

HEAVY VEHICLE MEDIAN BARRIER

a

report on

Contract No. DTFH61-84-C-00052

Prepared for

Office of Implementation
Federal Highway Administration
U. S. Department of Transportation

by

C. E. Buth
Research Engineer

R. M. Olson
Research Engineer

J. R. Morgan
Assistant Research Engineer

W. L. Campise
Research Associate

Texas Transportation Institute
The Texas A&M University System

March 1986

NOTICE

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no liability for its contents or use thereof.

The contents of this report reflect the views of the Texas Transportation Institute, which is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official policy of the Department of Transportation.

This report does not constitute a standard, specification, or regulation.

The United States Government does not endorse products or manufacturers. Trade or manufacturers' names appear herein only because they are considered essential to the object of this document.

1. Report No. FHWA-TS-88-024	2. Government Accession No. MS 9 - 117 075 /AS	3. Recipient's Catalog No.	
4. Title and Subtitle HEAVY VEHICLE MEDIAN BARRIER		5. Report Date March 1986	
		6. Performing Organization Code	
7. Author(s) C. E. Buth, R. M. Olson, J. R. Morgan, and W. L. Campise		8. Performing Organization Report No. RF 7015	
9. Performing Organization Name and Address Texas Transportation Institute Texas A&M Research Foundation Texas A&M University College Station, TX 77843		10. Work Unit No. (TRAIS)	
		11. Contract or Grant No. DTFH61-84-C-00052	
12. Sponsoring Agency Name and Address Federal Highway Administration Research, Development & Technology 6300 Georgetown Pike McLean, Virginia 22101		13. Type of Report and Period Covered Final Report August 1984 - November 1985	
		14. Sponsoring Agency Code	
15. Supplementary Notes FHWA contract manager: James A. Wentworth (HRT-20)			
16. Abstract Performance of the Heavy Vehicle Median Barrier (HVMB) is discussed and criteria for identifying situations where this barrier should be used are presented. The Heavy Vehicle Median Barrier (HVMB) is a modified (42-in-high) New Jersey Safety Shape Median Barrier and is capable of redirecting heavy vehicles such as busses and van-type tractor-trailers with low centers of gravity. It was originally developed to deter errant trucks from crossing the median and colliding with oncoming vehicles.			
17. Key Words Median barriers, Tractor-trailers, Crash tests		18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 58	22. Price A04

METRIC CONVERSION FACTORS

APPROXIMATE CONVERSIONS FROM METRIC MEASURES

SYMBOL WHEN YOU KNOW MULTIPLY BY TO FIND SYMBOL

LENGTH

in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km

AREA

in ²	square inches	6.5	square centimeters	cm ²
ft ²	square feet	0.09	square meters	m ²
yd ²	square yards	0.6	square meters	m ²
mi ²	square miles	2.6	square kilometers	km ²
	acres	0.4	hectares	ha

MASS (weight)

oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t

VOLUME

tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft ³	cubic feet	0.03	cubic meters	m ³
yd ³	cubic yards	0.76	cubic meters	m ³

TEMPERATURE (exact)

°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C
----	------------------------	----------------------------	---------------------	----

APPROXIMATE CONVERSIONS FROM METRIC MEASURES

SYMBOL WHEN YOU KNOW MULTIPLY BY TO FIND SYMBOL

LENGTH

mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi

AREA

cm ²	square centimeters	0.16	square inches	in ²
m ²	square meters	1.2	square yards	yd ²
km ²	square kilometers	0.4	square miles	mi ²
ha	hectares (10,000m ²)	2.5	acres	

MASS (weight)

g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000kg)	1.1	short tons	

VOLUME

ml	milliliters	8.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m ³	cubic meters	36	cubic feet	ft ³
m ³	cubic meters	1.3	cubic yards	yd ³

TEMPERATURE (exact)

°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F
----	---------------------	-------------------	------------------------	----



TABLE OF CONTENTS

<u>Section</u>	<u>Page</u>
INTRODUCTION.....	1
DESIGN OF HEAVY VEHICLE MEDIAN BARRIER (HVMB).....	3
Design Assumptions.....	3
MEDIAN PROFILE.....	6
SAFETY IMPROVEMENTS.....	7
DETAILS OF CONSTRUCTION: CONSTRUCTION TECHNIQUES.....	8
Precast Construction.....	8
Cast-in-Place Construction.....	9
Slip Form Construction.....	10
Summary.....	11
EVALUATION OF EXISTING BARRIER INSTALLATION.....	16
END TREATMENTS AND TRANSITION FOR MEDIAN BARRIERS.....	17
Available Designs.....	17
Recommendations.....	20
SELECTION GUIDELINES.....	23
Establish Need for Barrier.....	23
Identification of Problem Locations.....	23
Consideration of Alternatives.....	24
Benefit/Cost Analysis.....	24
Selection of Appropriate Barrier.....	25
APPENDIX A: Tests On A Load Measuring Wall.....	27
APPENDIX B: Tests On Heavy Vehicle Median Barrier.....	30
SERIES 1.....	30
Test Installation.....	30
Test No. 1-1: 2,190-lb vehicle.....	30
Test No. 1-2: 80,420-lb tractor-trailer.....	34
SERIES 2.....	37
Modified Test Installation.....	37
Test No. 2-1: 2,118-lb automobile.....	37
Test No. 2-2: 4,880-lb automobile.....	37
Test No. 2-3: 80,180-lb tractor-trailer.....	40
Summary of Test Results.....	43
REFERENCES.....	45

LIST OF FIGURES

<u>Figure</u>		<u>Page</u>
1.	Cross section of test barrier.....	4
2.	Construction site showing grading, reinforcing steel in place, and movable protective barriers.....	12
3.	Transit mixer, at left, unloads low slump concrete onto conveyor belt which transports the concrete to the slip form machine.....	13
4.	Slip form moves forward on crawlers leaving the HVMB in place. Hand finishing is required.....	14
5.	Complete barrier with asphalt shoulders in place.....	15
6.	GREAT installation.....	21
7.	Barrel/W-section crash cushion.....	22
8.	Median Barrier Warrants.....	26
9.	Load-measuring wall.....	28
10.	Cross section of test barrier.....	31
11.	Cross section of test barrier installation.....	32
12.	Summary of data for test 1-1.....	33
13.	Vehicle after test 1-2.....	35
14.	Summary of data for test 1-2.....	36
15.	Cross section of test barrier installation showing modified roadway cross section (test series 2).....	38
16.	Summary of data for test 2-1.....	39
17.	Summary of data for test 2-2.....	41
18.	Summary of data for test 2-3.....	42

LIST OF TABLES

<u>Table</u>		<u>Page</u>
1.	Recommended ultimate design loads for bridge railings that do not deflect significantly.....	29
2.	Summary of testing performed on New Jersey Heavy Vehicle Median Barrier.....	44

INTRODUCTION

For an acceptable level of safety, opposing traffic on high volume roadways may be separated either by a wide median or by a longitudinal traffic barrier. Current practice in median barrier installations employs a wide variety of designs and materials. Median barriers utilizing concrete safety shapes, steel W-shape beams and thrie beams have been constructed on the nation's highways. Until recently most barriers have been designed to contain and redirect automobiles. They were not intended for redirecting heavier vehicles such as trucks and busses. The standard 32-in high Concrete Median Barrier (CMB) has been widely installed, performs well in the field when struck by automobiles and has low maintenance costs. This barrier is more effective in containing and redirecting heavier vehicles than some median barriers, but does not perform well in some situations.

In this report performance of the Heavy Vehicle Median Barrier (HVMB) is discussed and criteria for identifying situations where this barrier should be used are presented. The Heavy Vehicle Median Barrier (HVMB) is a modified (42-in-high) New Jersey Safety Shape Median Barrier and is capable of redirecting heavy vehicles such as busses and van-type tractor-trailers with low centers of gravity. It was originally developed to deter errant trucks from crossing the median and colliding with oncoming vehicles. It has been installed on several portions of the New Jersey Turnpike.

Engineers with the New Jersey Turnpike Authority were responsible for the design of the barrier and construction details. They were also heavily involved in selecting the roadway cross section and other test conditions. Their contributions are recognized and appreciated.

This report contains information obtained from full-scale crash tests on a load-measuring wall, which was used to prepare recommendations for barrier design loads; see appendix A.⁽¹⁾

Design of the cross section of the HVMB and the adjacent pavement is discussed. These are important considerations, because they provide satisfactory vertical and horizontal redirection of colliding vehicles. This design information is supported by the full-scale crash tests, details of which are presented in appendix B.^(2,3)

Finally, guidelines for selecting the appropriate barrier are presented in this report. These guidelines include:

- Identification of problem locations.
- Consideration of alternatives.
- Discussion of benefit/cost analysis.
- Determination of need for a barrier.
- Selection of appropriate barrier.

DESIGN OF HEAVY VEHICLE MEDIAN BARRIER (HVMB)

The primary concern in design of the Heavy Vehicle Median Barrier was containment of heavy vehicles. However, due to the present trend toward increasing numbers of small automobiles on the highways it was also necessary to preserve the capability to safely contain and redirect smaller vehicles.

The HVMB is a reinforced concrete section derived from the MB5 concrete safety shape (New Jersey profile) median barrier. The slopes of the barrier face were the same as the MB5 (see figure 1). However, the upper face was increased from 19 to 32 in. The lower vertical face remained at 3 in but differed from the MB5 design in that the vertical face was embedded in asphalt as shown in figure 1. These modifications increased the effective height of the barrier to 42 in. This height helps limit the roll of heavy vehicles and allows visibility across the median for police and emergency vehicles.

Design Assumptions

An 80,000-lb articulated tractor-trailer was the design vehicle. However, since no test data were available for an 80,000-lb tractor-trailer colliding at 60 mi/h and 15 degrees, Hirsch estimated the impact loading to be between 160,000 lb and 280,000 lb distributed along 8 ft of the barrier.⁽⁴⁾ Thus, the design load for the proposed barrier was assumed to be 200,000 lb distributed over an 8-ft length of barrier. The resultant of the load was assumed to act no higher than 2 inches below the top of the barrier.

For the strength analyses of the barrier, a rectangular cross section of 45 in x 16.5 in was assumed. This provided an area of 742 in². The assumed failure modes were:

- Barrier sliding laterally being resisted by the asphalt against the 3 in vertical face.

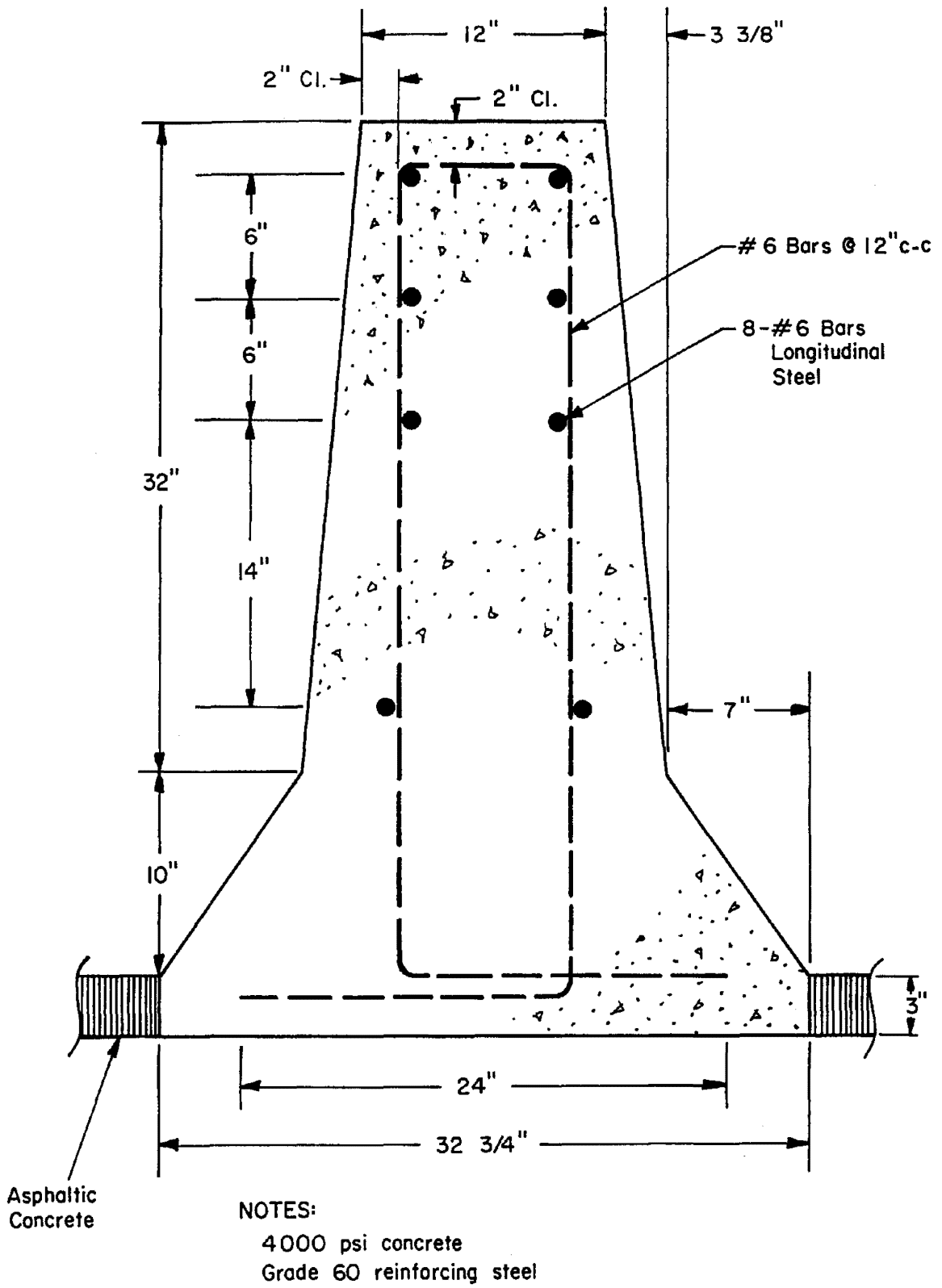


Figure 1. Cross section of test barrier.

- Torsional movement of the barrier resulting from a segment in the impact area rotating about a longitudinal axis with the torsional load being resisted by the upstream and downstream portions of the barrier.
- Overturning of a finite length of barrier (inertia of the barrier was ignored).

Full-scale crash tests proved that automobiles and heavy trucks were contained and smoothly redirected following collision with the barrier.^(2,3) Results of these tests are contained in appendix B.

MEDIAN PROFILE

Two series of tests were performed on the proposed Heavy Vehicle Median Barrier. The design of the barrier itself was identical in both series of tests; see figure 1. However, the cross section of the simulated roadway was changed after the first series. The cross section used in the first series of tests had a drainage depression located 8 ft from the centerline of the barrier with a 2 percent slope away from the barrier to the bottom of the depression to provide drainage. A small automobile rolled over in a 15-degree test on this installation. Computer simulations showed that the shape of the roadway cross section (i.e., the drainage depression) contributed to the rollover. An articulated tractor-trailer with a high-center-of-gravity load was used in the second test of the first series. The trailer rolled over the barrier. A discussion of the trailer behavior and other details of the first test series are contained in appendix B.

The roadway cross section was modified for the second test series. The depression was eliminated by constructing a 5 percent cross slope from the edge of the travelled way to the base of the barrier. Three tests were conducted using a 2,000-lb automobile, a 4,800-lb automobile, and an 80,000-lb tractor-trailer. Details of test series 2 are presented in appendix B.

SAFETY IMPROVEMENTS

Full-scale crash tests have shown that the HVMB improves safety by providing containment and smooth redirection of heavy vehicles as well as automobiles. The most severe test was made by an 80,000-lb tractor-trailer which was redirected after colliding with the barrier at an angle of 15 degrees and a speed of 50 mi/h. No other median barrier performs this well.

The following findings are supported by crash tests described in appendix B:

- Simulated occupants in the test vehicles were subjected to tolerable forces with a maximum lateral deceleration of 13.9 g's. The maximum allowable is 20 g's according to NCHRP Report 230.⁽⁵⁾
- The barrier will restrain and smoothly redirect small and large passenger vehicles; and van-type tractor-trailers having center-of-gravity heights to 64 in.
- The barrier will remain intact even when struck by a series of vehicles at the same spot. A small amount of concrete was chipped in one truck test; however, the damage was so slight that no repairs were required.

These findings lead to the conclusion that this barrier could be installed at locations where a barrier is warranted and where a large proportion of heavy vehicles exists in the traffic mix.

DETAILS OF CONSTRUCTION: CONSTRUCTION TECHNIQUES

A Heavy Vehicle Median Barrier must be placed on subgrade that will provide adequate structural support and maintain horizontal and vertical alignment. The subgrade must also provide adequate structural support for the asphaltic concrete to prevent sliding of the barrier.

Construction of the barrier is described in the following paragraphs.

Three methods may be used for the construction of the HVMB. These methods are (1) precast, (2) cast-in-place, and (3) slip form construction. Of these, precast construction (in spite of problems with connection details and foundations) is appropriate at sites without ready access to concrete suppliers, absence of specialized equipment, or where installation time or space requirements are at a premium. In sites where a steady supply of materials is assured, either cast-in-place or slip form construction could be employed. Cast-in-place construction requires little equipment but requires more time and space than does precast construction. Slip form construction can provide a savings in both time and labor as compared to cast-in-place but requires specialized equipment. It also requires more space than does precast, and even under ideal conditions could take more time on the roadway. The three methods of construction will be discussed in subsequent paragraphs.

Precast Construction

The HVMB weighs approximately 900 lb per linear foot. Barrier segments up to 20 ft in length can be installed using a 10 ton fork lift or crane. It has been found that 20-ft segments are easy to maneuver into position.

Proper site preparation and an adequate work zone will insure satisfactory installation and will produce a smooth precast barrier. In

locations where the median has not been improved previously, it may be necessary to grade and compact the area to provide an adequate foundation upon which to place the barrier. This, along with preparation for the anchorage system, limits the time during which the traffic flow, is disrupted or the crew is exposed to the traffic. In normal installations, a workzone of at least one-lane width adjacent to the barrier is required. In addition the barrier segments are placed in position, connected together, and leveled (with grout or shims). Once this is completed and the segments are secured to the pavement, normal traffic can resume.

The major problem with a precast concrete system lies in connecting the segments. In order for the barrier to function properly, it must be adequately anchored to the pavement to control lateral movement. Continuity must be provided between the segments to permit transfer of shear forces and bending moments to adjacent segments.

Cast-in-Place Construction

Cast-in-place construction requires installation of forms, nearby concrete suppliers, or an onsite batching plant, and sufficient supply of materials and qualified manpower.

Safety, adequate workspace, readily available materials, qualified workmen, good site and foundation preparation, and good quality control are essential to the proper completion of this type of construction. A work zone of at least one-lane width on each side of the proposed barrier and access routes to accommodate large concrete trucks and heavy equipment will be required. To obtain adequate strength and good workability, it is recommended that structural strength concrete be used. Once the forms are removed hand finishing may be required to patch voids and honeycombed areas.

The biggest problems associated with the cast-in-place barrier are the time and resource expended during the process of installing and removing the formwork. Extensive use of mortar may be required to obtain a proper finish.

Slip Form Construction

Specialized equipment and persons trained in slip forming operations will be required in addition to the normal requirements of any highway construction job. For the slip forming operation provisions must be made to assure an adequate supply of concrete delivered in a timely manner.

Safety, adequate workspace, readily available materials, qualified workmen, site preparation, and good quality control are essential to the proper completion of this type of construction. A work zone of at least one-lane width on each side of the proposed barrier and access routes to accommodate large concrete trucks and heavy equipment will be required. Site conditions and proper site preparation include grading of the construction area and careful placement of the reinforcing steel and anchors. Continuous delivery of concrete is required to avoid cold joints in the wall and to insure a smooth placement operation. The speed of placement is important in terms of geometric stability of the cross section of the barrier and texture of the concrete. Production rates of up to 700 ft per day have been achieved using structural strength concrete with a slump of 1/2 to 1-1/2 inches. Stability and sufficient time to finish the surface are provided by this slump range. Particular attention should be paid to the top of the wall during finishing. Brushing is required, and the top of the wall may have to be hand finished to provide acceptable appearance. Brushing and some patching is required for the sides of the wall. Contraction joints should be placed at intervals required to control cracking.

The most significant problems are (1) maintaining a proper slump in order that deviations from the desired 42-in height are minimized, and (2) the control of the inevitable cracking of a long continuous barrier section. The former is achieved by quality control of the concrete mix and controlled placement of concrete. Engineers involved with installation of the HVMB along the New Jersey Turnpike decided to use joints (through the barrier) at 250 ft intervals. The use of these joints resulted in uniformly spaced cracks between the joints. When installed

adjacent to concrete pavement or on bridges, barrier joints should conform to pavement or bridge joints.

Photographs taken during construction of the first Heavy Vehicle Median Barrier are shown in figures 2 through 5. A description of the various operations is contained in the title of each photograph.

Summary

Each of the methods discussed in this section have advantages and disadvantages which must be weighed in light of the conditions and requirements at each job site. The primary considerations in a choice between them will involve a determination of:

- Availability of materials.
- Cost of manpower.
- Cost of specialized equipment.
- Time to complete the project.
- Adequate work zones.
- Impact of traffic disruption.
- Weather, and other local considerations.

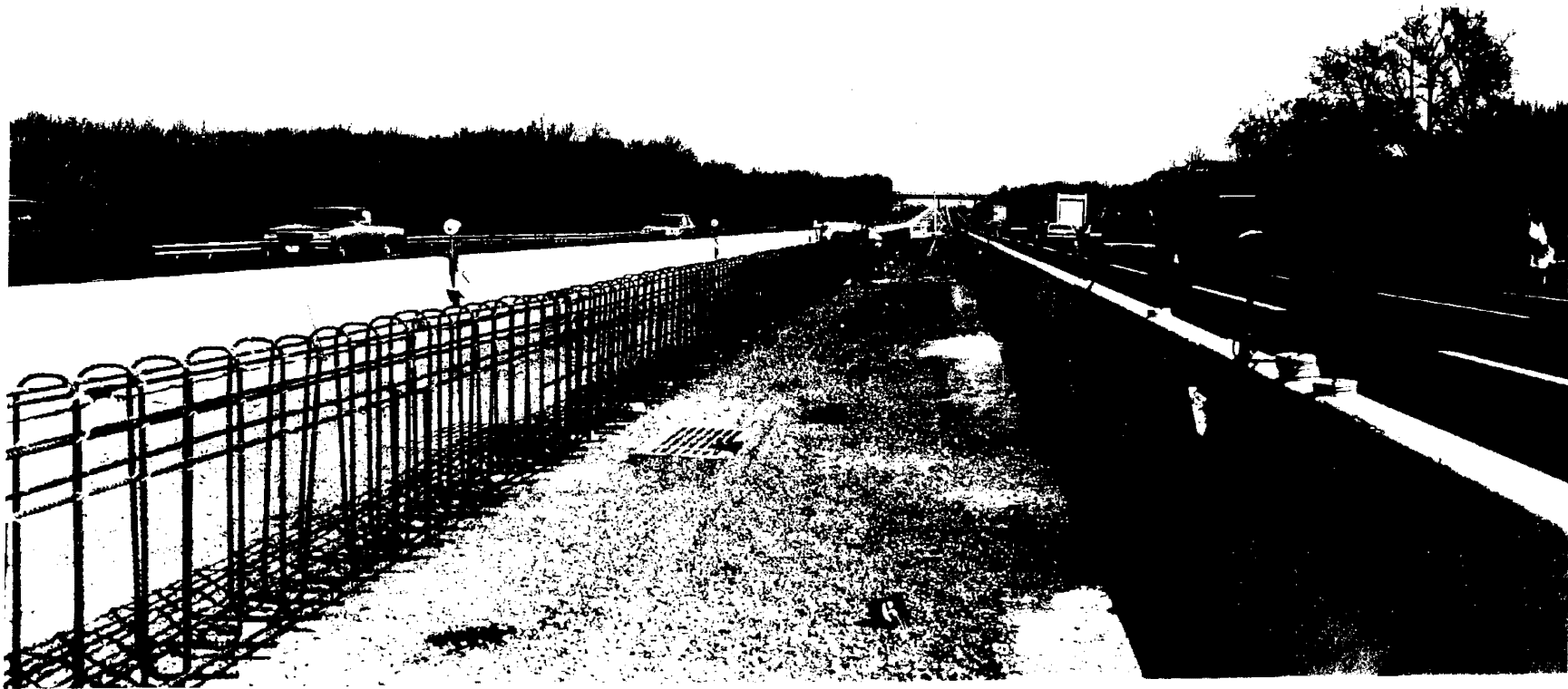


Figure 2. Construction site showing grading, reinforcing steel in place, and movable protective barriers.

Reproduced from
best available copy.



Reproduced from
best available copy.

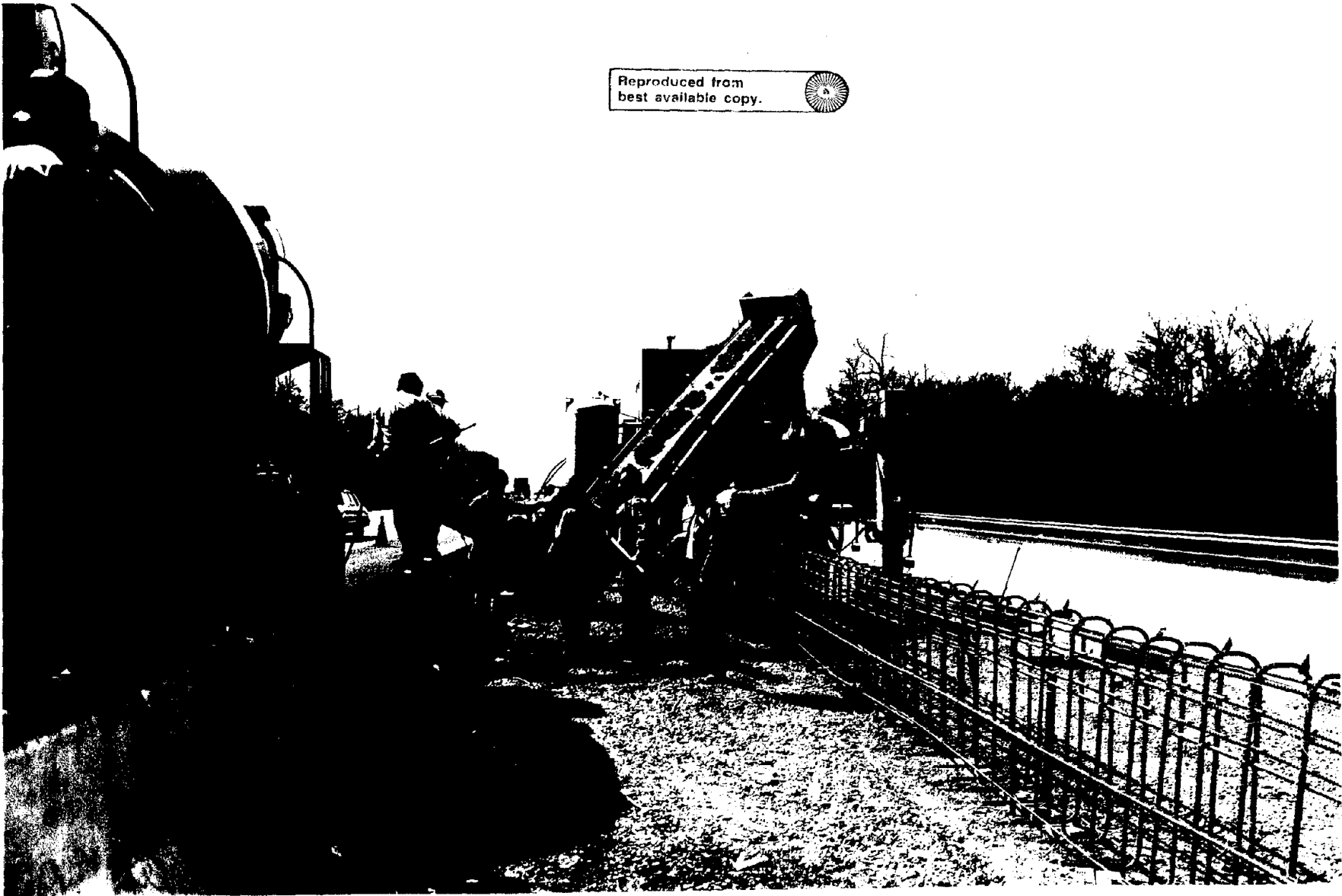
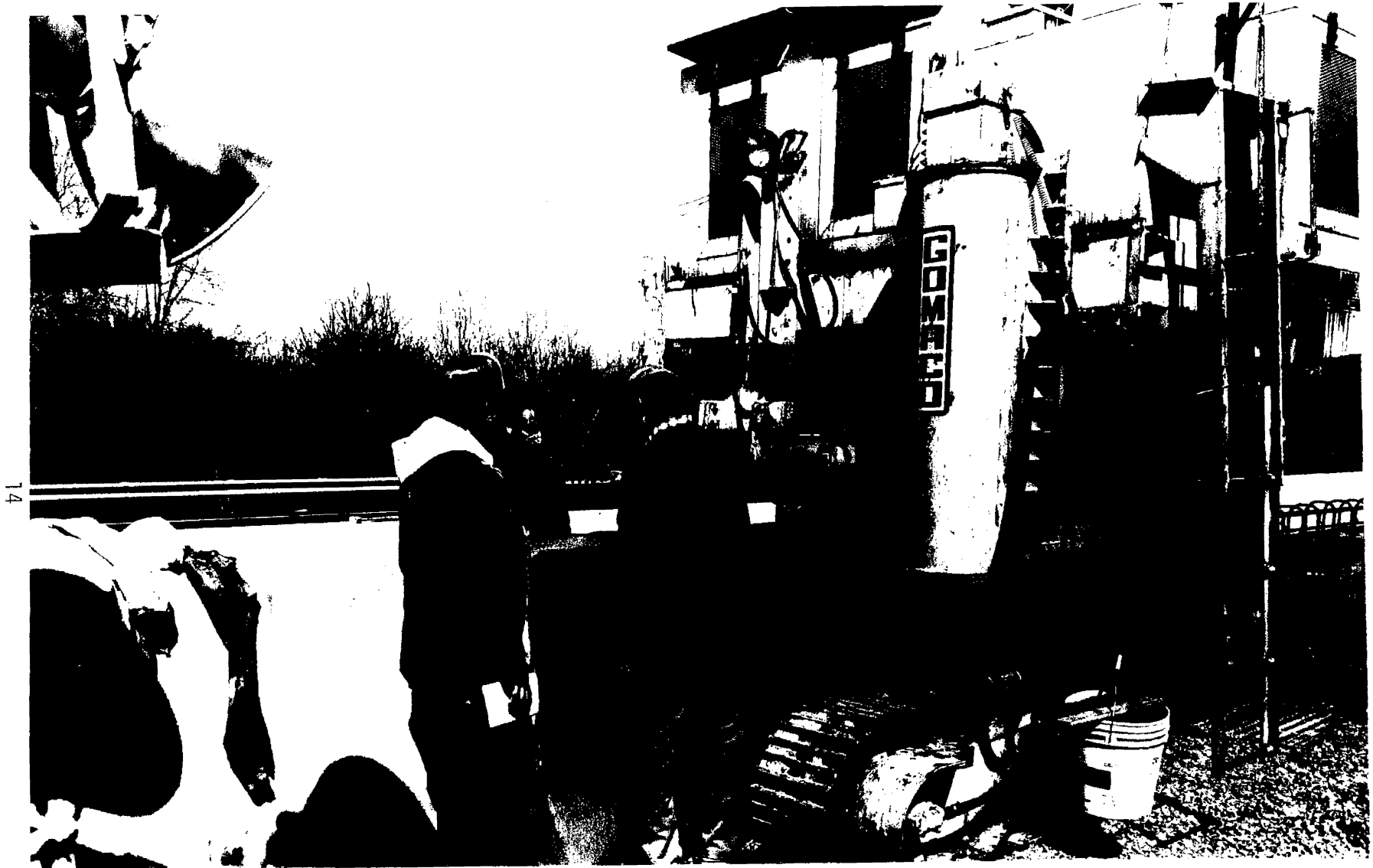


Figure 3. Transit mixer, at left, unloads low slump concrete onto conveyor belt which transports the concrete to the slip form machine.



14

Figure 4. Slip form moves forward on crawlers leaving the HVMB in place. Hand finishing is required.

Reproduced from
best available copy.



Reproduced from
best available copy.



15

Figure 5. Completed barrier with asphalt shoulders in place.

EVALUATION OF EXISTING BARRIER INSTALLATION

Approximately six miles of barrier are in service on the New Jersey Turnpike. Construction was completed in July 1985. At the time of this writing one accident involving a tractor-trailer had occurred. The tractor-trailer weighing approximately 51,000 lb struck the barrier at 20 degrees. After being in contact with the barrier for 100 ft the tractor-trailer was redirected at an exit angle of 12-13 degrees. The driver, who was wearing his seat belt, was hospitalized and released with minor injuries. According to the New Jersey Turnpike Authority: "The rig and barrier performed similar to those crash tests performed in Texas, safely redirecting the trailer and preventing a crossover into the southbound lanes at a very busy time of day."

END TREATMENTS AND TRANSITION FOR MEDIAN BARRIERS

Available Designs

Untreated median barrier terminals are narrow rigid objects and are extremely hazardous to impacting vehicles. In order to protect the occupants of an errant vehicle, impact attenuation devices have been installed on the nation's highways. The first successful crash test of a steel drum impact attenuator was conducted by the Texas Transportation Institute at the A&M Research and Extension Center on March 28, 1968. The steel drum system has been installed in a variety of configurations including median treatments and in temporary locations using portable systems.

Where space is adequate in the travelled way, any of several impact attenuation devices can be used as an end treatment. Another consideration would be to extend the median barrier beyond the point of need and install a crash cushion at the end.

Median barrier end treatments currently in use with concrete median barriers include the guardrail energy absorbing terminal (GREAT), sand-filled inertial barrels, and various crash cushions and various barrier-to-ground transitions such as an earth berm or a wedge-shaped terminal. A variety of other energy absorbing crash cushions also are utilized for median barrier end treatments. The median barrier breakaway cable terminal (MBCT) also has been developed. To date, only the GREAT terminal has been successfully crash tested with an 1,800-lb automobile as prescribed in NCHRP Report 230.⁽⁵⁾

The GREAT system consists of a series of diaphragms separated by a crushable material. The diaphragms support side panels which provide a redirecting surface for vehicles impacting the side of the terminal. Low-speed and low-angle side impacts do not significantly damage the treatment. When impacted on the nose, the material between diaphragms is crushed and the vehicle is smoothly decelerated to a stop. For low- and

moderate-speed head-on impacts, restoration of the system is accomplished by replacing the crushable material between the diaphragms. This system has proven to be crashworthy for most impacts. The GREAT system is proprietary, and is expensive. Although repair costs for this system are low compared to other end treatments currently in use, the repair costs are still a significant portion of the overall cost of this alternative.

Although not currently being used with concrete median barriers, the MBCT could be adapted to the HVMB. The median barrier breakaway cable terminal is designed for use with W-beam median barrier. This design consists of a standup sheet metal terminal with the first posts designed to break away during frontal impacts. The system relies on the buckling of the sheet metal and the breakaway posts to attenuate head-on impacts. Tension in the sheet metal for side impacts is provided by a cable anchored to the leading post. This system has not gained widespread acceptance due to sensitivity of the design to installation details and marginal impact performance for small cars. In recent crash tests with 1,800-lb cars from a research project currently underway, the occupant impact velocity was marginal at best. The initial cost of the MBCT is relatively low; however, even minor impacts with this terminal cause significant damage to the system, and therefore repair costs for the system are very high. Further, when this system is used with a concrete median barrier, the barrier must first be transitioned from concrete to W-beam and then to the terminal which greatly increases the cost of the treatment.

Energy-absorbing crash cushions include steel drums, water-filled cell, and crushable cell crash cushions. Steel drum crash cushions rely on the crushing of steel drums to attenuate head-on impacts. Side panels and steel cables provide redirective capability for the cushion. These cushions have been used widely and proven to be a crashworthy end treatment. Further, relatively simple design procedures have been developed which could allow modification of this design to accommodate minisize automobiles. Like the MBCT, steel drum crash cushions are

relatively inexpensive to install but require a great deal of maintenance. Other energy-absorbing crash cushions such as water-filled cell and crushable cell cushions are relatively costly to install. Although repair costs for these systems is significantly lower than for the MBCT or steel drum end treatments, they may not have an overall cost advantage over the two less expensive systems. All of the energy absorbing crash cushions currently in use often require more space than is available in narrow medians.

Inertial crash cushions such as sand-filled barrels are not capable of redirecting vehicles impacting on the side of the systems. Therefore, wide arrays of barrels are needed when they are used for median barrier terminals. Inertial cushions are relatively inexpensive initially, but maintenance and repair costs are very high.

Sloped end treatments for median barriers are not widely used because they tend to launch or roll impacting vehicles. Although these treatments are inexpensive to install and maintain, the prospect of successfully testing these systems with 1,800-lb cars is not very good.

The steel barrel attenuation system is another type of end treatment recently developed that combines the principles behind energy absorption and inertial crash cushions.⁽⁶⁾ This treatment is constructed from a single line of steel drums; see figure 7. Some of the steel drums are empty, some partially filled with sand, and others completely filled with sand. The empty barrels provide an energy absorbing mechanism, and the sand-filled barrels allow for momentum transfer. Thrie-beam side plates and steel cables redirect vehicles impacting the side of the treatment. This end treatment, although not yet used in the field, should have a relatively low initial installation cost. Furthermore, restoration of the treatment after crash tests has shown that repair is relatively inexpensive. Preliminary analysis of this end treatment, as it is currently designed, has shown that it may meet the impact criteria set forth in NCHRP Report 230.⁽⁵⁾ However, to date no tests have been conducted with 1,800-lb cars.

Recommendations

As discussed in the previous paragraphs, several impact-attenuating systems have been developed to provide a safe transition and terminal at the end of a concrete median barrier. Two types of end treatments are recommended for installation where space is limited:

- Guard Rail Energy Absorption Terminal (GREAT), figure 6.
- Sand-filled barrels.

The GREAT system performs very well when struck head-on, or at other locations including the point at which it joins a barrier. The system is also very effective in areas where lateral space is limited.

Reproduced from
best available copy.



Figure 6. GREAT installation.

Reproduced from
best available copy.

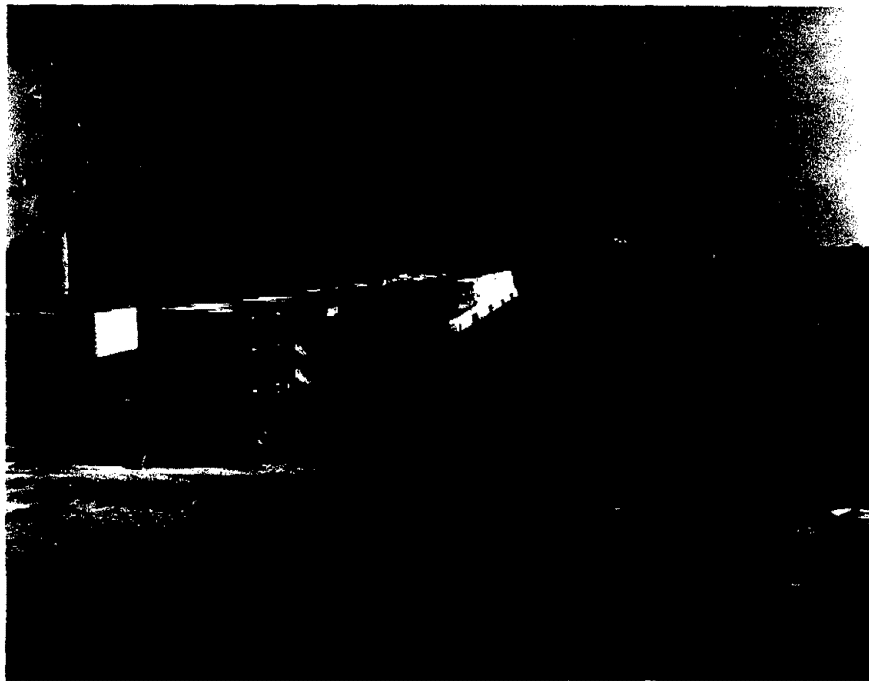
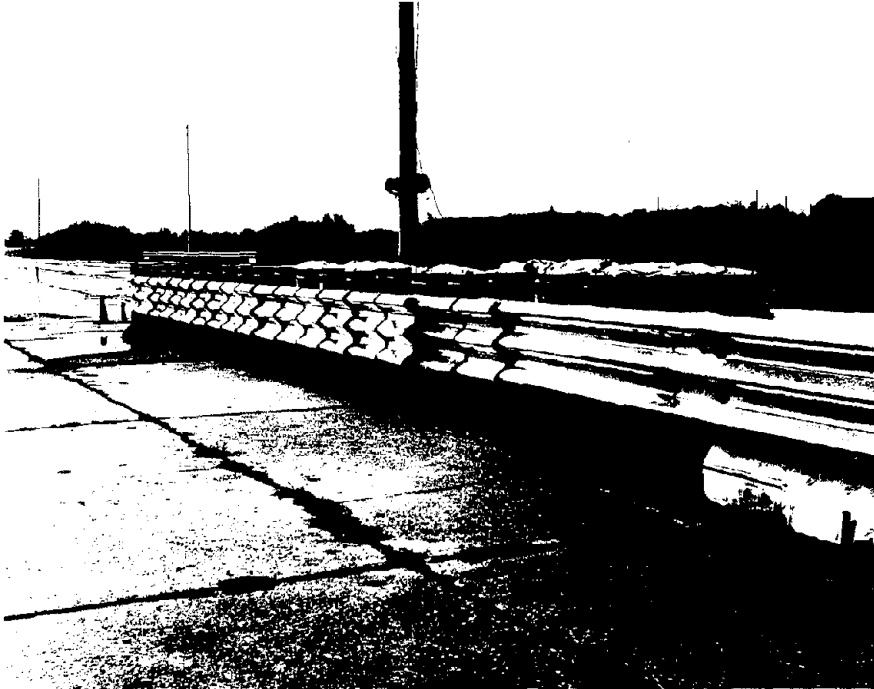


Figure 7. Barrel/W-section crash cushion.

SELECTION GUIDELINES

Establish Need for Barrier

The first step in selecting a barrier is to establish the need for the barrier. There are some locations where opposing lanes of traffic are separated by a sufficiently wide median (or where an even wider area between opposing travelled lanes is available). In such locations a barrier is not needed. When adequate spacing is not available, a median barrier may be needed depending upon the characteristics of the traffic, such as average daily traffic, proportions of various types of vehicles, and the traveling speed.

For less severe traffic characteristics, a barrier may not be justified. For somewhat more severe characteristics, a conventional median barrier may be warranted. Further, severity--such as might result from a high percentage of truck traffic--may create the need for a higher performance barrier.

Identification of Problem Locations

The second step in selecting a barrier is identification of a problem location. This identification process can be accomplished by considering (1) traffic behavior, and (2) roadway conditions. For example, traffic behavior can be established by reviewing highway patrol records. These records might reflect a high incidence of speeding, and careless, or even reckless, driving. A review of accident records should reveal the number of collisions with existing barriers. Traffic counts could be made to determine the traffic mix, i.e., automobiles, vans, medium trucks, busses, and tractor-trailers. Maintenance records should indicate the extent of damage to an existing barrier.

Next, roadway conditions should be considered. Roadway geometry, as well as horizontal and vertical curvature, are important indicators in the identification process, as are posted speed limit signs. Thus the identification process requires an examination of available information.

SELECTION GUIDELINES

Establish Need for Barrier

The first step in selecting a barrier is to establish the need for the barrier. There are some locations where opposing lanes of traffic are separated by a sufficiently wide median (or where an even wider area between opposing travelled lanes is available). In such locations a barrier is not needed. When adequate spacing is not available, a median barrier may be needed depending upon the characteristics of the traffic, such as average daily traffic, proportions of various types of vehicles, and the traveling speed.

For less severe traffic characteristics, a barrier may not be justified. For somewhat more severe characteristics, a conventional median barrier may be warranted. Further, severity--such as might result from a high percentage of truck traffic--may create the need for a higher performance barrier.

Identification of Problem Locations

The second step in selecting a barrier is identification of a problem location. This identification process can be accomplished by considering (1) traffic behavior, and (2) roadway conditions. For example, traffic behavior can be established by reviewing highway patrol records. These records might reflect a high incidence of speeding, and careless, or even reckless, driving. A review of accident records should reveal the number of collisions with existing barriers. Traffic counts could be made to determine the traffic mix, i.e., automobiles, vans, medium trucks, busses, and tractor-trailers. Maintenance records should indicate the extent of damage to an existing barrier.

Next, roadway conditions should be considered. Roadway geometry, as well as horizontal and vertical curvature, are important indicators in the identification process, as are posted speed limit signs. Thus the identification process requires an examination of available information.

Consideration of Alternatives

Once the need for a barrier has been established and a problem location has been identified, two alternatives must be considered. A 32-inch-tall barrier may be selected in a location which has a large proportion of automobiles, and the roadway conditions do not warrant a taller barrier. However, a 32-inch-tall barrier will not redirect vehicles with higher centers-of-gravity. A 42-inch-tall barrier will redirect vehicles with higher centers of gravity and should be selected when a large proportion of trucks (15 percent or more) operate in the problem location.

It should be noted that even the 42-inch-tall barrier will not redirect all vehicles; however it will perform better than a 32-inch-tall barrier. In one test, a tractor-trailer with a 64-inch-high center of gravity (of the trailer) struck the barrier. The vehicle was contained and redirected, and remained upright. In another test, a tractor-trailer with a 96-inch-high center of gravity (of the trailer) hit the same barrier (installed on a simulated roadway with a different cross slope), and rolled over the barrier.

More details on the 42-inch-tall barrier tests are presented in appendix B.

Benefit/Cost Analysis

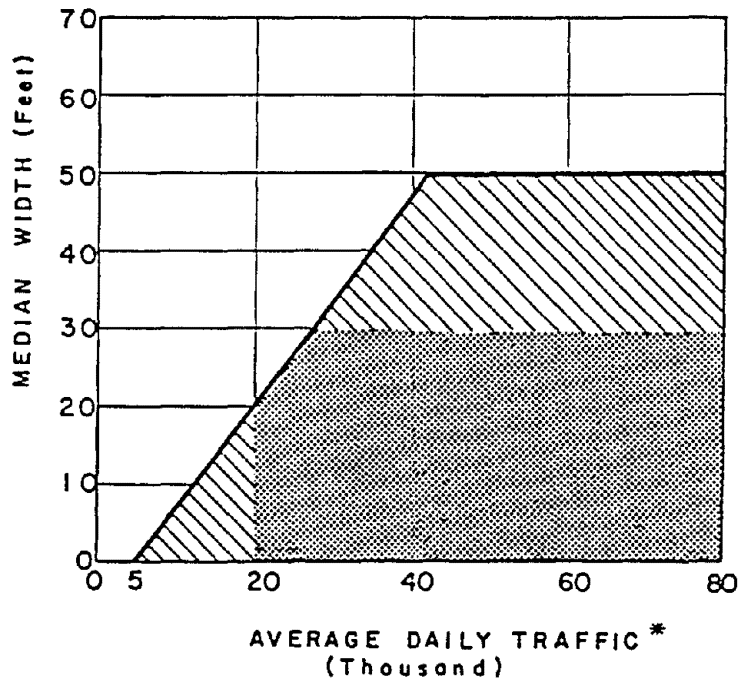
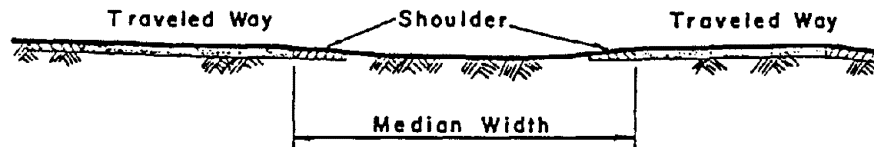
At present, the results of benefit/cost analysis do not provide an adequate basis for providing new warrants and criteria for distinguishing a heavy vehicle median barrier from a standard CMB or no barrier. FHWA personnel and others are working on a benefit/cost analysis method to provide warrants that will answer these questions.⁽⁷⁾ This method should be employed when it becomes available.

In the meantime it is suggested that criteria such as that presented in figure 8 and reference 8 be used. If a median barrier is warranted in

figure 8 and the traffic mix (or accident history) suggests a high incidence of truck encroachments then the heavy vehicle median barrier should be selected. If trucks represent 15 percent or less of the traffic, then a standard CMB should be used. If a standard barrier is not warranted using figure 8, then it is unlikely that any benefit would be derived from a heavy vehicle median barrier.

Selection of Appropriate Barrier

The 1977 AASHTO Barrier Guide procedure for Median Barrier Warrants could be used to select a Heavy Vehicle Median Barrier.⁽⁸⁾ Figure 8 is for all median barriers. In cases where trucks are crossing the median, the same curve could be used to warrant use of the HVMB.



* Based on a 5-year projection

METRIC CONVERSION
1 ft = 0.305 m

Warranted
Optional

Figure 8. Median barrier warrants.

APPENDIX A: Tests On A Load Measuring Wall

Engineers have conducted full-scale prototype tests on barrier designs for more than twenty years. Criteria have been developed for evaluating the effectiveness and performance of barriers subjected to collisions. Engineers have found this information to be useful in designing barriers, but the question, "What force should be used in designing a barrier?" remained unanswered until the late 1970's. At that time the Texas Transportation Institute constructed a solid reinforced concrete wall (see figure 9) with transducers installed to measure force of impact.

Lateral forces imposed by a variety of test vehicles at various impact speeds and angles were measured in the series of tests on the instrumented wall. Data from these tests were analyzed to determine magnitudes, locations of resultants, and distributions of forces. High-speed films from each test showed two distinct impacts (or impulses). The initial impulse occurred when the front corner of the vehicle was in contact with the wall and the vehicle was being redirected. The final impulse occurred when the rear of the vehicle swung against the wall. Each of these impulses was analyzed to determine the highest average force.

As a result of these tests and measurements, an answer to the question posed earlier has been found. Forces for designing a rigid barrier are contained in table 1.

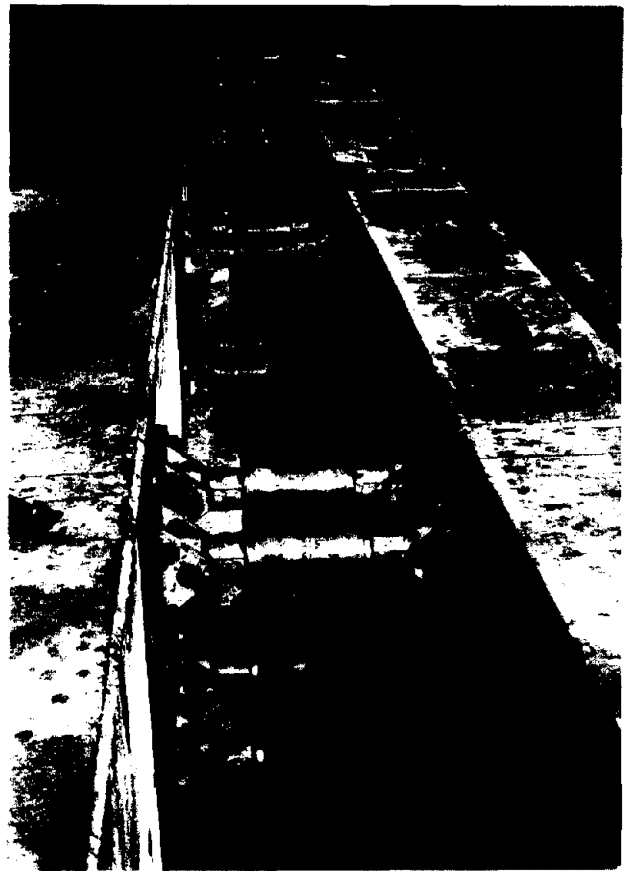
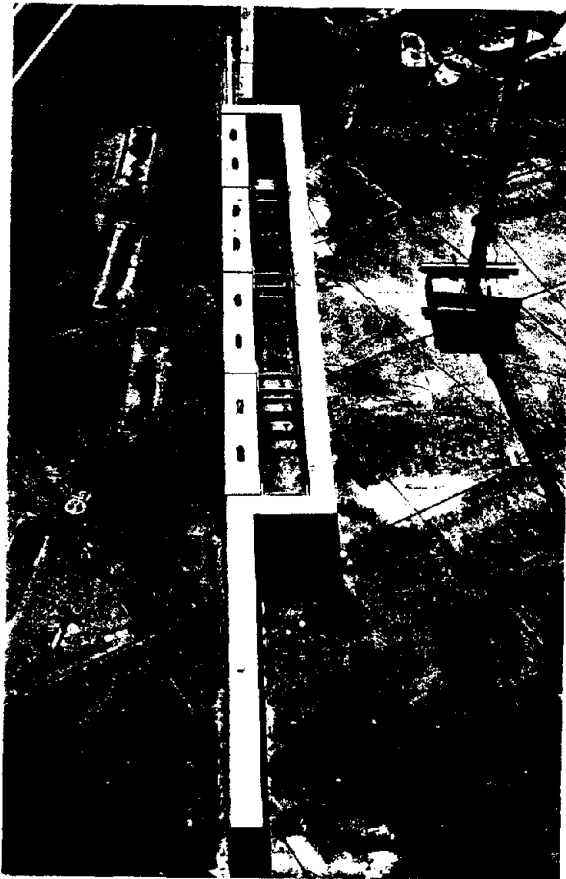
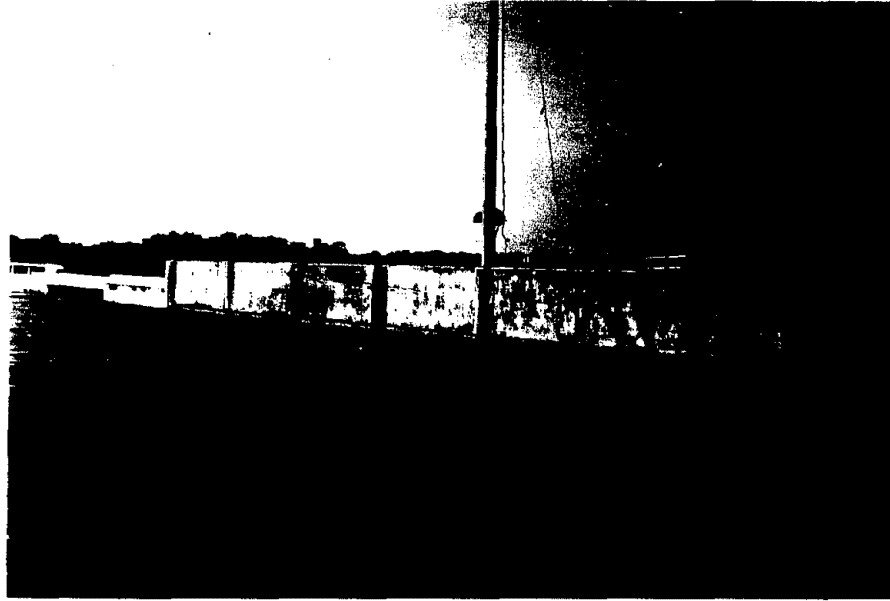
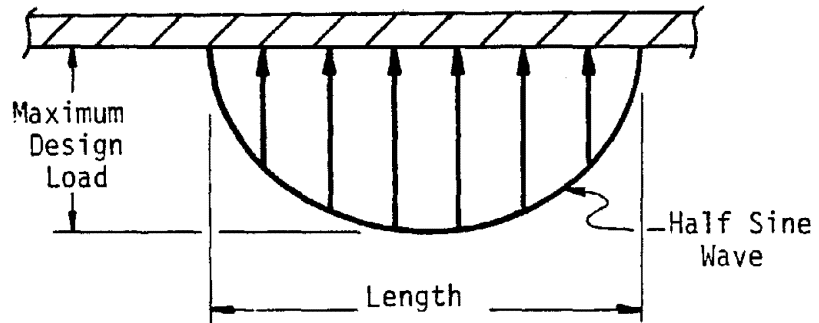


Figure 9. Load-measuring wall.

Table 1. Recommended ultimate design loads for bridge railings that do not deflect significantly.

Design Test Condition	Max. Design Load (k/ft)	Length of Load (ft)	Effective Height (in)
4,500 lb/60 mi/h/15 deg	11.2	7.3	24
4,500 lb/60 mi/h/25 deg	14.5	6.5	24
20,000 lb/60 mi/h/15 deg	8.1	12.3	34
32,000 lb/60 mi/h/15 deg	22.1	15.0	30

1 lb = 0.454 kg
 1 mi/h = 1.609 km/h
 1 k/ft = 1.356 kN-m
 1 ft = 0.305 m
 1 in = 25.40 mm



APPENDIX B: Tests On Heavy Vehicle Median Barrier

SERIES 1

The HVMB was designed to meet two requirements: (1) to smoothly redirect automobiles, busses, and trucks, and (2) to contain larger and heavier vehicles. Therefore, two tests were conducted. The results of these tests will be discussed in subsequent paragraphs.

Test Installation

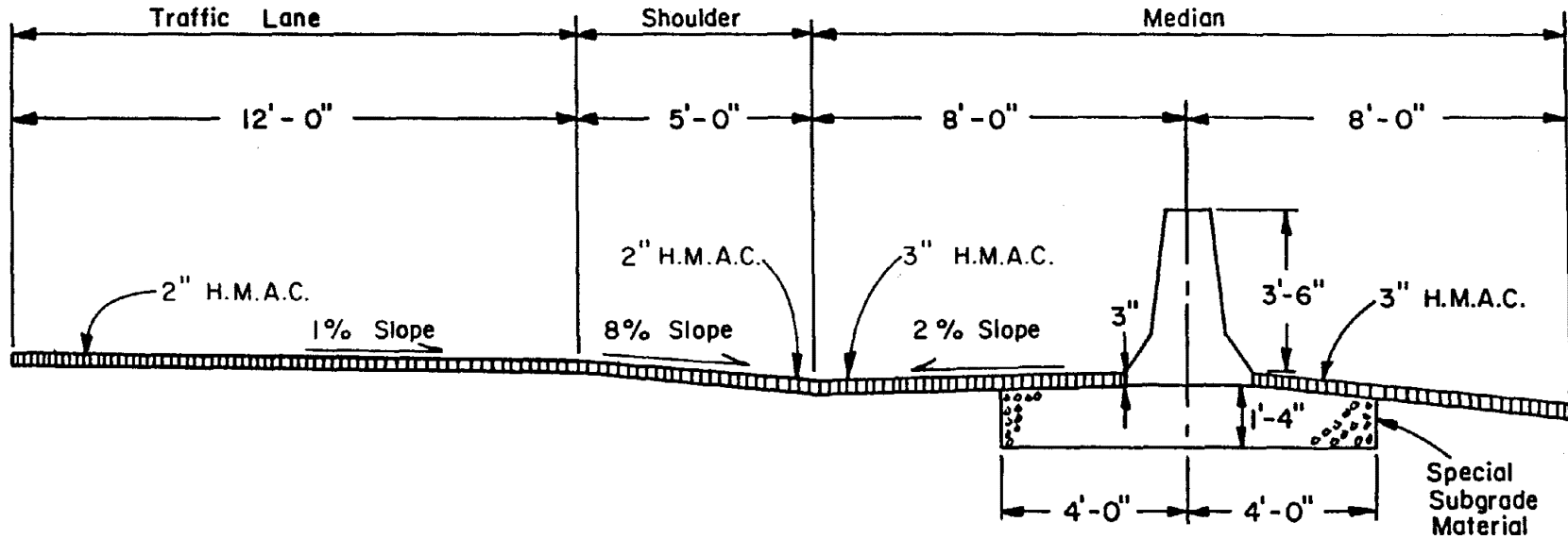
A cross section of the proposed Heavy Vehicle Median Barrier (shown in figure 10) with a simulated roadway cross section (as shown in figure 11) was constructed. The 250-ft-long barrier was cast in place. The design specified 4,000 psi concrete and grade 60 reinforcing steel. A paved transition between the highway cross section and the approach runway was constructed.

Test No. 1-1: 2,190-lb vehicle

The test vehicle used was a 1979 Honda Civic. The vehicle collided with the barrier at 62.6 mi/h and an approach angle of 15.0 degrees. The transmission was in neutral, the steering was unrestricted, and the vehicle was unrestrained prior to impact.

Following impact the vehicle rode up the face of the barrier and became airborne. The vehicle was in a nose down attitude with the front wheels steered to the right when it lost contact with the barrier. When the vehicle returned to the pavement it rolled and came to rest upright.

A summary of the results of this test is shown in figure 12. The roll behavior exhibited by the small vehicle was not acceptable according to performance standards set forth in NCHRP Report 230.⁽⁵⁾ Upon further study, it was determined that the prototype roadway cross section, which was not level, contributed to the roll of the vehicle.



H.M.A.C. - Hot Mix Asphaltic Concrete

Special Subgrade Material - Red sandy clay
subgrade material with a maximum
dry density (AASHTO T180) of 126.0 lb/ft³

Figure 11. Cross section of test barrier installation.

Reproduced from
best available copy.

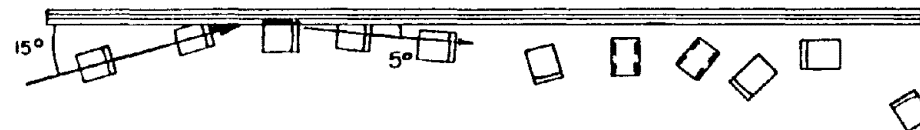


0.000 s

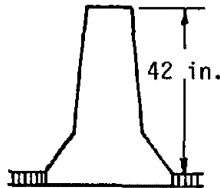
0.114 s

0.228 s

0.342 s



33



Continuous Mod.
Safety Shape

Test No.	1-1	Impact Speed.	100.7 km/h (62.6 mi/h)
Date	7-12-82	Impact Angle.	15.0 degrees
Rail	Continuous Mod. Safety Shape	Exit Speed.	91.3 km/h (56.8 mi/h)
Length of Installation . .	76.0 m (250.0 ft)	Exit Angle.	5.0 degrees
Vehicle.	1979 Honda CVCC	Vehicle Accelerations (Max. 0.050 sec Avg.)	
Vehicle Weight		Longitudinal.	-4.6 g
Test Inertia	843 kg (1860 lb)	Lateral	-8.3 g
Gross Static	993 kg (2190 lb)	Occupant Impact Velocity	
Vehicle Damage Classification		Longitudinal.	3.8 m/s (12.4 fps)
TAD--11LFQ4 SAE--11LFEW6		Lateral	5.2 m/s (17.1 fps)
Dummy Restraints		Occupant Ridedown Accelerations	
Driver	No Restraint	Longitudinal.	-2.3 g
Passenger.	Lap & Shoulder Belt	Lateral	-7.9 g

Figure 12. Summary of data for test 1-1.

Test No. 1-2: 80,420-lb tractor-trailer

This test with a heavy vehicle was considered primarily as a vehicle containment test. The vehicle was a 5-axle tractor-trailer unit consisting of a 1978 autocar/tractor and a 40-ft trailmobile van. The trailer was loaded with sandbags placed on wood pallets. The center-of-gravity height of the ballast was 98 in above the ground. Gross static mass of the vehicle was 80,420 lbs.

The vehicle impacted the barrier at 52.8 mi/h and an approach angle of 16 degrees. Shortly after impact the front of the tractor rode up the face of the barrier. As the front of the tractor returned to the pavement surface, the front of the trailer struck the barrier and pulled the rear of the tractor up and into the barrier. The rear of the trailer subsequently rolled onto and over the barrier while the tractor and front of the trailer remained on the impact side of the barrier. The vehicle remained in this attitude as it continued to slide along the barrier and off the end; the vehicle was severely damaged as shown in figure 13.

The barrier received minor damage and there was no measurable deflection. A summary of results is shown in figure 14.

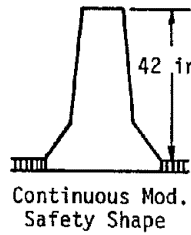
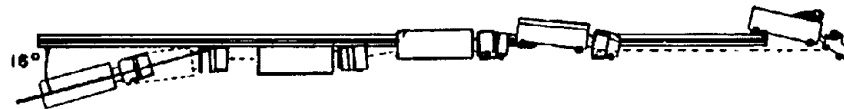
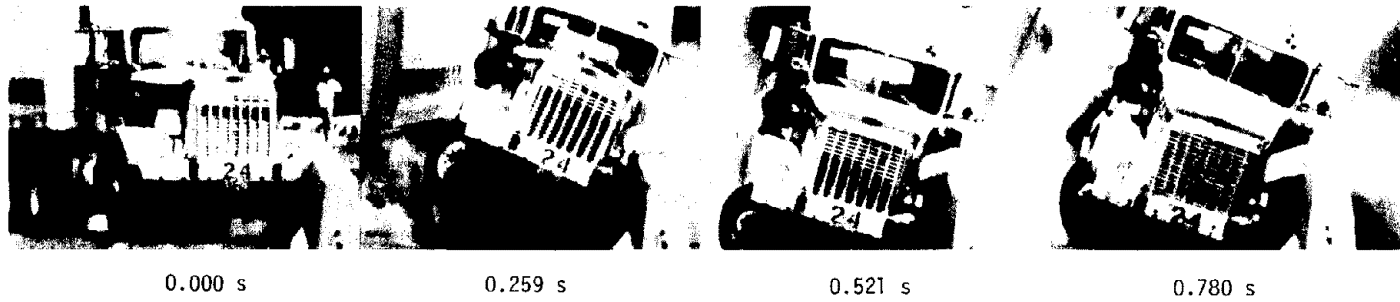
The tractor was contained and redirected; however, the trailer rolled and extended approximately 21 ft onto the opposite side of the barrier. After careful study of test results it was determined that the positioning of the ballast in the trailer represented an extreme case, which contributed to excessive movement of the trailer into the opposite side of the barrier. This unacceptable behavior led to a second series of tests. The results of these tests are discussed in the next section of this report.

Reproduced from
best available copy.



Figure 13. Vehicle after test 1-2.

Reproduced from
best available copy.



Test No.	1-2	Impact Speed.	85.0 km/h (52.8 mi/h)
Date	7-14-82	Impact Angle.	16.0 degrees
Rail	Continuous Mod. Safety Shape	Vehicle Accelerations (Max. 0.050 sec Avg.)	
Length of Installation	76.0 m (250.0 ft)	Longitudinal.	-2.3 g
Vehicle.	Autocar	Lateral	-11.4 g
	Tractor-Trailer	Dummy Restriants	
Vehicle Weight		Driver (only)	Lap Belt
Test Inertia	13,971 kg (30,800 lb)		
Gross Static	36,479 kg (80,420 lb)		

Figure 14. Summary of data for test 1-2.

SERIES 2

Modified Test Installation

The unacceptable performance with the 1,800-lb car rollover described in the preceding section led to modifications of the shoulder slopes to eliminate the drainage depression. Computer simulation of impacts confirmed that a modified roadway cross section was required. Further testing was performed. The same barrier cross section tested under series 1 was used; however, the shoulder and median cross slopes were modified to provide a smooth 5 percent cross slope as shown in figure 15. It was anticipated that this modified slope would prevent the roll behavior experienced earlier with the Honda automobile and the tractor-trailer. Tests proved this to be the case.

Three full-scale tests were conducted on this modified installation. These tests showed the importance of the test setup duplicating the planned field installation, i.e., the cross slope and median configuration.

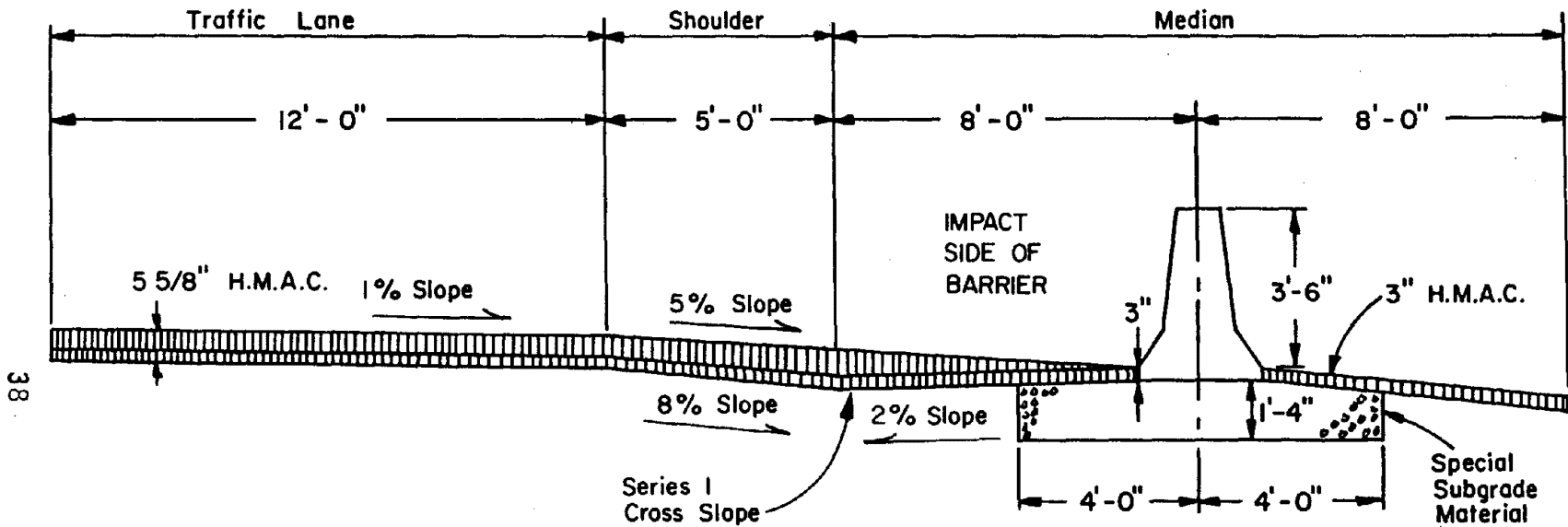
Test No. 2-1: 2,118-lb automobile

A 1977 Honda Civic was directed into the barrier.

The vehicle collided with the barrier at 59.9 mi/h and an approach angle of 14.5 degrees. The vehicle rode up the face of the barrier approximately 6 in, was redirected and lost contact with the barrier at a maximum roll angle of 10 degrees. The vehicle remained upright and relatively stable as it left the test area. A summary of data is shown in figure 16. Both the vehicle and barrier received minor damage.

Test No. 2-2: 4,880-lb automobile

A 1977 Plymouth was used in the second test.

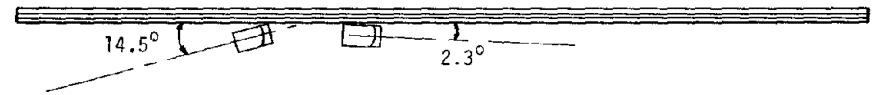
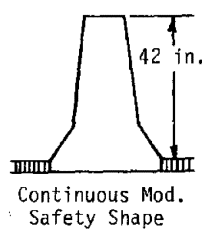
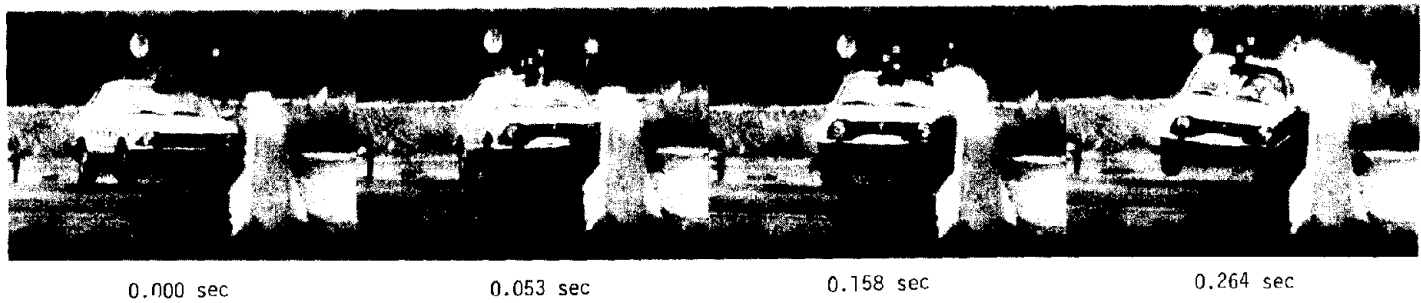


H.M.A.C. - Hot Mix Asphaltic Concrete

Special Subgrade Material - Red sandy clay
subgrade material with a maximum
dry density (AASHTO T180) of 126.0 lb/ft³

Figure 15. Cross section of test barrier installation showing modified roadway cross section (test series 2).

Reproduced from
best available copy.



Test No.	4798-1	Impact Speed.	59.9 mi/h (96.4 km/h)
Date	4/20/83	Impact Angle.	14.5 degrees
Rail	Continuous Mod. Safety Shape	Exit Speed.	55.3 mi/h (89.0 km/h)
Length of Installation	250 ft (76 m)	Exit Angle.	2.5 degrees
Rail Deflection		Vehicle Accelerations	
Permanent	0 ft (0 m)	(Max. 0.050 sec Avg)	
Maximum	0 ft (0 m)	Longitudinal	-4.6 g
Vehicle.	1977 Honda Civic	Lateral	-10.0 g
Vehicle Weight		Vertical	3.0 g
Test Inertia.	1783 lb (809 kg)	Resultant.	11.3 g
Gross Static.	2118 lb (962 kg)	Occupant Impact Velocity	
Vehicle Damage Classification		Longitudinal	12.5 fps (3.8 m/s)
TAD	11-LFQ-3	Lateral	19.7 fps (6.0 m/s)
SAE	11FLEK1 11LDES2	Occupant Ridedown Accelerations	
		Longitudinal	-1.0 g
		Lateral	-13.9 g

39

Figure 16. Summary of data for test 2-1.

The vehicle impacted the barrier at 58.6 mi/h and an approach angle of 16.5 degrees. Shortly after impact, the left front wheel rode up the face of the barrier approximately 5 in. The other wheels remained in contact with the pavement surface. The vehicle was smoothly redirected and was stable when it left the barrier. The barrier and vehicle received minor damage. A summary of the results of this test are presented in figure 17.

Test No. 2-3: 80,180-lb tractor-trailer

To determine vehicle containment characteristics of the barrier, a third test was conducted using a 1974 International cab-over-engine tractor with a 40-ft Fruehauf van-trailer. The trailer was loaded with sandbags placed on the floor and restrained with a plywood covering bolted to the floor. Total loaded weight of the unit was 80,180 lb and the center-of-gravity height of the trailer and ballast was estimated to be 64.4 in.

The tractor-trailer was directed into the barrier by remote control. The engine was shut off and steering released prior to impact. The vehicle impacted the barrier at 52.1 mi/h and 16.5 degrees. The vehicle was smoothly redirected with the trailer achieving a maximum roll angle of 52 degrees. The vehicle remained in contact with the barrier for 150 ft before leaving the end of the barrier. The vehicle remained upright and came to a relatively stable stop. Results of the test are summarized in figure 18.

The tractor sustained major damage to the left side while the trailer was only scraped and dented. The barrier was chipped and marred. There was no measurable deflection of the barrier and there was no structural distress.

Reproduced from
best available copy.

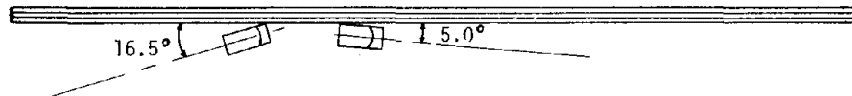
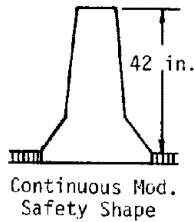


0.000 sec

0.098 sec

0.196 sec

0.295 sec



Test No.	4798-3	Impact Speed.	58.6 mi/h (94.3 km/h)
Date	5/24/83	Impact Angle.	16.5 degrees
Rail	Continuous Mod. Safety Shape	Exit Speed.	49.1 mi/h (79.0 km/h)
Length of Installation	250 ft (76 m)	Exit Angle.	5.0 degrees
Rail Deflection		Vehicle Accelerations	
Permanent	0 ft (0 m)	(Max. 0.050 sec Avg)	
Maximum	0 ft (0 m)	Longitudinal	-4.2 g
Vehicle.	1977 Plymouth	Lateral.	-7.9 g
Vehicle Weight		Vertical	1.8 g
Test Inertia.	4520 lb (2052 kg)	Resultant.	8.6 g
Gross Static.	4880 lb (2216 kg)	Occupant Impact Velocity	
Vehicle Damage Classification		Longitudinal	10.4 fps (3.2 m/s)
TAD	11-LFQ-4	Lateral.	18.2 fps (5.6 m/s)
SAE	11FLEK2 11LDES2	Occupant Ridedown Accelerations	
		Longitudinal	-2.4 g
		Lateral.	-7.0 g

Figure 17. Summary of data for test 2-2.

Reproduced from
best available copy.



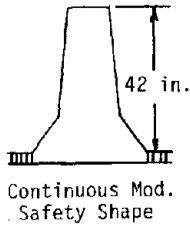
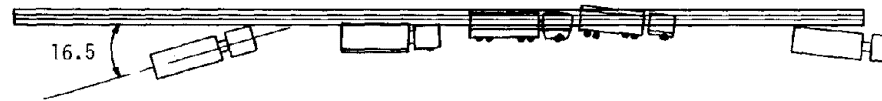
0.000

0.202

0.403

0.820

42



Test No.	4798-13	Impact Speed.	52.1 mi/h (83.8 km/h)
Date	5/26/83	Impact Angle.	16.5 degrees
Rail	Continuous Mod. Safety Shape	Tractor Accelerations at Drive Axles (Max. 0.050 sec Avg)	
Length of Installation	250 ft (76 m)	Longitudinal	-6.5 g
Rail Deflection		Lateral.	-3.1 g
Permanent	0 ft (0 m)	Vertical	-9.3 g
Maximum	0 ft (0 m)	Resultant.	11.1 g
Vehicle	Tractor/Trailer	Trailer Max. Roll Angle	52 degrees
Vehicle Weight			
Empty Weight.	29,600 lb (13,438 kg)		
Gross Static.	80,180 lb (36,402 kg)		

Figure 18. Summary of data for test 2-3.

Summary of Test Results

According to performance criteria set forth in NCHRP Report 230, performance of the barrier was acceptable in all three tests with the modified pavement cross section.⁽⁵⁾ Although the trailer rolled a maximum of 52 degrees in the tractor-trailer test, it eventually righted and the tractor-trailer left the barrier in a stable mode with no intrusion into the opposite side. Table 2 summarizes results from both series of tests.

Table 2. Summary of testing performed on New Jersey Heavy Vehicle Median Barrier.

TEST DESIGNATION AND DATE	TEST CONDITIONS lb/mi/h/deg	VEHICLE TYPE & TEST INERTIA WEIGHT	COMMENT
<u>Series 1</u>			
1-1 7/12/82	2,190/62.6/15.0	1979 Honda 1,860 lb	Vehicle rolled due to reverse pavement slopes.
1-2 7/14/82	80,420/52.8/16.0	1978 Autocar Tractor with Van Trailer 30,800 lb	Trailer rolled and extended over barrier maximum of 21 ft. Trailer center of gravity height reasoned to be worst case.
<u>Series 2</u> (modified pavement cross section)			
2-1 4/20/83	2,118/59.9/14.5	1977 Honda 1,783 lb	Acceptable performance.
2-2 5/24/83	4,880/58.6/16.5	1977 Plymouth 4,520 lb	Acceptable performance.
2-3 5/26/83	80,180/52.1/16.5	1974 International COE Tractor with Van Trailer 29,600 lb	Acceptable performance. Vehicle contained and smoothly redirected with maximum trailer roll angle of 52 deg.

REFERENCES

- (1) C. E. Buth, et al., "Safer Bridge Railings," Volume 2, Final Report on Contract DOT-FH-11-9181, Texas Transportation Institute, Texas A&M University, College Station, Texas, January 1983.
- (2) C. E. Buth, et al., "Development of a High-Performance Median Barrier," Final Report, Contract DOT-FH-11-9485, Texas Transportation Institute, College Station, Texas, April 1983.
- (3) Wanda L. Campise, and C. E. Buth, "Performance Limits of Longitudinal Barrier Systems," Volume 4, Texas Transportation Institute, Texas A&M University, College Station, Texas, November 1984.
- (4) T. J. Hirsch, W. L. Fairbanks, and C. E. Buth, "Concrete Safety Shape With Metal Rail On Top To Redirect 80,000 lb-Trucks," Research Report FHWA/TX-83/+416-1F, Texas Transportation Institute, College Station, Texas, December 1984.
- (5) Jarvis D. Michie, "Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances," NCHRP Report 230, Transportation Research Board, March 1981.
- (6) D. L. Sicking, and H. E. Ross, Jr., "Crash Cushion for Narrow Objects," Transportation Research Record No. 942.
- (7) Rex Bliss, James Hatton, Charles Liu, James Mekemson, Ray Owings, and James Wentworth, "Roadside Safety Technology Benefit Cost Analysis," U.S. Department of Transportation, Federal Highway Administration, 1985 (Unpublished).
- (8) "Guide For Selecting, Locating and Designing Traffic Barriers," American Association of State Highway and Transportation Officials, Washington, DC, 1977.

