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Design and Evaluation of Two Bridge Railings for Low-Volume Roads

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The U.S. Department of Agriculture (USDA) Forest Service, Forest Products Laboratory (FPL) and Headquarters Engineering Staff, in cooperation with the Midwest Roadside Safety Facility undertook the task of developing bridge railing systems for roads with low traffic volumes and low speeds. Two low-cost bridge railing systems were developed and successful full-scale crash tests were conducted for their use on timber bridge decks using longitudinal lumber laminations. A curb-type timber railing system was designed to redirect a 3/4-ton pickup truck hitting at a speed of 24 km/hr (15 mph) and an angle of 15 degrees. The curb-type rail system used square, trapezoidal, or rectangular rail shapes. A flexible railing system consisting of steel W-beam supported by breakaway timber posts was designed to redirect a 3/4-ton pickup truck hitting at a speed of 50 km/hr (31 mph) and an angle of 25 degrees. The flexible railing system was developed according to Test Level 1 of NCHRP Report 350, *Recommended Procedure for the Safety Performance Evaluation of Highway Features*.

Historically, bridge railing systems have not been developed for use on low-speed, low-volume roads; however, many U.S. Forest Service and National Forest utility and service roads often carry very low traffic volumes at operating speeds of 24

to 32 km/hr (15 to 20 mph) or less. These roads are often narrow, generally incorporating one- or two-lane timber bridges with span lengths between 4.6 and 10.7 m (15 and 35 ft). The bridge rails that have been designed for high-speed facilities may be too expensive for low-volume roads. In recognition of the need to develop bridge railings for this very low service level, the U.S. Department of Agriculture (USDA) Forest Service, Forest Products Laboratory (FPL) and Headquarters Engineering Staff, in cooperation with the Midwest Roadside Safety Facility (MwRSF), undertook the task of developing two bridge railing systems.

OBJECTIVE

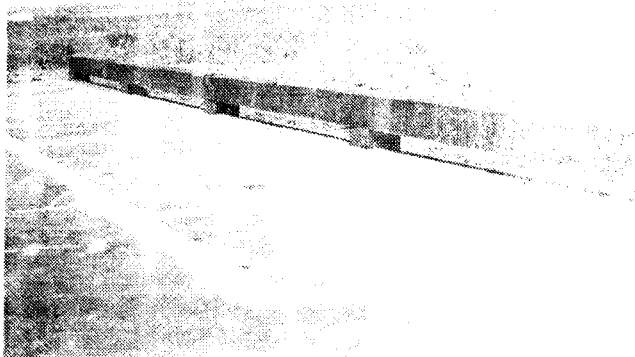
The objective of this research project was to develop two low-cost bridge railing systems for use on longitudinal timber bridge decks with low traffic volumes and speeds. A longitudinal glulam timber deck was selected for use in the development of the bridge railings because it is the weakest type of longitudinal timber deck for resisting transverse railing loads currently in use. Thus, any bridge railing not damaging the longitudinal glulam deck could be easily adapted to other, stronger, timber deck systems.

Curb-type railing systems were chosen as the basic design for the first bridge railing. A top-mounted curb type railing is shown in Figure 1 (a). Although curb barriers generally offer limited redirective capability at higher impact speeds, curb barriers can be very effective during low-speed impacts. A flexible railing with a breakaway post system was selected as the basic design for the second bridge railing. A side-mounted flexible railing is shown in Figure 1 (b).

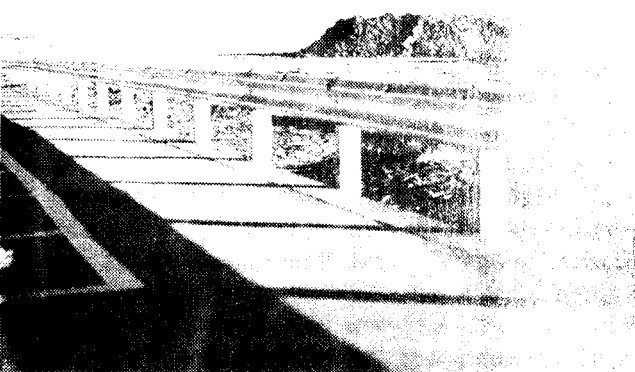
EVALUATION CRITERIA

Background

Currently, bridge railings are usually designed to satisfy the requirements provided in AASHTO's *Guide Specifications for Bridge Railings (1)*. More specifically, bridge railings should be designed according to the ap-



(a)



(b)

FIGURE 1 (a) Curb-type bridge railing and (b) flexible bridge railing.

propriate performance level of the roadway, based upon a number of factors such as design speed, average daily traffic (ADT), percentage of trucks, bridge rail offset, and number of lanes. These guide specifications include three performance levels, shown in Table 1, which provide criteria for evaluating the safety performance of bridge railings.

The recently published NCHRP Report 350, *Recommended Procedure for the Safety Performance Evaluation of Highway Features (2)*, provides for six test levels, shown in Table 1, for evaluating longitudinal barriers. Although this document does not contain objective criteria for selecting test level, safety hardware developed to meet the lower test levels is generally intended for use on lower-service-level roadways, and higher-test-level hardware is intended for use on higher-service-level roadways. The lowest performance level, Test Level 1, is suitable for applications on low-volume, low-speed facilities such as residential streets. However, operating speeds on these facilities are typically in the range of 48 km/hr (30 mph) or approximately twice as high as operating speeds on Forest Service utility roads. Thus, test impact conditions from Test Level 1 were deemed too severe for the low-cost curb-type bridge railing system envisioned. The second bridge railing, or flexible railing, was designed to meet Test Level 1 impact conditions because the increase in performance level could be achieved with little increase in cost.

Crash Test Conditions

Design impact conditions for narrow, low-volume utility roads were selected by the Forest Products Laboratory (FPL) of the USDA Forest Service in consultation with engineers of the Headquarters Engineering Staff. Reasonable design impact conditions for the curb-type bridge railings were estimated to involve a 3/4-ton pickup truck hitting at a speed of 24 km/hr (15 mph) and an angle of 15 degrees. The design impact conditions for the flexible bridge railing involved a 3/4-ton pickup truck hitting at a speed of 50 km/hr (31 mph) and an angle of 25 degrees according to Test Level 1 in NCHRP Report 350 (2). It is noted that a research study is in progress to develop a curb-type bridge railing to meet Test Level 1 of NCHRP Report 350 (2).

CURB-TYPE BRIDGE RAILINGS

Design Considerations

Timber was selected for use in the curb-type bridge railing designs on the basis of aesthetics and material availability. Further, curb railings were identified as a low-

TABLE 1 AASHTO Crash Test Conditions for Bridge Railings and NCHRP Report 350 Crash Test Conditions for Longitudinal Barriers

AASHTO Performance Level (1)	Impact Conditions				
	Small Car (816 kg)	Pickup Truck (2,449 kg)	Medium Single-Unit Truck (8,165 kg)	Van-Type Tractor-Trailer (22,680 kg)	
1	80.5 km/h and 20 deg	72.4 km/h and 20 deg			
2	96.6 km/h and 20 deg	96.6 km/h and 20 deg	80.5 km/h and 15 deg		
3	96.6 km/h and 20 deg	96.6 km/h and 20 deg		80.5 km/h and 15 deg	
NCHRP 350 Test Level (2)	Impact Conditions				
	Small Car (820 kg)	Pickup Truck (2,000 kg)	Single-Unit Van Truck (8,000 kg)	Tractor/Van Trailer (36,000 kg)	Tractor/Tank Trailer (36,000 kg)
1	50 km/h & 20 deg	50 km/h & 25 deg			
2	70 km/h & 20 deg	70 km/h & 25 deg			
3 (Basic Level)	100 km/h & 20 deg	100 km/h & 25 deg			
4	100 km/h & 20 deg	100 km/h & 25 deg	80 km/h & 15 deg		
5	100 km/h & 20 deg	100 km/h & 25 deg		80 km/h & 15 deg	
6	100 km/h & 20 deg	100 km/h & 25 deg			80 km/h & 15 deg

cost railing system and the most easily constructed design alternative for these low-service-level applications. Since most economical timber curb systems incorporate top-mounted single-railing designs, this type of structure was used for the new bridge rails.

Analysis of vehicular impacts with concrete and timber curbs revealed that the shape of the curb face could affect the redirective capacity of curb systems. A number of curb shape configurations were included in the design process. Each curb configuration was evaluated at different heights in order to determine the minimum height required to meet the selected performance criteria. Based on full-scale vehicle crash tests of curb systems 50.8 cm (20 in.) high (6) and a limited study of impacts with shorter curbs (unpublished research) using HVOSM computer simulation modeling (7), the researchers estimated that curbs 20.3 to 35.6 cm (8 to 14 in.) high should be able to meet the desired performance standard.

Peak lateral forces imparted to the curb railing were estimated to be approximately 9.5 kN (2.1 kips) using the procedures described by the NCHRP report, the AASHTO Guide, and Ritter et al. (3-5). Based on these findings, it was concluded that timber curb railings may be capable of withstanding design impact conditions without significant damage to the barrier or the timber

deck. Each railing was analyzed as a simply supported beam with pin connections at each end. Three rail shapes and sizes—a 20.3-cm (8-in.) by 20.3-cm (8-in.) square, a 20.3-cm (8-in.) by 22.9-cm (9-in.) trapezoid with a negative slope on the traffic-side face, and a 10.2-cm (4-in.) by 30.5-cm (12-in.) rectangle—were selected for a preliminary evaluation. A developmental testing program was then undertaken to evaluate the safety performance and height requirements for each of these curb rails.

Design Details

The basic curb design incorporated 6.10-m (20-ft) long rail sections mounted on scupper blocks. The rail elements, scupper blocks, and bridge deck were attached to each other with two 1.6-cm (5/8 -in.) diameter ASTM A307 galvanized bolts placed 15.2 cm (6 in.) apart at each end and in the middle of each rail element. A bolted lap splice was also incorporated to attach the ends of adjacent rail elements. The 11.9-m (39-ft) long curb rails were constructed from two 6.10-m (20-ft) long rail sections and a 0.30-m (1-ft) long lap splice. Two sizes of timber scupper blocks were used to mount the curb rail elements on the timber deck. The curb rail

sections and scupper blocks were constructed from No. 1 Grade Douglas fir using rough-sawn and SIS specifications, respectively. Timber curb rail and scupper materials were treated to meet AWWA Standard C14 with 192.22 kg/m^3 (12 pcf) creosote (8). Schematics of both a typical curb rail section mounted on the deck surface and a curb railing splice are shown in Figure 2.

The curb railings were attached to a longitudinal glulam timber deck supported by concrete abutments. The concrete abutments and the longitudinal glulam timber deck were the same as those used in the development of previously tested AASHTO PL-1 and PL-2 railing

systems (9-11). In addition, a 5.1-cm (2-in.) asphalt surface was placed on the top of the timber deck in order to represent actual field conditions.

Developmental Testing, Phase I

Developmental testing was used to determine critical heights for the three different curb shapes. The developmental testing used a 1985 Ford F-250 3/4-ton pickup truck with test inertial and gross static weights of 1999 kg (4,406 lb) and 2078 kg (4,581 lb), respec-

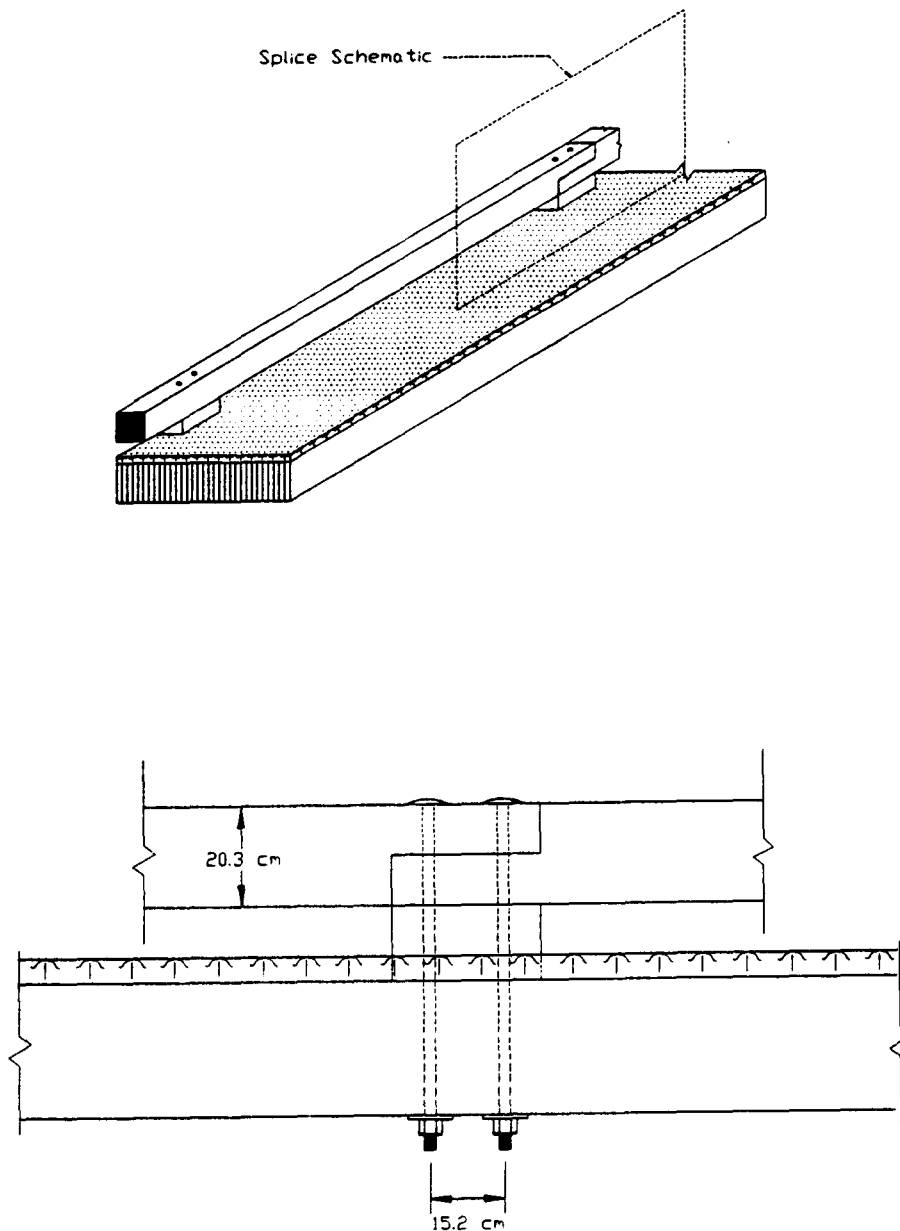


FIGURE 2 Typical curb section mounted to deck surface and curb railing splice.

tively. A pickup truck was driven into the rails at speeds of 24 and 32 km/hr (15 and 20 mph) and an angle of 15 degrees. No steering or braking inputs were applied to the vehicle during impact or until the vehicle had traveled an adequate distance downstream from the end of the rails.

The curb shapes were attached to a continuous concrete slab, as shown in Figure 3, with two 1.6-cm (5/8 in.) diameter ASTM A307 bolts spaced on 2.90-m (9-ft 6-in.) centers. If necessary, timber scupper blocks were placed below the rail shapes in order to mount the curb rails 20.3, 25.4, and 30.5 cm (8, 10, and 12 in.) above the surface.

Impact tests were performed on the three curb shapes mounted at three different heights for a total of nine curb configurations. The developmental testing phase consisted of 19 impact tests on the rail attached to the concrete slab, as shown in Table 2. For impacts at 24 km/hr (15 mph) and 15 degrees, the trapezoidal and rectangular shapes with a 20.3-cm (8-in.) mounting height successfully redirected the test vehicle with no tendency for the vehicle to climb. However, for the same impact conditions, the square shape with a 20.3-cm (8-in.) mounting height allowed the vehicle to climb over the top of the rail. Following these tests, it was determined that one full-scale vehicle crash test would be performed on one of the two successful curb shapes attached to the longitudinal timber deck. The trapezoidal shape with a 20.3-cm (8-in.) mounting height was selected for this crash testing because it appeared to provide a higher redirective capacity than the rectangular shape.

Full-Scale Crash Testing, Phase I

Full-scale crash testing used the same 3/4-ton pickup truck but with a test inertial and gross static weight of 1999 kg (4,406 lb), an impact speed of 24 km/hr (15 mph), and an angle of 15 degrees. The test vehicle was towed using a cable tow and guidance system and struck the rails attached to the longitudinal timber deck.

Originally, only one full-scale crash test was to be conducted on a 20.3-cm (8-in.) by 22.9-cm (9-in.) trapezoidal shape with 20.3-cm (8-in.) mounting height. However, because this test failed, two additional tests were conducted on the trapezoidal shape, one at the 20.3-cm (8-in.) mounting height and one at the 25.4-cm (10-in.) mounting height.

In Test LVCT-1a the vehicle struck the curb rail approximately 3.35 m (11 ft) from the upstream end of the 11.9-m (39-ft) long installation. During impact, the vehicle's right front tire climbed over the top of the curb. The vehicle came to rest on top of the curb at the end of the installation. In Test LVCT-1b the vehicle

struck the curb rail at the same location as in Test LVCT-1a. The vehicle's right front tire again climbed over the curb with little or no vehicle redirection. Following the two unsuccessful tests on the trapezoidal shape with a 20.3-cm (8-in.) mounting height, a third test was conducted on the trapezoidal shape with a 25.4-cm (10-in.) mounting height. The impact point for Test LVCT-1c was the same as that for the previous two tests. The vehicle's right front tire again climbed over



FIGURE 3 Square curb rail attached to concrete apron, three views.

TABLE 2 Summary of Curb-Type Bridge Railing Development, Phase I

Rail Type (cm x cm)	Rail Height (cm)	Test No.	Speed (km/h)	Results
Square - 20.3 x 20.3	20.3	1	24	Failed - vehicle over top of curb
Square - 20.3 x 20.3	25.4	2a 2b	24 24	Passed - right front tire briefly hopped onto curb Passed - right front tire popped into air
Trapezoid - 20.3 x 22.9	25.4	3a 3b 3c 3d	24 24 32 32	Passed - no climbing tendency Passed - no climbing tendency Passed - right-front tire popped into air Passed - right-front tire briefly hopped onto curb
Trapezoid - 20.3 x 22.9	20.3	4a 4b 4c	24 24 32	Passed - no climbing tendency Passed - no climbing tendency Failed - vehicle over top of curb
Trapezoid - 20.3 x 22.9	30.5	5	24	Passed - no climbing tendency
Square - 20.3 x 20.3	30.5	6a 6b	24 24	Passed - no climbing tendency Passed - no climbing tendency
Rectangle - 10.2 x 30.5	30.5	7a 7b	24 24	Passed - no climbing tendency Passed - no climbing tendency
Rectangle - 10.2 x 30.5	25.4	8a 8b	24 24	Passed - no climbing tendency Passed - no climbing tendency
Rectangle - 10.2 x 30.5	20.3	9a 9b	24 24	Passed - no climbing tendency Passed - no climbing tendency

the top of the curb, which allowed the tire to go over the side of the bridge rail. The vehicle came to rest on top of the curb at the end of the installation.

Results of these tests were inconsistent with the previous findings from the developmental testing program. Factors that may have affected the results include the following: (a) air temperatures were much warmer when testing on the timber deck than during developmental testing on the concrete slab (average daily temperatures during developmental testing, Phase I, and full-scale crash testing, Phase I, were -2.2°C (28°F) and 17°C (63°F), respectively); (b) the trapezoidal curb rail was coated with a latex water-based paint to aid in photography and documentation of tests; and (c) creosote on the surface of the treated timber may have dried and increased friction levels between the tires and timber rail.

Developmental Testing, Phase II

Following three unsuccessful full-scale vehicle crash tests on the longitudinal deck with the trapezoidal curb rail, developmental testing was once again conducted on the concrete slab to determine the critical mounting heights for the three different curb shapes. The curb shapes were attached to the concrete in the same manner as during the first phase of the developmental testing program. The 3/4-ton pickup truck was again

driven into the curb railings at a speed of 24 km/hr (15 mph) and an angle of 15 degrees. The trapezoidal shape rail was tested with the same coating of paint used during the full-scale crash tests and creosote that may have dried on the timber rail surface.

Impact tests were performed on the three curb shapes mounted at heights ranging from 20.3 to 35.6 cm (8 to 14 in.) A total of eight curb configurations were evaluated with 15 crash tests, as shown in Table 3. For impacts at 24 km/hr (15 mph) and 15 degrees, a 30.5-cm (12-in.) mounting height successfully redirected the test vehicle for both the square and rectangular shapes with no tendency for vehicle climbing. However, for the same impact conditions, a 35.6-cm (14-in.) mounting height was required to successfully redirect the vehicle for the trapezoidal shape. The trapezoidal shape with a 30.5-cm (12-in.) mounting height allowed the tire to climb up and over the curb. These tests indicated that inconsistencies in the previous testing were not caused by paint applied to the trapezoidal rail but may have been a result of the drying creosote or the temperature changes mentioned previously. Following these tests, it was determined that one full-scale vehicle crash test would be performed on one of the successful curb shapes. The square shape with a 30.5-cm (12-in.) mounting height was selected for full-scale vehicle crash testing because it offered the most cost-effective design alternative.

TABLE 3 Summary of Curb-Type Bridge Railing Development, Phase II

Rail Type (cm x cm)	Rail Height (cm)	Test No.	Speed (km/h)	Results
Trapezoid - 20.3 x 22.9	20.3	10a 10b 10c	24 24 24	Failed - vehicle over top of curb Failed - vehicle over top of curb Failed - vehicle over top of curb
Rectangle - 10.2 x 30.5	20.3	11	24	Failed - vehicle over top of curb
Rectangle - 10.2 x 30.5	25.4	12	24	Failed - vehicle over top of curb
Rectangle - 10.2 x 30.5	30.5	13a 13b	24 24	Passed - right-front tire briefly popped into air Passed - right-front tire briefly popped into air
Trapezoid - 20.3 x 22.9	30.5	14a 14b 14c	24 24 24	Passed - minor vehicle uplift action Passed - right-front tire climbed onto curb Failed - vehicle over top of curb
Trapezoid - 20.3 x 22.9	35.6	15a 15b	24 24	Passed - no climbing tendency Passed - no climbing tendency
Square - 20.3 x 20.3	35.6	16	24	Passed - no climbing tendency
Square - 20.3 x 20.3	30.5	17a 17b	24 24	Passed - no climbing tendency Passed - no climbing tendency

Full-Scale Crash Testing, Phase II

One full-scale crash test (LVCS-4) was conducted on the 20.3- by 20.3-cm (8- by 8-in.) square shape with a 30.5-cm (12-in.) mounting height attached to the longitudinal timber deck. In Test LVCS-4 the vehicle hit the curb rail at a speed of 23.2 km/hr (14.4 mph) and an angle of 15 degrees. Impact occurred approximately 3.35 m (11 ft) from the upstream end of the 11.9-m (39-ft) long installation, as shown in Figure 4. The square shape with a 30.5-cm (12-in.) mounting height successfully redirected the vehicle, which came to rest approximately 22.0 m (72 ft) downstream from the impact, as shown in Figure 4. A summary of the test results and the sequential photographs are presented in Figure 5.

Except for minor scuff marks on the right-side tires, there was no visible vehicle damage, as shown in Figure 4. No damage occurred to the curb rail or steel hardware. In addition, the glulam timber deck was not damaged.

The curb-type bridge rail contained and redirected the test vehicle without penetrating or overriding the bridge rail. Detached elements, fragments, or other debris from the bridge rail did not penetrate or show potential for penetrating the occupant compartment and would not present any hazard to other traffic or pedestrians. The integrity of the occupant compartment was maintained with no intrusion or deformation. The vehicle remained upright during and after collision, and the vehicle's trajectory did not intrude into adjacent

traffic lanes. The vehicle exit angle of approximately 0 degrees was less than 60 percent of the impact angle or 9 degrees.

The curb bridge railing successfully redirected a 1999-kg (4,406-lb) pickup truck driven at a speed of 23.2 km/hr (14.4 mph) and an angle of 15 degrees. The curb bridge railing met the performance evaluation criteria (i.e., structural adequacy, occupant risk, and vehicle trajectory) for crash testing bridge railings (1,2) but at the reduced impact conditions of 24 km/hr (15 mph) and 15 degrees.

BREAKAWAY BRIDGE RAILING

Design Considerations

A steel W-beam railing with timber bridge posts was selected for use in the flexible bridge railing design based on previously crash-tested metal beam bridge railings (12-14), economics, and material availability. Breakaway posts rather than stiff posts were chosen in order to keep material costs below \$33/m (\$10/ft) by reducing the required structural capacity of the post-to-deck attachment. The post-to-deck attachment was designed so that no damage would occur to the timber deck or connection hardware. A side-mounted post-to-deck attachment with no rail or post blockouts was selected in order to reduce the required minimum width of timber deck.



FIGURE 4 Impact location, vehicle trajectory, and vehicle damage, Test LVCS-4.

Static Post Testing

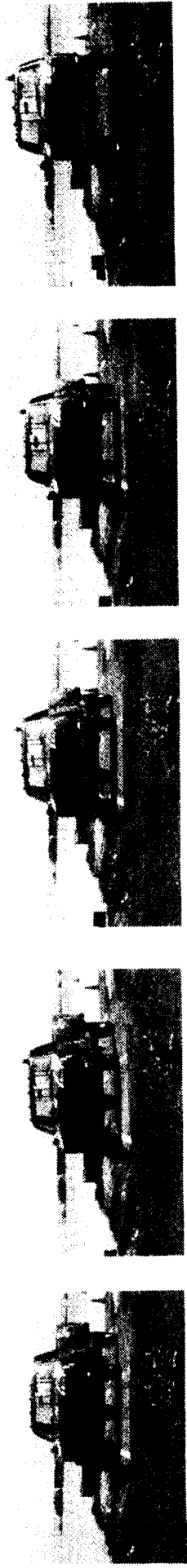
Static post testing was used to determine the force-deflection characteristics of two dimensions of lumber post sizes, 10.2-cm (4-in.) by 10.2-cm (4-in.) and 10.2-cm (4-in.) by 15.2-cm (6-in.) nominal. The cantilevered posts were bolted between two steel angles and attached to a rigid plate. Various angle sizes were used during

the testing in order to determine the optimum angle dimensions. Thirteen static tests were performed. A 10.2-cm (4-in.) by 15.2-cm (6-in.) lumber post measuring 83.8 cm (33 in.) long with steel angles measuring 12.7 cm (5 in.) by 12.7 cm (5 in.) by 1.0 cm (3/8 in.) was selected for the original design. The maximum static force for this post size was 10.7 kN (2.4 kips). The post and angle sizes were selected based on a maximum force level that would not damage the post-to-deck attachment hardware or the deck.

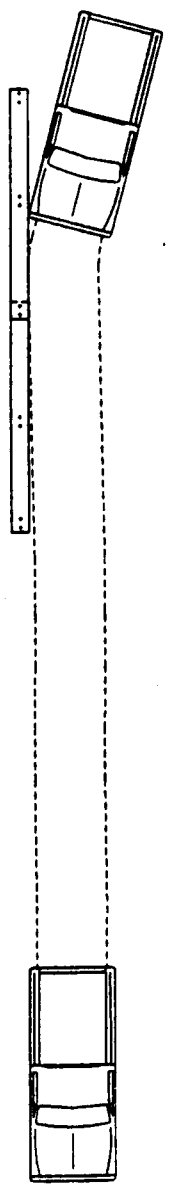
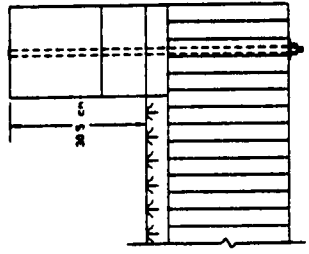
Following the failure of the first full-scale crash test, 24 additional static tests that included increasing the post height and placing saw cuts in the compression zone, tension zone, and combinations thereof were performed. A 10.2-cm (4-in.) by 15.2-cm (6-in.) lumber post measuring 93.3 cm (36.75 in.) long with steel angles measuring 12.7 cm (5 in.) by 12.7 cm (5 in.) by 1.0 cm (3/8 in.) was selected for the modified design. The modified posts also included a 2.5-cm (1-in.) horizontal saw cut placed on the tension side of the post 7.6 cm (3 in.) from the base of the post. The maximum static force for this post size was 5.8 kN (1.3 kips). Ritter et al (15) provide additional details for the static post testing.

Design Details

A standard 12-gauge W-beam rail was selected for the rail element with a 61.0-cm (24-in.) top mounting height. However, after failure of the first full-scale crash test, the rail height was modified to 55.0 cm (21.65 in.) as measured from the top of the asphalt surface to the center of the rail. This provided a new rail top mounting height of approximately 70.6 cm (27.78 in.). In addition, the flat washer located under the head of the W-beam bolt was removed. The bridge rail was supported by 15 posts spaced on 1.90-m (6-ft 3-in.) centers. The chromated copper arsenate (CCA) treated lumber posts measured 10.2-cm (4-in.) by 15.2-cm (6-in.) nominal or 8.9-cm (3.5-in.) by 14.0-cm (5.5-in.) actual dressed size. The lumber posts were manufactured using Douglas fir Grade No. 2 or better. A 1.6-cm (5/8 -in.) diameter by 17.8-cm (7-in.) long ASTM A307 galvanized hex head bolt attached the rail to each post. Each post was placed between two 12.7-cm (5-in.) by 12.7-cm (5-in.) by 1.0-cm (3/8-in.) by 15.2-cm (6-in.) long ASTM A36 galvanized steel angles. Two 1.6-cm (5/8 -in.) diameter by 14.0-cm (5 1/2-in.) long ASTM A325 galvanized hex head bolts attached the post between the angles. Each post with attached angles was rigidly fixed to the outside vertical surface of the timber deck with two 1.9-cm (3/4-in.) diameter by 30.5-cm (12-in.) long ASTM A307 galvanized lag screws. A



0.000 sec 0.064 sec 0.275 sec 0.437 sec 1.229 sec



Test Number LVCS-4
 Date 5/12/93
 Bridge Rail Installation Low-Volume Curb Bridge Rail
 Length 11.89 m
 Timber Curb Rail
 Size Square 20.3 cm x 20.3 cm
 Top Mounting Height 30.5 cm
 Material Douglas Fir
 Grade No. 1
 Preservative Treatment Creosote
 Timber Scupper Block
 Size 10.2 cm x 20.3 cm x 30.5 cm
 Material Douglas Fir
 Grade No. 1
 Preservative Treatment Creosote
 Anchorage Bolts
 Type ASTM A307, Galvanized
 Size Two 1.6-cm ϕ Bolts Per Location
 Length 71.1 cm
 Spacing 2.90-m Centers

Bridge Deck Installation Longitudinal Glulam Timber
 Panel Size 27.3 cm x 1.22 m x 5.72 m
 Material Glulam Timber Deck Comb.
 No. 2
 Vehicle Model 1985 Ford F-250 Pickup
 Test Inertial Mass 1,999 kg
 Gross Static Mass 1,999 kg
 Vehicle Speed
 Impact 23.2 km/h
 Exit Not Available
 Vehicle Angle
 Impact 15 degrees
 Exit 0 degrees
 Vehicle Snagging None
 Vehicle Stability Satisfactory
 Maximum Vehicle Rebound Distance Not Applicable
 Bridge Rail Damage None
 Vehicle Damage None
 Vehicle Stopping Distance 21.95 m

FIGURE 5 Summary of test results and sequential photographs, Test LVCS-4.

schematic of the modified breakaway bridge railing is shown in Figure 6.

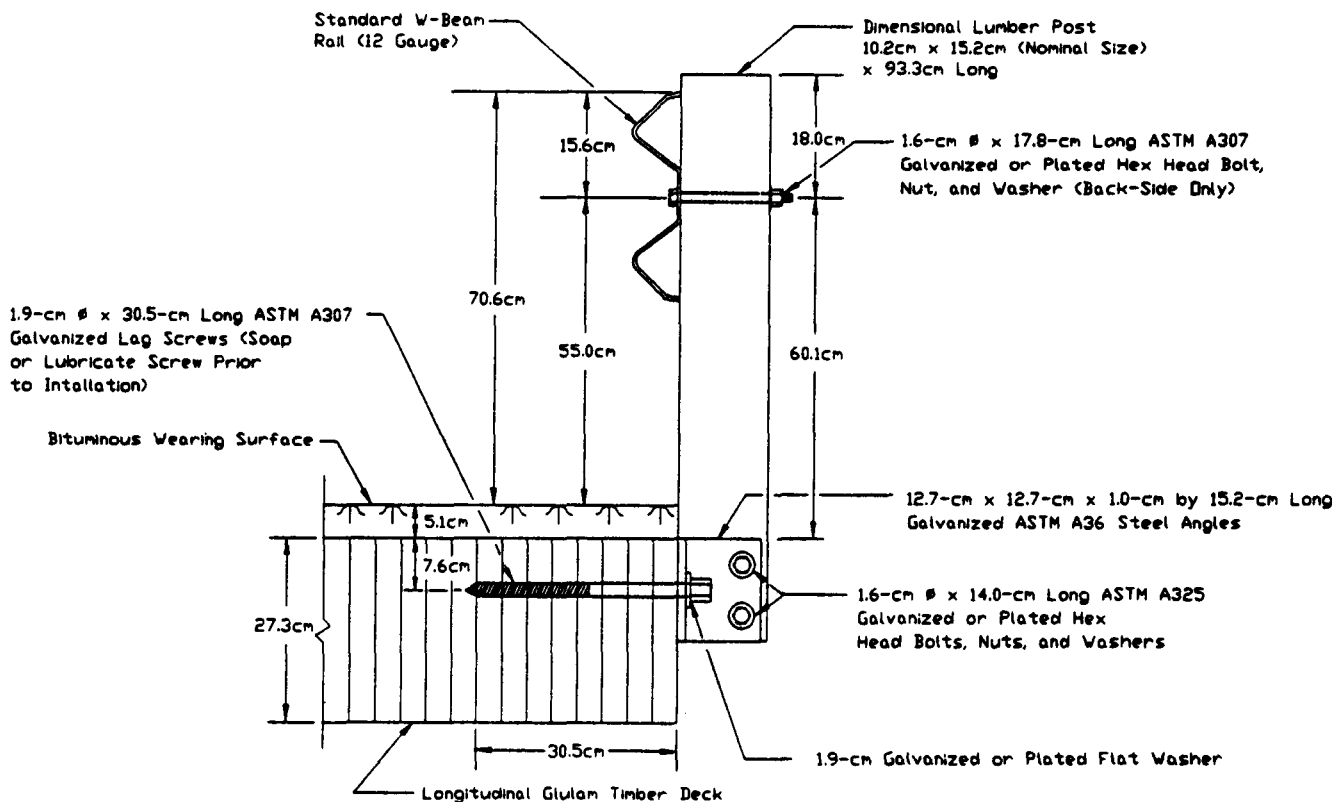
Approach guardrails were placed on each end of the bridge railing. The bridge railing with approach guardrails was 60.96 m (200 ft) long. Each W-beam approach guardrail was 15.24 m (50 ft long) and supported by 15.2-cm (6-in.) by 20.3-cm (8-in.) timber posts spaced on 1.90-m (6-ft 3-in.) centers. Guardrail anchorage was provided at each end by a modified breakaway cable terminal (MBCT) with steel foundation tubes, bearing plates, and channel struts.

The bridge railing was attached to a longitudinal glulam timber deck supported by concrete abutments. The concrete abutments, longitudinal glulam timber deck, and asphalt surface were the same as those used in the development of the curb-type systems.

BARRIER VII Computer Simulation Modeling

Following the preliminary design of the breakaway bridge railing, computer simulation modeling with BARRIER VII was performed to analyze the dynamic performance of the bridge railing before full-scale crash testing (16). Computer simulation was conducted modeling a 1996-kg (4,400-lb) pickup truck driven at 31 mph (500 km/hr) and an angle of 25 degrees according to Test Level 1 of NCHRP Report 350 (2).

The simulation results indicated that the original and modified breakaway bridge railing designs satisfactorily redirected the 1996-kg pickup truck. For the modified design, computer simulation predicted that eight breakaway lumber posts would be broken during impact, and the maximum permanent set and dynamic deflections



Notes:

- (1) Post Spacing 1.90m
- (2) Sawcut in post not shown.
- (3) Many details have been omitted.
- (4) 1in. = 2.54cm

FIGURE 6 Modified breakaway bridge railing.

of the W-beam were predicted to be 56.1 cm (22.1 in.) and 82.5 cm (32.5 in.), respectively. In addition, the predicted peak 0.050-sec average impact force perpendicular to the bridge railing was approximately 27 kN (6 kips).

Full-Scale Crash Testing

Two full-scale crash tests were performed with 3/4-ton pickup trucks on a breakaway bridge railing. The first test, LVBR-1, was conducted on a 61.0-cm (24-in.) high W-beam rail (original design), and the second test, LVBR-2, was conducted on a 70.6-cm (27.78 -in.) high W-beam rail with a 2.5-cm (1-in.) saw cut on the tension side of the post (modified design). It was not necessary to conduct a full-scale crash test with a 820-kg minicompact hitting at 50 km/hr (31 mph) and 20 degrees since there was no potential for occupant risk problems arising from wheel snagging caused by the weak timber posts and low impact speed.

Test LVBR-1 (Original Design)

A 1984 Chevrolet C-20 pickup truck weighing 2041 kg (4,499 lb) struck the bridge rail at Post No. 7 at 50.2 km/hr (31.2 mph) and 26.8 degrees. Upon impact, the vehicle's bumper was forced over the top of the W-beam rail. The vehicle's tires then climbed up the face of the W-beam and the vehicle vaulted over the bridge rail. Failure of the bridge rail was attributed to insufficient rail mounting height. Damage to the connection angles and lag screws was also noticed.

Test LVBR-2 (Modified Design)

A 1985 Chevrolet C-20 pickup truck weighing 2043 kg (4,504 lb) struck the bridge rail at Post No. 7 at 49.2 km/hr (30.6 mph) and 24.9 degrees, as shown in Figure 7. A summary of the test results and the sequential photographs are shown in Figure 8. The vehicle became parallel to the bridge railing at 0.652 sec with a velocity of 38.8 km/hr (24.1 mph). Although the vehicle was redirected, it did not exit the bridge railing. The vehicle came to rest 13.4 m (44 ft) downstream from impact with the vehicle's left-side tires and right-side undercarriage resting on the deck surface, as shown in Figure 7. At no time, during impact or at any time thereafter did the vehicle's right-side tires contact the ground.

Vehicle damage was minor. Following the crash test, the vehicle's right-side tires were lifted onto the deck, and the vehicle was driven away. Damage on the right-front quarter panel was caused by vehicle-rail contact, and damage to the right-side undercarriage was caused by contact with the outer top surface of the deck, as

shown in Figure 7. Bridge rail damage was also minimal, as shown in Figure 9. One 1.90-m (6-ft 3-in.) section of W-beam rail was permanently damaged. Eleven posts, Nos. 4 through 14, fractured away from the deck attachment. Five steel angles were deformed downstream of impact because of contact between the angles and the undercarriage of the vehicle.

The modified breakaway bridge rail contained and redirected the test vehicle without allowing it to penetrate or override the barrier. Detached elements, fragments, or other debris from the bridge rail did not penetrate or show potential for penetrating the occupant compartment and would not present any hazard to other traffic or pedestrians. The integrity of the occupant compartment was maintained with no intrusion or deformation. The vehicle remained upright during and after collision, and the vehicle's trajectory did not intrude into adjacent traffic lanes. Thus, the modified breakaway bridge railing successfully met all the evaluation criteria for Test Level 1 of NCHRP Report 350 (2).

CONCLUSIONS

Curb-Type Bridge Railing

The square-shaped bridge rail with a 30.5-cm (12-in.) mounting height successfully redirected the pickup truck after an impact at a speed of 23.2 km/hr (14.4 mph) and an angle of 15 degrees. This result is consistent with the results from Phase II of the developmental testing program. Full-scale crash tests were not performed on the trapezoidal and rectangular shapes with 35.6-cm (14-in.) and 30.5-cm (12-in.) mounting heights, respectively. However, based on findings from the developmental testing program, it was reasoned that these shapes would behave similarly to the square-shaped curb rail and did not require additional full-scale crash testing.

Thus, three curb-type bridge railings were developed for longitudinal timber decks located on low-volume roads, as shown in Figure 10. The top-mounted timber curb railings provide economic and aesthetically pleasing bridge railing alternatives. Material costs for the three curb-type bridge railing systems are reasonably low. The rectangular-shaped railing system has the lowest material costs at \$39.60/m (\$12.07/ft), and the trapezoidal-shaped railing system has the highest material costs at \$47.08/m (\$14.35/ft). In addition, the curb-type railing system is easy to install and should have low construction labor costs. These railing systems could easily be adapted to other types of longitudinal timber decks. Finally, no bridge deck or railing damage was observed during testing on a longitudinal glulam

deck system. Thus, maintenance and repair costs associated with the new curb designs should be very low.

Modified Breakaway Bridge Railing

A flexible railing with a breakaway post system was developed and successfully met the Test Level 1 crash

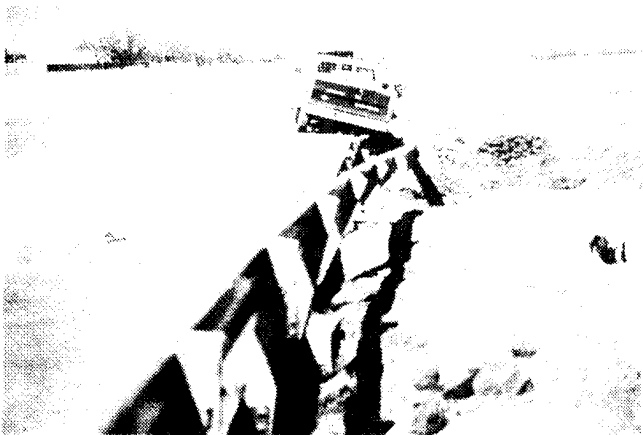
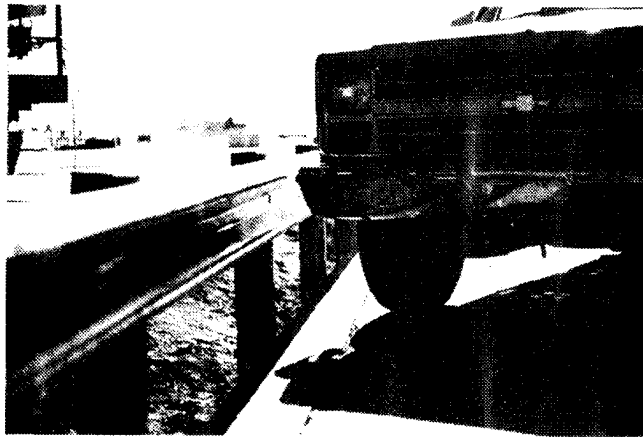


FIGURE 7 Impact location, vehicle trajectory, and vehicle damage, Test LVBR-2.

test conditions of NCHRP Report 350 (2). The 70.6-cm (27.78 -in.) high W-beam bridge rail successfully redirected a 3/4-ton pickup truck after an impact at 49.2 km/hr (30.6 mph) and an angle of 25 degrees. The side-mounted railing provides an economic railing with readily available materials. Material costs for the bridge railing system are reasonably low at approximately \$25.85/m (\$7.88/ft). In addition, the breakaway railing system is easy to install and should have low construction labor costs. This railing system should also be adaptable to other types of longitudinal timber decks. In addition, no bridge deck damage was observed after testing; therefore, repair costs should also be kept to an absolute minimum.

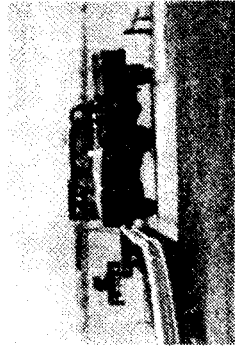
DISCUSSION AND RECOMMENDATIONS

The curb and breakaway bridge railings described herein were developed for low-impact condition requirements. The developmental testing program indicated that the redirective capacity of the curb railings could be increased by modifying the curb height and size, the rail-to-deck attachment, and the capacity of the rail splice connection. Curb railings should be able to meet the performance requirements of Test Levels 1 and 2 of NCHRP Report 350 (2). These higher-performance timber curb railings could be adapted for use in many different barrier applications. As bridge railings, the curbs would provide an aesthetic and economic alternative to conventional steel and concrete railings on many low-volume streets and highways with increased driver visibility. For flexible railings with breakaway posts, the full-scale crash testing program indicates that acceptable impact performance is possible although large dynamic rail deflections can be expected. Therefore, flexible railings with a modified post-to-deck attachment and stronger posts may be able to meet the performance requirements of Test Level 2 from NCHRP Report 350 (2).

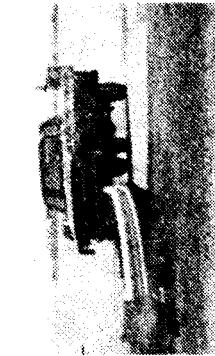
Thus, it is recommended that the research described herein be extended to develop higher-performance timber curb railings and barriers and flexible railings for timber bridge decks.

ACKNOWLEDGMENTS

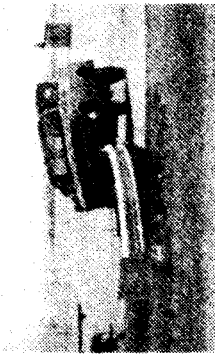
The authors would like to thank the following organizations for their contributions to the success of this research project: the American Institute of Timber Construction (AITC), Vancouver Washington, for donating the glulam materials for the deck construction and the Office of Sponsored Programs and the Center for Infra-



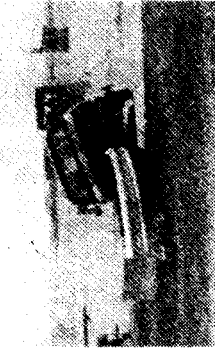
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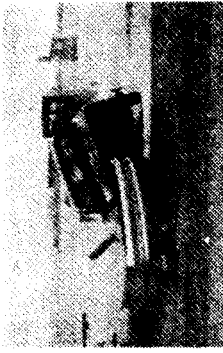
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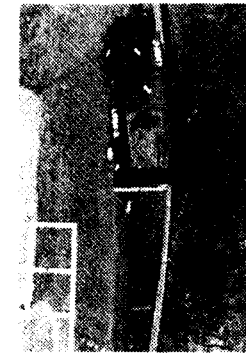
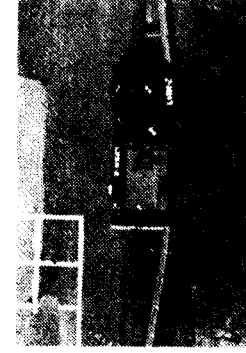
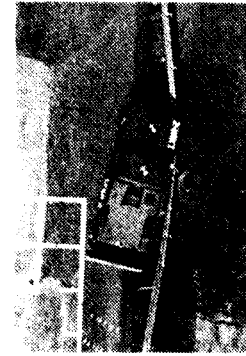
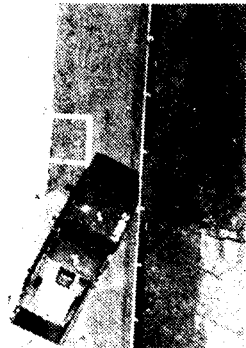
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Test Number	LVBR-2
Date	3/18/94
Bridge Rail Installation	Low-Volume Breakaway Bridge Rail
Length	30.48 m
Steel W-Beam Rail	
Size	12 Gauge
Top Mounting Height	70.6 cm
Posts (No. 1 through 15)	
Size	8.9 cm x 14.0 cm x 93.3 cm
Material	Dimension Lumber (CCA)
Grade	No. 2 or Better
Bridge Deck Installation	Longitudinal Glulam Timber Bridge Deck Panels
Panel Size	27.3 cm x 1.22 m x 5.72 m
Material	Glulam Timber Deck Comb. No. 2
Vehicle Model	1985 Chevrolet C-20 Pickup
Test Inertial Mass	2,043 kg
Gross Static Mass	2,043 kg
Vehicle Speed	
Impact	49.2 km/h
Exit	NA

Vehicle Angle	
Impact	24.9 degrees
Exit	NA
Vehicle Snagging	None
Vehicle Stability	Satisfactory
Effective Coefficient of Friction (μ)	0.28 (Fair)
Occupant Impact Velocity - normalized	
Longitudinal	2.2 m/s (9 m/s) (2)
Lateral	1.9 m/s (9 m/s) (2)
Occupant Ridedown Deceleration - 0.010-msec average	
Longitudinal	4.3 g's (15 g's) (2)
Lateral	3.8 g's (15 g's) (2)
Vehicle Damage	Minor
TAD	1-RFQ-1
VDI	01RFEW1
Maximum Vehicle Rebound Distance	Not Applicable
Bridge Rail Damage	Minor Rail Deformation and Eleven Fractured Posts
Maximum Dynamic Deflection	131.8 cm
Maximum Permanent Set Deflection	115.3 cm

FIGURE 8 Summary of test results and sequential photographs, Test LVBR-2.

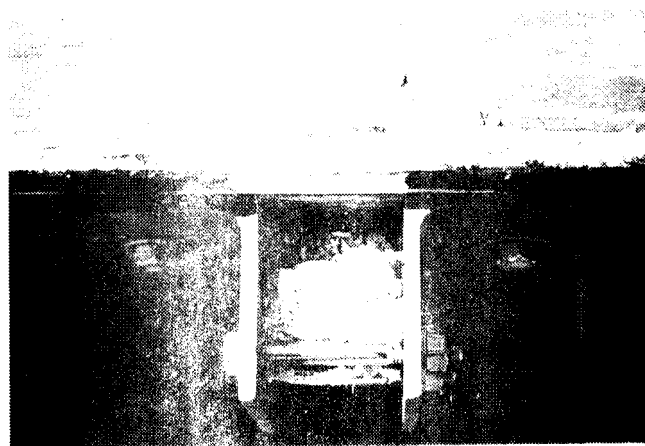
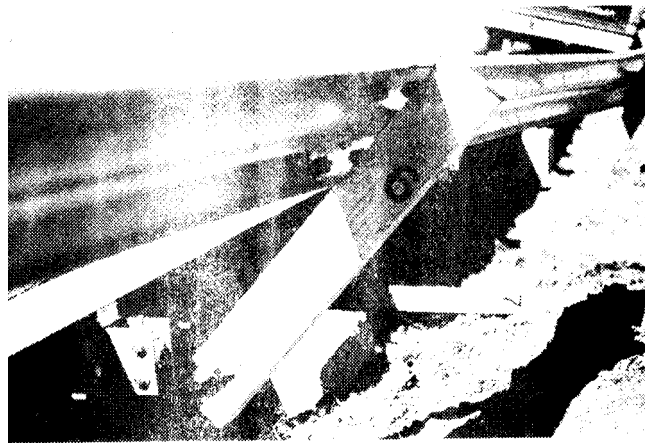
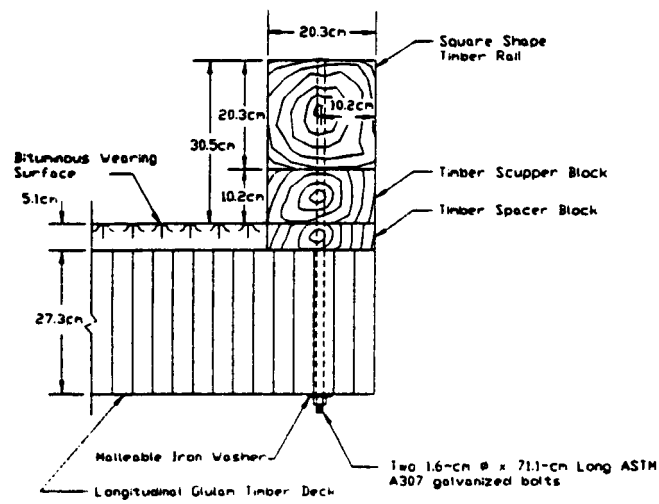
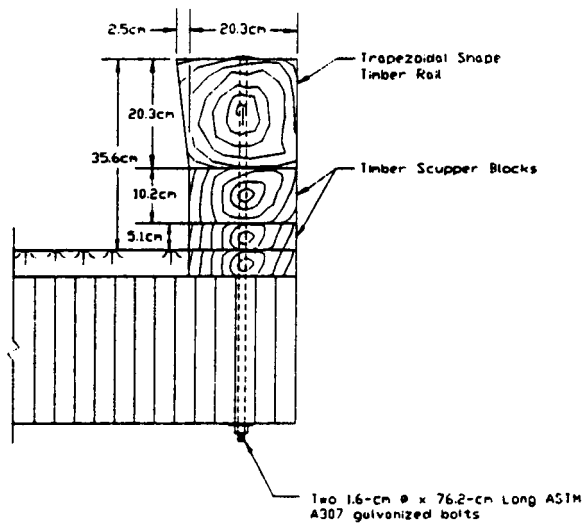


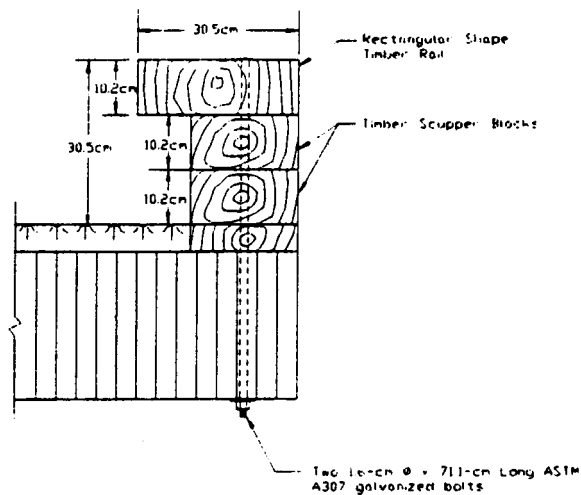
FIGURE 9 Bridge rail damage, Test LVBR-2, three views.



(a)



(b)



(c)

FIGURE 10 (a) Square-shaped curb, (b) trapezoidal-shaped curb, (c) rectangular-shaped curb.

structure Research, University of Nebraska-Lincoln, Lincoln, for matching support.

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