DEVELOPMENT OF LOW-VOLUME CURB-TYPE BRIDGE RAILINGS FOR TIMBER BRIDGE DECKS

by

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ABSTRACT

Three low-height, curb-type timber bridge railings, 12-in. high square and rectangular curbs and a 14-in. high trapezoidal curb, were developed for longitudinal timber bridge decks located on very low-volume roads. The crash test program included 34 developmental tests and four full-scale vehicle crash tests. All curb rails successfully redirected a 3/4-ton pickup truck impacting at a speed of 15 mph and an angle of 15 degrees. The safety performance of all three curb-type bridge railings was acceptable according to the general evaluation criteria for longitudinal barriers described in the National Cooperative Highway Research Report No. 350, *Recommended Procedures for the Safety Performance Evaluation of Highway Features*.

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1 INTRODUCTION

1.1 Problem Statement

Historically, bridge railing systems have been developed for use on high-speed, heavily-traveled highways. However, many U.S. Forest Service and National Forest utility and service roads are designed to carry extremely low traffic volumes at operating speeds of 15 mph or less. These roads are very narrow and generally incorporate one-lane, timber bridges. As a result of the narrow roadways and low operating speeds, bridge rails designed for high-speed facilities are inappropriate for these highways. In recognition of the need for bridge railings designed for the extremely low service levels found on some service and utility roads, the United States Department of Agriculture (USDA) Forest Service, Forest Products Laboratory (FPL) in cooperation with the Midwest Roadside Safety Facility (MwRSF) undertook the task of developing low-cost, low-service bridge railings.

1.2 Objective

The primary objective of this research project was to develop a low-cost, low performance bridge railing system applicable for use on longitudinal glulam timber bridge decks. Longitudinal glulam timber decks were selected for use in development of the low performance bridge railings because it is the weakest type of timber deck now in wide use. Thus, any new bridge railing designs could be easily adapted to other, stronger timber deck systems. Impact performance requirements for the new bridge railings were selected by the FPL in consultation with USDA Forest Service and FHWA engineers. The new bridge railings were designed to withstand 3/4-ton pickup trucks impacting at a speed of 15 mph and an angle of 15 degrees.

Curb railing systems were chosen as the basic design for the new railing systems.

Although curb barriers generally offer very limited performance capability, these railing systems can be constructed at a much lower cost than other types of barriers. Thus, if a curb system can be developed to meet the necessary performance standards, it would provide the lowest possible cost.

2 EVALUATION CRITERIA

2.1 Background

Currently, bridge railings must satisfy the requirements provided in the American Association of State Highway and Transportation Official's (AASHTO's) *Guide Specifications for Bridge Railings* (1) in order to be accepted for use on new construction projects. More specifically, bridge railings must be designed according to the appropriate performance level of the roadway, based upon a number of factors including 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.

More recently, the National Cooperative Highway Research Program (NCHRP) Report No. 350, *Recommended Procedures for the Safety Performance Evaluation of Highway Features* (2), provided six test levels for evaluating longitudinal barriers (Table 2). Selection of the appropriate test level at any site includes consideration of factors such as traffic conditions, site conditions, traffic volume and mix, and the cost-effectiveness of candidate safety alternatives. In general, safety hardware developed to meet the lower test levels are intended for use on lower service level roadways and certain types of work zones while higher test level hardware is intended for use on higher service level roadways. The lowest test level, level 1, is intended for applications on low-volume, low-speed facilities such as residential streets. However, operating speeds on these facilities are typically in the 30 mph range or approximately twice as high as operating speeds on Forest Service utility roads. Thus, test impact conditions from level 1 were deemed to be too severe for the bridge railing applications addressed herein.

Table 1. AASHTO Crash Test Conditions for Bridge Railings (1)

Performance Level	Impact Conditions			
	Small Car (1,800 lbs)	Pickup Truck (5,400 lbs)	Medium Single-Unit Truck (18,000 lbs)	Van-Type Tractor-Trailer (50,000 lbs)
1	50 mph and 20 degrees	45 mph and 20 degrees		
2	60 mph and 20 degrees	60 mph and 20 degrees	50 mph and 15 degrees	
3	60 mph and 20 degrees	60 mph and 20 degrees		50 mph and 15 degrees

Table 2. NCHRP 350 Crash Test Conditions for Longitudinal Barriers (2)

Test Level	Impact Conditions				
	Small Car (1,808 lbs)	Pickup Truck (4,409 lbs)	Single-Unit Van Truck (17,637 lbs)	Tractor/Van Trailer (79,366 lbs)	Tractor/Tank Trailer (79,366 lbs)
1	31.1 mph & 20 deg	31.1 mph & 25 deg			
2	43.5 mph & 20 deg	43.5 mph & 25 deg			
3 (Basic Level)	62.1 mph & 20 deg	62.1 mph & 25 deg			
4	62.1 mph & 20 deg	62.1 mph & 25 deg	49.7 mph & 15 deg		
5	62.1 mph & 20 deg	62.1 mph & 25 deg		49.7 mph & 15 deg	
6	62.1 mph & 20 deg	62.1 mph & 25 deg			49.7 mph & 15 deg

2.2 Crash Test Conditions

Design impact conditions were selected by the USDA Forest Service, Forest Products Laboratory (FPL) in consultation with Forest Service and FHWA engineers. Reasonable design impact conditions for bridge railings on narrow, low-volume, utility roads were estimated to involve a 3/4-ton pickup truck impacting at a speed of 15 mph and an angle of 15 degrees. The full-scale vehicle crash tests were conducted and reported in accordance with the procedures provided in NCHRP 350 (2).

3 CURB SYSTEM DEVELOPMENT

3.1 Dynamic Lateral Impact Force

The design of the low-volume curb-type bridge railing required an estimate of the dynamic lateral impact force applied to the railing. Two common methods were used: (1) an approximate method to predict the lateral impact force using a mathematical model taken from NCHRP Report No. 86 (3) and the 1977 AASHTO Barrier Guide (4), and (2) an approximate method using impulse - momentum and the coefficient of restitution.

The first method or mathematical model (3,4) is represented by Equations 1 and 2:

$$F_{\text{lat. ave.}} = \frac{W\ V_I^2\ \sin^2\theta}{2g\,[A\,L \sin\theta - B\,(1 - \cos\theta) + D]} \qquad \textbf{(1)}$$

and

$$F_{\text{lat. peak}} = F_{\text{lat. ave}}\ \text{x}\ DF \qquad \textbf{(2)}$$

where $F_{\text{lat. ave.}}$ = average lateral impact force (lbs)
$F_{\text{lat. peak}}$ = peak lateral impact force (lbs)
W = vehicle weight (4,500 lbs)
V_I = impact velocity (22.0 ft/sec)
θ = impact angle (15 degrees)
g = acceleration due to gravity (32.2 ft/sec^2)
AL = distance from vehicle's front end to center of mass (8.66 ft)
$2B$ = vehicle width (6.5 ft)
D = lateral displacement of railing (assumed 0 ft)
DF = dynamic factor ($\pi/2$ to 2)

The equations above estimate the average and peak forces that are applied to the vehicle from the point of initial impact until the vehicle becomes parallel to the barrier. An estimate of the duration of this phase of impact, Δt, is expressed by Equation 3 (3).

$$\Delta t = \frac{[A\,L \sin\theta - B\,(1 - \cos\theta) + D]}{\frac{1}{2} V_I \sin\theta} \qquad \textbf{(3)}$$

For a 4,500-lb pickup impacting a bridge railing at a speed of 15 mph and an angle of 15 degrees, $F_{lat.\ ave}$ can be shown to be 1,063 lbs and $F_{lat.\ peak}$ ranges from 1,670 lbs to 2,126 lbs. Equation 3 predicts that the vehicle will become parallel to the barrier approximately 0.75 sec after initial impact. The vehicle would be expected to move approximately 16.0 ft down the rail during this time.

Impulse - momentum and the coefficient of restitution can also be used to estimate the lateral impact force. The coefficient of restitution, e, is the ratio between the pre and post impact velocities as shown in Equation 4. The coefficient of restitution is a measure of the amount of energy absorbed by vehicle and barrier deformations. Higher values indicate less energy absorption and higher impulses imparted to the vehicle. Since the coefficient of restitution cannot be greater than 1, this value gives an upper bound on the impulse imparted on the vehicle and hence will yield a measure of the maximum force that can be applied to the barrier.

$$e = \frac{V_{B2} - V_{A2}}{V_{A1} - V_{B1}} = \frac{|\text{relative velocity of separation}|}{|\text{relative velocity of approach}|} \qquad \textbf{(4)}$$

where
V_{A1} = velocity of auto before impact (ft/sec)
V_{A2} = velocity of auto after impact (ft/sec)
V_{B1} = velocity of barrier before impact (ft/sec)
V_{B2} = velocity of barrier after impact (ft/sec)

The impulse, or change in momentum during the impact is estimated using equations 5 through 7 shown below.

$$I = \int_{t_1}^{t_2} F\,dt = M_F - M_I \quad \textbf{(5)}$$

$$M_I = m_A V_{A1} + m_B V_{B1} \quad \textbf{(6)}$$

$$M_F = m_A V_{A2} + m_B V_{B2} \quad \textbf{(7)}$$

where I = total impulse
F = impact force function (lbs)
t_1 = initial time of impact (sec)
t_2 = final time of impact (sec)
M_I = momentum of objects before impact (lb-sec)
M_F = momentum of objects after impact (lb-sec)
m_A = mass of vehicle (lb-sec^2/ft)
m_B = mass of barrier (lb-sec^2/ft)

For an oblique impact between a vehicle and a rigid longitudinal barrier (i.e., mass of barrier infinitely large and velocity of barrier always zero, as shown in Figure 1), Equation 4 can be simplified to:

$$e = \frac{-V_{A2}}{V_{A1}} \quad \textbf{(8)}$$

For an impact at 15 mph and 15 degrees, V_{A1} is as follows:

$$V_{A1} = 22\text{fps}\ (\sin 15^\circ\,\hat{i} + \cos 15^\circ\,\hat{j}) = 5.7\text{fps}\ \hat{i} + 21.3\text{fps}\ \hat{j} \quad \textbf{(9)}$$

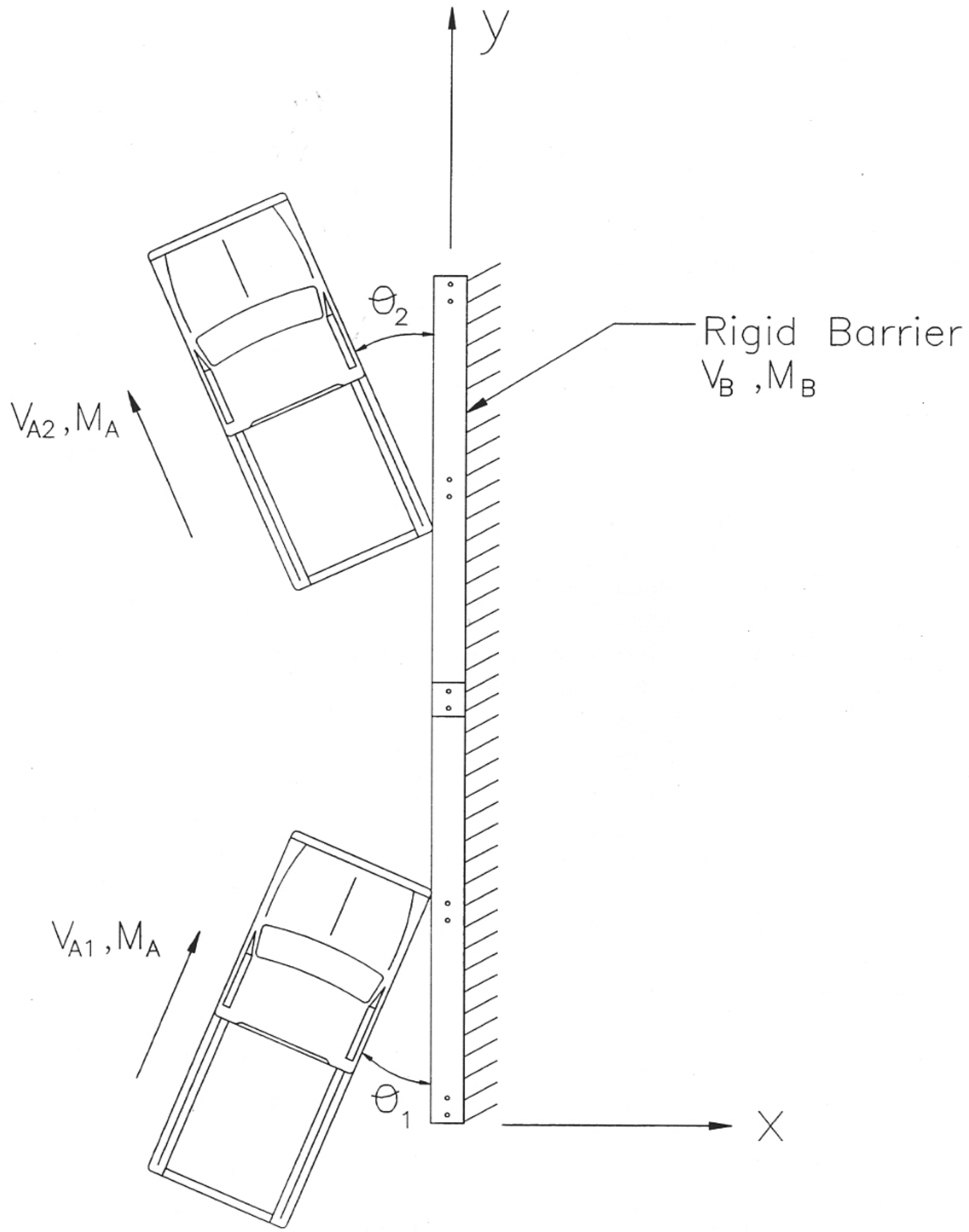


Figure 1. Impact Schematic

Using the coefficient of restitution, e=1.0, conservation of momentum in the x-direction, and the x-component of V_{A1} in Equation 9, the x-component of V_{A2} can be found as follows:

$$V_{A2_x} = -5.7\text{fps} \qquad \textbf{(10)}$$

The momentum in the x-direction before and after impact is shown by Equations 11 and 12.

$$M_{I_x} = m_A V_{A1_x} \qquad \textbf{(11)}$$

$$M_{F_x} = m_A V_{A2_x} \qquad \textbf{(12)}$$

Using Equations 11 and 12 with a 4,500-lb vehicle and substituting into Equation 5, the impulse imparted to the vehicle during impact becomes:

$$\int_{t_1}^{t_2} F_x\,dt = M_{F_x} - M_{I_x} = \left(\frac{4{,}500\text{lbs}}{32.2\text{ft/sec}^2}\right) \text{x } (-5.7\text{fps} - 5.7\text{fps}) \qquad \textbf{(13)}$$

$$\int_{t_1}^{t_2} F_x\,dt = -1{,}593 \text{ lbs} - \text{sec}$$

Assuming a single, symmetrical saw-tooth forcing function, as shown in Figure 2, the impulse is equal to the area under the triangle or $\frac{1}{2}(2\Delta t)F_{\text{lat. peak}}$. If the time from impact until the vehicle becomes parallel to the bridge railing is 0.75 sec, as estimated previously, the peak lateral impact force is estimated to be 2,124 lbs. Thus both procedures predict that the peak lateral impact force should be approximately 2,125 lbs.

3.2 Design Considerations

Timber was selected for use in the low service level bridge railing designs based on

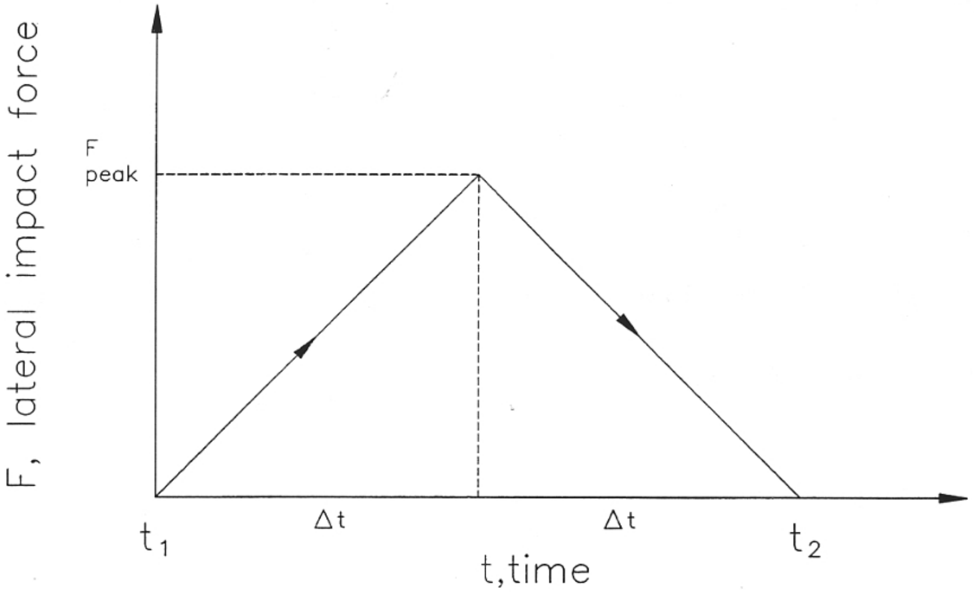


Figure 2. Saw-Tooth Forcing Function

aesthetic and material availability considerations. Further, curb railings were identified as the lowest cost and 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 utilized for the new bridge rails.

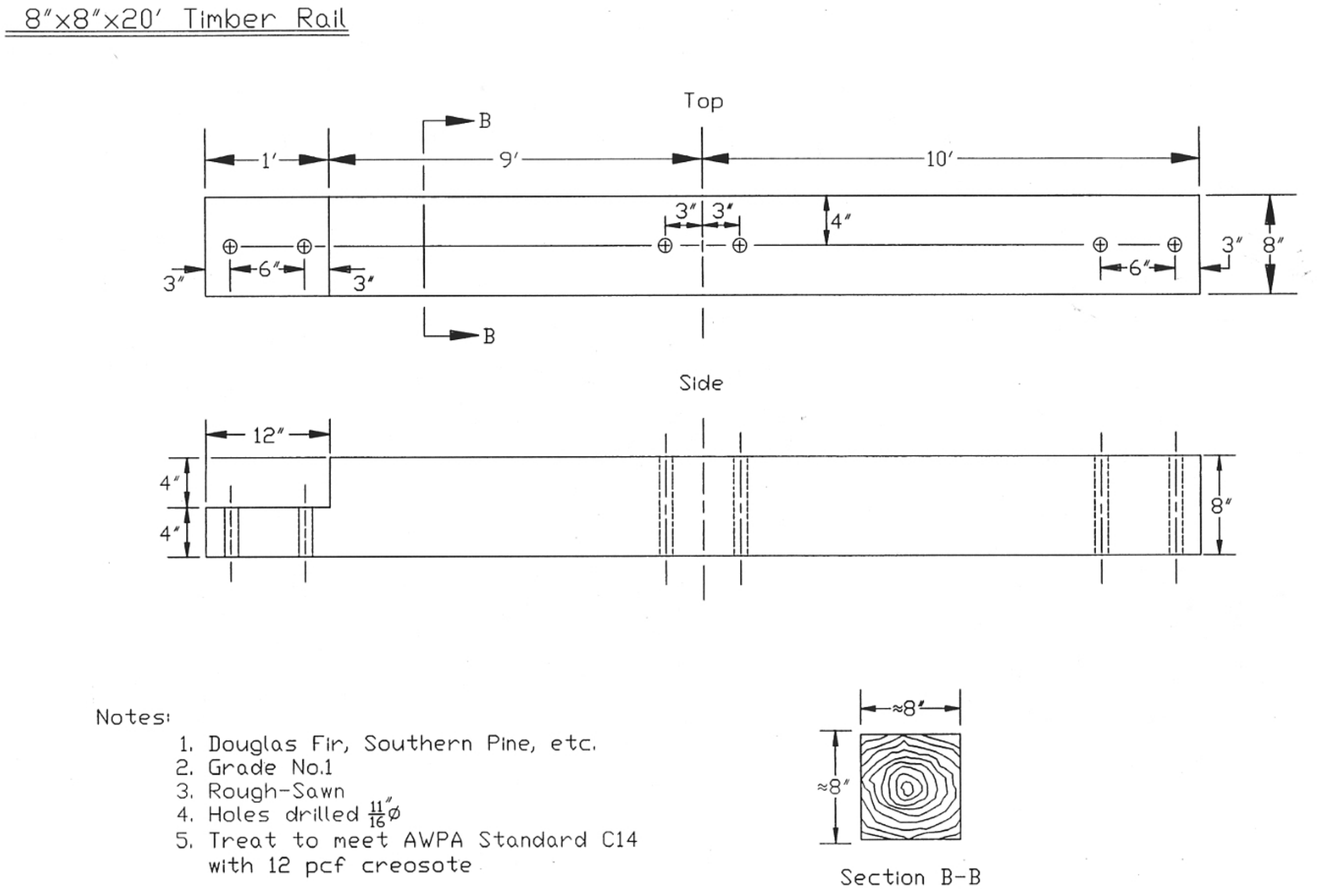
Analysis of vehicular impacts with concrete and timber curbs revealed that the shape of the side of the curb could have an important effect on the redirective capacity of curb systems. A number of different curb shape configurations were therefore included in the design process. Each curb configuration was evaluated at several different heights in order to determine the minimum height required to meet the selected performance criteria. Based on full-scale vehicle crash tests of 20-in high curb systems (5) and a limited study of impacts with shorter curbs (unpublished research) using HVOSM computer simulation modeling (6), the researchers estimated that 14-in. high curbs would be capable of meeting the desired performance standard and that curbs shorter than 8-in. would not.

As described previously, peak lateral forces imparted to the curb railing were estimated to be relatively low. 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. Curb railings were therefore designed to withstand design impact conditions under a static load. Each railing was analyzed as a simply-supported beam with pin connections at each end. Three rail shapes and sizes were selected for a preliminary evaluation including - an 8-in. x 8-in. square, an 8-in. x 9-in. trapezoid with a negative slope on traffic-side face, and a 4-in. x 12-in. rectangle. A developmental testing program was then undertaken to evaluate the safety performance and height requirements for each of these curb shapes.

4 DESIGN DETAILS

The three timber rail shapes selected for preliminary evaluation are shown in Figures 3 through 5. The basic curb design incorporated 20-ft long rail sections mounted on scupper blocks. Attachment between the rail elements, scupper blocks, and bridge deck was provided with two 5/8-in. diameter ASTM A307 galvanized bolts placed 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 developmental testing was conducted on 39-ft long curbs constructed from two 20-ft long rail sections and a 1-ft long lap splice, as shown in Figure 6. Two sizes of timber scupper blocks, as shown in Figure 7, were used to mount the curb rail elements to the timber deck. The curb rail sections and scupper blocks were constructed from No. 1 Grade, Douglas Fir using rough-sawn and S1S specifications, respectively. Timber curb rail and scupper materials were treated to meet AWPA Standard C14 with 12 pcf creosote (7). Schematics of both a typical curb rail section mounted to the deck surface and a curb railing splice are shown in Figures 8 and 9, respectively.

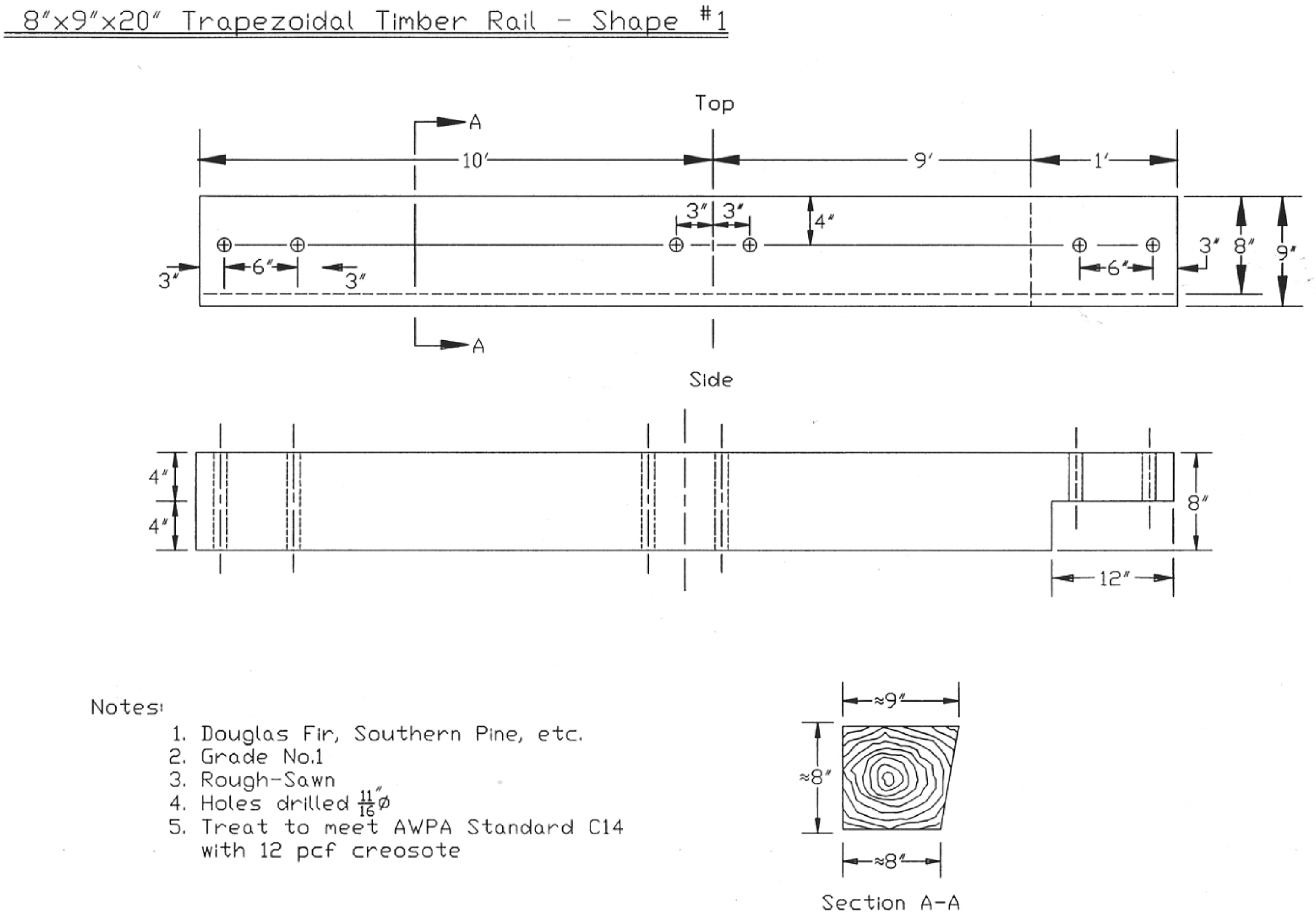
The curb railings were attached to a longitudinal glulam timber deck supported by concrete abutments. The concrete abutments and the longitudinal glulam timber deck were the same as that used in the development of the AASHTO PL-1 and PL-2 railing systems (8,9,10). In addition, a 2-in. asphalt surface was placed on the top of the timber deck in order to represent actual field conditions.



Notes:

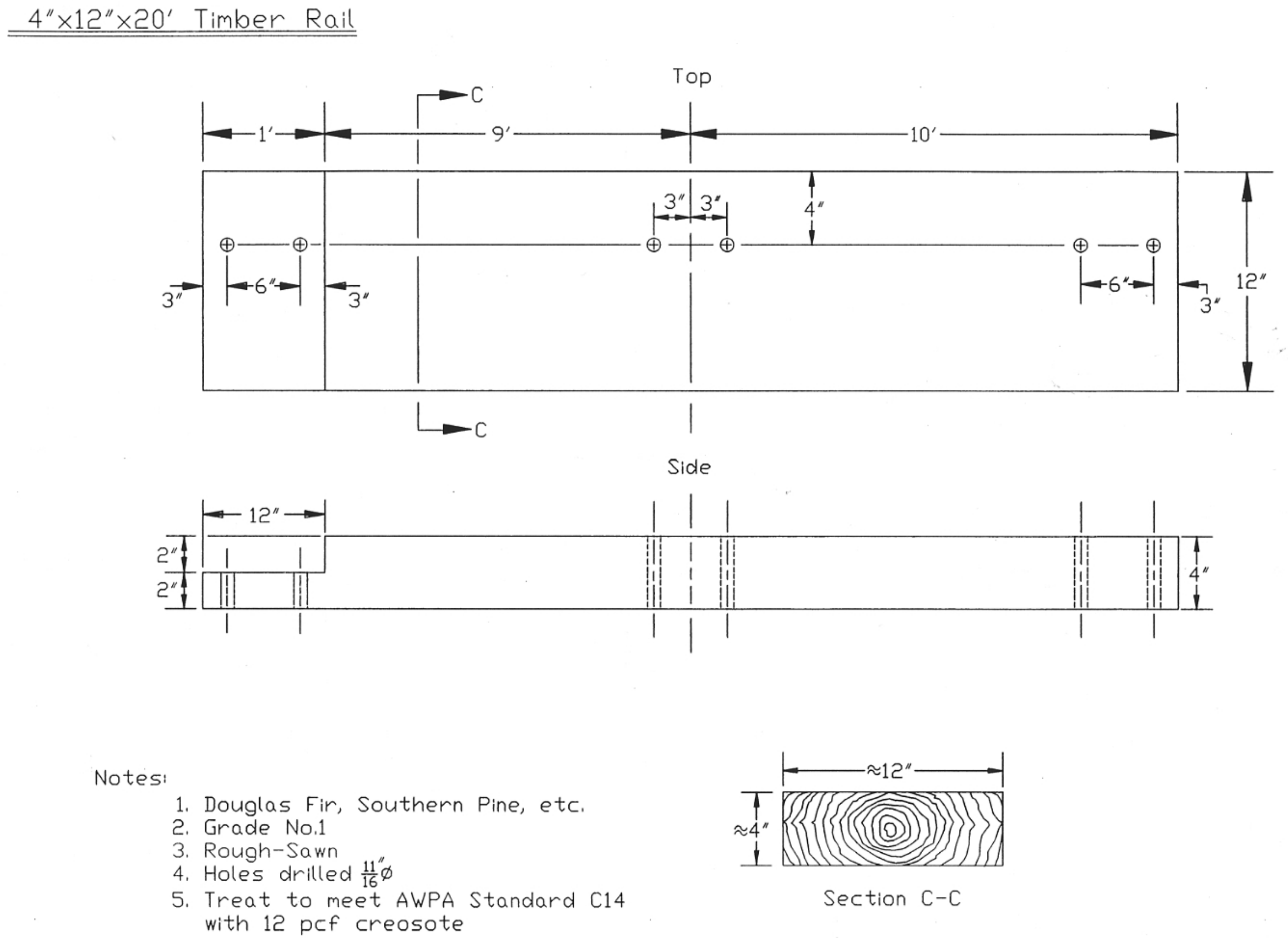
1. Douglas Fir, Southern Pine, etc.
2. Grade No.1
3. Rough-Sawn
4. Holes drilled $\frac{11}{16}''\varnothing$
5. Treat to meet AWPA Standard C14 with 12 pcf creosote

Figure 3. Schematic of Square-Shaped Curb Rail



Notes:
1. Douglas Fir, Southern Pine, etc.
2. Grade No.1
3. Rough-Sawn
4. Holes drilled $\frac{11}{16}$"ø
5. Treat to meet AWPA Standard C14 with 12 pcf creosote

Figure 4. Schematic of Trapezoidal-Shaped Curb Rail



Notes:

1. Douglas Fir, Southern Pine, etc.
2. Grade No.1
3. Rough-Sawn
4. Holes drilled $\frac{11}{16}"\phi$
5. Treat to meet AWPA Standard C14 with 12 pcf creosote

Figure 5. Schematic of Rectangular-Shaped Curb Rail

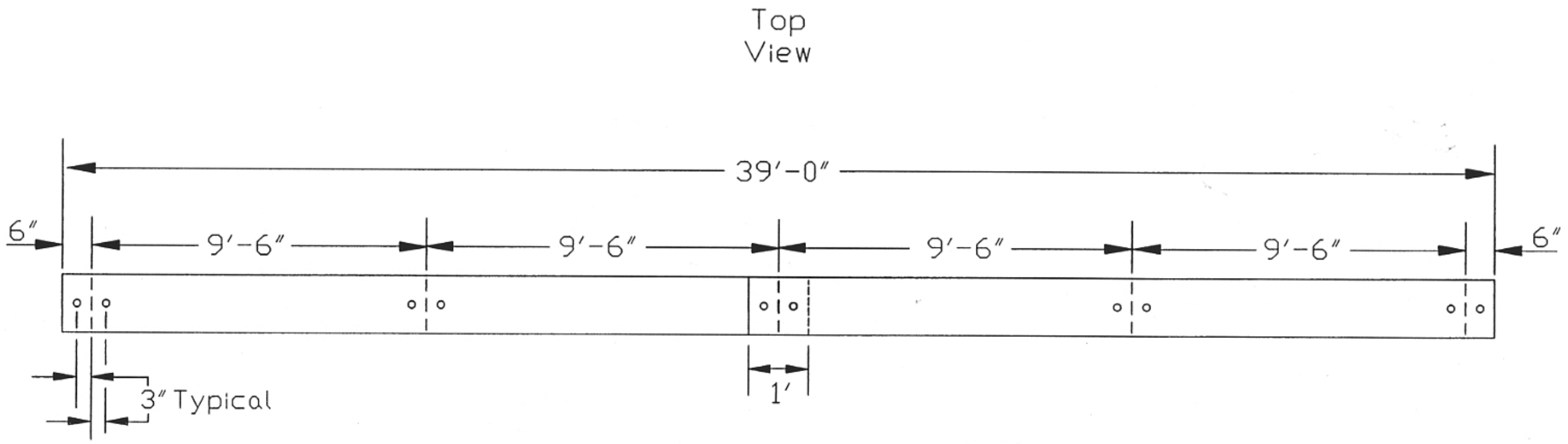
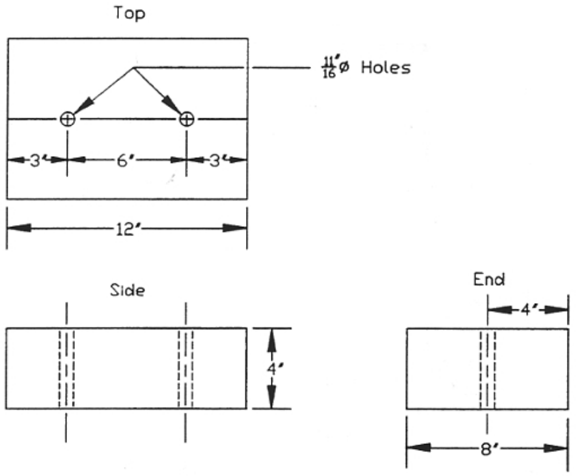


Figure 6. Rail Layout and Attachment Spacing

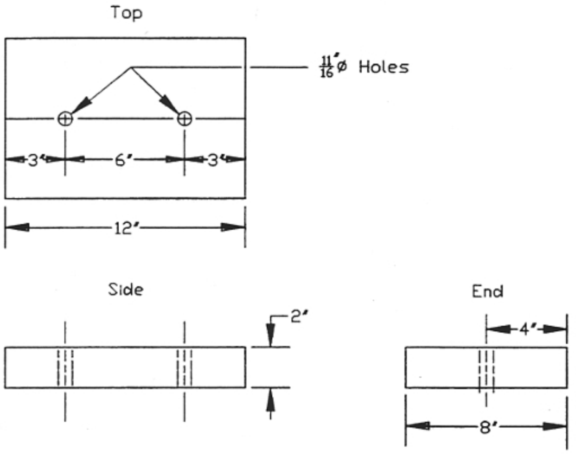
4″x8″ Scupper Block



Notes:

1. Douglas Fir, Southern Pine, etc.
2. Grade No.1
3. S1S 4'
4. Treat to meet AWPA Standard C14 with 12pcf creosote

2″x8″ Scupper Block



Notes:

1. Douglas Fir, Southern Pine, etc.
2. Grade No.1
3. S1S 2'
4. Treat to meet AWPA Standard c14 with 12 pcf creosote

Figure 7. Timber Scupper Block Details

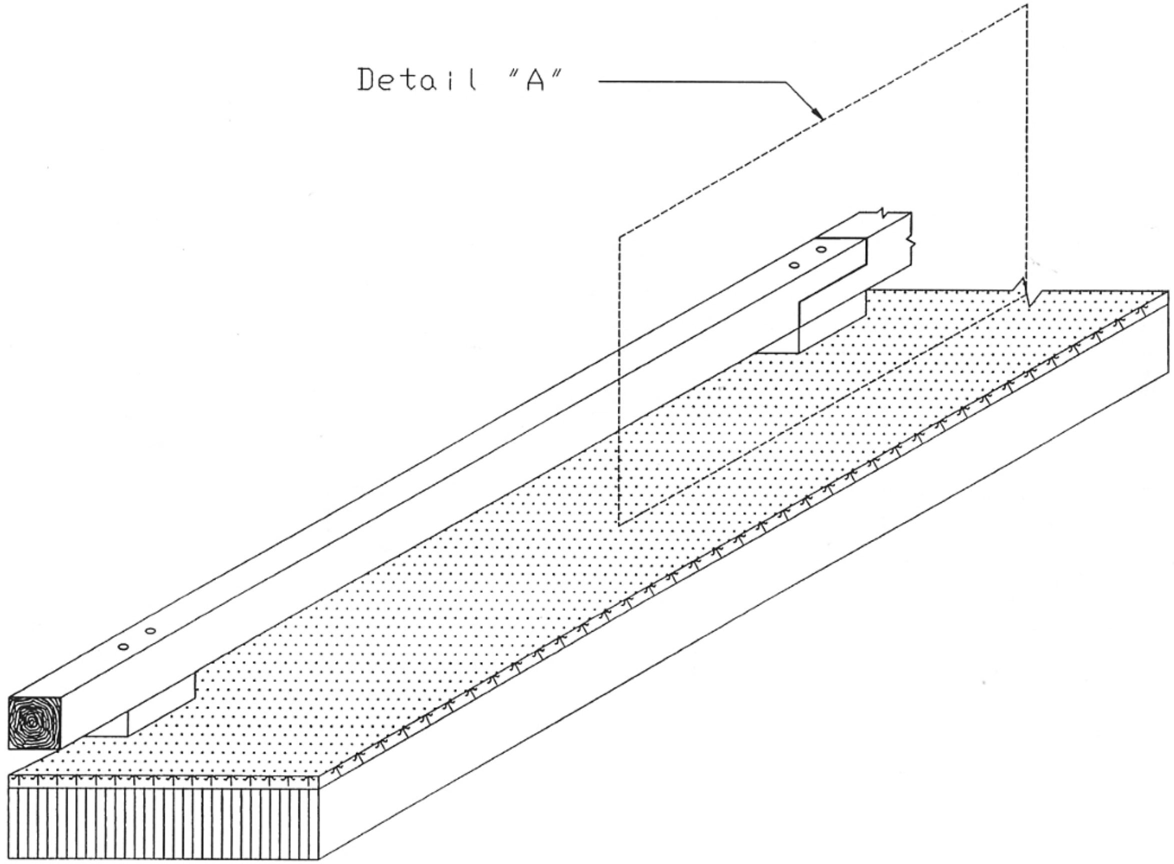


Figure 8. Typical Curb Section Mounted to Deck Surface

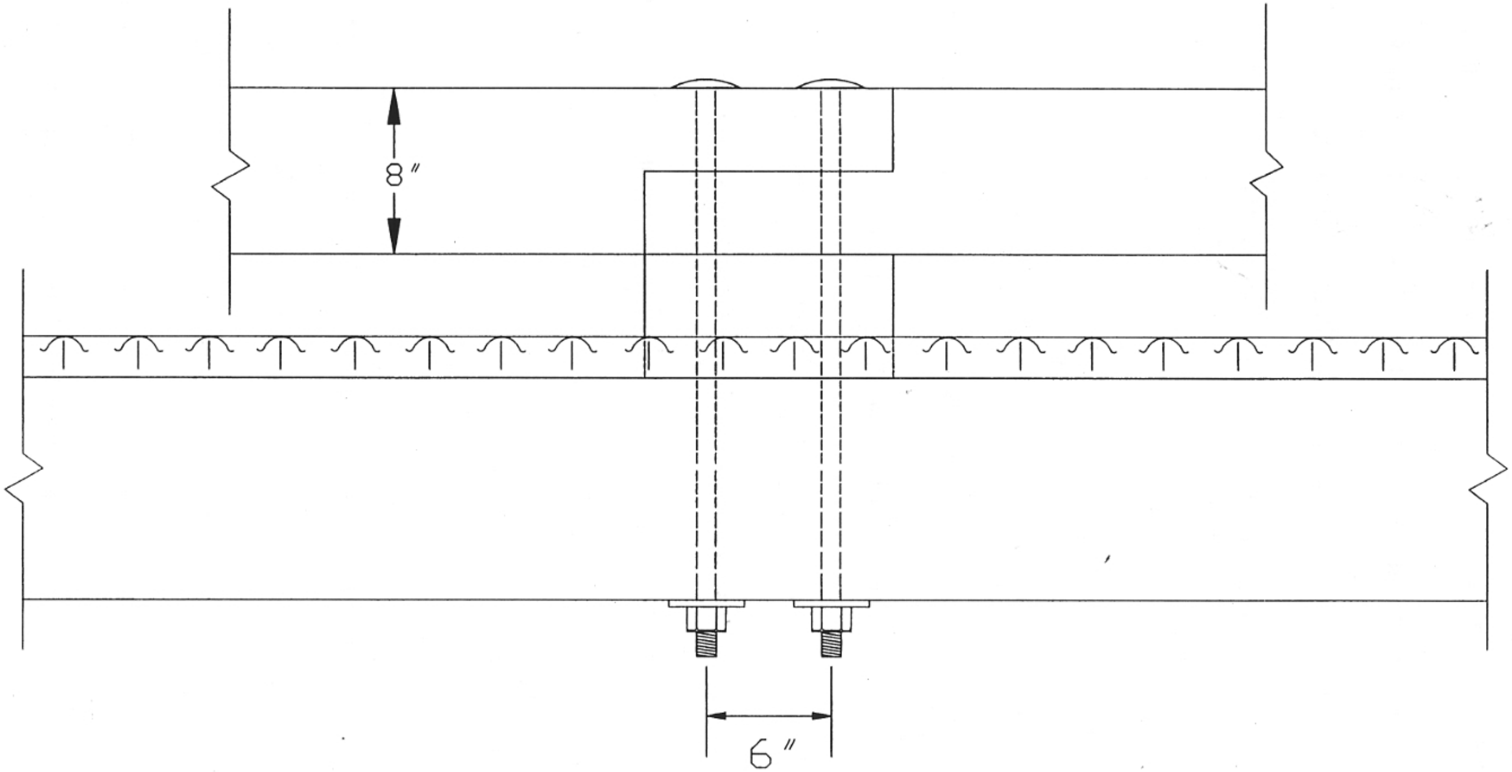


Figure 9. Detail A - Typical Curb Railing Splice

5 TEST CONDITIONS

5.1 Test Vehicle

A 1985 Ford F-250 3/4-ton pickup truck was used as the test vehicle. The test inertial weight and gross static weight of this vehicle was 4,406 lbs. Figure 10 shows a photo of the test vehicle, and its dimensions are shown in Figure 11. Steel plates were used to ballast the pickup up to the desired weight. The longitudinal position of the ballasted vehicle's center of gravity was determined using the measured axle weights.

Three 12-in. square, black and white targets were placed on the vehicle, as shown in Figure 10, to aid in the analysis of the high-speed film. One target was placed on the center of gravity on the driver's side of the vehicle and the remaining targets were located for reference so that they could be viewed from the perpendicular high-speed camera.

The front wheels of the test vehicle were aligned for camber, caster, and toe-in values of zero to reduce vehicle guidance problems. Two 5B flash bulbs were mounted on the hood of the vehicle and fired by a tape switch located on the vehicle's front bumper to pinpoint the time of impact with the bridge rail on the high-speed film.

5.2 Data Acquisition Systems

5.2.1 Accelerometers

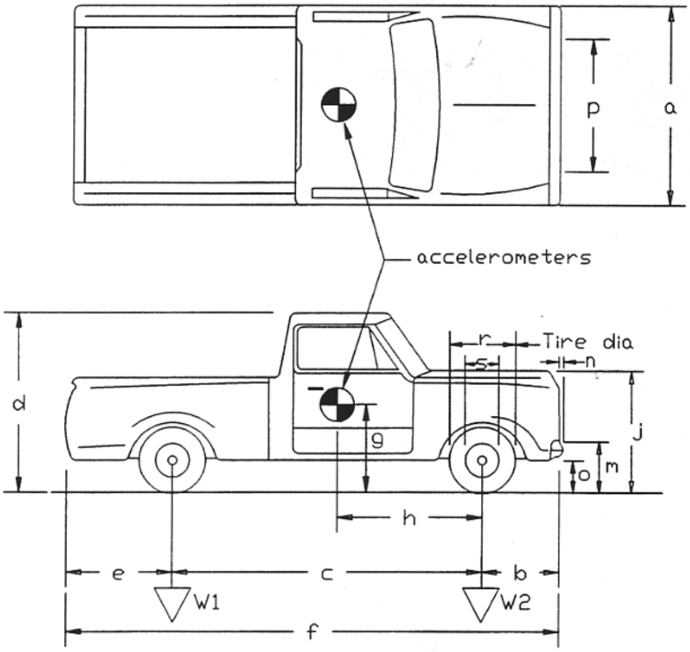
Endevco Model 7264 piezoresistive accelerometer systems with a range of ±200 g's were used to measure the acceleration in the longitudinal, lateral, and vertical directions. Two accelerometers were mounted in each of the three directions and were rigidly attached to a metal block mounted at the center of gravity. Accelerometer signals were received and conditioned by an onboard Series 300 Multiplexed FM Data System built by Metraplex Corporation. The

Figure 10. Crash Test Vehicle, Test LVCS-4

Date: 4/23/93 Test No.: LVCS-4 and LVCT-(1a-1c) Vehicle I.D. #: 1FTHF25Y63

Tire Size: 235/85R15 Odometer: 109320

Model: F-250 3/4 ton (custom) Year: 1985 Make: Ford



Vehicle Geometry - inches

a	75	b	29
c	133	d	72.5
e	50.75	f	212.75
g		h	
i		j	49.5
k		l	
m	27.5	n	3.0
o	19.25	p	front 65.75 / rear 64.5
r	31	s	17.5

Engine Type: 6 cyl.

Engine Size: 300 cu. in.

4 - wheel weight: lf____ rf____ lr____ rr____

Transmission Type:

Automatic or [✓ Manual]

FWD or [✓ RWD] or 4WD

Weight - pounds	Curb	Test Inertial	Gross Static
W1	1840	1973	1973
W2	2260	2433	2433
Wtotal	4100	4406	4406

Note any damage prior to test: none

Figure 11. Vehicle Dimensions, Test LVCS-4

multiplexed signal was then transmitted to the Honeywell 101 Analog Tape Recorder. Computer software, "EGAA" and "DSP" were used to digitize, analyze, and plot the accelerometer data.

5.2.2 Rate Transducer

A Humphrey 3-axis rate transducer with a range of 250 deg/sec in each of the three directions (pitch, roll, and yaw) was used to measure the rates of motion of the test vehicle. The rate transducer was rigidly attached to the vehicle near the center of gravity of the test vehicle. Rate transducer signals were received and conditioned by an onboard Series 300 Multiplexed FM Data System built by Metraplex Corporation. The multiplexed signal was then transmitted by radio telemetry to a Honeywell 101 Analog Tape Recorder. Computer software, "EGAA" and "DSP" were used to digitize, analyze, and plot the rate transducer data.

5.2.3 High-Speed Photography

For test LVCS-4, three high-speed 16-mm cameras, with operating speeds of approximately 500 frames/sec, were used to film the crash test. A Photec IV, with an 80-mm lens, and a Red Lake Locam, with a 76-mm lens, were placed downstream from the impact point and had a field of view parallel to the bridge rail. A second Locam with a 25-mm lens, was placed on the traffic side of the bridge rail and had a field of view perpendicular to the bridge rail. A schematic of all three camera locations is shown in Figure 12. In addition, a Bolex camera, with an operating speed of approximately 64 frames/sec, was used as a documentary camera. The film was analyzed using a Vanguard Motion Analyzer. Actual camera speeds and camera divergence factors were considered in the analysis of the high-speed film.

5.2.4 Speed Trap Switches

Four pressure-activated tape switches spaced at 5-ft intervals were used to determine the

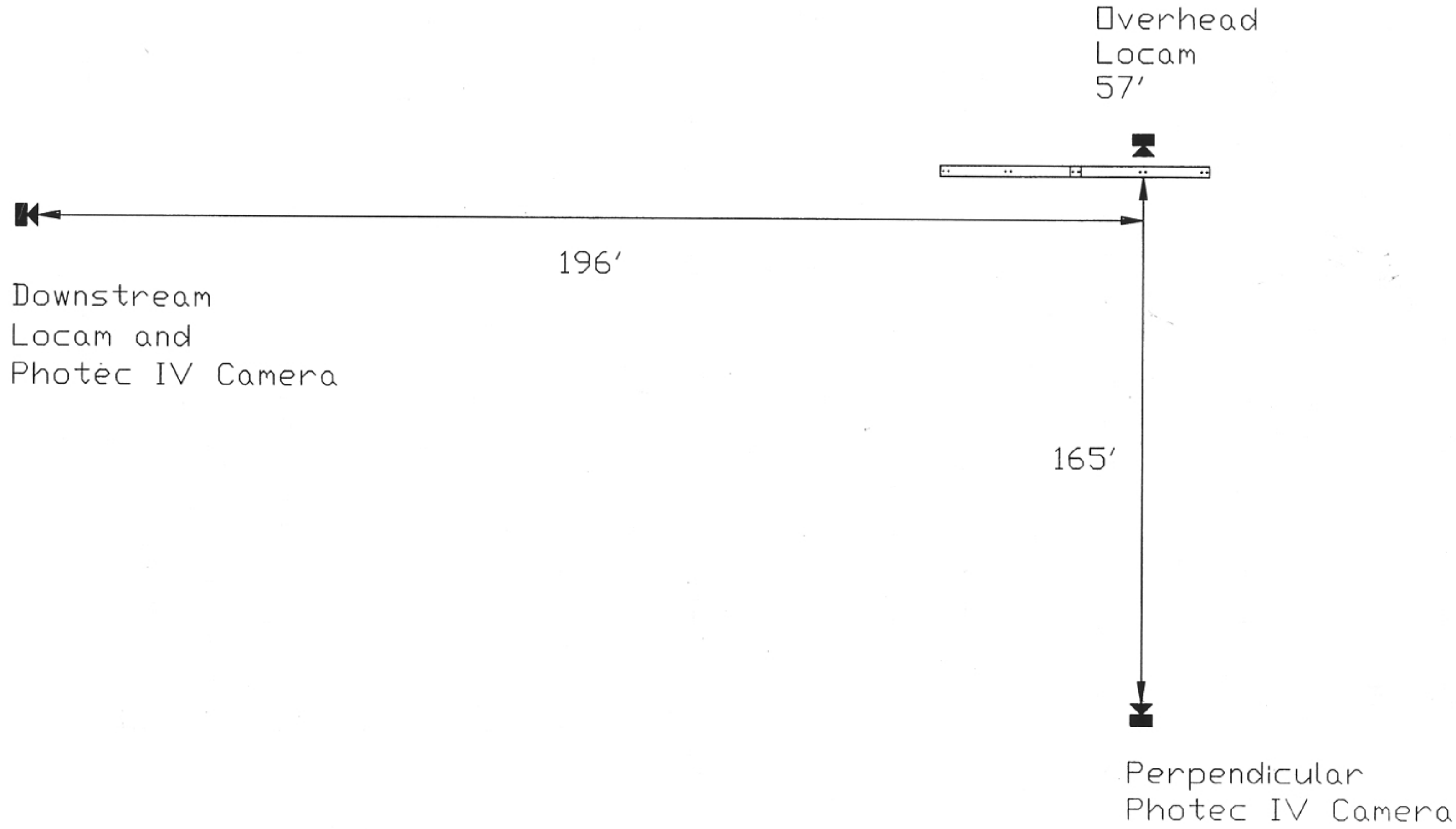


Figure 12. High-Speed Camera Locations, Test LVCS-4

speed of the vehicle before impact. As the vehicle's left-front tire rolled over each tape switch, a strobe light fired and sent an electronic timing signal to the data acquisition system. Test vehicle speeds were determined from electronic timing mark data recorded on "EGAA" software. Strobe lights and high-speed film analysis are used only as a backup in the event that vehicle speeds cannot be determined from the electronic data.

6 DEVELOPMENTAL TESTING - PHASE I

Developmental testing was used to determine critical heights for the three different curb shapes. As previously mentioned, three rail shapes and sizes were selected for a preliminary evaluation, an 8-in. x 8-in. square rail, an 8-in. x 9-in. trapezoidal rail, and a 4-in. x 12-in. rectangular rail. The curb shapes were rigidly attached to the existing concrete apron with two 5/8-in. diameter ASTM A307 bolts spaced on 9-ft 6-in. centers (Figure 13). The curb rails were mounted at 8, 10, and 12 in. Timber scupper blocks were placed below the rail in order to attain the derived rail height.

A 3/4-ton pickup truck was driven into the rails and impacted at speeds of 15 and 20 mph and at an angle of 15 degrees. Weather conditions for the two days of testing were recorded. Between 8:00 a.m. and 6:00 p.m. on 3/11/93, the minimum and maximum air temperatures were 22.0°F and 33.0°F, respectively. Between 8:00 a.m. and 6:00 p.m. on 3/12/93, the minimum and maximum air temperatures were 24.8°F and 29.8°F, respectively.

Impact tests were performed on the three curb shapes mounted at three different heights for a total of nine curb configurations as shown in Figures 14 through 16. Nineteen full-scale crash tests were conducted as summarized in Table 3. For impacts at 15 mph and 15 degrees, a 8-in. mounting height successfully redirected the test vehicle for both the trapezoidal and rectangular shapes with no tendency for vehicle climbing. However, for the same impact conditions, the square shape, with an 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 should be performed on one of the two successful curb shapes for an 8-in. mounting height. The trapezoidal shape, was selected for full-scale vehicle crash testing, because it appeared to provide

Figure 13. Square Curb Rail Attached to Concrete Apron

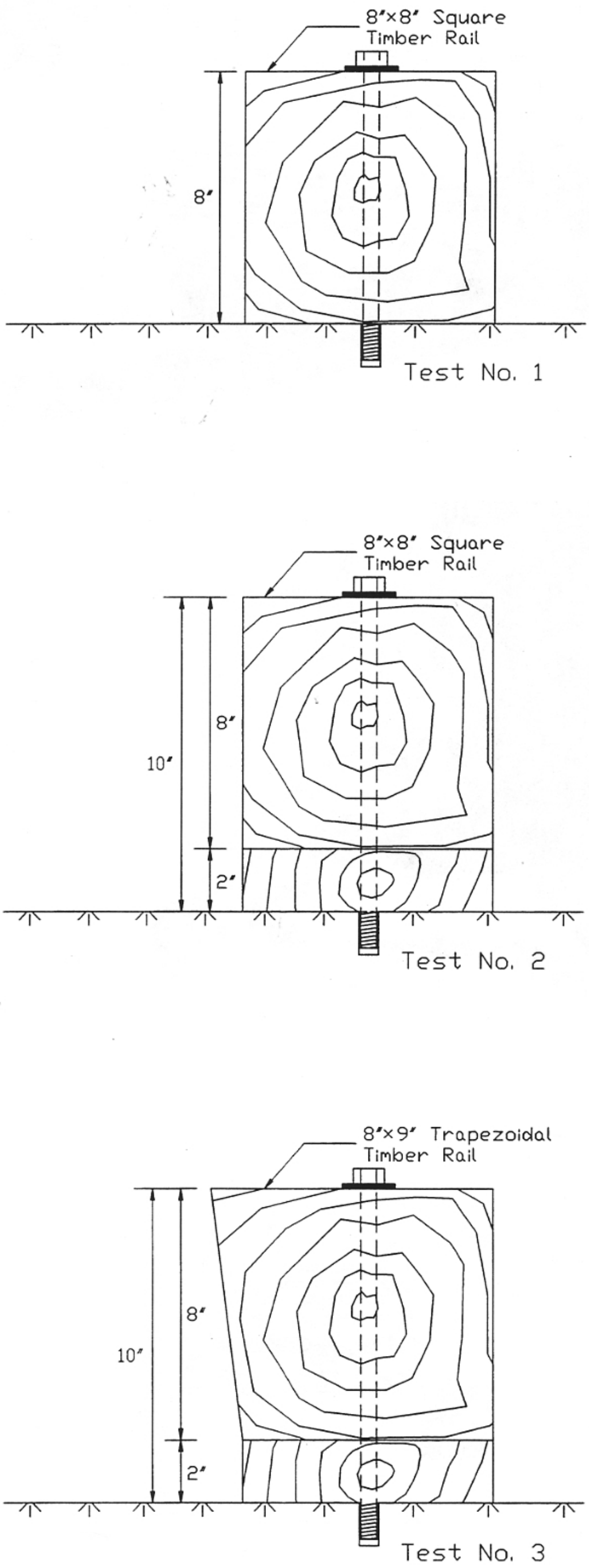
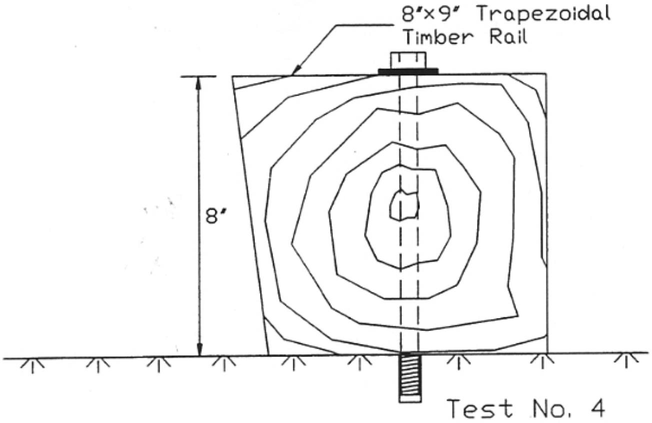
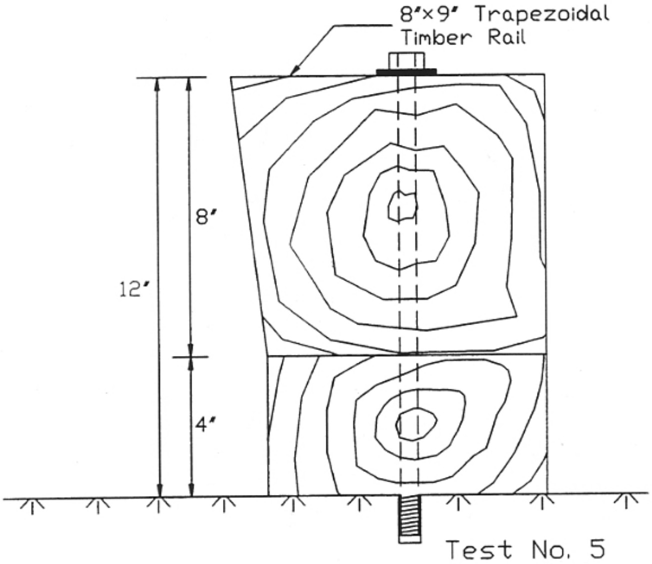


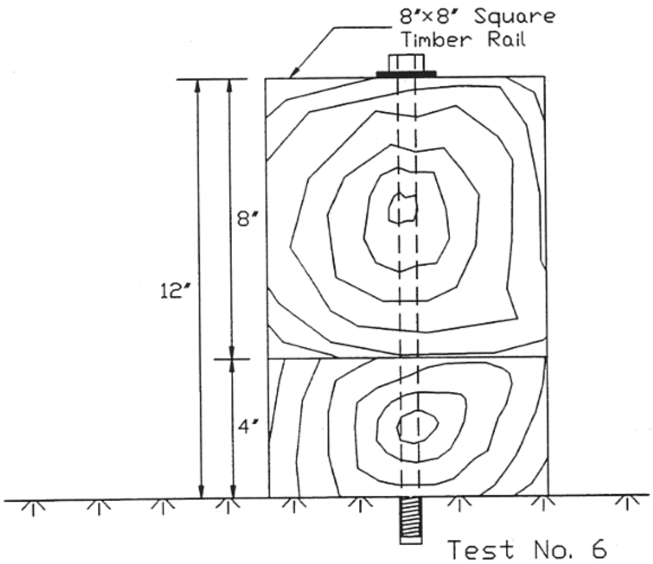
Figure 14. Curb Configurations for Developmental Testing - Phase I



Test No. 4

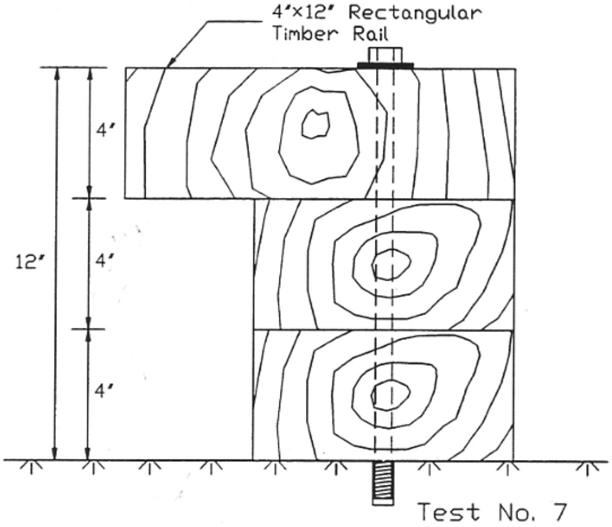


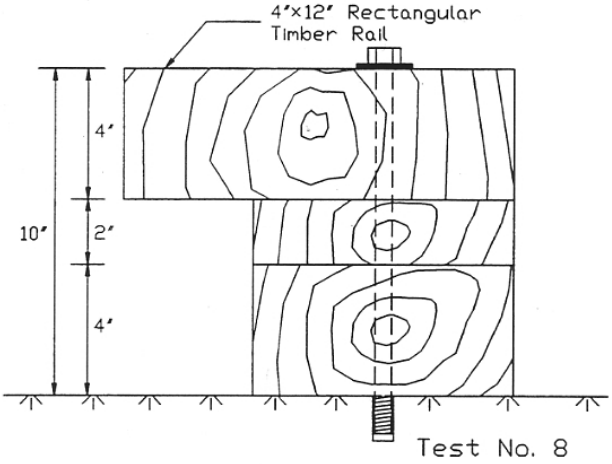
Test No. 5



Test No. 6

Figure 15. Curb Configurations for Developmental Testing - Phase I (con't)





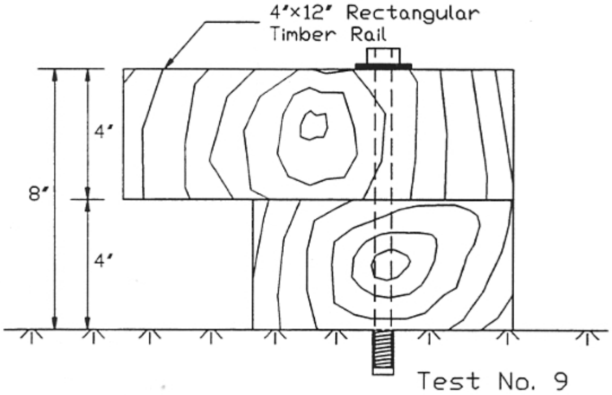


Figure 16. Curb Configurations for Developmental Testing - Phase I (con't)

Table 3. Summary of Developmental Testing - Phase I

Date	Rail Type	Rail Height (in.)	Test No.	Speed (mph)	Results
3/11/93	Square - 8" x 8"	8	1	15	Failed - vehicle over top of curb
3/11/93	Square - 8" x 8"	10	2a	15	Passed - right front tire briefly hopped onto curb
			2b	15	Passed - right front tire popped into air
3/11/93	Trapezoid - 8" x 9"	10	3a	15	Passed - no climbing tendency
			3b	15	Passed - no climbing tendency
			3c	20	Passed - right-front tire popped into air
			3d	20	Passed - right-front tire briefly hopped onto curb
3/11/93	Trapezoid - 8" x 9"	8	4a	15	Passed - no climbing tendency
			4b	15	Passed - no climbing tendency
			4c	20	Failed - vehicle over top of curb
3/12/93	Trapezoid - 8" x 9"	12	5	15	Passed - no climbing tendency
3/12/93	Square - 8" x 8"	12	6a	15	Passed - no climbing tendency
			6b	15	Passed - no climbing tendency
3/12/93	Rectangle - 4" x 12"	12	7a	15	Passed - no climbing tendency
			7b	15	Passed - no climbing tendency
3/12/93	Rectangle - 4" x 12"	10	8a	15	Passed - no climbing tendency
			8b	15	Passed - no climbing tendency
3/12/93	Rectangle - 4" x 12"	8	9a	15	Passed - no climbing tendency
			9b	15	Passed - no climbing tendency

higher redirective capacity than the rectangular shape.

7 FULL-SCALE CRASH TESTING - PHASE I

Originally, only one full-scale crash test was to be conducted on an 8-in. x 9-in. trapezoidal shape curb rail with an 8-in. mounting height. However, due to a failure of this test, two additional tests were conducted on the trapezoidal shape. One additional test was conducted on an 8-in. height and one additional test on a 10-in. height. All three tests were conducted with a 4,406-lb pickup truck impacting at 15 mph and 15 degrees (Figures 10 and 11). The weather conditions during the day of testing were recorded. Between 8:00 a.m. and 6:00 p.m. on 4/23/93, the minimum and maximum air temperatures were 55.5°F and 70.6°F, respectively.

7.1 Test LVCT-1a (8" x 9" Trapezoidal Shape - 8" high)

Test LVCT-1a impacted the curb rail at approximately 11 ft from the upstream end of the 39-ft long installation, as shown in Figures 17 and 18. A schematic of the curb configuration is shown in Figure 19. During impact, the vehicle climbed over the top of the curb. Tire contact marks on the front face of the curb are shown in Figure 20. The vehicle came to rest on top of the curb at the end of the installation, as shown in Figure 21. The results of test LVCT-1a were inconsistent with the previous results from Phase I of the developmental testing program.

7.2 Test LVCT-1b (8" x 9" Trapezoidal Shape - 8" high)

A second test was conducted on the 8-in. high trapezoidal shape curb to verify the observed differences in curb performance. Test LVCT-1b involved a vehicle impacting the curb rail at approximately 11 ft from the upstream end of the 39-ft long installation. The vehicle's tires again climbed over the curb with little or no vehicle redirection.

7.3 Test LVCT-1c (8" x 9" Trapezoidal Shape - 10" high)

Following the two unsuccessful tests on the 8-in. high trapezoidal shape curb, a third test

Figure 17. Impact Location, Test LVCT-1a

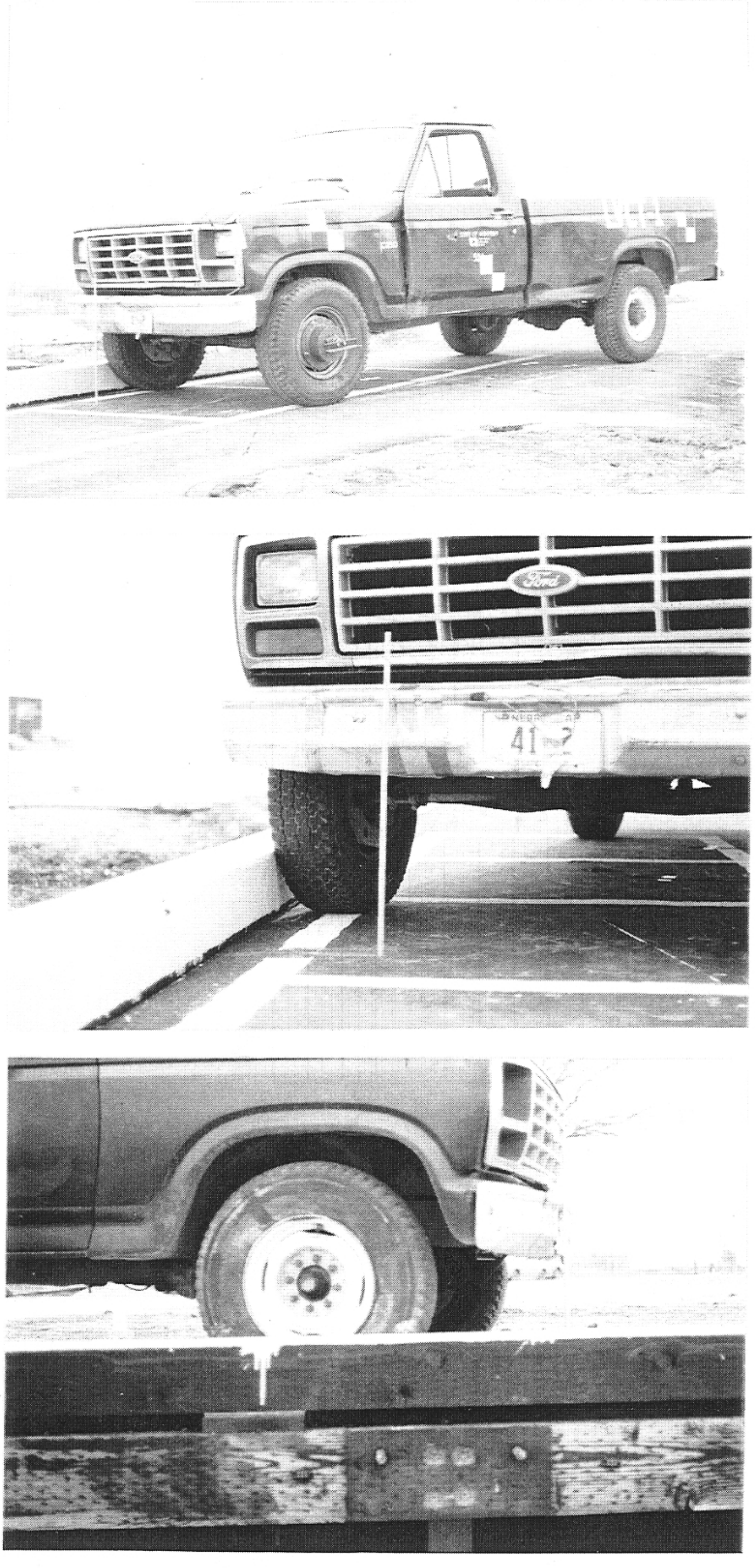


Figure 18. Impact Location, Test LVCT-1a

TRAPEZOID

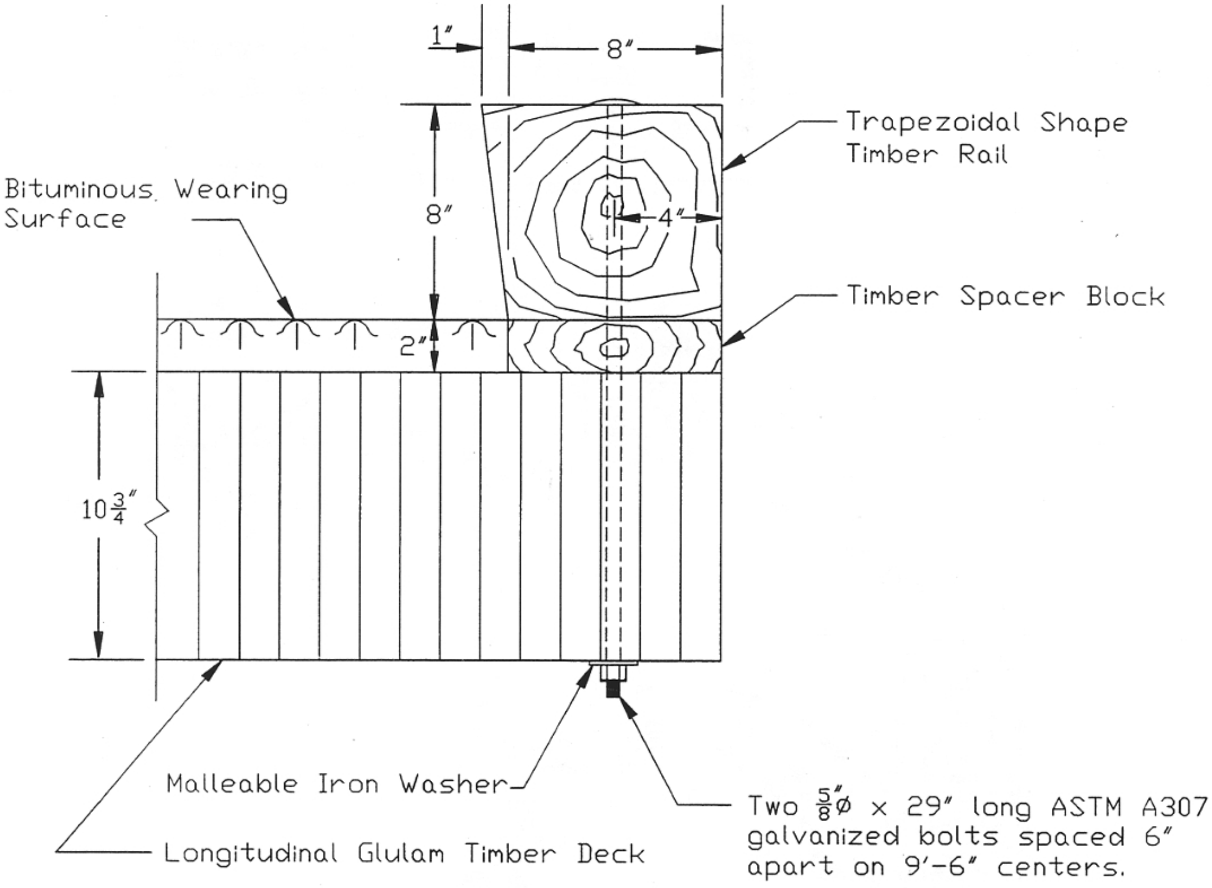


Figure 19. Schematic of 8-in. High, 8-in. x 9-in. Trapezoidal Shape, Test LVCT-1a

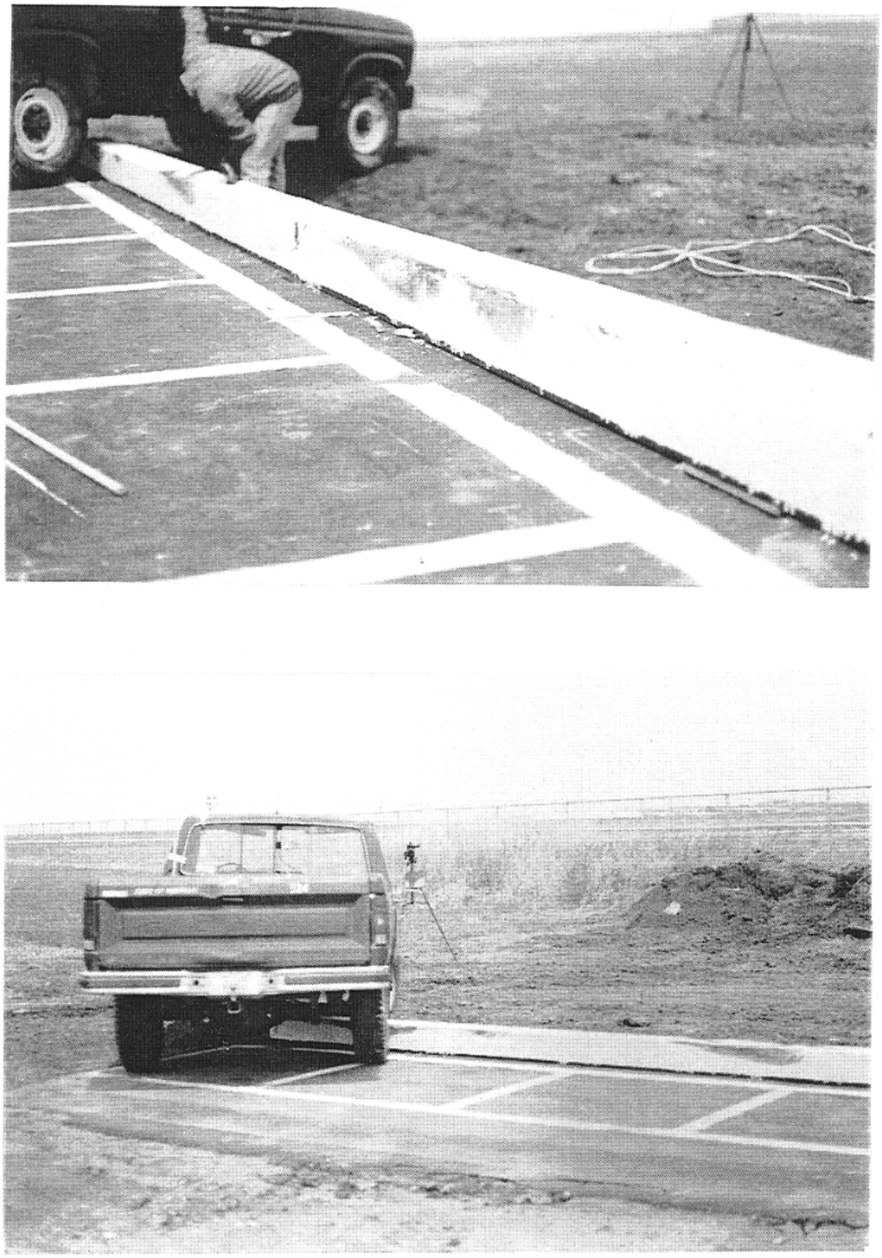


Figure 20. Tire Marks on Rail, Test LVCT-1a

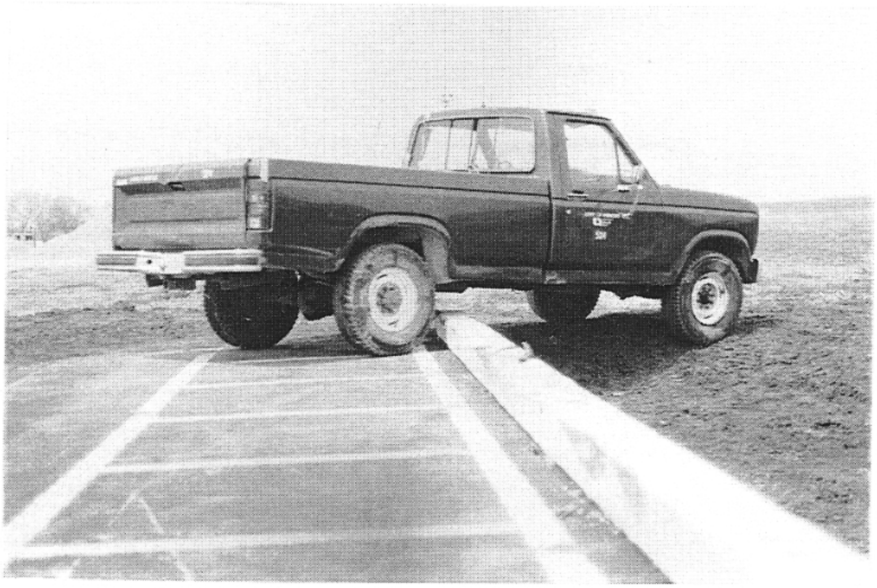


Figure 21. Vehicle Trajectory, Test LVCT-1a

was conducted on a 10-in. high trapezoidal shape curb in order to further check the results of the Developmental Testing - Phase I. The impact point for test LVCT-1c was the same as for the previous two tests. A schematic of the curb configuration is shown in Figure 22 and photographs of the installation are shown in Figure 23. The vehicles' tires again climbed over the top of the curb allowing the tires 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, as shown in Figure 24.

Results of this test were also inconsistent with the previous findings from the developmental testing program. Factors that may have affected the results include: (1) air temperatures were warmer during full-scale vehicle crash testing than during developmental testing; (2) curb rail was coated with a latex, water-based paint to aid in photography and documentation of tests; and (3) creosote on the surface of the treated timber may have dried and increased friction levels between the tires and timber rail.

TRAPEZOID

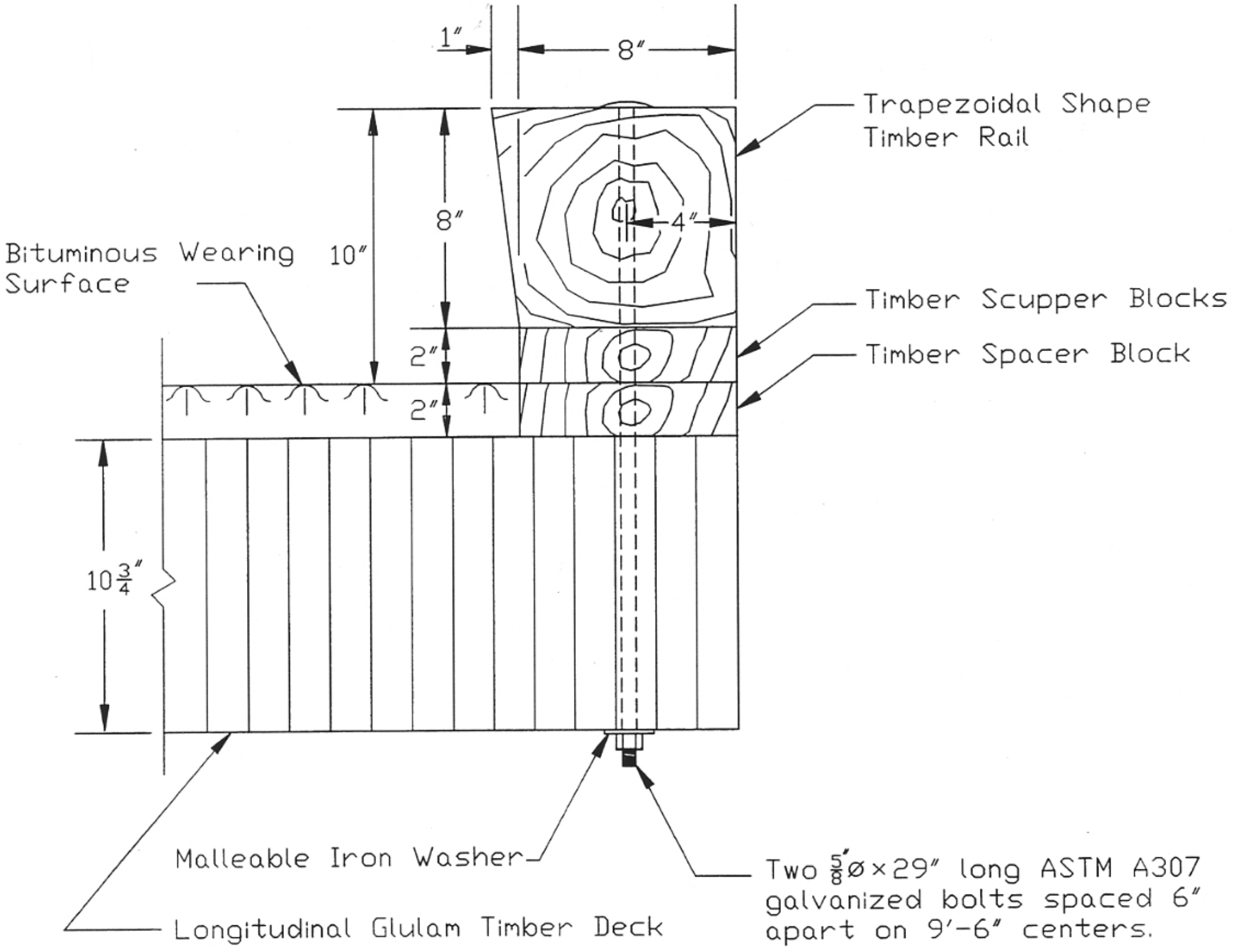


Figure 22. Schematic of 10-in. High, 8-in. x 9-in. Trapezoidal Shape, Test LVCT-1c

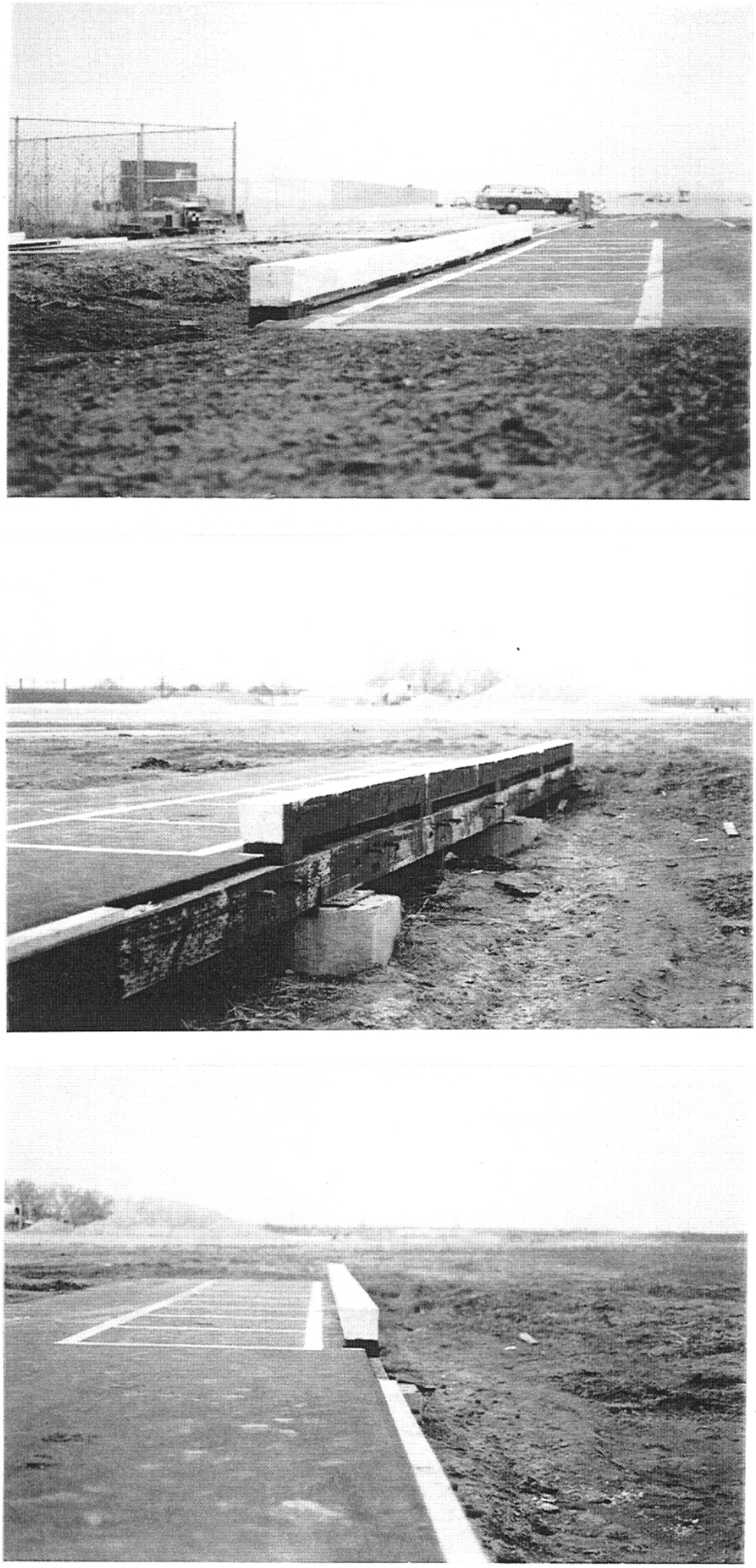


Figure 23. Trapezoidal-Shape Timber Curb Rail, Test LVCT-1c

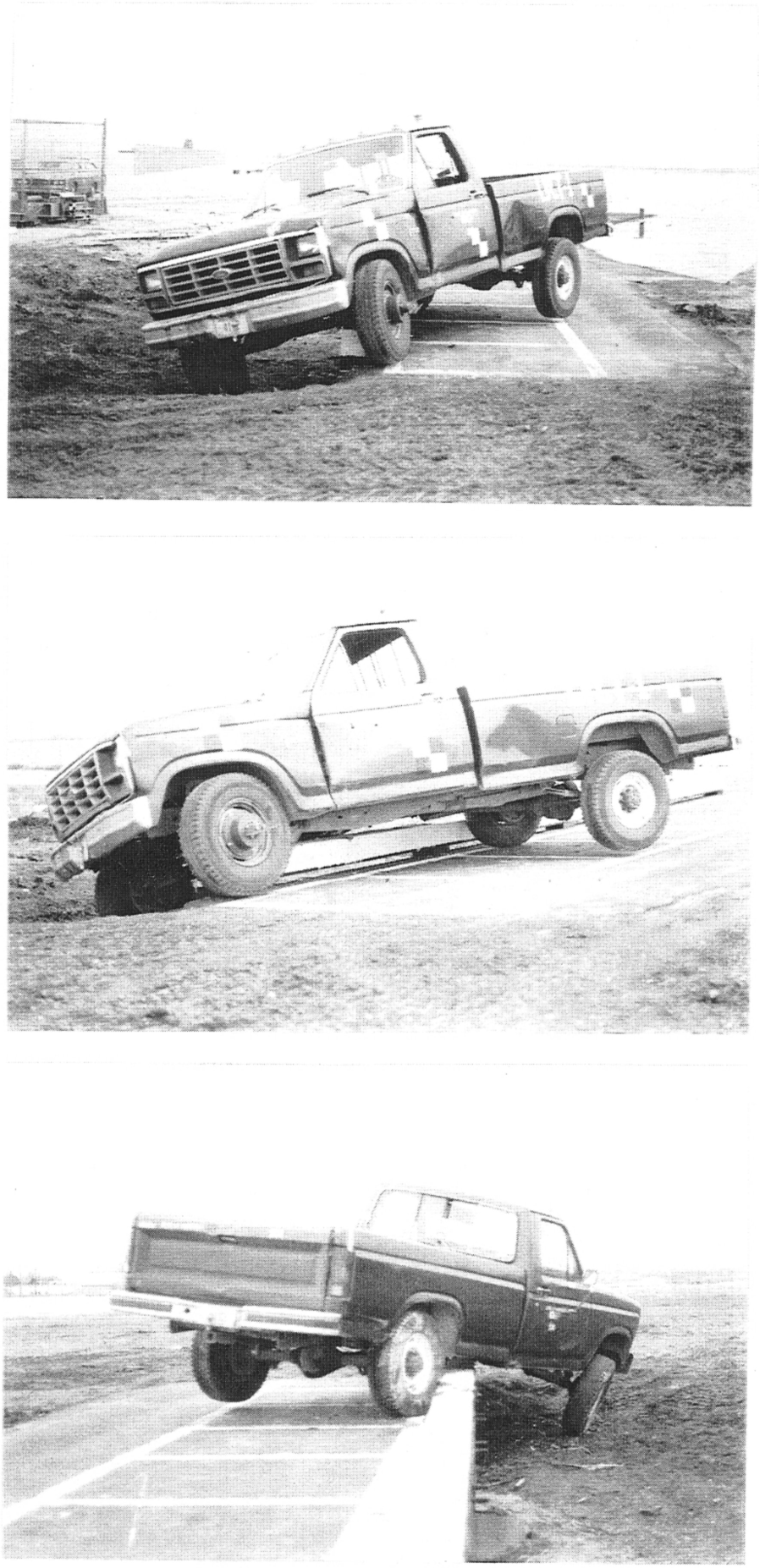


Figure 24. Vehicle Trajectory, Test LVCT-1c

8 DEVELOPMENTAL TESTING - PHASE II

Following three unsuccessful full-scale vehicle crash tests on the trapezoidal shape curb rail, developmental testing was once again used to determine the critical mounting heights of the three different curb shapes. The curb shapes were rigidly attached to the existing concrete apron in the same manner as during the first phase of the developmental testing program. A 3/4-ton pickup truck was driven into the curb railings and impacted at a speed of 15 mph and an angle of 15 degrees. The weather conditions during the day of testing were recorded. Between 8:00 a.m. and 6:00 p.m. on 4/26/93, the minimum and maximum air temperatures were 51.6°F and 75.0°F, respectively.

Impact tests were performed on the three curb shapes mounted at heights ranging from 8 to 14 in. A total of eight curb configurations were evaluated as shown in Figures 25 through 27. Fifteen tests were conducted and are summarized in Table 4. For impacts at 15 mph and 15 degrees, a 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 14-in. mounting height was required for the trapezoidal shape. For the 12-in. high trapezoidal shape, the sharp corner extending outward from the top of the front face was low enough to allow the tire to climb up and over the curb. Following these tests, it was determined that one full-scale vehicle crash test should be performed on one of the successful curb shapes. The 12-in. high, square shape was selected for full-scale vehicle crash testing since it offered the most economical design alternative.

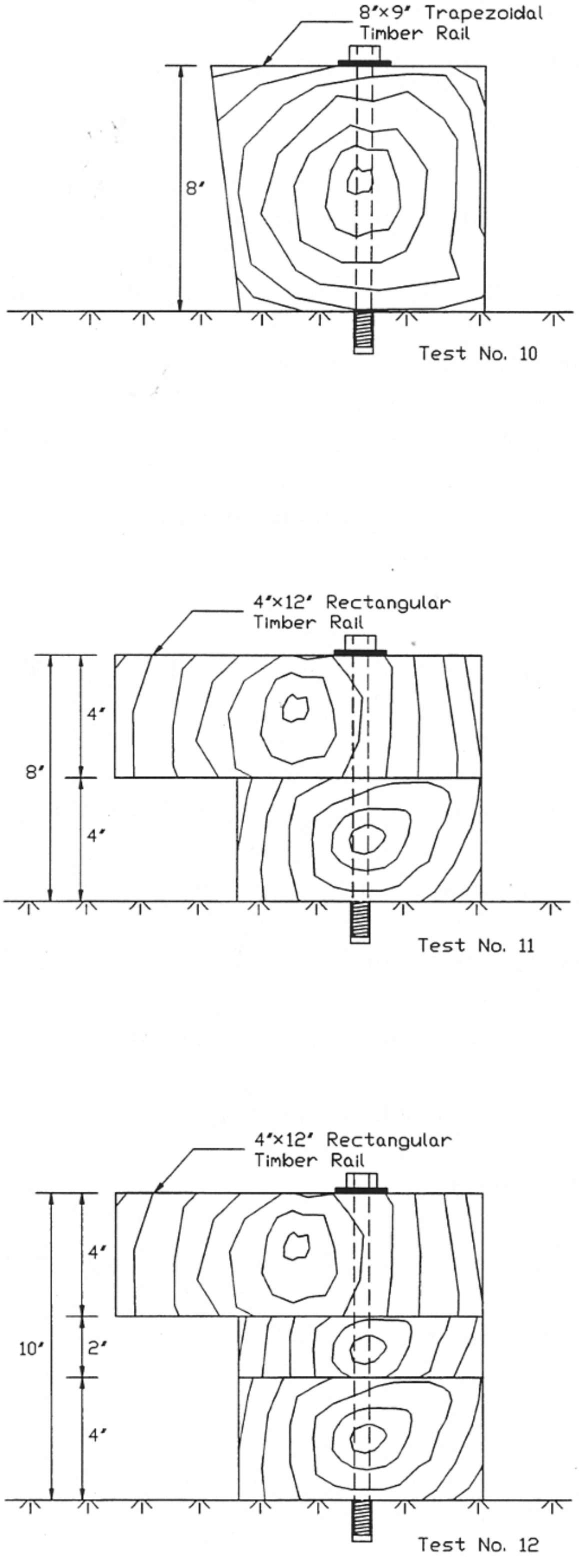


Figure 25. Curb Configurations for Developmental Testing - Phase II

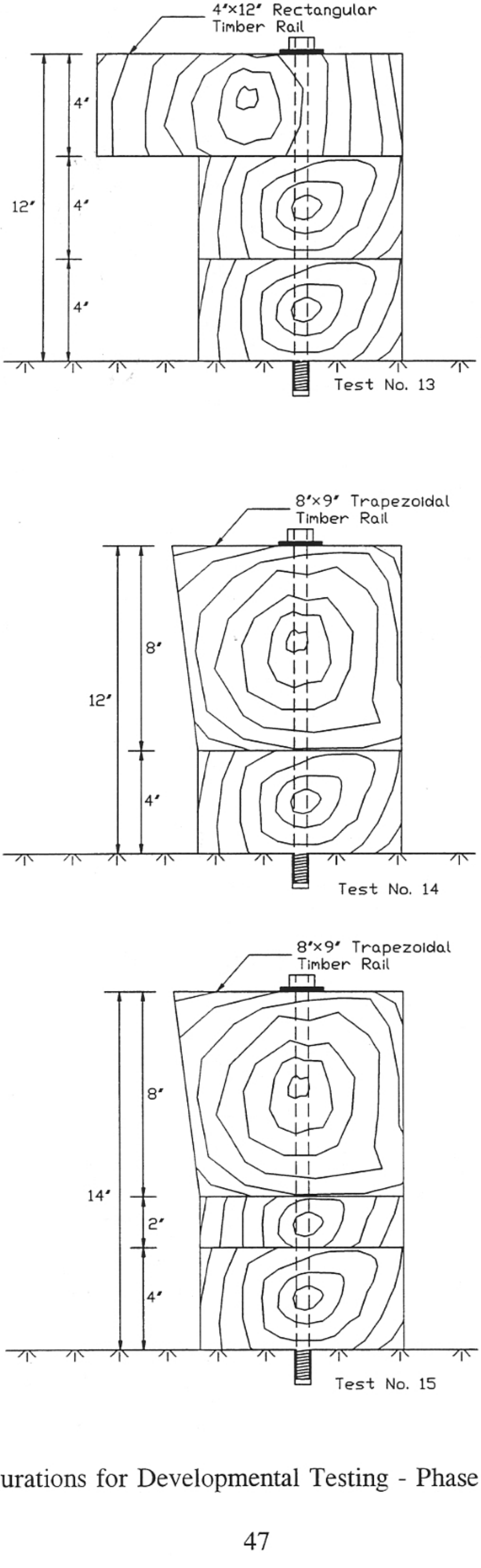
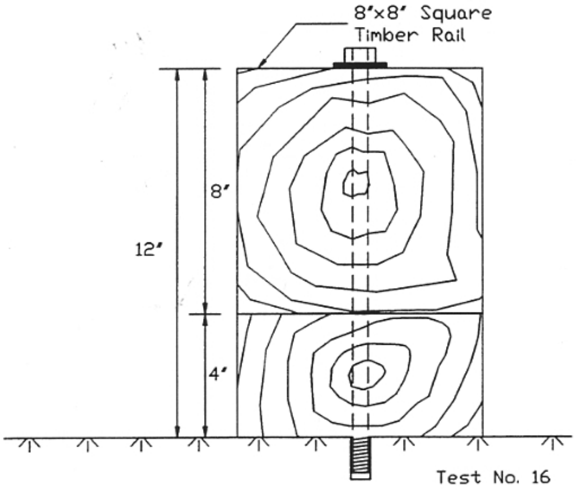


Figure 26. Curb Configurations for Developmental Testing - Phase II (con't)



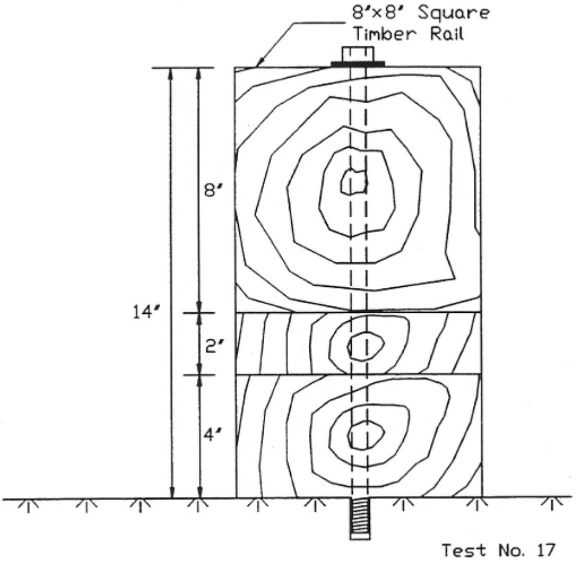


Figure 27. Curb Configurations for Developmental Testing - Phase II (con't)

Table 4. Summary of Developmental Testing - Phase II

Date	Rail Type	Rail Height (in.)	Test No.	Speed (mph)	Results
4/26/93	Trapezoid - 8" x 9"	8	10a	15	Failed - vehicle over top of curb
			10b	15	Failed - vehicle over top of curb
			10c	15	Failed - vehicle over top of curb
4/26/93	Rectangle - 4" x 12"	8	11	15	Failed - vehicle over top of curb
4/26/93	Rectangle - 4" x 12"	10	12	15	Failed - vehicle over top of curb
4/26/93	Rectangle - 4" x 12"	12	13a	15	Passed - right-front tire briefly popped into air
			13b	15	Passed - right-front tire briefly popped into air
4/26/93	Trapezoid - 8" x 9"	12	14a	15	Passed - minor vehicle uplift action
			14b	15	Passed - right-front tire climbed onto curb
			14c	15	Failed - vehicle over top of curb
4/26/93	Trapezoid - 8" x 9"	14	15a	15	Passed - no climbing tendency
			15b	15	Passed - no climbing tendency
4/26/93	Square - 8" x 8"	14	16	15	Passed - no climbing tendency
4/26/93	Square - 8" x 8"	12	17a	15	Passed - no climbing tendency
			17b	15	Passed - no climbing tendency

9 FULL-SCALE CRASH TESTING - PHASE II

One full-scale crash test was conducted on a 12-in. high, square shape curb rail as shown in Figures 28 through 30. A schematic of the curb configuration is shown in Figure 31. The weather conditions during the day of testing were recorded. Between 8:00 a.m. and 6:00 p.m. on 5/12/93, the minimum and maximum air temperatures were 62.4°F and 81.9°F, respectively.

9.1 Test LVCS-4 (8" x 8" Square Shape - 12" high)

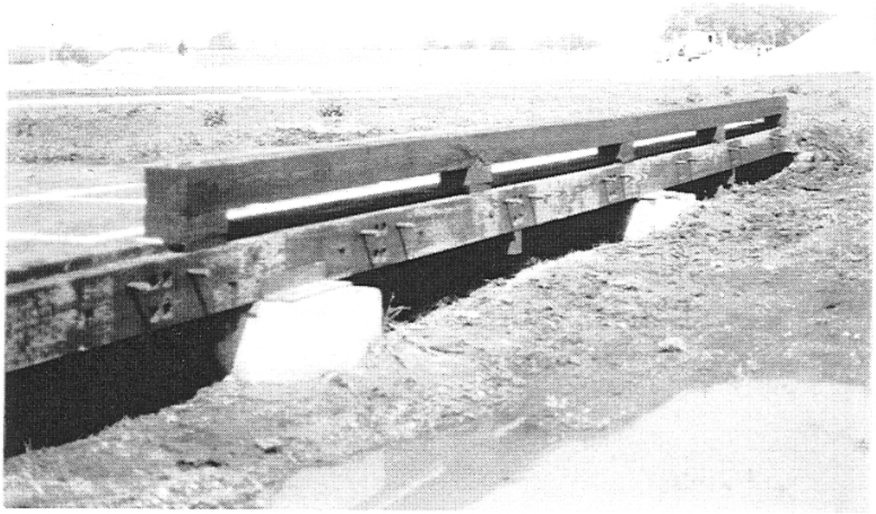
Test LVCS-4 impacted the curb rail at a speed of 14.4 mph and an angle of 15 degrees. Impact occurred approximately 11 ft from the upstream end of the 39-ft long installation as shown in Figures 32 and 33. A summary of the test results and the sequential photographs is presented in Figure 34. Documentary photographs of the crash test are shown in Figures 35 through 37.

Following the impact with the curb, redirection of the front tires was evident at approximately 0.064 sec, while vehicle redirection began at 0.275 sec. At 0.437 sec after impact, the rear tires and pickup box began to travel toward the curb. The pickup became parallel to the curb at approximately 1.229 sec. The vehicle came to rest approximately 72 ft downstream from impact, as shown in Figure 38.

Except for minor scuff marks on the right-side tires, there was no visible vehicle damage, as shown in Figure 39. No damage occurred to the curb rail or steel hardware as shown in Figure 38. In addition, the glulam timber deck was not damaged.

The curb-type bridge rail contained and redirected the test vehicle without penetration or overriding of 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

Figure 28. Square-Shape Timber Curb Rail, Test LVCS-4



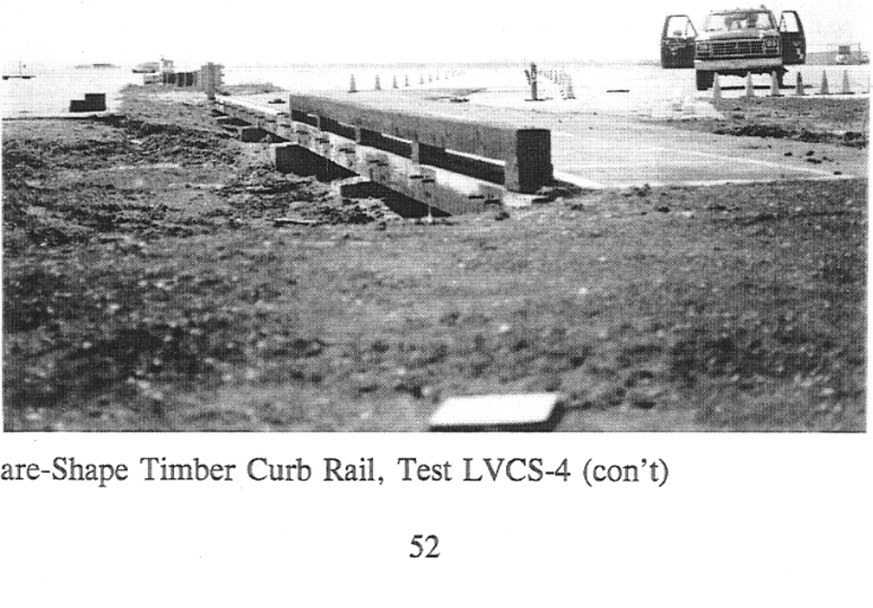


Figure 29. Square-Shape Timber Curb Rail, Test LVCS-4 (con't)

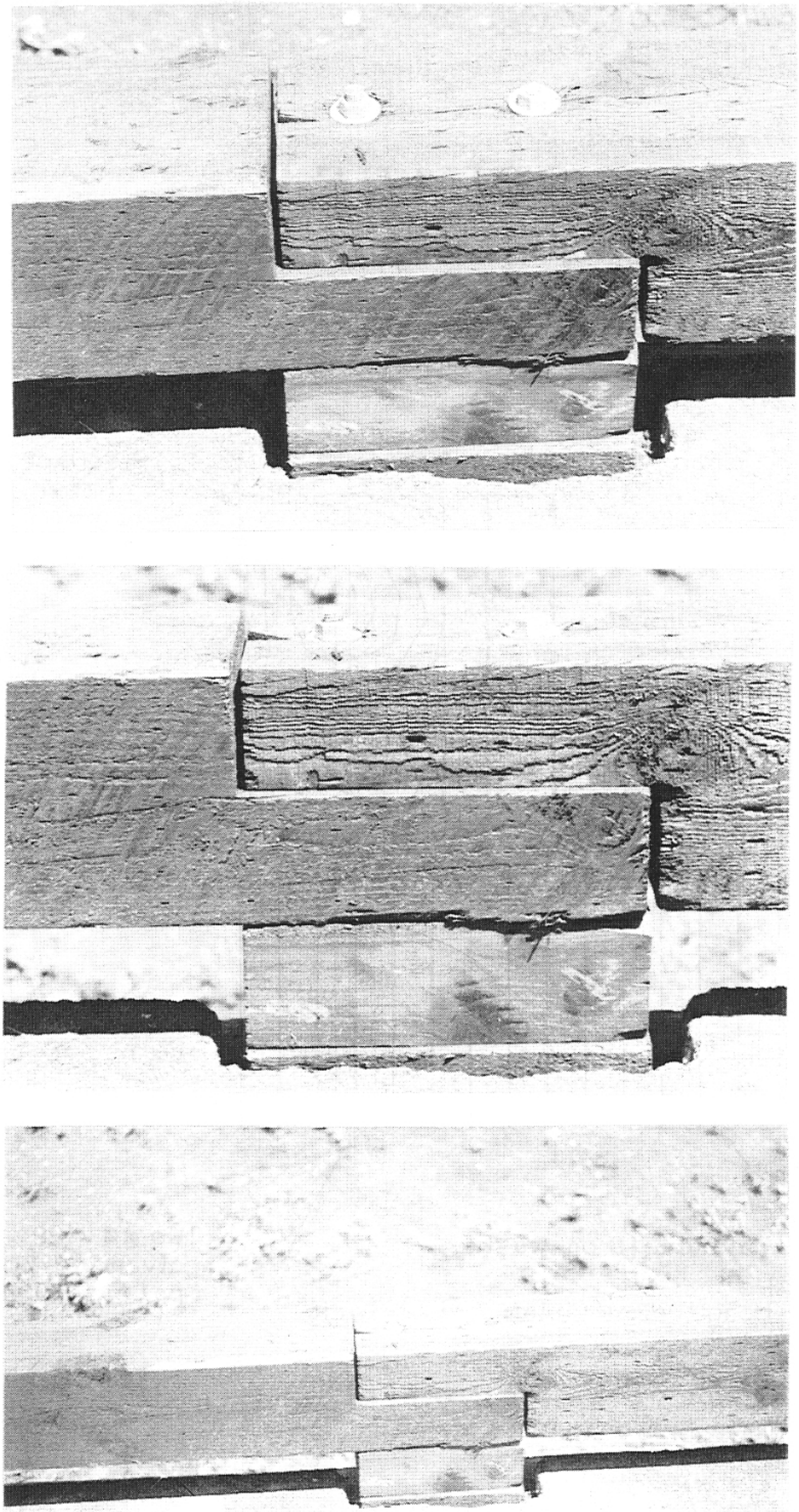


Figure 30. Square Curb Rail Splice, Test LVCS-4

SQUARE

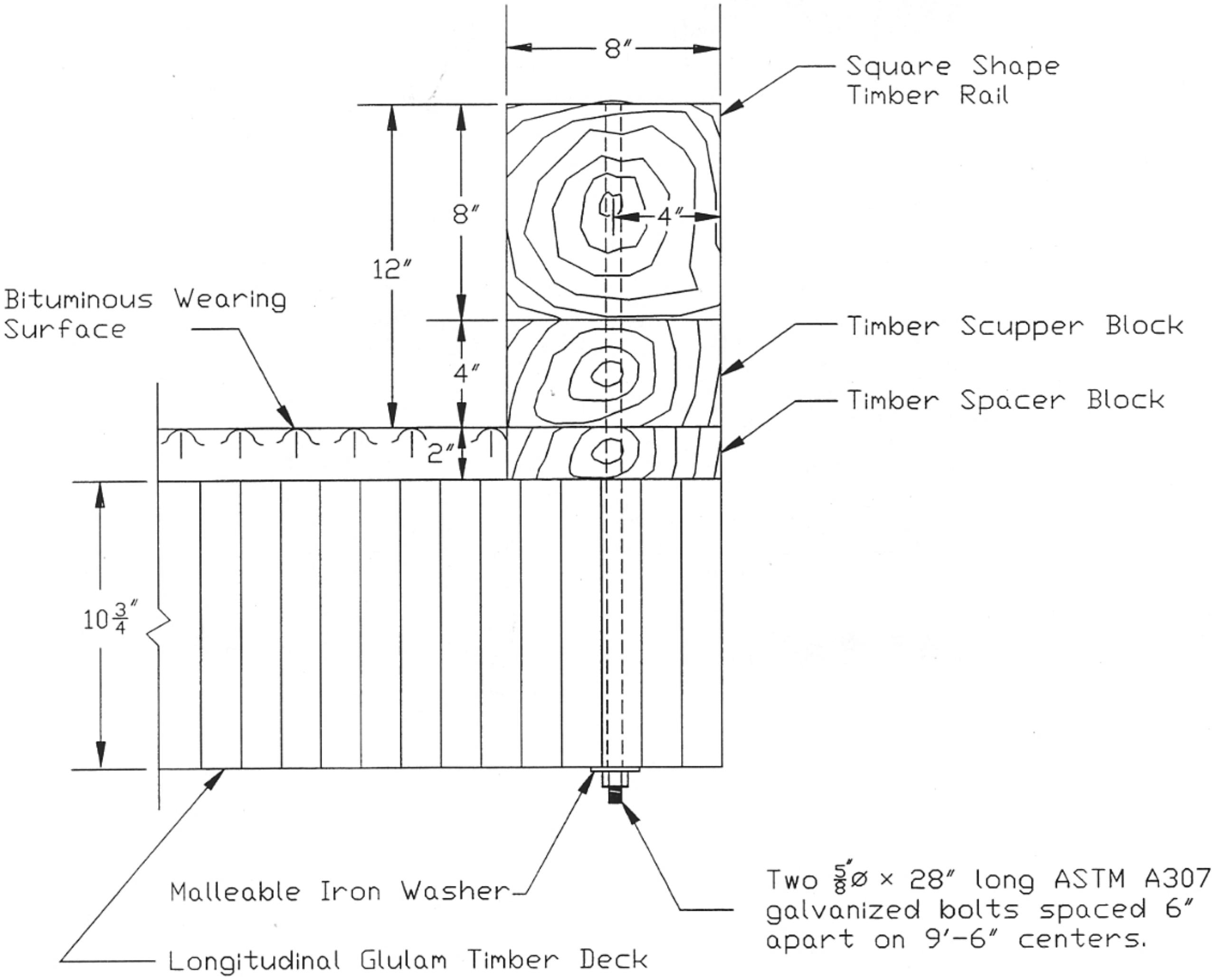


Figure 31. Schematic of 12-in. High, 8-in. x 8-in. Square Shape, Test LVCS-4

Figure 32. Impact Location, Test LVCS-4

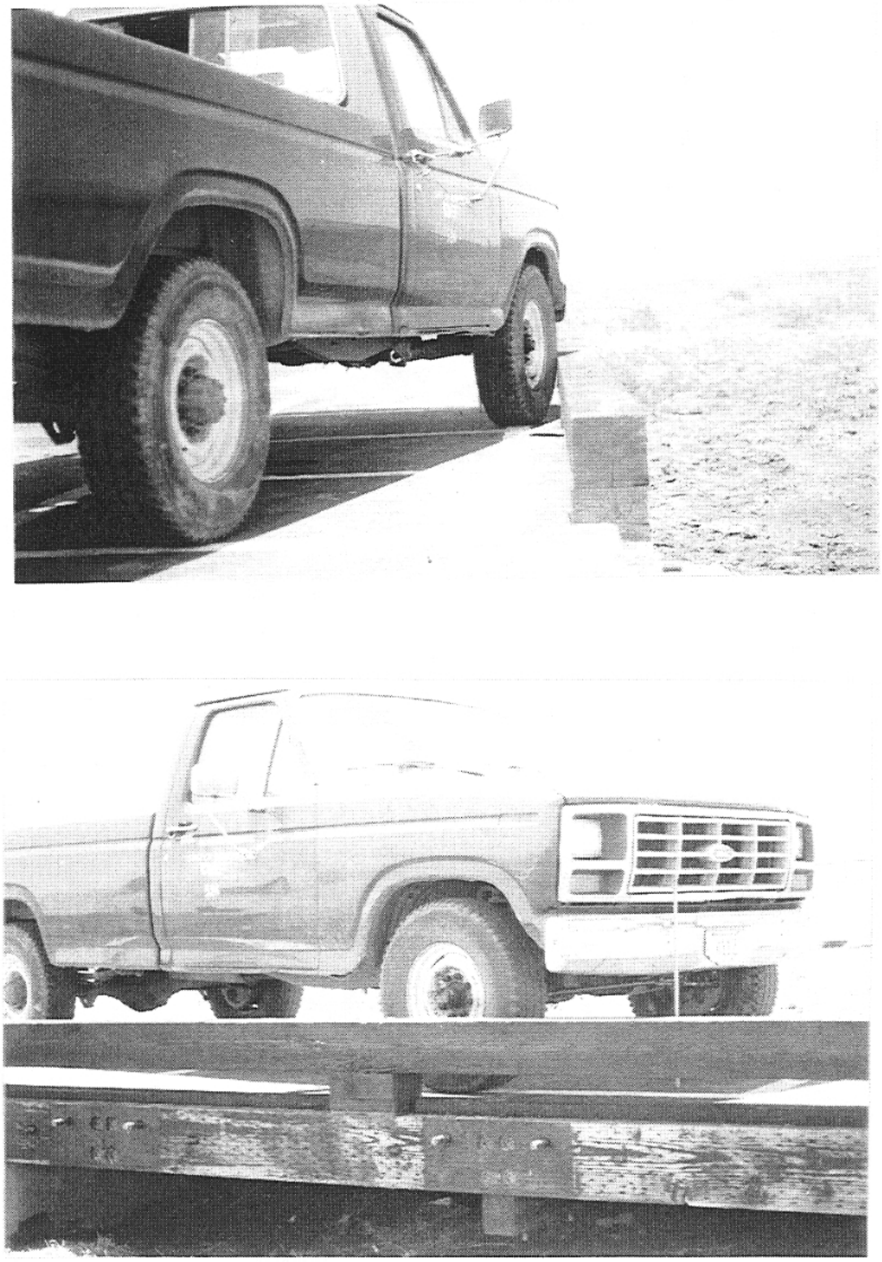
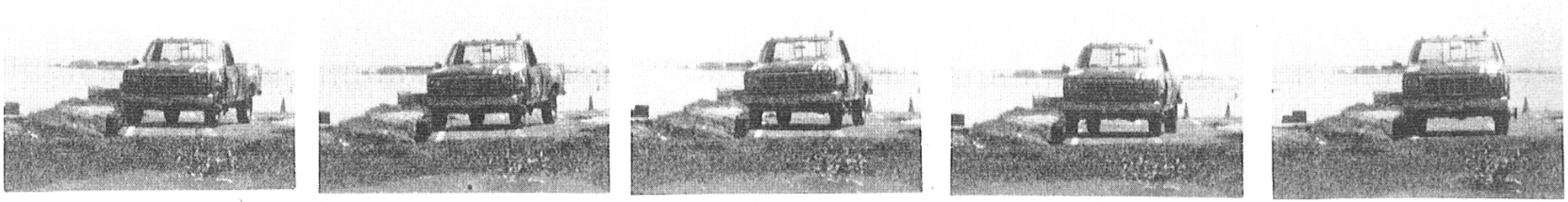
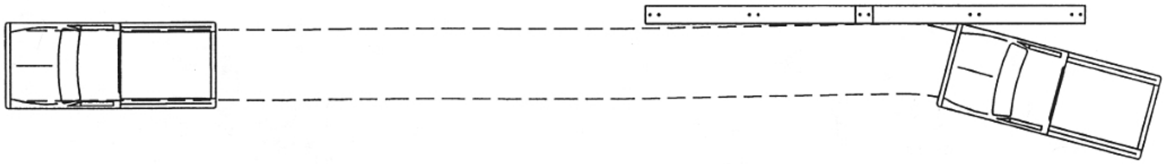
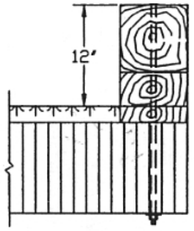


Figure 33. Impact Location, Test LVCS-4



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 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 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 34. Summary of Test Results and Sequential Photographs, Test LVCS-4

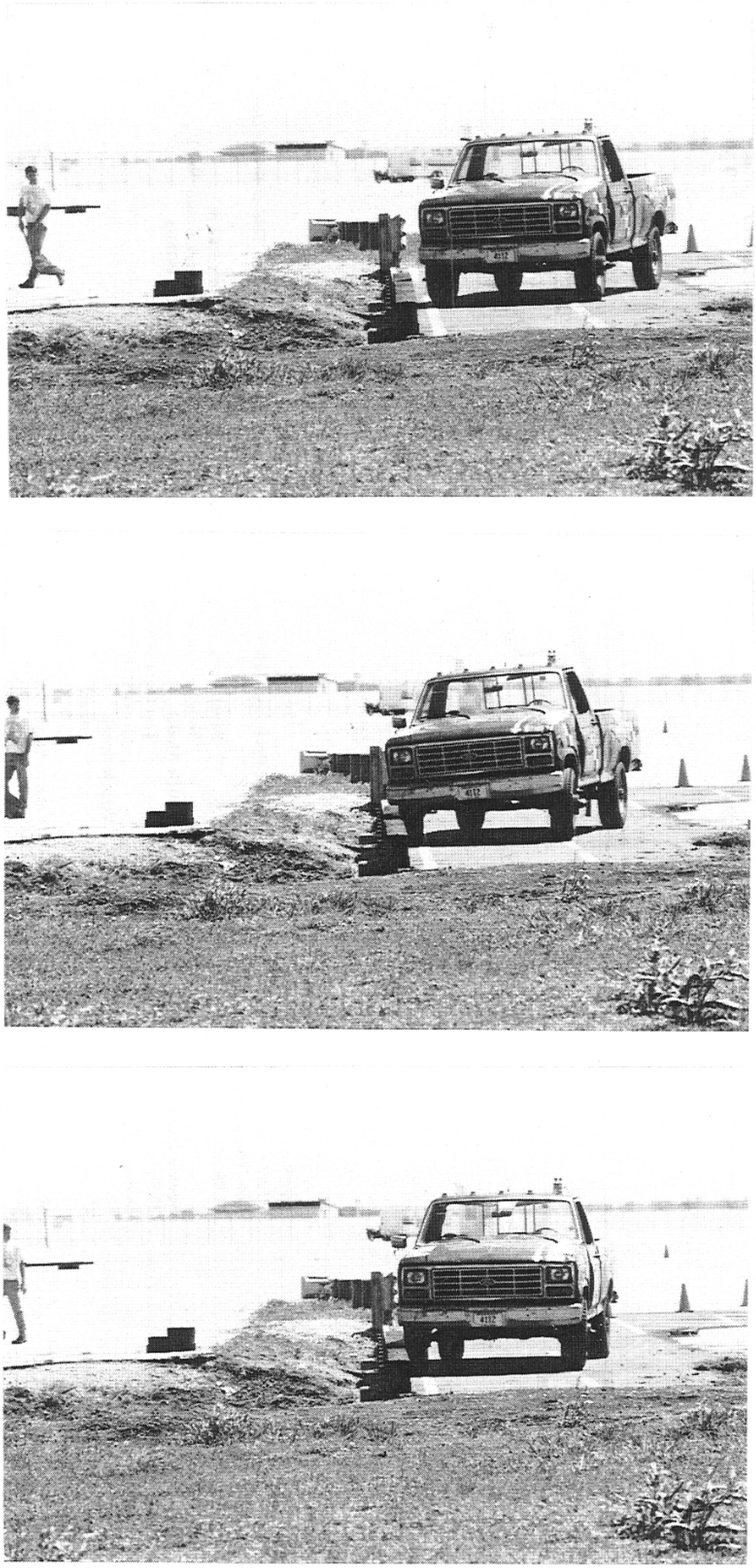


Figure 35. Full-Scale Crash Test, Test LVCS-4

Figure 36. Full-Scale Crash Test, Test LVCS-4 (con't)

Figure 37. Full-Scale Crash Test, Test LVCS-4 (con't)

Figure 38. Vehicle Trajectory, Test LVCS-4

Figure 39. Vehicle Damage, Test LVCS-4

present any hazard to other traffic or pedestrians. The integrity of the occupant compartment was maintained with no intrusion and no deformation. The vehicle remained upright during and after collision. After collision, 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. Thus, the curb bridge railing successfully met all performance criteria for the selected crash test condition.

10 DISCUSSION AND CONCLUSIONS

The 12-in. high, square shape bridge rail successfully redirected the pickup truck when impacted at a speed of 14.4 mph and an angle of 15 degrees. This result is consistent with the results from the Phase II of the developmental testing program. Full-scale crash tests were not performed on the 14-in. high trapezoidal (Figure 40) and 12-in. high rectangular (Figure 41) shapes. However, based on findings from the developmental testing program, it was reasoned that these shapes should behave similarly to the square shape curb rail and do not require full-scale crash testing.

Thus, three curb-type bridge railings were developed for longitudinal timber decks located on low-volume roads. 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 shown in Table 5. The rectangular shape railing system has the lowest material costs ($12.07 per lineal foot) while the trapezoidal shape railing system has the highest material costs ($14.35 per lineal foot). In addition, the curb-type railing system was easy to install and should have low construction labor costs. These railing systems should also be adaptable to other types of longitudinal timber decks. Finally, no bridge deck or railing damage was observed during testing on a weak longitudinal glulam deck system. Thus, maintenance and repair costs associated with the new curb designs should be very low.

TRAPEZOID

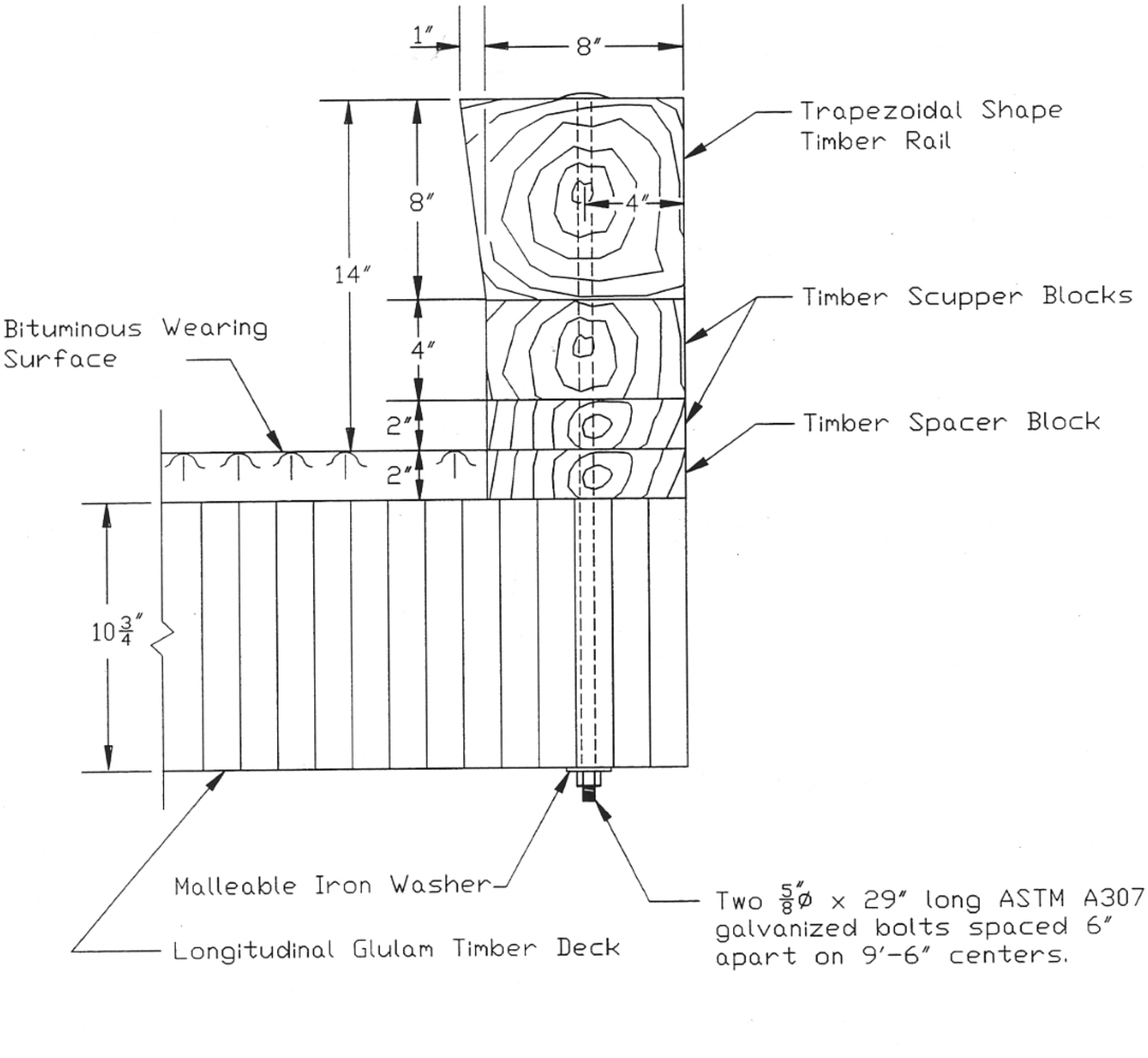


Figure 40. Schematic of 14-in. High, 8-in. x 9-in. Trapezoidal Shape

RECTANGLE

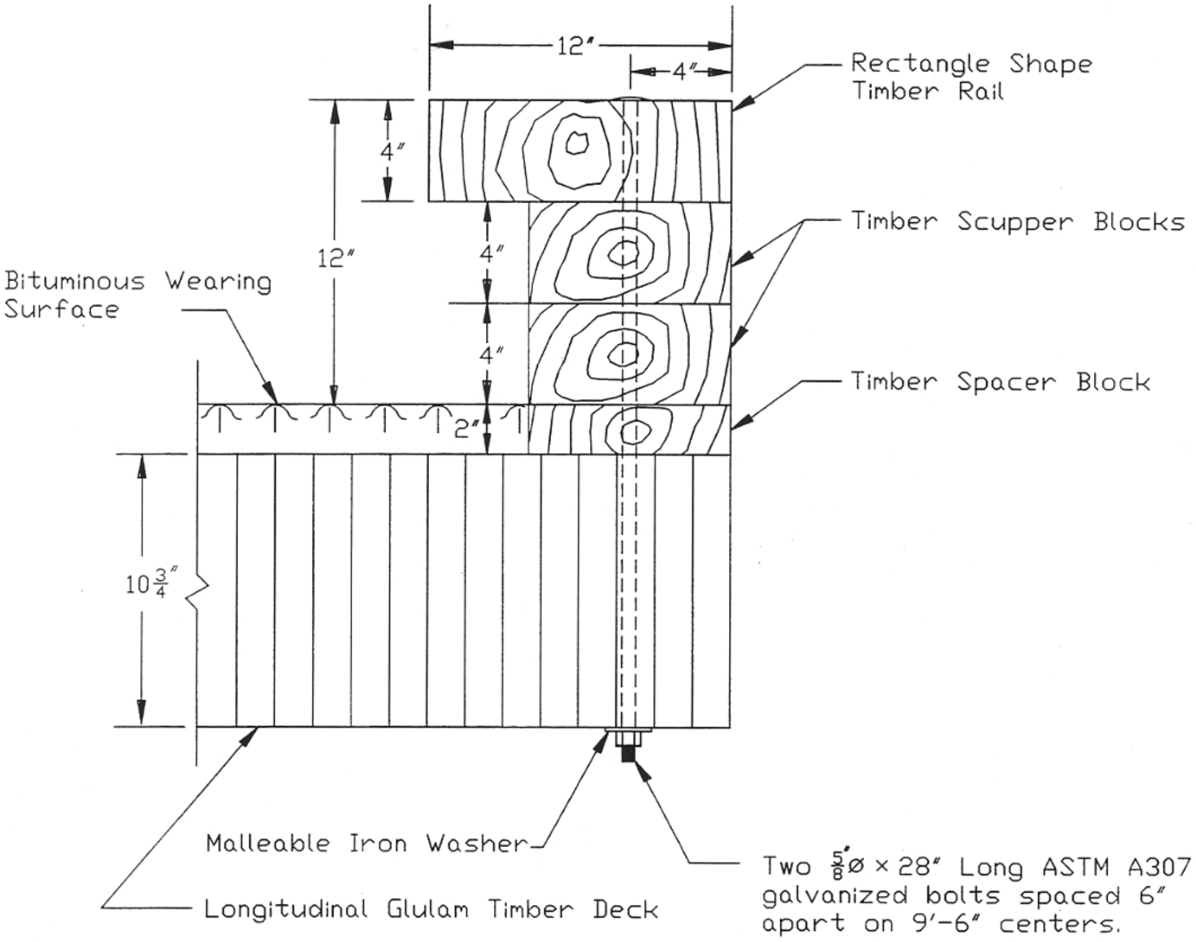


Figure 41. Schematic of 12-in. High, 4-in. x 12-in. Rectangular Shape

Table 5. Bridge Railing Material Costs

Curb Rail				Scupper Blocks			Bolts, Nuts, & Washers		Total Cost ($/ft)
Shape	Size	Mounting Height	Average Cost[1] ($/ft)	Quantity	Size	Average Cost[1] ($/ft)	Size	Average Cost ($/ft)	
Square	8" x 8"	12"	11.77	1	4" x 8" x 12"	0.62	5/8"ϕ x 28"	1.30	13.69
Rectangle	4" x 12"	12"	9.53	2	4" x 8" x 12"	1.24	5/8"ϕ x 28"	1.30	12.07
Trapezoid	8" x 9"	14"	12.11	1 1	4" x 8" x 12" 2" x 8" x 12"	0.62 0.29	5/8"ϕ x 30"	1.33	14.35

[1] - Based upon costs from three timber suppliers.

11 RECOMMENDATIONS

The curb railings described herein were developed for very low impact performance requirements. However, the developmental testing program indicated that the capacity of these curbs could easily be increased by increasing the curb height. Curb railings should be capable of meeting the performance requirements of test levels 1 or 2 from 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. As temporary barriers, these timber curbs could provide low cost protection for restricted work zones and the low profile would eliminate driver visibility problems frequently encountered in these areas. Thus, it is recommended that the research described herein be extended to develop higher performance timber curb barriers.

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