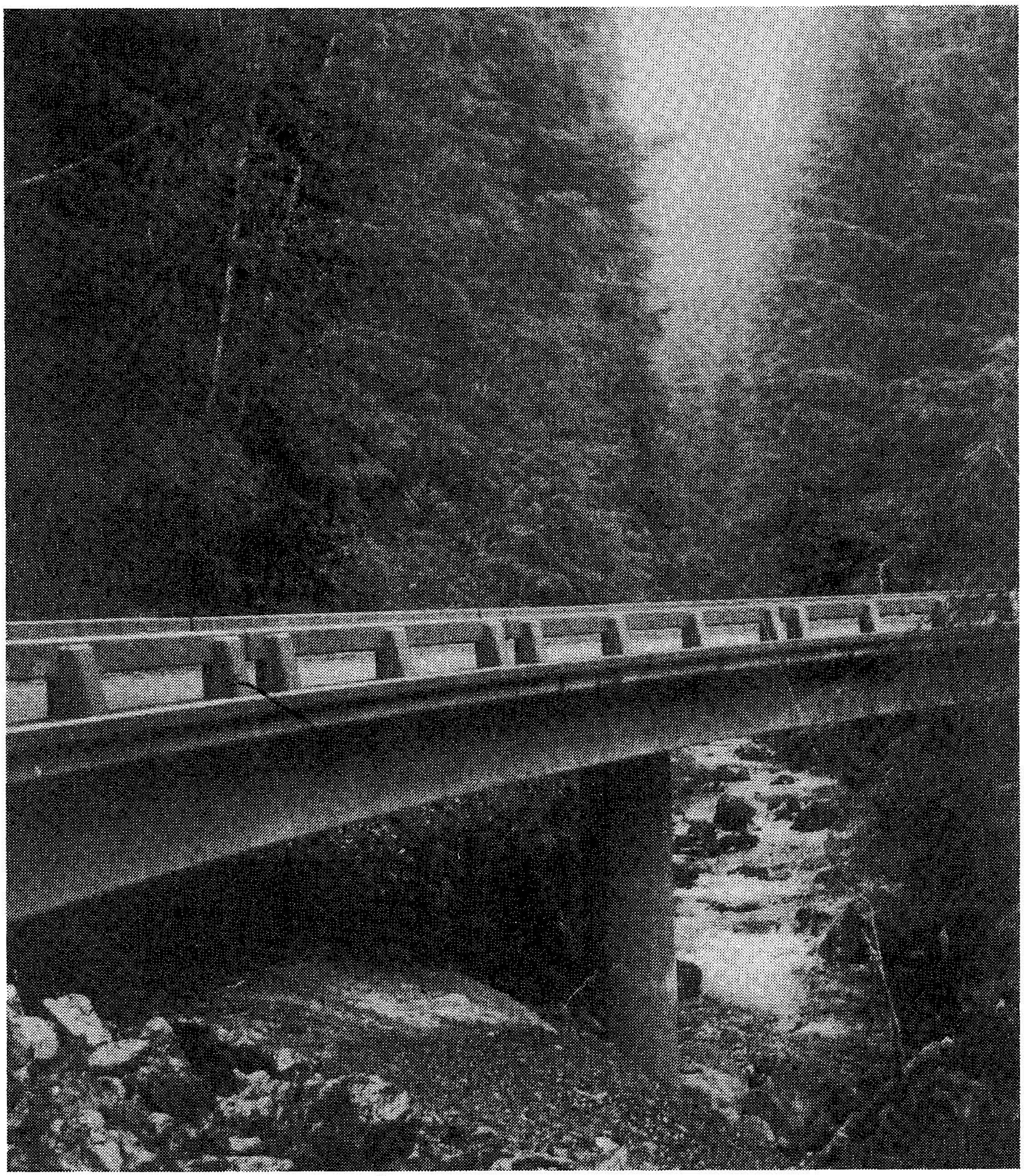
.Department
Transportation
deral Highway
dministration

Summary Report on Aesthetic Bridge Rails and Guardrails



Report No. FHWA-SA-91-051

June 1992

Technical Report Do[illegible]

1. Report No. FHWA-SA-91-051	2. Government Accession No.	3. Recipient's [illegible]
4. Title and Subtitle Summary Report on Selected Aesthetic Bridge Rails and Guardrails		5. Report Date June 1992
		6. Performing Organization Code
7. Author(s) Malcolm H. Ray		7. Performing Organization Report No. FHWA7589-3
9. Performing Organization Name and Address Momentum Engineering 1103 Dickinson Lane Franklin, Tennessee 37064		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. DTFH61-89-R-00075
12. Sponsoring Agency Name and Address Federal Highway Administration Office of Technology Applications State and Local Programs Branch		13. Type of Report and Period Covered Final September 1989 - December 1991
		14. Sponsoring Agency Code

15. Supplementary Notes

Contracting Officer's Technical Representative: Janet Coleman, HTA-12

16. Abstract

Providing safe roadside barrier hardware on scenic roadways and parkways is as important as safety on more typical roads. Recently a number of guardrails and bridge railings have been developed for these types of scenic roads. This report summarizes the development, testing and field experience for three aesthetic bridge railing designs and three guardrail designs: the glue-laminated wood bridge railing, the Federal Lands Highways Modified Kansas corral bridge railing, the stone masonry bridge rail, the steel-backed timber guardrail, the stone masonry guard-wall and the pre-cast simulated stone guardwall. This report describes the history of each barrier system and summarizes the crash tests. The features and components of each system are discussed and drawings are presented.

17. Key Words construction, highway accidents, bridge railings, crash tests, highway safety, aesthetics, aesthetic barriers	18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia, 221161.

19. Security Classif.(of this report)	20. Security Classif.(of this page)	21. No. of Pages	22. Price
Unclassified		Unclassified	

Facsimile of Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

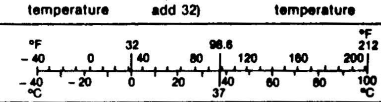
Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
in	inches	2.54	millimetres	mm
ft	feet	0.3048	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
	AREA			
in^2	square inches	645.2	millimetres squared	mm^2
ft^2	square feet	0.0929	metres squared	m^2
yd^2	square yards	0.836	metres squared	m^2
mi^2	square miles	2.59	kilometres squared	km^2
ac	acres	0.395	hectares	ha
	MASS (weight)			
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
	VOLUME			
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft^3	cubic feet	0.0328	metres cubed	m^3
yd^3	cubic yards	0.0765	metres cubed	m^3

NOTE: Volumes greater than 1000 L shall be shown in m^3.

Symbol	When You Know	Multiply By	To Find	Symbol
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
	AREA			
mm^2	millimetres squared	0.0016	square inches	in^2
m^2	metres squared	10.764	square feet	ft^2
km^2	kilometres squared	0.39	square miles	mi^2
ha	hectores (10 000 m^2)	2.53	acres	ac
	MASS (weight)			
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1 000 kg)	1.103	short tons	T
	VOLUME			
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m^3	metres cubed	35.315	cubic feet	ft^3
m^3	metres cubed	1.308	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



These factors conform to the requirement of FHWA Order 5190.1A.

* SI is the symbol for the International System of Measurements

Table of Contents

List of Figures

List of Tables

Introduction

Guardrails and bridge railings serve a vital role on the highway system by preventing motorists from becoming involved in more serious collisions. Although there are a host of effective highway barriers, most of them are utilitarian in appearance. The primary goal of barrier hardware designers has typically been to develop effective hardware at the minimum cost: aesthetics have not typically been a high priority. Only in recent years has the importance of more intangible qualities like aesthetics become a concern in developing hardware for the roadside.

The primary function of roads in parks, historical communities or scenic areas is to provide access to aesthetically sensitive areas. Many typical guardrails would compromise this basic function of scenic roadways. The need to provide safe roadways does not, however, stop at the boundaries of a scenic or historic area. The 386-mile (620-km) long Natchez Trace Parkway, to cite a particular example, experienced 200 accidents in 1986 of which 5 involved fatalities. In 1990 there were 7,831 traffic accidents in National Parks, 40 of these accidents were fatal. There are almost 8,000 miles (12,900 km) of roadways in National Parks alone, more than half of this mileage (4,856 miles (7,818 km)) is paved. There are 2.35 million vehicle miles travelled on National Park roadways so the accident and fatal accident rates are 33 and 0.17 accidents per 100 million vehicle miles traveled (1). The fatality rate on all roadways in the United States was 2.43 deaths per 100 million vehicle miles travelled in 1990 (2). Although the fatality rate is an order of magnitude less than the national average rate, it is still not negligible. There has been a need to develop barrier systems that fit in with a variety of aesthetically sensitive surroundings so that the twin goals of protecting scenic beauty and providing safe roads do not conflict.

This report summarizes the development and testing of six aesthetic barrier systems: three guardrails and three bridge railings. The guardrails discussed are the steel-backed timber guardrail, the stone masonry guardwall and the pre-cast simulated stone guardwall. The bridge railings discussed are the glue-laminated wood bridge railing, the Federal Lands Highways modified Kansas corral bridge railing and the stone masonry bridge railing. The bridge railings are appropriate for use as performance level 1 railings as described in the American Association of State Highway and Transportation Officials' (AASHTO) *Guide Specifications for Bridge Railings* (3). The PL-1 category requires two full-scale crash tests: an 1800-lb (814-kg) passenger car striking the bridge railing at 50 mi/h (80 km/h) and 20 degrees and a 5400-lb (2442-kg) pickup truck striking the bridge railing at 50 mi/hr (80 km/h) and 20 degrees.

Steel-Backed Timber Guardrail

History

Timber guardrails have been used for decades in National Parks and Forests as traffic barriers and traffic control devices. Timber is an attractive material in situations where blending in with the natural surroundings is important. Unfortunately, barriers made of unreinforced timber are not effective in many types of real collisions. Typical timber guardrails have a mounting height that is too low and there is no continuity between rail segments.

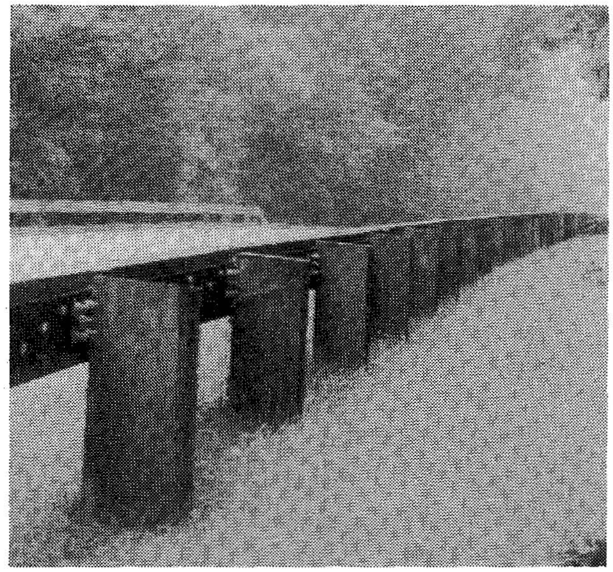


Figure 1. Unblocked-out Steel-Backed Timber Guardrail -- Colonial Parkway.

The steel-backed timber guardrail, shown in figure 1, was developed to overcome these deficiencies while still taking advantage of the aesthetic qualities of wood. A number of steel-backed timber guardrails have been installed, primarily in the eastern district. There are earlier versions of the steel-backed timber guardrail on the southern part of the George Washington Parkway and the Colonial Parkway, both in Virginia. An installation conforming to the drawings shown in this report is being built along the northern part of the Natchez Trace National Parkway in Williamson County, Tennessee.

Design Principals and System Components

The steel-backed timber guardrail functions much like any post and beam guardrail system. The timber and steel rail prevent a vehicle from penetrating the barrier line. The rail loads are transmitted to the ground through the posts. Details of the steel-backed timber guardrail system are shown in figure 4 at the end of this section. Full scale crash tests performed in a recent research project are summarized in table 1 (4). Detailed specifications for construction of this barrier can be found in the *Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects* (5).

There have been several versions of this guardrail system installed in several National Parks. The Federal Lands Highways Division of the Federal Highway Administration has two versions of this system in its most current standards: a blocked-out and an unblocked-out version. The unblocked-out version, shown in figure 1, has been successfully crash tested for lower speeds. The blocked out version is thought to be a more crashworthy system because the blockout minimizes the chance of vehicle wheels snagging on the posts. The addition of the blockout does not significantly affect the cost of the system. The Federal Lands Highways Division of the Federal Highway Administration recommends use of the blocked-out version for all installation unless there is an objection for aesthetic reasons.

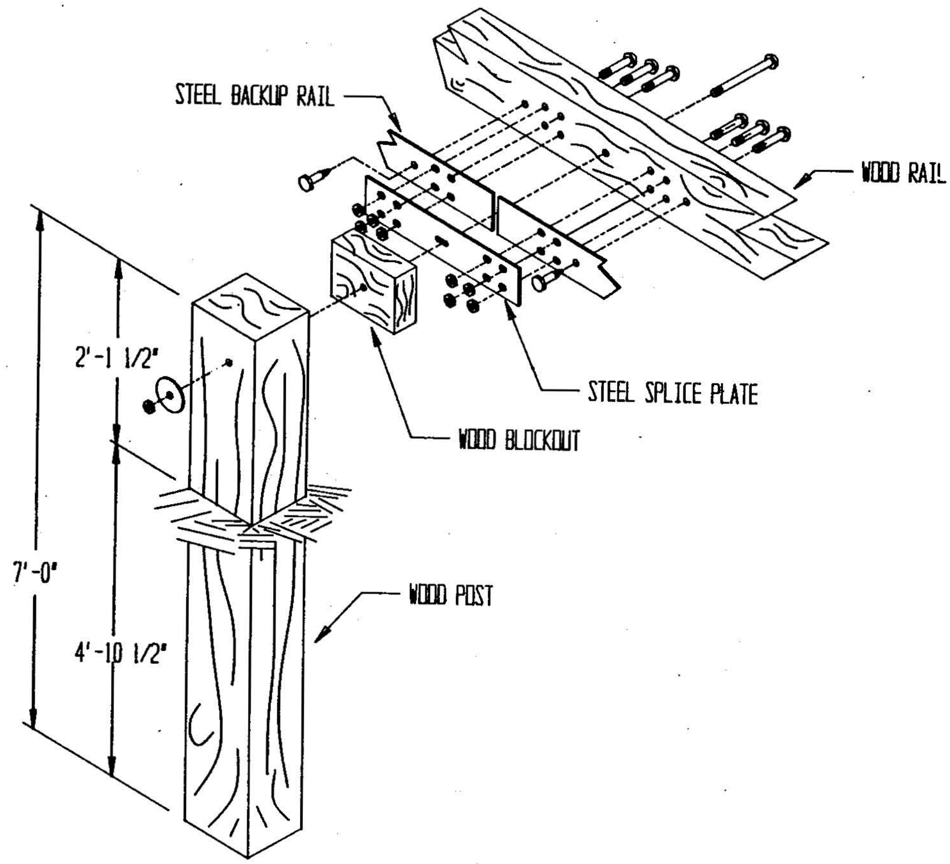


Figure 2. Blocked-out Steel-Backed Timber Guardrail -- Exploded View.

Posts -The wood posts, shown in figure 2 on the blocked-out version, measure 10-by-12 in (254-by-305 mm). In most typical wooden-post guardrails the widest dimension of the post is perpendicular to the travelled way. This system, however, uses a post that is oriented with the 12-in (305-mm) side parallel to the edge of the road. A small 4-by-9 in (102-by-229 mm) blockout is included between the post and rail to minimize the chance of vehicle wheels snagging on the post. The top of the post is not flat but slopes away from the roadway. Earlier versions of this system had a counter-sunk hole in the back of the guardrail post to accommodate the head of the post-rail attachment bolt. Problems with wood splitting between the top of the post and the hole resulted in the elimination of this detail in the most recent Federal Lands Highways specifications (5).

Wood Rail - The rail element is a wooden rail on the traffic face backed by a reinforcing rail made of steel plate. The wood rail is a 6-by-10 in (152-by-250 mm) rectangular section that is 9-ft 11.5 in (3.04 m) long. The top of the rail is mounted 27 in (686 mm) above the ground at the traffic face.

Steel Backup Rail and Splice Plate - Typical unreinforced timber rails were attached to the posts but not each other. In an impact the entire tensile and bending load in the rail had to be resisted

Table 1. Steel-Backed Timber Guardrail Crash Tests (4).

Blocked-out Version

Test No.	1818-5-6-87		1818-8-88	
Date	10-26-87		12-21-88	
Vehicle				
Year	1978		1982	
Make	Ford		Honda	
Model	LTD		Civic	
Test Wght - lbs (kg)	4309	(1955)	1812	(822)
Impact Velocity - mi/h (km/h)	62.4	(100)	63.5	(19.4)
Impact Angle - deg.	24.4		20	
Occupant Impact Velocity				
Longitudinal ft/sec (m/sec)	26.7	(8.1)	26.0	(7.9)
Lateral ft/sec (m/sec)	18.3	(5.6)	21.4	(6.5)
Occupant Ridedown Accelerations - g's				
Longitudinal	12.8		7.4	
Lateral	11.6		9.6	

Unblocked-out Version

Test No.	1818-14-88	
Date	7-20-88	
Vehicle		
Year	1981	
Make	Plymouth	
Model	Gran Fury	
Test Wght - lbs (kg)	4302	(1951)
Impact Velocity - mi/h (km/h)	51.1	(81.8)
Impact Angle - deg.	25	
Occupant Impact Velocity		
Longitudinal ft/sec (m/sec)	27.7	(8.4)
Lateral ft/sec (m/sec)	15.1	(4.6)
Occupant Ridedown Accelerations - g's		
Longitudinal	12.3	
Lateral	11.9	

by the two posts supporting the rail. Since the load could not be distributed to other posts and rails in the system, the impacted components would fracture letting the vehicle penetrate the system.

The steel backup rail provides continuity between rail elements. Impact loads can be distributed to other posts in the system as well as the anchor, since the wooden rails and the steel backup rails are all spliced together. The steel backup rails are 9-ft 9-in (2.97 m) long plates made of weathering steel that are joined together with a steel splice plate at each post. Lag screws spaced 10-in (254 mm) apart attach the steel and wooden rail elements together ensuring that they behave as a single composite beam. The steel is placed on the back side (non-traffic face) of the rail primarily for aesthetic reasons but tensile bending stresses are greatest on the non-traffic face of the rail. Steel is a more effective material in tension than wood so the backup plate is placed at the location where it is most effective.

The steel components of this system are manufactured using weathering steel. A thin layer of rust will form over this type of steel making the rail an earth-toned brown. The steel is corrosion resistant so the surface rust does not weaken the component over time.

Terminal - Providing an adequate terminal is an important though difficult design task. The Federal Lands Highways division of the FHWA recommends the use of a terminal that is tapered back from the road and sloped into the ground or an earth berm as shown in figure 3 (5). If the site includes a backslope, the end of the barrier can be tapered back and buried in the slope. This is probably an even safer alternative than the simple turned-down and tapered-back terminal. A concrete block is buried in the ground to provide anchorage for the guardrail system. Details of the terminal designs are shown in figure 5. The taper used is the same as is suggested in the AASHTO 1989 *Roadside Design Guide* for other types of guardrails (6).
This terminal design is probably adequate for installations where traffic volumes are small and speeds are moderate. This type of low service level roadway is typical in many scenic areas. The tapered-back and turned-down terminal should not be used on high speed, high volume roadways because there is a chance that the terminal would launch vehicles striking it head-on at high speeds. Standard guardrail terminals could also be used on this barrier but aesthetic considerations usually preclude this option.

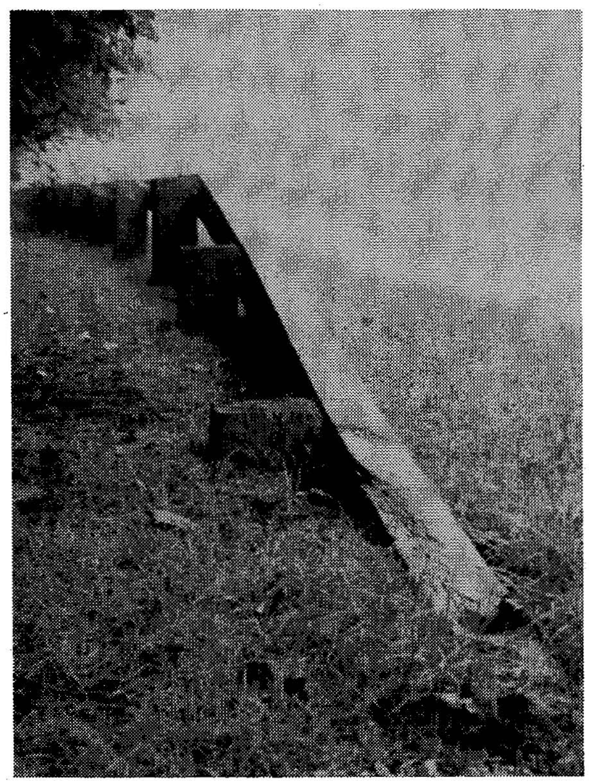


Figure 3. Steel-Backed Timber Guardrail Terminal.

Recommended Applications
The steel-backed timber guardrail is ideal for sites where a strong post w-beam guardrail would normally be used if aesthetics were not a factor. Only the wooden elements of the system can be seen from the road so it is more aesthetically pleasing that a typical w-beam or thrie-beam barrier. The steel elements of the barrier are manufactured from weathering steel which blends in with surrounding natural colors.

in with surrounding natural colors.

There have been a number of installations of this barrier system but none of them conform exactly to the drawings shown in this section. The design of the barrier has evolved over the past several years; each installation incorporating improved features. All the installations to date have used the unblocked out system rather than the blocked out guardrail shown in the figure 4. The Federal Lands Highways Division encourages the use of the blocked out system in all situations but allows the unblocked out version to be used on roads where the speed is less than 50 mph (81 kph) (5).

Construction Procedures
Construction procedures for the steel-backed timber guardrail are similar to other strong post post-and-beam guardrails. The planned traffic face is first established with a string line. The post locations should then be identified and the holes dug using a truck or trailer mounted soil auger. The rail elements should be laid out along the roadway. The steel backup beam is then connected to the wooden rail element using lag screws inserted at the pre-drilled locations in the steel plate. Pre-tapped holes in the wood rail make installing the lag screws easier but the tap holes can be drilled in the field if necessary. The splice plate is attached to the post and blockout using a 15-in (381 mm) long carriage bolt. A 12d nail toe-nailed between the post and blockout is hammered in to keep the blockout from rotating while in service. The composite rail element can now be lifted into place. Four 8.5-in (216 mm) carriage bolts are used to bolt together the splice plate, wood beam and steel rail. Assembly of the rail then continues down the roadway until the entire rail has been installed.

The steel-backed timber guardrail is very stiff so it should sustain little damage in all but the most severe collisions. After a serious collision, several posts or rail elements might be damaged. Damaged elements should be replaced using essentially the same procedures used in constructing the device. If posts are displaced in the soil but otherwise undamaged, the post should be realigned using a chain and truck. The soil behind the re-aligned post should be re-tamped with a compactor if possible. Aside from repairing damage from collisions, this system should require no routine maintenance.

The Federal Lands Highways Division of the FHWA reports a range of construction costs from as low as 26 $/ft (85 $/m) to as high as 50 $/ft (164 $/m). Construction costs for the steel-backed timber guardrail averaged $40 per foot of barrier on the Colonial Parkway installations in 1988; this is probably a good median cost for planning purposes. Typical strong post guardrails like the G4(1S) generally cost about 18 $/ft (59 $/m): a little less than half the cost of the steel-backed timber system. Although it is more expensive than a more typical barrier, the steel-backed timber guardrail is the least expensive of all the aesthetic guardrails discussed in this report.

Accident Experience
This system has only recently been installed in the field so there is no accident experience as yet.

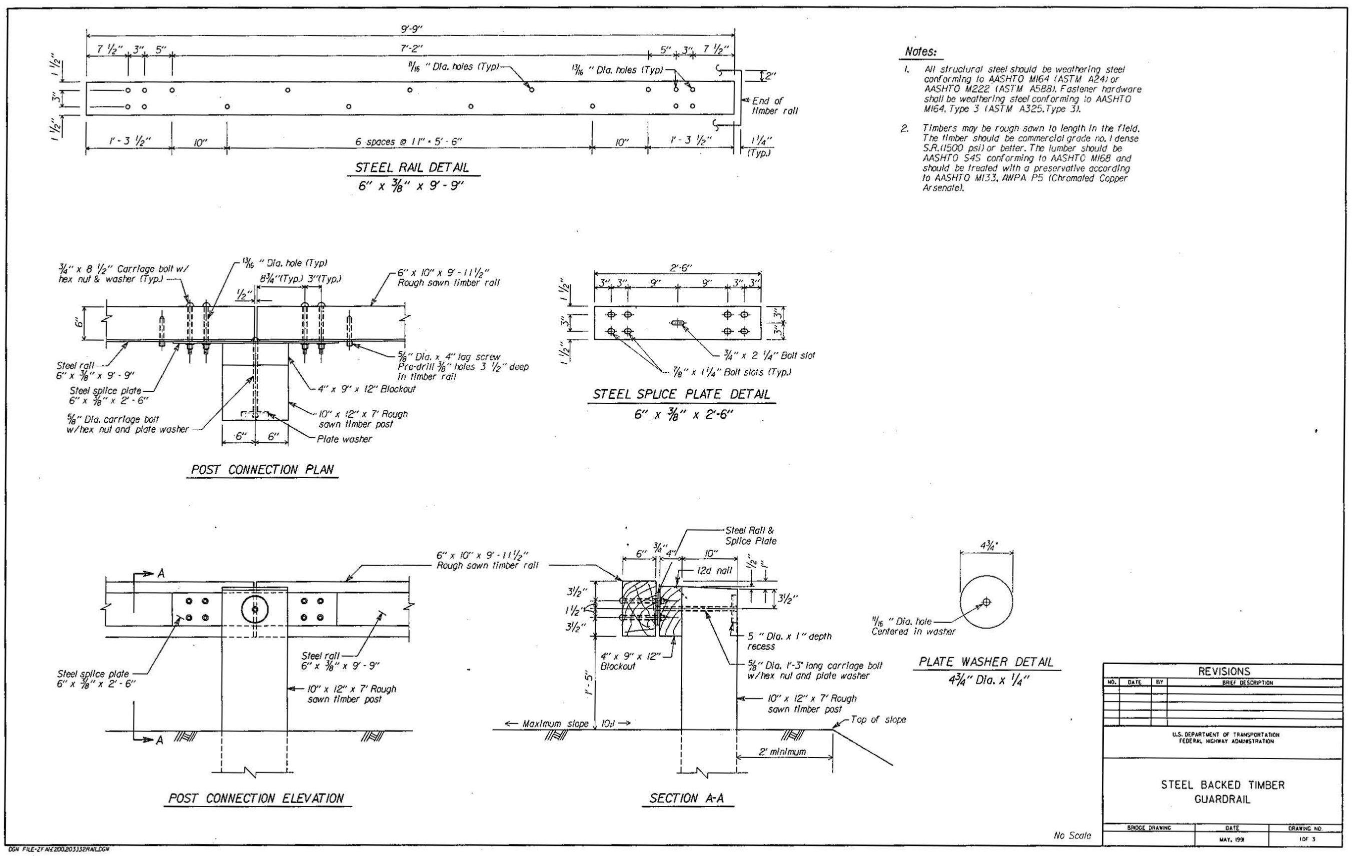
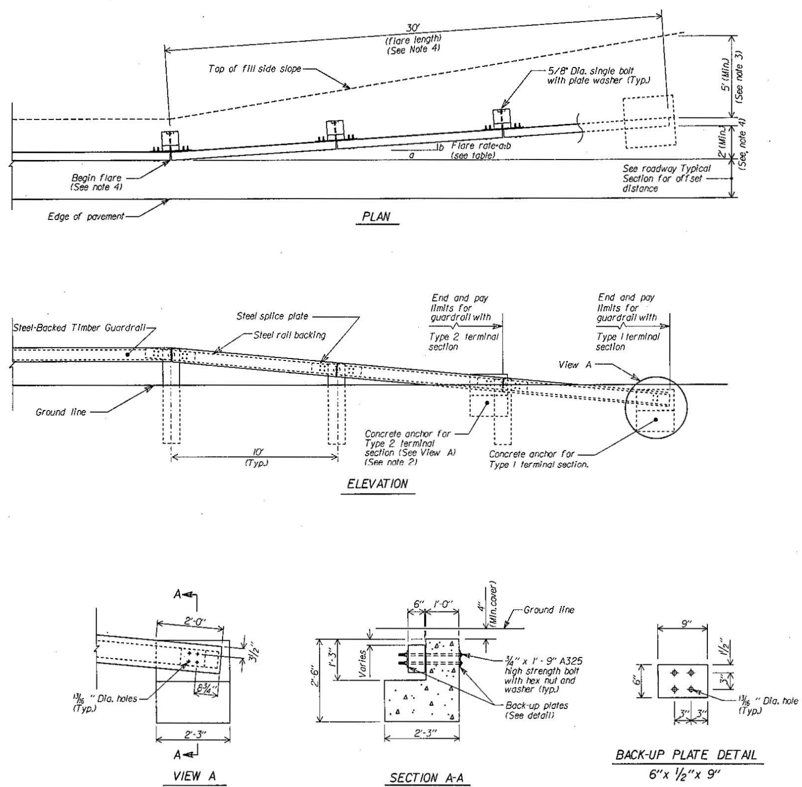


Figure 4. Steel-Backed Timber Guardrail -- Drawings.



Notes:

1. The Type 1, 30-foot long stand alone, terminal section or the Type 2, 20-foot long berm, terminal section shall be used as specified.
2. For the Type 2 terminal section the third rail on the Type 1 terminal section is deleted and the concrete anchor is relocated to the end of the second rail.
3. For the Type 1 terminal section, the fill widening shall be extended a minimum of 5 feet behind the guardrail, unless otherwise directed.
4. The guardrail flare shown in the plan view is the minimum length and rate required. The guardrail should be flared so the terminal section is outside the clear zone. When this is not practical, it should be flared as far from the road as practical at the maximum rate indicated on the Guardrail Flare Rates table.
5. The block-outs shall be included in the terminal section, except on the concrete anchor.
6. This terminal design has not been crash tested and may not be appropriate on higher speed roadways.

GUARDRAIL FLARE RATES

Design Speed (mph)	Flare rate a:b
60	13:1
50	11:1
40	9:1
30 and less	7:1

REVISIONS

NO.	DATE	BY	BRIEF DESCRIPTION

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

STEEL-BACKED TIMBER GUARDRAIL TERMINAL SECTION, TYPE 1 & TYPE 2

BRIDGE DRAWING	DATE	DRAWING NO.
	MAY, 1991	2 OF 3

Figure 5. Steel-Backed Timber Guardrail -- Terminal Details.

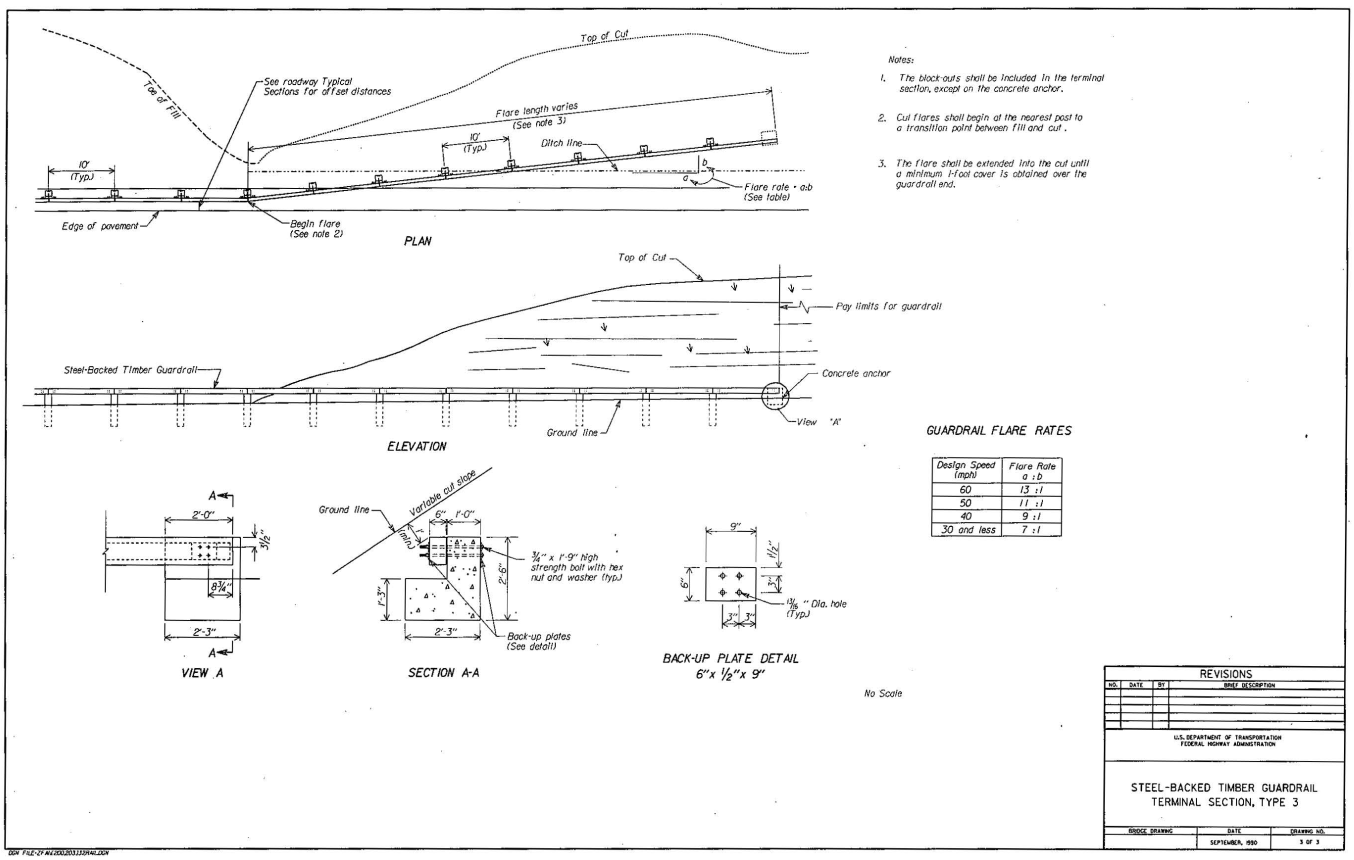


Figure 5. Steel-Backed Timber Guardrail -- Terminal Details (continued).

Stone Masonry Guardwall

History

Native stone walls have been used along roadways in scenic areas for many decades. Dry-stone walls in some parks were originally built in the 1930's as part of the Works Progress Administration (WPA) and therefore have become historically significant in themselves. Most of these walls were built primarily to keep pedestrians and motorists from intentionally leaving the road or falling over a steep precipice. They were usually not designed or intended to safely redirect errant motor vehicles.

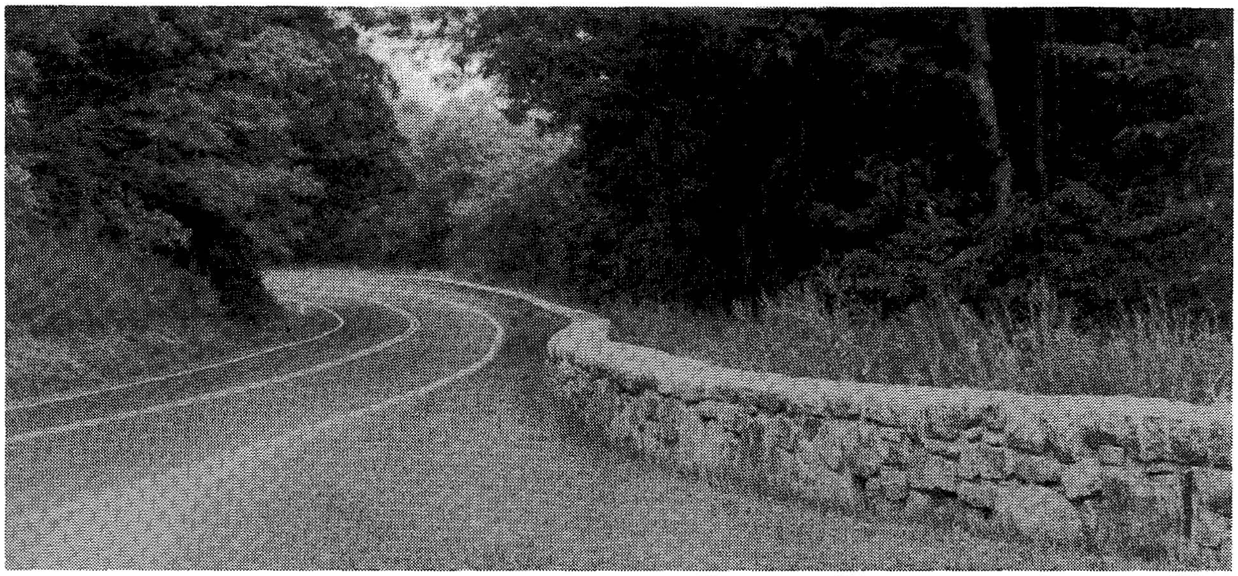


Figure 6. Stone Masonry Guardwall -- Skyline Drive, Virginia.

In a collision, dry and mortared stone walls usually do not perform well. Such walls are often not high enough to prevent the striking vehicle from vaulting over the wall. Unreinforced stone walls are also not structurally adequate to withstand the impact loading of a typical passenger vehicle. The rough stone can cause extensive vehicle damage. Though a lot of energy may have been dissipated, the vehicle would often still penetrate the wall.

The stone masonry guardwall is actually a mortared stone wall built over a reinforced concrete core wall. The core wall provides the required strength while the stone provides a visually appealing surface. Stone masonry guardwalls like those described in this section have been built along the Skyline Drive through the Shenandoah National Park in Northern Virginia, as well as on the Foothills Parkway near the Great Smokey Mountains National Park in eastern Tennessee.

Design Principals and System Components

The stone masonry guardwall functions like a typical rigid concrete barrier. The impact forces are distributed to the foundation and ground through a reinforced concrete core wall. Drawings of the system are shown in figure 8 at the end of this section. Detailed specifications for the barrier system can be found in *Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects (FP-85)* (5).

Crash tests of this system were performed in a recent research project (4). The test results are summarized in table 2. The occupant risk values in these tests were much higher than those usually observed in longitudinal barrier tests. Usually, the lateral occupant impact velocity is the critical value in a longitudinal barrier test. In these tests, however, the occupant impact velocity was high in both the lateral and longitudinal directions. One possible reason may be the roughness of the stone. The rough stone digs into the sheet metal of the vehicle causing it to slow down rapidly. This quick deceleration results in higher occupant responses.

Table 2. Stone Masonry Guardwall Crash Tests (4).

Test No.	1818-5-3-87	1818-5-4-87	1818-5-88
Date	10-29-87	11-05-87	05-23-88
Vehicle			
Year	1981	1978	1978
Make	Honda	Ford	Plymouth
Model	Civic	LTD	Gran Fury
Test Wght - lbs (kg)	1810 (821)	4311 (1955)	4325 (1962)
Impact Velocity - mi/h (km/h)	61.2 (99)	60.8 (97)	61.0 (98)
Impact Angle - deg.	20.2	25.0	24.0
Occupant Impact Velocity			
Longitudinal ft/sec (m/sec)	29.3 (8.9)	34.8 (10.6)	*
Lateral ft/sec (m/sec)	27.5 (8.4)	18.9 (5.8)	*
Occupant Ridedown Accelerations - g's			
Longitudinal	13.6	7.9	*
Lateral	13.8	11.7	*

* These values were not reported in the test report since they are not specifically required for *NCHRP Report 230* test number 10.

Foundation - The stone facia and core wall are supported by a continuous reinforced concrete mat foundation. The foundation is 6-in (152 mm) thick and is poured on a bed of compacted gravel. The top of the foundation is placed 4 in (102 mm) below the expected final grade.

Reinforced Concrete Core Wall -The core wall provides most of the shear and bending strength required in an impact. The wall is 6 in (152 mm) thick at the top and 9 in (229 mm) at the bottom. The reinforcement is relatively light since the wall is very thick and the core wall is near the neutral axis of the wall. Longitudinal bars provide flexural strength and vertical bars that are hooked into the foundation provide flexural strength about the longitudinal axis. The core wall can be cast in place or pre-cast. A key is formed in both the foundation and the core wall to provide a positive mechanical interlock that is effective in resisting the lateral shear load of an impacting vehicle.

Crash test experience has shown that the top of the core wall must be at least 20 in (508 mm) above the finished ground line. If the core wall is lower than 20 in (508 mm) an impact may cause the stone work on the top of the barrier to break.

Stone Facia - The stone facing is built using natural stone and masonry. The details shown in figure 6 require building the face in front of, on top of and behind the core wall. The installations on the Skyline Drive in northern Virginia used native mica schist stone in the facing wall. The impact performance will be affected by the smoothness of the stone work on the traffic face. FP-85 requires that none of the stone work projects more than 1.5 in (38 mm) beyond the neat line as shown in figure 7 (5). The mortar joints are to be raked 2-in deep and the beds should be between 2 in (50 mm) and 3 in (76 mm) thick as shown in figure 7. These limitations on stone projects and rake thickness are intended to set a standard for the roughness of the stone face. The smoother the stone face is the better the impact performance will be. If the mortar beds are thicker, the mortar may break apart during a collision.

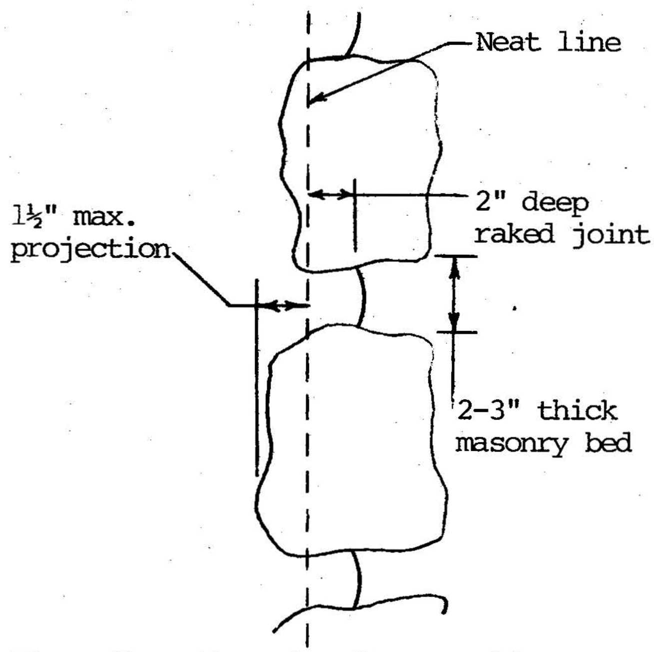


Figure 7. Rough Stone Masonry Specifications.

Terminals - This system is terminated by sloping the barrier away from the roadway so that the offset from the edge of the pavement is at least 2 ft (0.61 m). The wall is also sloped vertically as shown in figure 9. Sometimes the barrier can be buried in an earth berm. Berm details for median and roadside aesthetic barriers are shown in the appendix. These details, while probably adequate for low speed facilities, are not recommended for high speed, higher performance roadways.

Recommended Applications

Since the stone guardwall requires a foundation, it is more expensive than typical guardrail systems. To date, this system has been used primarily in road segments cut into steep slopes where there is a steep and tall embankment. There is little or no room for barrier deflections so the use of a rigid barrier system like the stone guardwall is justified.

The stone masonry guardwall is a good choice for aesthetically sensitive areas, or for historic communities where more typical barriers might be too austere. Locations that would normally warrant a rigid concrete barrier if aesthetics were not considered would be well suited to the stone masonry guardwall.

The Federal Lands Highways Division of FHWA recommends this barrier for roadways where the design speed is 60 mph (97 kph) or less (5). This system should not be used in combination with a curb since no crash tests have been performed for this situation. The guardwall can not be used as a median barrier because the non-traffic face is battered rather than vertical.

Construction and Maintenance Procedures

Construction of this system requires excavation for the foundation over the entire length of the project. The foundation is formed in place, the reinforcement positioned and the concrete is poured. The core wall can be either formed on the foundation and cast in place or pre-cast and installed at the site. Once the foundation and core wall have been built, the stone masonry wall is built.

This rigid system should require very little maintenance. Most collisions will not damage the barrier at all and there are no routine maintenance needs. A more serious collision may damage the stone face or the core wall. If the core wall is undamaged, the broken or dislodged stones in the facia may be replaced. Damage to the core wall will probably require reconstruction of a segment of the wall.

Since this system requires a significant amount of manual labor by skilled tradesmen, it is the most expensive aesthetic barrier system covered in this report. The construction cost for this system according to the Federal Lands Highways Division of FHWA can be between 265 $/ft (870 $/m) and 500 $/ft (1640 $/m). The 1988 price for the stone masonry guardwall installations on the Foothills Parkway in east Tennessee was 265 $/ft (870 $/m). Local availability of specific types of stone and skilled stone masons will have a dramatic affect on the cost of this barrier for specific construction projects.

Accident Experience

This system has only recently been installed in the field so there is no accident experience as yet.

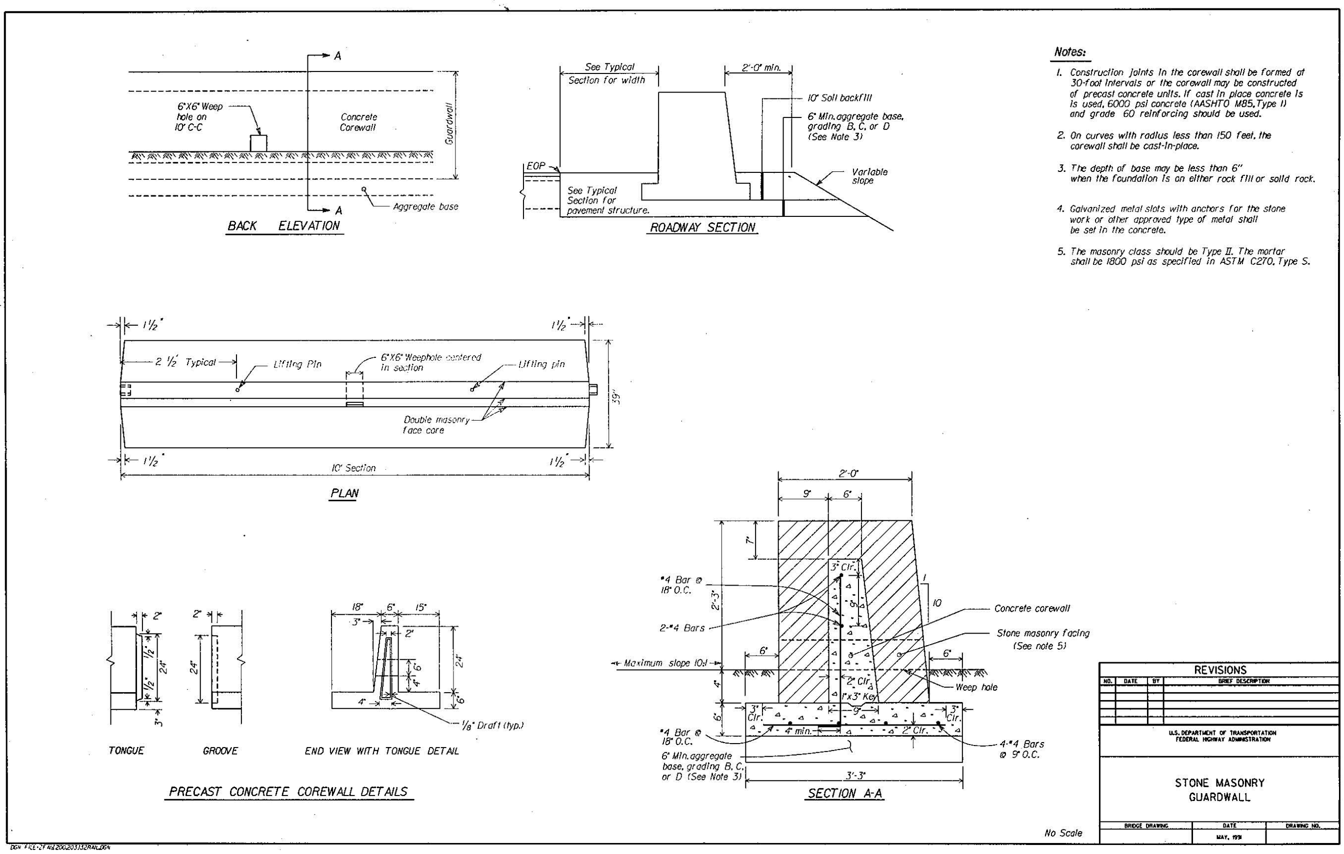


Figure 8. Stone Masonry Guardwall - Drawings.

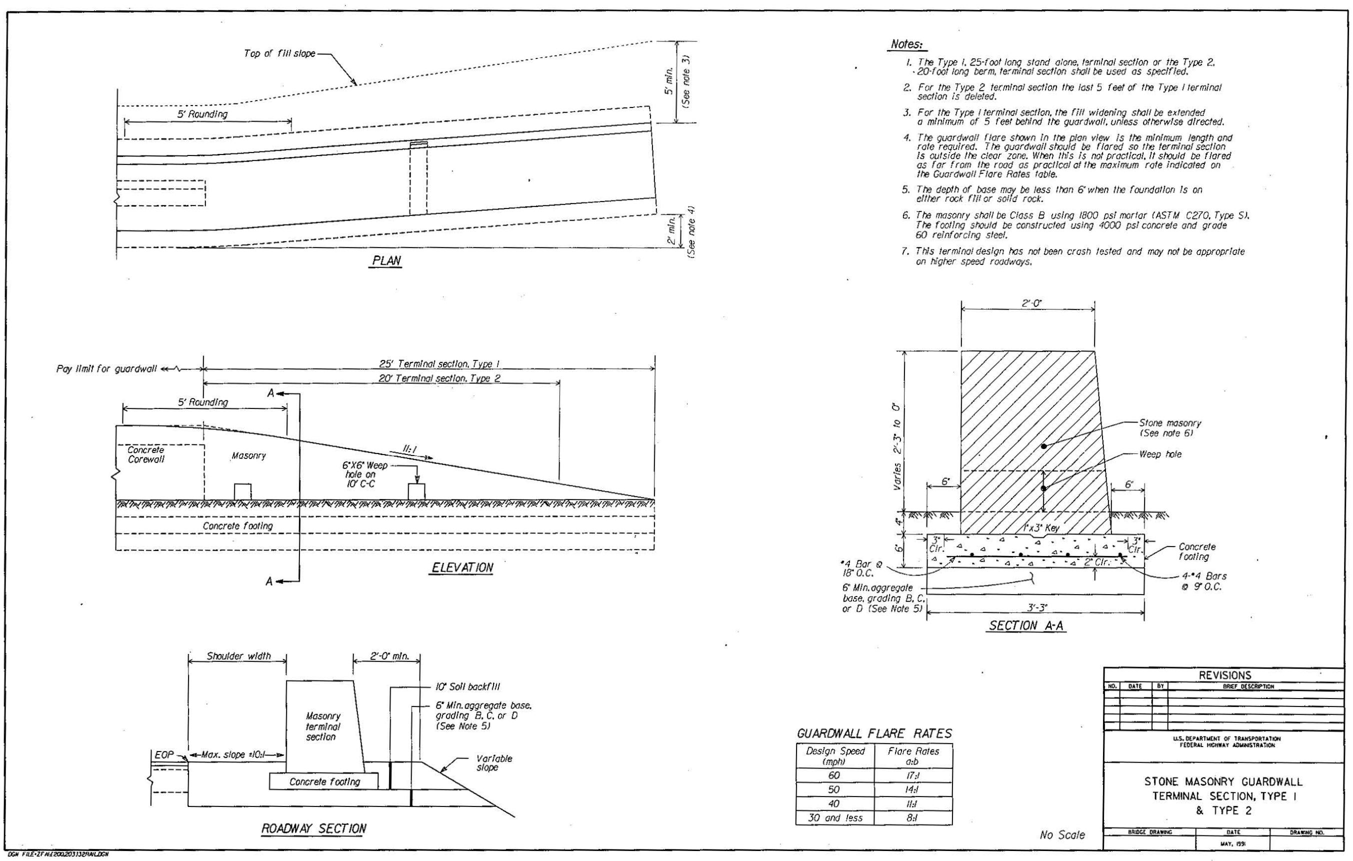


Figure 9. Stone Masonry Guardwall -- Terminal Details.

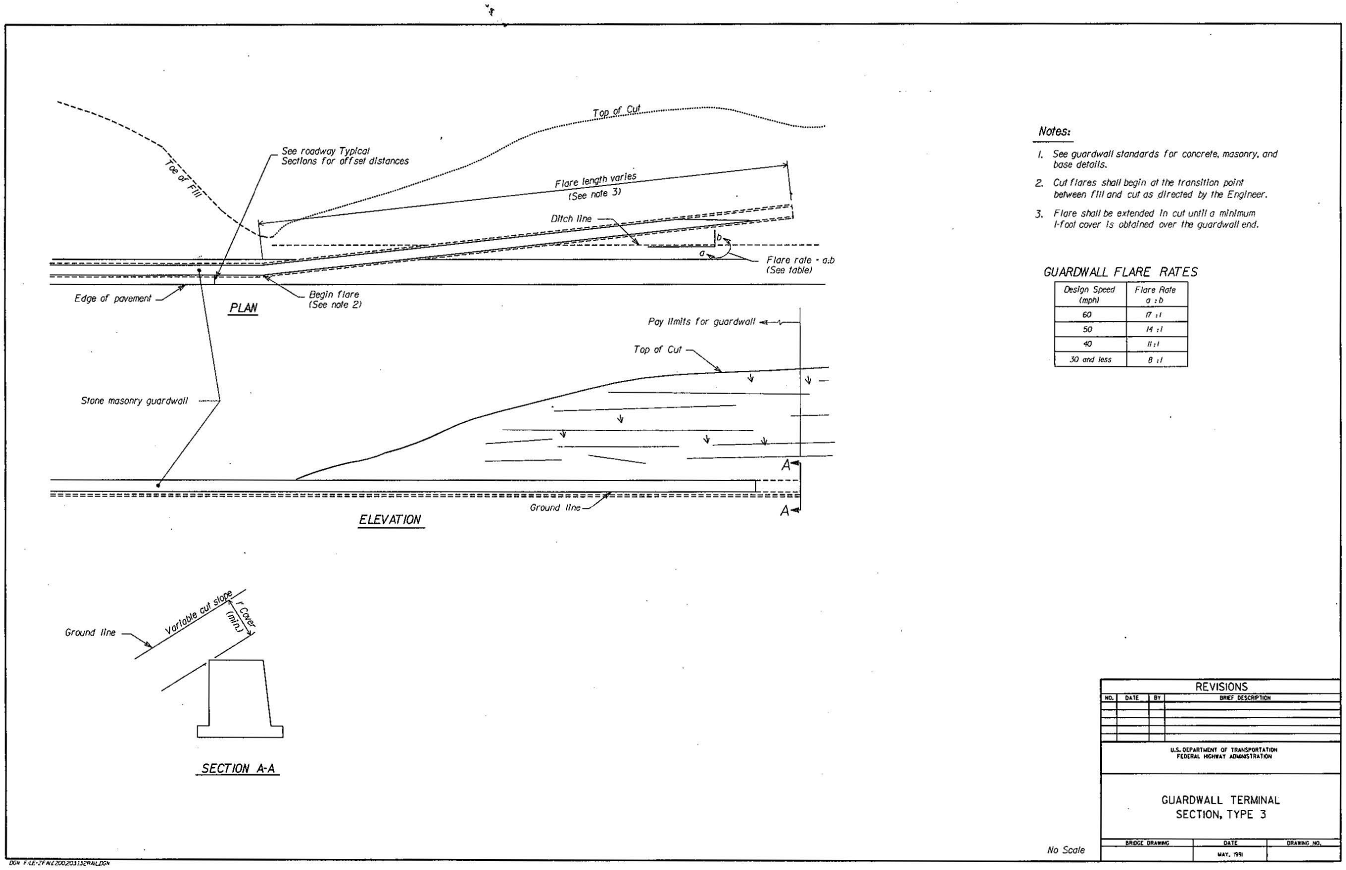


Figure 9. Stone Masonry Guardwall -- Terminal Details (continued).

Pre-Cast Simulated Stone Guardwall

History
Although the barrier in figure 10 looks like natural stone it is actually made of pre-cast concrete panels textured and colored to simulate natural stone masonry. This guardwall has been installed on the Baltimore-Washington Parkway. The ability to design the color and pattern of the stone work is an architectural advantage to this system which is useful when the barrier is to be installed near existing stone masonry structures. The pigments used to color the simulated stone on the barriers shown in figure 10 were selected specifically to match the stone work on existing bridges on the Baltimore-Washington Parkway.

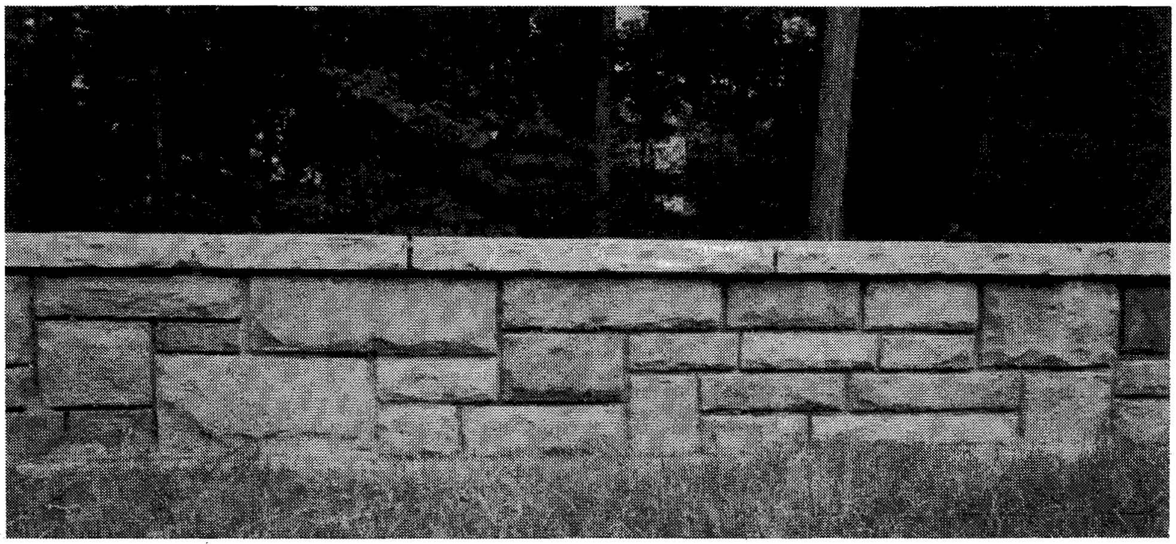


Figure 10. Pre-Cast Simulated Stone Guardwall -- Baltimore-Washington Parkway.

Design Principals and System Components
The pre-cast simulated stone guardwall functions like other rigid concrete barriers. Table 3 summarizes the two crash tests performed on this system (4). The design details are shown in the drawings in figure 12.

Pre-cast Panels - The 24 in (610 mm) thick 10-ft (3 m) long pre-cast panels are ship-lapped at the ends. When assembled the panel joints appear to be mortar beds in a stone masonry wall. The panel is constructed such that both faces look like a wall of randomly laid quarried stone. A variety of stone coloring schemes can be used to give the appearance of a natural stone wall. The particular colors and textures can be designed to match existing stone structures on or near the roadway.

Table 3. Pre-Cast Simulated Stone Guardwall Crash Tests (4).

Test No.	1818-7-88	1818-12-88
Date	12-01-88	09-29-88
Vehicle		
Year	1982	1981
Make	Honda	Plymouth
Model	Civic	Fury
Test Wght - lbs (kg)	1796 (815)	4356 (1976)
Impact Velocity - mi/h (km/h)	61.3 (99)	61.5 (99)
Impact Angle - deg.	21	25
Occupant Impact Velocity		
Longitudinal ft/sec (m/sec)	24.8 (7.6)	27.1 (8.3)
Lateral ft/sec (m/sec)	30.3 (9.2)	23.6 (7.2)
Occupant Ridedown Accelerations - g's		
Longitudinal	12.3	5.5
Lateral	16.3	11.7

The panels are connected with a tongue-and-grove connection. A silicone sealant is used at the real joints. The silicone color should be matched to the color of the false joints to simulate the color of masonry.

The panels have an inverted T-shaped cross section. The wide part of the section provides a foundation for the upper part of the panels. The top edge of the inverted T should be flush with the finished ground line.

Cap Stone - A cap stone is set on the top of the pre-cast panel. A tongue-and-grove connection is used to align the cap stone on the panel. The joint between the panel and the cap stone is sealed with the same silicone sealant used between panel joints.

Foundation - A proper foundation is necessary for transmitting collision forces to the ground as well as ensuring that the wall will not settle over time. The pre-cast panels are set directly on a bed of compacted aggregate.

Curb - The crash tests summarized in table 3 were all performed with the barrier located 12 ft (3.7 m) behind a 3.5-in (89 mm) high mountable curb. The slope of the approach terrain should be 10:1 or flatter (5). The 12-ft (3.7 m) offset was considered to be the critical lateral offset rather than the minimum offset so the barrier can be used at any offset with a 3.5-in (89 mm) high mountable curb.

Terminals - The terminal details are shown in figure 13. The terminal section is sloped vertically to eliminate the otherwise blunt end as shown in figure 11. Although this detail is probably adequate for most low speed roadways, it is not recommended on high speed facilities since the sloped end can launch a vehicle if the impact is head-on. Other, more conventional terminals could be used with this barrier, but aesthetic considerations will usually preclude this option.

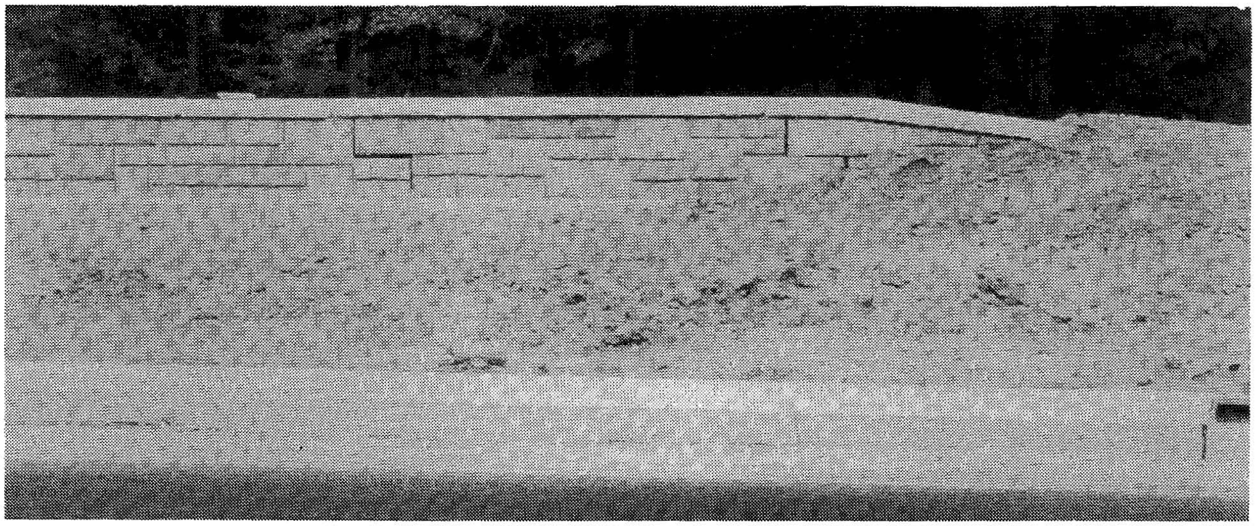


Figure 11. Pre-Cast Simulated Stone Guardwall Terminal Buried in a Backslope.

Recommended Applications
This barrier is a good choice for sites that would normally require a concrete barrier at non-aesthetically sensitive sites. The ability to tailor the pattern and coloring of the simulated stone is an advantage if the guardwall must blend in with other structures near the roadway. Since the barrier is made of pre-cast units, the on-site phase of construction can probably be accomplished more quickly than if a cast-in-place system were used. If the intended site is busy or congested this system might help minimize the disruption to the travelling public.

As shown in table 3, this barrier satisfied the *Report 230* criteria for longitudinal barriers (7). The pre-cast guardwall can, therefore, be used at any location that warrants a longitudinal barrier. The Federal Lands Highways Division of the FHWA has approved this barrier for roadways with design speeds of 60 mph (97 kph) or less (5).

This barrier system can also be used as a median barrier since both faces of the barrier are simulated stone. The Federal Lands Highways Division of the Federal Highway Administration allows the use of this barrier system as a median barrier located at any offset behind a mountable 3.5-in (89-mm) high curb.

Construction and Maintenance Procedures
The most difficult aspect of constructing this barrier system involves finding a pre-cast contractor capable of manufacturing the panels. Site preparation involves excavating a foundation trench and back-filling it with aggregate. After the aggregate is compacted the pre-cast panels can be placed. The panels are attached by tongue-and-grove connections in the ship-lapped ends. For modest degrees of curvature the panels can be rotated to conform with the roadway alignment. After the panels are connected the cap stone should be placed. The silicone sealant is then applied to the real joints and the cap-stone joint. The terrain between the wall and the curb should then be graded to the final grade and seeded with grass if necessary.

The stone masonry guardwall is a maintenance-free system. The guardwall will not usually require repair after a collision unless the collision was very severe. In such cases, a segment of the guardwall may need to be replaced.

The Federal Lands Highways Division of the FHWA reports the cost of this barrier varies between 103 and 210 $/ft (338 and 690 $/m). The availability of contractors capable of building the pre-cast units could effect the cost of this system in certain locations. Currently, two different contractors have been approved by the Federal Lands Highways Division to produce these units.

Accident Experience
This system has only been installed in the field for several years so there is no accident experience with it as yet. It is expected to perform like most other rigid concrete barriers.

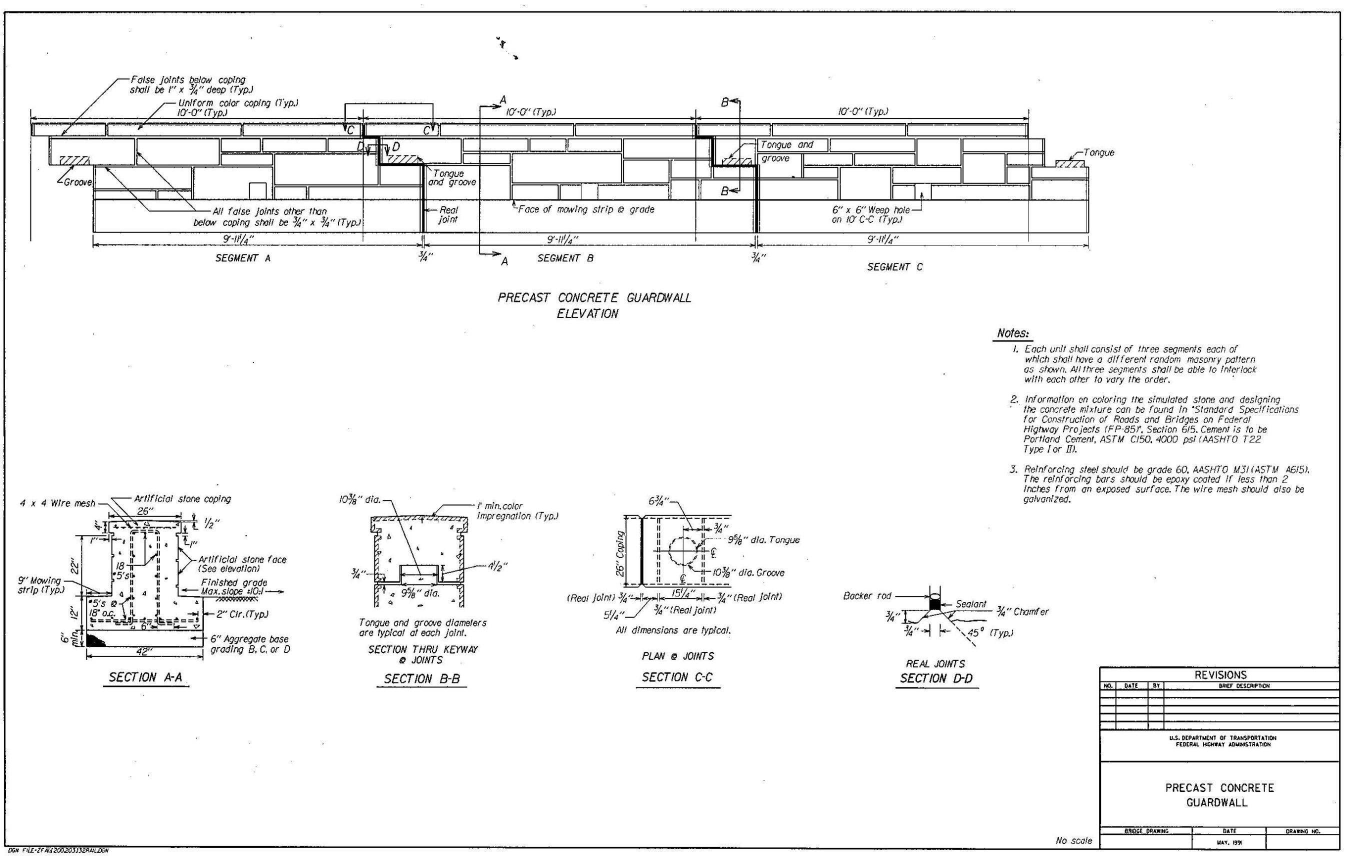


Figure 12. Pre-Cast Concrete Guardwall -- Drawings.

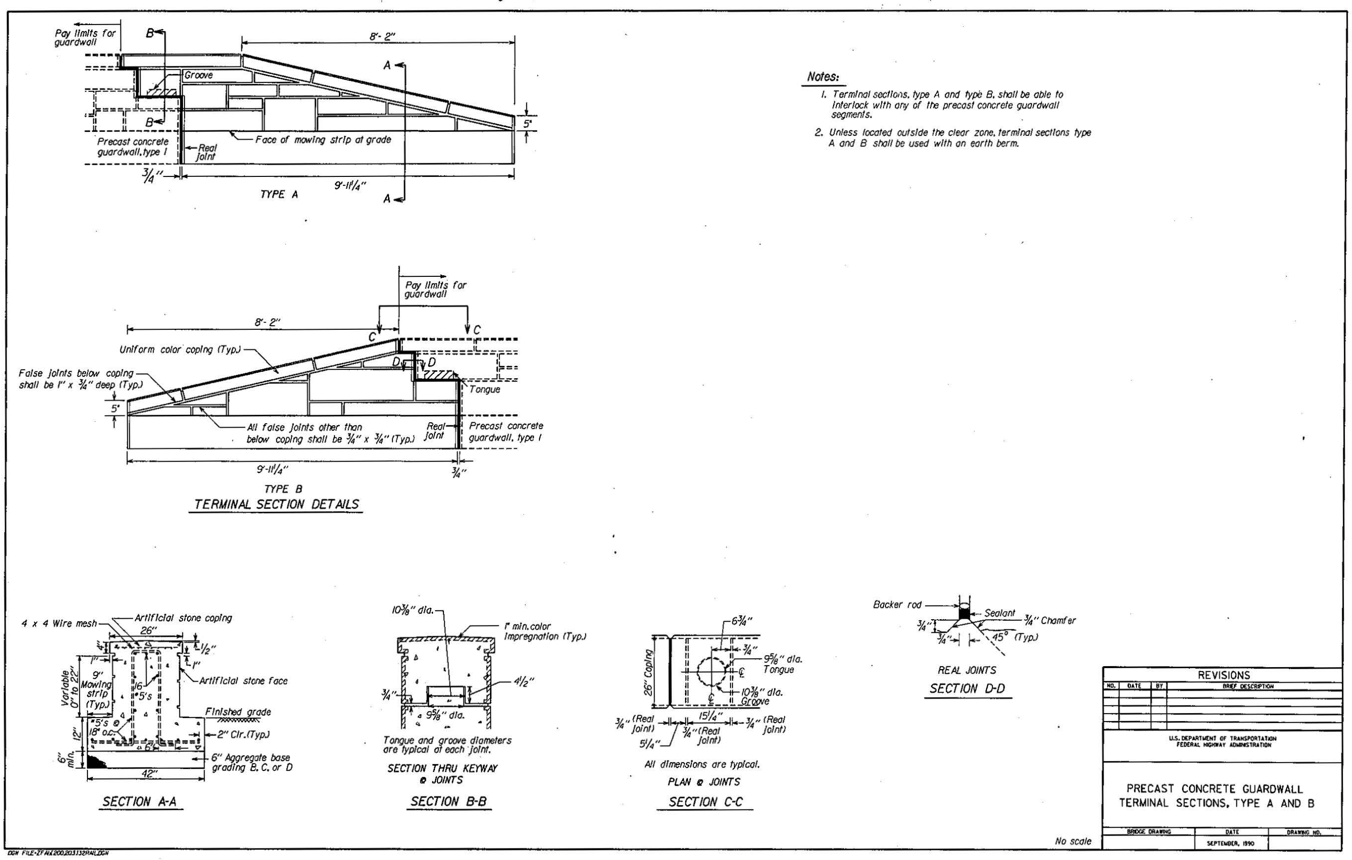


Figure 13. Pre-Cast Concrete Guardwall -- Terminal Details.

Glue-Laminated Wood Bridge Railing

History

Wooden bridges are an attractive alternative on many roadways in scenic areas, especially when the bridge span and traffic conditions are modest. The performance of wooden structures has been greatly enhanced recently by the development of relatively low cost, prefabricated, glue laminated wood structures (8). Glue laminated structures are much stronger and will last much longer than typical wood construction. The U.S. Forest Service has installed many of these prefabricated glue laminated bridges in National Forests and on rural county roads that provide access to National Forests.

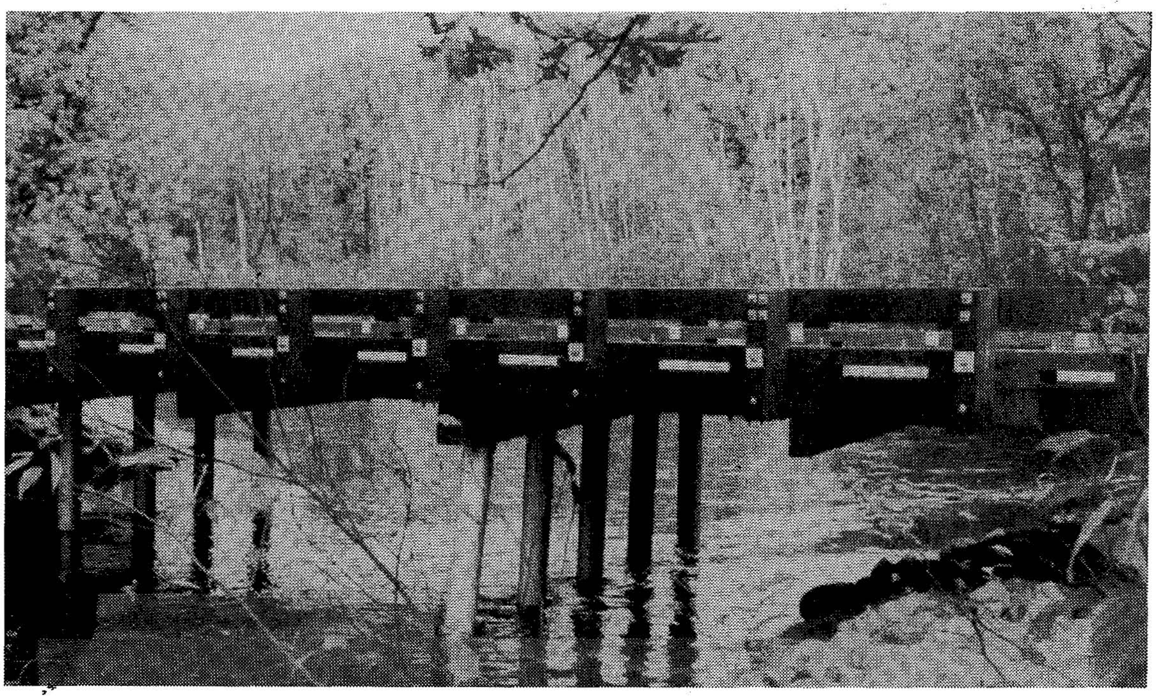


Figure 14. Glue-Laminated Wood Bridge (10).

Two full-scale crash tests of the Glue-Laminated bridge railing were performed in a recent research project (9). Since this bridge railing is intended for use on low service level bridges, the tests were performed at conditions less demanding than those typically recommended in *NCHRP Report 230* (6). The tests conform to the recommendations for performance level 1 bridge railings in AASHTO's *Guide Specifications for Bridge Railings* (3). These tests demonstrated acceptable performance according to both the Report 230 criteria and the AASHTO PL-1 bridge railing criteria. A summary of the two tests is shown in table 4.

Table 4. Glue-Laminated Wood Bridge Rail Crash Tests (8).

Test No.	WB-1		WB-2	
Date	09-12-88		09-27-88	
Vehicle				
Year	1982		1982	
Type	Car		Pickup	
Make	Volkswagen		Ford	
Model	Rabbit		F150	
Test Wght - lbs (kg)	1983	(900)	5419	(2458)
Impact Velocity - mi/h (km/h)	59	(96)	48	(76)
Impact Angle - deg.	20		20	
Occupant Impact Velocity				
Longitudinal ft/sec (m/sec)	11	(3)	8	(2)
Lateral ft/sec (m/sec)	19	(6)	17	(5)
Occupant Ridedown Accelerations - g's				
Longitudinal	5		3	
Lateral	9		5	

Design Principals and System Components

The bridge railing shown in figure 15 is an integral part of an entire pre-fabricated wooden bridge system. Information about the prefabricated wood bridges themselves can be obtained from the manufacturer (10). The same type of bridge railing concept can be used on other types of wooden bridges. This bridge railing is a post and beam system with a blockout. The rail and post elements are made from wooden strips glued together under pressure. Design details are shown in the system drawings in figure 16.

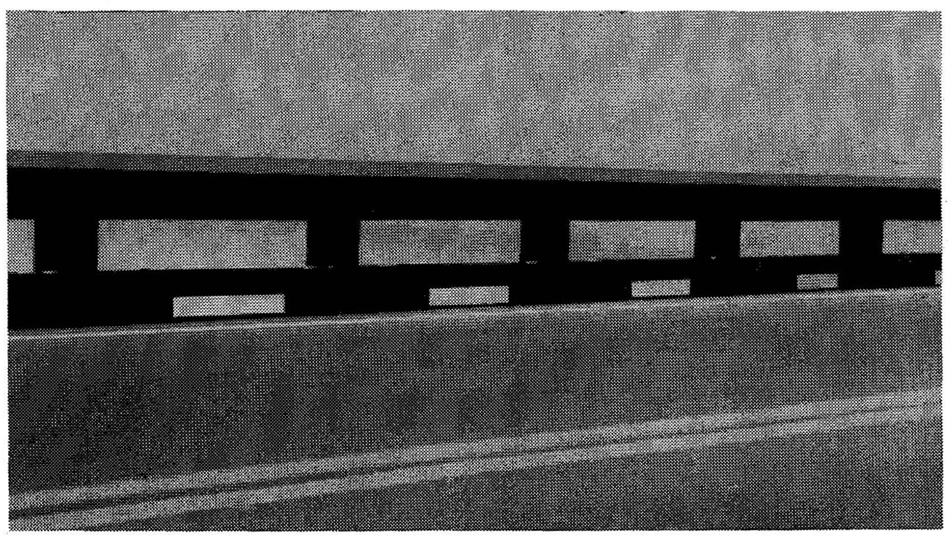


Figure 15. Traffic Face of the Glue-Laminated Bridge Railing.

Railing - The rail element is a 6-in (152-mm) by 10.75-in (273-mm) glue laminated wood beam. The beam is attached to the post using two 26-in (660-mm) long dome-head bolts that pass through the rail, blockout and post. The blockout has the same cross-section as the rail element.

Posts - The post is an 8-in (203-mm) by 12-in (305-mm) glue laminated wood member. The post is attached directly to the face of the bridge deck using 30-in (762-mm) long spikes. The post is also held in place by the bolts attaching the curb rail and scupper blocks to the deck.

Curb and Scupper - A wooden beam is placed on blocks bolted to the bridge deck to form a combination curb and scupper. Two wooden blocks are bolted to the bridge deck on each side of the post. A continuous wooden rail is then placed on top of the blocks. This effectively forms a 12-in (305-mm) high curb. The open space between the lower blocks forms a scupper that allows water to drain off the bridge deck.

Recommended Applications

The glue-laminated bridge railing shown in this section has been most often used as an integral part of a prefabricated wooden bridge. These bridges have enjoyed substantial use in recent years in National Forests and in local jurisdictions that provide access to national and state forests. At least one prefabricated glue-laminated wooden bridge (including the railings) has been used in Florida as a temporary bridge between Sanibel and Captiva Islands near Fort Meyers. The temporary bridge was built next to the location where a new concrete structure is being built. When the new bridge is complete, the wooden bridge will be taken apart and stored for a later project.

The tests summarized in table 4 indicate this bridge railing is suitable for use on AASHTO performance level 1 bridges (3). The PL-1 category requires two full-scale crash tests: an 1800-lb (814-kg) passenger car striking the bridge railing at 50 mi/h (80 km/h) and 20 degrees and a 5400-lb (2442-kg) pickup truck striking the bridge railing at 50 mi/hr (80 km/h) and 20 degrees. These bridges are usually characterized by automobile and light truck traffic and relatively modest volumes and speeds. This is exactly the type of traffic many bridges in scenic or historic areas might experience.

Construction and Maintenance Procedures

This system should require little maintenance. If the railing is damaged in a collision it may be necessary to replace the damaged post or beam elements. It would be prudent to carefully inspect the railing and the deck after any collisions to ensure that all the damaged elements have been identified and replaced. An impact can sometimes cause de-lamination of the wood which can be difficult to observe unless it is inspected carefully. The fastening hardware is made of galvanized steel so it should not be affected by weathering for many years. The glue laminated wood should be pressure treated to retard the deterioration of the wood. Properly treated wood should perform satisfactorily for many years.

All the bridges that use this railing have been part of an entire prefabricated glue laminated wood bridge. It is not known what portion of the cost of the bridges is represented by the bridge railing.

Accident Experience

This system has only recently been installed in the field, so to date, there is no accident experience.

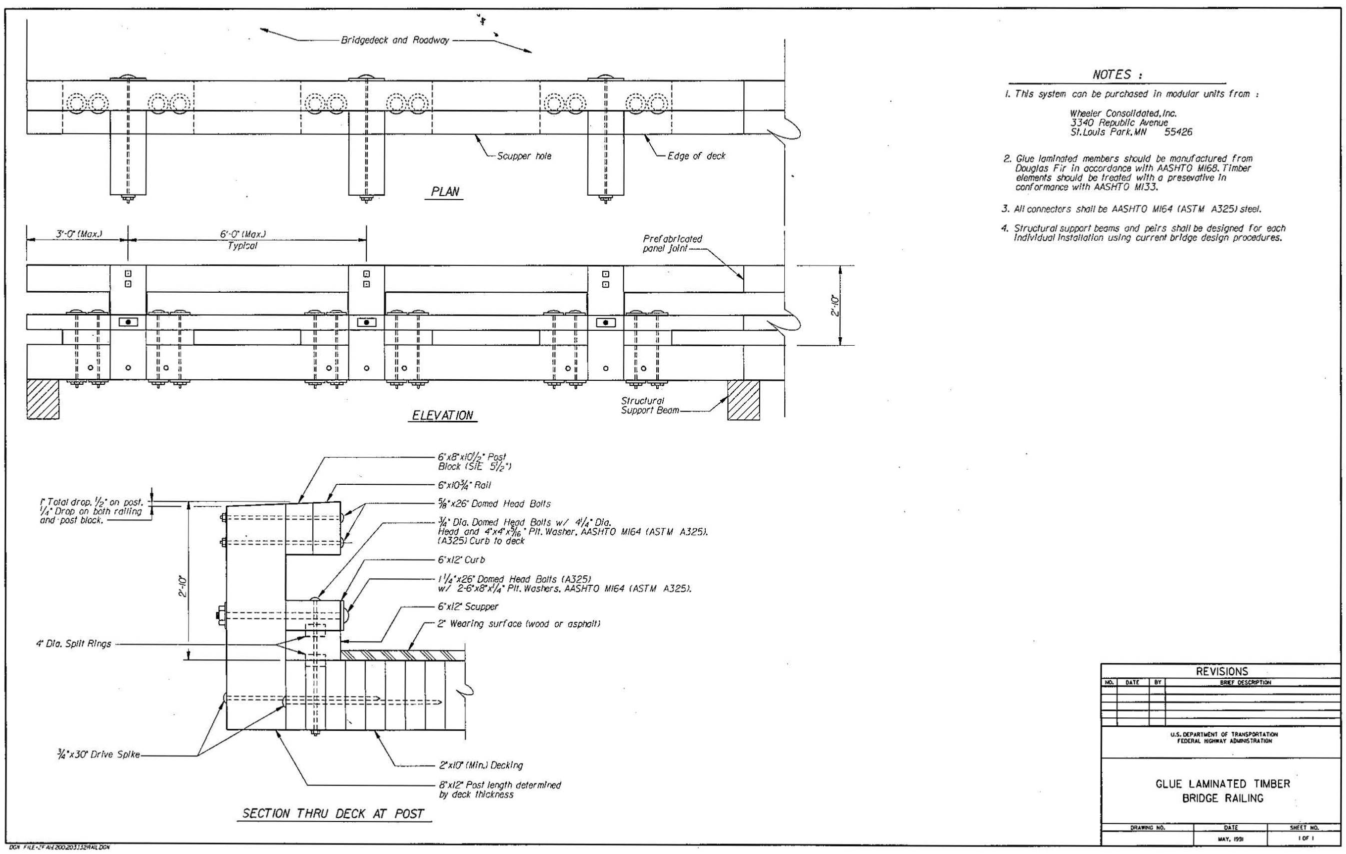


Figure 16. Glue Laminated Wood Bridge Railing.

Federal Lands Highways Modified Kansas Corral Bridge Railing

History

The Federal Lands Highways version of the Modified Kansas Corral Bridge Railing is a concrete post and beam railing that evolved from a system used in Kansas. The Kansas Corral Bridge Railing was tested in a pooled-fund project in the mid-1980's (11). The tests showed that some design changes were required to ensure continuity of the concrete rail and also increase the shear resistance of the concrete posts. This redesigned version of the Kansas Corral is known as the modified Kansas Corral Bridge Railing.

Figure 17. Federal Lands Highways Modified Kansas Corral Bridge Railing -- Olympic National Park.

The Federal Lands Highways Division of the FHWA redesigned the modified Kansas Corral to enhance its aesthetics. This further modified system has been called the Federal Lands Highways Modified Kansas Corral bridge railing. This system has been used in several National parks. Six new bridges on the north and south shore roads around Lake Quinault in the Olympic

National Park use this bridge railing. New bridges being built in the Grand Tetons and the Painted Desert in Arizona are also scheduled to make use of this system. The Federal Lands Highways Modified Kansas Corral is a very attractive bridge railing that can be readily adapted for use on new concrete bridges.

Design Principals and System Components
This bridge railing is a 27-in (685-mm) high post and beam bridge railing. The more open profile of this railing is one of the features that makes it attractive for aesthetically sensitive

Table 5. Federal Lands Highways Modified Kansas Corral Bridge Railing Crash Tests (9).

Test No.	KM-1	KM-2
Date	11-18-88	08-17-89
Vehicle		
Year	1982	1983
Type	Car	Pickup
Make	Honda	Ford
Model	Civic	Pickup
Test Wght - lbs (kg)	1990 (902)	5410 (2454)
Impact Velocity - mi/h (km/h)	51 (82)	46 (75)
Impact Angle - deg.	21	20
Occupant Impact Velocity		
Longitudinal - ft/sec (m/sec)	11 (3)	7 (2)
Lateral - ft/sec(m/sec)	17 (5)	21 (7)
Occupant Ridedown Accelerations - g's		
Longitudinal	1	--
Lateral	10	10

locations. The beam element interacts with the vehicle, preventing it from penetrating the barrier and leaving the bridge. The impact loads are transmitted to the bridge deck through the posts. Crash tests performed using this bridge railing are summarized in table 5 and the design details are shown in figure 20.

Concrete Rail - The reinforced concrete rail is approximately 10 in (254 mm) by 10 in (254 mm) and projects about 5 in (127 mm) in front of the post. The concrete rail is heavily reinforced for shear loads with number 3 stirrups spaced every 3.5 in (89 mm). The face of the rail has a slight vertical slope of 1 to 10.

Posts - The primary difference between the modified Kansas corral and the Federal Lands Highways modified Kansas corral is the shape of the post. The Federal Lands Highways version, shown in figure 18, uses a more aesthetically shaped post that enhances the architectural character of the bridge while retaining the required strength. The post is heavily reinforced with

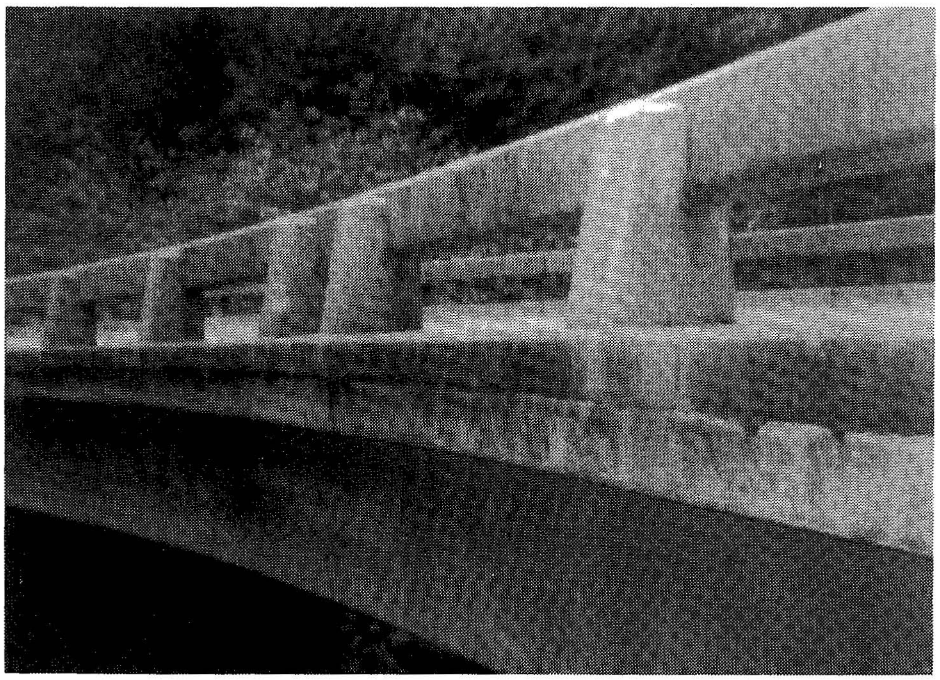


Figure 18. Federal Lands Highways Modified Kansas Corral Bridge Railing -- View of Posts.

number 4 reinforcing bars for shear loadings.

Curb - This design includes a 6-in (152 mm) high curb. Like all other bridge railings, the connection between the railing and the deck is important. If the reinforcement is inadequate, the impact may cause serious structural damage to the bridge deck.

End wall - The end of the bridge railing is a vertical wall that can easily be modified to accommodate a transition to a w- or thrie-beam guardrail. Details for crash tested transitions to this bridge railing can be found in FHWA Technical Advisory T5040.26 (12). Figure 19 shows the end block of the Federal Lands Highways Modified Kansas Corral bridge railing.

Recommended Applications

This system is a good choice on any concrete bridge where a 27-in (688-mm) high rail is acceptable. The open profile is attractive and allows vehicle occupants to see through the railing. This bridge railing was tested in a recent research project (9); the two crash tests are summarized in table 5. These tests demonstrated that the system satisfied the AASHTO performance level 1 evaluation criteria (3).

Construction and Maintenance Procedures

Like most concrete bridge railings, the Kansas corral requires no routine maintenance. A very severe collision may cause spalling or cracking that might indicate a segment of the railing needs to be removed and reconstructed.

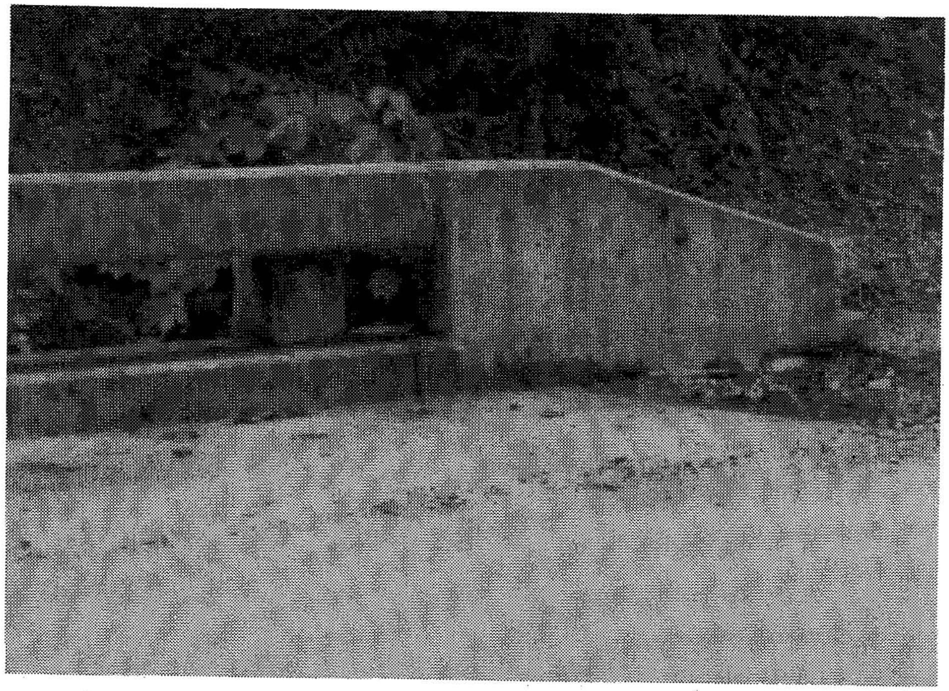


Figure 19. Federal Lands Highway Modified Kansas Corral Bridge Railing End Block.

This system is best suited for new construction. The Federal Lands Highways Division of the FHWA reports an average construction cost for this bridge railing of 56 $/ft (184 $/m).

Accident Experience
This system has only recently been installed in the field, so to date, there is no accident experience.

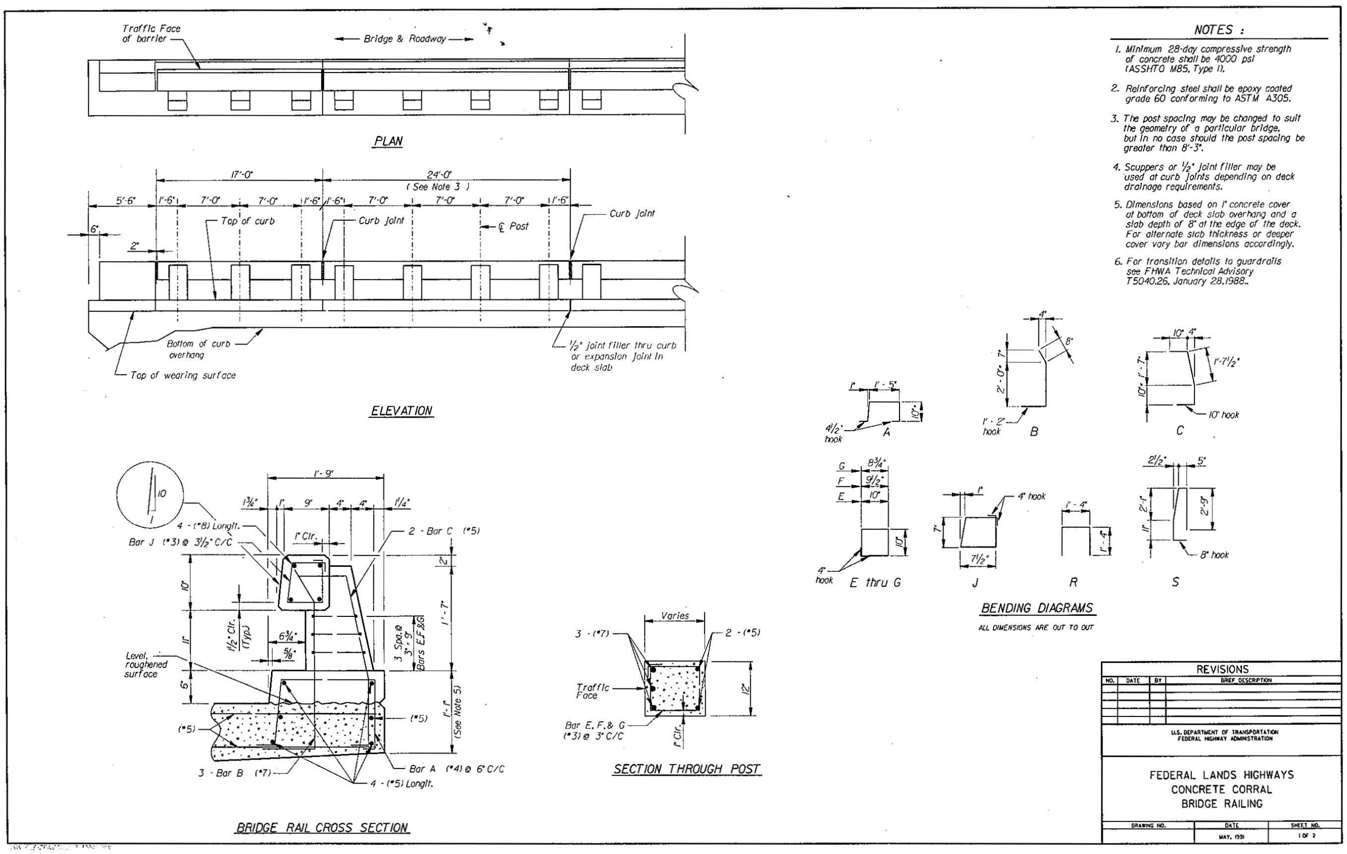


Figure 20. Federal Lands Highways Modified Kansas Coral Bridge Railing -- Drawings.

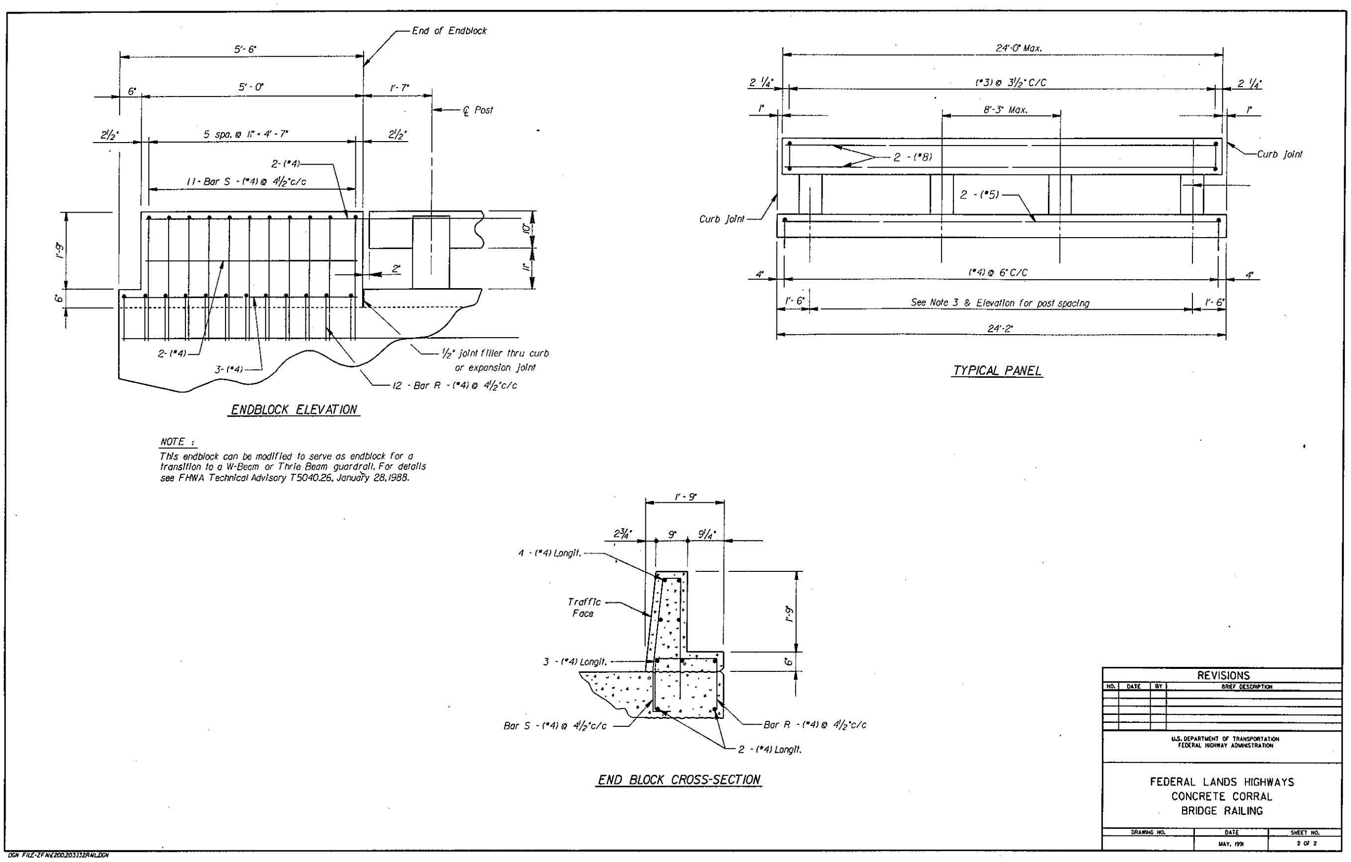


Figure 20. Federal Lands Highways Modified Kansas Corral Bridge Railing -- Drawings (continued).

Stone Masonry Bridge Railing

History
Stone has been used as a material for building bridges for thousands of years. Bridge structures that use natural stone are particularly attractive in historical communities and scenic areas. The stone masonry bridge railing was developed to provide a safe alternative on this type of bridge. The design described in this section has not been built in the field as yet although a crash test using a large passenger car has demonstrated its impact performance. This bridge railing was originally designed for use on bridges on the Baltimore-Washington Parkway.

Design Principals and System Components
The stone masonry bridge railing is actually a reinforced concrete wall with a mortared stone wall built in front of it. The total height of the bridge railing including the core wall and cap stone is 32 in (812 mm). This bridge railing functions much like a vertical concrete wall. Details of this design are shown in figure 21. The single full-scale crash test performed on this system is summarized in table 6.

Core Wall - The core is a 27-in (685-mm) high reinforced concrete wall that is designed to provide most of the strength of the barrier. The core wall is 9 in (228 mm) thick.

Stone Facing - The traffic face of this system is a mortared stone wall built in front of the concrete core wall. The test installation of the stone masonry bridge railing used North Carolina granite (80 percent) and Maryland mica (20 percent). The stone used was quarried rather than rubble, so the face of the rail was much smoother than the stone masonry guardwall discussed earlier in the report. The smoother surface should enhance the performance of the railing by decreasing the number of snag points.

Cap Stone - The top of the concrete core wall and the stone masonry facing wall is covered with a 20-in (508 mm) wide cap stone. The cap stone is 5-in (127 mm) thick at the traffic face. The cap stone is placed on top of the 27-in (685-mm) high core and stone masonry walls making the bridge rail 32 in (812 mm) high. The cap stone is attached to the wall by inserting 10-in (254-mm) long number 6 reinforcing bars into pre-drilled holes that extend into the core wall. The reinforcing bars are grouted into the holes using an epoxy. The cap stone extends 1 in (25 mm) beyond the edge of both the traffic face and back of the rail .

Recommended Applications
This bridge railing is suitable in most places where a 27-in (686 mm) high concrete bridge rail would normally be used in areas where aesthetics were not a primary concern. This system would probably be suitable for AASHTO performance level 1 bridges (3) although the appropriate tests were not performed. As shown in table 6, only the large car test, the so-called strength test, was performed on this system. The AASHTO guide specifications requires tests with two vehicles for the first performance level: an 1800-lbs (816 kg) passenger car and a 5400-lbs (2450-kg) pickup truck (3). Both AASHTO tests are to be performed at 20°. The *Report 230* test 10 results shown in table 6 correspond approximately to the pickup truck test. A 4500-

lbs (2040-kg) passenger sedan striking the barrier at 25° delivers the same impact energy as a 5400-lbs pickup truck striking the barrier at 20° (13). The stone masonry bridge railing should have the adequate strength for the AASHTO pickup truck test. In view of prior testing of other rigid bridge railings, it would be very surprising if this barrier system did not pass the small car test. This bridge railing should satisfy the AASHTO PL-1 criteria.

Although this bridge railing is 32 in (813 mm) high, it is not known if it is suitable for use as a performance level 2 bridge railing. A vertical-faced 32-in (813 mm) high reinforced concrete bridge rail has been fully tested for the second performance level and found to be satisfactory (14). The concrete vertical wall is 8-in (203-mm) high and has reinforcement details similar to the stone masonry guardwall. More tests are required to determine if the cap stone on the stone masonry bridge rail retains its integrity in the AASHTO single-unit truck test.

Table 6. Stone Masonry Bridge Railing Crash Tests (4).

Test No.	1818-9-90	
Date	4-20-90	
Vehicle		
Year	1981	
Make	Plymouth	
Model	Gram Fury	
Test Wght - lbs (kg)	4694	(2130)
Impact Velocity - mi/h (km/h)	60.4	(97)
Impact Angle - deg.	25	
Occupant Impact Velocity		
Longitudinal ft/sec (m/sec)	27.6	(8.4)
Lateral ft/sec (m/sec)	29.8	(9.1)
Occupant Ridedown Accelerations - g's		
Longitudinal	6.4	
Lateral	7.8	

Construction and Maintenance Procedures

This bridge railing system is best suited for new concrete construction. The core wall is formed and poured with the rest of the bridge structure. After the concrete portion of the structure is complete the stone masonry wall can be built on the traffic face. The cap stone is then grouted in place over the finished concrete and stone masonry walls.

The stone masonry bridge railing, like most rigid bridge railings requires no routine maintenance beyond occasional cleaning of sand and debris. If the bridge railing is damaged in a severe impact, the stone wall may need to be partially removed and reconstructed.

This system has not been used in the field, so there is no cost data available.

Accident Experience

This system has not been installed in the field as yet, so there is no accident experience to report. This bridge railing is expected to perform much like other rigid concrete barriers.

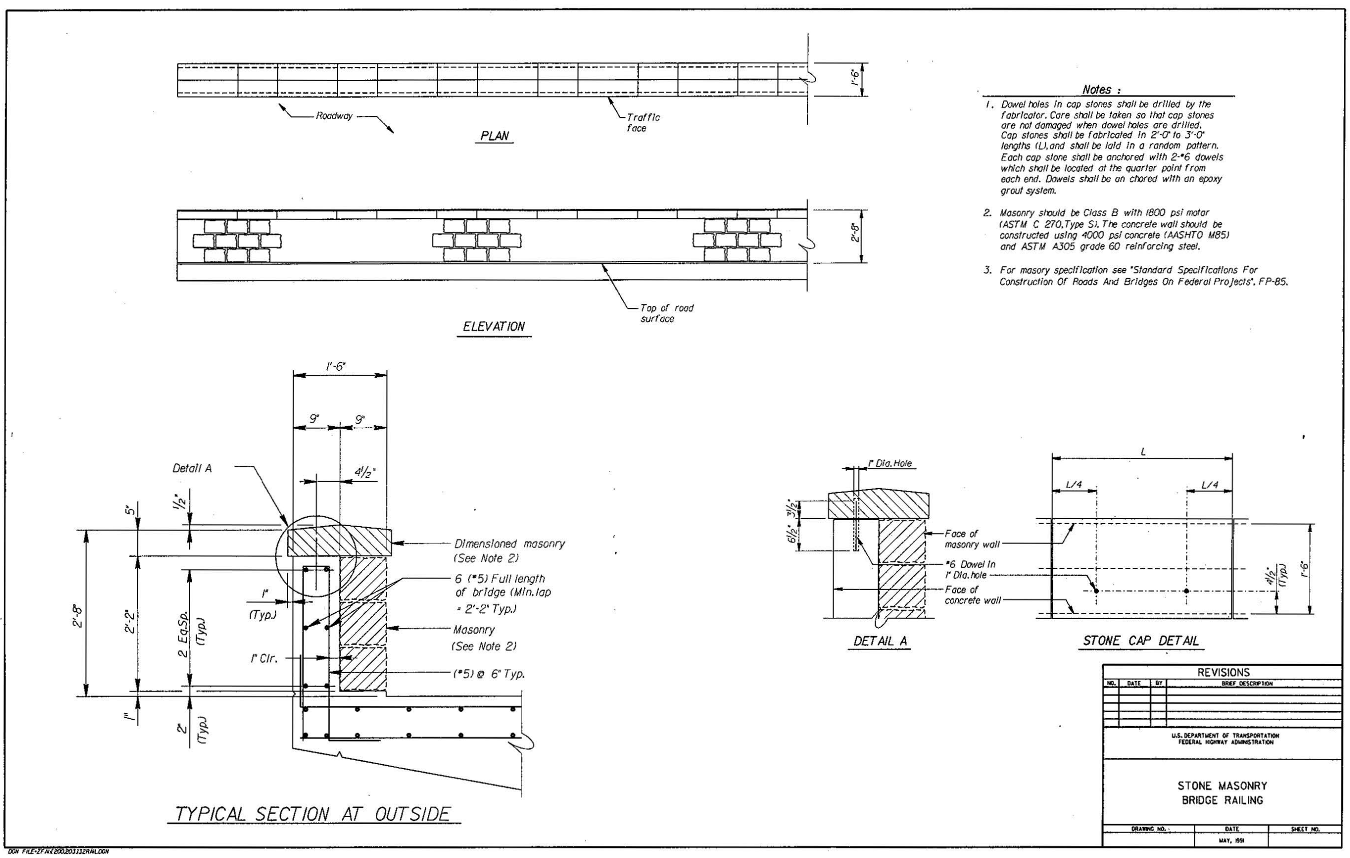


Figure 21. Stone Masonry Bridge Railing -- Drawings.

References

1. Unpublished information obtained from the National Park Service, Western Division, Denver, CO, 1991.

2. Highway Users Federation, *1989 Highway Fact Book*, The Highway Users Federal and the Automotive Safety Foundation, 1776 Massachusetts Avenue, N.W., Washington, D.C. 1990.

3. AASHTO-ARTBA-AGC, *Guide Specifications for Bridge Railings*, American Association of State Highway and Transportation Officials, Washington, D.C., 1989.

4. Dale Stout, John Hinch and Doug Sawyer, *Guardrail Testing Program*, Report No.FHWA-RD-90-087, Federal Highway Administration, Washington, D.C., June, 1990.

5. FHWA, *Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects*, Federal Highway Administration, Federal Lands Highways Division, FP-85, Washington, D.C., 1985.

6. Richard Powers and Harry Taylor, *Roadside Design Guide*, American Association of State Highway and Transportation Officials (AASHTO), Washington, D.C., 1989.

7. J.D. Michie, *Recommended Procedures for the Safety Performance Evaluation of Highway Safety Appurtenances*, National Cooperative Highway Research Program Report Number 230, Transportation Research Board, Washington, D.C., 1981.

8. *A Bridge to Cross*, Colorado State University, Colorado Transportation Information Center, Fort Collins, CO, 1989.

9. K. L. Hancock, A. G. Hansen, and J. B. Mayer, Jr., *Aesthetic Bridge Rails, Transitions and Terminals for Park Roads and Parkways*, Federal Highway Administration, FHWA-RD-90-052, Washington, D.C., 1990.

10. Staff, *Bridges*, Sales literature from Wheeler Consolidated, Inc., St. Louis Park, MN, 1990.

11. M.E. Bronstad, J.D. Michie, L.R. Calcote, K.L. Hancock and J.B. Mayer, Jr., *Bridge Rail Design and Performance Standards*, Federal Highway Administration, FHWA-RD-87-049 through 051, Washington, D.C.,1986.

12. *Guardrail to Bridge Rail Transitions*, FHWA Technical Advisory T 5040.26, Federal Highway Administration, Washington, D.C., January 28, 1988.

13. Malcolm H. Ray, Joe B. Mayer, Jr. and Jarvis D. Michie, *Replacing the 4500-lbs Passenger Car in Report 230 Crash Tests*, Volume 6 in Evaluation of Design Analysis Procedures and Acceptance Criteria for Roadside Hardware, Federal Highway Administration, Report No. FHWA-RD-87-101, 1987.

14. M.H. Ray, *Summary Report on Selected Bridge Railings*, Federal Highway Administration, Report Number FHWA-SA-91-049, Washington, D.C., 1992.

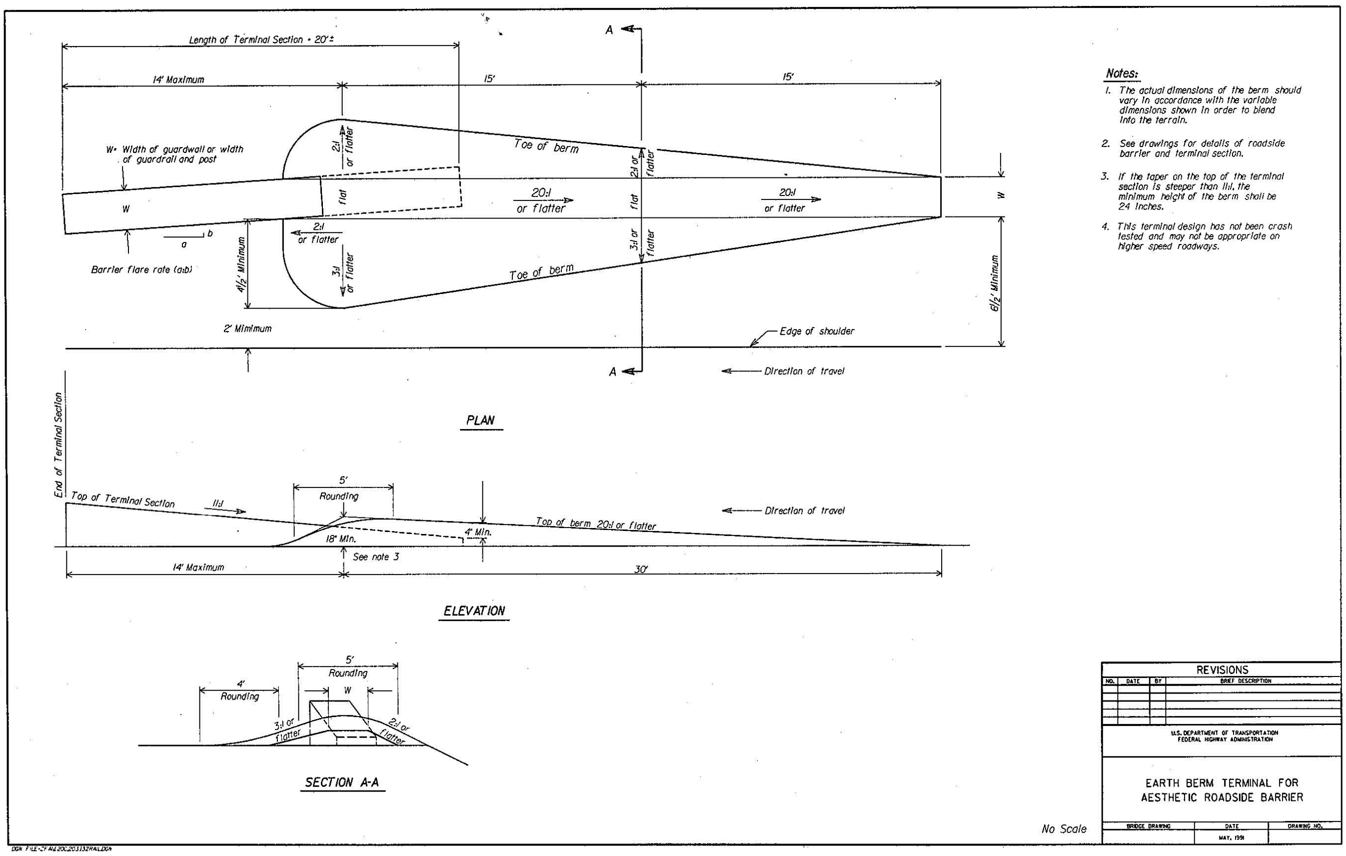


Figure 22. Earth Berm Details for Aesthetic Roadside Barriers.

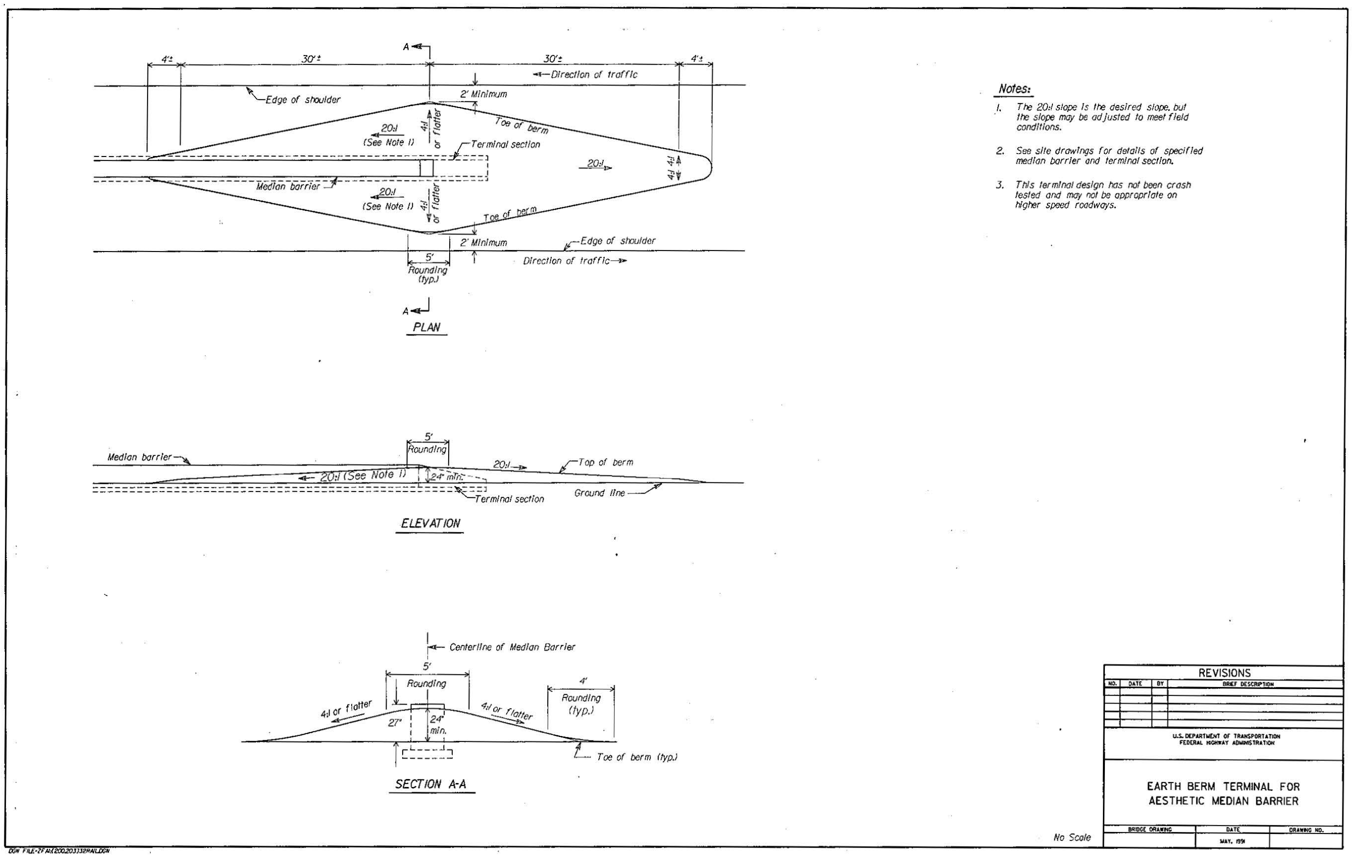


Figure 23. **Earth Berm Details for Aesthetic Median Barriers.**

HT A-12/RT AP/12-92(600)Q

HT A-12/RT AP/12-92(600)Q