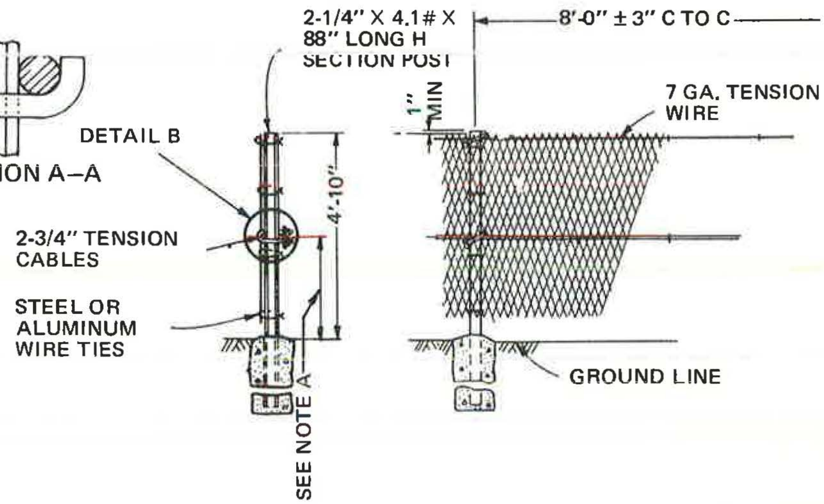
GENERAL NOTES

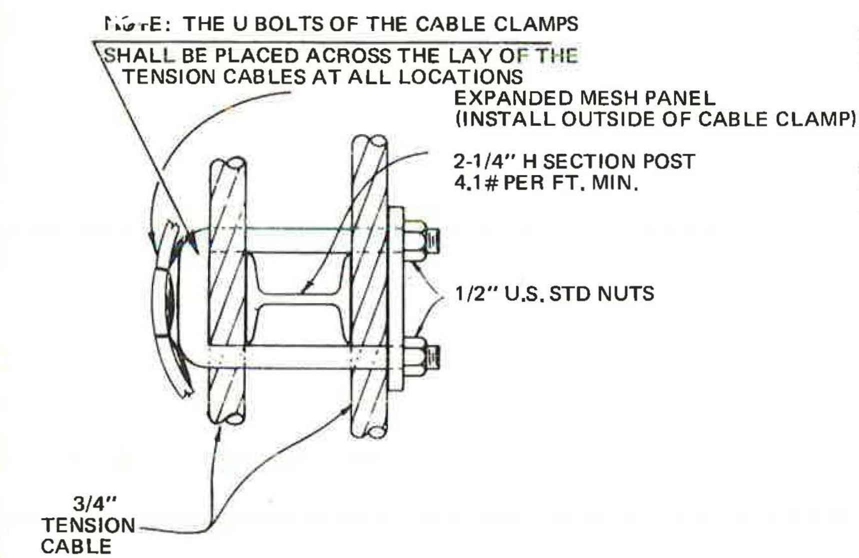
1. These connection details apply to bridge rails, abutments, piers, retaining walls and other flat surface concrete objects. Anchor bolts for piers, abutments, retaining walls should be epoxy grouted in 9 in. X 2 in.-dia. drilled holes.
2. End sections may be cut from standard terminal sections or fabricated.
3. Direction of traffic indicated by ⇦
4. For post size and spacing see Type 1 Flare on Sheet 3.
5. When metal box spacer is installed, place 1-1/4" X 5" and 1-1/4" X 4" pipe spacers on 1" bolts passing through interior of box.

SHEET 5
CONNECTION DETAILS
BLOCKED OUT "W" BEAM
DATE June 68 REV. 1971
DEVELOPED BY California

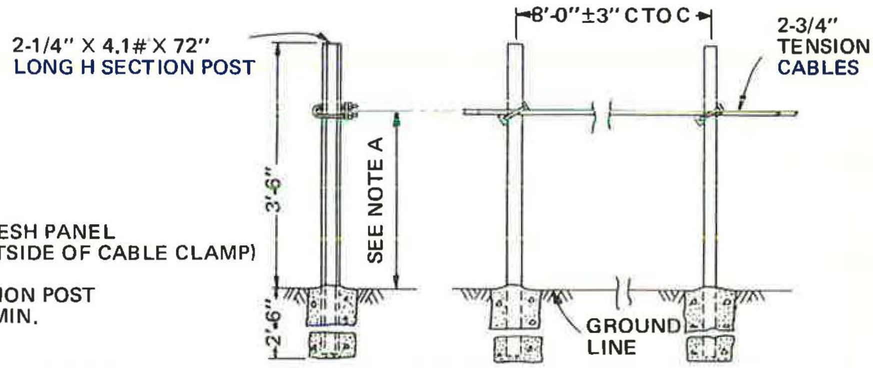


DETAIL A
END POST ASSEMBLY



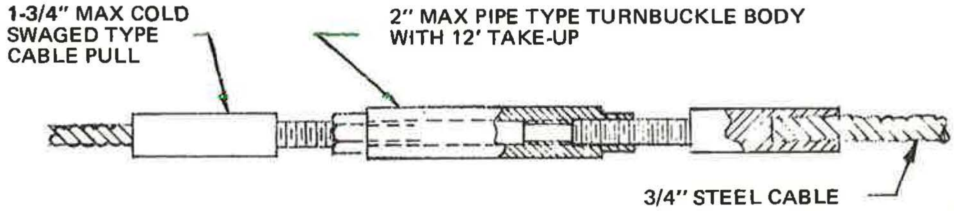


DETAIL B
LINE POST ASSEMBLY

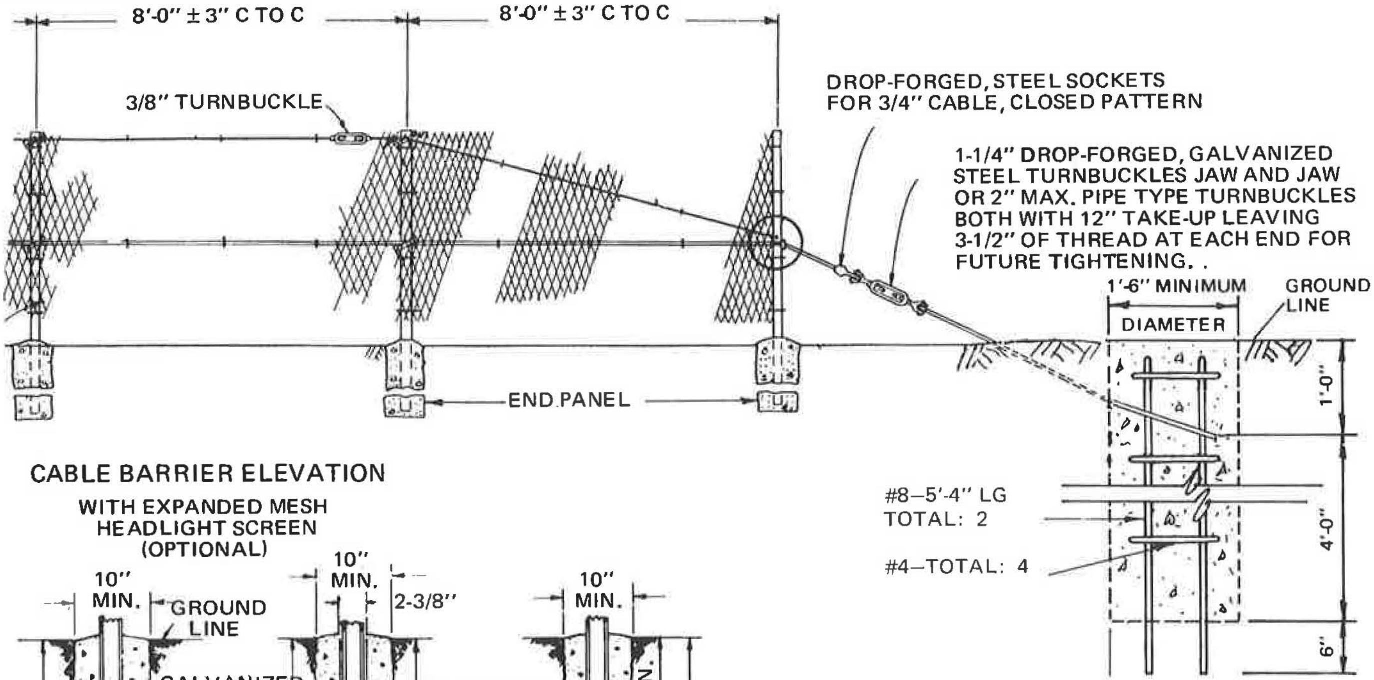


CABLE BARRIER
WITHOUT EXPANDED MESH HEADLIGHT SCREEN

NOTE A: NORMAL HEIGHT 2'-3" TO 2'-4", 2'-6" FOR SPECIAL CASES WHERE DIRECTED BY THE ENGINEER.

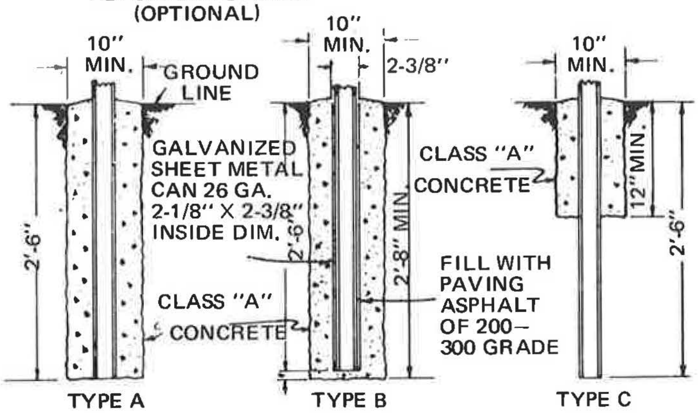


DETAIL C
LINE TURNBUCKLE



CABLE BARRIER ELEVATION

WITH EXPANDED MESH HEADLIGHT SCREEN (OPTIONAL)



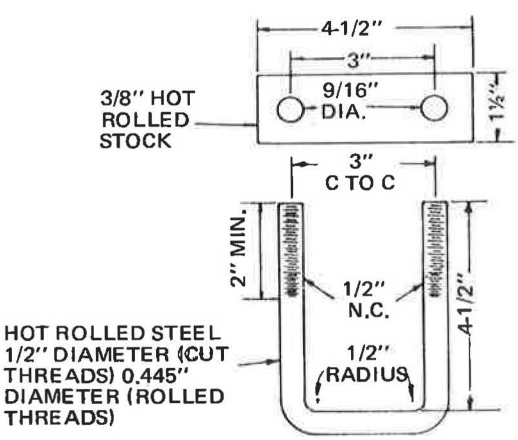
POST FOOTINGS

NOTE For cable anchor details see Sheet 2, Blocked-Out "W" beam Details.

GENERAL NOTES

1. Line turnbuckles (those used in intermediate panels) should be constructed as shown in Detail C. The diameter of the turnbuckle body should be two inches maximum and the breaking strength of the complete unit greater than that of the cable. Two turnbuckles should not occur in the same panel.

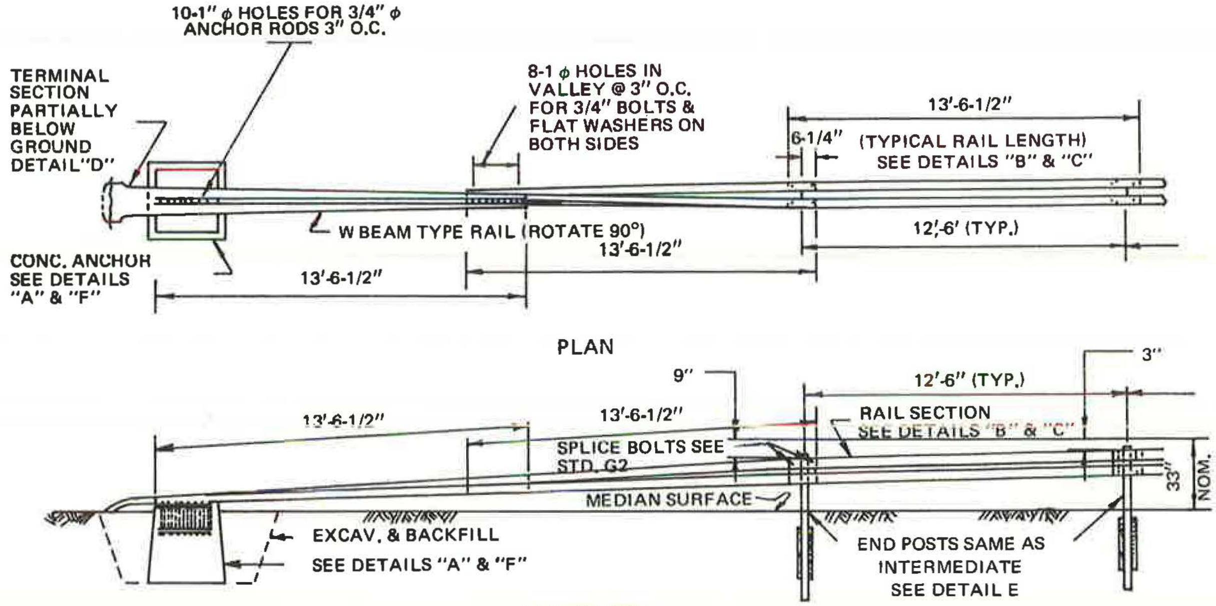
2. The tension cables should be placed no more than 30 inches nor less than 27 inches above the ground. When practical, on paved medians the cable height should be maintained as close to 27 inches as possible.



CABLE CLAMP DETAIL

MEDIAN BARRIER
SYSTEM MB 1
CABLE

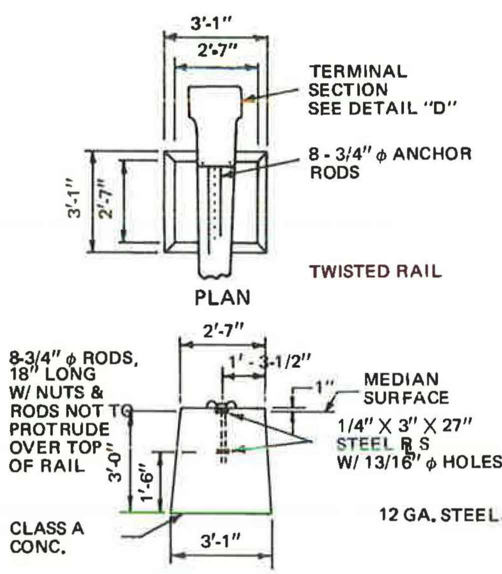
DATE June 68 REV. 1971
DEVELOPED BY California



TYP. END ANCHORAGE

ELEVATION

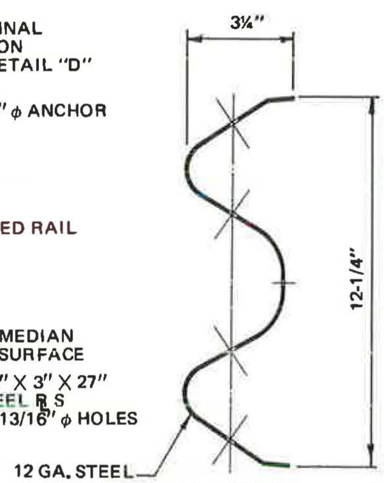
TYPICAL MEDIAN BARRIER SECTION



ELEVATION

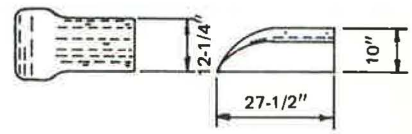
DETAIL A

CONCRETE ANCHOR

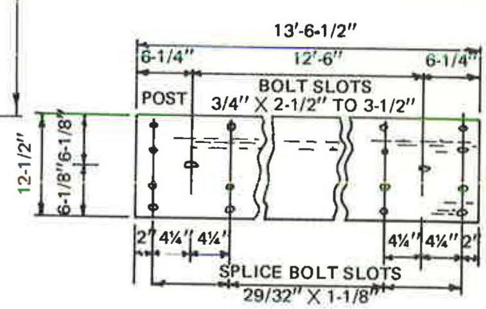


DETAIL B

RAIL ELEMENT

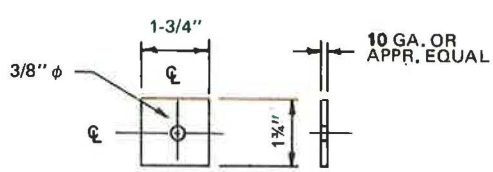


DETAIL D



DETAIL C

TYPICAL RAIL SECTION



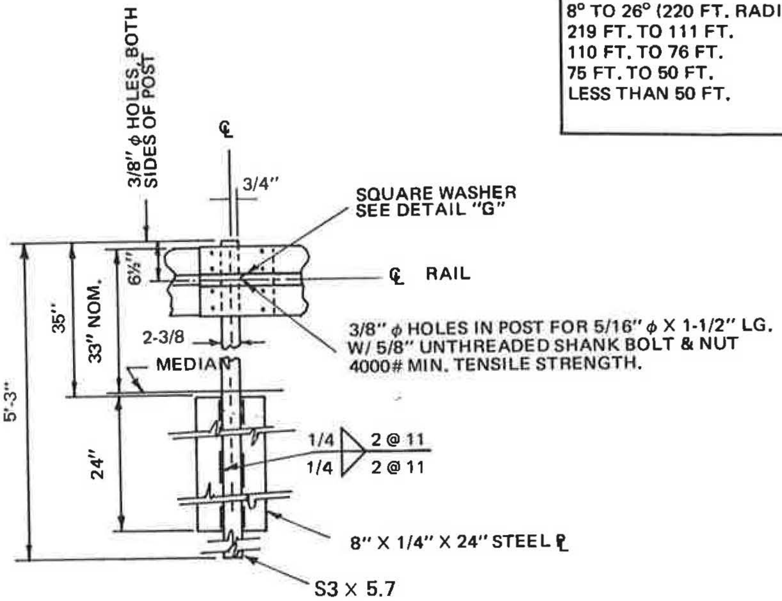
PLACE WASHER IN VALLEY OF BEAM WHEN MOUNTING BEAM TO INTERMEDIATE POST

DETAIL G

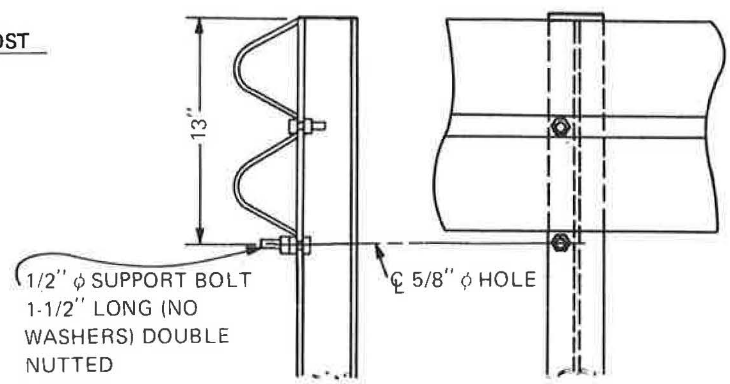
SQUARE WASHER

TABLE A

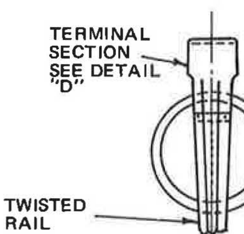
CURVATURE DEGREE OR RADIUS	POST SPACING
8° OR LESS	12'-6"
8° TO 26° (220 FT. RADIUS)	12'-6"
219 FT. TO 111 FT.	6'-3"
110 FT. TO 76 FT.	4'-2"
75 FT. TO 50 FT.	3'-1-1/2"
LESS THAN 50 FT.	USE NOT RECOMMENDED



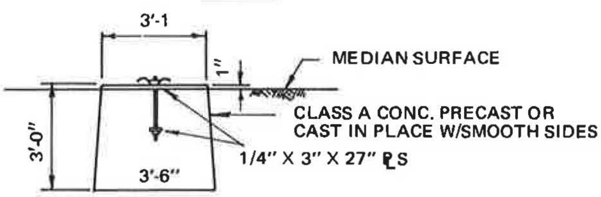
DETAIL E
INTERMEDIATE POST



DETAIL H
SUPPORT BOLT DETAIL
(Optional; for Areas of Heavy Snowfall)

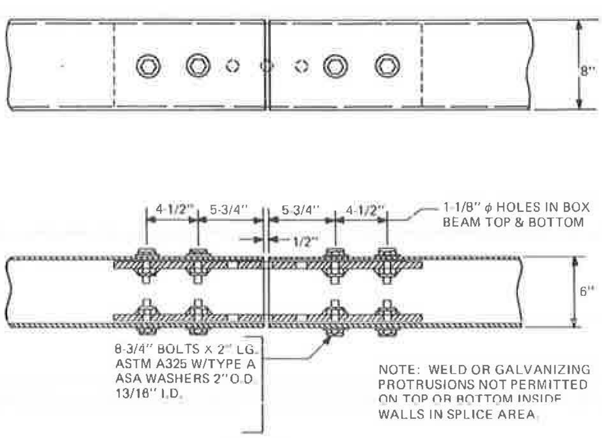


PLAN

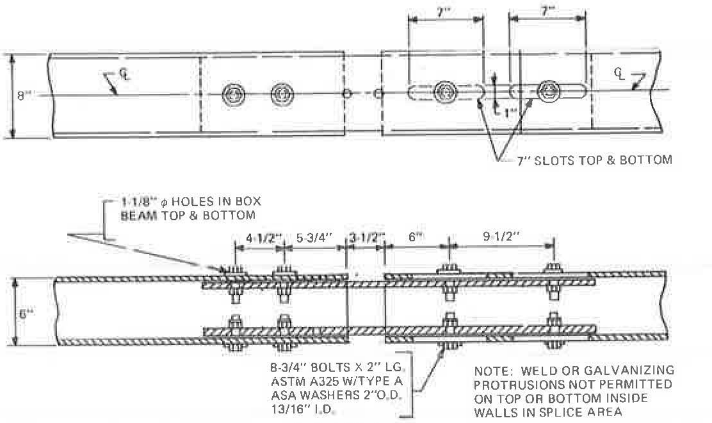


ELEVATION
DETAIL F
ALTERNATE CONC. ANCHOR

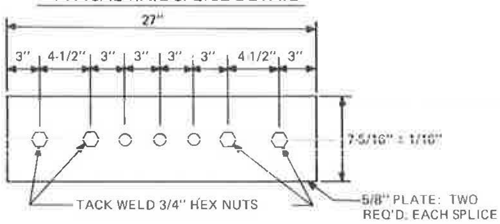
MEDIAN BARRIER
SYSTEM MB 2
"W" BEAM
DATE June 1968 REV. 1971
DEVELOPED BY New York



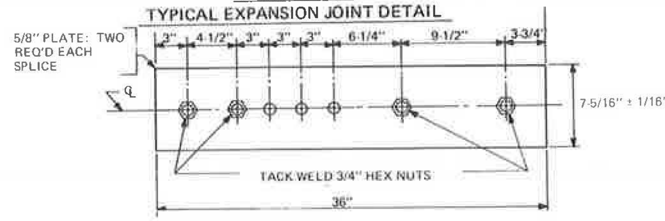
SECTION A–A
TYPICAL RAIL SPLICE DETAIL



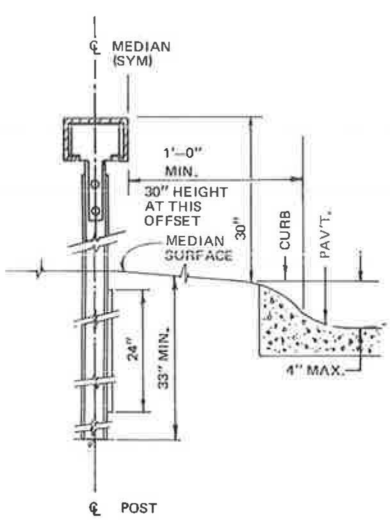
SECTION B–B
TYPICAL EXPANSION JOINT DETAIL



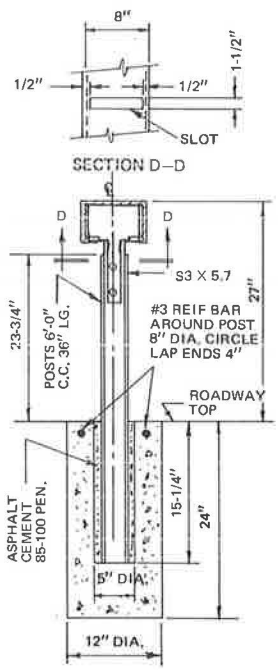
DETAIL A
SPLICE PLATE



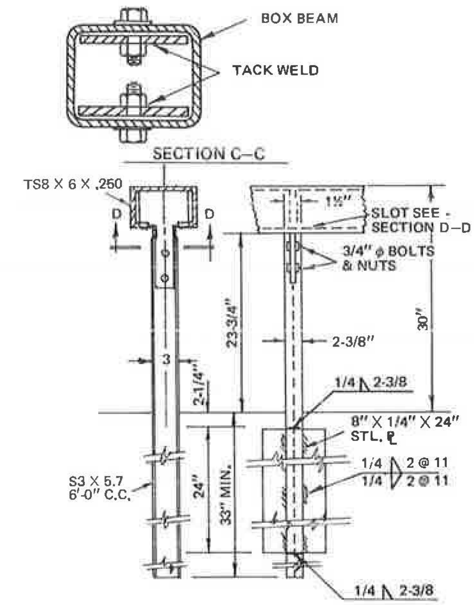
DETAIL B
SPLICE PLATE FOR EXPANSION JOINT



TYPICAL SECTION
OF RAISED MEDIAN
POSTS: 3I @ 5.7#

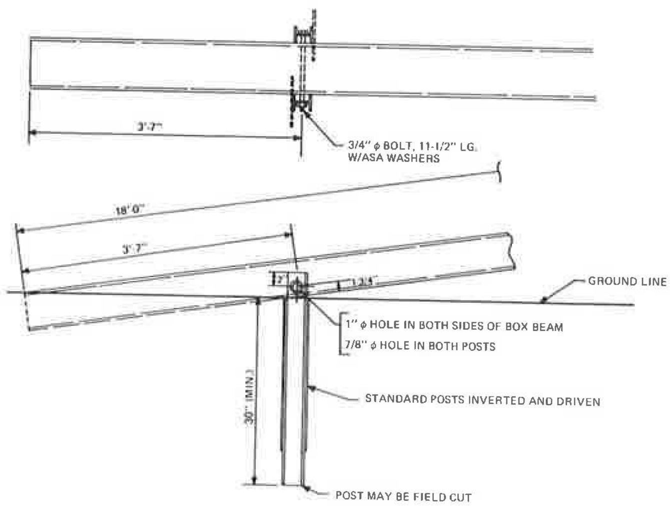


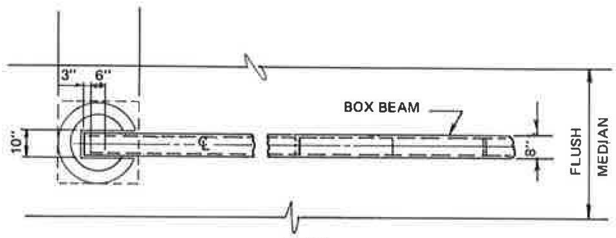
ALTERNATE POST ANCHOR
FOR PAVED MEDIANS



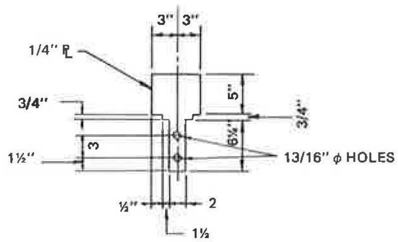
TYPICAL SECTION
FOR FLUSH MEDIAN

BOX BEAM MEDIAN BARRIER
TYPICAL END TREATMENT (WIDE MEDIANS)

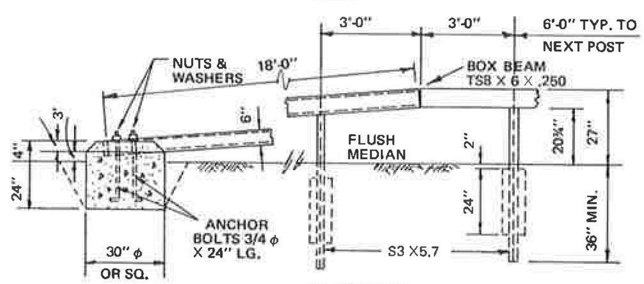




PLAN



PADDLE DETAIL
TWO PIECE PADDLE IS ACCEPTABLE ALTERNATE

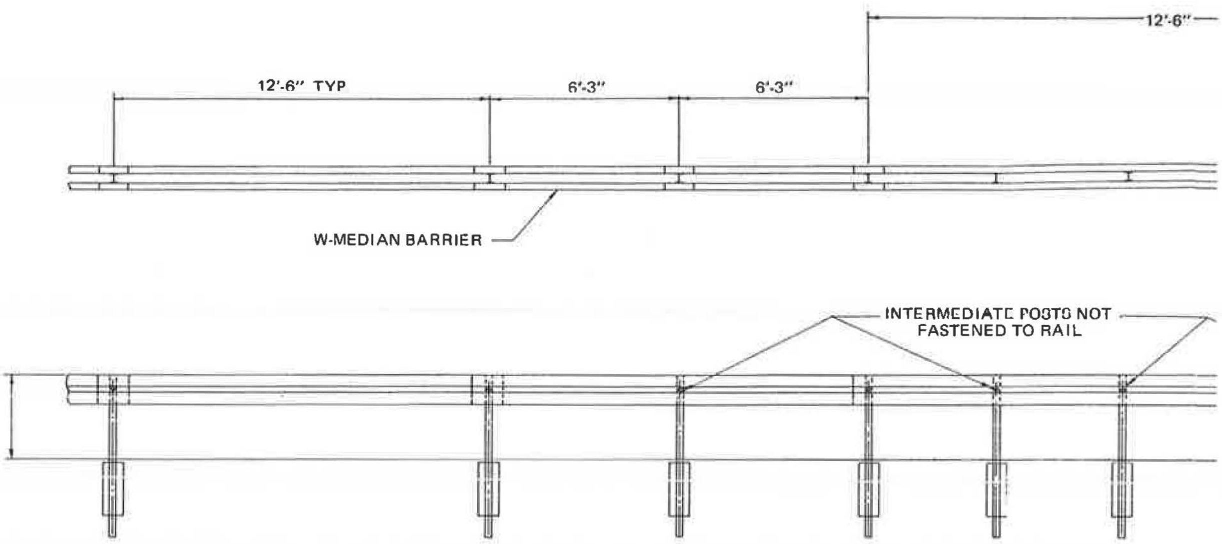


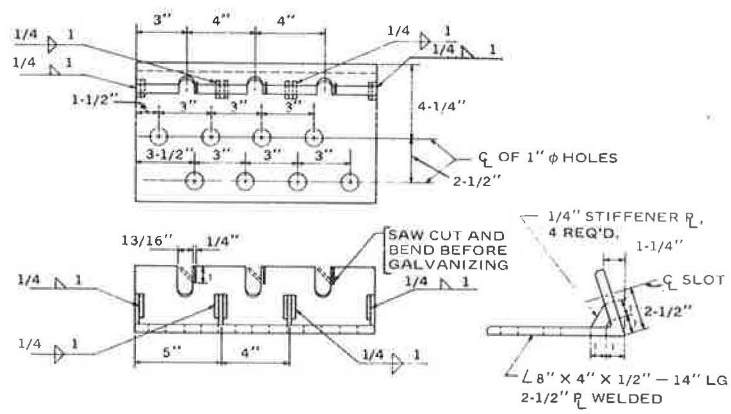
ELEVATION
TYPICAL END TREATMENT TYPE A NARROW MEDIANS

MB 3 GENERAL NOTES:

1. Min. length of rail tube to be 18′ nom.
2. Rail alignment to be straight at splices. No lateral bend permitted within the splice. This does not preclude the shop fabrication of bent splices.
3. Curved Median Barrier—For curves greater than 3°-15°—Box beam shall be shop worked to the required curvature.

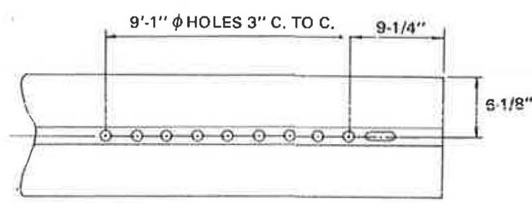
MEDIAN BARRIER
SYSTEM MB 3
BOX BEAM
DATE June 1968 REV. 1971
DEVELOPED BY New York



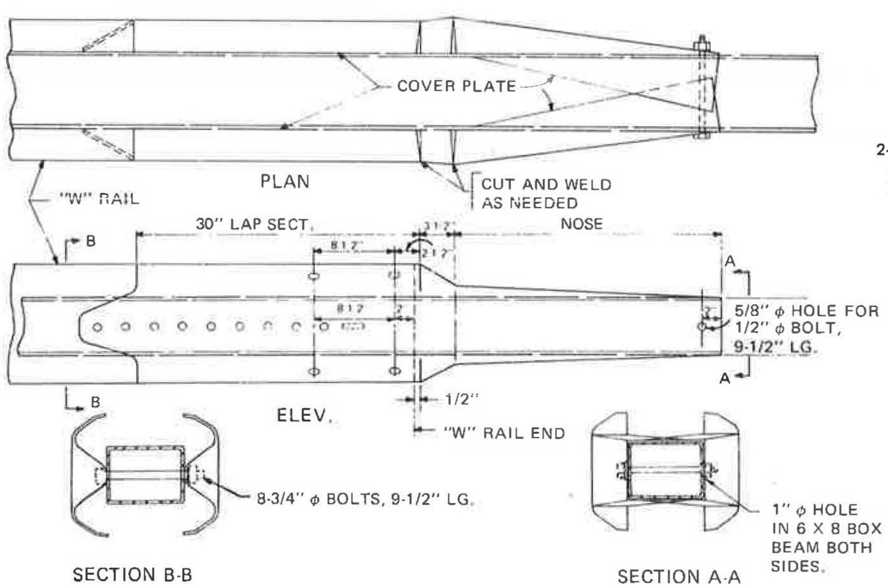


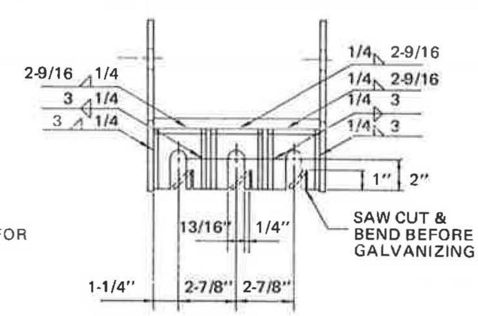
DETAIL F

ANCHOR ANGLE

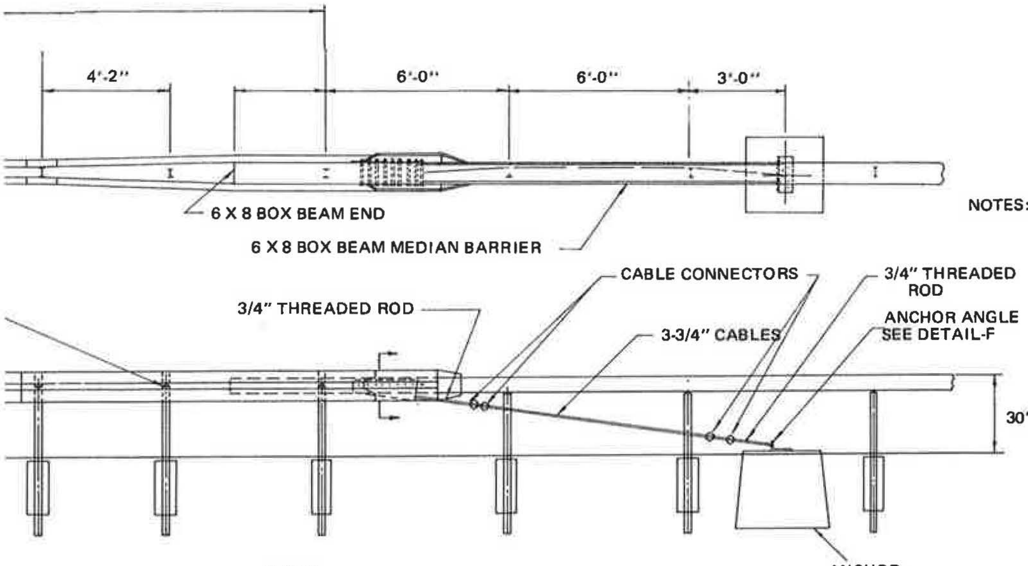


W-RAIL
DETAIL-A

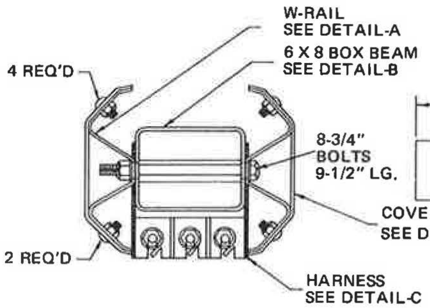




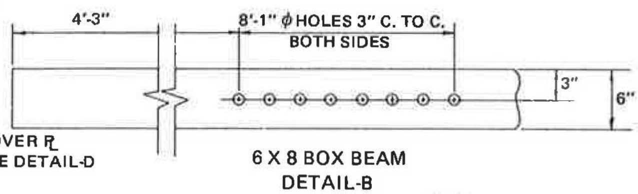
DETAIL D



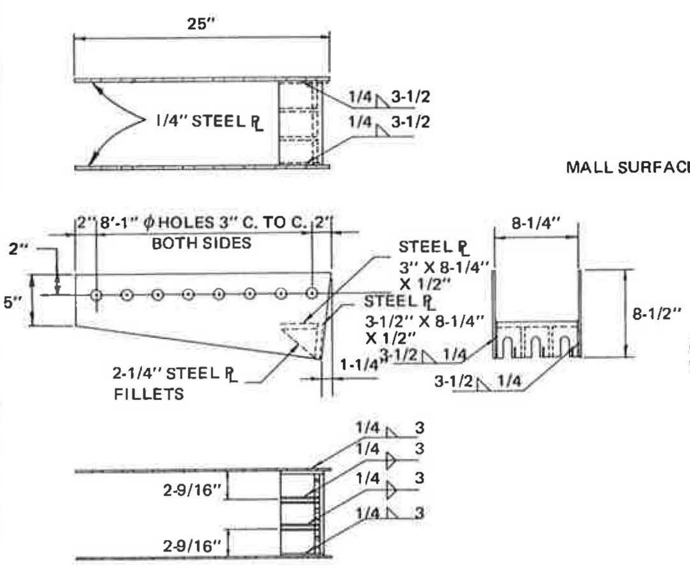
NOTES: FOR POST DETAILS, SEE STD.



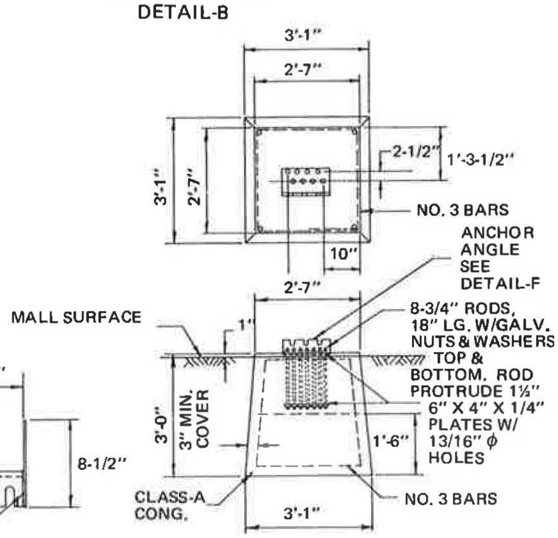
SECTION A-A



6 X 8 BOX BEAM
DETAIL-B

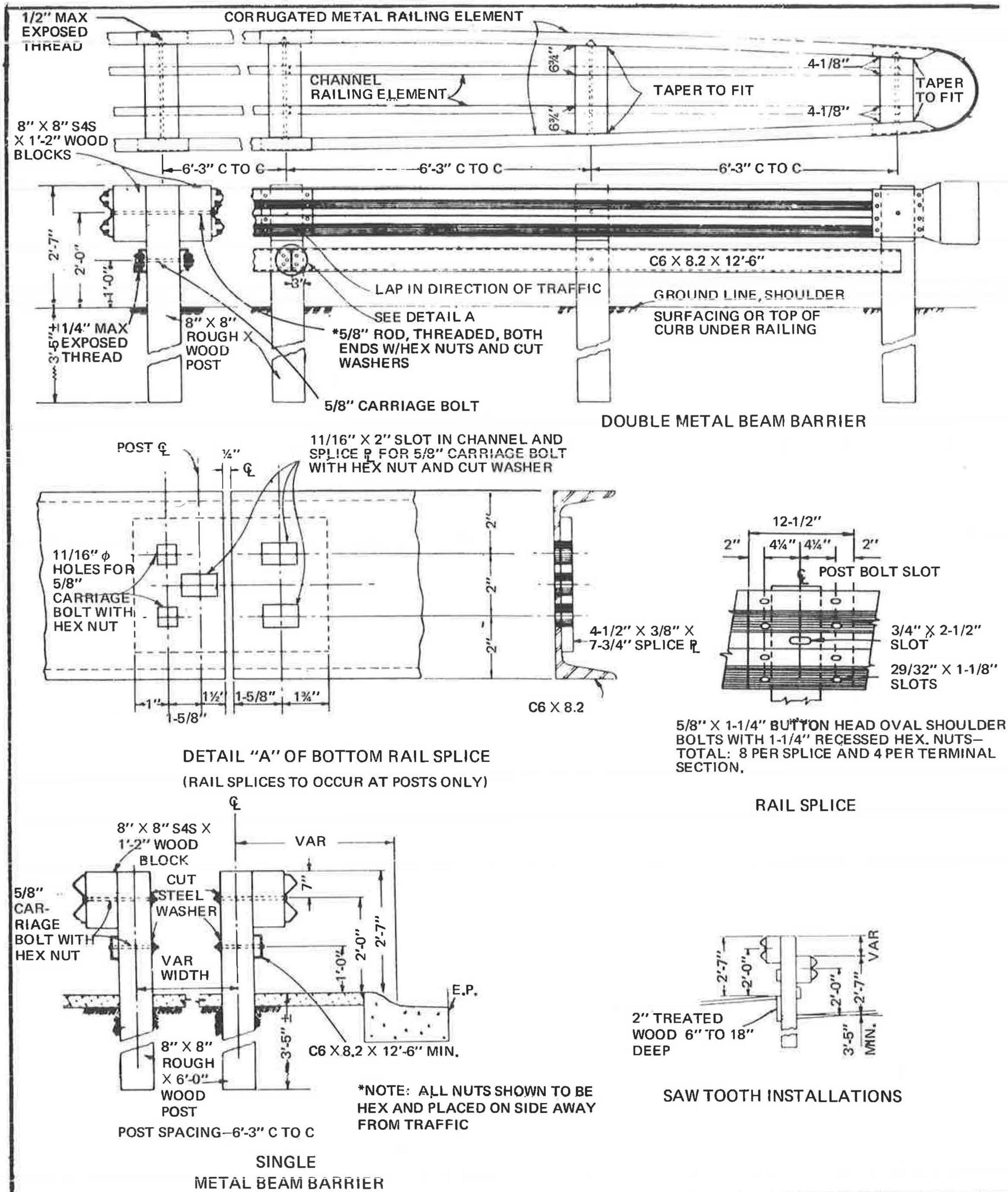


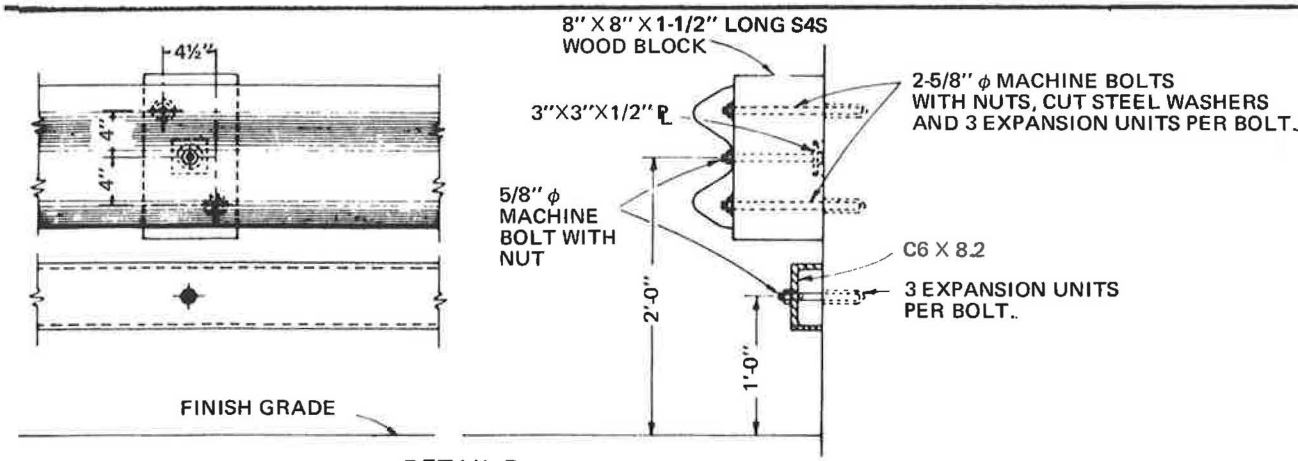
HARNESS
DETAIL-C



ANCHOR
DETAIL–E

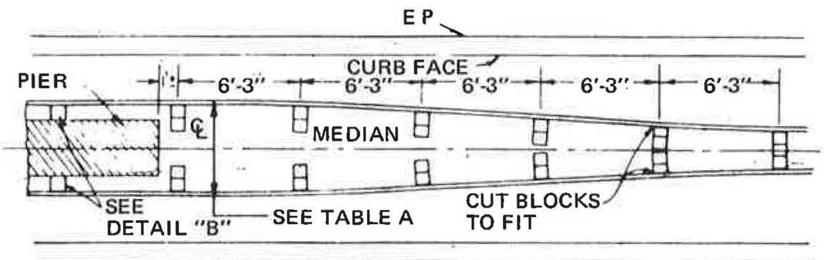
SHEET 6
TRANSITION DETAILS
MB 2, MB 3
DATE 1971 REV.
DEVELOPED BY New York


1/2" MAX EXPOSED THREAD
CORRUGATED METAL RAILING ELEMENT
CHANNEL RAILING ELEMENT
6¾"
6¾"
TAPER TO FIT
4-1/8"
4-1/8"
TAPER TO FIT
8" X 8" S4S X 1'-2" WOOD BLOCKS
6'-3" C TO C
6'-3" C TO C
6'-3" C TO C
2'-7"
2'-0"
1'-0"
3'-5"
1/4" MAX EXPOSED THREAD
8" X 8" ROUGH X WOOD POST
3"
C6 X 8.2 X 12'-6"
LAP IN DIRECTION OF TRAFFIC
GROUND LINE, SHOULDER SURFACING OR TOP OF CURB UNDER RAILING
SEE DETAIL A
*5/8" ROD, THREADED, BOTH ENDS W/HEX NUTS AND CUT WASHERS
5/8" CARRIAGE BOLT
DOUBLE METAL BEAM BARRIER
POST ℄
¼"
℄
11/16" X 2" SLOT IN CHANNEL AND SPLICE ℙ FOR 5/8" CARRIAGE BOLT WITH HEX NUT AND CUT WASHER
11/16" ϕ HOLES FOR 5/8" CARRIAGE BOLT WITH HEX NUT
2"
2"
2"
1"
1½"
1-5/8"
1¾"
1-5/8"
4-1/2" X 3/8" X 7-3/4" SPLICE ℙ
C6 X 8.2
DETAIL "A" OF BOTTOM RAIL SPLICE
(RAIL SPLICES TO OCCUR AT POSTS ONLY)
12-1/2"
2"
4¼"
4¼"
2"
℄ POST BOLT SLOT
3/4" X 2-1/2" SLOT
29/32" X 1-1/8" SLOTS
5/8" X 1-1/4" BUTTON HEAD OVAL SHOULDER BOLTS WITH 1-1/4" RECESSED HEX. NUTS— TOTAL: 8 PER SPLICE AND 4 PER TERMINAL SECTION.
RAIL SPLICE
℄
8" X 8" S4S X 1'-2" WOOD BLOCK
VAR
CUT STEEL WASHER
5/8" CARRIAGE BOLT WITH HEX NUT
7"
2'-0"
2'-7"
1'-0"
VAR WIDTH
E.P.
3'-5"
8" X 8" ROUGH X 6'-0" WOOD POST
C6 X 8.2 X 12'-6" MIN.
POST SPACING—6'-3" C TO C
SINGLE METAL BEAM BARRIER
*NOTE: ALL NUTS SHOWN TO BE HEX AND PLACED ON SIDE AWAY FROM TRAFFIC
2'-7"
2'-0"
VAR
2'-0"
2'-7"
3'-5" MIN.
2" TREATED WOOD 6" TO 18" DEEP
SAW TOOTH INSTALLATIONS



DETAIL B

(USED ONLY WHEN NECESSARY)

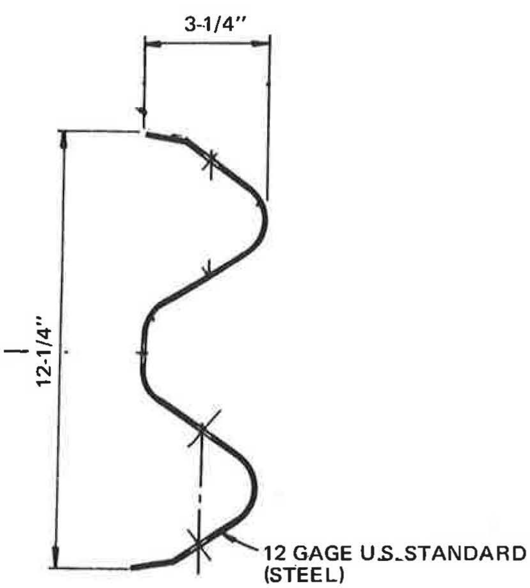


METAL BEAM BARRIER OBSTRUCTION DEFLECTOR

PLAN AT BRIDGE PIERS OR MEDIAN OBSTRUCTIONS

TABLE A

MEDIAN WIDTH FT.	DEFLECTOR WIDTH–FT.
22	6
23	7
24	8
25	9
26 and over	10



SECTION THRU RAIL ELEMENT

GENERAL NOTES

1. Except where noted, cut washers are required at all bolt installations where nut would bear on wood.
2. See Sheet 2 for Anchorage Details.
3. See Sheets 3 and 4 for Flare Details.
4. See Sheet 5 for Connection Details.

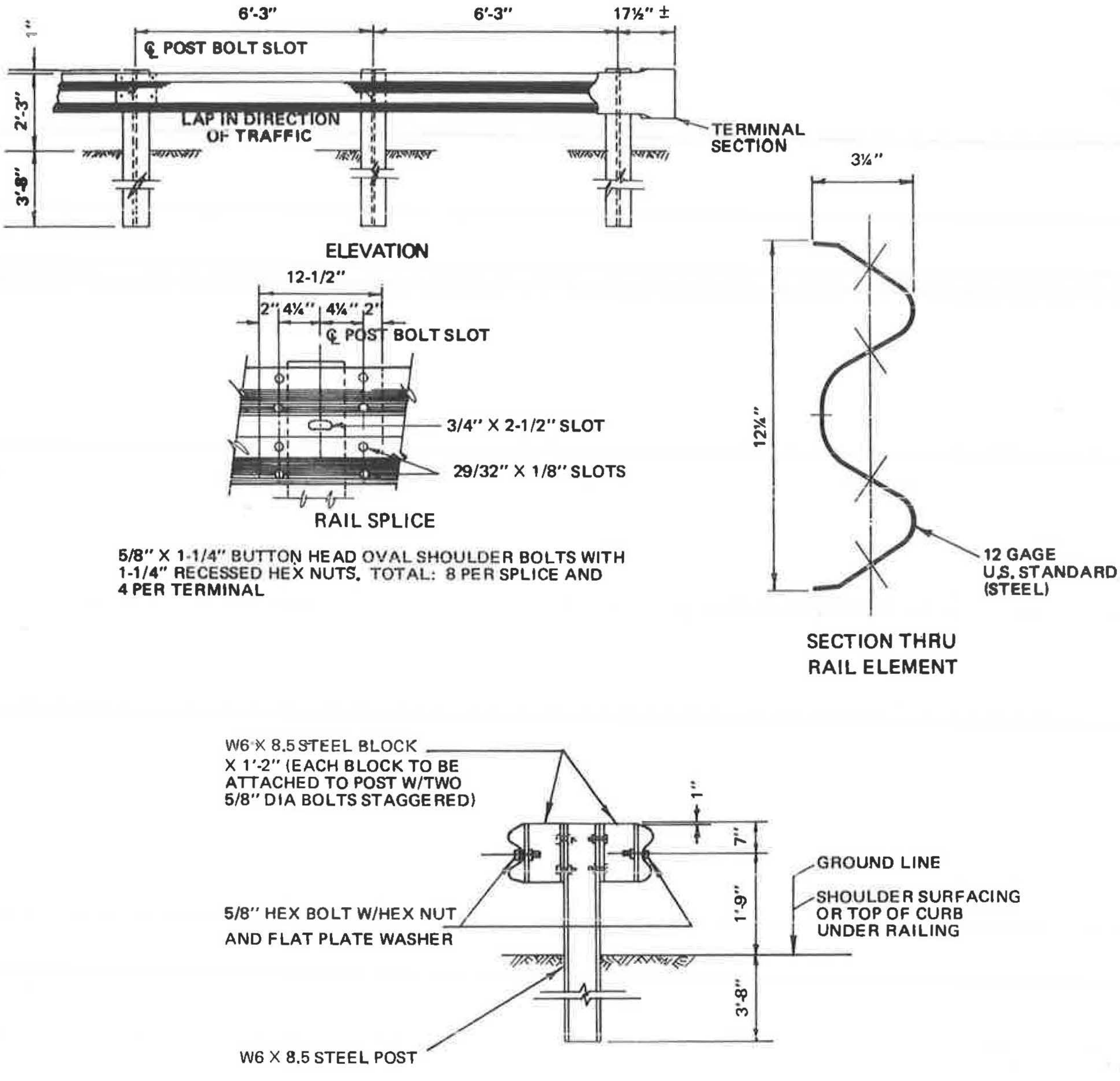
MEDIAN BARRIER

SYSTEM MB 4 W

BLOCKED OUT "W" BEAM

DATE June 68 REV. 1971

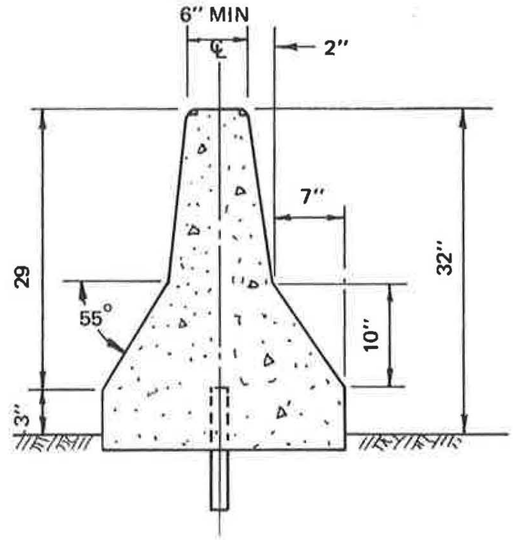
DEVELOPED BY California



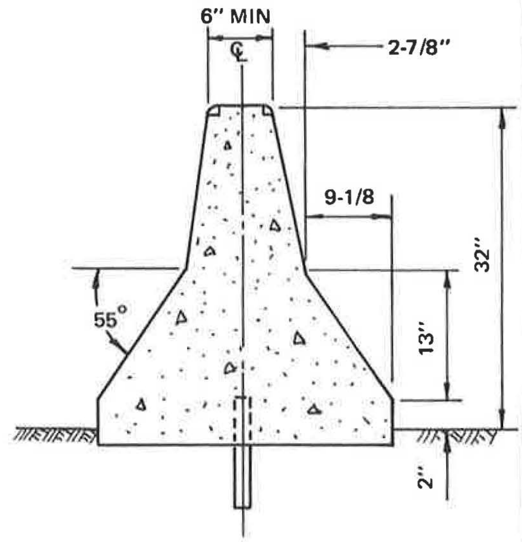
GENERAL NOTES

1. See Sheet 2 for Anchorage Details.

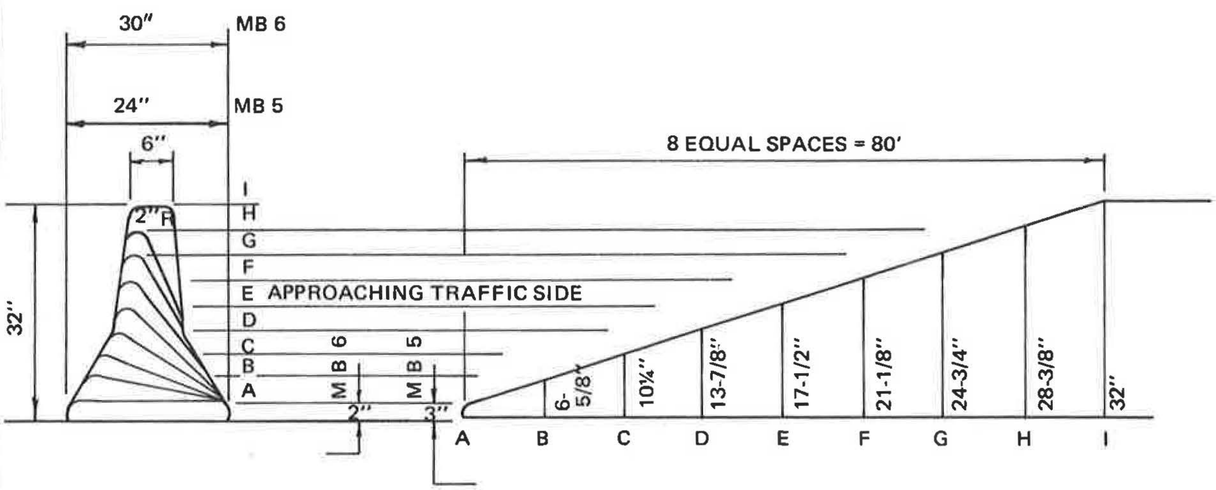
MEDIAN BARRIER
SYSTEM MB4 S
BLOCKED OUT "W" BEAM
STEEL POST
DATE 1971 REV. ______



BARRIER MB 5



BARRIER MB 6

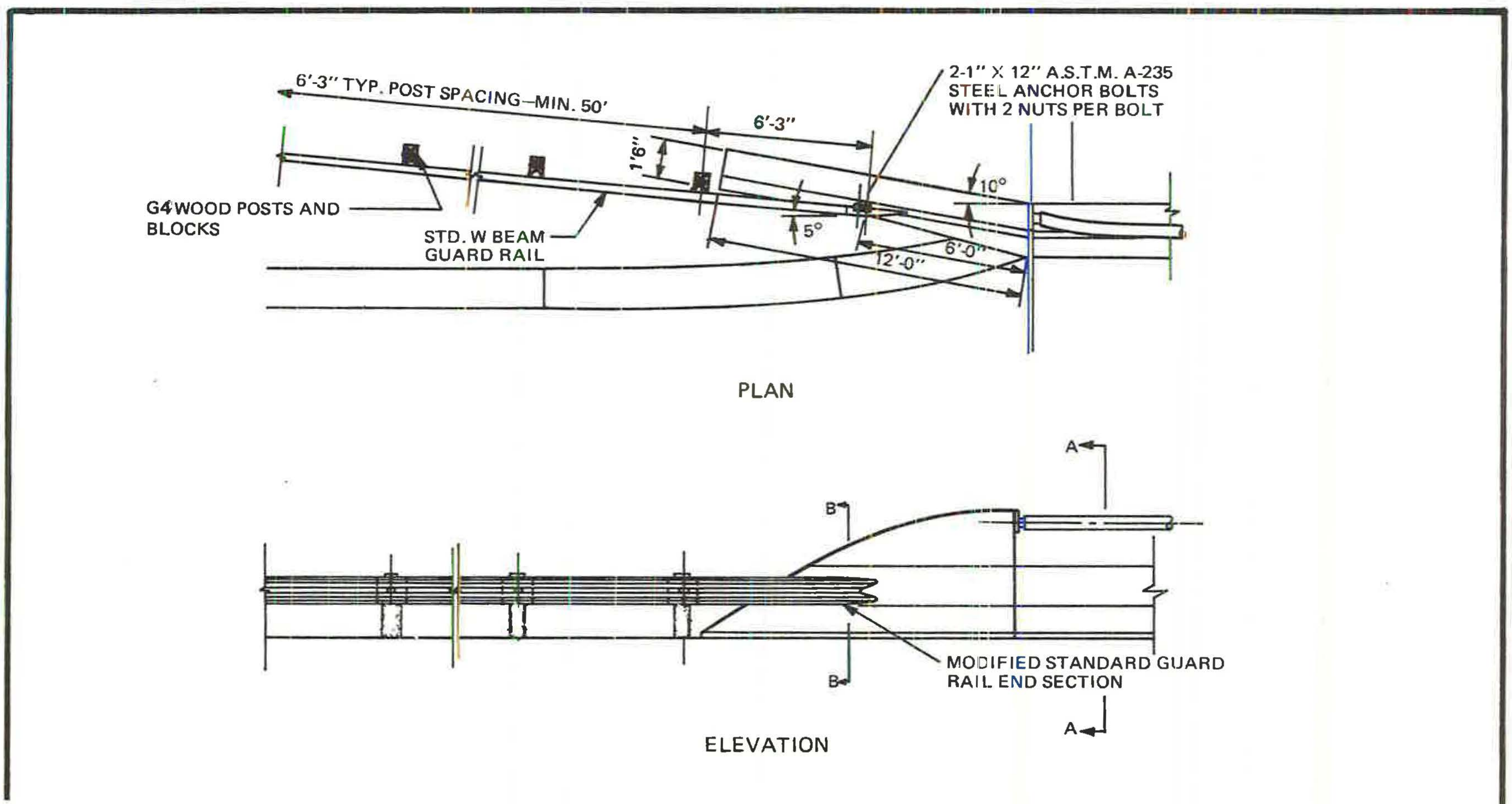


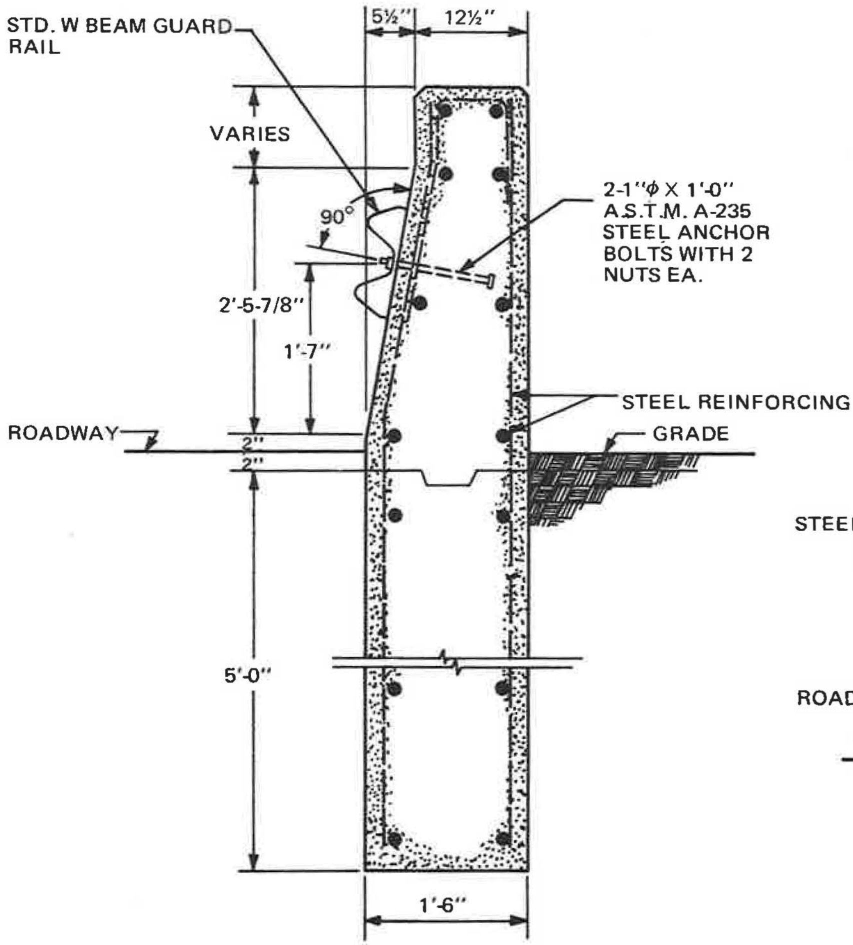
DETAIL SHOWING TRANSITION AT END OF INSTALLATION

GENERAL NOTES

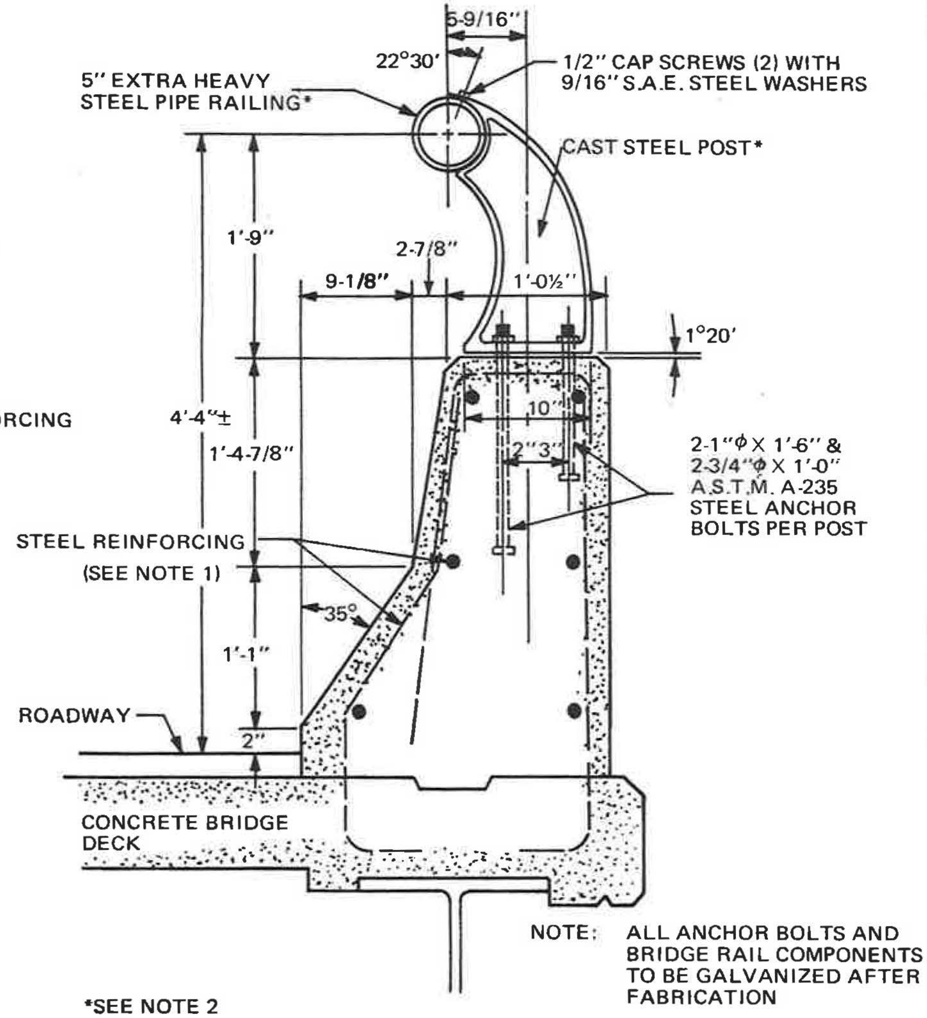
1. Concrete shall be Class B (AASHO).
2. Dowels 1" ϕ X 8" long shall be used if barrier is placed on existing paved median. (4'-0" C.C. spacing)
3. Transverse joints are recommended at 20-ft intervals.

MEDIAN BARRIERS
SYSTEMS MB 5–MB 6
CONCRETE
DATE June 1968 REV. 1971
MB 5 DEVELOPED BY New Jersey
MB 6 DEVELOPED BY General Motors


6'-3" TYP. POST SPACING—MIN. 50'
6'-3"
1'6"
2-1" X 12" A.S.T.M. A-235
STEEL ANCHOR BOLTS
WITH 2 NUTS PER BOLT
10°
G4 WOOD POSTS AND
BLOCKS
STD. W BEAM
GUARD RAIL
5°
6'-0"
12'-0"
PLAN
A
B
B
MODIFIED STANDARD GUARD
RAIL END SECTION
A
ELEVATION



SECTION B-B

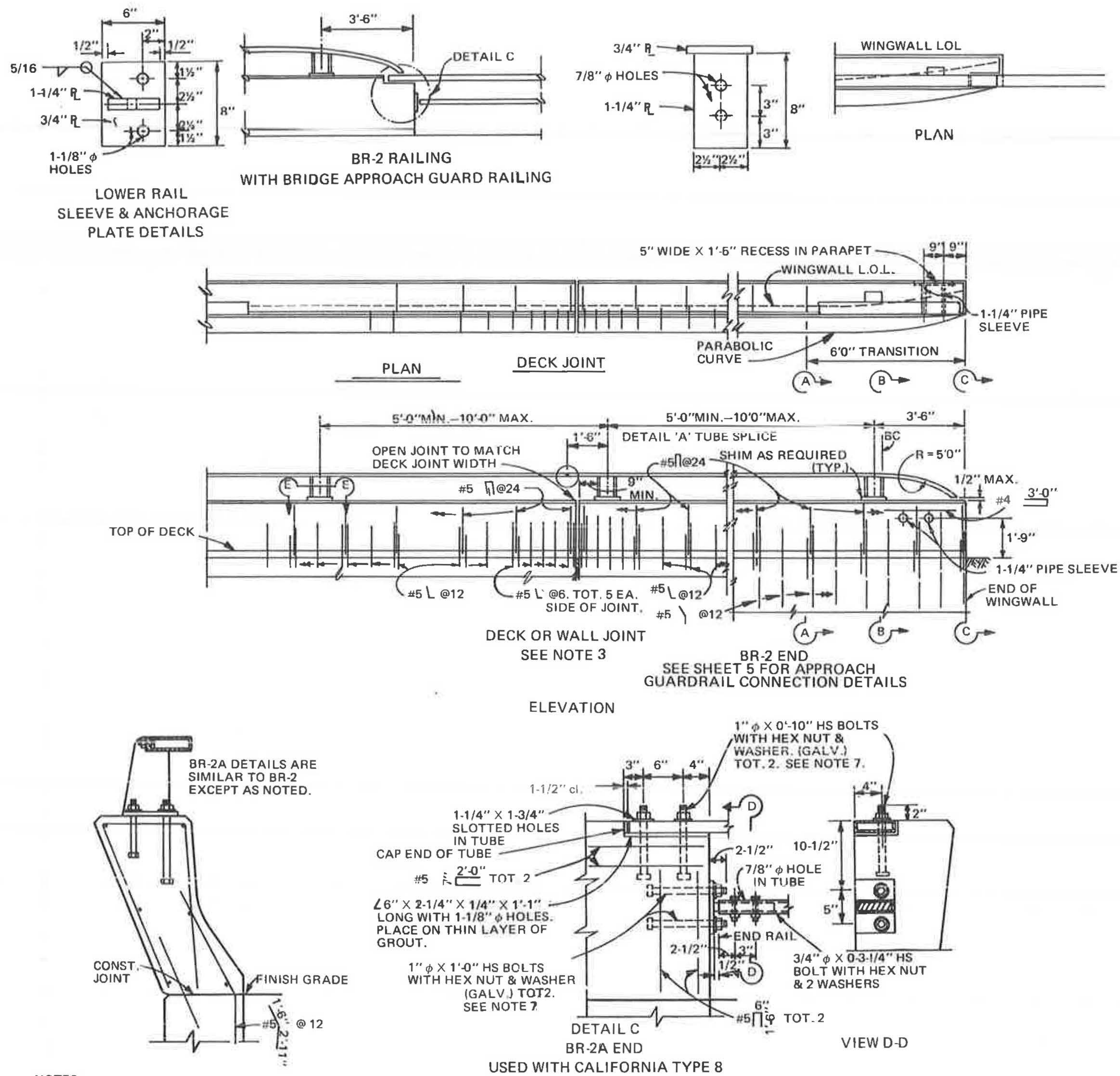


SECTION A-A

NOTES

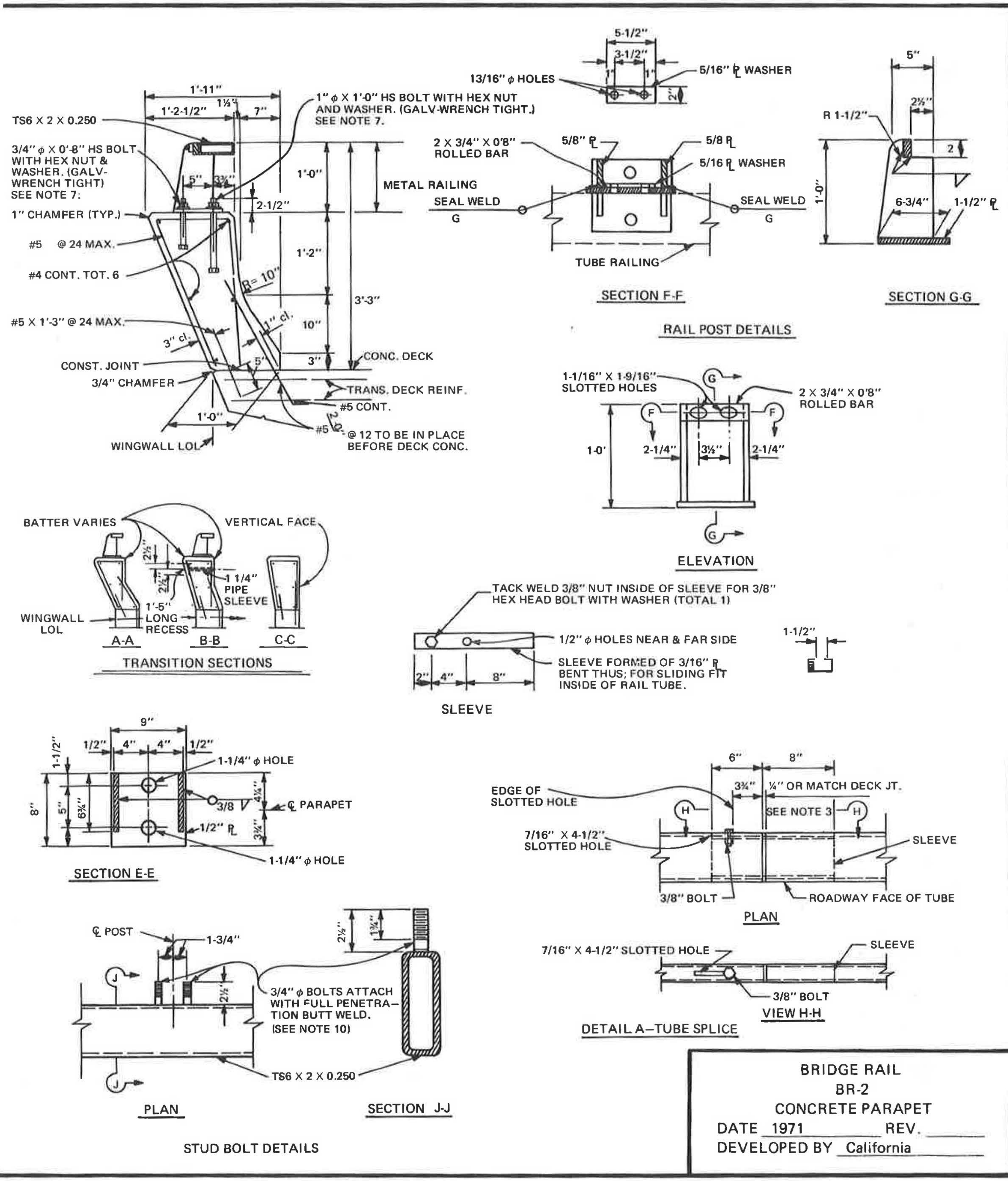
1. Design parapet according to "A.A.S.H.O. Specification for Highway Bridges," Tenth Edition, 1969.
2. Metal railing is optional.GM design is shown, but other railing may be used.

BRIDGE RAIL
BR-1
CONCRETE PARAPET
DATE 1971 REV.____________
DEVELOPED BY GENERAL MOTORS



NOTES:

1. TUBING SHALL BE SHOP BENT OR FABRICATED TO FIT HORIZONTAL CURVE WHEN RADIUS IS LESS THAN 950'.
2. POSTS SHALL BE NORMAL TO RAILING.
3. TUBE SPLICE SHALL BE LOCATED IN THE TUBE SPANNING DECK JOINTS. INCREASE JOINT WIDTH IN TUBE TO MATCH DECK OPENING AND INCREASE SLEEVE LENGTH CORRESPONDINGLY.
4. CLEARANCE TO REINFORCING STEEL IN CURB AND RAILING TO BE 1". LONGITUDINAL REINFORCEMENT TO STOP AT ALL JOINTS.
5. TORQUE RAIL TO POST NUTS TO 175 FT. LB.
6. TUBING SHALL BE CONTINUOUS OVER NOT LESS THAN TWO POSTS EXCEPT A SHORT LENGTH IS PERMITTED NEAR DECK JOINTS, ELECTROLIERS OR OTHER RAILING DISCONTINUITIES.
7. HIGH STRENGTH RODS THREADED BOTH ENDS WITH 2 NUTS AND WASHERS (ALL GALV.) MAY BE SUBSTITUTED FOR HIGH STRENGTH ANCHOR BOLTS.
8. GALVANIZE RAIL ASSEMBLY AFTER FABRICATION.
9. FOR W BEAM GUARDRAIL CONNECTION DETAILS, SEE SHEET 5.
10. STUD BOLD STEEL SHALL BE ASTM A108; ANCHOR BOLTS SHALL BE HIGH STRENGTH CONFORMING TO ASTM A325 (GALV).



TS6 X 2 X 0.250
3/4" ϕ X 0'-8" HS BOLT WITH HEX NUT & WASHER. (GALV-WRENCH TIGHT) SEE NOTE 7:
1" CHAMFER (TYP.)
#5 @ 24 MAX.
#4 CONT. TOT. 6
#5 X 1'-3" @ 24 MAX.
CONST. JOINT
3/4" CHAMFER
WINGWALL LOL
1" ϕ X 1'-0" HS BOLT WITH HEX NUT AND WASHER. (GALV-WRENCH TIGHT.) SEE NOTE 7.
METAL RAILING
CONC. DECK
TRANS. DECK REINF.
#5 CONT.
#5 @ 12 TO BE IN PLACE BEFORE DECK CONC.
13/16" ϕ HOLES
5/16" PL WASHER
2 X 3/4" X 0'8" ROLLED BAR
SEAL WELD
TUBE RAILING
SECTION F-F
SECTION G-G
RAIL POST DETAILS
1-1/16" X 1-9/16" SLOTTED HOLES
ELEVATION
BATTER VARIES
VERTICAL FACE
1 1/4" PIPE SLEEVE
WINGWALL LOL
1'-5" LONG RECESS
A-A
B-B
C-C
TRANSITION SECTIONS
TACK WELD 3/8" NUT INSIDE OF SLEEVE FOR 3/8" HEX HEAD BOLT WITH WASHER (TOTAL 1)
1/2" ϕ HOLES NEAR & FAR SIDE
SLEEVE FORMED OF 3/16" PL BENT THUS; FOR SLIDING FIT INSIDE OF RAIL TUBE.
SLEEVE
1-1/4" ϕ HOLE
℄ PARAPET
SECTION E-E
EDGE OF SLOTTED HOLE
¼" OR MATCH DECK JT.
SEE NOTE 3
7/16" X 4-1/2" SLOTTED HOLE
SLEEVE
3/8" BOLT
ROADWAY FACE OF TUBE
PLAN
VIEW H-H
DETAIL A–TUBE SPLICE
℄ POST
3/4" ϕ BOLTS ATTACH WITH FULL PENETRATION BUTT WELD. (SEE NOTE 10)
TS6 X 2 X 0.250
PLAN
SECTION J-J
STUD BOLT DETAILS
BRIDGE RAIL
BR-2
CONCRETE PARAPET
DATE 1971 REV.
DEVELOPED BY California

APPENDIX E

MECHANICS OF CRASH CUSHIONS

A moving body such as a highway vehicle possesses kinetic energy that is determined by

$$KE = \frac{W V^2}{2g} \qquad \text{(E-1)}$$

in which W is the body weight (lb), V is the body speed (ft/sec), and g is acceleration due to gravity (ft/sec²). For instance, a 4,500-lb car traveling at 60 mph (88 ft/sec) possesses kinetic energy of $\frac{4500(88)^2}{2(32.2)} = 540{,}000$ ft-lb. In a similar manner, kinetic energy of a 2,000-lb car traveling at 60 mph is calculated to be 240,000 ft-lb.

In stopping a car under normal operating conditions, the car's kinetic energy is dissipated by air drag, rolling friction, and braking forces. However, these forces are of such low magnitude that considerable distance (i.e., several hundred feet) is traversed by the car during stoppage. At critical highway sites where errant vehicles must be safely stopped and the normal vehicle stopping distance is unavailable, crash cushions are used to decelerate the vehicle at a controlled rate.

As shown in Figure E-1, vehicle average deceleration (i.e., from a selected impact speed) is a function of distance, regardless of vehicle weight. For example, it is impossible to stop a vehicle traveling at 60 mph in 20 ft at less than 6g average deceleration. Distance values taken from Figure E-1 are theoretical minimums and are increased due to crash cushion inefficiency.

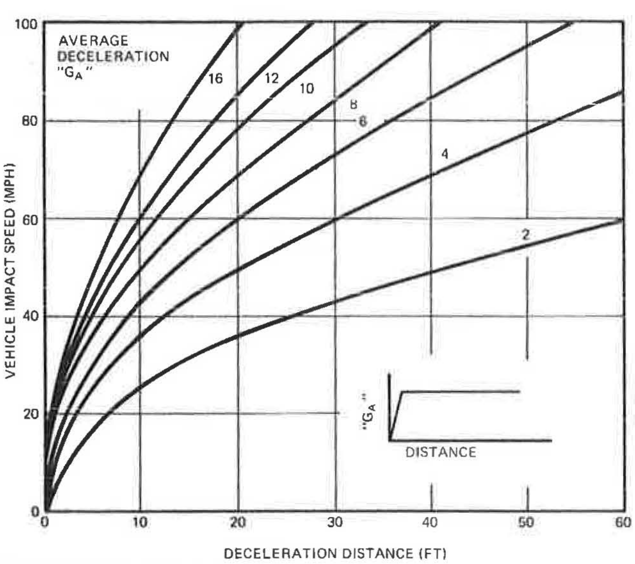


Figure E-1. Theoretical vehicle speed-deceleration distance relationship.

Crash cushion behavior may be analyzed by either of two approaches: (1) work-energy or (2) linear impulse-momentum. Selection of the analytical approach is normally made on the basis of convenience. As a guide, the *work-energy* approach is generally used for crash cushions such as barrel nests and entrapment nets, where the vehicle's kinetic energy is dissipated in plastic deformation of material. On the other hand, the *linear impulse-momentum* approach is used for crash cushion devices such as sand container systems, where the vehicle's kinetic energy is transferred to the cushion and then dispersed during the cushion disintegration into individual sand particles. These principles of mechanics are further described and illustrated with example problems in the following sections.

WORK-ENERGY ANALYSIS

The vehicle's kinetic energy dissipated by the crash cushion is equal to the work, U, of the crash cushion performed on the car. The work is determined by

$$U = \int_0^d F_x dx \qquad \text{(E-2)}$$

in which F_x is the crash cushion force acting on the car through a small crash cushion deformation, dx. For a cushion that deforms with a constant force, F, the work, U, is the product of F and the total cushion deformation, d. It is apparent from the simplified work equation $U = (F)(d)$ that there is an infinite number of force and displacement combinations that will produce a specified work. For instance, a 1,000-lb force displaced through 1 ft is the same work as a 1-lb force acting through 1,000 ft. However, there are two constraints imposed on a crash cushion that restrict the force and displacement combinations. First, the space available at a crash cushion site may be geometrically restricted. And, second, the crash cushion force must be less than that which will produce decelerations in the car that consequently cause occupant injuries and fatalities.

Deceleration intensity induced in the vehicle is a function of crash cushion force and vehicle weight. By Newton's second law, this deceleration can be expressed by

$$a = Fg/W \text{ (ft/sec}^2\text{)} \qquad \text{(E-3}a\text{)}$$

or

$$a' = \frac{F}{W} \text{ (}g\text{'s)} \qquad \text{(E-3}b\text{)}$$

in which F and W are, respectively, crash cushion force and vehicle weight, both in pounds. Thus, for a certain crash cushion force, deceleration is inversely proportional to vehicle weight—the heavier the car, the smaller the deceleration.

One approach to the design of a crash cushion is to establish the barrier force so that it will not produce excessive deceleration in the small 2,000-lb car and then determine the required crash cushion deformation length based on the standard size car and work Eq. E-2; unfortunately, the resulting installation is extremely long, and hence not too practical. On a basis of least space used to safely stop vehicles with widely varying weights, an optimum crash cushion design exhibits a force that increases with barrier deflection; this increase can be linear, a step function, or closely related to one of the theoretical curves in Figure E-2 (*11*). A small car impacting one of such designs is decelerated to a stop by the initial part of the barrier, prior to excessive buildup of force. A heavier car is decelerated at a slower rate during the initial part of barrier deformation; thereafter, deceleration increases to a more effective level with increased deformation.

Design of Barrel Nest Crash Cushion (*5, 13*)

Static crush tests of barrels * show that they are deformed to 25 percent of their original diameter; thus a 2-ft diameter barrel will crush to approximately 0.5 ft. The average static crushing force and static energy consumed have been determined to be:

Static force, $f_s = 6$ kips.

Static energy consumption, $e_s = 9$ ft-kips.

Also, the average dynamic crushing force and dynamic energy consumption have been experimentally determined to be 1.5 times the corresponding static values, or:

Dynamic force, $f_d = 1.5(6) = 9$ kips.

Dynamic energy consumption, $e_d = 1.5(9) = 13.5$ ft-kips.

Performance Mechanisms

Figure E-3 shows the successive crushing of barrels when the system is impacted head-on by a vehicle. As the vehicle deforms the crash cushion, a stopping force is applied to the vehicle.

The force necessary to crush the first row of barrels (two abreast) is $2f_d = 18$ kips. Similarly, after the next eight rows of barrels have been crushed (at $3f_d$), the total crushing force is $4f_d$ during the crushing of the last three rows (four abreast). The kinetic energy consumed in crushing all 38 barrels is $KE = N_b\, e_d = 38(13.5) = 513$ ft-kips.

Design Example

A crash cushion device is to be placed at an elevated gore to safely decelerate 2,000- to 4,500-lb vehicles traveling at 60 mph. A 20-gauge, 55-gal steel barrel with a 7-in.-diameter hole in the center of each end is the basic element. The problem is to determine the number and the arrangement of barrels that will fulfill these design criteria.

* 55-gal, 20-gauge steel drums with 7-in.-diameter hole in top and bottom.

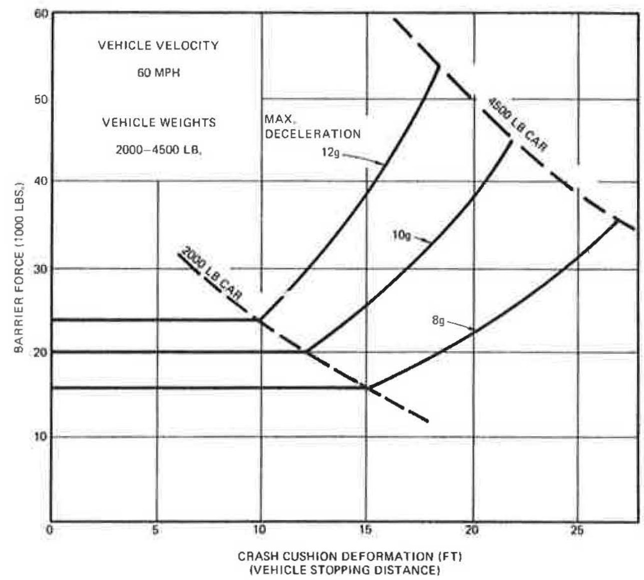


Figure E-2. Theoretical barrier force-deformation relationship (11).

Kinetic energy of the two vehicles as determined previously:

KE = 540 ft-kips (4,500-lb vehicle).

KE = 240 ft-kips (2,000-lb vehicle).

The minimum number of barrels needed in the crash cushion is found by

$$N_b = \frac{KE}{e_d} = \frac{540 \text{ ft-kip}}{13.5 \text{ ft-kip/barrel}} = 40 \text{ barrels for the 4,500-lb vehicle}$$

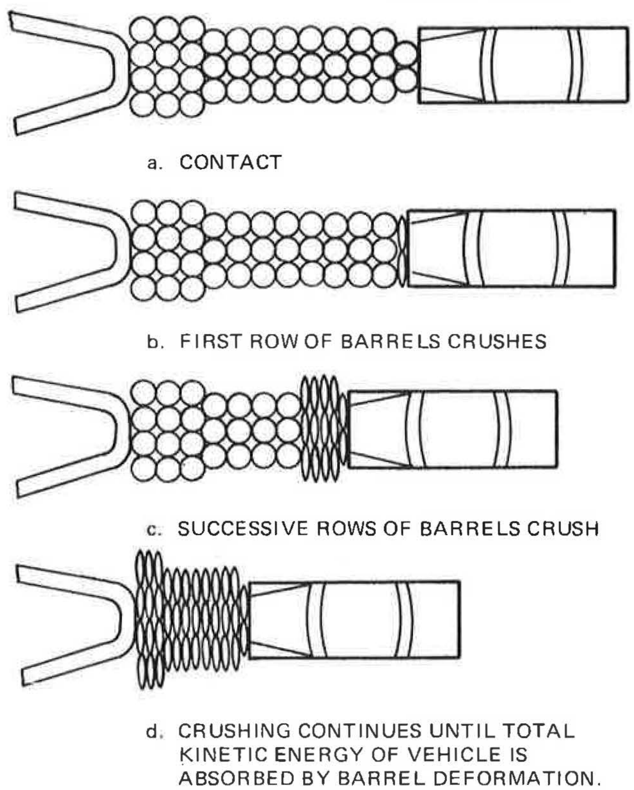


Figure E-3. Successive crushing of crash cushion system C1.

and

$$N_b = \frac{KE}{e_d} = \frac{240 \text{ ft-kip}}{13.5 \text{ ft-kip/barrel}} = 17.8, \text{ use 18 barrels for the 2,000-lb vehicle.}$$

It now remains to arrange the barrels in such a way that an acceptable deceleration level will be achieved. As shown in Table E-1, vehicle deceleration level is determined by the number of barrels in a row and the vehicle weight. A deceleration level of 12g's, as *averaged over the entire stopping distance,* has been accepted by FHWA (*15*) as a practical limit that should not be exceeded if passenger injuries are to be minimized or avoided. Even though the three-barrel row will produce a high momentary deceleration level (13.5g's) in the 2,000-lb car, the *average* deceleration over the entire stopping distance can be obtained by using one- and two-barrel rows. One barrel nest configuration is shown in Figure E-4; the barrier stopping force is a stepped function corresponding to the number of barrels in a row.

Vehicle penetration into the crash cushion is determined by equating vehicle impact kinetic energy to the area under the curve in Figure E-4 and bound by the unknown vehicle penetration abscissa. The general expression is

TABLE E-1

VEHICLE DECELERATION LEVEL

NO. OF BARRELS IN ROW	DYNAMIC CRUSHING FORCE (KIPS)	VEH. DECEL. LEVEL (G'S) 2,000-LB CAR	4,500-LB CAR
1	9	4.5	2.0
2	18	9.0	4.0
3	27	13.5	6.0
4	36	18.0	8.0
5	45	22.5	10.0

$$U = \int_0^d F_x dx = \sum_{\text{Cushion Segment } i}^{n} a_i f_d b_i \qquad \text{(E-4)}$$

in which a_i is the number of barrels in the width of the crash cushion segment, f_d is the average dynamic crushing force of a single barrel, and b_i is the cushion segment deformation. (The calculations are based on laboratory and full-scale crash test observations that a 2-ft-diameter, 55-gal, 20-gauge steel barrel with 7-in.-diameter holes in top and bottom deforms 1.5 ft with an average dynamic crushing force of 9 kips.) Referring to Figure E-4, penetration

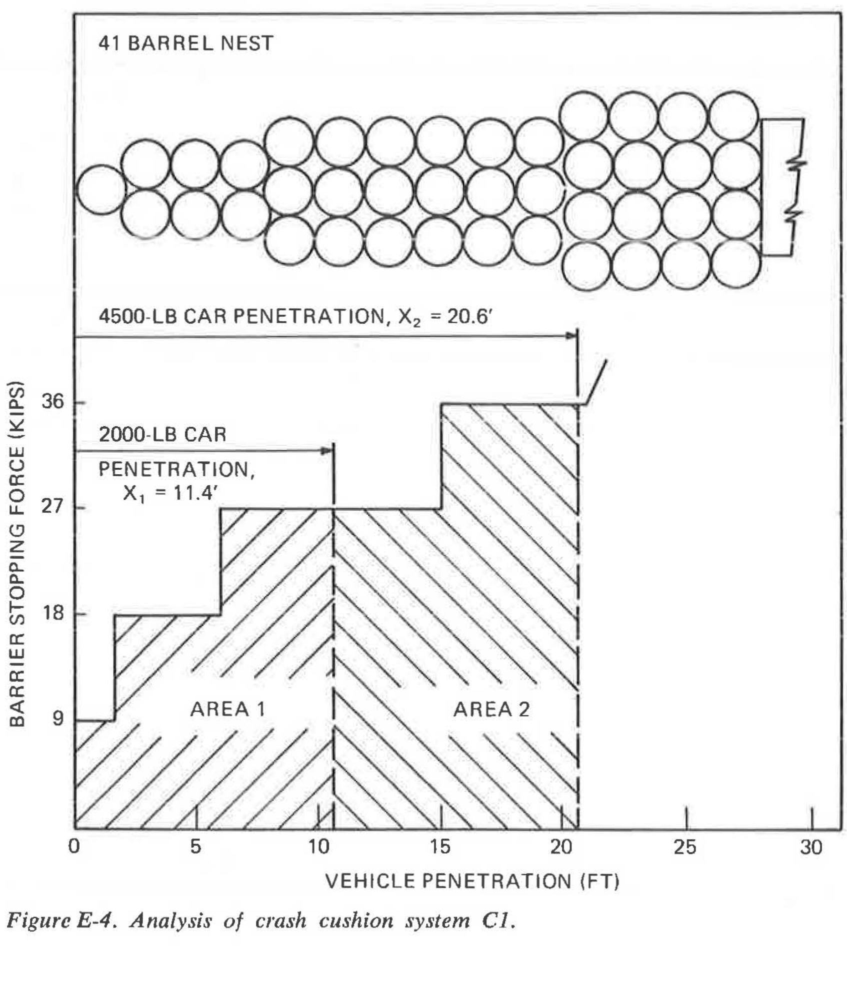


Figure E-4. Analysis of crash cushion system C1.

for the 2,000-lb vehicle is calculated from Eq. E-4 (Area 1) as 240 ft-kip $= (1)(9)(1.5) + (2)(9)(6-1.5) + (3)(9)(X_1-6)$

or

$X_1 = 11.4$ ft from impact with barrier.

In a similar manner, the 4,500-lb vehicle penetration is determined (refer to Fig. E-4, Area 1 + Area 2) as 540 ft-kip $= 240$ ft-kip $+ (3)(9)(15-11.4) + 4(9)(X_2-15)$

or

$X_2 = 20.6$ ft from impact with the barrier.

The average deceleration level * for each vehicular impact by the proposed barrier configuration is calculated to determine compliance.

$$G_a = \frac{V^2}{2g\,X_i} \qquad \text{(E-5}a\text{)}$$

or

$$X_i = \frac{V^2}{2g\,G_a} \qquad \text{(E-5}b\text{)}$$

in which V is vehicle impact velocity (ft/sec), g is acceleration due to gravity, and X_i is vehicle penetration (or stopping) distance.

For a 2,000-lb vehicle:

$$G_a = \frac{(88)^2}{2(32.2)(11.4)} = 10.5g\text{'s, less than } 12.0g\text{'s, acceptable.}$$

For a 4,500-lb vehicle:

$$G_a = \frac{(88)^2}{2(32.2)(20.6)} = 5.8g\text{'s, less than } 12.0g\text{'s, acceptable.}$$

The foregoing example illustrates the work-energy analysis approach for crash cushions subjected to head-on impacts; a similar procedure for side impacts is not available. As with the longitudinal traffic barrier systems, the engineer should exercise extreme caution in making modifications to a system design that has performed satisfactorily in full-scale crash tests.

LINEAR IMPULSE-MOMENTUM ANALYSIS *(2)*

The collision between two bodies, such as a car and a barrier, where relatively large contact forces exist during a very short interval of time, is called "impact." If there are no external forces of magnitude and the mass of the barrier put into motion is small, the law of conservation of momentum as applied to such a system is

$$(M)(dV) = (V)(dm) \qquad \text{(E-6)}$$

where M and V are the vehicle mass and speed, respectively, at impact with a small stationary barrier of mass dm; dV is the small loss of vehicle speed. Furthermore, the barrier mass per unit length is expressed by dm/ds, where ds is an increment along the barrier side. Solving Eq. E-6 for dm, and dividing by ds,* and also by dt (time) in the numerator and denominator on the right, the barrier mass per unit length is expressed as

$$\frac{dm}{ds} = \frac{M\,dV/dt}{V\,ds/dt} \qquad \text{(E-6}a\text{)}$$

Inasmuch as dV/dt is acceleration, and ds/dt is velocity, Eq. E-6a can be recast into

$$\frac{dm}{ds} = \frac{M\,a}{V^2} \qquad \text{(E-6}b\text{)}$$

or

$$a = \frac{dm}{ds}\,\frac{V^2}{M} \qquad \text{(E-6}c\text{)}$$

which states that vehicle deceleration is directly proportional to the barrier mass per unit length and the vehicle velocity squared, and inversely proportional to vehicle mass. Accordingly, minimum decelerations are induced in the heavier vehicles impacting the barrier at low speeds. This equation also implies that vehicle deceleration can be kept low by extending the mass of the barrier over a great length, thereby decreasing dm/ds.

For a barrier with a constant mass throughout its length, maximum vehicle deceleration will occur during the initial phase of impact and then decrease rapidly as the vehicle slows. Moreover, the mass of this system should be relatively low in order to maintain the maximum vehicle deceleration within human tolerance levels. Hence, length of the constant-mass barrier will be unnecessarily long because the average deceleration force will be well below human tolerance.

A more appropriate design approach is to proportion the barrier mass in such a manner that vehicle deceleration is constant throughout impact. Because V^2/a (from $s = V^2/2a$) is twice the stopping distance from velocity, V, at constant deceleration, a, Eq. E-6c becomes

$$\frac{dm}{ds} = \frac{M}{2s} \qquad \text{(E-7)}$$

This states that, for constant deceleration, the mass per unit length required at any point in the barrier is simply one-half the mass of the vehicle divided by the distance remaining to a fixed stopping point. Note that, for this analysis, the barrier mass put into motion must be small in comparison to the vehicle mass. The barrier mass requirement, according to Eq. E-7, approaches infinity as the distance approaches zero. However, in practice, dm/ds has a maximum feasible value corresponding to a final value of s (namely, s_f), which is determined by

$$s_f = \frac{M}{2\left(\dfrac{dm}{ds}\right)_{max}} \qquad \text{(E-8)}$$

where $\left(\dfrac{dm}{ds}\right)_{max}$ is the maximum feasible module mass per

* This procedure should be used only when the deceleration-time history is reasonably flat (e.g., not applicable for plots with high peaks or when the device bottoms out).

* s is referenced to vehicle terminal point of penetration, whereas x in Eq. E-2 is referenced to the point of impact.

unit length. Incremental module masses are then determined by

$$\frac{dm}{ds} = \left(\frac{dm}{ds}\right)_{max} \frac{s_f}{s_f + s_i} \qquad \text{(E-9)}$$

in which s_i are consecutive integers (model diameters) beginning with 0.

The constant vehicle deceleration will depend on barrier length and vehicle impact speed. Generally, length of the inertia phase of the barrier is determined by selecting a design impact speed and an acceptable vehicle deceleration level; length is then calculated from Eq. E-5b, in which G_a is the acceptable average vehicle deceleration in gravitational units.

Eq. E-7 cannot be practically satisfied as the distance, s, becomes small. Fortunately, the vehicle is decelerated to a relatively low speed (i.e., 10 to 15 mph) as it nears the end of the barrier's inertia phase. At this point, vehicle kinetic energy is dissipated by friction in the sand as the car bulldozes into this final barrier part. From practical experience, it has been determined that this second barrier part, or bulldozing phase, should consist of about 5 tons of sand.*

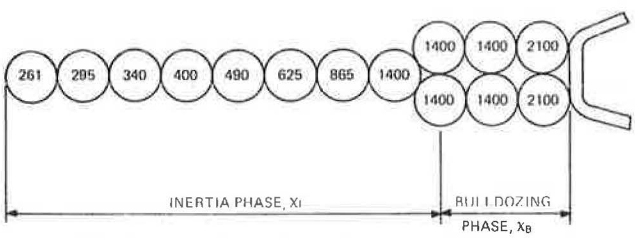


Figure E-5. Layout of crash cushion system C3.

Design Example

A C3-type crash cushion is to be placed at an elevated gore to safely decelerate a 2,000-lb and a 4,500-lb car impacting at 60 mph.

A vehicle deceleration of 5g's is selected. Also, inertial barrier modules of 3-ft diameter will be used; maximum module weight is 1,400 lb.

(a) Length of inertia part (Eq. E-5b) $= \frac{88^2}{(2)(32.2)(5)} =$ 24 ft, or about $2\frac{4}{3}$, or 8, modules long.

(b) Determine s_f (Eq. E-8) $= \frac{4500/32.2}{2(1400)/32.2} = 1.61$ module diameters.

(c) Determine modules weights (Eq. E-9) $= [(1400)] \frac{1.61}{(1.61 + 0, 1, 2, 3, 4, 5, 6, 7)} =$ 1400, 865, 625, 490, 400, 340, 295, 261 lb.

(d) Bulldozing phase, X_B: Five tons of sand can be provided by four 1,400-lb modules and two 2,100-lb modules.

Figure E-5 shows a layout of the C3 crash cushion system of the design example; it is not to be used as a suggested or recommended actual installation design layout without corroboration from full-scale crash testing. It is also to be noted that angle or side impacts were not considered in the design example.

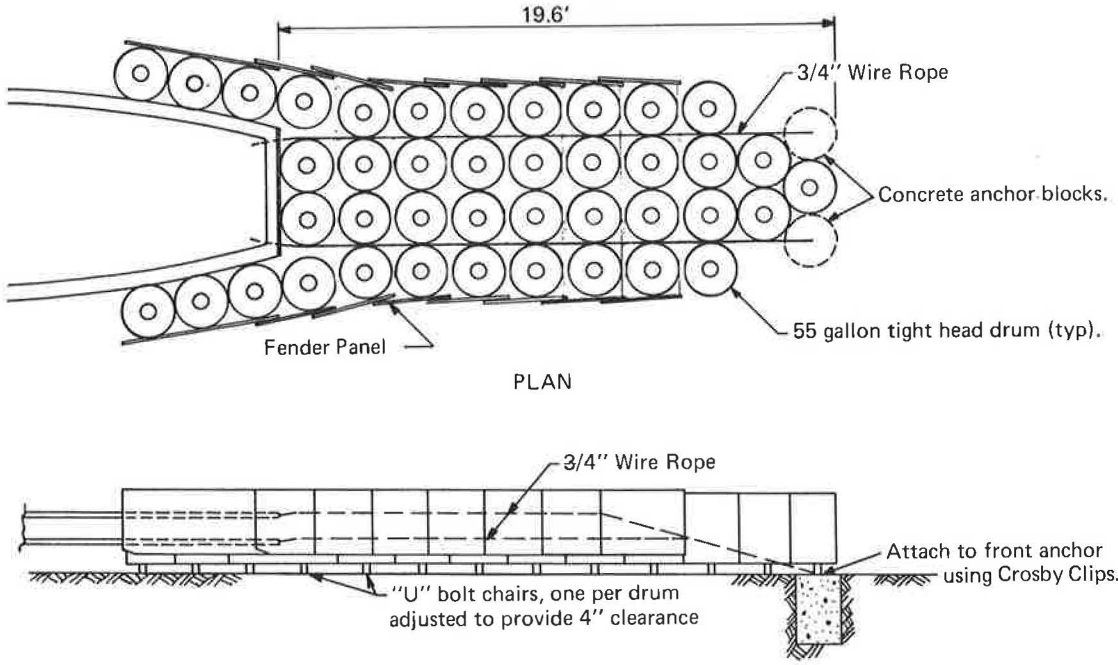
* The discussion in this paragraph is applicable to the crash cushion system C3.

APPENDIX F

CRASH CUSHION BARRIER SYSTEMS

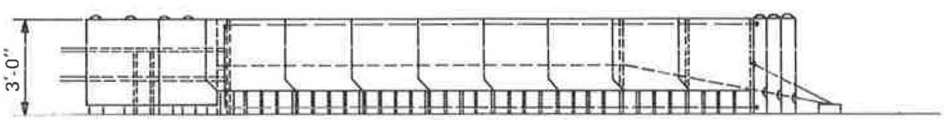
Examples of crash cushions are contained in this appendix. The information is of a general nature, inasmuch as the crash cushion barrier is in a relatively early stage of development and, therefore, subject to rapid change.

For a specific installation, the designer should contact the agency listed under "Information Source" for the current design details recommendation.

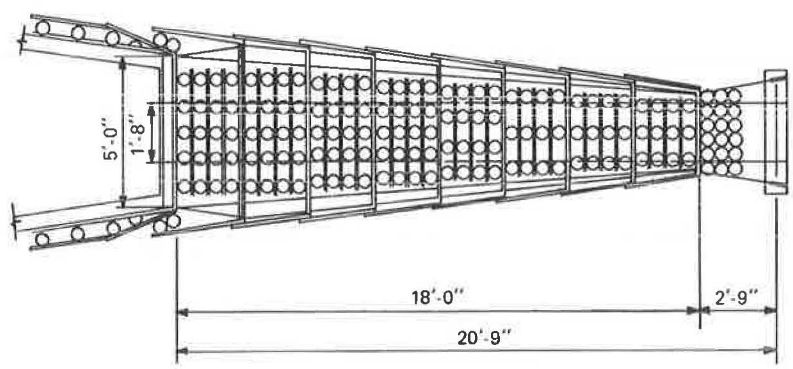


CRASH CUSHION SYSTEM C1

Operating Principle	Barrels are arranged in modular clusters at the hazard. Successive crushing of the barrels applies tolerable stopping forces to vehicle.
Developed By	Texas Transportation Institute in cooperation with Texas Highway Department and Federal Highway Administration
Tested By	Texas Transportation Institute, California Normal Impacts X Angle Impacts X
Field Installations	Texas, Indiana, Iowa, W. Virginia, Oregon, Florida, and California
Accident Experience	Several "hits" have been recorded including a 70 mph head-on in Houston. One fatality has been reported; otherwise experience thus far has been good.
Approximate Installation Costs	$4200 (Based on reports from six states on thirteen installations)
Information Source	Office of Research and Development, Federal Highway Administration, U.S. Steel
Remarks	This is one of the most well documented of all crash cushions with extensive crash test experience as well as field experience.
STATUS	OPERATIONAL

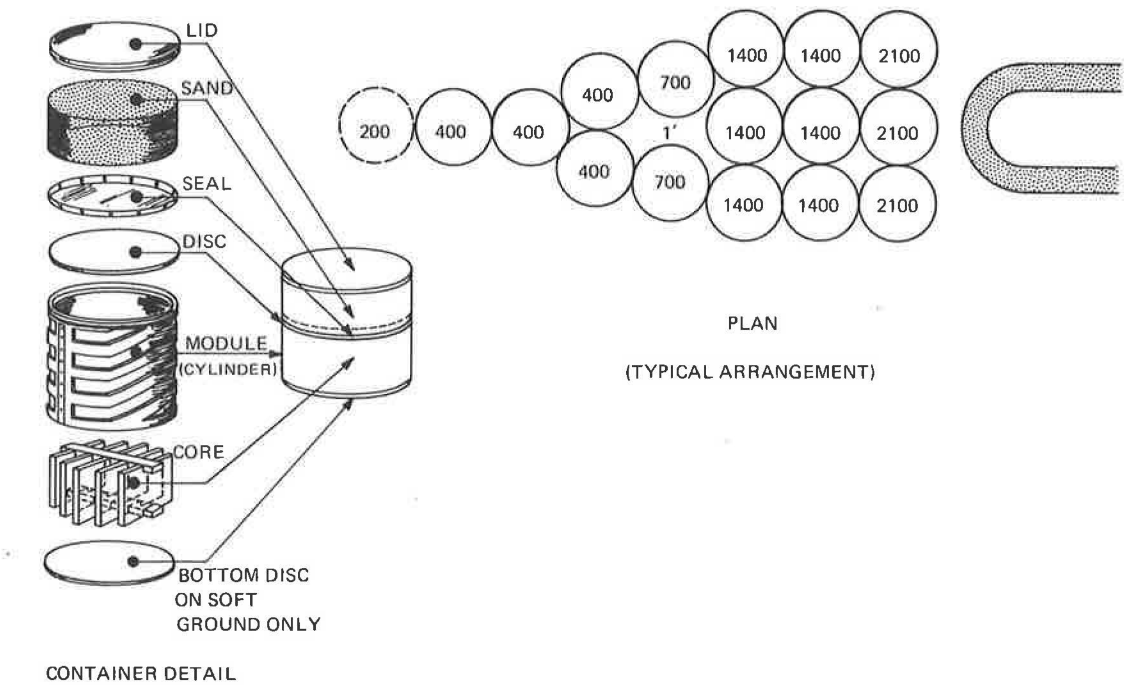


ELEVATION



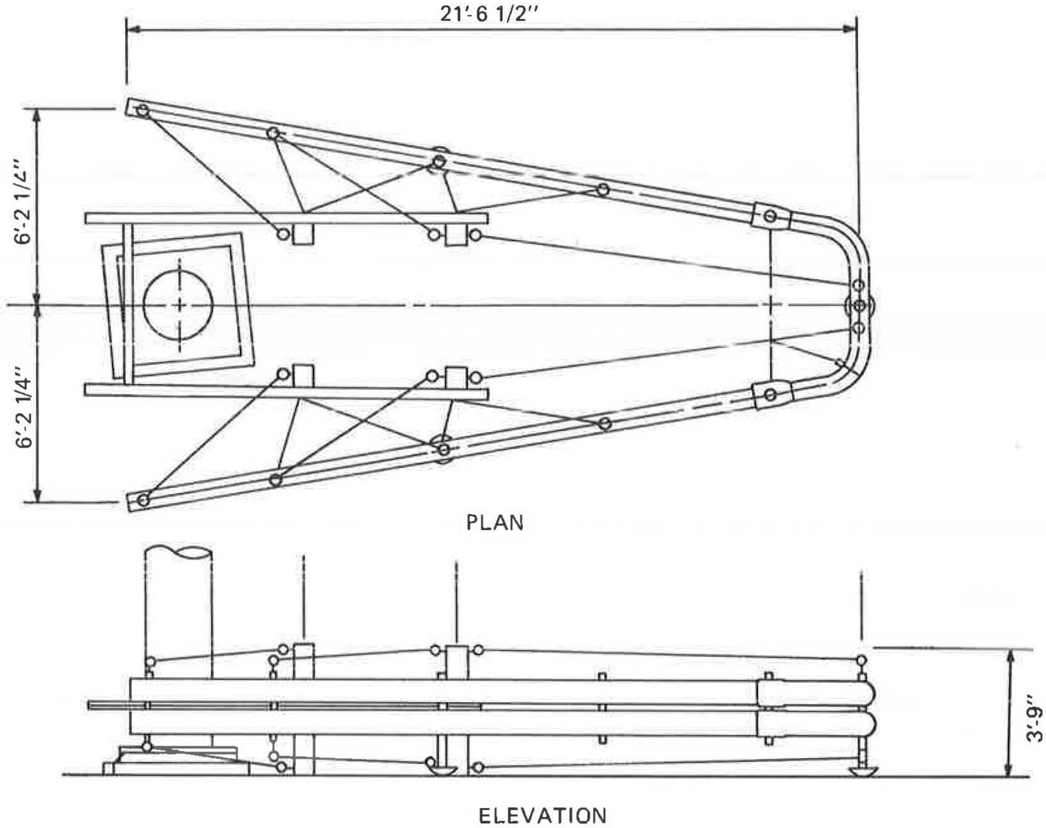
PLAN

CRASH CUSHION SYSTEM C2	
Operating Principle	Plastic cylinders filled with water are arranged in modular clusters. Energy is attenuated by forcing water out of cylinders.
Developed By	John Rich Enterprises, Inc* and Brigham Young University under contract sponsored by the Federal Highway Administration
Tested By	John Rich Enterprises, Inc., Brigham Young University, State of California, Texas Transportation Institute Normal Impacts __X__ Angle Impacts __X__
Field Installations	California, Louisiana, Kentucky, Pennsylvania, Hawaii, Oregon, and New Mexico
Accident Experience	Yes—New Mexico, Louisiana, and Hawaii have documented experience
Approximate Barrier Cost	$6000 (Based on reports from six states on 24 installations)
Damage Repair Cost Estimate	
Information Source	Energy Absorption Systems, Inc.; Federal Highway Administration (Office of Research and Development)
Remarks	*Energy Absorption Systems, Inc. of Chicago has purchased rights to Rich barriers.
STATUS	OPERATIONAL

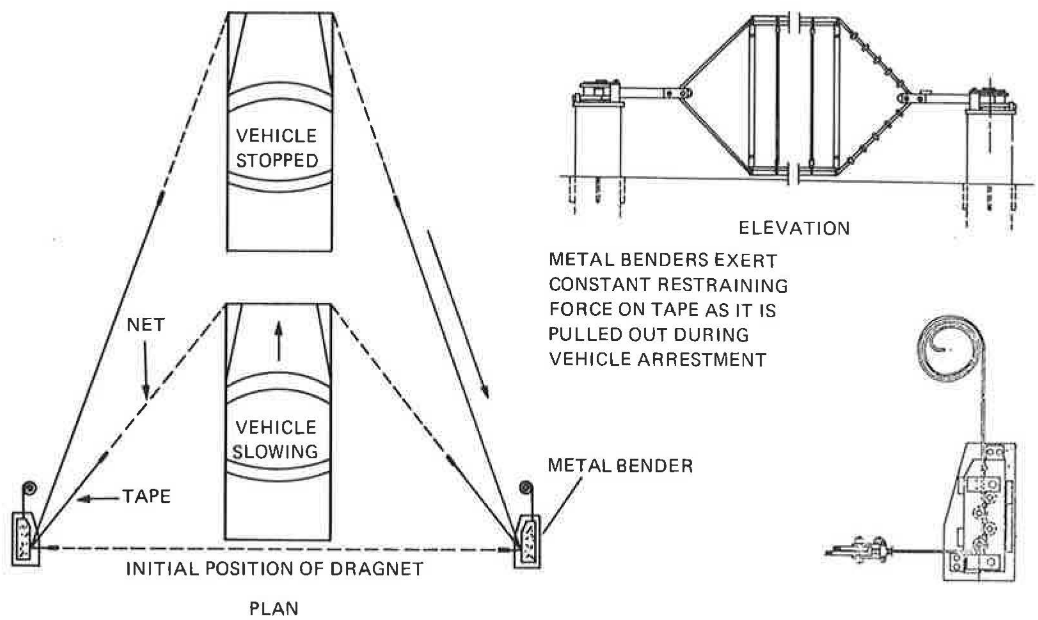


CRASH CUSHION SYSTEM C3

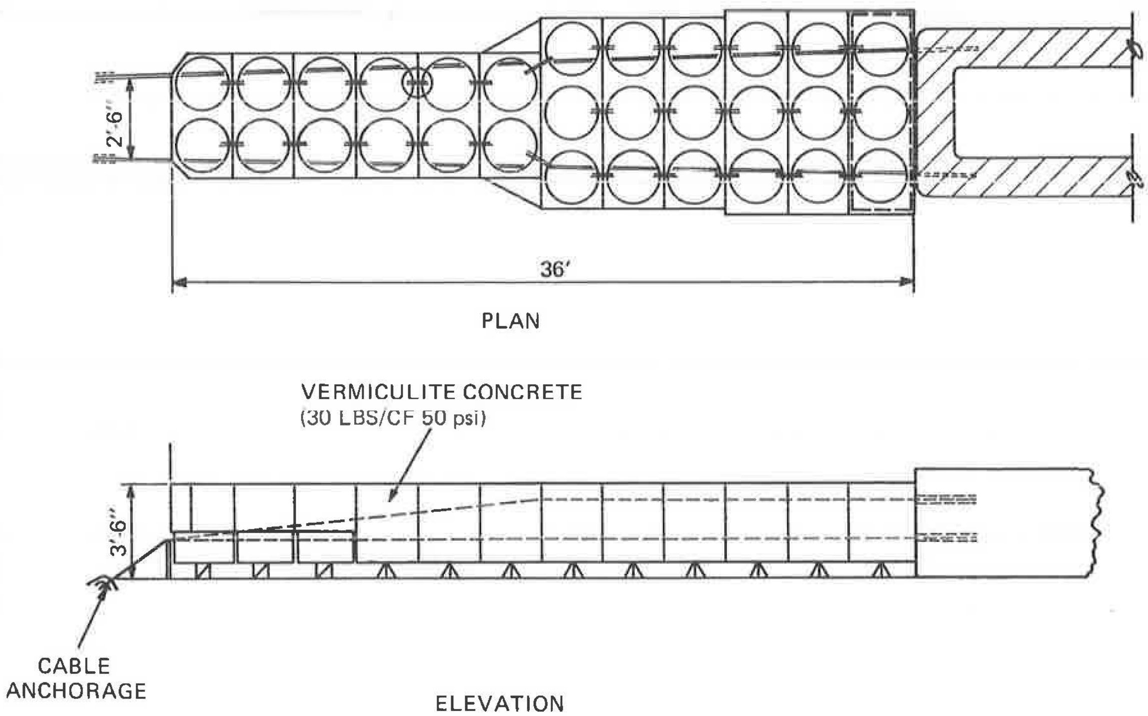
Operating Principle	Plastic barrels with top segment filled with sand are arranged in clusters at the hazard. Impacting vehicle energy is attenuated by displacing sand.
Developed By	John Fitch; marketed by FIBCO Inc., Hartford, Conn.
Tested By	FIBCO, California Normal Impacts Yes Angle Impacts Yes
Field Installations	Connecticut, Idaho, Canada, Kentucky, Pennsylvania, Oregon, Washington, Delaware, Massachusetts, and California.
Accident Experience	Yes—Connecticut has documented experience
Approximate Installed Cost	$4000 (Based on reports from five states on 27 installations)
Damage Repair Cost Estimate	
Information Source	FIBCO Incorporated, Hartford, Conn., Federal Highway Administration (Office of Research and Development)
Remarks	
STATUS	OPERATIONAL



CRASH CUSHION SYSTEM C4	
Operating Principle	Basic energy absorption is accomplished by compressing axially loaded cylinders. The energy attenuation is accomplished by deforming a steel torus placed between "telescoping" concentric cylinders. These axially loaded members are supported from the fixed hazard and attached to a protective tubular railing. This railing transmits crash loads to the energy absorbers.
Developed By	Aerospace Research Associates
Tested By	Aerospace Research Associates, Texas Transportation Institute under contract to the Federal Highway Administration Normal Impacts __X__ Angle Impacts __X__
Field Installations	Kansas, New Mexico, Delaware, North Carolina, Maryland, and Florida
Accident Experience	Yes–Kansas, Delaware, and New Mexico have documented experience
Approximate Installation Cost	$6000 (Based on reports from four states on 13 installations)
Damage Repair Cost Estimate	
Information Source	Federal Highway Administration (Office of Research and Development)
Remarks	System restricted for use on highways with posted speed of 50 mph or less.
STATUS	OPERATIONAL (Qualified; see Remarks)

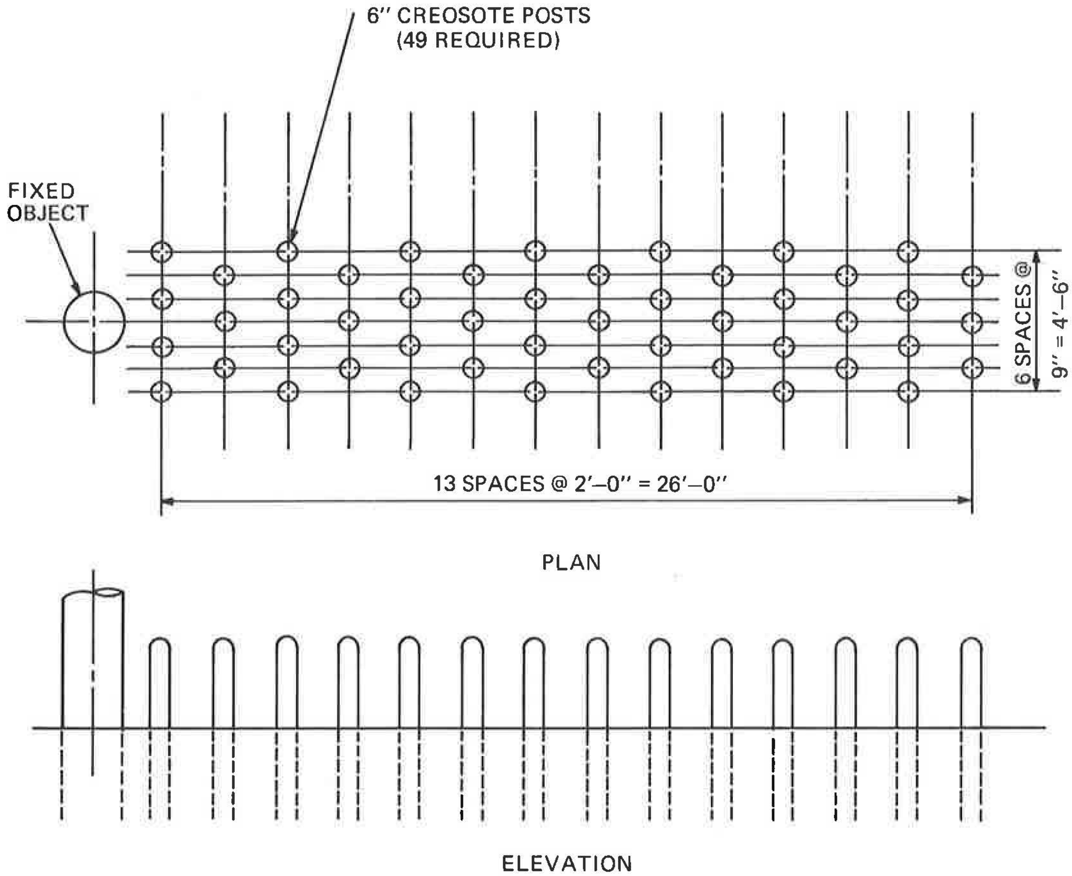


CRASH CUSHION SYSTEM XC-(a)	
Operating Principle	Vehicle kinetic energy is dissipated by Metal Benders energy absorbing device.
Developed By	Van Zelm Associates, Inc.
Tested By	Texas Transportation Institute under contract to Federal Highway Administration. Normal Impacts __X__ Angle Impacts __X__
Field Installations	None reported
Accident Experience	
Approximate Installed Cost	
Damage Repair Cost Estimate	
Information Source	Developer, Federal Highway Administration (Office of Research and Development)
Remarks	
STATUS	EXPERIMENTAL



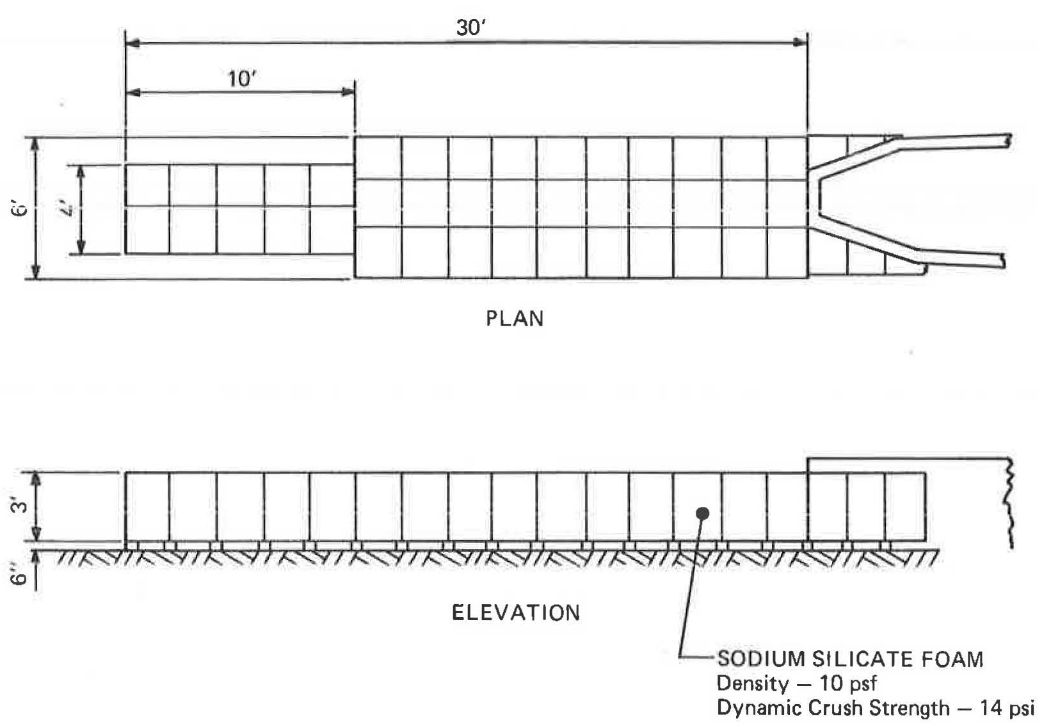
CRASH CUSHION SYSTEM YC-(b)

Attenuation System:	Lightweight cellular concrete
Operating Principle	Vehicle impacting energy is absorbed by successively crushing lightweight concrete modules.
Developed By	Texas Transportation Institute under contract with Federal Highway Administration
Tested By	Texas Transportation Institute Normal Impacts X Angle Impacts X
Field Installations	None
Accident Experience	
Approximate Installed Cost	
Damage Repair Cost Estimate	
Information Source	Federal Highway Administration (Office of Research and Development)
Remarks	
STATUS	R&D



CRASH CUSHION SYSTEM YC-(c)

Operating Principle	Vehicle impacting energy is absorbing by the breaking of posts and/or deformation of post in soil. (Other frangible members may be suitable alternate to timber posts.)
Developed By	Texas Transportation Institute and FHWA
Tested By	Texas Transportation Institute and FHWA Normal Impact Yes Angle Impact No
Field Installation	Mississippi
Accident Experience	None reported
Installation Cost	$2400
Damage Repair Cost	None reported
Information Source	Federal Highway Administrative (Office of Research and Development)
Remarks	Test results indicate system configuration requires modification.
STATUS	R&D



CRASH CUSHION SYSTEM YC-(d)

Operating Principle	Vehicle impacting energy is absorbed by the crushing of foamed sodium silicate.
Developed By	Southwest Research Institute
Tested By	Wayne State University under contract with Michigan State Highway Commission and through FHWA. Normal Impacts Yes Angle Impacts No
Field Installations	None
Accident Experience	None
Approximate Installed Cost	
Damage Repair Cost Estimate	
Information Source	Federal Highway Administration (Office of Research and Development)
Remarks	
STATUS	R&D

APPENDIX G

SUMMARY OF FULL-SCALE CRASH TEST RESULTS FOR SELECTED BARRIER SYSTEMS

Table G-1 contains a summary of published full-scale crash test results on barrier systems presented in this document. In general, the tests were conducted in accord with recommendations of *HRB Circular 482* (i.e., 4,000-lb car, 60 mph, and 25-deg impact angle). In several cases, test conditions significantly differed from the recommended values; nevertheless, results from these "off-spec" tests provide the designer with some insight into a barrier's performance.

Acquiring and reporting the test results from the various tests have lacked uniformity in both selection of parameters and measuring techniques. For instance, vehicle deceleration data are derived from micromotion analysis of high-speed cine, electronic instrumentation, and mechanical impactographs. Furthermore, instruments such as accelerometers are sensitive to mounting location, recording/playback equipment, filtering devices, and other variables. Accordingly, caution should be exercised in using test result values for purposes other than first-order approximation.

To determine deceleration ratings for barrier systems in Tables 6, 7, and 8, specific tests were selected that closely agreed with test conditions of Table 4; these tests are denoted in Table G-1.

TABLE G-1

FULL-SCALE CRASH TEST DATA

System	Reference	Vehicle Weight (lb)	Impact Speed (mph)	Impact Angle (deg)	Vehicle Decelerations* (g's) Longitudinal	Lateral	Maximum	Maximum Dynamic Deflection (ft)	Remarks
Guardrails									
G1	26(b)	3500	44	25	--	--	6.1	11.0	Smooth redirection (exit angle, 15 deg)
G2	26(a)	3500	54	25	--	--	2.7	6.8	Smooth redirection (exit angle, 14 deg)
	26(a)	3500	35	35	--	--	2.8	9.0	Car came to rest in contact with rail
	26(a)	3500	57	6	--	--	1.0	0.0	Smooth redirection (exit angle, 1 deg)
	▶ 39(a)	4051	59.2	27.8	2.9	3.8	--	7.3	Smooth redirection, vehicle airborne for 50 ft (exit angle, 9 deg)
	36	3800	62	25	--	--	--	--	33-In. mounting height appears to be satisfactory
	36	2000	65	25	--	--	--	--	33-In. mounting height appears to be satisfactory
G3	26(b)	3500	50	25	--	--	5.5	3.0	Exit angle, 11 deg
	26(b)	3500	49	35	--	--	7.2	5.1	Exit angle, 12 deg
	▶ 39(b)	4031	57.7	26	2.8	5.8	--	4.8	Excellent redirection, vehicle came to rest parallel to rail
G4W	42	4570	60	25	--	--	--	--	Exit angle, 13 deg
	▶ 39	4042	55.3	30.5	4.6	4.6	--	4.25	Exit angle, 18 deg
	39	3856	54.7	25.2	--	--	--	2.4	Exit angle: 12.5 deg; vehicle turned back to rail
	39	4123	60.1	22.2	3.0	6.1	--	2.8	Exit angle: 15 deg; vehicle turned back to rail
	42	4540	56	30	--	--	--	--	Exit angle, 7 deg
	42	4540	59	28	--	--	--	--	Exit angle, 24 deg
G4S	▶ 39	3813	56.8	28.4	3.9	6.6	--	4.05	Exit angle: 8 deg
XG-(1)	▶ 19	4242	63.1	28.3	2.9	3.7	--	6.5	Exit angle, 18 deg
	19	4407	70.8	26.7	2.8	4.4	--	7.2	Exit angle, 7 deg
YG-(2)	22(c)	4000	56	25	--	10.4(e)	--	--	Exit angle, 20 deg
	22(d)	4000	59	15	--	5.3(e)	--	--	Exit angle, 10 deg
YG-(3)	▶ 47	3000	57.3	25	3.0	1.2	--	6.0	Vehicle spun out (exit angle, 70 deg)
YG-(4)	▶ 46	4057	59.0	24.3	4.95	4.05	--	6.0	Excellent redirection
Median Barriers									
MB1	24	4300	87	25	--	--	--	17.0	Spin out occurred, but no penetration
MB2	36	3680	56	25					Car redirected
MB3	26(b)	3500	56	25	--	--	5.3	5.5	Exit angle 9 deg
	26(b)	3500	43	35	--	--	10.2	5.6	Exit angle 18 deg
	▶ 39(b)	3761	51	26.9	3.2	4.7	--	4.6	Vehicle came to rest parallel and in contact with rail
	41(b)	4540	64	25	--	--	--	4.05	Exit angle 6 deg
	41(b)	4540	49	10	--	--	--	0.75	Exit angle 3 deg
MB4 S	26	3500	67	16	--	--	5.7	1.5	Exit angle 9 deg
MB4 W	18	4000	60	32	--	--	--	3.1	High exit angle
	18	17,500	41	36	--	--	--	4.8	High exit angle
	23	4570	69	25	--	--	--	---	Exit angle 15 deg

MB5	41	4540	38	7	--	--	--	---	
	41	4540	65	7	--	--	--	---	
	41	4540	63	25	--	--	--	---	
	40(f)	4980	45	7	--	--	--	0	Exit angle 0 deg
	40(f)	4980	66	7	--	4.8	--	0	Exit angle 1 deg
	40(f)	4980	64	7	<1.0	4.8	--	0	Exit angle 1 deg
MB6	37	Several remotely controlled high-speed impacts were made at speeds up to 50 mph and angles to 12 deg							
XMB - (1)	22	4000	65	25	4.0(e)	1.4(e)		3.0	
	22	4000	53	15	--	--	--	1.5	
	22(g)	4000	60	25	3.5(e)	--	--	3.0	
	▶ 38	4057	62.7	26.6	3.7	4.05	--	7.2	Vehicle came to rest parallel and in contact with rail
	17	4000±	50	25	--	--	5.0(e)	2.0	Vehicle snagged
XMB - (2)	20	4000	56	25	9.0(e)	4.0(e)	--	---	Vehicle redirected parallel to rail about 5 ft. out
	20	4000	51	7	1.0	0.7	--	---	Exit angle, 3 to 5 deg
Bridge <u>Rails</u>									
BR - 1	37	Several remotely controlled high-speed impacts were made at speeds up to 50 mph and angles to 12 deg.							
BR - 2	40	4980	45	7	--	--	--	0	Exit angle, 0 deg
	40	4980	66	7	--	4.8	--	0	Exit angle, 1 deg
	40	4980	64	7	<1.0	4.8	--	0	Exit angle, 1 deg
	40	4900	64	15	--	--	--	0	Exit angle, 10 deg
	▶ 40	4900	66	25	14.8	9.1	--	0	Exit angle, 3 deg
XBR - 3	31	3200	58.3	25	7.0	5.5	--	0.5	
	▶ 31	4720	54.8	25	6.5	7.0	--	1.3	
	31	1560	46.1	25	8.0	5.5	--	0	
YBR - 4	26(h)	3500	55	25	--	--	12.3	0	Exit angle, 1 deg
YBR - 5	▶ 45	3620	61.4	25	2.5	13.0	--	0.2	
YBR - 6	No tests on this design; however tests have been conducted by California on vertical parapets, ref 25.								
YBR - 7	21(i)	1956 Plymouth	58	27	--	--	--	---	Exit angle near 0 deg
YBR - 8	48	3800	55.4	25	1.3(k)	4.8(k)		1.5	
Crash <u>Cushions</u>	(The references shown should be consulted for design details).								
C1	43	4690	64.2	Head-on	10.3	--		16.5	Maximum vehicle crush was 16.5 in.
	43	4760	59.8	11°(side)	6.6	5.3	---	---	Test of California design for side impacts
	43	4740	53.6	9°(nose)	10.9	--		13.2	Vehicle penetrated 13.2 ft., rotated clockwise, rebounded 2 ft.
	32	3200	60.2	Head-on	9.1(j)	--		13.3	Almost negligible damage to vehicle
	32	4460	55.7	Head-on	6.5(j)	--		16.0	Crash cushion length was 23.5 ft.
	32	3360	52.6	Head-on	7.6(j)	--		12.1	Crash cushion length was 19 ft.
	32	3640	41.3	30	3.5(j)	--	--	16.2	Development tests for angle hits
	32	3540	49.9	30	6.3(j)	6.4(l)	--	13.2	Development tests for angle hits
	32	3860	40.8	30	4.0(j)	7.4(l)	--	13.7	Development tests for angle hits
	29	3000	56.9	20	6.8(j)	1.1(l)	--	--	Latest reported tests in C1 system
	29	3080	59.3	25	7.4(j)	3.2(l)	--	--	Latest reported tests in C1 system
	29	4180	46.6	Head-on	6.2(j)	--	--	11.7	Latest reported tests in C1 system
	29	4350	56.8	20	4.0(j)	0.6(l)	--	--	Latest reported tests in C1 system
	29	1500	58.2	Head-on	9.1(j)	--	--	12.4	Latest reported tests in C1 system

TABLE G-1 (Continued)

System	Reference	Vehicle Weight (lb)	Impact Speed (mph)	Impact Angle (deg)	Vehicle Decelerations* (g's) Longitudinal	Lateral	Maximum	Maximum Dynamic Deflection (ft)	Remarks
Crash Cushions									
C2	27	1820	42	Head-on	4.5(j)	--	--	13.2	Vehicle damage not serious
	27	4650	64	Head-on	7.9(j)	--	--	17.3	Vehicle stopped with little direction change
	27	4410	54	20	5.8(j)	5.7(l)	--	--	Cable failure occured after vehicle veer being redirected
	27	1680	59	Head-on	7.1(j)	--	--	16.3	Vehicle rolled over after most of kinetic energy had been absorbed
	27	3710	59	20	4.9(j)	9.0(e)	--	--	Vehicle redirected, but rolled on side before coming to rest
	44	4690	57.5	Head-on	7.0	--	--	9.3	Vehicle rolled
	44	4690	61.8	Head-on	9.8	--	--	18.0	Vehicle stopped with little direction change
	44	4760	57.0	9(side)	8.4	--	--	--	Vehicle redirected
	44	4760	59.2	8(nose)	10.2	--	--	--	Vehicle stopped with little direction change
C3	35	Testing has been performed under National Highway Safety Bureau Grant, results were not available for inclusion in this table.							
C4	33	4600	Head-on	34.1	6.6(j)	--	--	5.90	See reference for test details
	33	2520	Head-on	53.5	12.3(j)	--	--	7.21	See reference for test details
	33	4940	Head-on	59.4	9.9(j)	--	--	12.87	See reference for test details
	33	5000	30	49.9	8.1(j)	--	--	13.96	See reference for test details
XC - (a)	28	1460	Head-on	42	5.8(j)			10.2	
	28	4300	Head-on	60	6.1(j)			19.4	
	28	1620	30	48	5.5(j)			13.8	
	28	4520	30	54	4.1(j)			23.5	
	28	3760	Head-on	56	4.0(j)			26.3	
	28	3880	30	62	2.4(j)			29.5	Tape was pulled out on right side.
YC - (b)	34	3650	41.1	Head-on	6.3(j)	--	--	9.0	Development tests
		3200	58.8	Head-on	10.3(j)	--	--	11.2	Development tests
		4560	63.6	Head-on	6.3(j)	--	--	21.4	Development tests
YC - (c)	30	3880	54.5	Head-on	9.0(m)	--	--	27.3	Development test; vehicle ramped.
YC - (d)	50	3300	60.9	Head-on	7.7(j)	--	--	15.75	Good performance
	50	3940	61.1	Head-on	--	--	--	10.0	After 10 ft. displacement, the car ramped

▶ Test(s) used for deceleration rating (Table 5)

*Maximum deceleration averaged over a period of 0.05 sec unless otherwise noted.

(a) Top of rail cable mounted 30 in. above grade.
(b) Top of rail mounted 27 in. above grade.
(c) Post spacing, 8'-0".
(d) Post spacing, 13'-4".
(e) From mechanical peak-g accelerometer.
(f) Tested as bridge rail, results are valid for median barrier also as no contact was made with upper rail.
(g) Based on average of 5 tests of identical system.
(h) Tested with 10-in. curb, 8' - 9" post spacing.
(i) Tested with 10-in. curb.
(j) Calculated from stopping distance.
(k) Decelerations averaged from vehicle contact to time vehicle reached minimum angle with rail (5°).
(l) Maximum value from electronic accelerometer.
(m) Decelerations averaged over first 351.5 msec.

APPENDIX H

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