Research Report
352

THE SAFETY BARRIER DILEMMA

by

James H. Havens
Director

Don Cornette
Research Engineer Associate

and

William M. Seymour
Research Engineer Associate

Division of Research
DEPARTMENT OF HIGHWAYS
Commonwealth of Kentucky

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"Ran-off-the-road" fatal accidents currently account for approximately 65 percent of all freeway fatalities *(1)*. Accordingly, ever-increasing emphasis has been given to the development of effective safety barrier systems, from guardrails to earth berms to median barriers to energy absorbing barriers and mires. However, highway designers have also recognized that safety barriers are hazards in themselves, misfits in the highway environment, and that they are items to be eliminated wherever possible. In a study of fatal accidents on the Interstate Highway System, it was found that fixed object collisions have been the leading source of fatalities, accounting for 43 percent of the 1968-1969 fatal accidents *(2)*. Ironically, guardrails were found to be the most frequent objects struck first -- accounting for 31 percent of the total. Furthermore, this same study estimates that, excluding non-interstate and secondary urban roads, 6,300 miles of guardrail were constructed on public roads in 1969. Statistics such as these illustrate the risks facing today's drivers on the Interstate Highway System. Until a major modification is made that produces a significant reduction in such risks, less mobility (through travel restrictions) will be required to produce a significant reduction in fatalities per year *(3)*.

Safety barriers are a direct result of the adoption of minimal design standards for our freeway systems. Most highway designers realize that more liberal, optimum designs would actually cost little more over the life of a facility and would increase its useful life span. Nevertheless, minimum design standards are frequently the accepted criteria for the design of highways. The reason given, ironically, is economy. A mininum of expense is highly desirable; but the road which is truly the cheapest is not the one which has cost the least money, but the one which makes the most profitable returns in proportion to the amount which has been expended upon it *(cf 4)*.

The purpose of any safety barrier is to reduce the number of highway fatalities and to minimize personal injuries. Also to be remembered is the order of emphasis for service requirements: first to safety, second to economics, and third to aesthetics *(5)*. The highway designer is faced with a choice between equally unsatisfactory alternatives. He is faced with the safety barrier dilemma. On one hand, he may select the more economical, in the short term, minimal design which always warrants the installation of myriads of safety barriers; these items are conceded by most to be traffic hazards in themselves. On the other hand, he may choose optimum design standards with their higher short-term cost but lower, overall long-term cost arising from the decrease in the number of accidents and corresponding reductions in accident and maintenance costs. In particular then, the highway designer may "protect" steep 2:1 sideslopes with guardrail; or he may choose sideslopes so flat (6:1, for example) that in most instances they do not need to be "protected" by guardrail. He may "protect" fixed objects with guardrail; or he may provide a 30-foot clear zone in which all objects are of frangible design. He may "protect" median bridge piers with guardrails or earth berms; or he may choose to eliminate median bridge piers entirely. He may choose a narrow median requiring a median barrier or simply choose a wide, 60- to 90-foot median. Finally, he must decide between installation of energy-absorbing barriers at hazardous gores or the elimination of hazardous gores by contour grading.

A longitudinal barrier, such as guardrail and median barriers, affords only a relative degree of protection to vehicle occupants; a collision with this type of barrier can result in a severe and possible compound accident. Therefore, longitudinal barriers are warranted only at locations where the severity of a collision with the roadside feature or an opposing vehicle or of traversing an embankment would be greater than a collision with the safety barrier *(5)*. Figure 1 illustrates a steep sideslope "protected" with guardrail; and Figure 2 illustrates a flatter sideslope without guardrail "protection".

Embankment guardrail need has, in the past, been determined on the basis of Figure 3 *(6)*. However, the results obtained from this figure are subject to modification by considerations of cost, alignment, grade, traffic volume, climate, and accident experience. The curve is also subject to future change to reflect: 1) improved guardrail performance, 2) improved accident cost computing methods, 3) variation in weights and dimensions of future automobiles, and 4) improvements to vehicle crashworthiness and "safety packaging" of occupants *(5)*. Giving due consideration to each of these variables, the designer finds himself in a dilemma. The choice between guardrail and flatter embankments is not so cut-and-dried when these other variables are considered.

Other warranting features for guardrails are the existence of fixed objects and non-traversable roadside hazards. Nearly one-third of all highway fatalities occur when vehicles leave the roadway and strike a roadside obstacle *(5)*. A study at the General Motors Proving Ground *(7)* indicates that 80 percent of the vehicles leaving the pavement did not travel more than 29 feet from the edge of the pavement, as shown in Figure 4. It is important to note that the roadside at the General Motors Proving Ground has embankments with 10:1 slopes. The effectiveness of the magical 30-foot clear zone where slopes are greater than 10:1 is suspect. Thus, the designer who plans guardrail to "protect" 2:1 and 3:1 slopes and who provides 30-foot clear zones (Figure 5) on these slopes is, insofar as safety is concerned, inadequate at his job. By providing flatter side slopes, although at greater initial construction cost, the designer can in most cases eliminate the need for guardrail and can provide a 30-foot (minimum) clear zone more realistically capable of enabling errant drivers to return their vehicles safely to the pavement. Intuitively, the issue is not as simple as has been stated. The initial cost of providing 5:1 and flatter slopes at all but the highest (60 foot and over) fill locations is often seen as prohibitive. However, when the perhaps more theoretical long-term cost, with its lower maintenance and accident cost components, is considered, this option proves to be a judicious choice. This is but another example of the safety barrier dilemma facing highway designers today.

The AASHO Traffic Safety Committee *(1)* has recommended that where overpasses over divided highways are being designed, two-span structures with supports in the center of wide medians are generally the optimum design. The merits of a single span structure are even more obvious. Furthermore, the "Yellow Book" states that the median piers necessitated by the former design should, where close to the roadway, be protected for the safety of the motorists. The highway designer must choose the best safety barrier for this critical task. The two barriers used most commonly to "protect" median piers are guardrail and earth berms. Neither alternative is completely satisfactory, but a choice between the two must be made. Double-beam guardrail with flared terminal sections (Figure 6), although expensive, is currently considered by most to be the optimum guardrail design *(1)*. A second alternative, though not as well documented, is the use of earth berms (Figure 7) to divert wayward vehicles from median bridge piers. Furthermore, earth berms may be considered more economical since most of the work involved in constructing the mound can be done during grade-and-drain construction using materials available on location. In Ohio and West Virginia, the mound in the median is virtually continuous for most sections where it is employed. Maryland has mounds in the median which extend 500 feet in both directions from bridge piers. Illinois has experimented with earth berms on either side of the approach near the pier but not around the pier itself. A preliminary study of earth berms conducted by the Kentucky Department of Highways *(8)* concluded that, for low-speed encroachments, the following improvements in mound design are justified

1) In order to minimize ramping effects, the mound should extend 500 feet in both directions from the bridge piers.
2) The mound nose should be warped off-center to present a greater rightward deflecting surface and to lessen the tendency for vehicles to become airborne and (or) mount the ridge and descend on the wrong side.
3) The mound should transition from 3:1 to 2:1 on the side slopes and also have an increasing slope in the top of the mound as shown in Figure 8.
4) The application of a wood-chip mulch to the mound, thought by the investigators to enhance the energy-absorbing characteristics of the installation, should be deleted. The energy-absorbing characteristics of plantings, such as shrubs and flowering quince, were not evaluated.

Further complicating the choice, as previously mentioned, is the use of single-span structures with 30-foot clear shoulder zones -- structures which eliminate median bridge piers entirely, and which result in increased bridge construction costs, as well as decreased accident costs.

Historically, median barriers (Figure 9) have been used to prevent across-the-median, head-on collisions between automobiles in opposing traffic streams. Warrants for these barriers have been based on median width and traffic volume as in Figure 10 *(5)*. Except on the basis of adverse accident experience, median barriers have generally not been warranted if median width exceeds 50 feet (Figure 11). However, headlight glare research by Webster and Yeatman *(9)* concluded that speeds would need to be limited to 40 mph with the 6-foot lateral separations and 50 mph for the 33-, 72-, and 94-foot lateral separations in order to assure adequate stopping sight distance to high-reflectance targets under low beam conditions. The secondary function of rigid median barriers as glare screens is undeniable. Such findings tend to undermine the confidence of those highway designers who have come to consider the wider median types as the optimum design. The dilemma once again is apparent. With due consideration to right-of-way costs, barrier costs, maintenance costs, and accident costs, which is the better design: the wide (greater than 50 feet), obstacle-free medians or the narrower (less than 50 feet) medians with longitudinal barriers, which physically separate opposing traffic streams and provide improved nighttime visibility as well as reduced motorist distraction during the daytime?

A final example may be found in the treatment of roadside gore areas where the rate of accidents is approximately four times as great as the rate of "ran-off-the-road" accidents at other locations *(1)*. There are two basic alternatives in providing adequate safety at off-ramp gores which are not located on structures. One is to keep the gore area and the area beyond free of all hazardous obstructions so as to provide a clear recovery area for out-of-control vehicles. This entails the exclusive use of break-away signs, light standards, etc., in the gore area and often contour grading (Figure 12) to keep the gore as nearly level with the roadway as is practicable so that errant vehicles will not be upset or abruptly stopped by steep slopes. The second alternative is to protect erratic drivers and vehicle occupants from hazardous gores by means of an impact attenuating device. At the present time, there are three predominant types (illustrated in Figures 13-15) of impact attenuators available: 1) Hi-Dro Cushions, 2) Fitch Barrels and 3) steel drums. Other than space available for the cushion, there are three factors that should be used in selecting an appropriate energy-absorbing device: installation, maintenance, and damage repair costs. Unfortunately at the present time, installation, maintenance, and damage repair data are insufficient to establish which of the above three (or more) systems is the most cost effective. Furthermore, accident data establishing the relative dynamic performance among impact attenuators is lacking -- necessitating the assumption that, for the present, all three systems are equal in performance. In summary, the choices for increased safety at hazardous gores (not on structure) are principally contour grading and installation of an energy-abosrbing barrier.

The safety treatment of existing off-ramp gores on structures consists simply of the installation of an energy-absorbing barrier. For all new construction, the Federal Highway Administration *(10)* currently recommends that space be reserved, according to Figure 16, for potential crash-cushion installations. A safer, but more radical, approach to this problem would be the elimination of off-ramp gores from structures. Though the feasibility of this approach is admittedly unknown, it seems to be worthy of further investigation.

In conclusion, the safety barrier dilemma is apparent. What is not apparent is how the highway designer is to select from the alternatives presented here. How is the designer to make a rational decision? How is he to choose one particular solution? The answer, though complex, seems to lie primarily in more daring design innovations which provide a better match between man and his behavioral patterns.

References

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2. Hosea, Harold R., *Fatal Accidents on Completed Sections of the Interstate Highway System, 1968-69*, **Public Roads**, Volume 36, No. 6, pp. 133-135, February 1971.

3. Baker, R. F., **The Highway Risk Problem -- Policy Issues in Highway Safety**, Wiley-Interscience, 1971.

4. Winfrey, R., **Economic Analysis for Highways**, International Textbook Company, May 1969.

5. Michie, J. O., and Bronstad, M. E., *Location, Selection and Maintenance of Highway Traffic Barriers*, **NCHRP Report 118**, Highway Research Board, 1971.

6. Glennon, J. C., and Tamburri, T. N., *Objective Criteria for Guardrail Installation*, **Record 174**, Highway Research Board, 1967.

7. Stonex, K. A., *Roadside Design for Safety*, **Proceedings**, Volume 39, Highway Research Board, pp. 120-156, 1960.

9. Garner, G. R. and Venable, J. B., *A Preliminary Evaluation of Mounds to Divert Wayward Vehicles Away from Rigid Obstructions*, Kentucky Department of Highways, August 1969.

9. Webster, L. A. and Yeatman, F. R., *An Investigation of Headlight Glare as Related to Lateral Separation of Vehicles*, **Engineering Experiment Station 496**, University of Illinois, 1968.

10. *Impact Attenuators in Gores*, **Instructional Memorandum 40-1-70**, Federal Highway Administration, U.S. Department of Transportation, July 1970.

Figure 1. Steep Sideslope "Protected" with Guardrail.

Figure 2. Flat Sideslope without Guardrail.

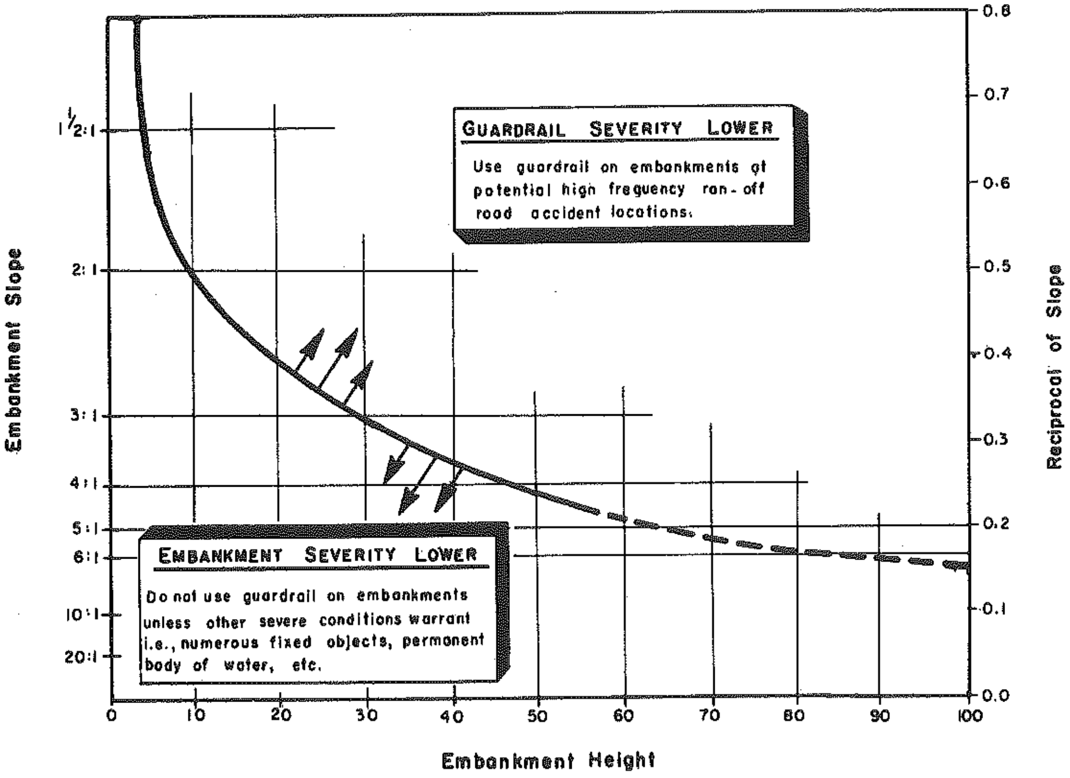


Figure 3. Severity Comparison of Embankments vs. Guardrail *(6)*

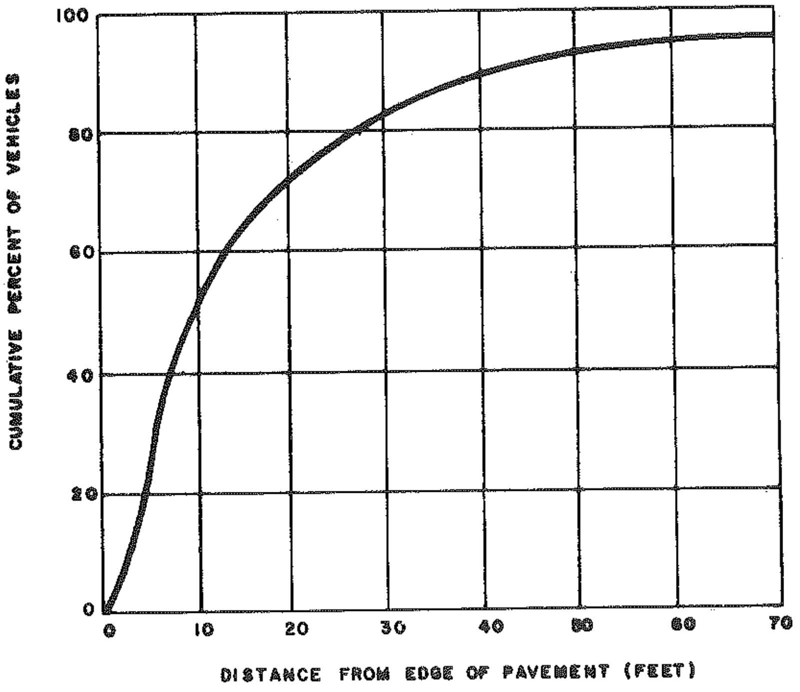


Figure 4. Distribution of Off-the Road Incidents *(7)*.

Figure 5. 30-Foot Clear Zone.

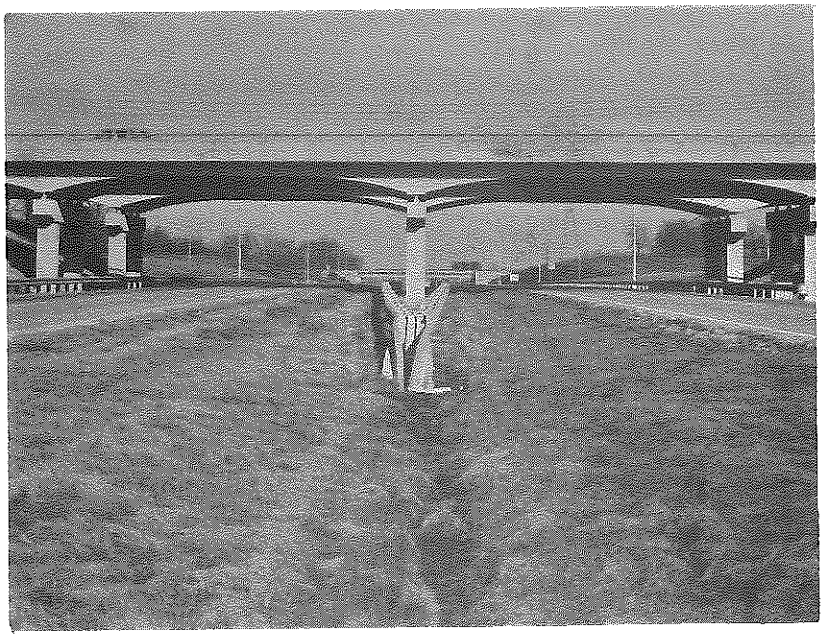


Figure 6. Median Bridge Piers "Protected" with Guardrail.

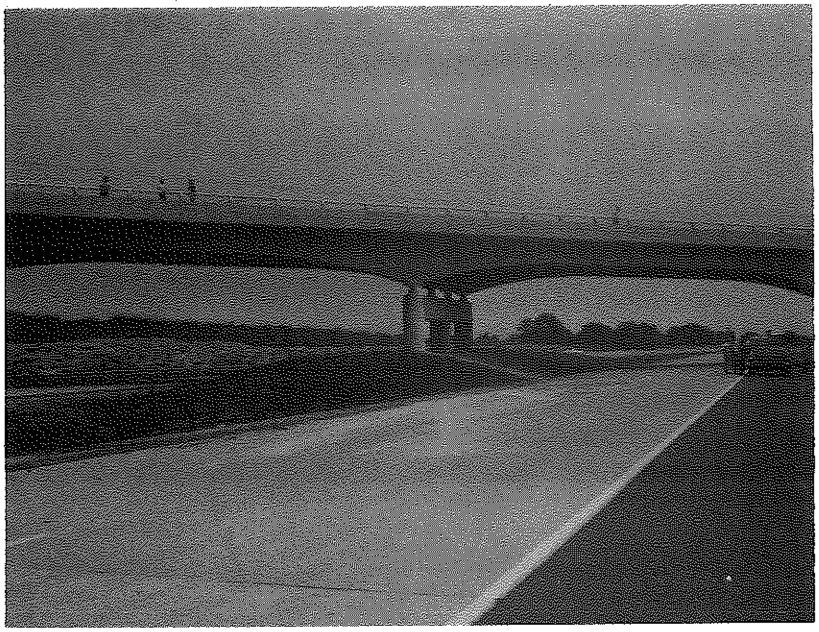
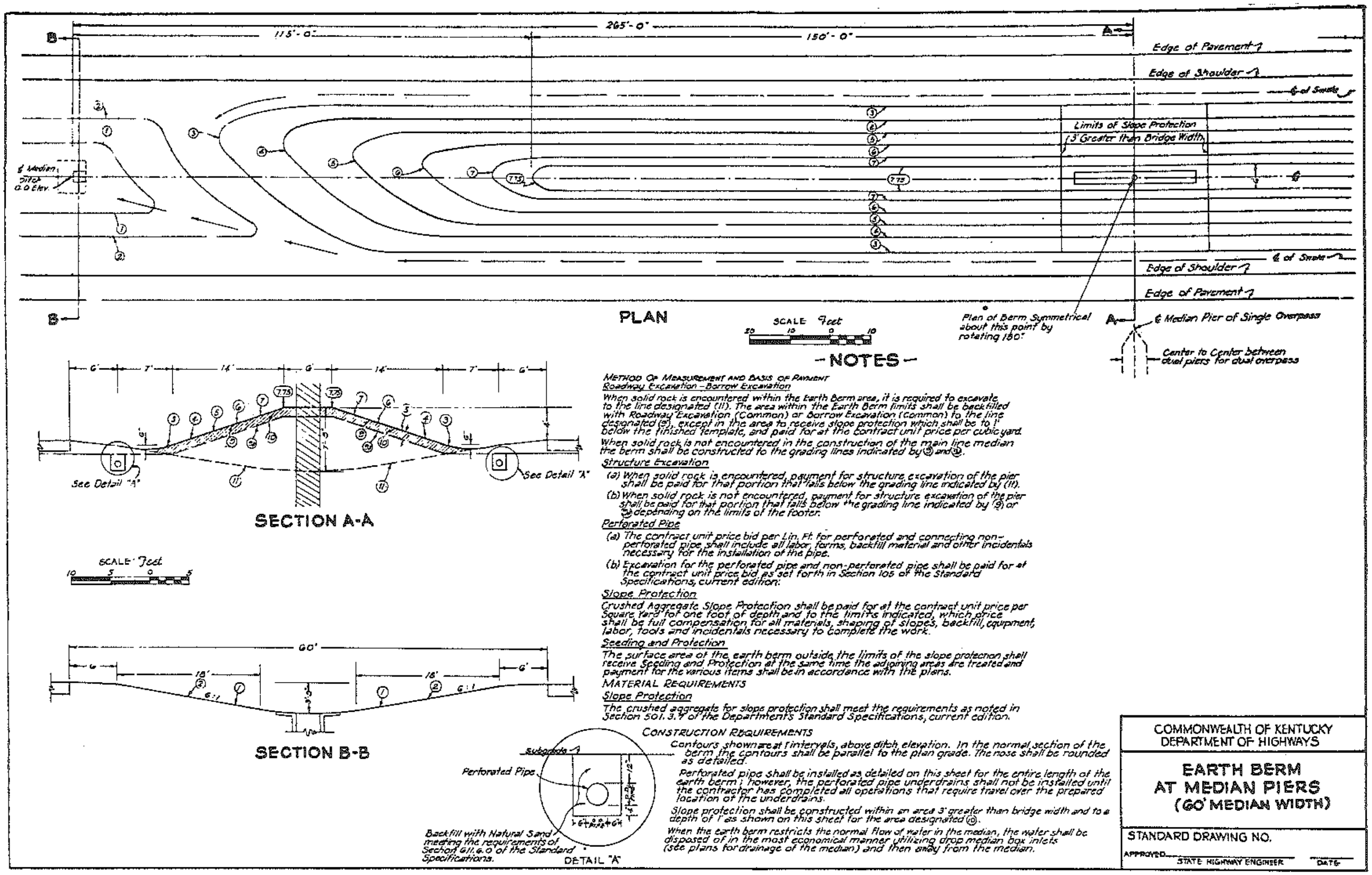


Figure 7. Median Bridge Piers "Protected" with Earth Berm.



-NOTES-

METHOD OF MEASUREMENT AND BASIS OF PAYMENT

Roadway Excavation – Borrow Excavation

When solid rock is encountered within the Earth Berm area, it is required to excavate to the line designated (11). The area within the Earth Berm limits shall be backfilled with Roadway Excavation (Common) or Borrow Excavation (Common) to the line designated (9), except in the area to receive slope protection which shall be to 1' below the finished template, and paid for at the contract unit price per cubic yard.

When solid rock is not encountered in the construction of the main line median the berm shall be constructed to the grading lines indicated by ③ and ⑪.

Structure Excavation

(a) When solid rock is encountered, payment for structure excavation of the pier shall be paid for that portion that falls below the grading line indicated by (11).

(b) When solid rock is not encountered, payment for structure excavation of the pier shall be paid for that portion that falls below the grading line indicated by ⑨ or ⑪ depending on the limits of the footer.

Perforated Pipe

(a) The contract unit price bid per Lin. Ft. for perforated and connecting non-perforated pipe shall include all labor, forms, backfill material and other incidentals necessary for the installation of the pipe.

(b) Excavation for the perforated pipe and non-perforated pipe shall be paid for at the contract unit price bid as set forth in Section 105 of the Standard Specifications, current edition.

Slope Protection

Crushed Aggregate Slope Protection shall be paid for at the contract unit price per Square Yard for one foot of depth and to the limits indicated, which price shall be full compensation for all materials, shaping of slopes, backfill, equipment, labor, tools and incidentals necessary to complete the work.

Seeding and Protection

The surface area of the earth berm outside the limits of the slope protection shall receive Seeding and Protection at the same time the adjoining areas are treated and payment for the various items shall be in accordance with the plans.

MATERIAL REQUIREMENTS

Slope Protection

The crushed aggregate for slope protection shall meet the requirements as noted in Section 501.3.7 of the Department's Standard Specifications, current edition.

CONSTRUCTION REQUIREMENTS

Contours shown are at 1' intervals, above ditch elevation. In the normal section of the berm the contours shall be parallel to the plan grade. The nose shall be rounded as detailed.

Perforated pipe shall be installed as detailed on this sheet for the entire length of the earth berm; however, the perforated pipe underdrains shall not be installed until the contractor has completed all operations that require travel over the prepared location of the underdrains.

Slope protection shall be constructed within an area 3' greater than bridge width and to a depth of 1' as shown on this sheet for the area designated ⑩.

When the earth berm restricts the normal flow of water in the median, the water shall be disposed of in the most economical manner utilizing drop median box inlets (see plans for drainage of the median) and then away from the median.

COMMONWEALTH OF KENTUCKY
DEPARTMENT OF HIGHWAYS

EARTH BERM
AT MEDIAN PIERS
(60' MEDIAN WIDTH)

STANDARD DRAWING NO.

APPROVED ______ STATE HIGHWAY ENGINEER ______ DATE

Figure 8. Earth Berm Design with Warped Nose and Variable Sideslopes.

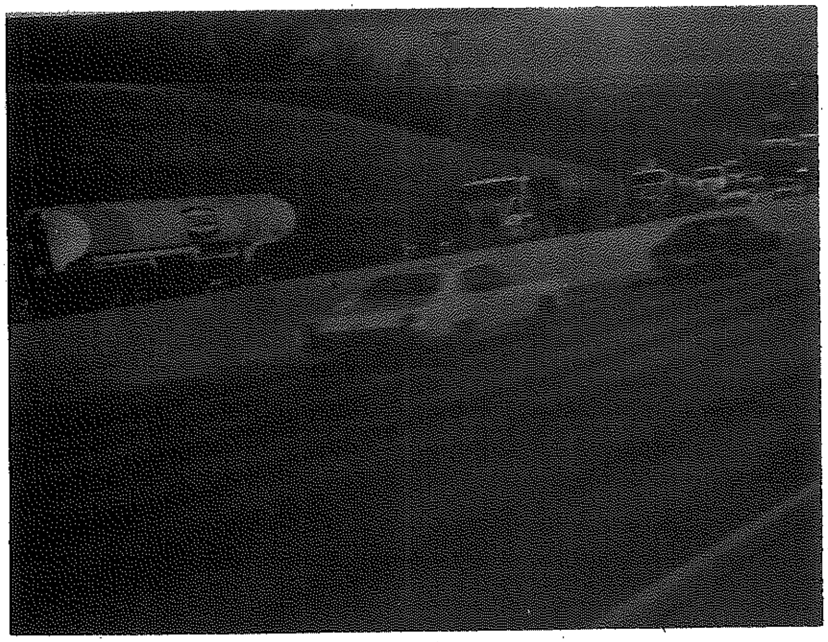


Figure 9. Narrow Median Requiring a Barrier.

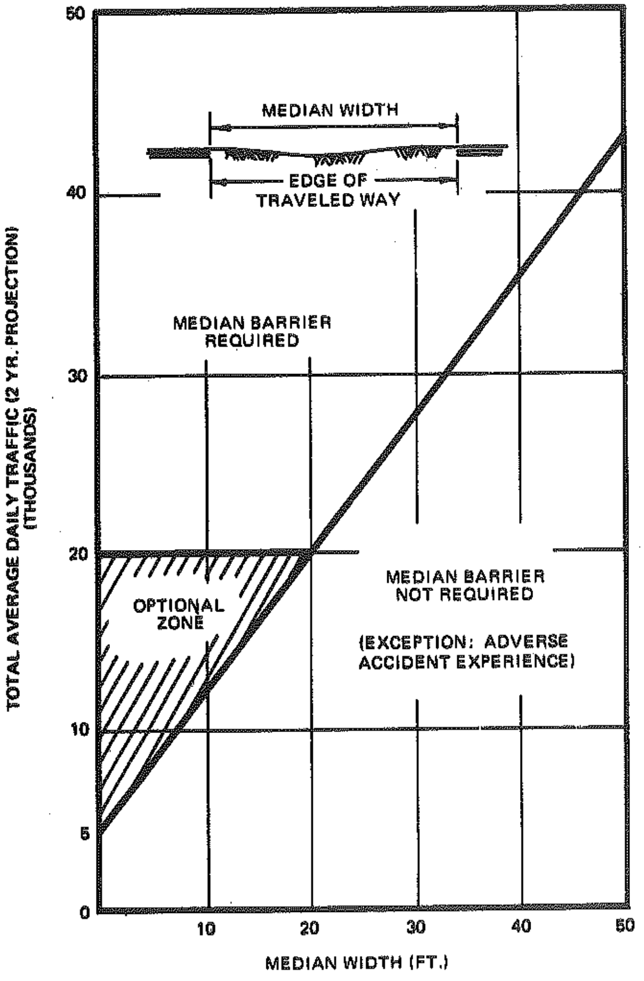


Figure 10. Median barrier requirements *(5).*

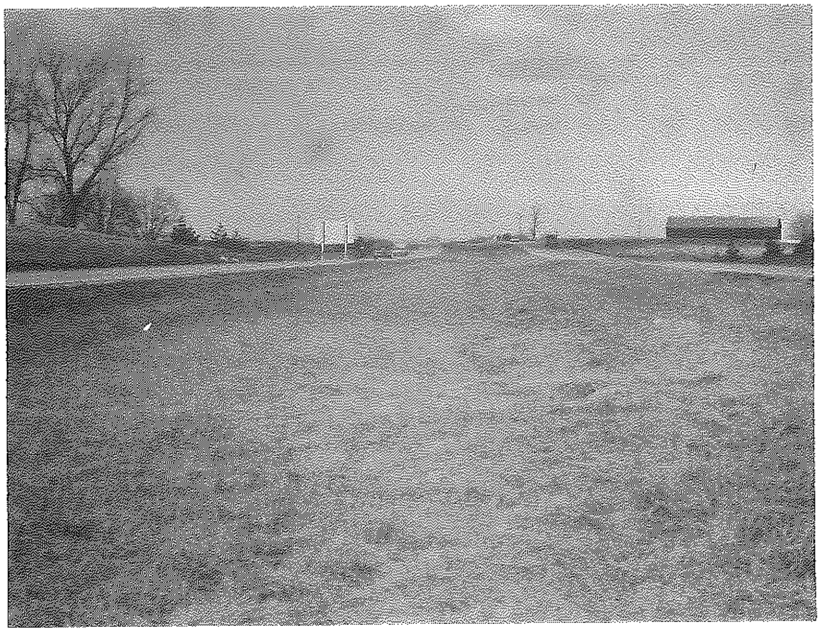


Figure 11. Wide 60-Foot Median.

Figure 12. Elimination of Hazardous Gores by Contour Grading.

Figure 13. Hi-Dro Cushion Type Impact Attenuator.

Figure 14. Fitch Type Impact Attenuator.

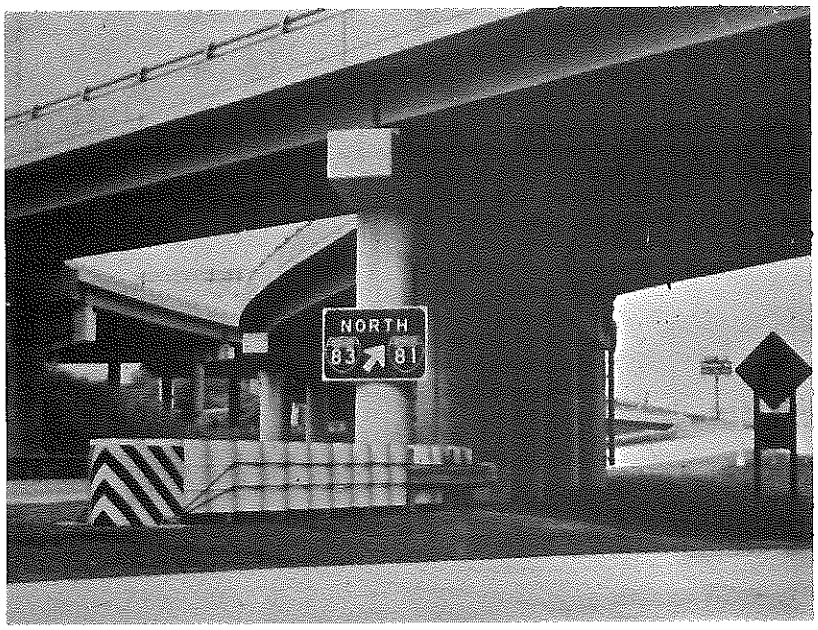
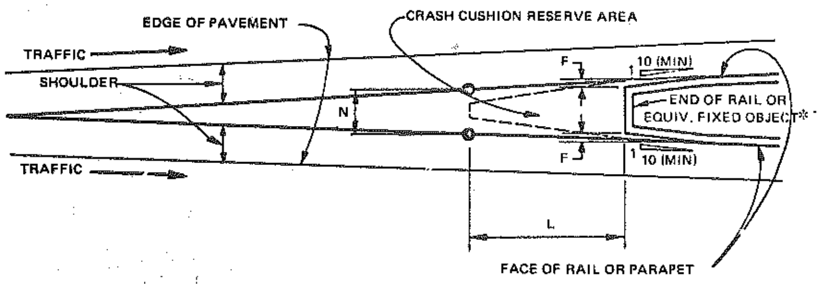


Figure 15. Steel Drum Type Impact Attenuator.



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:

†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.

Figure 16. **Reserve Area for Off-Ramp Gores** *(5)*.