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Aesthetic Bridge Rails, Transitions, and Terminals For Park Roads and Parkways

U.S. Department of Transportation
Federal Highway Administration

Research, Development, and Technology
Turner-Fairbank Highway Research Center
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McLean, Virginia 22101-2296

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16. Abstract

The objective of this project was to test aesthetic bridge rails for park roads, parkways, and other roads under Federal jurisdiction. Four designs were analyzed and evaluated: the Modified Kansas Corral bridge rail, the Forest Service glulam bridge rail, the Natchez Trace bridge rail, and the aluminum tri-rail bridge rail with sidewalk. Two designs were tested and evaluated: the Forest Service glulam bridge rail and the Modified Kansas Corral bridge rail. Two full-scale crash tests were conducted with each design.

The Forest Service glulam bridge rail and the Modified Kansas Corral bridge rail passed both small sedan and pickup truck full-scale tests. Vehicle behavior during and after impact was, in all cases, acceptable. Computer simulation on the Modified Kansas Corral bridge rail and the Natchez Trace bridge rail indicated that the vehicle would be redirected with no vaulting. The Aluminum Tri-Rail bridge rail has a high snagging potential.

Both the Modified Kansas Corral and Natchez Trace designs should be submitted for certification as acceptable for use on Federal Lands highways, including Indian Reservation roads, National Park roads and parkways, and forest highways. Based on the analyses conducted, the Natchez Trace bridge rail should be tested in its current design to Performance Level 1 of the 1989 AASHTO guide specifications. The Aluminum Tri-Rail bridge rail should be modified and submitted for full-scale testing to Performance Level 1.

17. Key Words Guardrail, Bridge rail, Transition, Crash test, Highway safety		18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.	
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1. INTRODUCTION AND RESEARCH APPROACH

a. Statement of the Problem

The work reported here is part of the Coordinated Federal Lands Highway Technology Implementation program. It is intended to serve the immediate needs of those individuals who design and construct Federal Lands highways, including Indian Reservation roads, National Park roads and parkways, and forest highways. The results of this study can be used for all of these entities.

A varied assortment of bridge rails, transitions and terminals from approach guardrails to the bridge rail itself are being used on bridges under the jurisdiction of the National Park Service and other Federal agencies. These devices are intended to blend in with the roadside to preserve the visual integrity of parks and parkways. However, few have ever been crash tested. Therefore, this program was instituted to begin an evaluation process to ensure that devices used are safe for the traveling public.

b. Objectives and Scope

The objective of this effort was to crash-test aesthetic bridge rails for roads, under Federal jurisdiction. Four designs were analyzed and evaluated: the Modified Kansas Corral bridge rail, the glulam bridge rail, the Natchez Trace bridge rail, and the Aluminum Tri-Rail bridge rail with sidewalk. Two designs were evaluated by testing: the glulam bridge rail and the Modified Kansas Corral bridge rail. Two full-scale crash tests were conducted with each design.

c. Research Approach and Report Organization

This project was composed of three principal tasks which are discussed below. Section 2 presents a summary of the analyses and tests conducted, and section 3 lists the conclusions and recommendations. Drawings of the evaluated bridges are given in section 2. The results of the computer simulations are presented in appendix A. Appendix B includes a copy of the test report for each of the four tests.

Task A. Barrier analysis and design. Structural analysis and computer simulations were used to evaluate certain barrier designs before testing. These analyses led to some proposed changes in the rail designs to improve their safety performance without significantly affecting aesthetics, construction and/or maintenance costs.

Task B. Full-scale tests. Four full-scale tests were conducted during this program, as shown in table 1. All test vehicles procured during the testing program were 1982 or later models. In addition, all test procedures, test instrumentation, and the test report contents were in accordance with the guidelines in National Cooperative Highway Research Program (NCHRP) Report No. 230, and the American Association of State Highway and Transportation Officials (AASHTO) Guide Specifications for Bridge Railings, 1989. [1,2]

Table 1. Test matrix.

No.	Vehicle	Impact Speed	Impact Angle	Barrier Installation
WB-1	1800 lb sedan	50 mi/h	20°	Glulam bridge rail
WB-2	5400 lb pickup	45 mi/h	20°	Glulam bridge rail
KM-1	1800 lb sedan	50 mi/h	20°	Modified Kansas Corral rail
KM-2	5400 lb pickup	45 mi/h	20°	Modified Kansas Corral rail

1 lb = 0.454 kg
1 mi/h = 0.447 m/s

Reporting requirements included the vehicle maximum 50 m/s accelerations and changes in vehicle velocity and momentum. High-speed and real-time films, slides, and still photographs were made of each test. The vehicle crush depth was measured using a minimum of six points before and after each test. The depth measurement points were equally spaced along the length of the damaged area to generally describe the damage penetration profile. In addition, the maximum static crush was measured. The vehicle trajectory after impact was also measured.

One uninstrumented restrained anthropomorphic dummy was used in the driver's seat of each test vehicle to assess the probability of occupant injury. Each dummy was a 50th percentile male. An onboard camera was utilized to record the motions of the dummy.

Task C. Final report. The final task for this contract was preparation of the final report, which describes the tests conducted, and a comprehensive discussion of conclusions and recommendations derived from the effort. In addition, a separate two page summary was prepared that highlights the objectives, research approach, results and conclusions, and which references the final report.

2. SUMMARY OF ANALYSIS

Design reviews, analyses conducted, final designs, test procedures, and test results are briefly described in this section. Detailed information on the test installations and results is contained in appendix B (Full-Scale Crash Test Reports).

a. Design Reviews

Four bridge rail designs were reviewed as part of this contract as listed below:

1. Glulam bridge rail
2. Modified Kansas Corral bridge rail
3. Natchez Trace bridge rail
4. Aluminum Tri-Rail bridge rail with sidewalk.

Drawings of each system are presented in figures 1 through 4, a, b, and c respectively. A discussion of the different analyses performed on each system is presented in the next section and the suggested modification to the Aluminum Tri-Rail bridge rail is given in the following section.

Glulam Bridge Rail.

Design calculations were obtained from Wheeler Consolidated Industries, the manufacturer, for this system. These were reviewed prior to testing and no modifications were recommended.

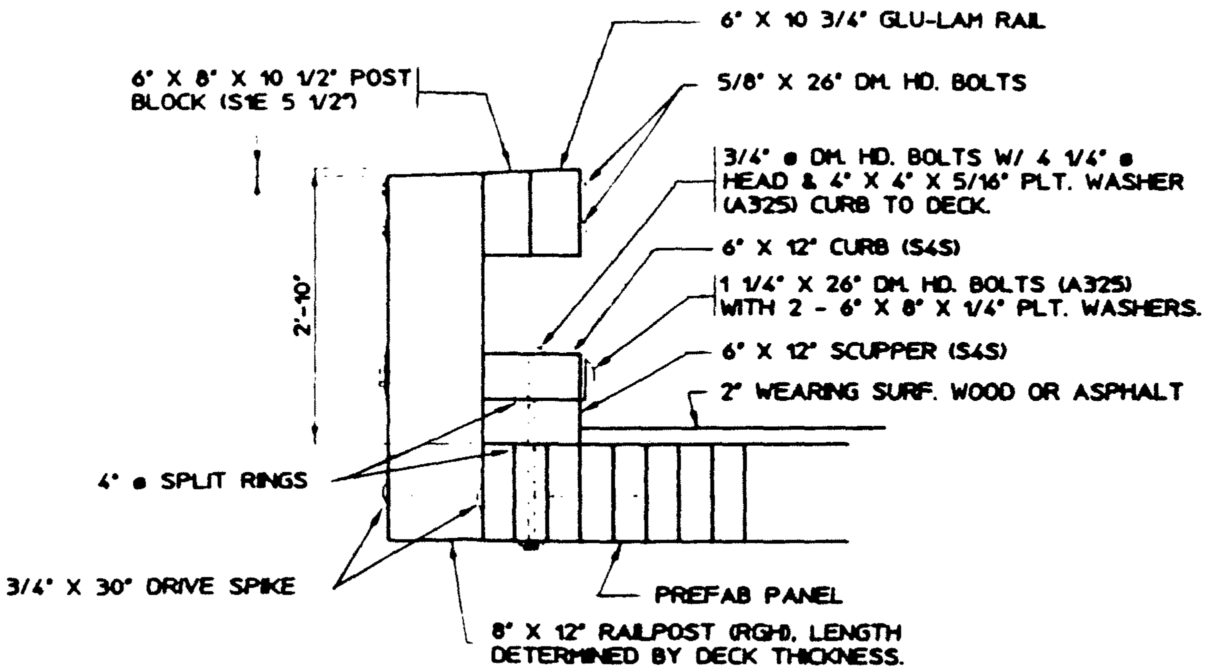
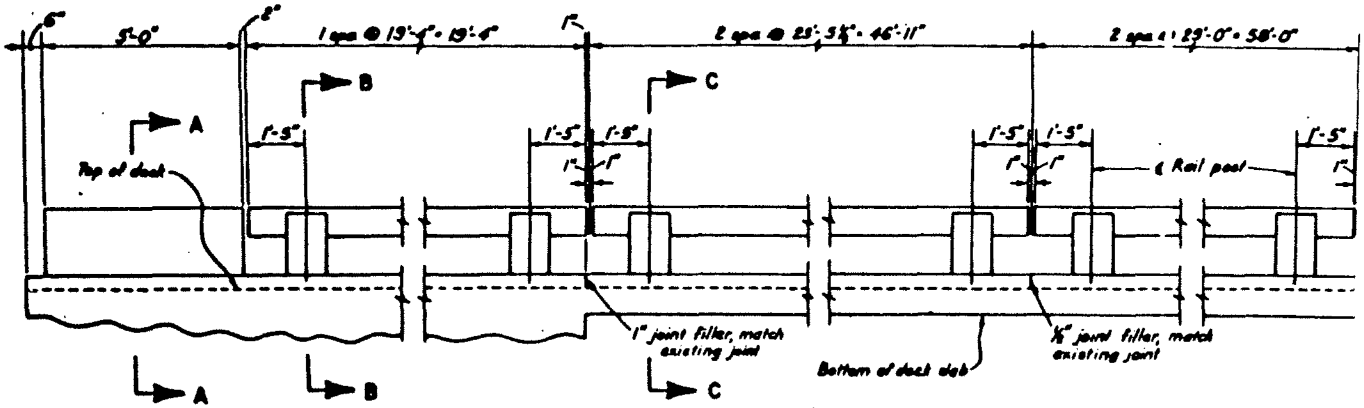
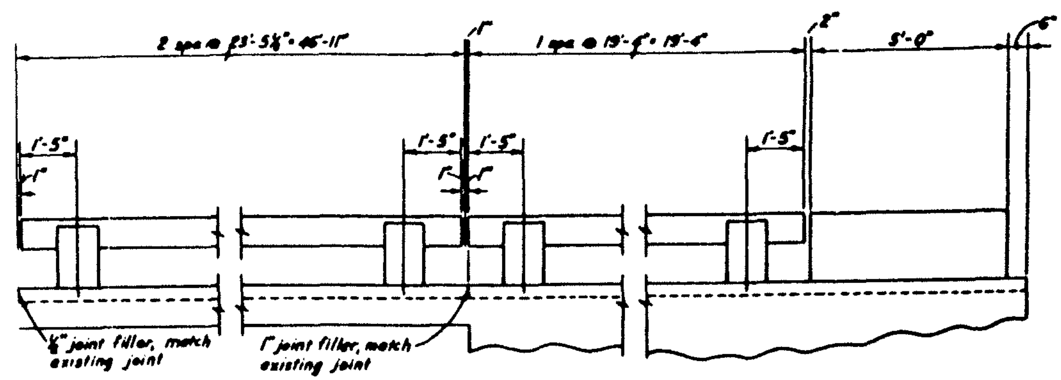


Figure 1. Glulam bridge rail.

Curb and rail elevation
(Scale ½ in = 1 ft)



Left section



Right section

Figure 2a. Modified Kansas Corral bridge rail.

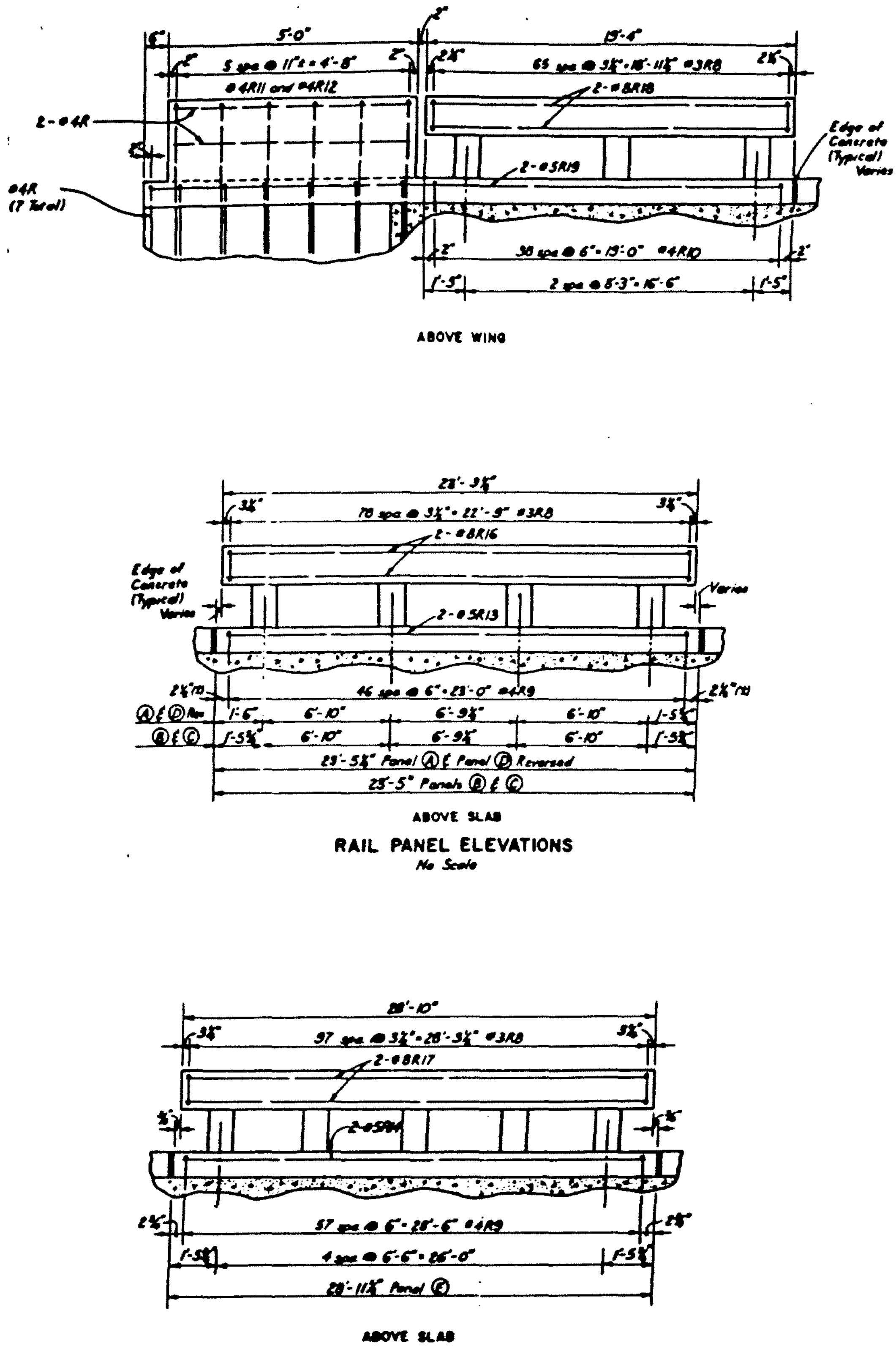


Figure 2b. Modified Kansas Corral bridge rail (continued).

Section details

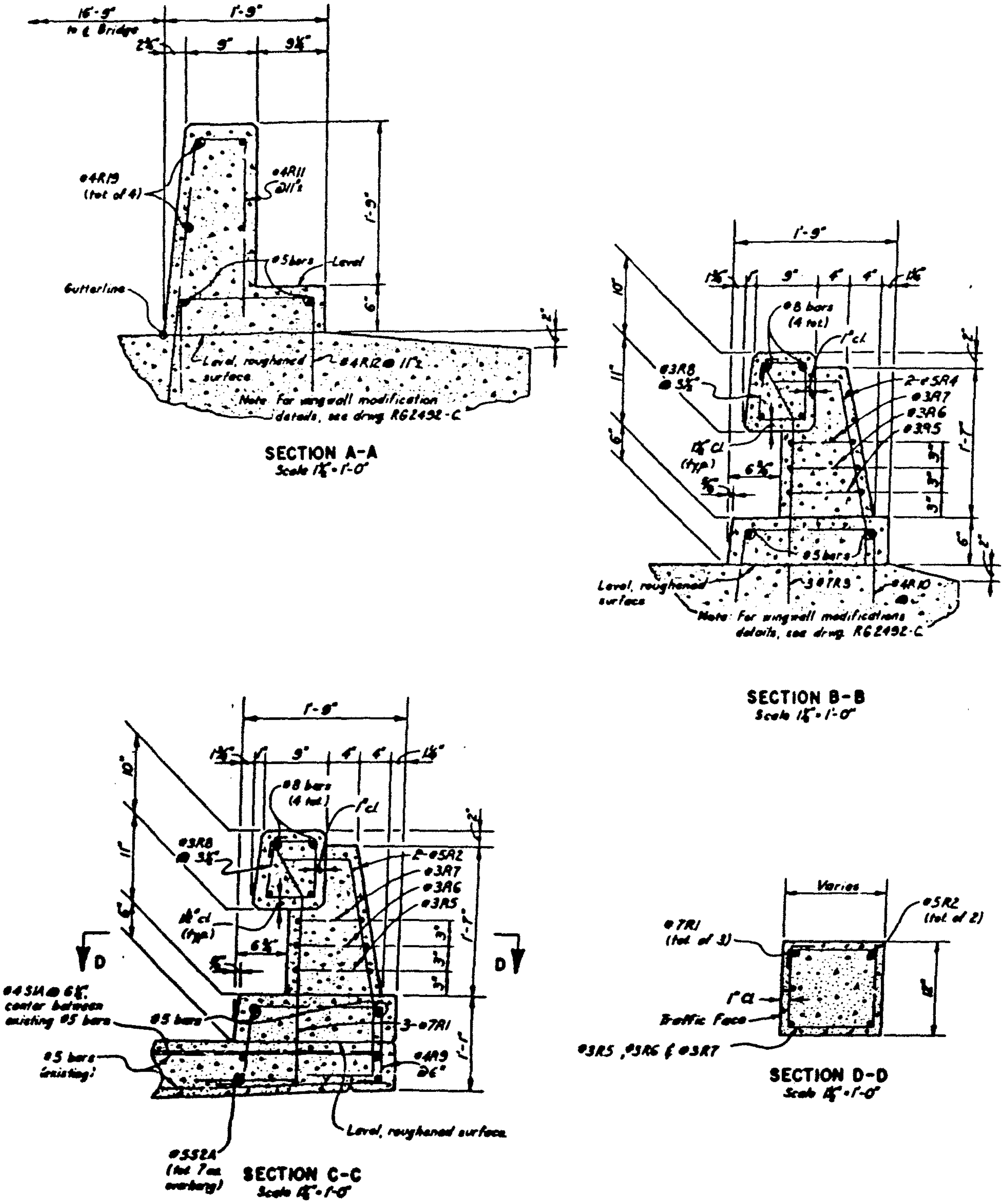
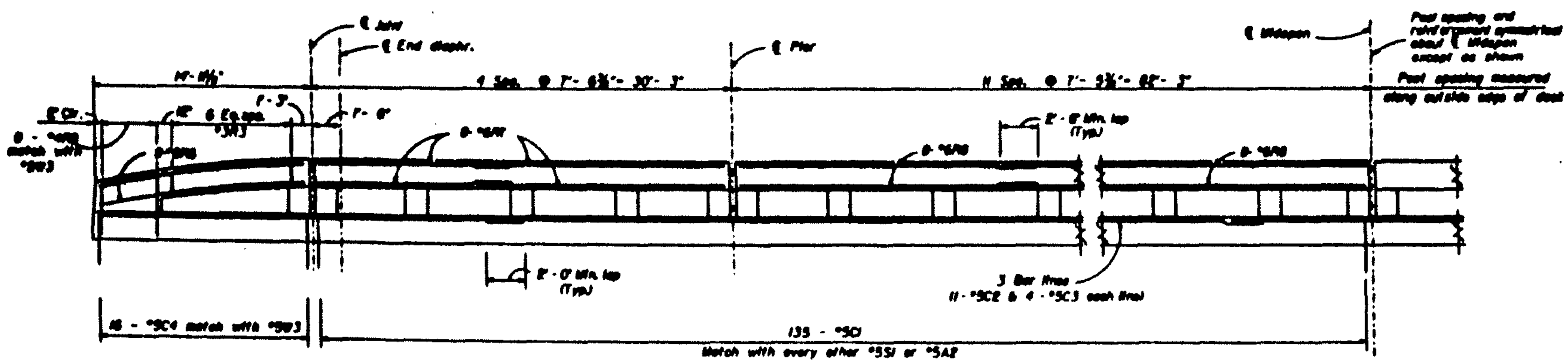
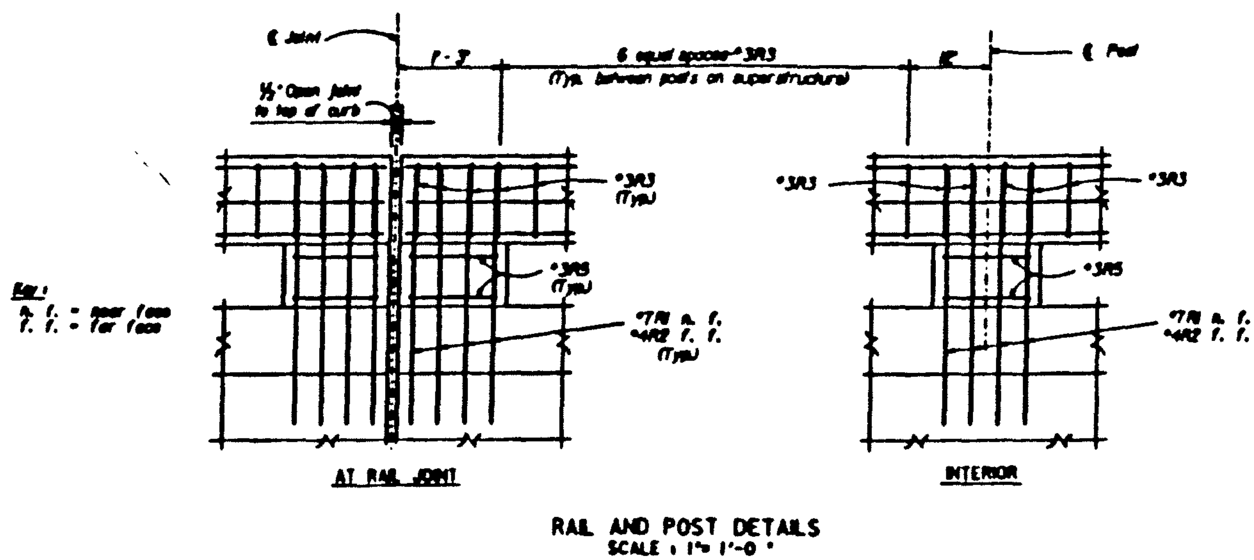


Figure 2c. Modified Kansas Corral bridge rail (continued).



RAIL AND POST ELEVATION
NO SCALE

Figure 3a. Natchez Trace bridge rail.



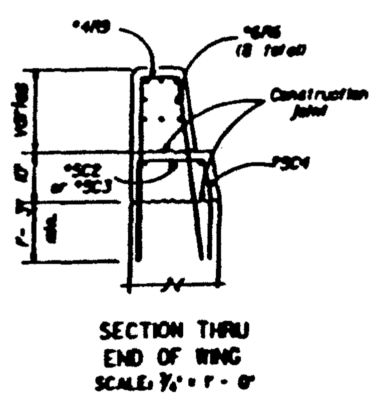
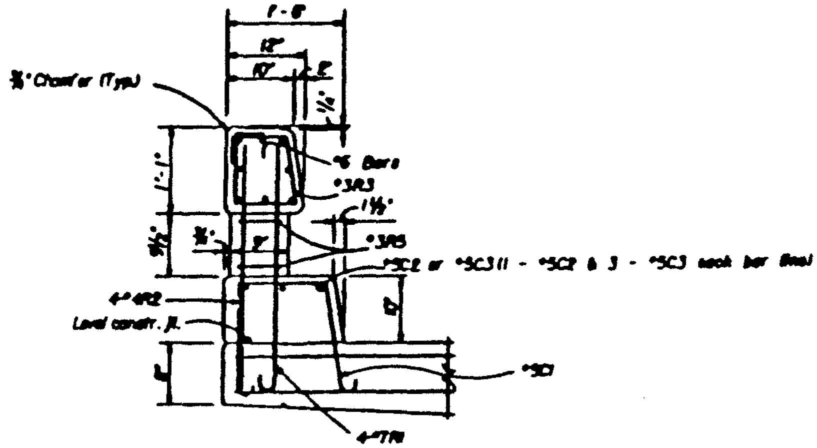
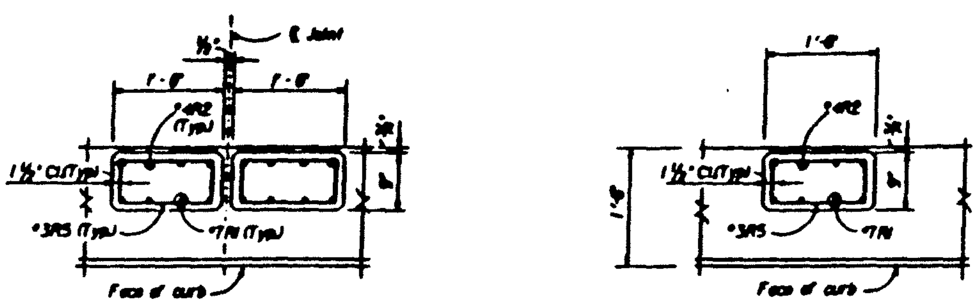


Figure 3b. Natchez Trace bridge rail (continued).



CURB AND RAIL SECTION
SCALE : 1"= 1'-0"



SECTION THRU POSTS
SCALE : 1"= 1'-0"
(Typ. for posts on superstructure and wingwalls)

Figure 3c. Natchez Trace bridge rail (continued).

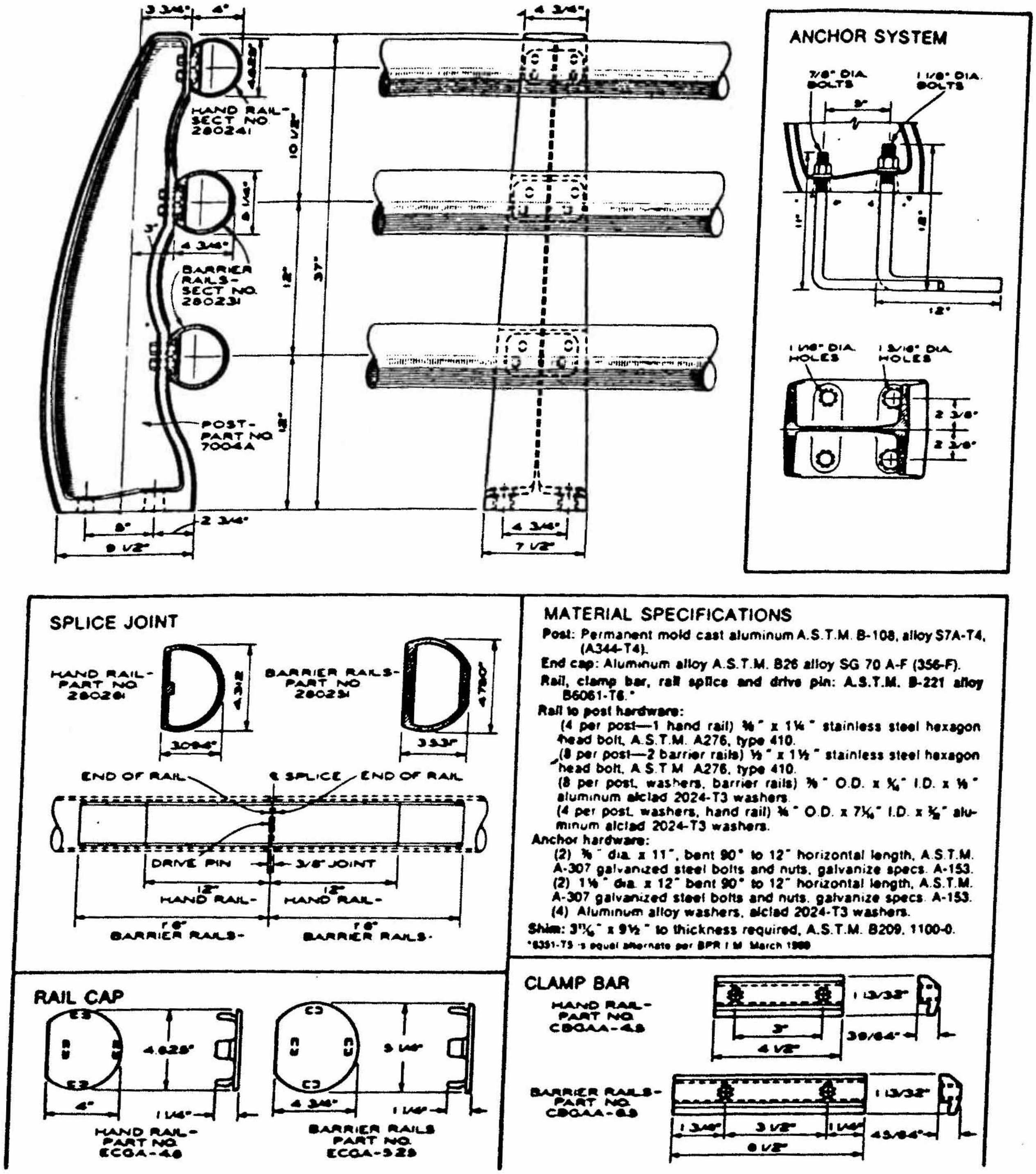


Figure 4a. Aluminum Tri-Rail bridge rail with sidewalk.

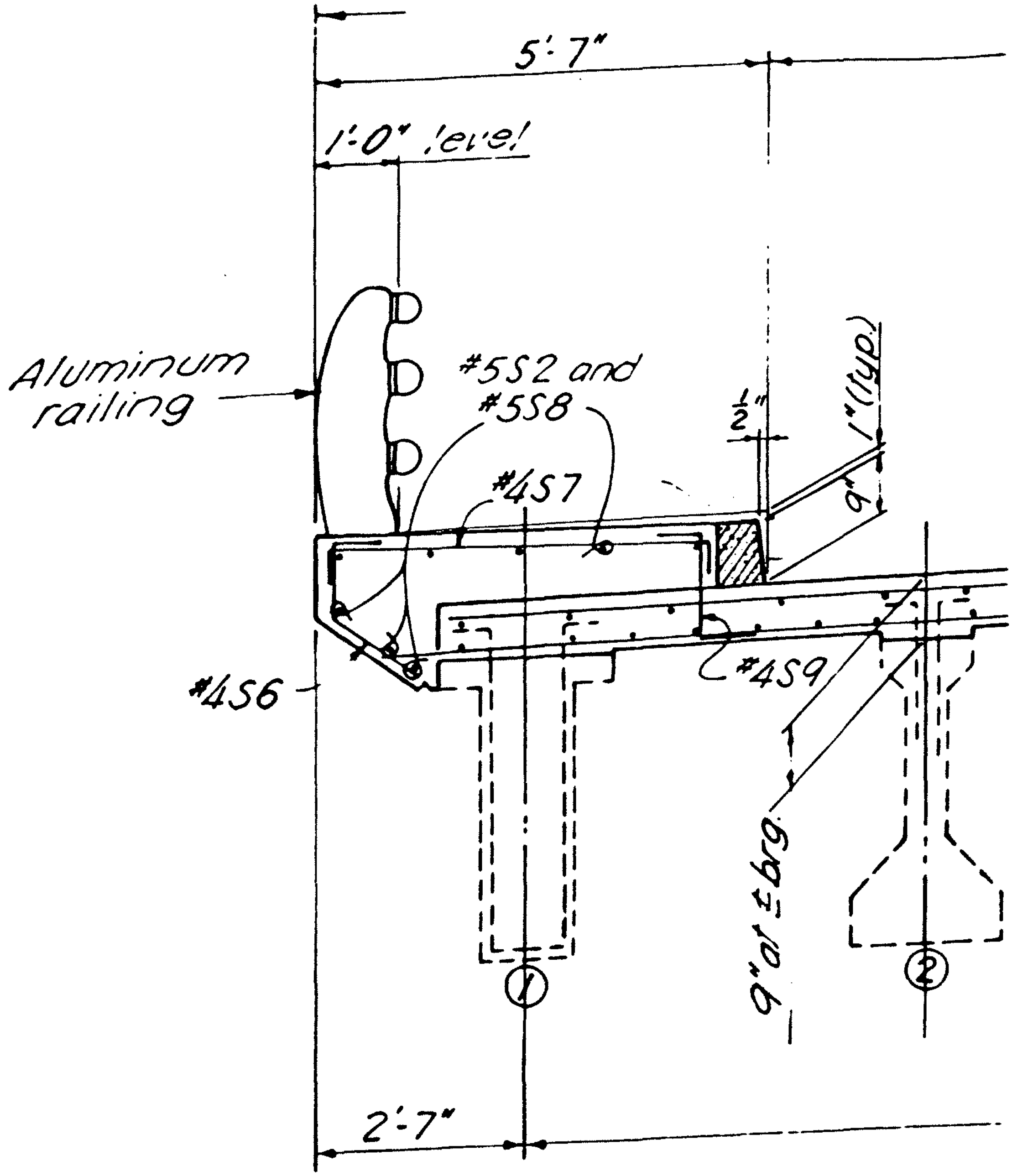


Figure 4b. Aluminum Tri-Rail bridge rail with sidewalk (continued).

Modified Kansas Corral Bridge Rail.

Strength analyses were performed on this system prior to testing to ensure that this design is equal to or superior to the previously tested Modified Kansas Corral.[3] In addition, a computer simulation was performed to provide insight into vehicle stability while impacting this profile. After reviewing this information, it was determined that this design would perform satisfactorily with no modifications and it was correspondingly evaluated by crash test.

Natchez Trace Bridge Rail.

Two computer simulations were performed on this design to provide insight into vehicle behavior while impacting this profile. No modifications were recommended for this system. This was not confirmed because no full-scale tests were performed.

Aluminum Tri-Rail Bridge Rail With Sidewalk.

Two computer simulations were performed on this design to provide insight into vehicle behavior while impacting this profile. Because of limited modeling capabilities of the simulation program, additional review was performed based on guidelines provided in reference 3. From figure 5, this system indicates a high snagging potential. A blockout is recommended for the upper two rails to reduce this potential. This is shown in section 2-c. Full-scale crash tests were not performed on this design.

b. Analyses Conducted

Three types of analyses were performed during this study: strength, computer simulation, and wheel snagging using graphs.

Strength.

Elastic analyses were conducted on the Modified Kansas Corral bridge rail using the BRIDGE program (3) and the yield line analyses used by Hirsch and Bronstad. (4,5) Results from these were compared with the same analyses of the Modified Kansas Corral bridge rail that was tested and reported in reference 3. In all cases, the Western Bridge Rail was equivalent or stronger than the tested rail.

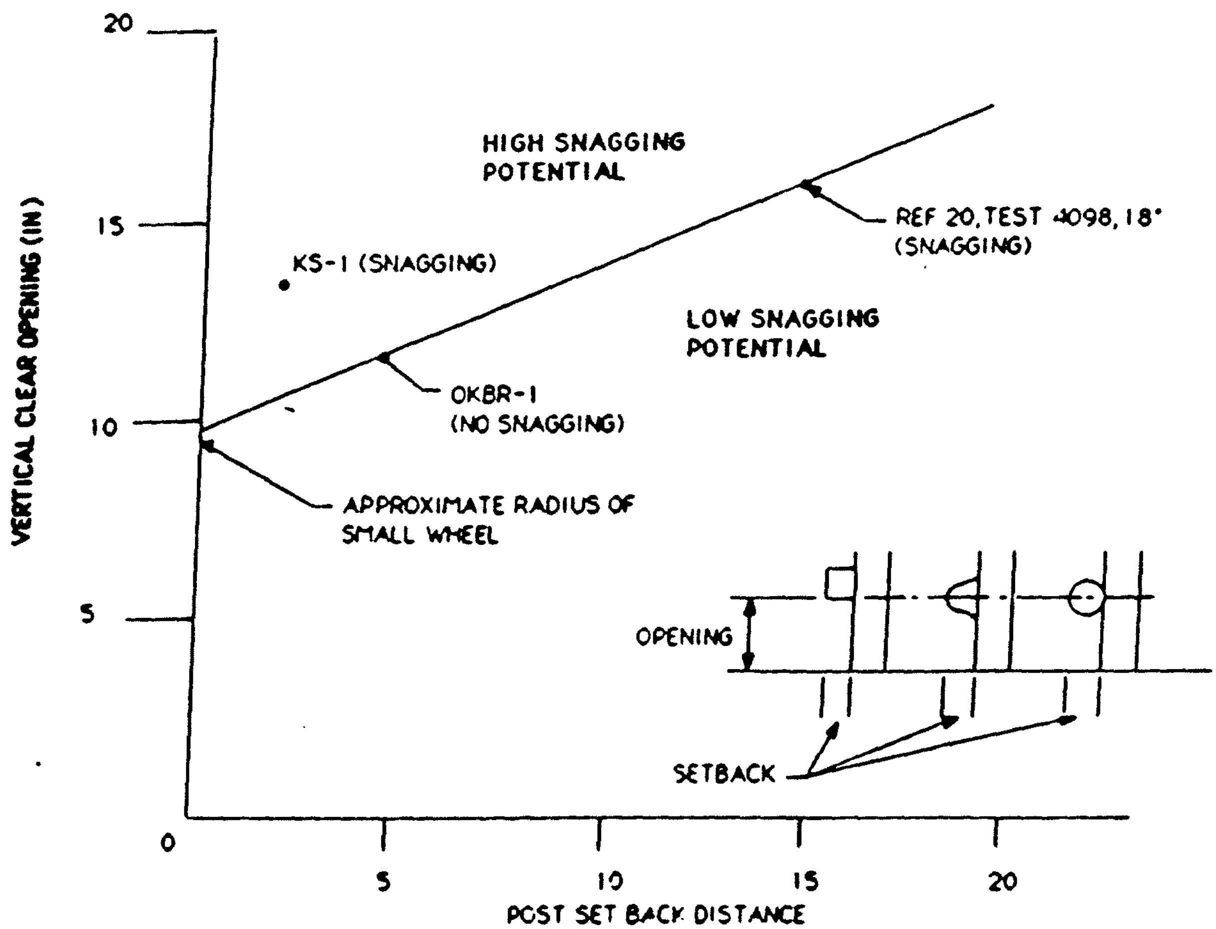


Figure 5. Graphic determination of snagging potential.

Computer Simulation.

Computer simulations were performed on the Modified Kansas Corral bridge rail, the Natchez Trace bridge rail, and the Aluminum Tri-Rail bridge rail with sidewalk. NARD was the computer program that was used because of its three-dimensional capability. The impact conditions that were used correspond to Performance Level 1 from the 1989 AASHTO guidelines, the 1800-lb (817-kg) mini-sedan at 50 mi/h (80.5 km/h) and a 20 degree angle and the 5400-lb (2450-kg) pickup at 45 mi/h (72.4 km/h) and a 20 degree angle. The profiles of the railings were accurately modeled, while the rails themselves were simplified because of the limited number of barrier elements available in NARD and limited funding available for simulation. This limitation particularly affected the Aluminum Tri-Rail bridge rail. The results of the simulations are presented in appendix A and should be used sparingly to predict trends only. In all cases, the vehicles were smoothly redirected with no indication of vaulting.

Graphs.

Guides for wheel snagging were developed in reference 3. Figure 5 presents the design guideline. This was used to determine the potential of the Aluminum Tri-Rail bridge rail for snagging.

c. Final Designs

Every bridge rail reviewed, with the exception of the Aluminum Tri-Rail bridge rail, remained unchanged. The drawings presented in section B represent the final design. The Aluminum Tri-Rail was modified to include blockouts at the top two rails as shown in figure 6. This configuration was not submitted to full-scale crash evaluation.

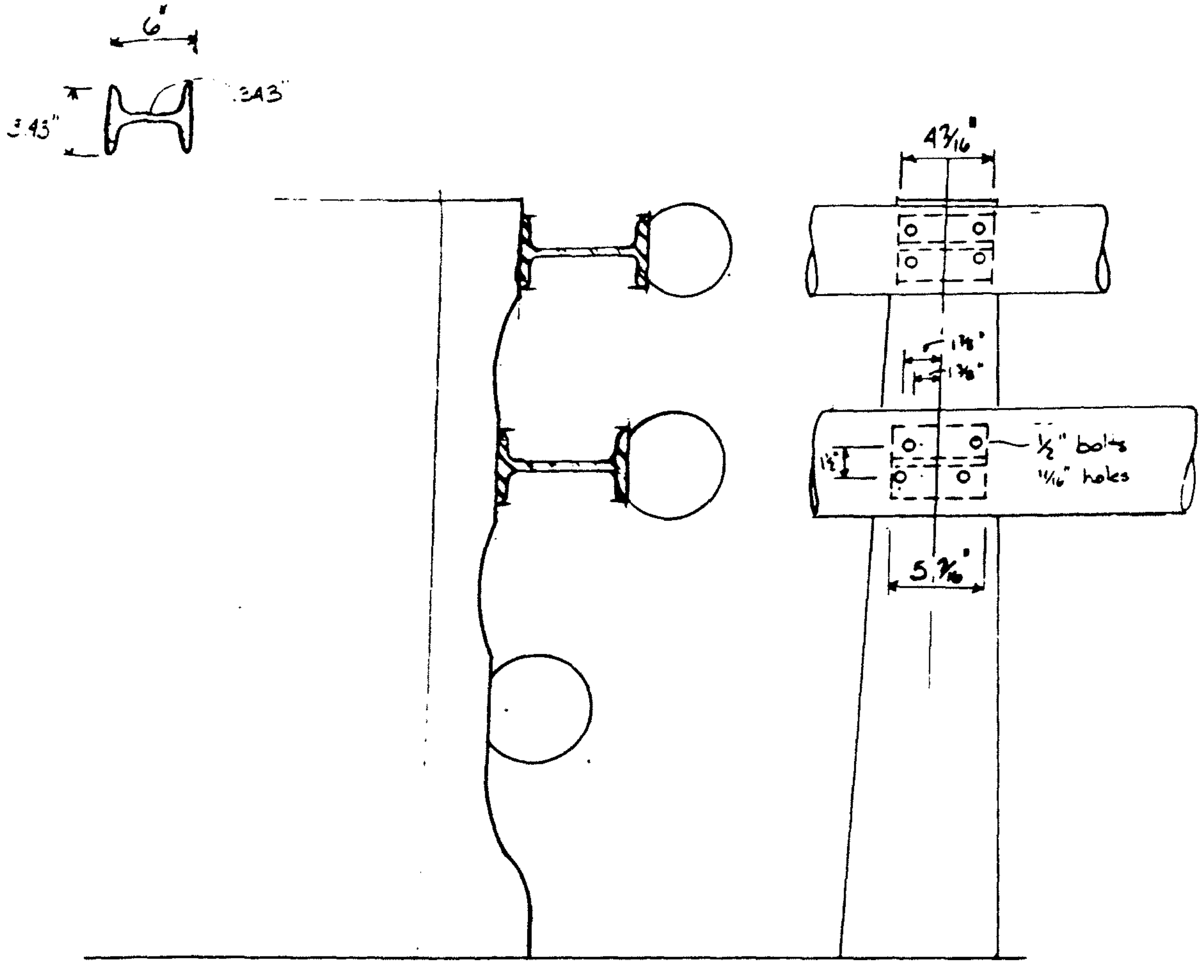


Figure 6. Aluminum Tri-Rail recommended modification.

d. Test Procedures

Two bridge rail designs were evaluated as part of this contract, the Glulam bridge rail and the Modified Kansas Corral rail. For each design, two tests were conducted, one with an 1800-lb (817-kg) sedan and one with a 5400-lb (2450-kg) pickup truck. The test matrix is presented in section 1.

Impact events were recorded from transducers mounted on the vehicle. Extensive high speed and real time film coverage also documented the barrier, vehicle and dummy behavior. Color slides and black and white photographs were taken before, during and after the test to provide additional documentation.

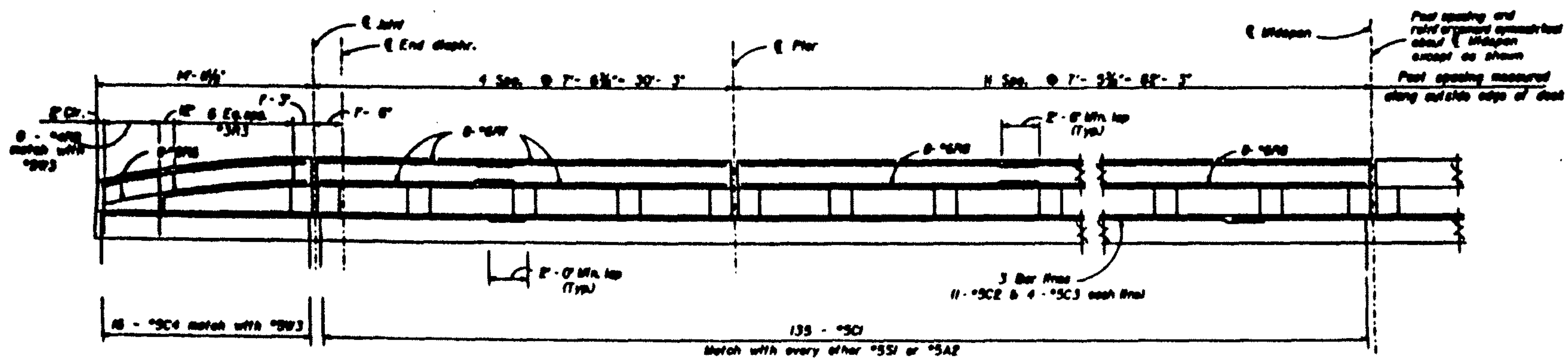
e. Full-Scale Crash Tests

(1) Glulam Bridge Rail

The Glulam bridge rail system was manufactured and provided by Wheeler Consolidated Industries, Inc., of St. Louis Park, Minnesota. The barrier system consists of 18-ft (5.5-m) long by 7-ft (2.1-m) wide by 10-in (25.4-cm) thick laminated wood bridge deck panels. For each test, four panels were used to construct a simulated bridge 72 ft (21.9 m) in length. The panels were positioned and fastened to an existing reinforced concrete deck at the test site. The curb/scuppers, posts, and rail were attached to the deck, according to the instructions given by the manufacturer. Details of the system are shown in figure 1.

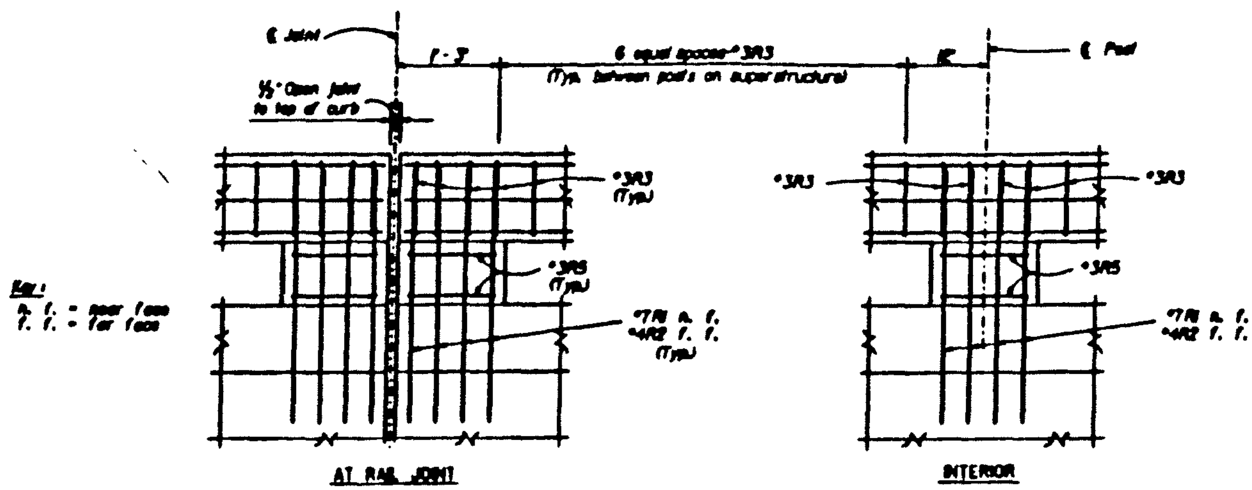
Test WB-1. Small sedan. The purpose of this test was to investigate the dynamic interactions of a small car with the bridge rail and curb. The goals for this test were: (1) the vehicle should be smoothly redirected without exhibiting any tendency to snag or pocket; (2) the vehicle should remain upright throughout the event; and (3) the vehicle after-collision trajectory should not present an undue hazard to other traffic.

The vehicle used in the test was a 1982 Volkswagen Rabbit. The gross test weight, including the dummy and instrumentation, was 1983 lb (900 kg). Figures 7a and 7b contain photographs of the barrier and test vehicle.

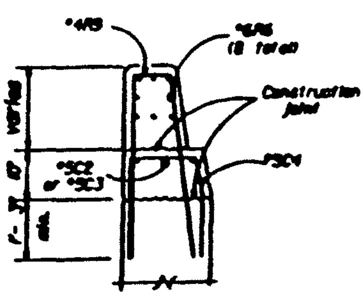


RAIL AND POST ELEVATION
NO SCALE

Figure 3a. Natchez Trace bridge rail.

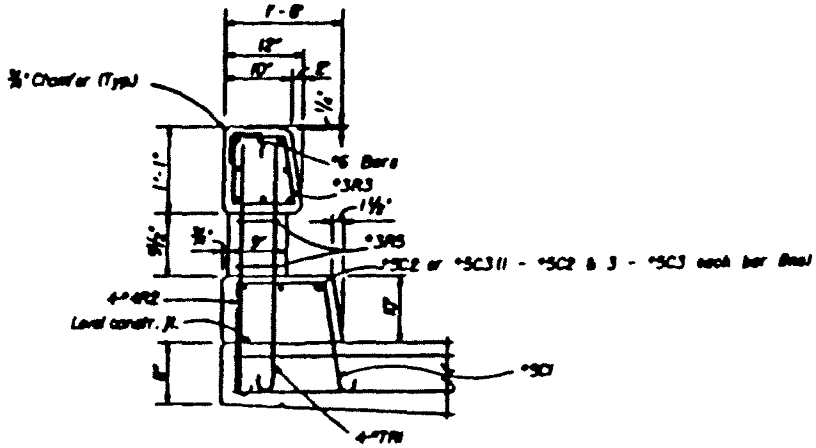


RAIL AND POST DETAILS
SCALE: 1" = 1'-0"



SECTION THRU
END OF WING
SCALE: 3/4" = 1'-0"

Figure 3b. Natchez Trace bridge rail (continued).



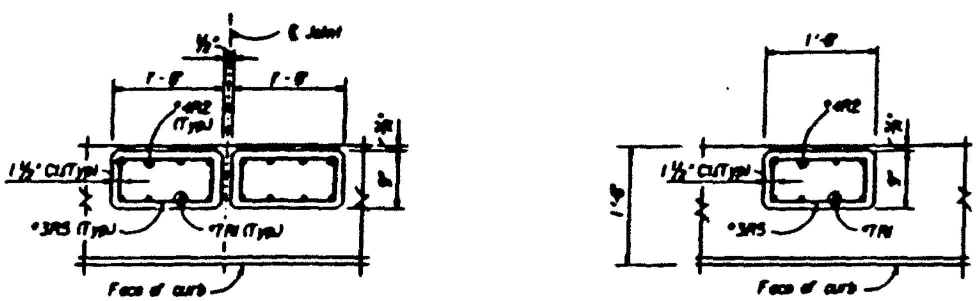
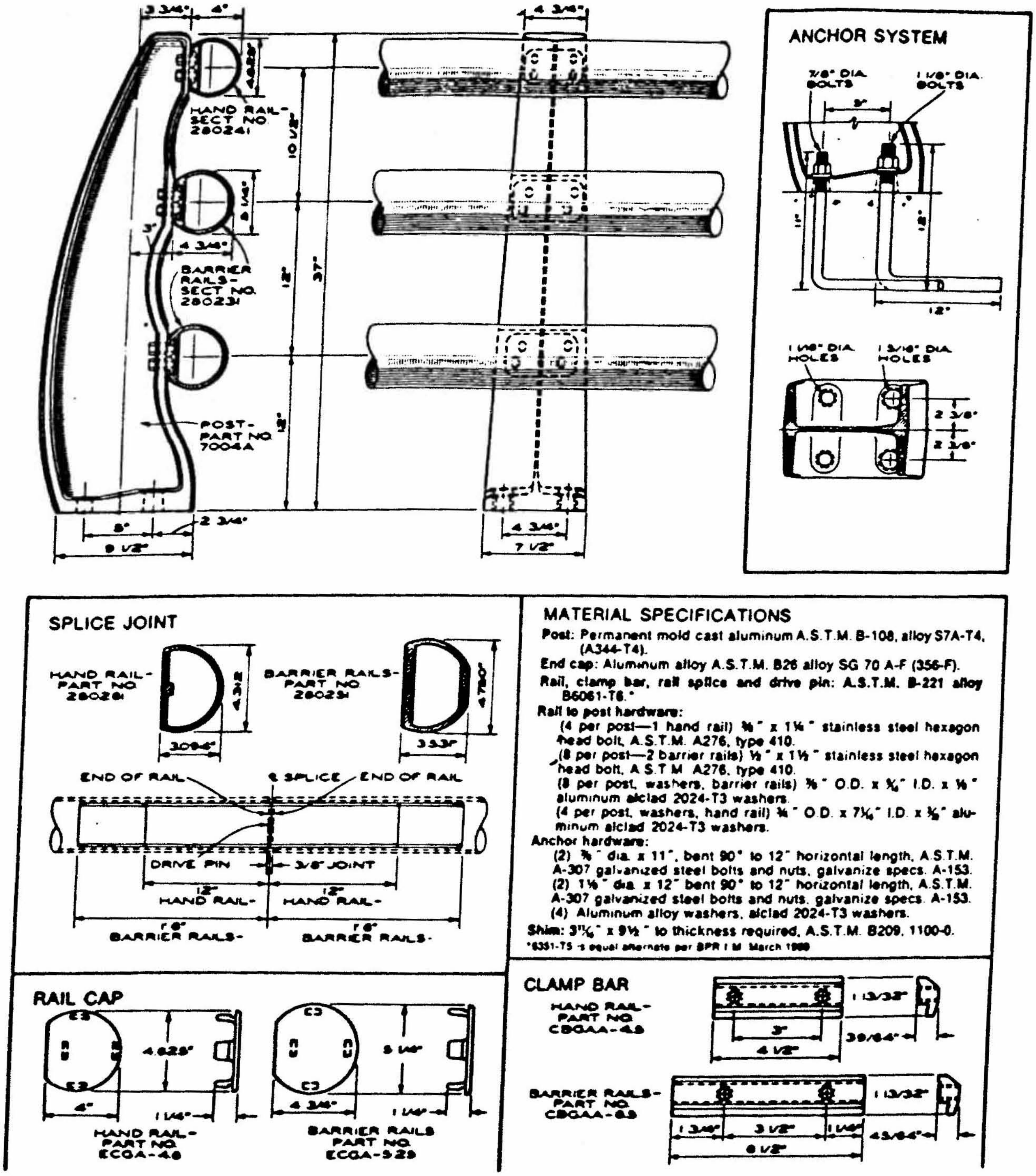


Figure 3c. Natchez Trace bridge rail (continued).



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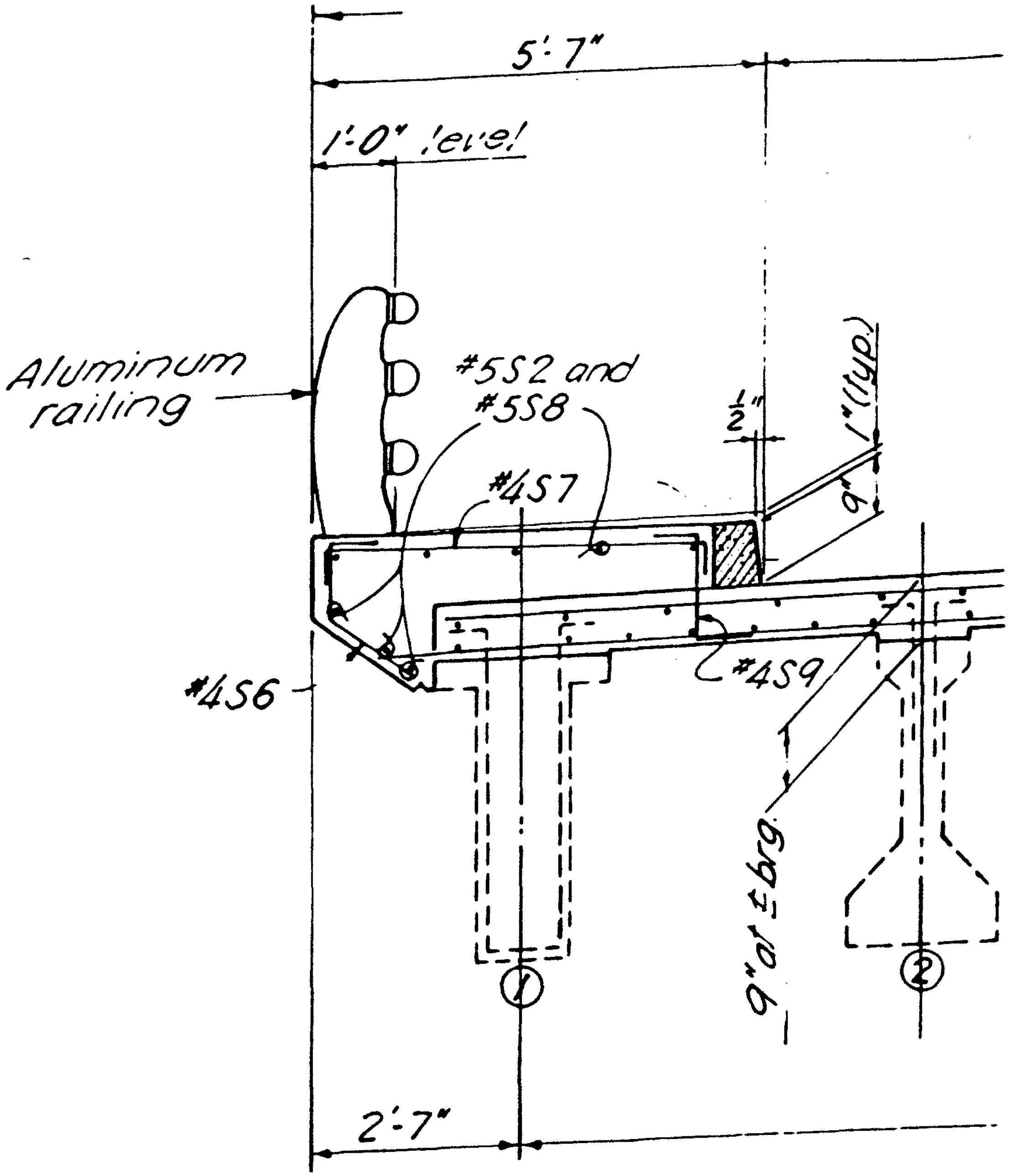

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Strength analyses were performed on this system prior to testing to ensure that this design is equal to or superior to the previously tested Modified Kansas Corral. [3] In addition, a computer simulation was performed to provide insight into vehicle stability while impacting this profile. After reviewing this information, it was determined that this design would perform satisfactorily with no modifications and it was correspondingly evaluated by crash test.

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Two computer simulations were performed on this design to provide insight into vehicle behavior while impacting this profile. No modifications were recommended for this system. This was not confirmed because no full-scale tests were performed.

Aluminum Tri-Rail Bridge Rail With Sidewalk.

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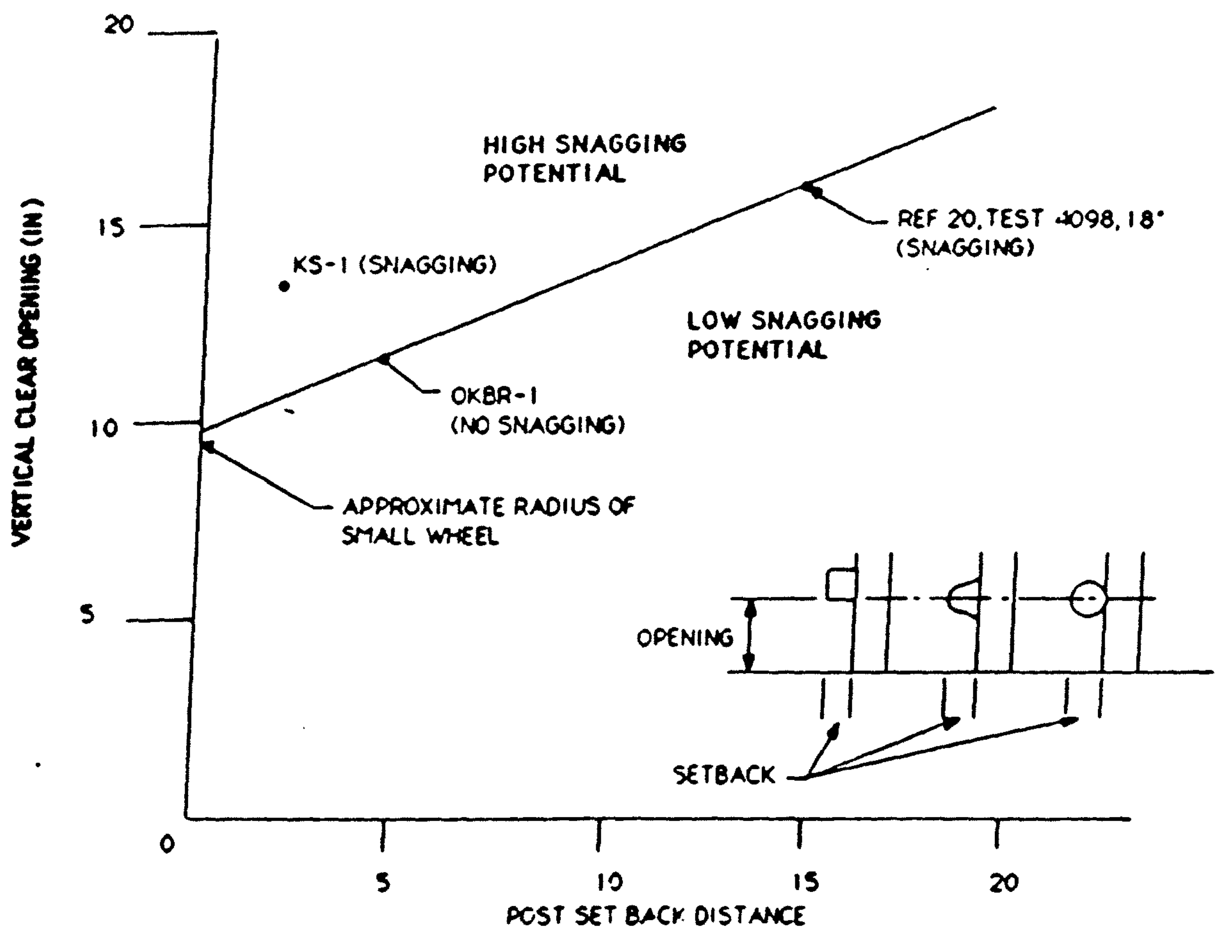
b. Analyses Conducted

Three types of analyses were performed during this study: strength, computer simulation, and wheel snagging using graphs.

Strength.

Elastic analyses were conducted on the Modified Kansas Corral bridge rail using the BRIDGE program (3) and the yield line analyses used by Hirsch and Bronstad. (4,5) Results from these were compared with the same analyses of the Modified Kansas Corral bridge rail that was tested and reported in reference 3. In all cases, the Western Bridge Rail was equivalent or stronger than the tested rail.



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Guides for wheel snagging were developed in reference 3. Figure 5 presents the design guideline. This was used to determine the potential of the Aluminum Tri-Rail bridge rail for snagging.

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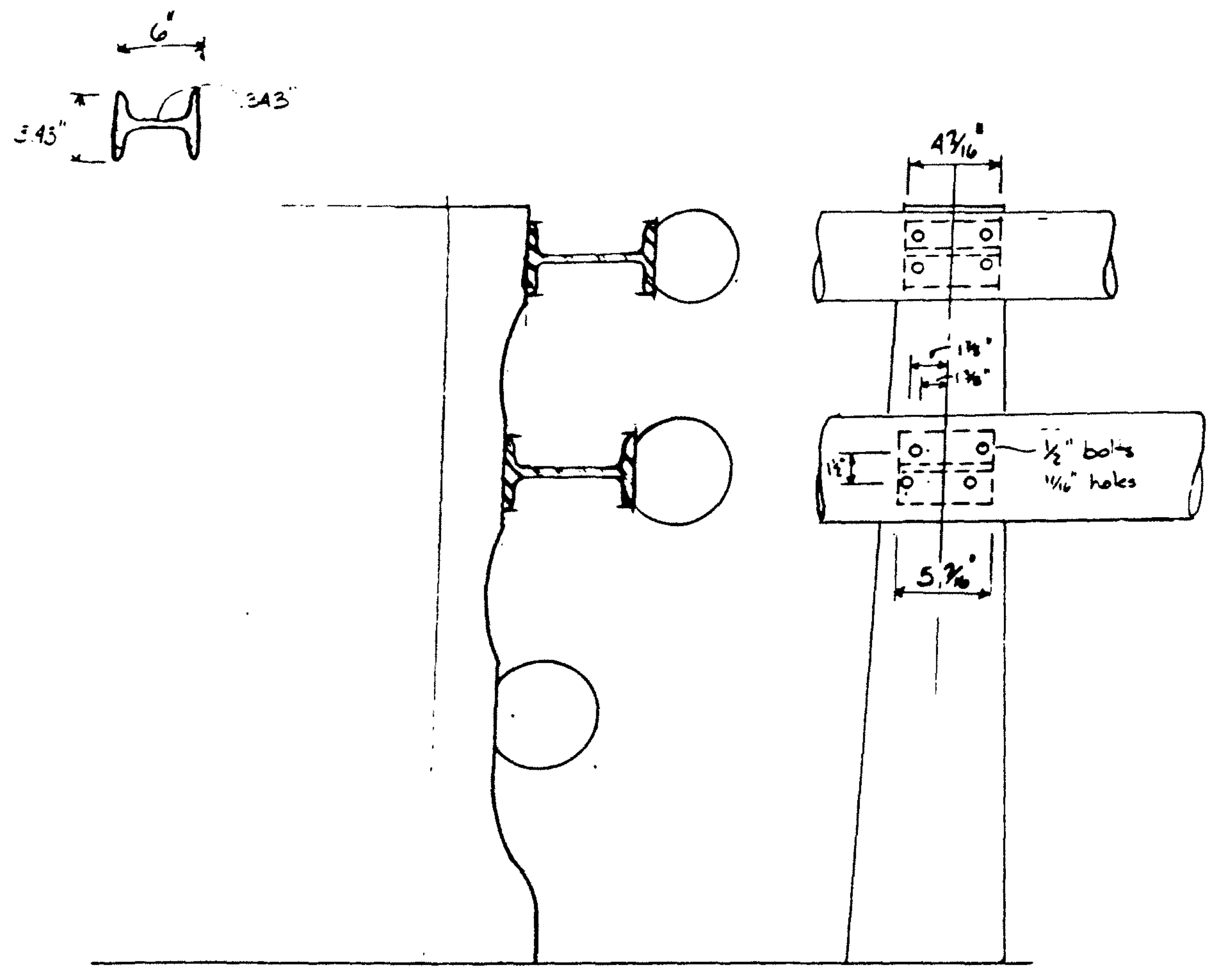


Figure 6. Aluminum Tri-Rail recommended modification.

d. Test Procedures

Two bridge rail designs were evaluated as part of this contract, the Glulam bridge rail and the Modified Kansas Corral rail. For each design, two tests were conducted, one with an 1800-lb (817-kg) sedan and one with a 5400-lb (2450-kg) pickup truck. The test matrix is presented in section 1.

Impact events were recorded from transducers mounted on the vehicle. Extensive high speed and real time film coverage also documented the barrier, vehicle and dummy behavior. Color slides and black and white photographs were taken before, during and after the test to provide additional documentation.

e. Full-Scale Crash Tests

(1) Glulam Bridge Rail

The Glulam bridge rail system was manufactured and provided by Wheeler Consolidated Industries, Inc., of St. Louis Park, Minnesota. The barrier system consists of 18-ft (5.5-m) long by 7-ft (2.1-m) wide by 10-in (25.4-cm) thick laminated wood bridge deck panels. For each test, four panels were used to construct a simulated bridge 72 ft (21.9 m) in length. The panels were positioned and fastened to an existing reinforced concrete deck at the test site. The curb/scuppers, posts, and rail were attached to the deck, according to the instructions given by the manufacturer. Details of the system are shown in figure 1.

Test WB-1. Small sedan. The purpose of this test was to investigate the dynamic interactions of a small car with the bridge rail and curb. The goals for this test were: (1) the vehicle should be smoothly redirected without exhibiting any tendency to snag or pocket; (2) the vehicle should remain upright throughout the event; and (3) the vehicle after-collision trajectory should not present an undue hazard to other traffic.

The vehicle used in the test was a 1982 Volkswagen Rabbit. The gross test weight, including the dummy and instrumentation, was 1983 lb (900 kg). Figures 7a and 7b contain photographs of the barrier and test vehicle.

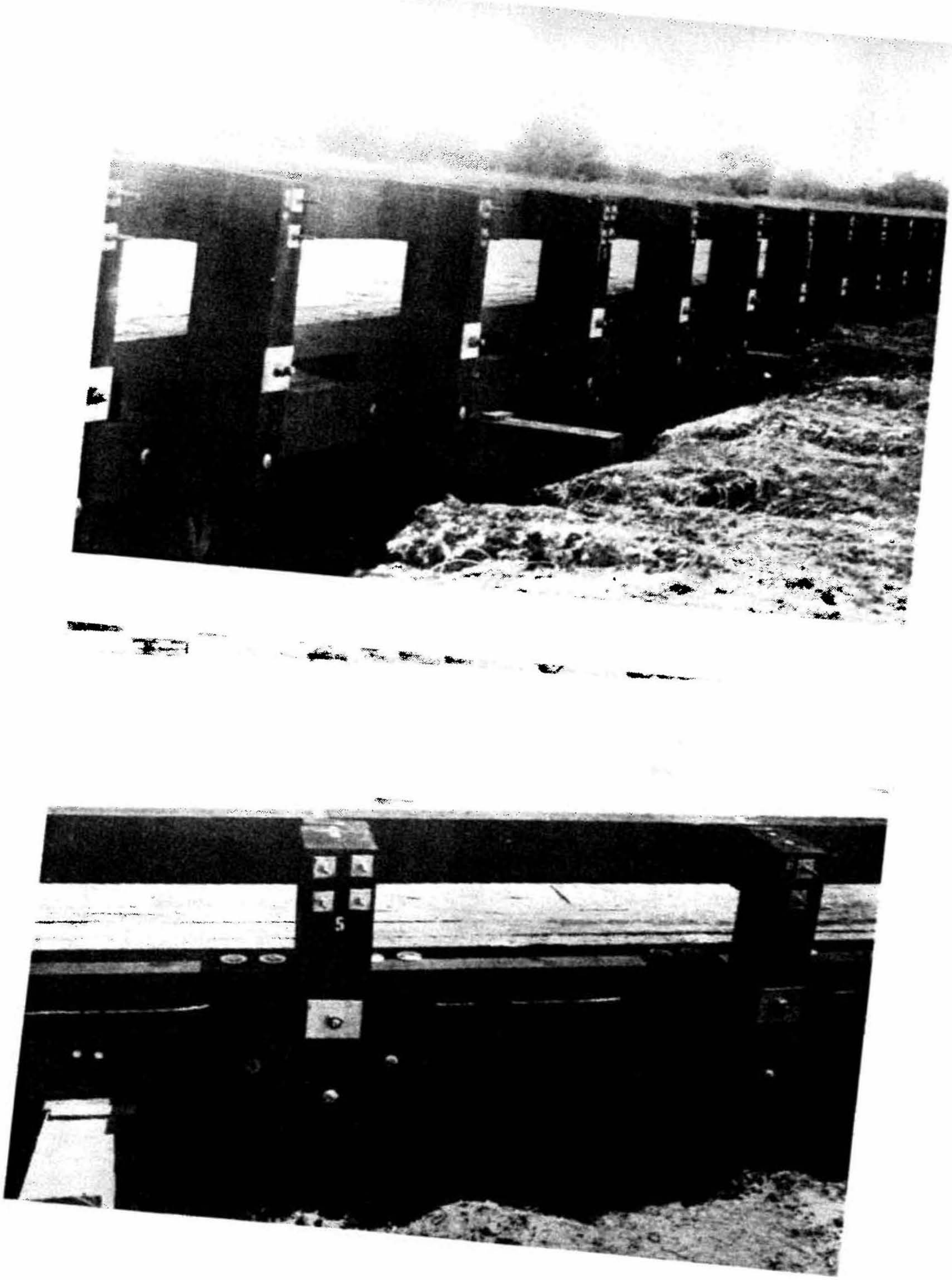


Figure 7a. Test WB-1 pre-test details.

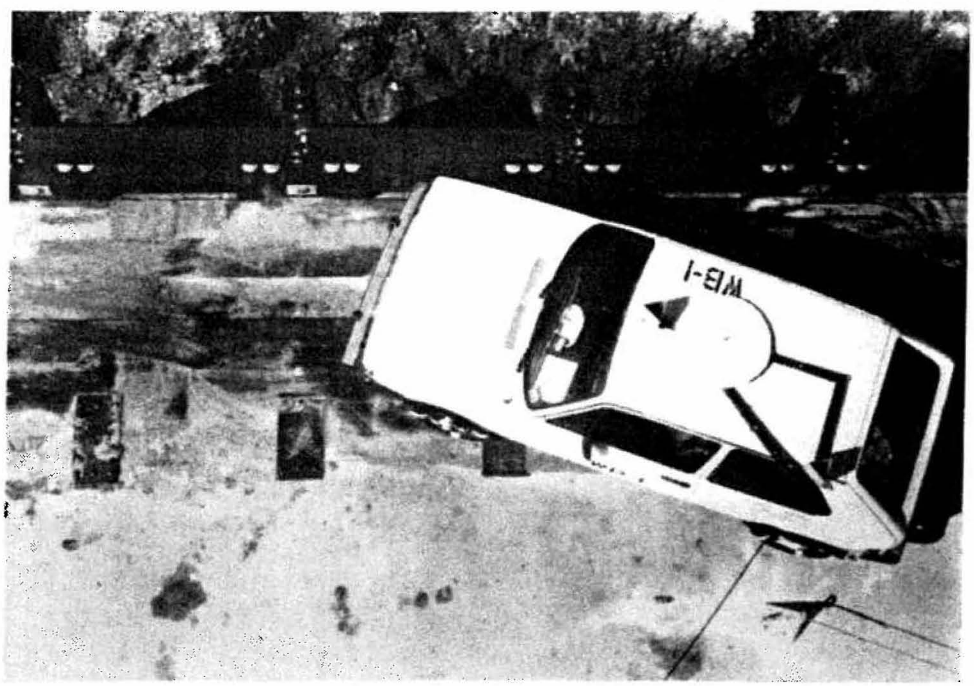
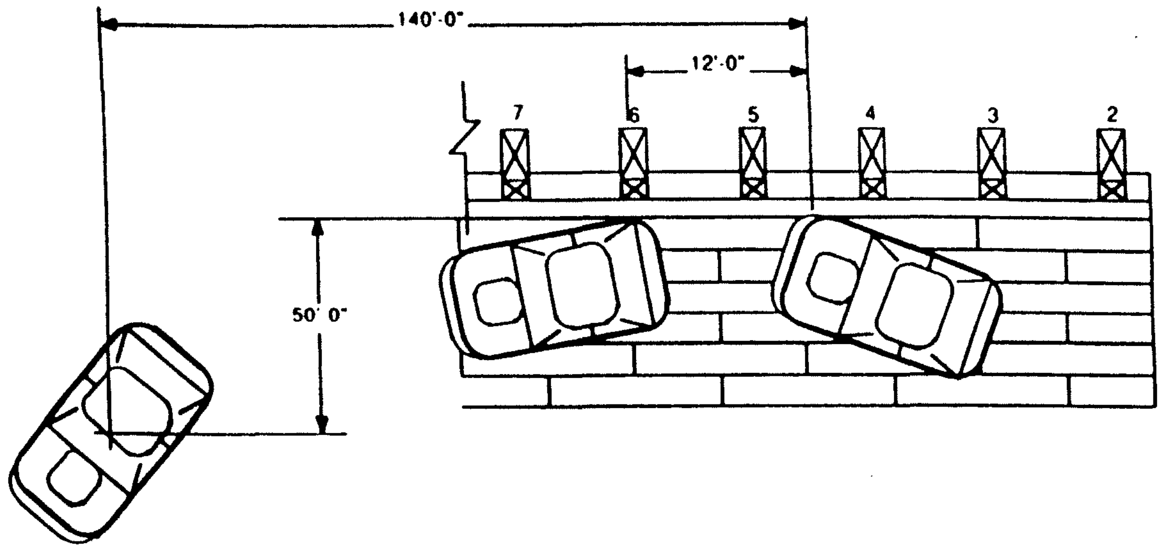


Figure 7b. Test WB-1 pre-test details (continued).

Test results are summarized in figure 8. Impact conditions were 59.2 mi/h (95.3 km/h) at a 20.0° impact angle. The vehicle impacted the barrier 29 inches downstream of post 5. The vehicle remained in contact with the barrier for 12.5 ft (3.8 m) before redirection at a -12.0° angle. During the impact sequence, the right front tire/wheel became engaged between the top of the curb and the bottom of the rail. Measurements of the tire/wheel path indicated a maximum of 5 in (13 cm) of lateral engagement. Since the curb is 12 in (30.5 cm) wide, there was no propensity for the wheel to snag on a post during impact.



Test No.	WB-1
Test Date	Sept. 21, 1988
Installation Length - ft [m]	72 [22]
Beam	
Member	6-in (15.2 cm) x10-3/4-in (27.3) laminated wood
Length - ft [m]	18.0 [5.5]
Maximum Deflections - in. [cm]	
Permanent	1.5 [3.8]
Dynamic	6.3 [16.0]
Post	
Details of the posts, blockouts, curb, and deck are included in figure 8.	
Vehicle	1982 V.W. Rabbit
Mass - lb [kg]	
Test Inertia	1818 [825]
Dummy	165 [75]
Gross Test Weight	1983 [900]
Speed - mi/h [km/h]	59.2 [95.3]

Angle - degrees	
Impact	20
Exit	-12.0
Occupant Impact Velocity - ft/s [m/s]	
Forward (accel)	-10.6 [-3.2]
Lateral (accel)	-18.6 [-5.7]
Occupant Ridedown Accelerations - g's	
Forward (accel)	-0.7
Lateral (accel)	7.6
Maximum 50 m/s Avg Accelerations - g's	
Longitudinal (accel)	-5.0
Lateral (accel)	8.5
Vehicle Damage	
TAD	01-FR-4
VDI	01FREE6

Figure 8. WB-1 small sedan test results.

No significant pitch, roll or yaw was noted during impact and redirection. The vehicle came to rest 140 ft (43 m) downstream of the impact point and 50 ft (15 m) out from the barrier plane. The vehicle brakes were applied at approximately 100 ft (30 m) after impact. Table 2 presents the after impact vehicle trajectory.

Table 2. After impact vehicle trajectory, test WB-1.

Location[1]	Distance[2]
0	0
10	-0.2
20	1.5
30	3.3
40	5.2
50	9.0
60	10.5
70	12.8
80	16.1
90	19.8
100	24.5

[1] Distance measured in the downstream direction with 0 as the point of impact.

[2] Measured perpendicular to the barrier plane at the front tire on the impact side of the vehicle.

All dimensions are in feet. 1 ft = 0.305 m

Maximum dynamic barrier deflection observed from the overhead data camera was 6.3 in (16.0 cm). Measurements of the barrier after the test showed a maximum of 1.5 in (3.8 cm) permanent deflection. Maximum 50 m/s average accelerations from transducer data were -5.0 g's (longitudinal) and 7.6 g's (lateral). These results are exhibited in table 3.

Table 3. Permanent barrier deflections, test WB-1.

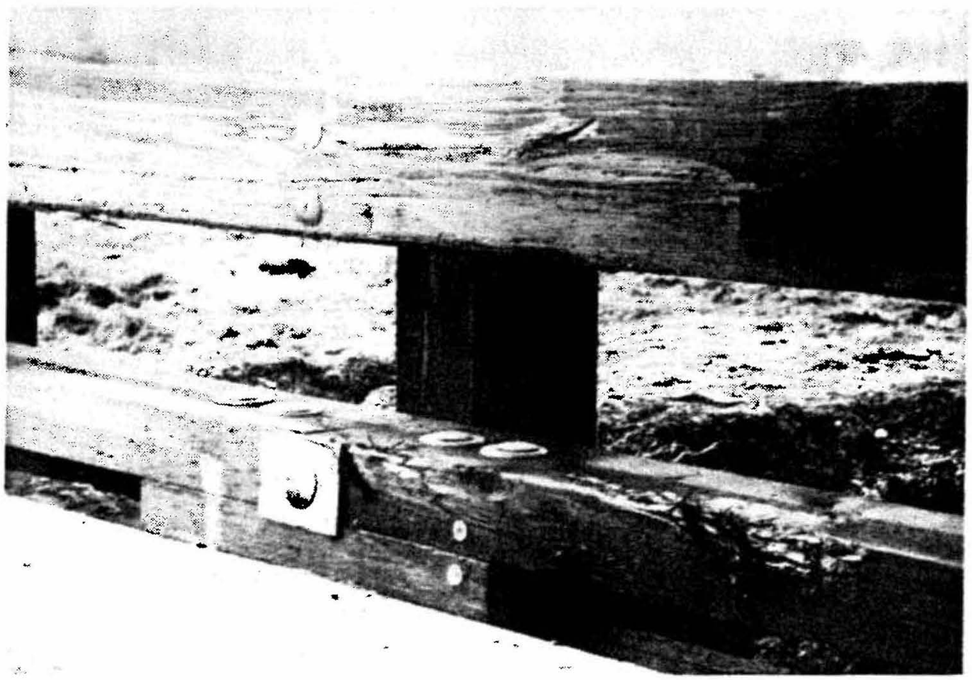
Post/Location	Deflection
3	0.3
4	0.4
5	0.5
6	0.8
7	1.5
8	1.3
9	0.8
10	0.4
11	0.2

All dimensions are in inches. 1 in = 2.54 cm

Figures 9a through 9c present photographs of damage to the vehicle and barrier. Damage to the barrier consisted of scuff marks and minor gouging on the rail and curb. Inspection of the barrier system revealed no fractured posts or beam members. Observation of the deck showed delamination between the second and third deck timbers in the impact area. The delamination of the deck occurred from the location of post 3 to post 9 with a maximum separation of 0.5 in (1.3 cm) on the top surface of the deck, approximately 3 ft (0.9 m) downstream from post 6. Maximum separation observed on the bottom surface of the deck was 0.1 in (0.3 cm). Several drive spikes in the impact affected area of the deck showed evidence of minor pullout.

Damage to the vehicle consisted of sheet metal deformation of the hood, right front fender, side, and rear fender. The windshield was cracked because of a pillar deformation. Both right side tires were blown out during impact. Vehicle damage was considered commensurate with the severity of the impact. Measurements of vehicle damage are given in table 4.

Figure 9a. Test WB-1 post-test details.



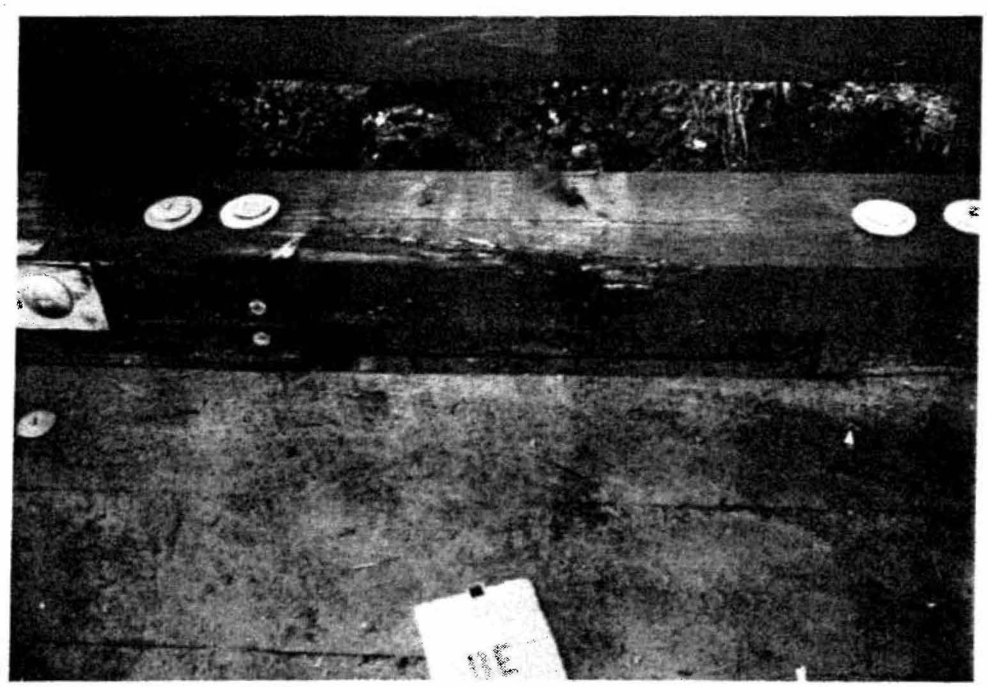


Figure 9b. Test WB-1 post-test details (continued).

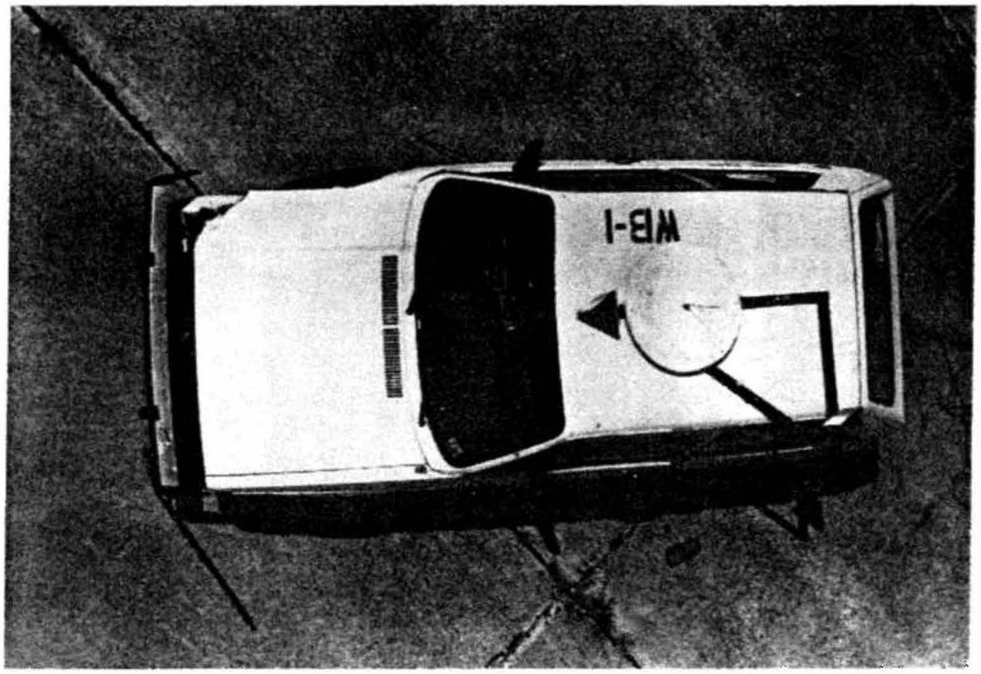


Figure 9c. Test WB-1 post-test details (continued).

Table 4. Vehicle damage measurements, test WB-1.

	Before Test	After Test	Crush
L	52	52	Not Applicable
C-1	2.0	2.0	0.0
C-2	0.0	5.6	5.6
C-3	0.0	6.0	6.0
C-4	0.0	7.5	7.5
C-5	3.0	10.0	7.0
C-6	4.0	12.1	8.1

Maximum crush of 12.0 at a location of 15.0 to the right of vehicle centerline.

All dimensions are in inches. 1 in = 2.54 cm

Test WB-2. Pickup truck. The purpose of this test was to investigate the dynamic interactions of the pickup truck with the bridge rail and curb. Goals for this test were: (1) the vehicle must not penetrate or vault over the system; (2) the vehicle should remain upright throughout the event; and (3) the vehicle after-collision trajectory should not present an undue hazard to other traffic.

The barrier selected was the same as that used in test WB-1. However, one deck panel with curb/rail was replaced in the impact area to ensure system integrity. The vehicle used was a 1984 Ford F150 pickup truck. The gross test weight, including the dummy and instrumentation, was 5419 lb (2458 kg). Figures 10a and 10b contain photographs of the barrier and test vehicle.

Test results are summarized in figure 11. Impact conditions were 47.5 mi/h (76.4 km/h) at a 20° impact angle. The vehicle impacted the barrier midway between post 5 and 6. The vehicle remained in contact with the barrier

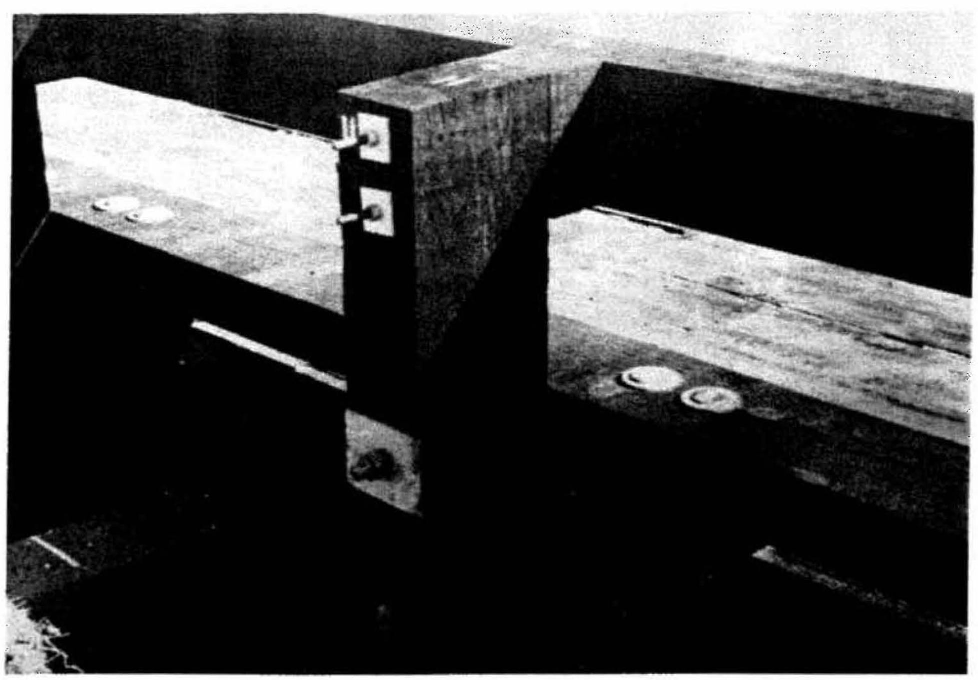
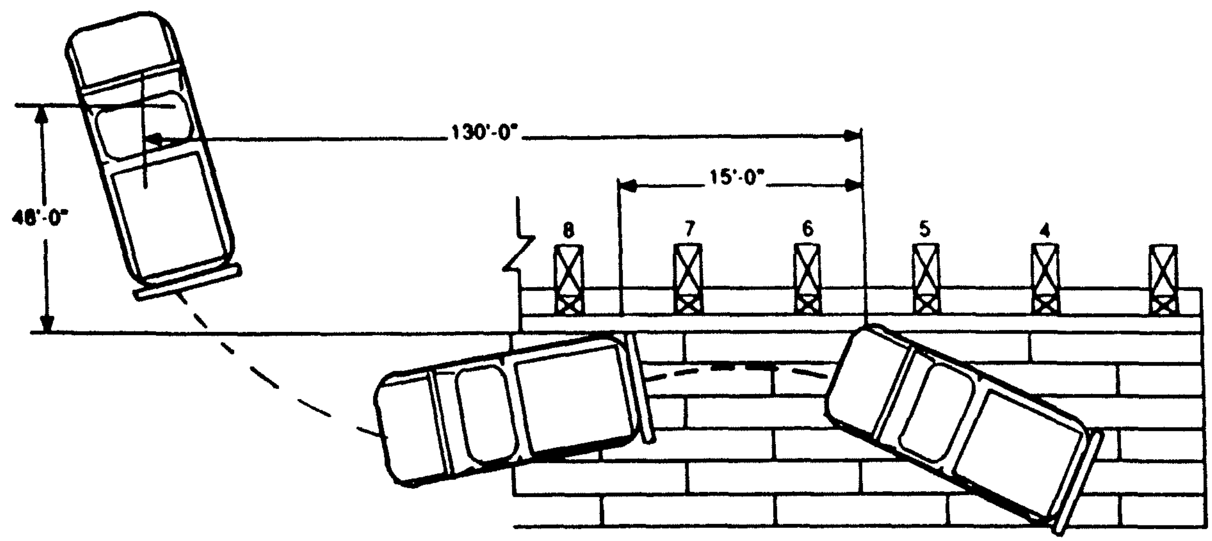


Figure 10a. Test WB-2 pre-test details.

Figure 10b. Test WB-2 pre-test details (continued).



Test No.	WB-2
Test Date	Sept. 27, 1988
Installation Length - ft [m]	72 [22]
Beam	
Member	6-in (15.2 cm) x 10-3/4 -in (27.3 cm) laminated wood
Length - ft [m]	18.0 [5.5]
Maximum Deflections - in. [cm]	
Permanent	2.3 [5.8]
Dynamic	8.5 [21.6]
Post	
Details of the posts, blockouts, curb, and deck are included in figure 11.	
Vehicle	1984 Ford F150 Pickup
Mass - lb [kg]	
Test Inertia	5254 [2383]
Dummy	165 [75]
Gross Test Weight	5419 [2458]
Speed - mi/h [km/h]	47.5 [76.4]

Angle - degrees	
Impact	20
Exit	-4.9
Occupant Impact Velocity - ft/s [m/s]	
Forward (accel)	8.1 [2.5]
Lateral (accel)	-17.2 [-5.2]
Occupant Ridedown Accelerations - g's	
Forward (accel)	-1.7
Lateral (accel)	6.9
Maximum 50 m/s Avg Accelerations - g's	
Longitudinal (accel)	-3.2
Lateral (accel)	5.2
Vehicle Damage	
TAD	01-FR-4
VDI	01FREE6

Figure 11. WB-2 pickup truck test results.

for 15.0 ft (4.6 m) before redirection at an angle of -4.9°. The vehicle showed no tendency to snag on the curb or posts during the impact sequence. No significant pitch, roll or yaw was noted during impact and redirection. The vehicle came to rest 130 ft (40 m) downstream of the impact point and 48 ft (15 m) out from the barrier plane. The vehicle brakes were applied at approximately 100 ft (30 m) after impact. Table 5 presents the vehicle trajectory after impact.

Table 5. After impact vehicle trajectory, test WB-2.

Location[1]	Distance[2]
0	0
10	-0.1
20	0.2
30	1.5
40	2.0
50	3.4
60	1.4
70	0.0
80	-3.0
90	-6.1
100	11.2

[1] Distance measured in the downstream direction with 0 as the point of impact.

[2] Measured perpendicular to the barrier plane at the front tire on the impact side of the vehicle.

All dimensions are in feet. 1 ft = 0.305 m

Maximum dynamic barrier deflection observed from the overhead data camera was 8.5 inches (21.6 cm). Measurements of the barrier after the test, listed in table 6, show a maximum permanent deflection of 2.3 in (5.8 cm). Maximum 50 ms average accelerations from transducer data were -3.2 g's (longitudinal) and 5.2 g's (lateral).

Table 6. Permanent barrier deflections, test WB-2.

Post/Location	Deflection
3	0.5
4	0.8
5	1.0
6	1.5
7	2.3
8	2.3
9	1.5
10	1.0
11	0.5

All dimensions are in inches. 1 in = 2.54 cm

Damage to the vehicle consisted of sheet metal deformation of the right front fender, side, and rear fender. The windshield remained intact, and the right front tire was blown out during impact. The tire remained on the wheel during redirection, but became detached during subsequent vehicle retrieval from the runout path. Vehicle damage was considered commensurate with the severity of the impact. Vehicle damage measurements are contained in table 7.

Table 7. Vehicle damage measurements, test WB-2.

	Before Test	After Test	Crush
L	58	58	Not Applicable
C-1	0.4	0.3	-0.1
C-2	0.8	3.3	+2.5
C-3	0.0	2.5	+2.5
C-4	0.0	4.0	+4.0
C-5	0.0	7.1	+7.1
C-6	1.5	11.5	+10.0

Maximum crush of 15.8 at a location of 25 to the right of vehicle centerline.

All dimensions are in inches. 1 in = 2.54 cm

Figures 12a and 12b present photographs of damage to the vehicle and barrier. Damage to the barrier consisted of scuff marks and minor gouging on the rail and curb. Inspection of the barrier system revealed no fractured posts or beam members. Observation of the deck showed delamination between the second and third deck timbers in the impact area. The delamination of the deck occurred from the location of post 3 to post 9 with a maximum separation of 0.8 in (2.0 cm) on the top surface of the deck about 3 ft (0.9 m) downstream from post 6. Maximum separation observed on the bottom surface of the deck was 0.1 in (0.3 cm). Several drive spikes in the impact affected area of the deck showed evidence of minor pullout.

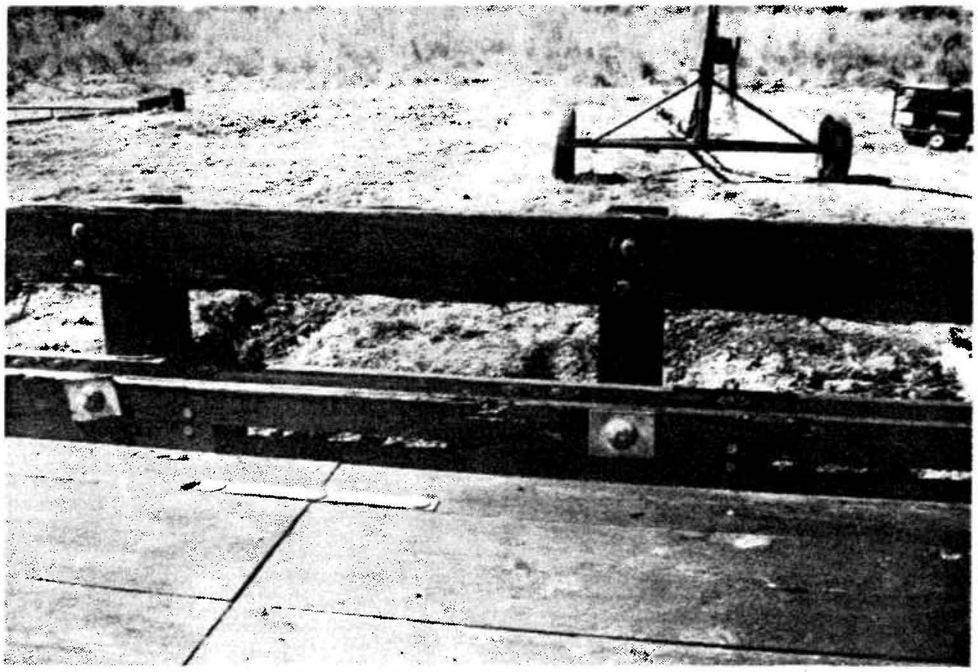


Figure 12a. Test WB-2 post-test details.

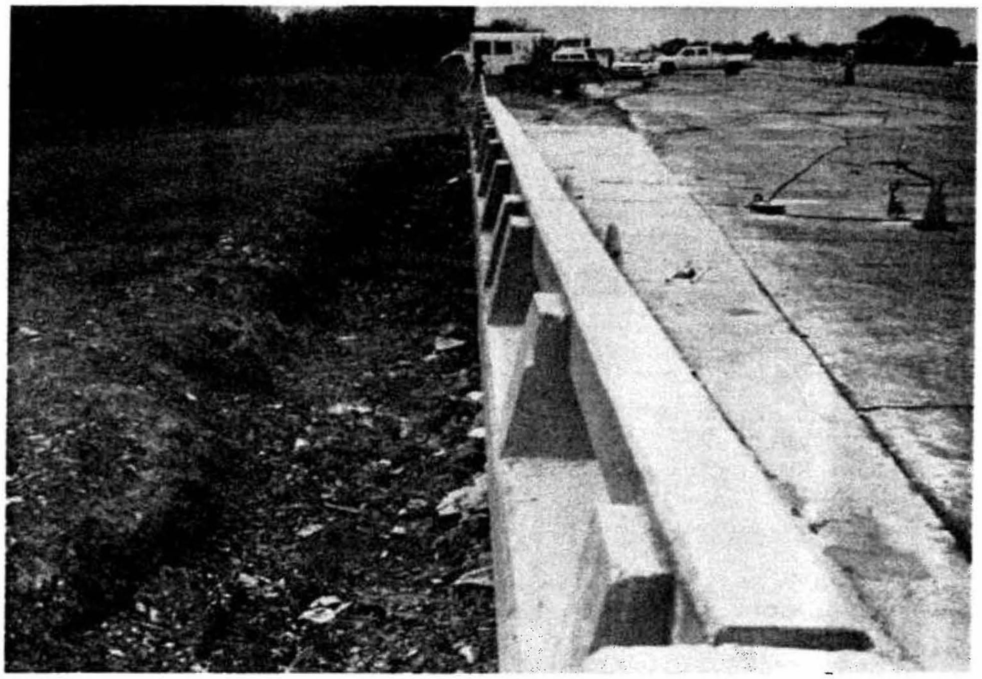
Figure 12b. Test WB-2 post-test details (continued).

(2) Modified Kansas Corral Bridge Rail

The Modified Kansas Corral bridge rail consisted of concrete posts, rails and a 6 in (15 cm) curb, and was constructed on a simulated bridge deck. The total length of the system was 69 ft (21 m). Details of the system are shown in figure 2.

Test KM-1. Small sedan. The purpose of this test was to investigate the dynamic interactions of the small car with the bridge rail and curb. The goals for this test were: (1) the vehicle should be smoothly redirected without exhibiting any tendency to snag or pocket; (2) the vehicle should remain upright throughout the event; and (3) the vehicle after-collision trajectory should not present undue hazard to other traffic.

The vehicle used in this test was a 1982 Honda Civic. Gross test weight, including the dummy and the instrumentation, was 1990 lb (902 kg). Figures 13a and 13b contain photographs of the barrier and test vehicle.



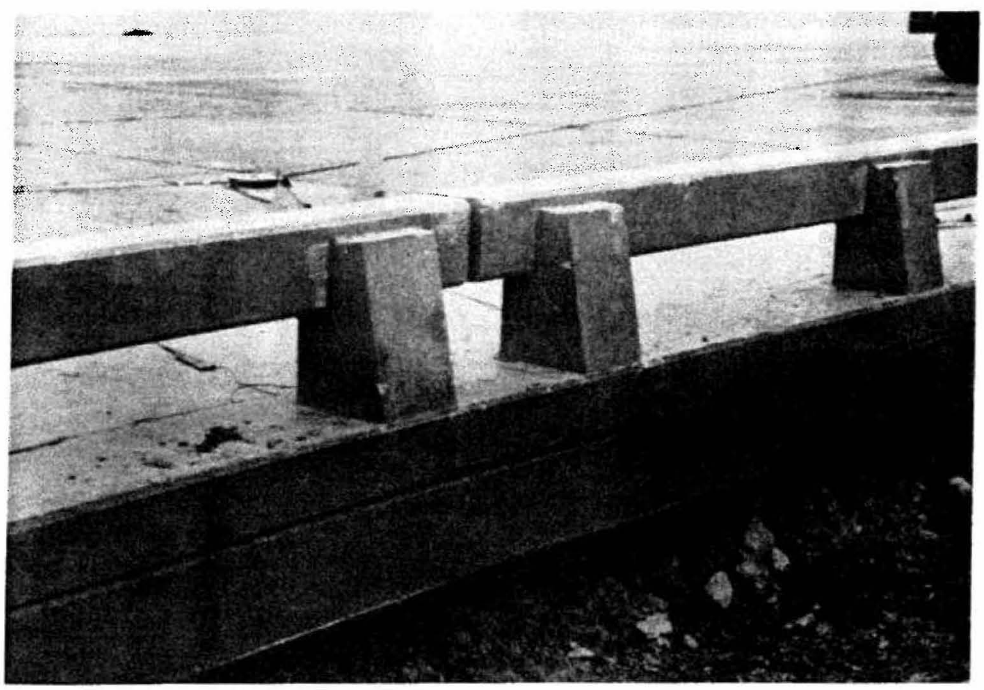
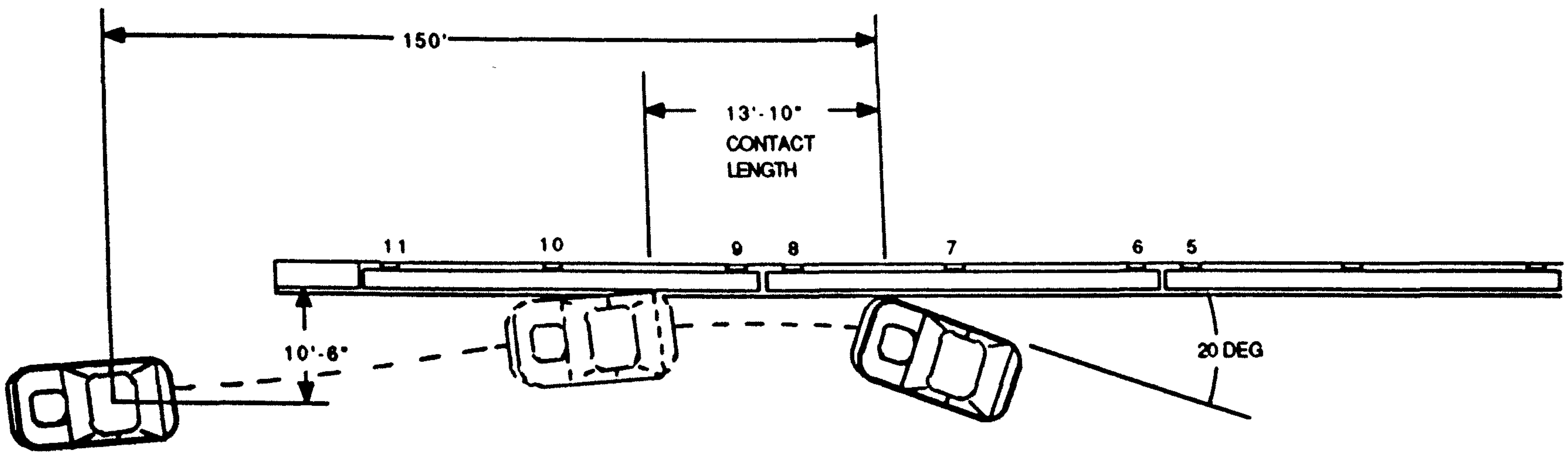


Figure 13a. Test KM-1 pre-test details.

Figure 13b. Test KM-1 pre-test details (continued).

Test results are summarized in figure 14. Impact conditions were 51.0 mi/h (82.0 km/h) at a 20.5° impact angle. The vehicle impacted the barrier midway between posts 7 and 8. The vehicle remained in contact with the barrier for 13.8 ft (4.2 m) before redirection at a -3.7° angle. During the impact sequence, the right front tire/wheel became engaged between the top of the curb and the bottom of the rail, with the wheel hub contacting post 8. Although post 8 exhibited minor gouging, observation of the test film showed no significant snag potential.



Test No.	KM-1
Test Date	Nov, 18, 1988
Installation Length - ft [m]	69 [21]
Beam	
Member	9-in (22.8 cm)x 10-in (25.4 cm) reinforced concrete
Length - ft [m]	2 @ 24 (7.3) and 1 @ 16 (4.9)
Maximum Deflections - in. [cm]	
Permanent	none
Dynamic	none
Post	
Details of the posts, blockouts, curb, and deck are included in figure 14.	
Vehicle	1982 Honda Civic
Mass - lb [kg]	
Test Inertia	1825 [827]
Dummy	165 [75]
Gross Test Weight	1990 [902]
Speed - mi/h [km/h]	51.0 [82.0]

Angle - degrees	
Impact	20.5
Exit	-3.7
Occupant Impact Velocity - ft/s [m/s]	
Forward (film/accel)	10.6 [3.2]/9.2 [2.8]
Lateral (film/accel)	-15.6 [-4.8]/-16.7 [-5.1]
Occupant Ridedown Accelerations - g's	
Forward (accel)	-1.1
Lateral (accel)	10.0
Maximum 50 m/s Avg Accelerations - g's	
Longitudinal (accel)	-2.8/-5.4
Lateral (accel)	4.0/8.1
Vehicle Damage	
TAD	01-FR-4
VDI	01FREE6

Figure 14. KM-1 small sedan test results.

The vehicle remained stable during impact and redirection. It came to rest 150 ft (46 m) downstream of the impact point and 10.5 ft (3.2 m) out from the barrier plane. The vehicle brakes were not applied after impact. Table 8 presents the vehicle trajectory after impact.

Table 8. After impact vehicle trajectory, test KM-1.

Location[1]	Distance[2]
0	0
10	-0.2
20	0.8
30	1.5
40	2.3
50	3.2
60	4.0
70	4.8
80	5.6
90	6.3
100	6.9

[1]Distance measured in the downstream direction with 0 as the point of impact.

[2]Measured perpendicular to the barrier plane at the front tire on the impact side of the vehicle.

All dimensions are in feet. 1 ft = 0.305 m

The barrier did not deflect during impact. The film data indicated maximum 50 m/s average accelerations of -2.8 g's (longitudinal) and 4.0 g's (lateral). Maximum 50 m/s average accelerations from transducer data were -5.4 g's (longitudinal) and 8.1 g's (lateral).

Figures 15a and 15b show photographs of vehicle and barrier damage. Damage to the barrier consisted of cosmetic scuff marks on the rail and curb. Minor gouging was noted on post 8. Inspection of the barrier system revealed no fractured posts or rail members. The barrier was considered undamaged.

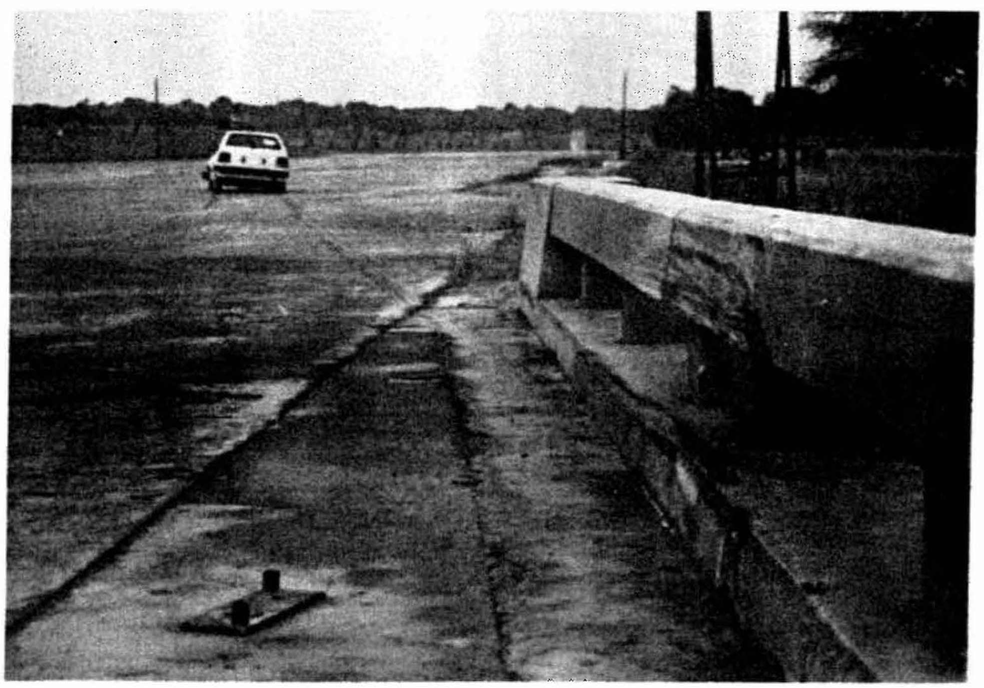


Figure 15a. Test KM-1 post-test details.

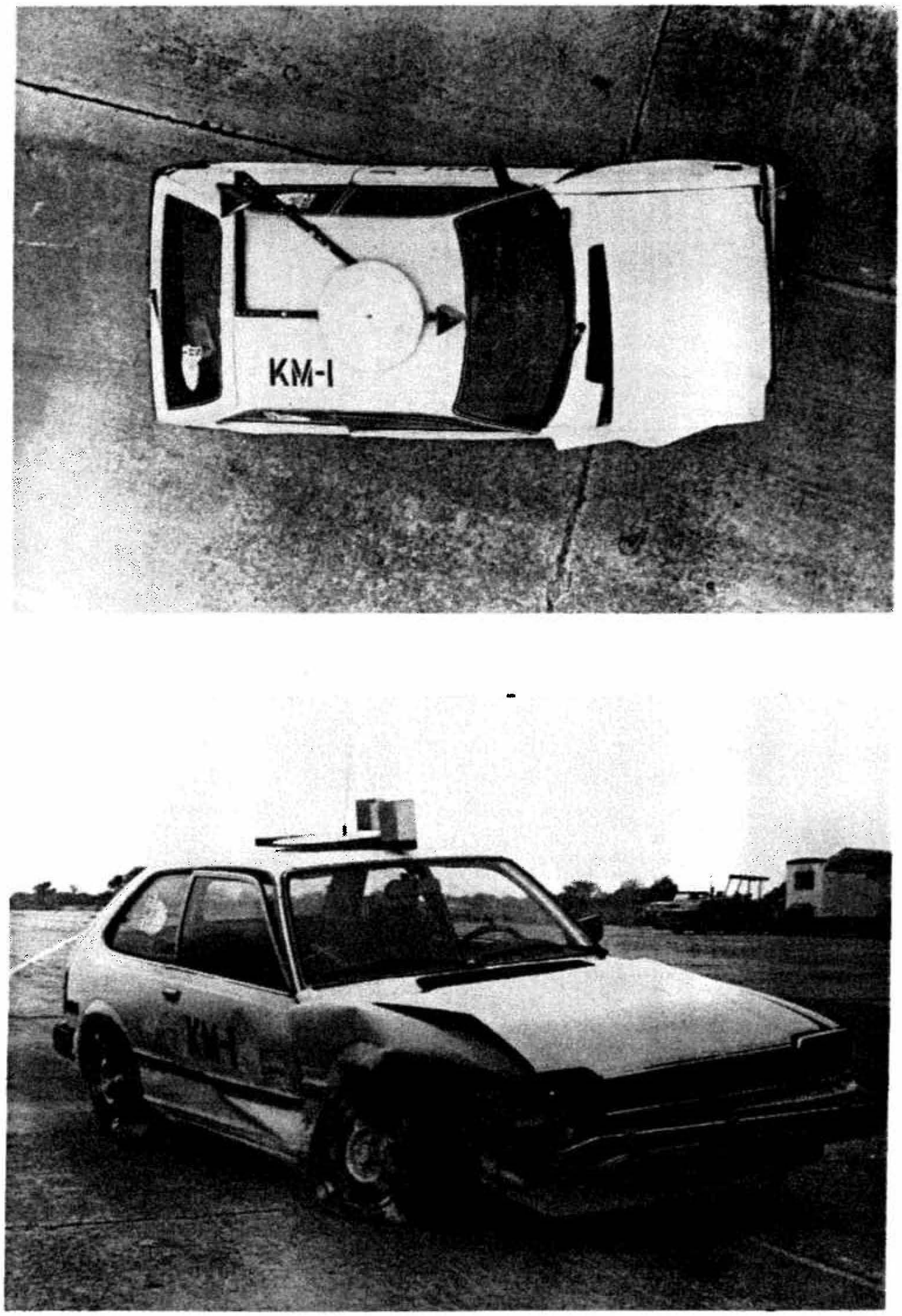


Figure 15b. Test KM-1 post-test details (continued).

Damage to the vehicle consisted of sheet metal deformation of the hood, right front fender, side, and rear fender. The right front tire was blown out during impact, and the A-frame was displaced rearward to the fender well. Vehicle damage was considered commensurate with the severity of the impact. Vehicle damage measurements are contained in table 9.

Table 9. Vehicle damage measurements, test KM-1.

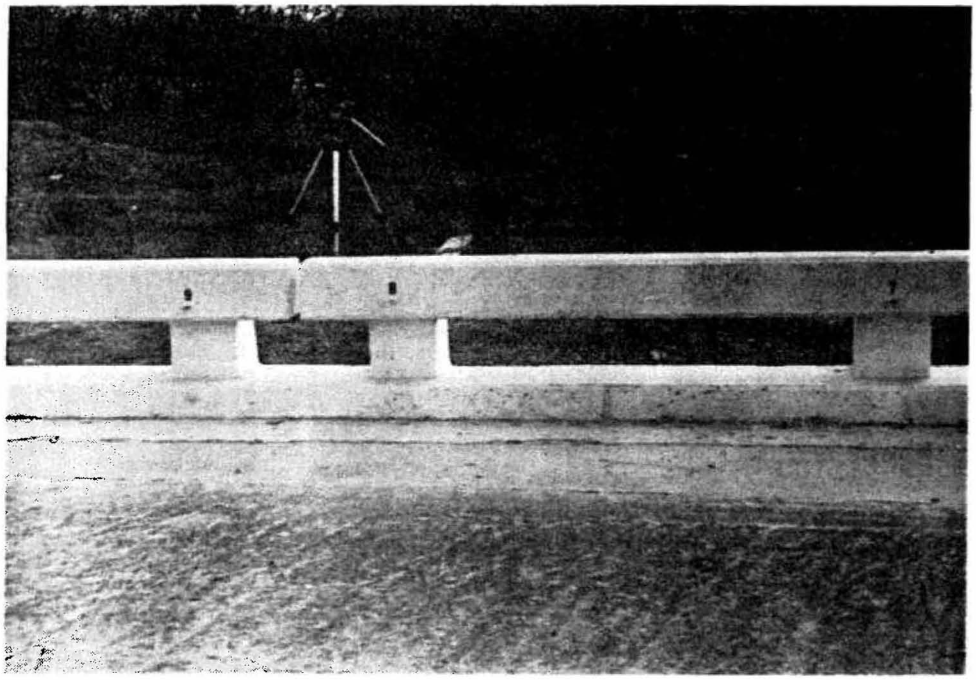
	Before Test	After Test	Crush
L	48	48	Not Applicable
C-1	1.3	4.0	2.7
C-2	0.0	2.8	2.8
C-3	0.0	-0.8	+0.8
C-4	0.0	8.8	8.8
C-5	0.3	8.5	8.2
C-6	0.3	10.0	9.7

Maximum crush of 10.5 at a location of 22.0 to the right of the vehicle centerline.

All dimensions are in inches. 1 in = 2.54 cm

Test KM-2. Pickup truck. The purpose of this test was to investigate the dynamic interactions of the pickup truck with the bridge rail and curb. Goals for this test were: (1) the vehicle must not penetrate or vault over the system; (2) the vehicle should remain upright throughout the event; and (3) the vehicle after-collision trajectory should not present an undue hazard to other traffic.

The barrier was the same as that used in test KM-1. The vehicle used was a 1984 Ford F150 pickup truck. Gross test weight, including the dummy and instrumentation, was 5419 lb (2458 kg). Figures 16a and 16b contains photographs of the barrier and the test vehicle.



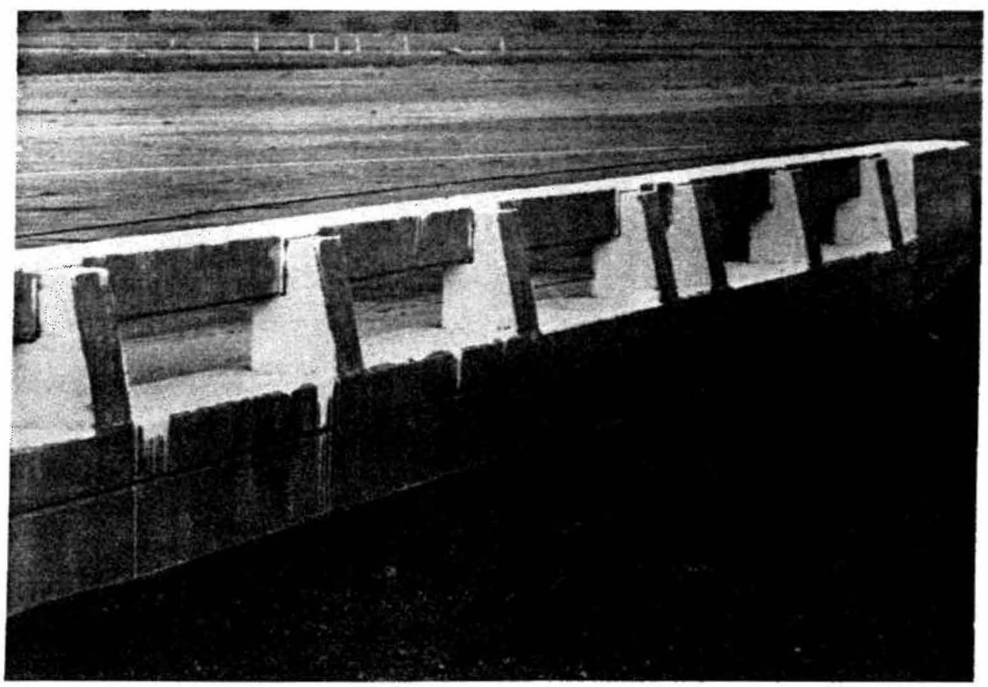
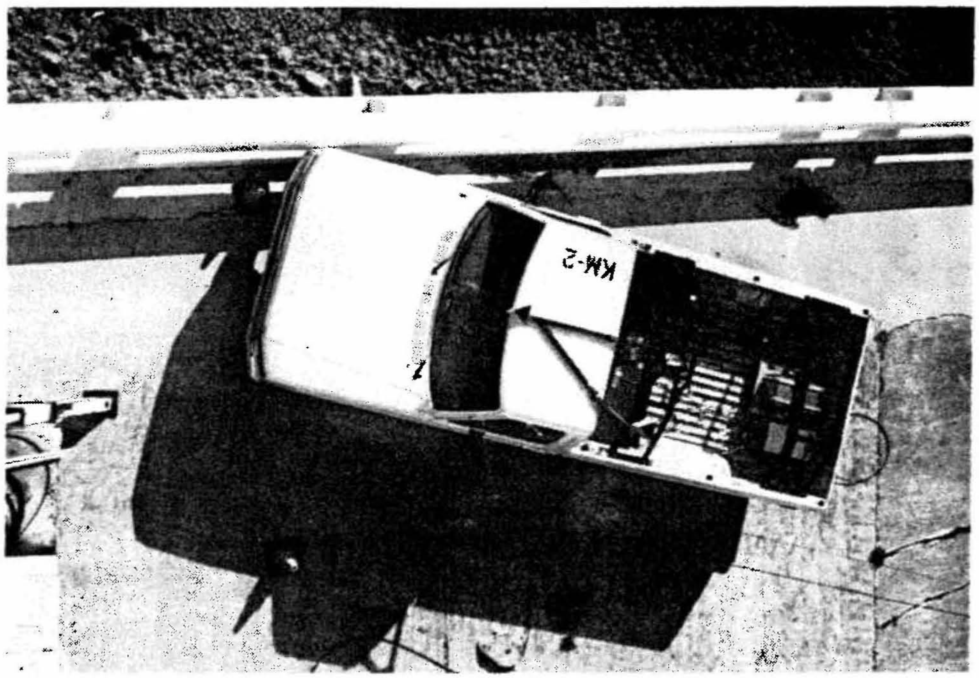


Figure 16a. Test KM-2 pre-test details.



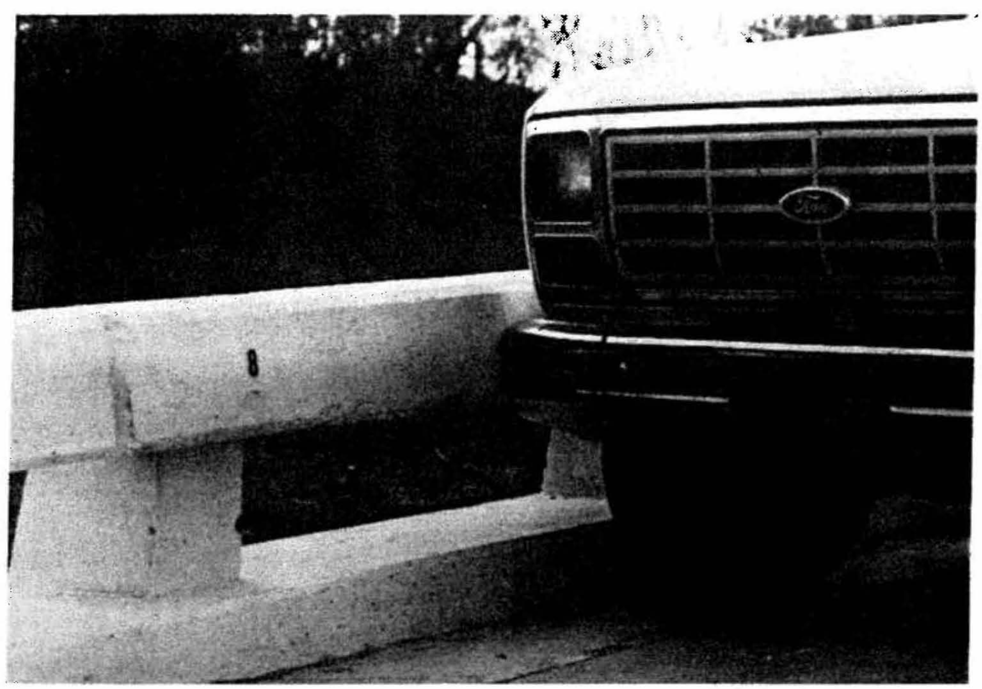
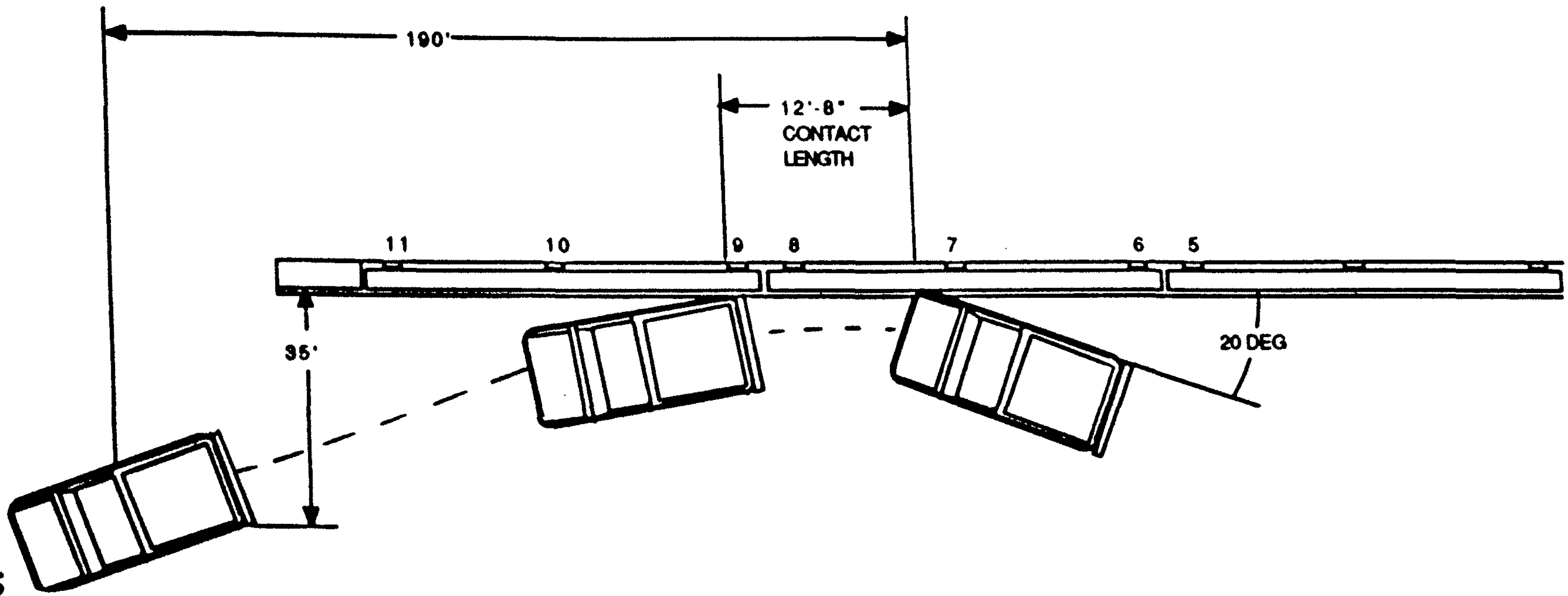


Figure 16b. Test KM-2 pre-test details (continued).

Test results are summarized in figure 17. Impact conditions were 46.6 mi/h (74.9 km/h) at a 20.0° impact angle. The vehicle impacted the barrier 0.8 ft (0.2 m) downstream of post 7. The vehicle remained in contact with the barrier for 15.0 ft (4.6 m) before redirection at a -2.4° angle. The vehicle showed no tendency to snag on the curb or posts during the impact sequence. No significant pitch, roll or yaw was noted during impact and redirection.



Test No. KM-2
Test Date . . . . Aug. 17, 1989
Installation Length - ft [m] . . . . 69 [21]
Beam
  Member . . . . 9-in (22.8cm)x 10-in (25.4 cm) reinforced concrete
  Length - ft [m] . . . . 2 @ 24 (7.3) and 1 @ 16 (4.9)

Maximum Deflections - in. [cm]
  Permanent . . . . none
  Dynamic . . . . none
Post
  Details of the posts, blockouts, curb, and deck are included in figure 17.

Vehicle . . . . 1983 Ford F150 Pickup

Mass - lb [kg]
  Test Inertia . . . . 5245 [2379]
  Dummy . . . . 165 [75]
  Gross Test Weight . . . . 5410 [2454]
Speed - mi/h [km/h] . . . . 46.6 [75.0]

Angle - degrees
  Impact 20
  Exit . . . . -2.4

Occupant Impact Velocity - fps [m/s]
  Forward (accel) . . . . 2.3 [0.7]/7.2 [2.2]
  Lateral (accel) . . . . -18.2 [-5.5]/-21.3 [-6.5]

Occupant Ridedown Accelerations - g's
  Forward (accel) . . . . *
  Lateral (accel) 9.7

Maximum 50 m/s Avg Accelerations - g's
  Longitudinal (film/accel) . . . . -2.7/-3.4
  Lateral (film/accel) 4.9/8.8

Vehicle Damage
  TAD 01-FR-4
  VDI 01FREE6

Figure 17. KM-2 pickup truck test results.

The vehicle came to rest 190 ft (58 m) downstream of the impact point and 35 ft (11 m) out from the barrier plane. The vehicle brakes were applied at approximately 130 ft (40 m) after impact. Table 10 present the vehicle trajectory after impact. The barrier did not deflect during the impact. Film data indicated maximum 50 m/s average accelerations of -2.7 g's (longitudinal) and 4.9 g's (lateral). Maximum 50 m/s average accelerations from transducer data were -3.4 g's (longitudinal) and 8.8 g's (lateral).

Table 10. After impact vehicle trajectory, test KM-2.

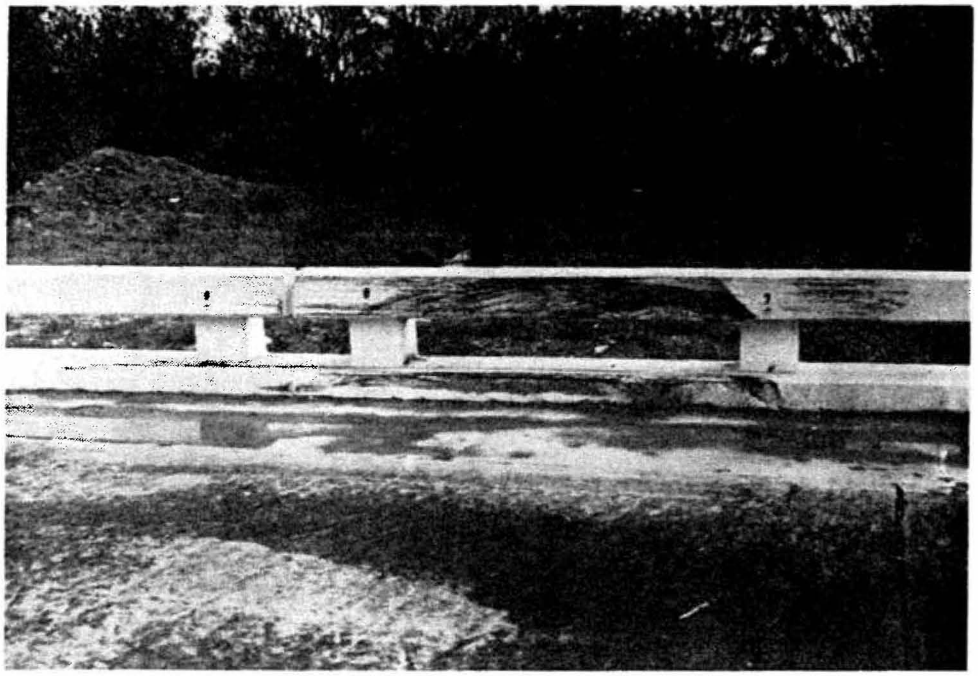
Location[1]	Distance[2]
0	0
10	-0.3
20	1.0
30	2.3
40	2.4
50	3.3
60	4.3
70	5.2
80	6.3
90	7.5
100	8.8

[1]Distance measured in the downtown direction with 0 as the point of impact.

[2]Measured perpendicular to the barrier plane at the front tire on the impact side of the vehicle.

All dimensions are in feet. 1 ft = 0.305 m

Figures 18a and 18b present photographs of damage to the vehicle and barrier. Damage to the barrier consisted of cosmetic scuff marks on the rail and curb. Minor gouging from wheel contact was noted on the lower edge of the rail in the impact area. Inspection of the barrier system revealed no fractured posts or rail members. The barrier was considered undamaged.



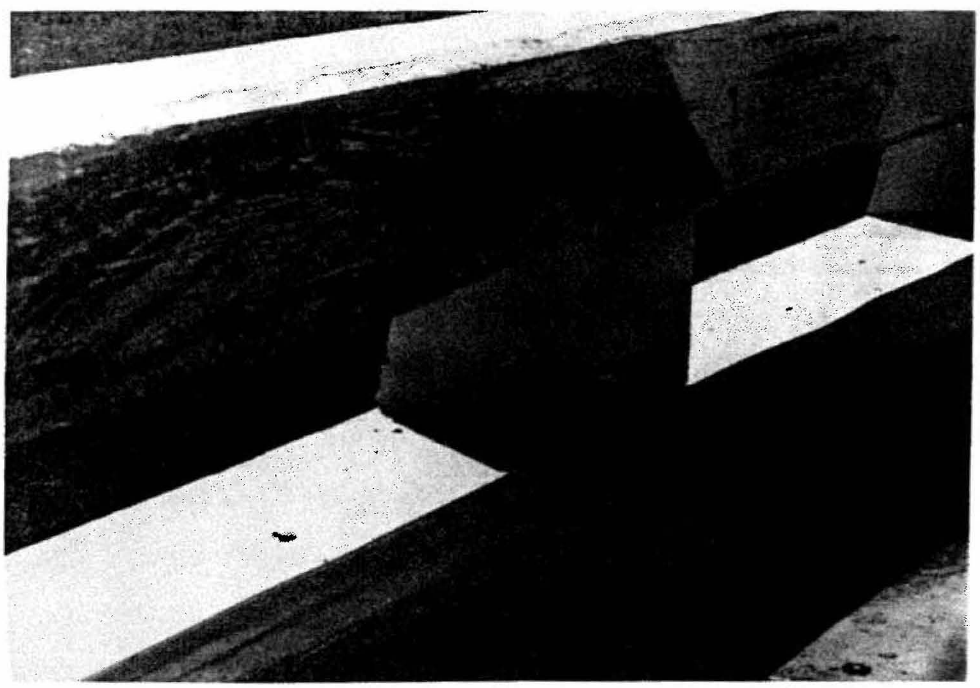


Figure 18a. Test KM-2 post-test details.

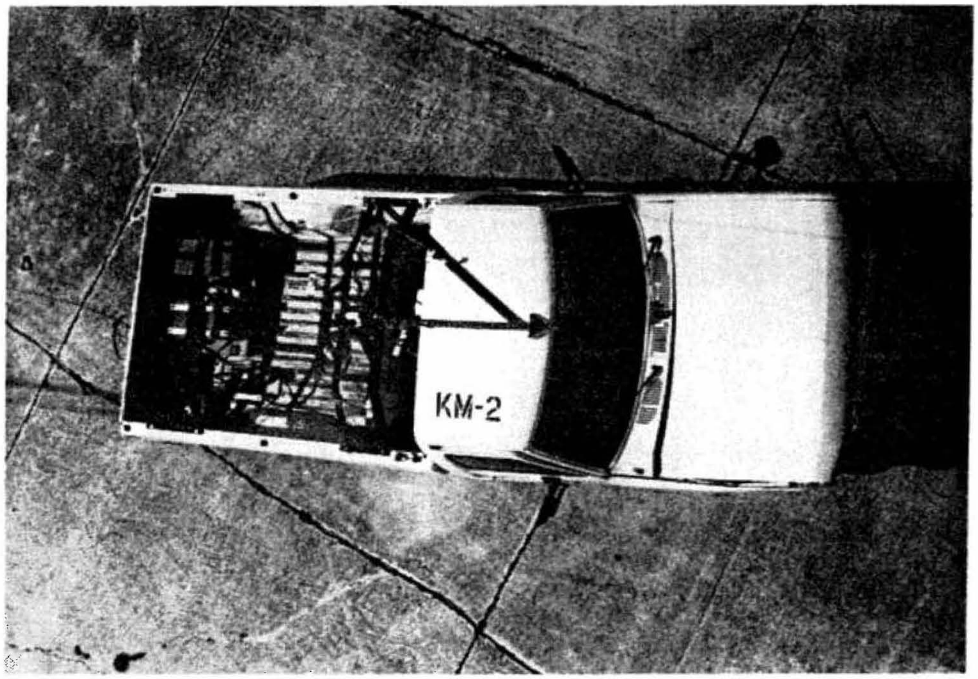


Figure 18b. Test KM-2 post-test details (continued).

Damage to the vehicle consisted of sheet metal deformation of the right front fender, side, and rear fender. The front bumper was deformed inward at the impact area. The right front tire was blown out during impact. Vehicle damage was considered commensurate with the severity of the impact. Vehicle damage measurements are listed in table 11.

Table 11. Vehicle damage measurements, test KM-2.

	Before Test	After Test	Crush
L	56	56	Not Applicable
C-1	2.0	3.8	1.8
C-2	1.0	5.5	4.5
C-3	0.0	4.0	4.0
C-4	0.0	3.5	3.5
C-5	1.0	15.6	14.6
C-6	2.0	14.0	12.0

Maximum crush of 16.0 at a location of 25.0 to the right of vehicle centerline.

All dimensions are in inches. 1 in = 2.54 cm

3. CONCLUSIONS AND RECOMMENDATIONS

Two bridge rail designs have been evaluated using full-scale tests employing both a small sedan and a pickup truck. Also, analyses of two additional designs have been conducted. Conclusions and recommendations based on the results of this effort are presented below.

a. Conclusions

The Glulam bridge rail and the Modified Kansas Corral bridge rail passed both the small sedan and the pickup truck full-scale tests. The rails did not fail in any of the tests, and the vehicle behavior during and after impact was, in all cases, acceptable. Analyses conducted on the Modified Kansas Corral bridge rail indicated that it was equally as strong or stronger than the Modified Kansas Corral rail tested in reference 3.

Computer simulation on the Modified Kansas Corral bridge rail and the Natchez Trace bridge rail indicated that the vehicle would be redirected with no vaulting.

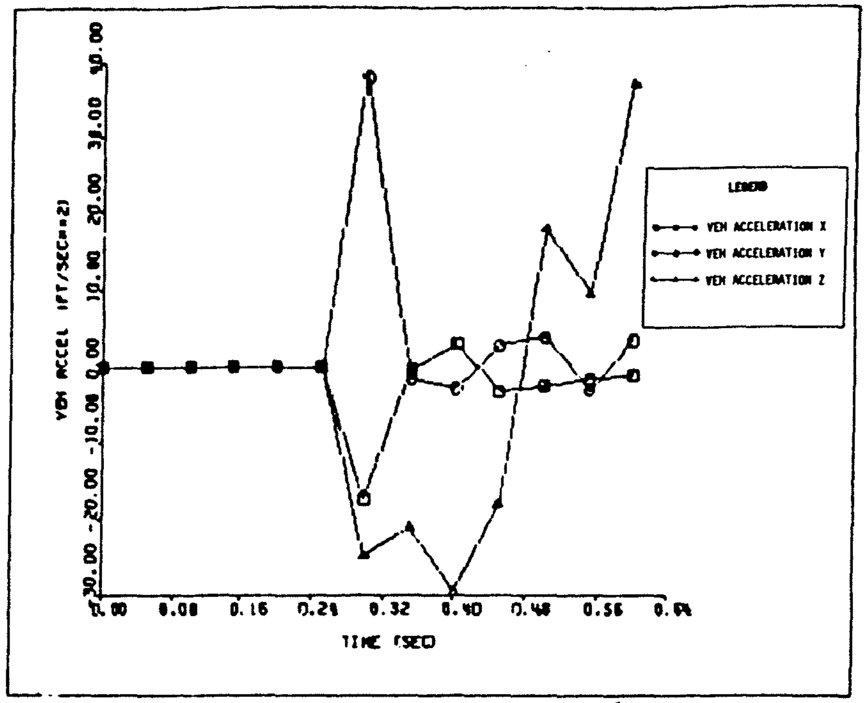
The Aluminum Tri-Rail bridge rail has a high snagging potential according to guidelines developed in reference 3.

b. Recommendations

Because the Modified Kansas Corral and Glulam bridge rail designs passed the full-scale tests, they should both be certified as acceptable for use on Federal Lands highways.

Based on the analyses conducted, the Natchez Trace bridge rail should be tested in its current design to Performance Level 1 of the 1989 AASHTO guide specifications.

The Aluminum Tri-Rail bridge rail should be modified as recommended and submitted for full-scale testing to Performance Level 1.



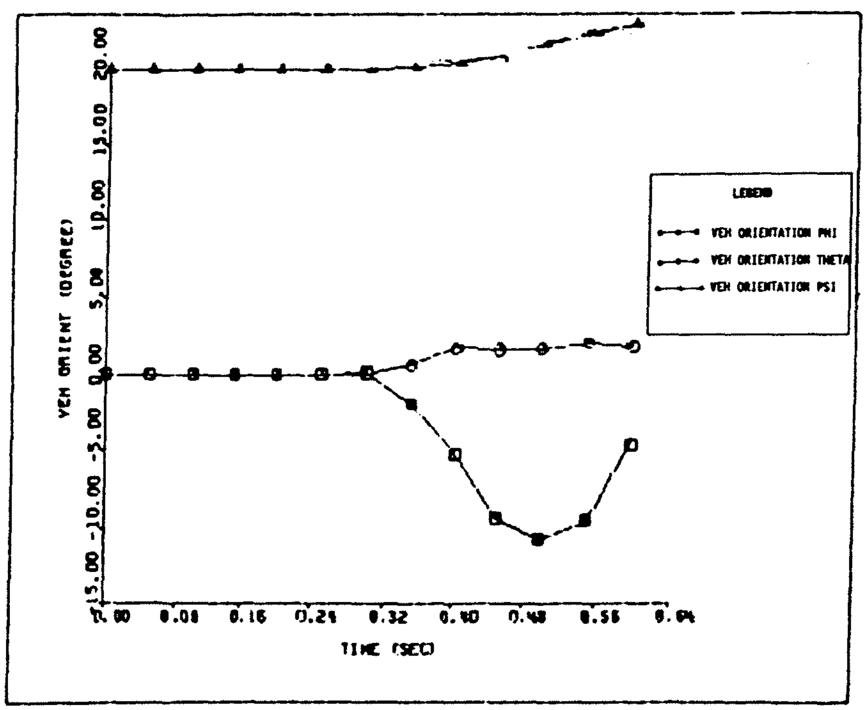


Figure 19a. Modified Kansas Corral bridge rail with 1800-lb (817kg) computer simulation results.

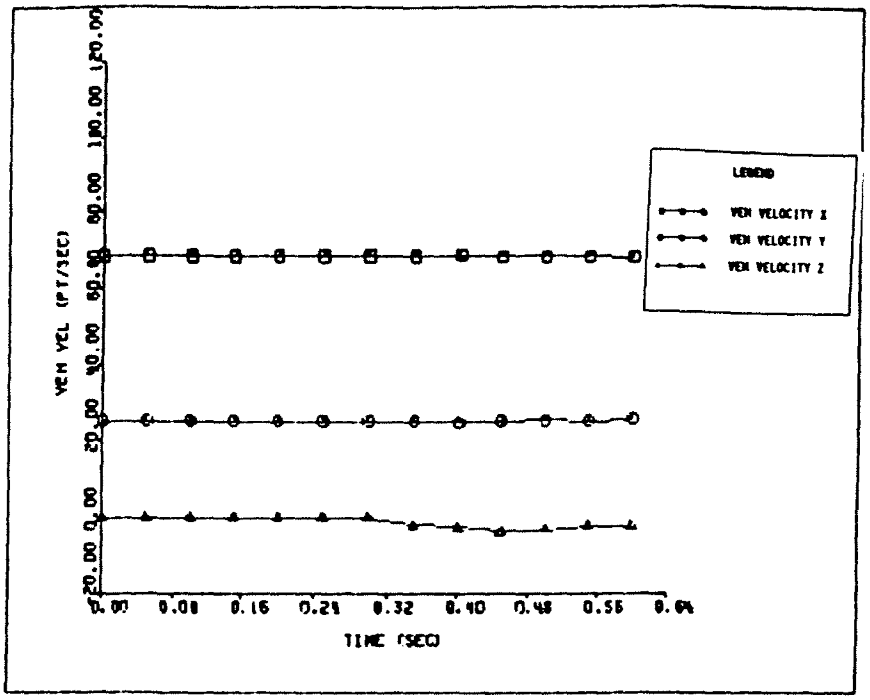
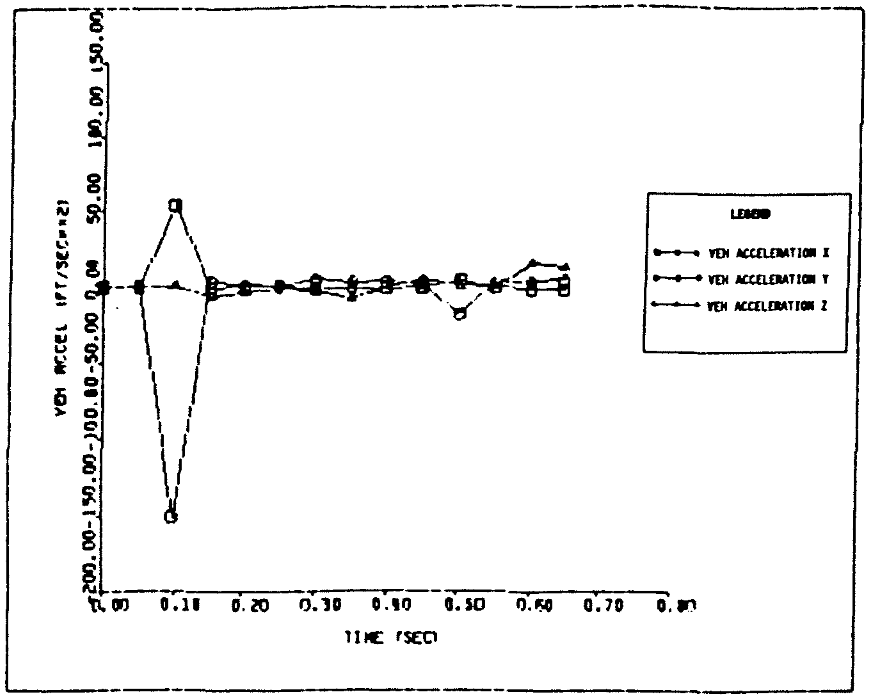


Figure 19b. Modified Kansas Corral bridge rail with 1800-lb (817kg) computer simulation results (continued).



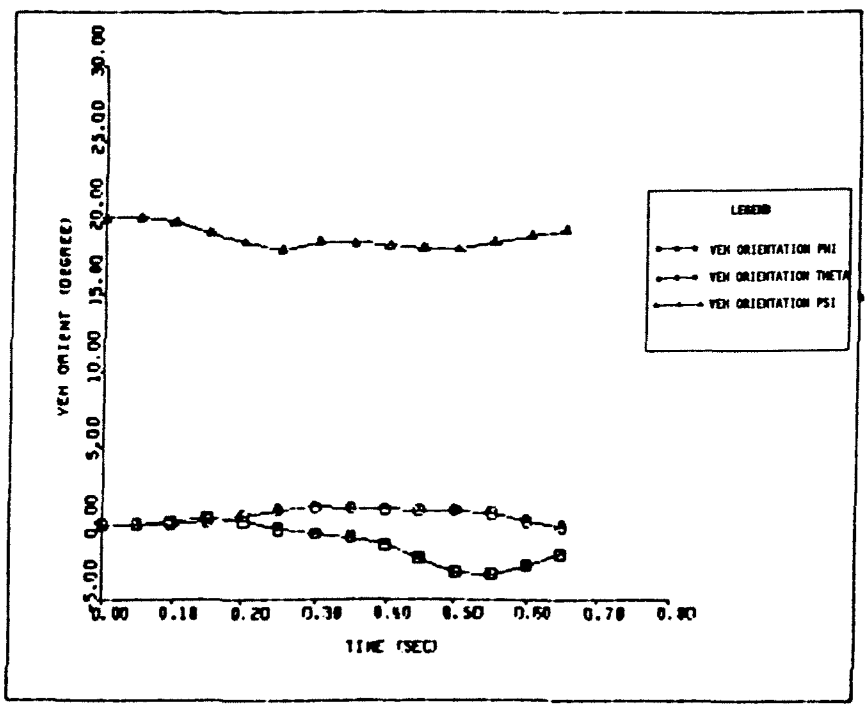


Figure 20a. Modified Kansas Corral bridge rail with 5400-lb (2450kg) computer simulation results.

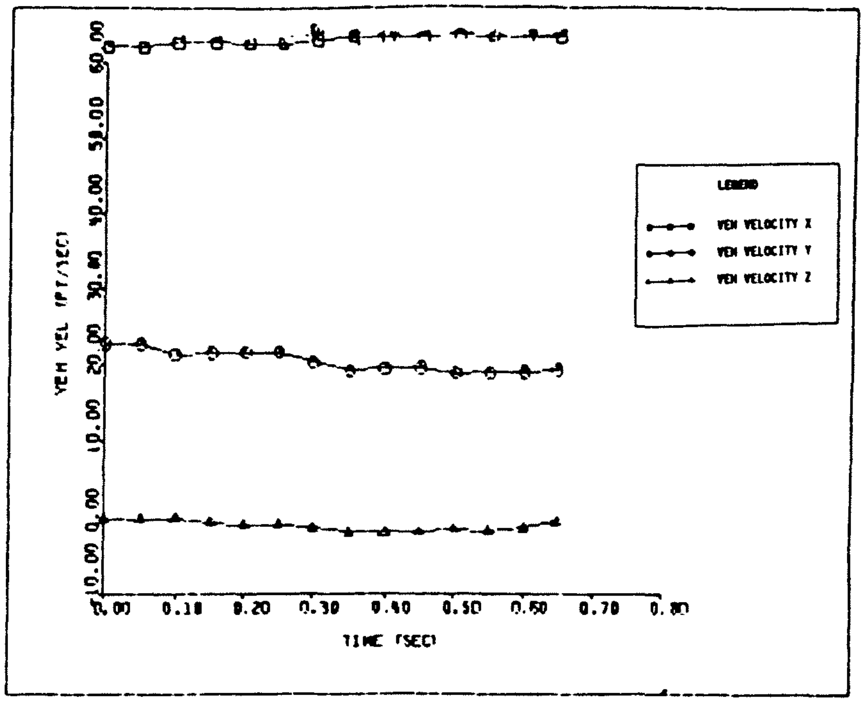
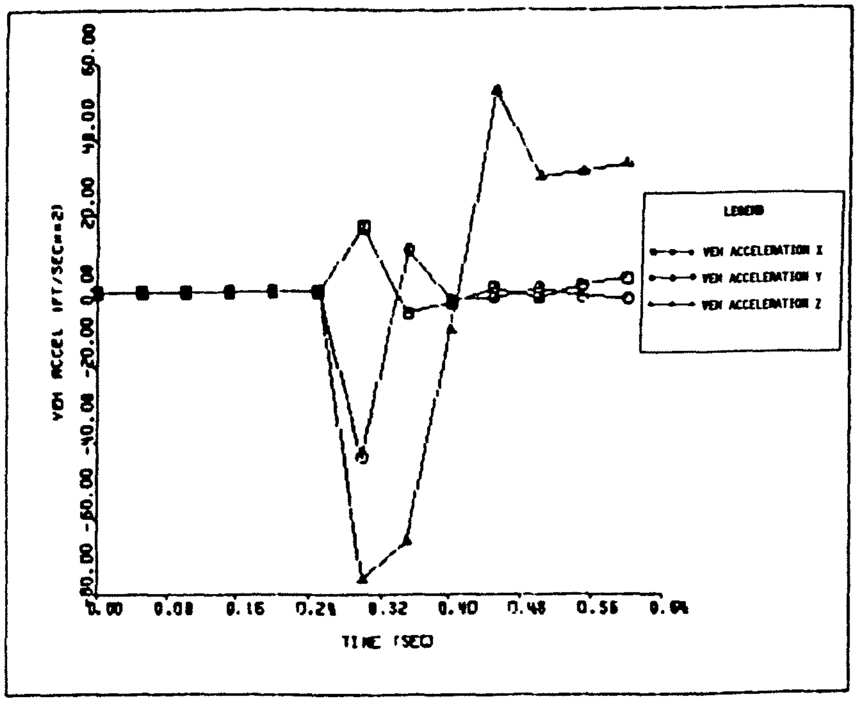


Figure 20b. Modified Kansas Corral bridge rail with 5400-lb (2450kg) computer simulation results (continued).



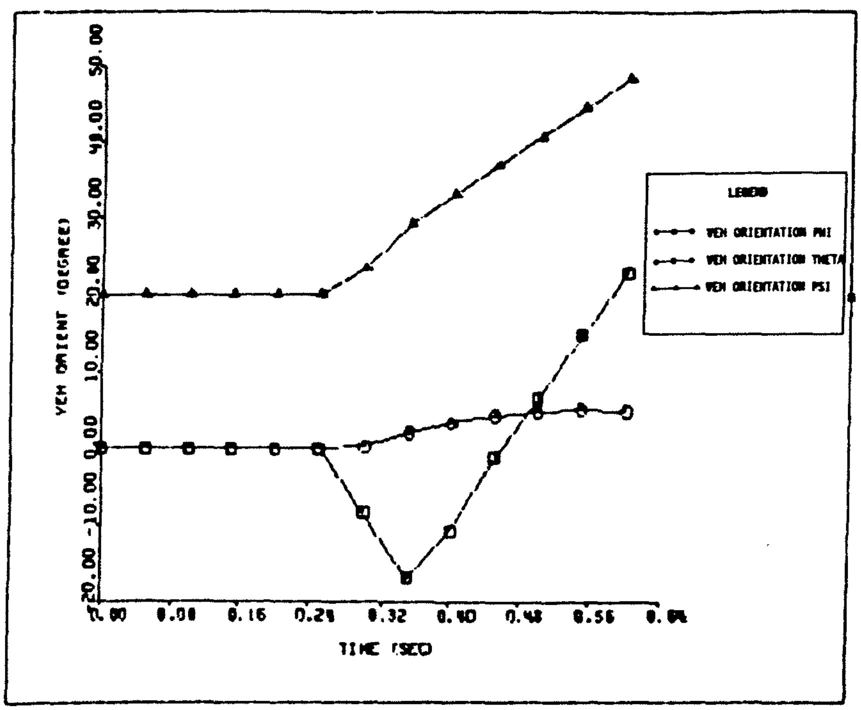


Figure 21a. Natchez Trace bridge rail with 1800-lb (817kg) computer simulation results.

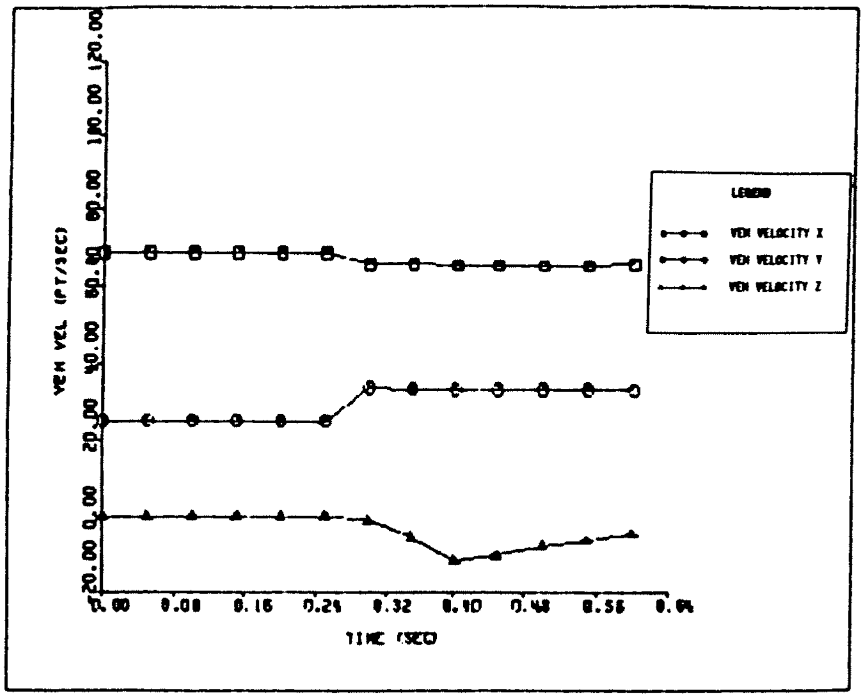
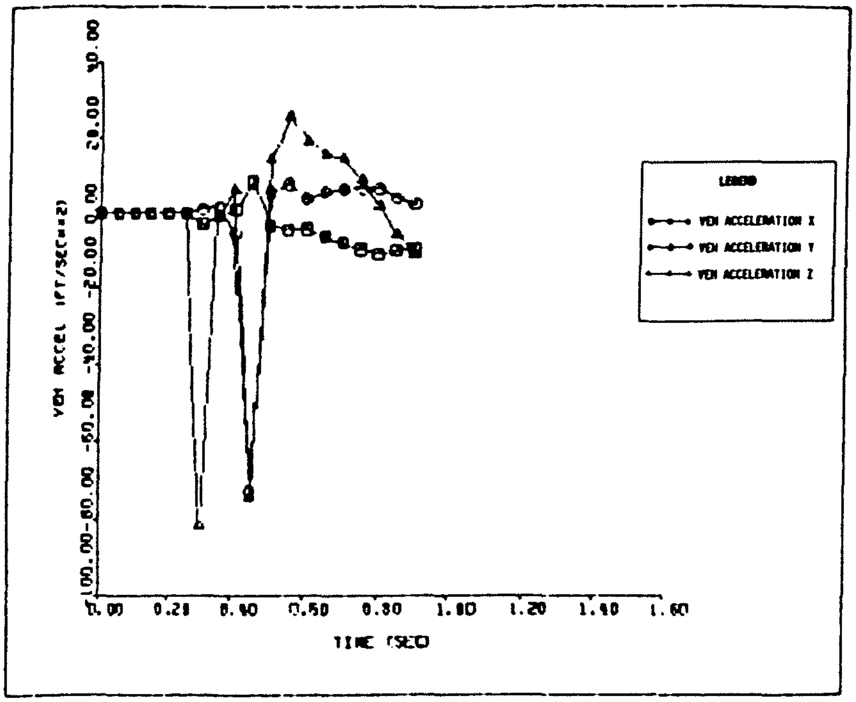


Figure 21b. Natchez Trace bridge rail with
1800-lb (817kg) computer simulation results (continued).



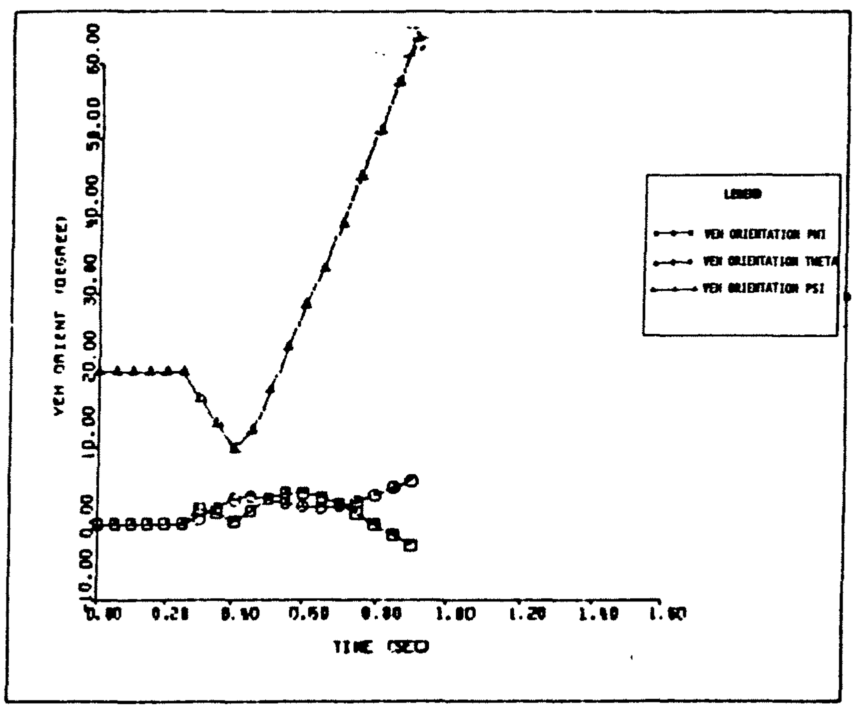


Figure 22a. Natchez Trace bridge rail with 5400-lb (2450kg) computer simulation results.

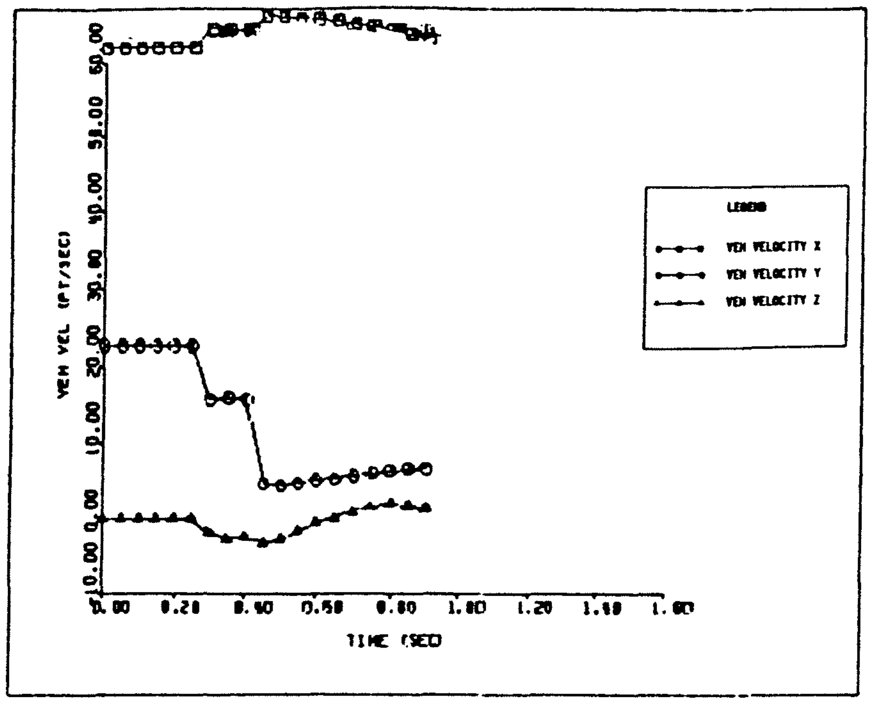


Figure 22b. Natchez Trace bridge rail with 5400-lb (2450 kg) computer simulation results (continued).

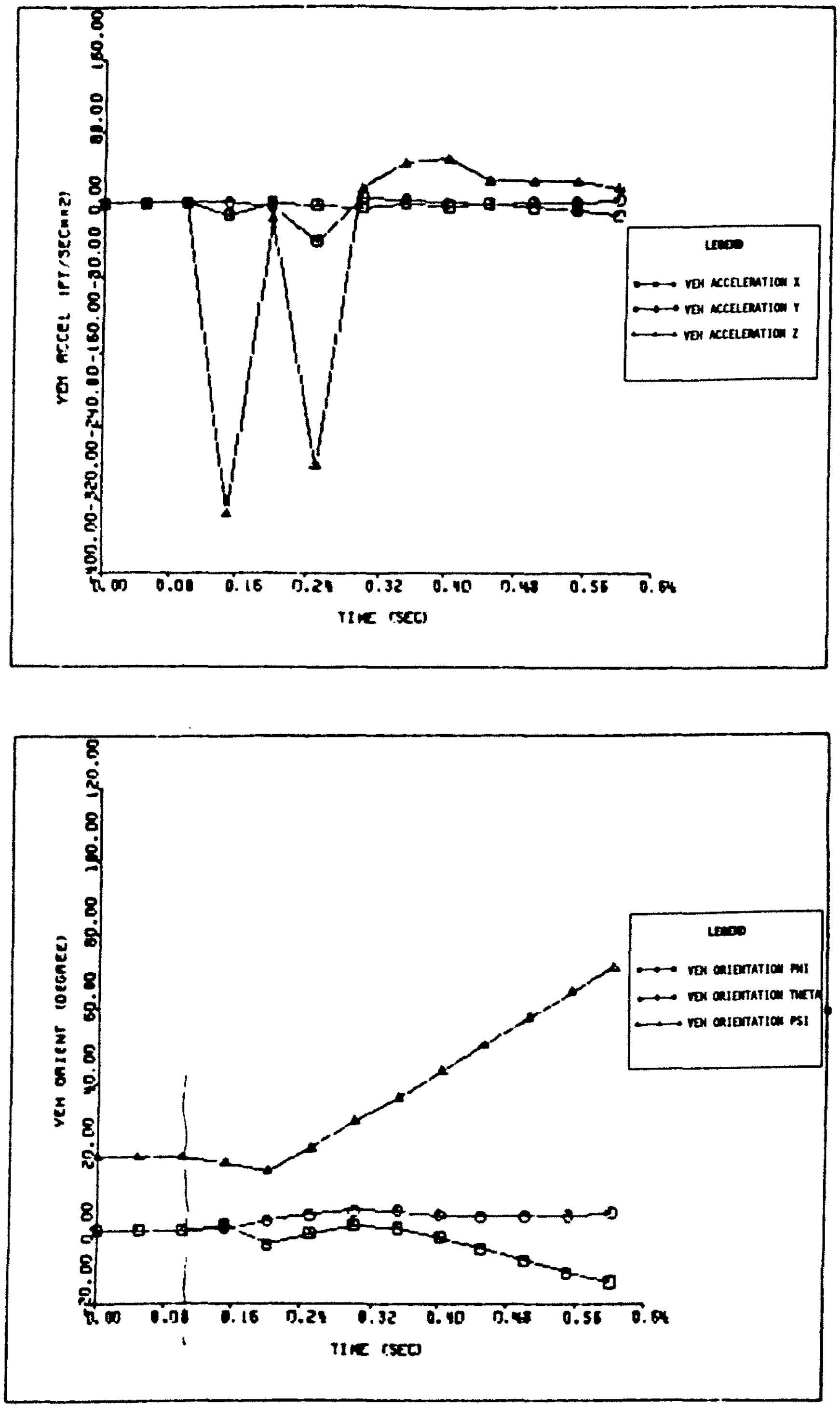


Figure 23a. Aluminum Tri-Rail bridge rail with sidewalk 1800-lb (817 kg) computer simulation results.

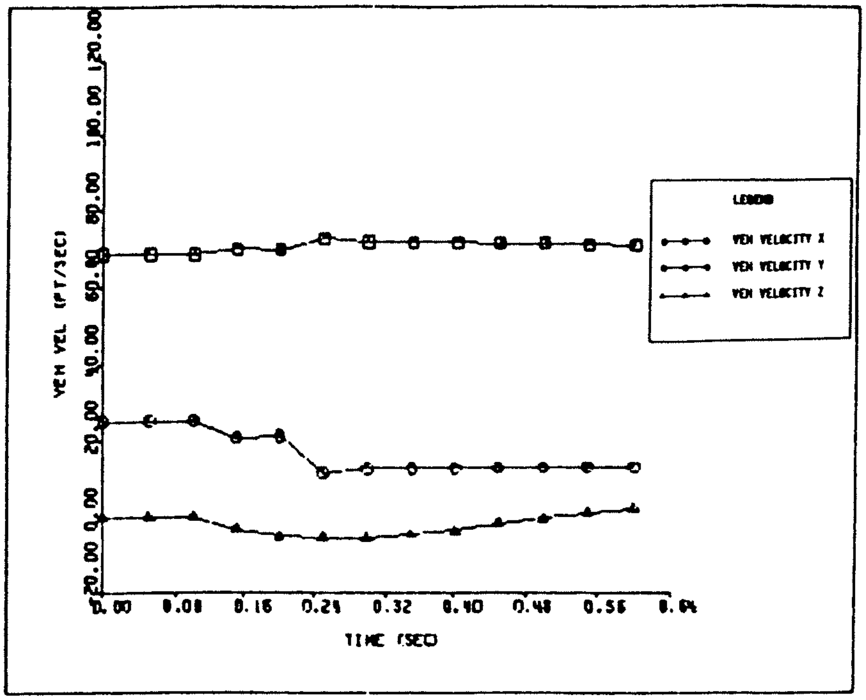
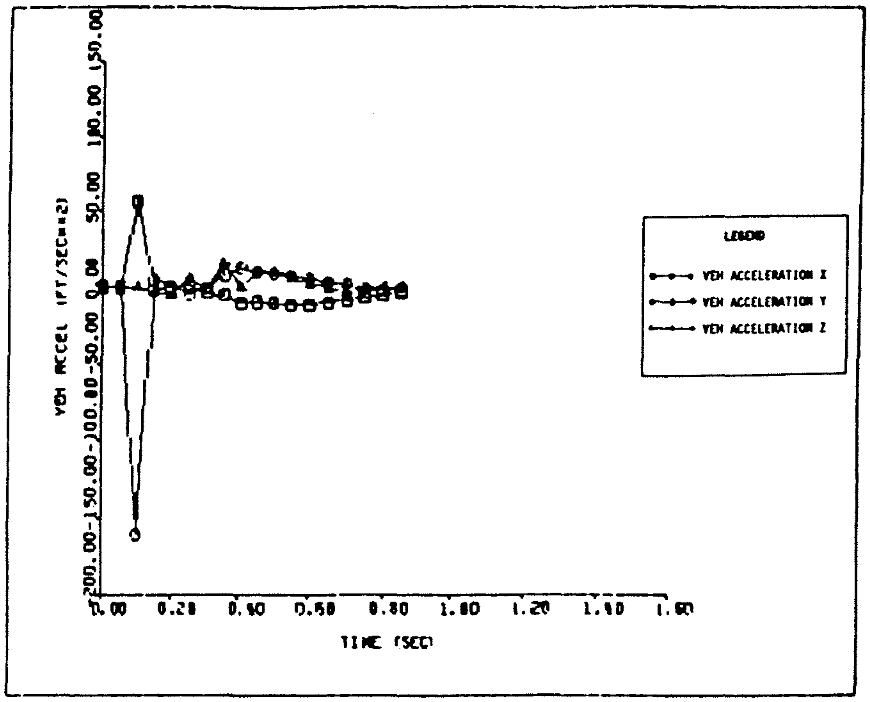


Figure 23b. Aluminum Tri-Rail bridge rail with sidewalk 1800-lb (817kg) computer simulation results (continued).



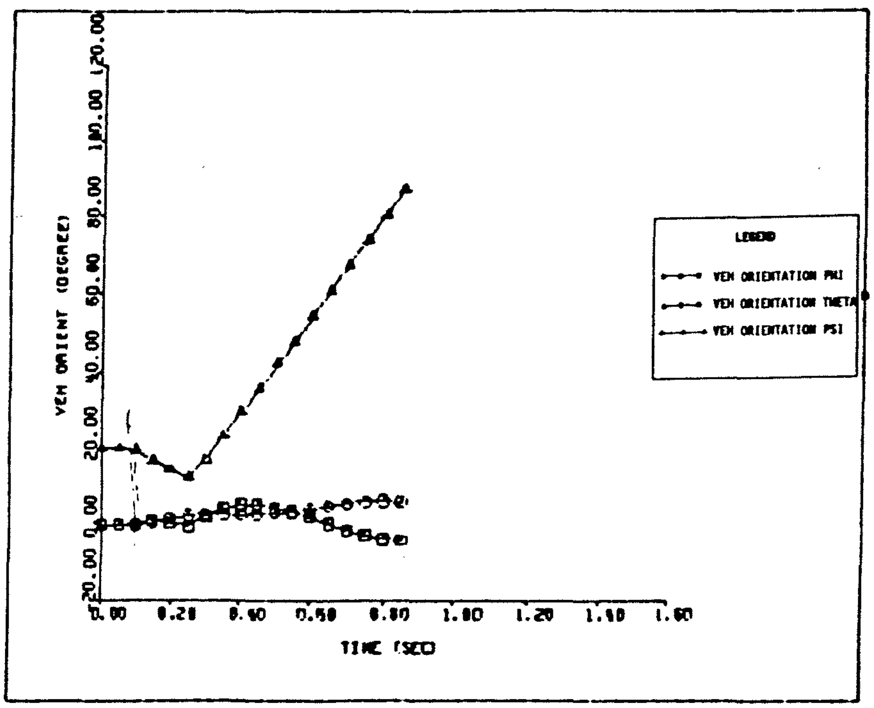


Figure 24a. Aluminum Tri-Rail bridge with sidewalk 5400-lb (2450 kg) computer simulation results.

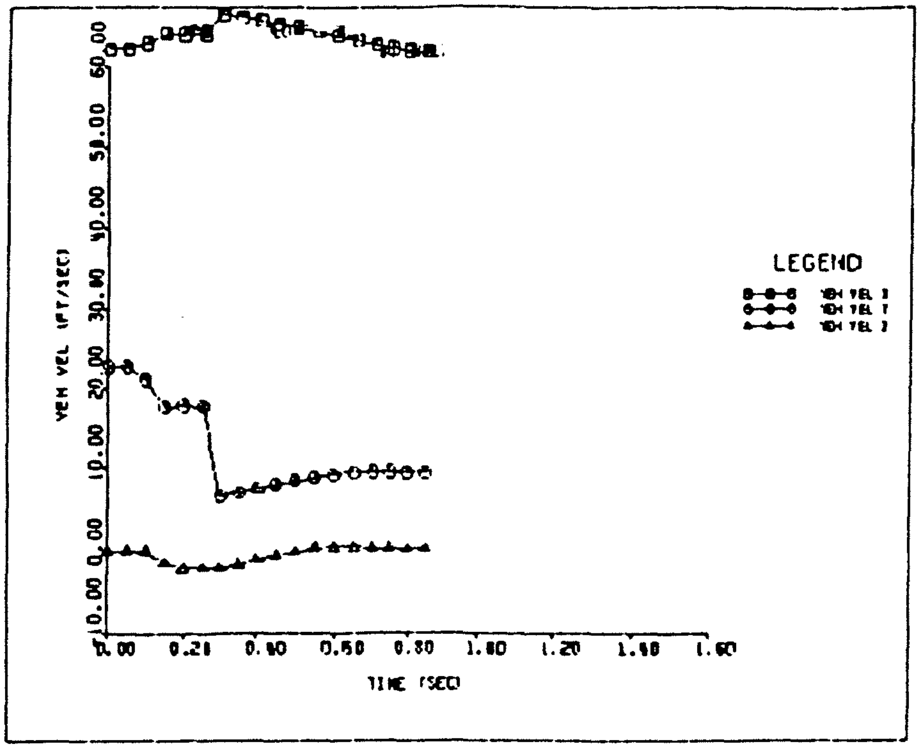


Figure 24b. Aluminum Tri-Rail bridge with sidewalk 5400-lb (2450 kg) computer simulation results (continued).

APPENDIX B: FULL-SCALE CRASH TEST REPORTS

TO: Mr. Charles McDevitt, P.E., FHWA

FROM: Ken Johnson

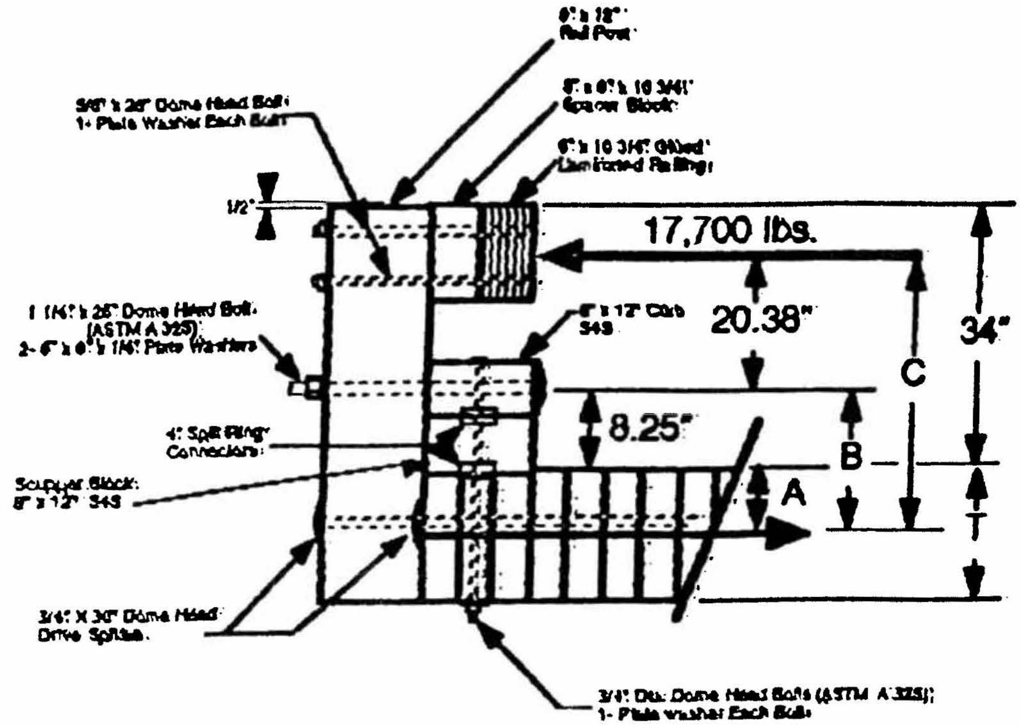
SUBJECT: Timber Bridge Rail Details

Transmitted herewith are the DRAFT calculations of the bridge rail. Please give me a call ((218) 927-3370) to help explain any of those areas which may not be clear.

Thank you,

WHEELER CONSOLIDATED, INC.

Kenneth Johnson



TYPICAL CROSS SECTION OF CURB AND RAIL

The indicated load of 17,700 pounds is the estimated maximum lateral load from a 1,800 pound vehicle traveling at 60 MPH and striking the rail at 20°.

TABLE NO. 1 (LOAD ON POST BOLT)

$$P = \frac{17{,}700 \times C}{B}$$

DECK THICKNESS (T)	DIMENSION B - 2/3(T + 8.25)	DIMENSION A - B - 8.25"	DIMENSION C - 20.38" + B	LOAD ON POST BOLT (LBS.) - P
10"	12.17"	3.92"	32.55"	47,341
12"	13.50"	5.25"	33.88"	44,420
14"	14.83"	6.58"	35.21"	42,024
16"	16.17"	7.92"	36.55"	40,008
18"	17.50"	9.25"	37.88"	38,313

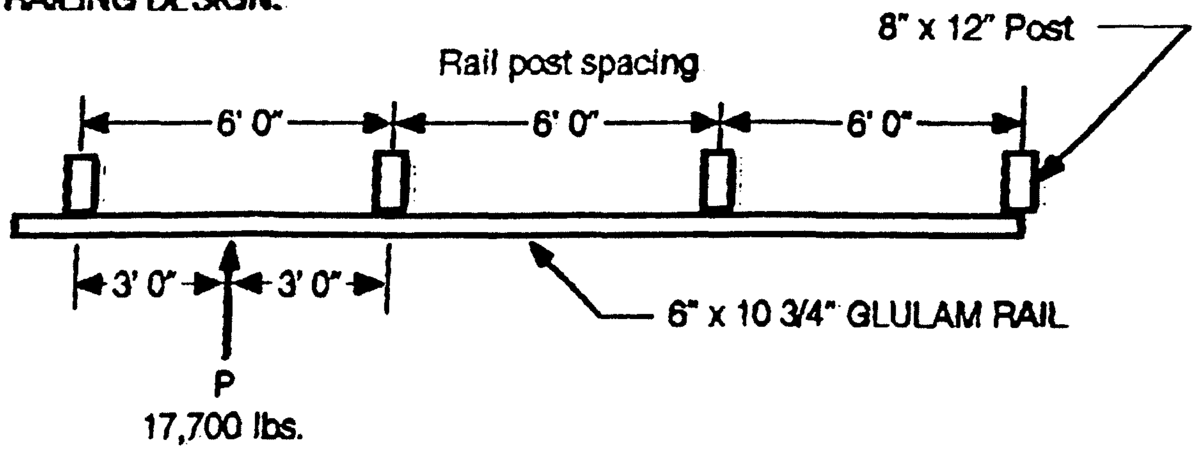
NOTE: The 1 1/4" diameter by 26" Dome Head Bolt connecting the rail post to the curb has a Root Area of 0.890 sq. in. and a Tensile Stress Area of .969 sq. in.
The minimum ultimate stress for A 325 in applied tension is 120,000 psi (.25" to 1" dia. bolts)
The minimum ultimate stress for A 325 in applied tension is 105,000 psi. (> 1" dia. bolt)
The minimum ultimate strtess for A 307 in applied tension is 60,000 psi
Allowable load based on Tensile Stress Area - .969 x 105,000 - 101,175 pounds.
Allowable load based on Tensile Stress Area - .969 x 60,000 - 58,140 pounds

ULTIMATE UNIT STRESSES: Ref. *Ultimate stress values from page 4-15. WOOD Handbook, Forest Products Laboratory.*

Specie - Douglas-fir

Modulus of rupture (F_b) = 12,800 psi
Modulus of elasticity (E) = 1,970,000 psi
Compresion parallel to grain, max. crushing strength = 7,260 psi
Compression perpendicular to grain, at portional limit (F_c) = 870 psi
Shear parallel to grain, max. shearing strength (F_v) = 1,380 psi

RAILING DESIGN:



BENDING STRESS COMPUTATIONS: (formula from AISC, 8th. Ed., page 2-124)

Maximum moment = $M = \frac{13\,PL}{64} = \frac{13 \times 17{,}700 \times 6 \times 12}{64} = 258{,}863$ in-lbs.

Section modulus = $S = \frac{bd^2}{6} = \frac{10.75 \times 6^2}{6} = 64.5\ in^3$

$f_b = \frac{258{,}863\text{ in-lbs.}}{64.5\ in^3} = 4{,}013$ psi < 12,800 psi OK

HORIZONTAL SHEAR:

Check with load at 3d = 1/4 L = 1.5' from support

$V = R = \frac{17{,}700 \times 4.5}{6} = 13{,}275$ lbs.

POST DESIGN:

Check bending moment at 1 1/4" bolt hole.
Maximum moment = M = 17,700 x 20.38" = 360,726 in-lbs.
Net section of post = 8" - 1 1/4" = 6 3/4"

Section modulus $= S = \frac{bd^2}{6} = \frac{6.75 \times 12^2}{6} = 162 \text{ in}^3$

$f_b = \frac{M}{S} = \frac{360{,}726 \text{ in-lbs.}}{162 \text{ in}^3} = 2{,}227 \text{ psi.} < 12{,}800 \text{ psi}$ OK

HORIZONTAL SHEAR:

V = 17,700 lbs.

$f_v = \frac{3V}{2bd} = \frac{3 \times 17{,}700}{2 \times 8 \times 12} = 277 \text{ psi} < 1{,}380$ OK

LOAD ON 1 1/4" POST BOLT:

Ultimate unit stress for A 325 Steel bolt (1.25" dia.) in tension = 105,000 psi.
Load on bolt (from sheet 1 Of 16 sheets) = 47,341 lbs.

Net section required $= \frac{47{,}341 \text{ lbs.}}{105{,}000 \text{ psi}} = 0.45 \text{ sq. in.}$

Tensile Area of 1 1/4" bolt = 0.969 sq. in. (AISC, 8th. Ed., page 4-141)

WASHER DESIGN FOR POST BOLT:

Try 6" X 8"

$\frac{47{,}341 \text{ lbs.}}{48 \text{ sq. in.}} = 986 \text{ psi} > 870 \text{ psi}$ NOT OK

CURB TO FLOOR SPLIT RING CONNECTIORS:

Design Value/Ultimate Value = 4.0 to 4.5 (page 7-18 WOOD Handbook)

1. Seasoned lumber
2. Group "B" species
3. Angle of load to grain = 90°
4. Over 3" thick both faces

Allowable load on 4" split ring connector and 3/4" bolt = 3,360 x 4 = 13,440 lbs.

Number of bolts required $= \frac{V}{\text{Allowable}} = \frac{17{,}700}{13{,}440} = 1.32$ Bolts

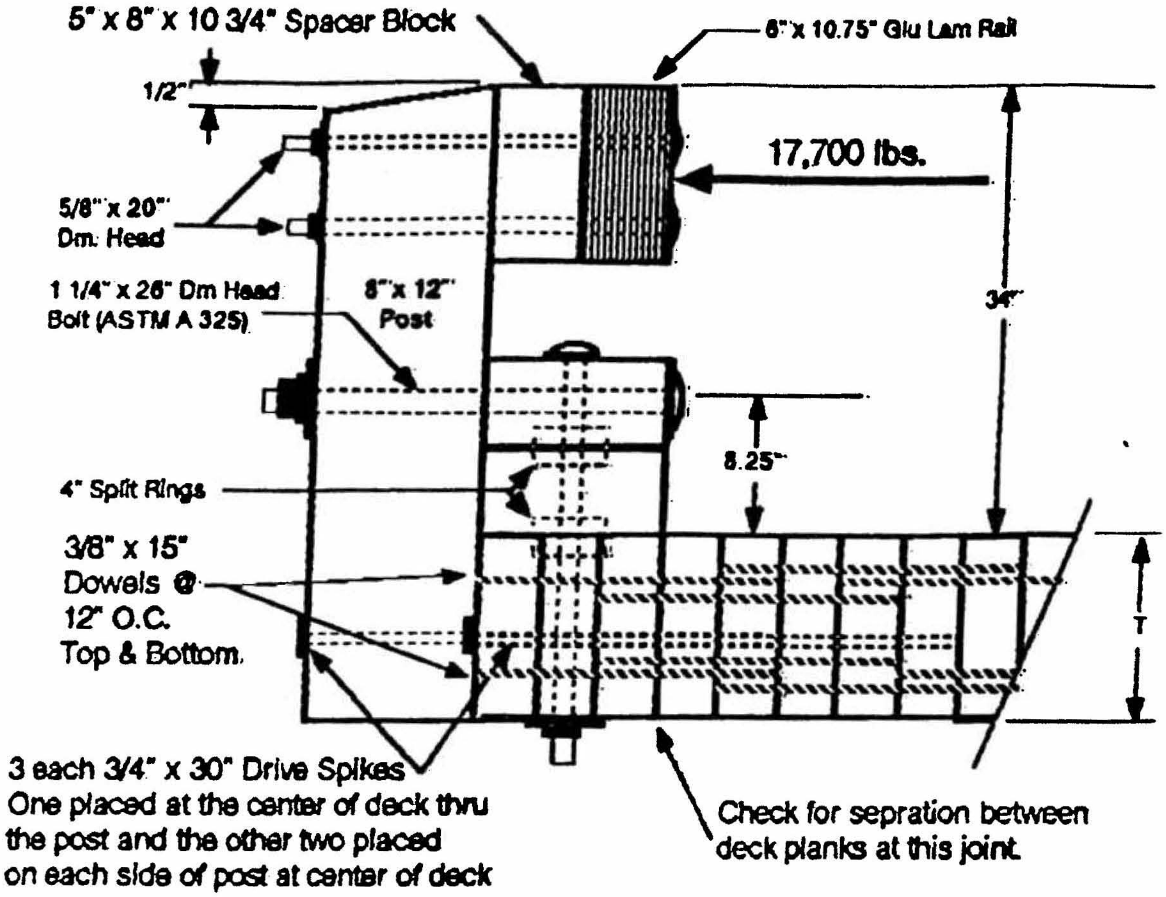
Use 4 bolts, two on each side.

CURB TO FLOOR BOLTS:

Check bolts in tension ,use ASTM A 325 Bolts

$\frac{17{,}700 \text{ lbs.} \times 20.38 \text{ in.}}{6 \text{ in.}} = 60{,}121$ pounds to be resisted by bolts

Tensile Stress Area for 3/4" diameter bolt = 0.334 sq. in.
Allowable load for 3/4" diameter bolt = 120,000 x 0.334 = 40,080 lbs. per bo



TYPICAL CROSS SECTION OF CURB AND RAIL

CHECK WITHDRAWAL FORCES IN DECK:

Compute withdrawal resistance of 3/4" x 30" Drive Spikes

P_w = Ultimate withdrawal resistance *WOOD Handbook, page 7-6*

$P_w = 6{,}600 \times G^2 \times D \times L$ Where G = Specific gravity = .49 , D =, Diameter = .75"

$P_w = 6{,}600 \times .49^2 \times .75 \times 1 = 1{,}188$ lbs./in. Ultimate Value.

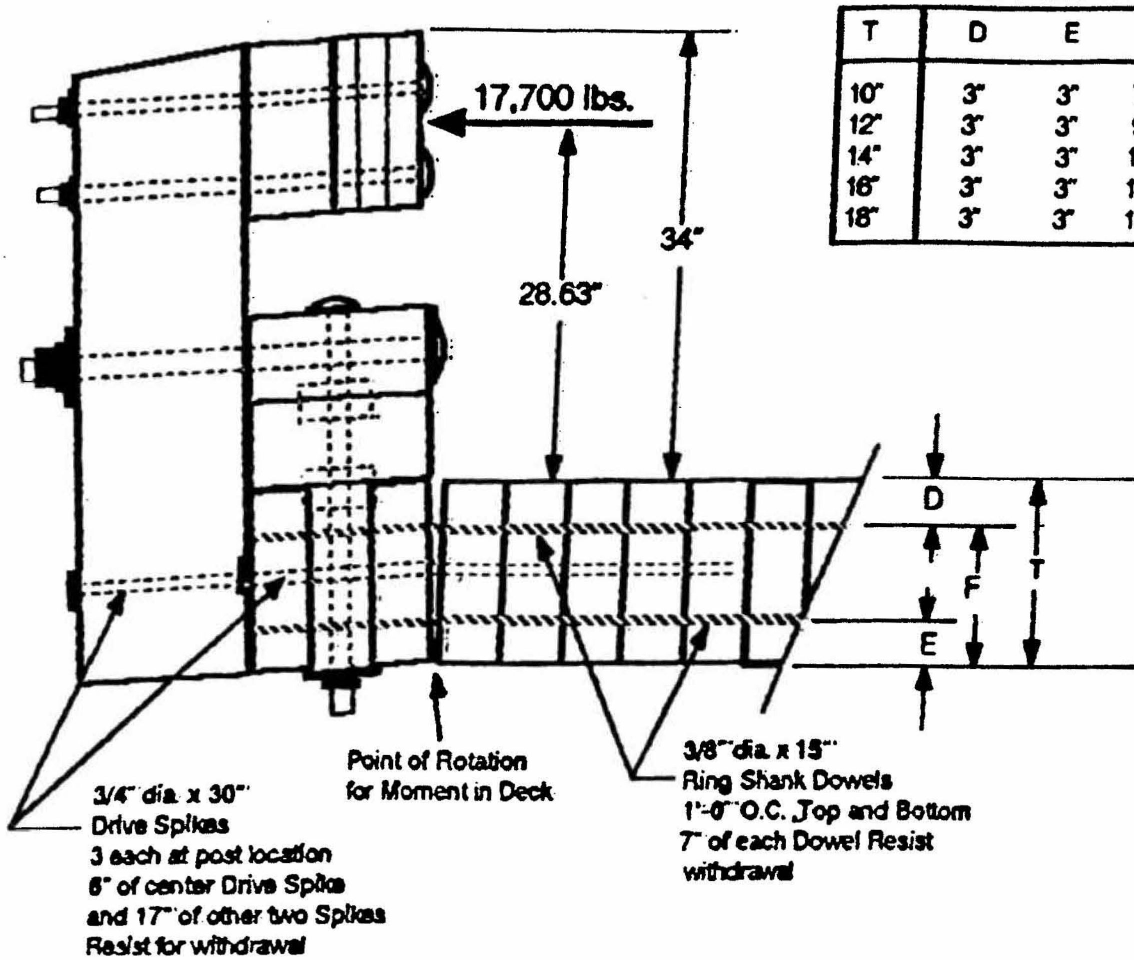
$P_w = 1{,}188 \times (6 + 17 + 17) = 47{,}520$ pounds > 17,700 pounds OK

Compute withdrawal resistance of 3/8" x 15" Deck Dowels

P_w = Ultimate withdrawal resistance *WOOD Handbook, page 7-6*

$P_w = 6{,}600 \times G^2 \times D$ Where G = Specific gravity = .49 , D =, Diameter = .375"

$P_w = 6{,}600 \times .49^2 \times .375 \times 1.0 = 594$ lbs./in. UltimateValue.



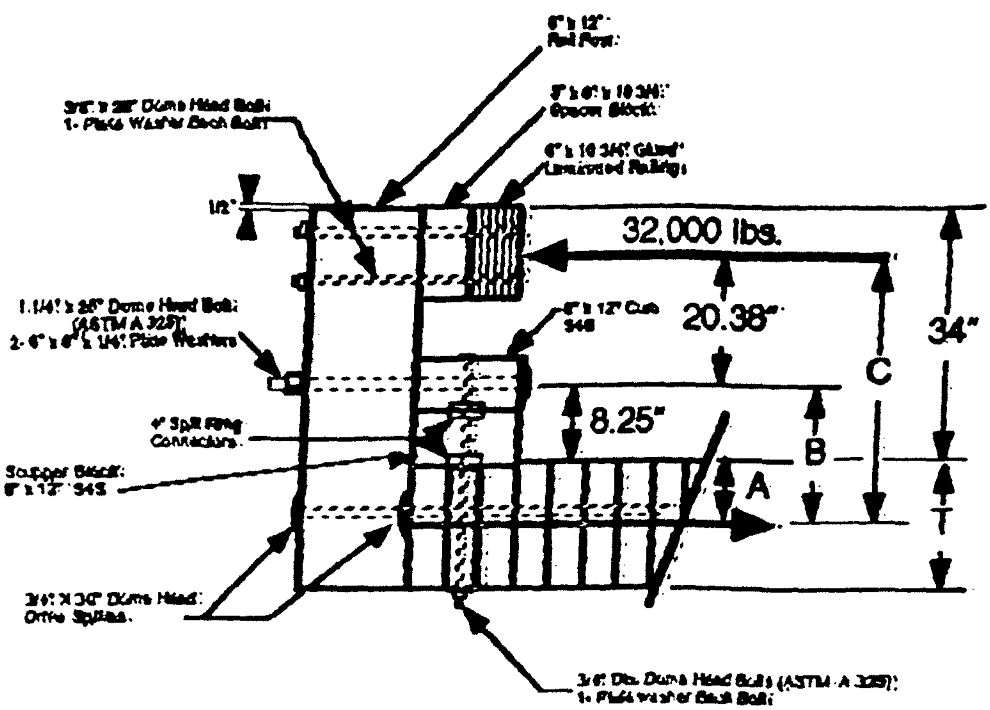
Deck Dowel Dimensions

T	D	E	F
10"	3"	3"	7"
12"	3"	3"	9"
14"	3"	3"	11"
16"	3"	3"	13"
18"	3"	3"	15"

TYPICAL CROSS SECTION OF CURB AND RAIL

TABLE NO. 2 (DECK RESISTANCE TO BENDING MOMENT):

DECK THICKNESS in.	TOTAL MOMENT TO BE RESISTED (T + 28.63)P in-lbs.	RESISTING MOMENT FROM DOWELS (E + F) 12 x 4,158 in-lbs.	RESISTING MOMENT FROM DRIVE SPIKES 3 [(T/2) x 40 x 1,188] in-lbs.	TOTAL RESISTING MOMET in-lbs.
10"	683,751	498,960	712,800	1,211,760
12"	719,151	598,752	855,360	1,454,112
14"	754,551	698,544	997,920	1,696,464
16"	789,951	798,336	1,140,480	1,938,816
18"	825,351	898,128	1,283,040	2,181,168



TYPICAL CROSS SECTION OF CURB AND RAIL

The indicated load of 32,000 pounds is the estimated maximum lateral load from a 5,400 pound vehicle travelling at 60 MPH and striking the rail at 20°.

TABLE NO. 1 (LOAD ON POST BOLT)

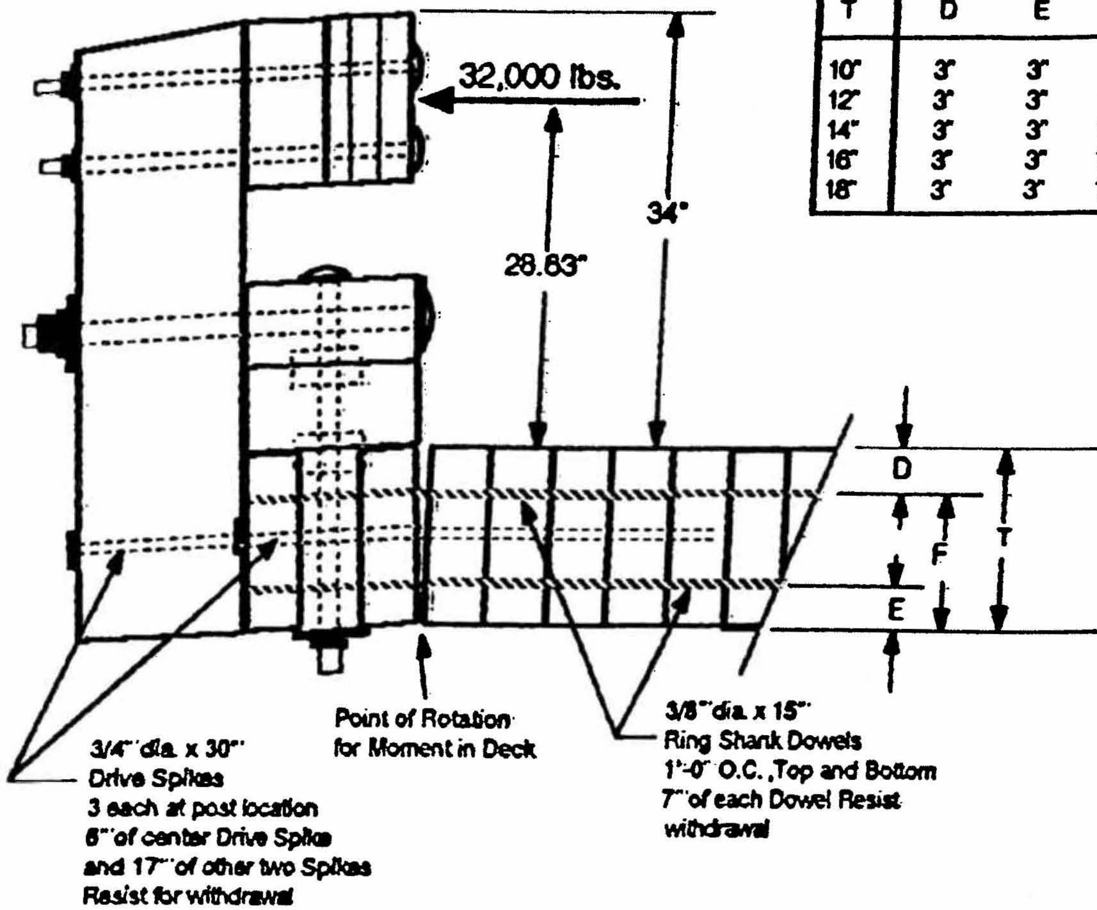
$$P = \frac{32{,}000 \times C}{B}$$

DECK THICKNESS (T)	DIMENSION B = 2/3(T + 8.25)	DIMENSION A = B - 8.25"	DIMENSION C = 20.38" + B	LOAD ON POST BOLT (LBS.) = P
10"	12.17"	3.92"	32.55"	85,588
12"	13.50"	5.25"	33.88"	80,308
14"	14.83"	6.58"	35.21"	75,976
16"	16.17"	7.92"	36.55"	72,331
18"	17.50"	9.25"	37.88"	69,266

NOTE: The 1 1/4" diameter by 26" Dome Head Bolt connecting the rail post to the curb has a Root Area of 0.890 sq. in. and a Tensile Stress Area of .969 sq. in.
The minimum ultimate stress for A 325 in applied tension is 120,000 psi (.25" to 1" dia. bolts).
The minimum ultimate stress for A 325 in applied tension is 105,000 psi. (> 1" dia. bolt).
The minimum ultimate stress for A 307 in applied tension is 60,000 psi.
Allowable load based on Tensile Stress Area = .969 x 105,000 = 101,175 pounds.
Allowable load based on Tensile Stress Area = .969 x 60,000 = 58,140 pounds.

Deck Dowel Dimensions

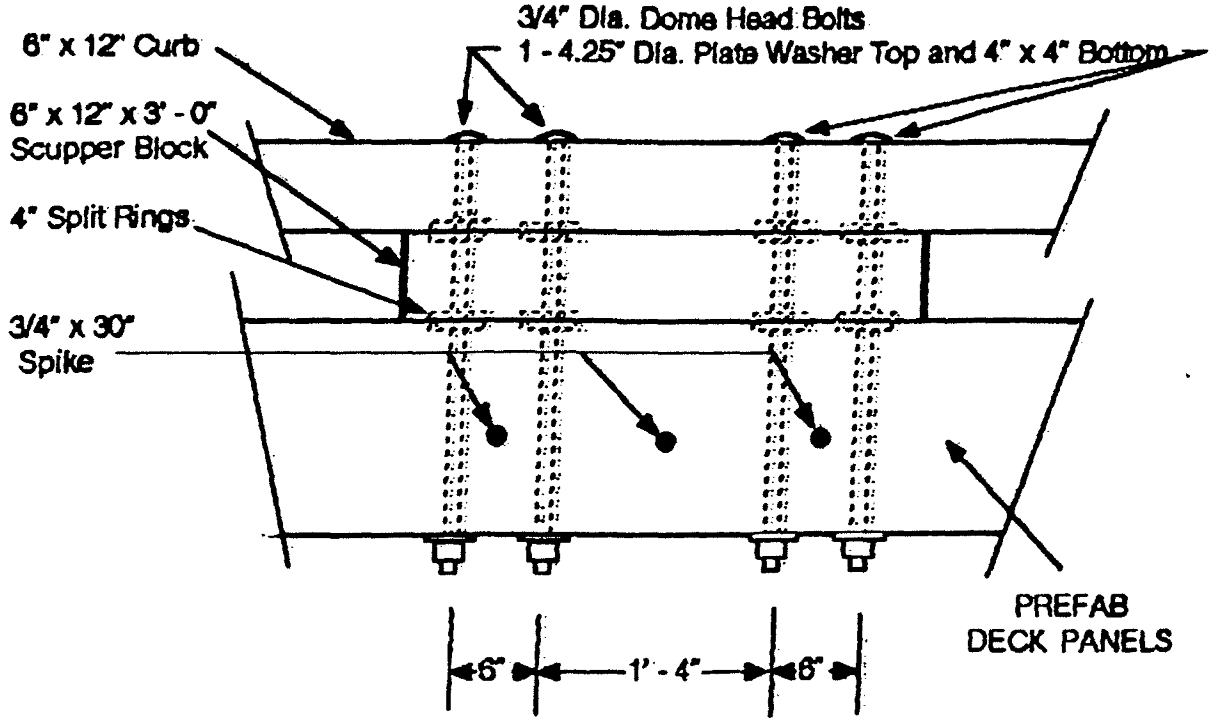
T	D	E	F
10"	3"	3"	7"
12"	3"	3"	9"
14"	3"	3"	11"
16"	3"	3"	13"
18"	3"	3"	15"



TYPICAL CROSS SECTION OF CURB AND RAIL

TABLE NO. 2 (DECK RESISTANCE TO BENDING MOMENT):

DECK THICKNESS in	TOTAL MOMENT TO BE RESISTED (T + 28.83)P in-lbs	RESISTING MOMENT FROM DOWELS (E + F) 12 x 4,158 in-lbs	RESISTING MOMENT FROM DRIVE SPIKES 3 [(T/2) x 40 x 1,188] in-lbs	TOTAL RESISTING MOMET in-lbs
10"	1,236,160	498,960	712,800	1,211,760
12"	1,300,160	598,752	855,360	1,454,112
14"	1,364,160	698,544	997,920	1,696,464
16"	1,428,160	798,336	1,140,480	1,938,816
18"	1,492,160	898,128	1,283,040	2,181,168



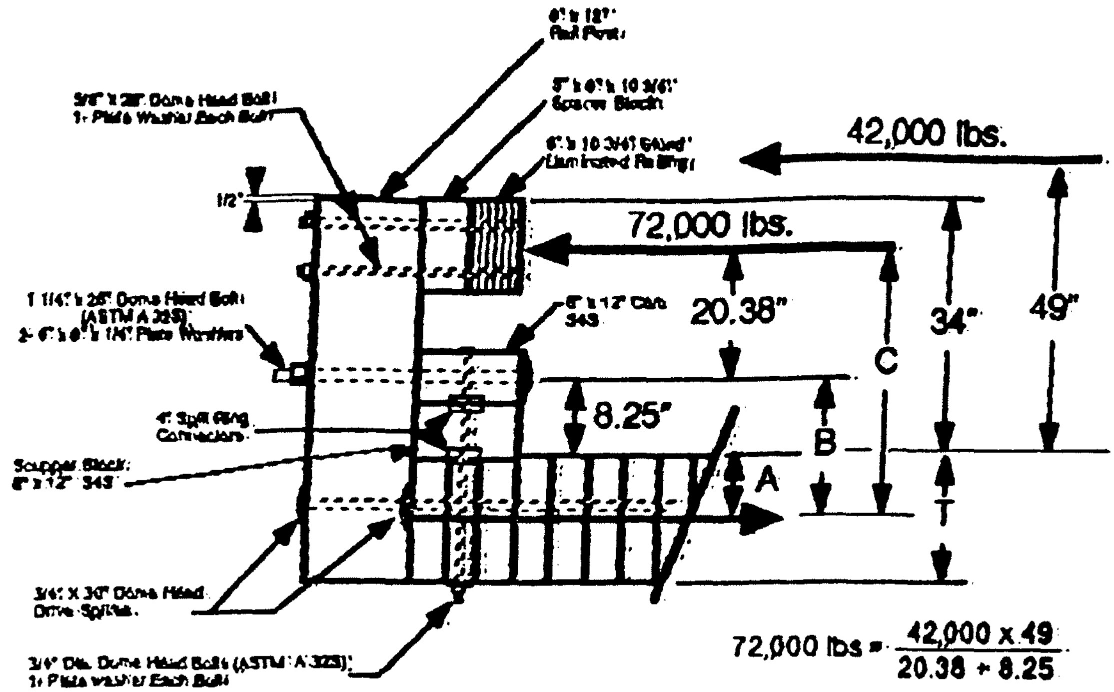
ELEVATION VIEW
CURB AND SCUPPER
ASSEMBLY DETAIL

——— Prefab Timber Deck Panels

NOTE:

The prefabricated deck panels to be dowel laminated using 3/8" x 15" galvanized dowels.

DESIGN NOTES:
Rail posts spaced maximum of 6 feet
Tabulated design values for the strength properties of the timber components are to be modified where appropriate using Duration-of-Load Factor (1.65) for 5 minute loading and horizontal shear adjustment factor of 1.67.



$$72{,}000 \text{ lbs} = \frac{42{,}000 \times 49}{20.38 + 8.25}$$

TYPICAL CROSS SECTION OF CURB AND RAIL

The indicated load of 60,500 pounds is the estimated maximum lateral load from a 18,000 pound vehicle traveling at 50 MPH and striking the rail at 20° with center of mass 49" above bridge deck.

$$P = \frac{72{,}000 \times C}{B}$$

TABLE NO. 1 (LOAD ON POST BOLT)

DECK THICKNESS (T)	DIMENSION B = 2/3(T + 8.25)	DIMENSION A = B - 8.25"	DIMENSION C = 20.38" + B	LOAD ON POST BOLT (LBS.) = P
10"	12.17"	3.92"	32.55"	192,572
12"	13.50"	5.25"	33.88"	180,693
14"	14.83"	6.58"	35.21"	170,945
16"	16.17"	7.92"	36.55"	162,746
18"	17.50"	9.25"	37.88"	155,849

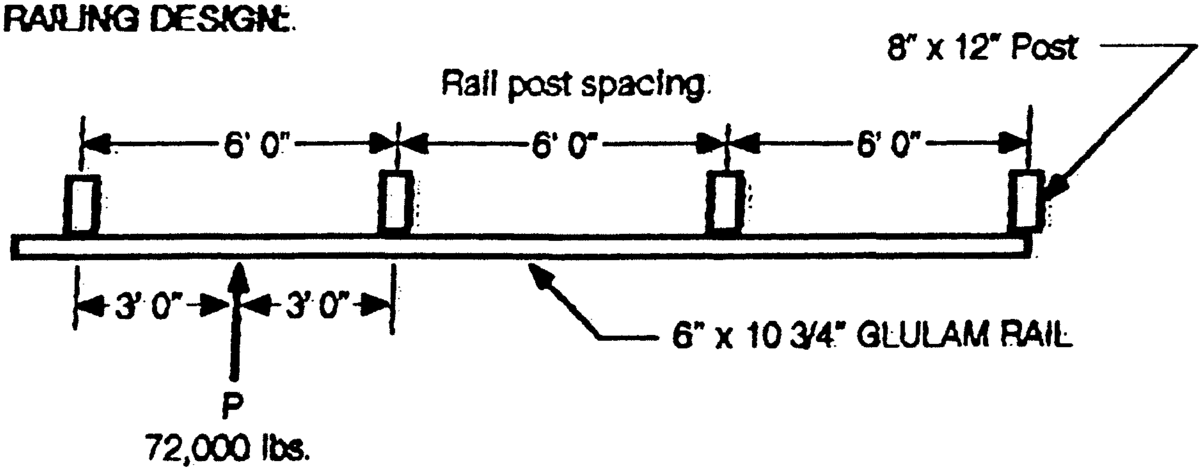
NOTE: The 1 1/4" diameter by 26" Dome Head Bolt connecting the rail post to the curb has a Root Area of 0.890 sq. in. and a Tensile Stress Area of .969 sq. in.
The minimum ultimate stress for A 325 in applied tension is 120,000 psi (.25" to 1" dia. bolts)
The minimum ultimate stress for A 325 in applied tension is 105,000 psi. (> 1" dia. bolt)
The minimum ultimate stress for A 307 in applied tension is 60,000 psi
Allowable load based on Tensile Stress Area = .969 x 105,000 = 101,175 pounds.
Allowable load based on Tensile Stress Area = .969 x 60,000 = 58,140 pounds

ULTIMATE UNIT STRESSES: Ref. *Ultimate stress values from page 4-15. WOOD Handbook, Forest Products Laboratory.*

Specie - Douglas-fir

Modulus of rupture (F_b) = 12,800 psi
Modulus of elasticity (E) = 1,970,000 psi
Compresion parallel to grain, max. crushing strength = 7,260 psi
Compression perpendicular to grain, at portional limit (F_c) = 870 psi
Shear parallel to grain, max. shearing strength (F_v) = 1,380 psi

RAILING DESIGN:



BENDING STRESS COMPUTATIONS: (formula from AISC, 8th Ed., page 2-124)

$$\text{Maximum moment} = M = \frac{13\ PL}{64} = \frac{13 \times 72{,}000 \times 6 \times 12}{64} = 1{,}053{,}000 \text{ in-lbs.}$$

$$\text{Section modulus} = S = \frac{bd^2}{6} = \frac{10.75 \times 6^2}{6} = 64.5 \text{ in}^3$$

$$f_b = \frac{1{,}053{,}000 \text{ in-lbs.}}{64.5 \text{ in}^3} = 16{,}326 \text{ psi} > 12{,}800 \text{ psi} \quad \text{NOT OK}$$

HORIZONTAL SHEAR:

Check with load at 3d = 1/4 L = 1.5' from support.

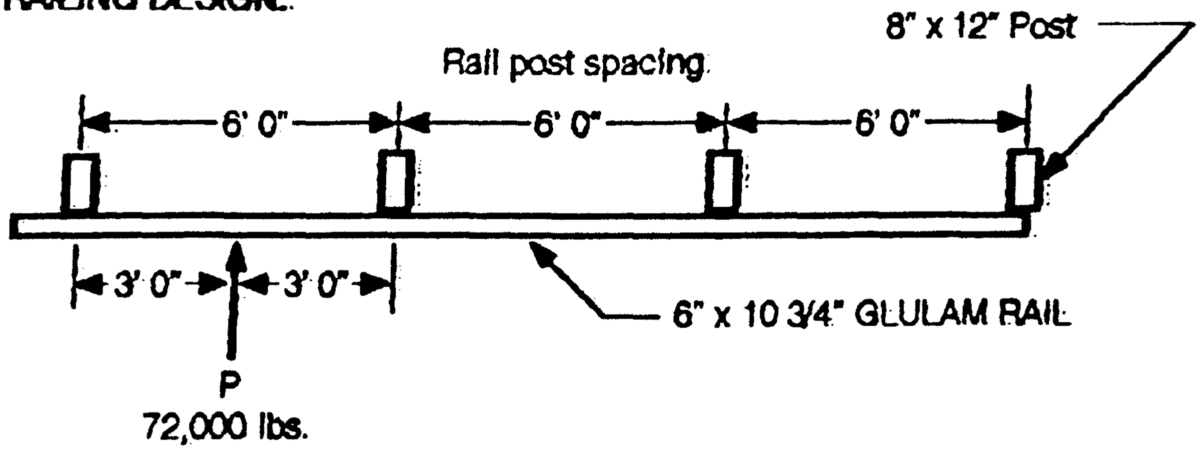
$$V = R = \frac{72{,}000 \times 4.5}{6} = 54{,}000 \text{ lbs.}$$

ULTIMATE UNIT STRESSES: Ref. *Ultimate stress values from page 4-15. WOOD Handbook, Forest Products Laboratory.*

Specie - Douglas-fir

Modulus of rupture (F_b) = 12,800 psi
Modulus of elasticity (E) = 1,970,000 psi
Compresion parallel to grain, max. crushing strength = 7,260 psi
Compression perpendicular to grain, at portional limit (F_c) = 870 psi
Shear parallel to grain, max. shearing strength (F_v) = 1,380 psi

RAILING DESIGN:



BENDING STRESS COMPUTATIONS: (formula from AISC, 8th Ed., page 2-124)

$$\text{Maximum moment} = M = \frac{13\ PL}{64} = \frac{13 \times 72{,}000 \times 6 \times 12}{64} = 1{,}053{,}000 \text{ in-lbs.}$$

$$\text{Section modulus} = S = \frac{bd^2}{6} = \frac{10.75 \times 6^2}{6} = 64.5 \text{ in}^3$$

$$f_b = \frac{1{,}053{,}000 \text{ in-lbs.}}{64.5 \text{ in}^3} = 16{,}326 \text{ psi} > 12{,}800 \text{ psi} \quad \text{NOT OK}$$

HORIZONTAL SHEAR:

Check with load at 3d = 1/4 L = 1.5' from support

$$V = R = \frac{72{,}000 \times 4.5}{6} = 54{,}000 \text{ lbs.}$$

POST DESIGN:

Check bending moment at 1 1/4" bolt hole.

Maximum moment = M = 72,000 x 20.38" = 1,467,360 in-lbs.

Net section of post = 8" - 1 1/4" = 6 3/4"

$$\text{Section modulus} = S = \frac{bd^2}{6} = \frac{6.75 \times 12^2}{6} = 162 \text{ in}^3$$

$$f_b = \frac{M}{S} = \frac{1{,}467{,}360 \text{ in-lbs.}}{162 \text{ in}^3} = 9{,}058 \text{ psi.} < 12{,}800 \text{ psi} \quad \text{OK}$$

HORIZONTAL SHEAR:

V = 72,000 lbs.

$$f_v = \frac{3V}{2bd} = \frac{3 \times 72{,}000}{2 \times 8 \times 12} = 1{,}125 \text{ psi} < 1{,}380 \quad \text{OK}$$

LOAD ON 1 1/4" POST BOLT:

Ultimate unit stress for A 325 Steel bolt (1.25" dia.) in tension = 105,000 psi.

Load on bolt (from sheet 11 Of 16 sheets) = 192,572 lbs.

$$\text{Net section required} = \frac{192{,}572 \text{ lbs.}}{105{,}000 \text{ psi}} = 1.83 \text{ sq. in.} > 0.969 \quad \text{NOT OK!}$$

Tensile Area of 1 1/4" bolt = 0.969 sq. in. (AISC, 8th. Ed., page 4-141)

WASHER DESIGN FOR POST BOLT:

Try 6" X 8"

$$\frac{192{,}572 \text{ lbs.}}{48 \text{ sq. in.}} = 4{,}012 \text{ psi} > 870 \text{ psi} \quad \text{NOT OK}$$

CURB TO FLOOR SPLIT RING CONNECTIORS:

Design Value/Ultimate Value = 4.0 to 4.5 (page 7-18 WOOD Handbook)

1. Seasoned lumber
2. Group "B" species
3. Angle of load to grain = 90°
4. Over 3" thick both faces

Allowable load on 4" split ring connector and 3/4" bolt = 3,360 x 4 = 13,440 lbs.

$$\text{Number of bolts required} = \frac{V}{\text{Allowable}} = \frac{42{,}000}{13{,}440} = 3.13 \text{ Bolts}$$

Use 4 bolts, two on each side.

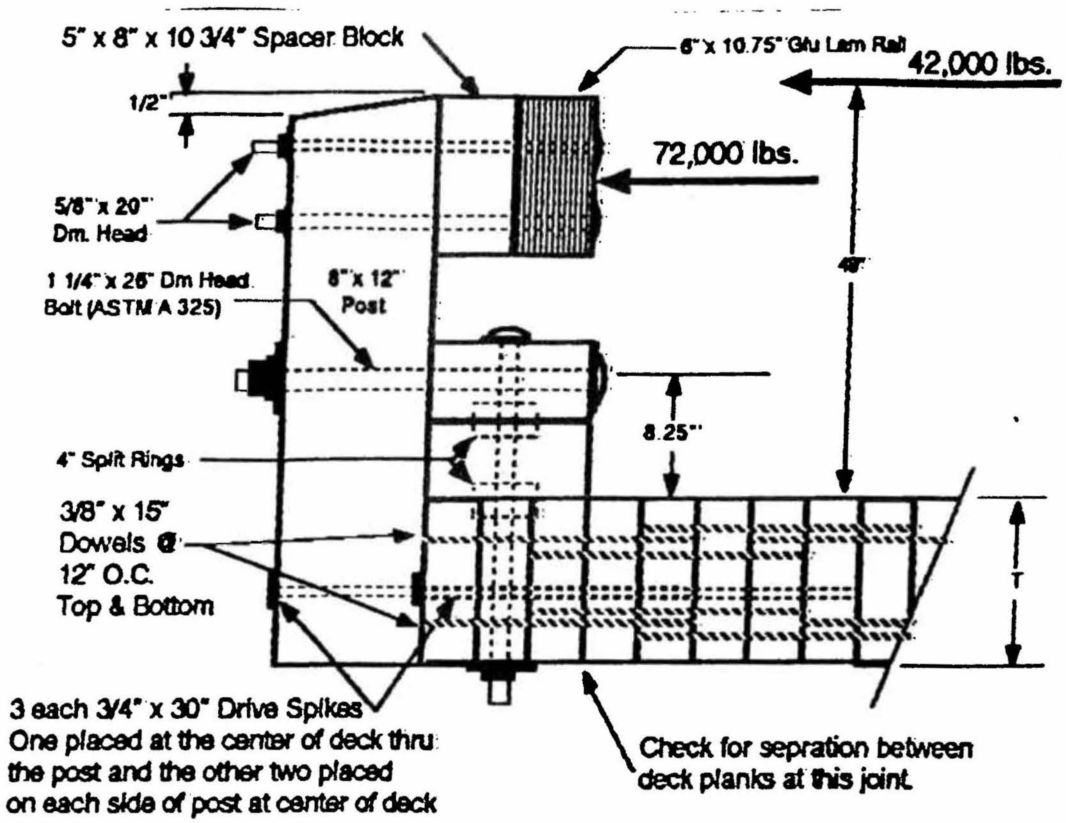
CURB TO FLOOR BOLTS:

Check bolts in tension, use ASTM A 325 Bolts

$$\frac{72{,}000 \text{ lbs.} \times 20.38 \text{ in.}}{6 \text{ in.}} = 244{,}560 \text{ pounds to be resisted by bolts}$$

Tensile Stress Area for 3/4" diameter bolt = 0.334 sq. in.

Allowable load for 3/4" diameter bolt = 120,000 x 0.334 = 40,080 lbs. per bolt



TYPICAL CROSS SECTION OF CURB AND RAIL

CHECK WITHDRAWAL FORCES IN DECK:

Compute withdrawal resistance of 3/4" x 30" Drive Spikes

P_w = Ultimate withdrawal resistance *WOOD Handbook, page 7-6*

$P_w = 6{,}600 \times G^2 \times D \times L$ Where G = Specific gravity = .49 , D = Diameter = .75"

$P_w = 6{,}600 \times .49^2 \times .75 \times 1 = 1{,}188$ lbs./in. Ultimate Value.

$P_w = 1{,}188 \times (6 + 17 + 17) = 47{,}520$ pounds > 42,000 pounds OK

Compute withdrawal resistance of 3/8" x 15" Deck Dowels

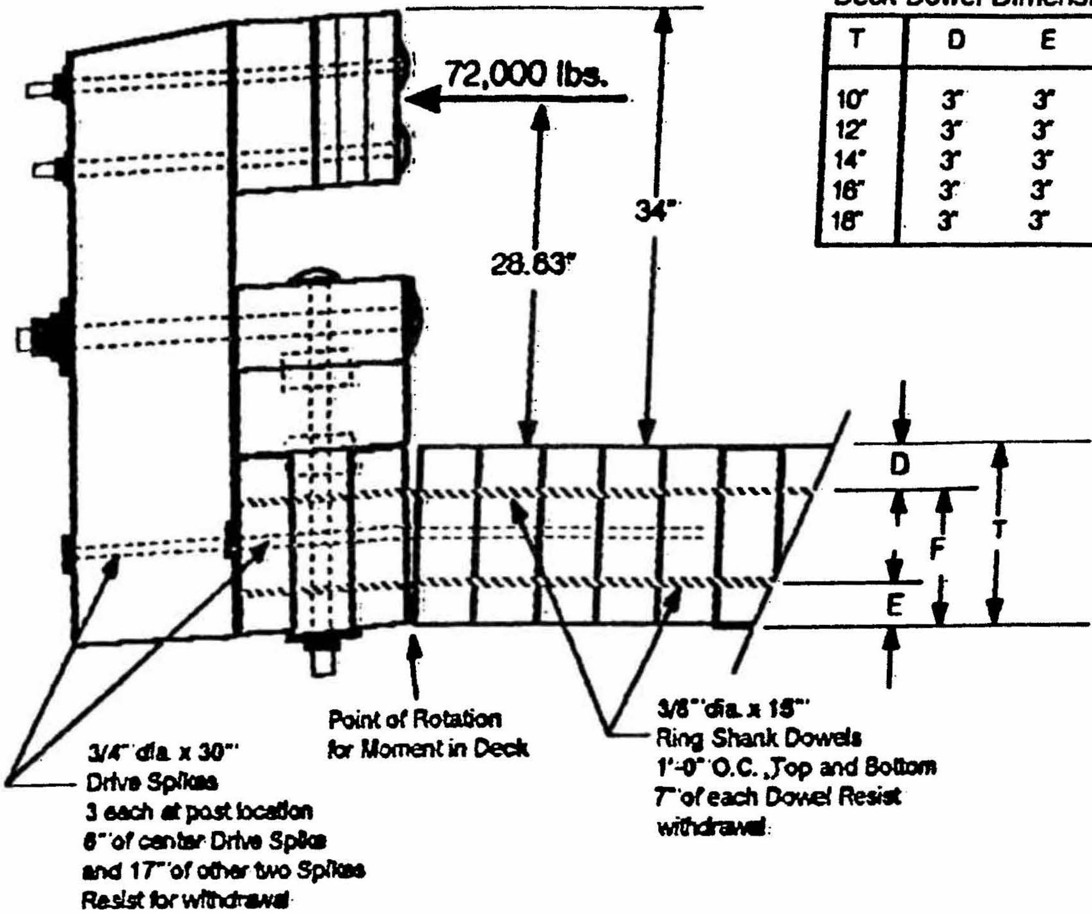
P_w = Ultimate withdrawal resistance *WOOD Handbook, page 7-6*

$P_w = 6{,}600 \times G^2 \times D$ Where G = Specific gravity = .49 , D = Diameter = .375"

$P_w = 6{,}600 \times .49^2 \times .375 \times 1.0 = 594$ lbs./in. Ultimate Value.

Deck Dowel Dimensions

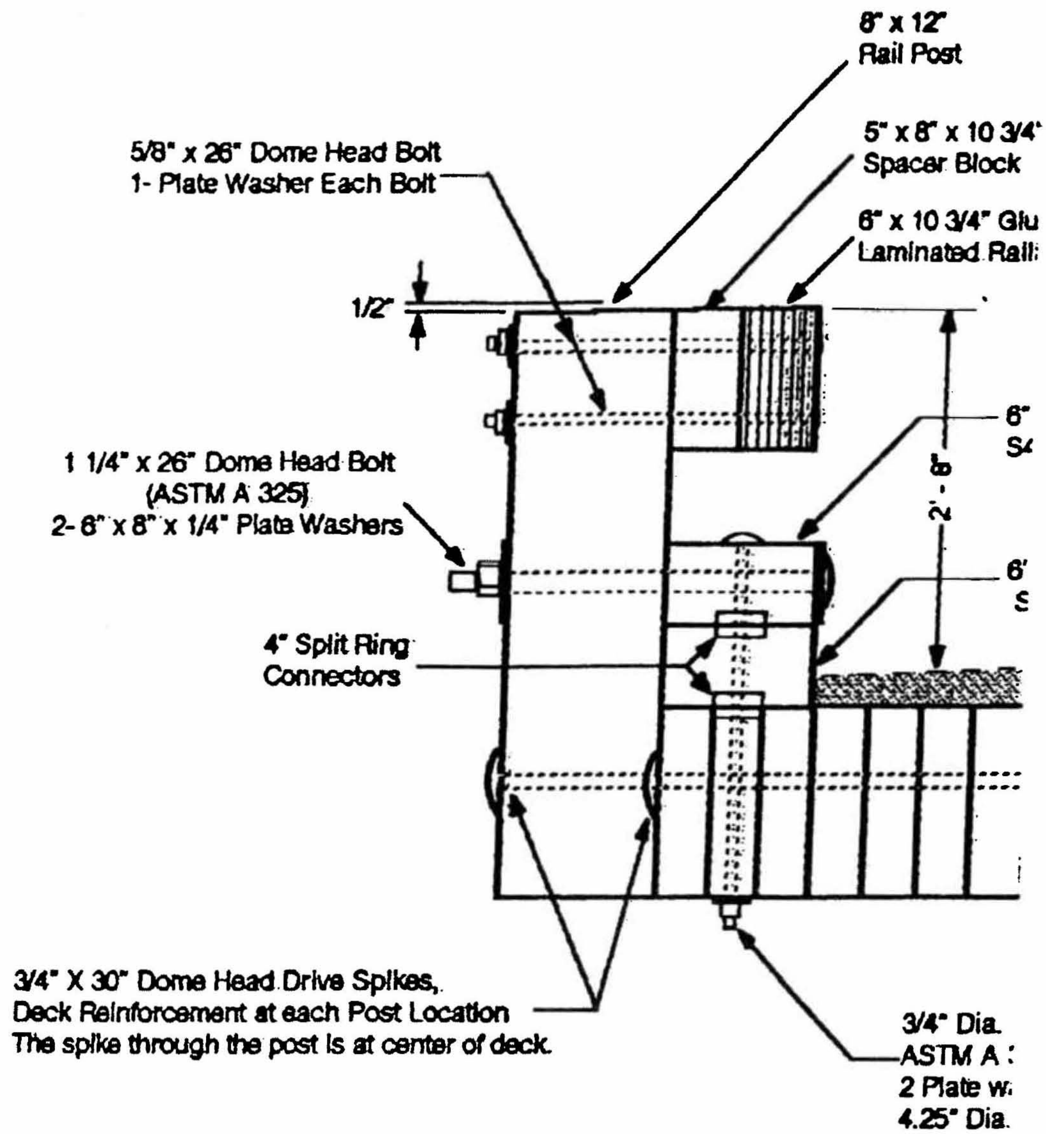
T	D	E	F
10"	3"	3"	7"
12"	3"	3"	9"
14"	3"	3"	11"
16"	3"	3"	13"
18"	3"	3"	15"



TYPICAL CROSS SECTION OF CURB AND RAIL

TABLE NO. 2 (DECK RESISTANCE TO BENDING MOMENT):

DECK THICKNESS in.	TOTAL MOMENT TO BE RESISTED (T+28.63)P in-lbs.	RESISTING MOMENT FROM DOWELS (E+F) 12 x 4,158 in-lbs.	RESISTING MOMENT FROM DRIVE SPIKES 3 [(T/2) x 40 x 1,188] in-lbs.	TOTAL RESISTING MOMET in-lbs.
10"	2,761,360	498,960	712,800	1,211,760
12"	2,925,360	598,752	855,360	1,454,112
14"	3,069,360	698,544	997,920	1,696,464
16"	3,213,360	798,336	1,140,480	1,938,816
18"	3,357,360	898,128	1,283,040	2,181,168



CROSS SECTION AT RAIL POST

NOTE:
All timber to be Douglas Fir. The stress grade as follows:

Rail Posts - Post and Timber, Dense Select Structural

APPENDIX C: SUMMARY OF RESULTS, TEST WB-1

Test No. WB-1
Test Date . . . . Sept. 21, 1988
Installation Length - ft [m] . . . . . . 72 [22]

Beam
- Member . . 6" x 10-3/4" laminated wood
- Length - ft [m] . . . . 18.0 [5.5]

Maximum Deflections - in. [cm]
- Permanent . . . . 1.5 [3.8]
- Dynamic . . . . 6.3 [16.0]

Post
- Details of the posts, blockouts, curb, and deck are included in Figure 1.

Vehicle . . . . 1982 V. W. Rabbit

Mass - lb [kg]
- Test Inertia . . . . 1818 [825]
- Dummy . . . . 165 [75]
- Gross Test Weight . . . . . 1983 [900]

Speed - mph [km/h] . . . . 59.2 [95.3]

Angle - degrees
- Impact 20
- Exit . . . . -12.0

Occupant Impact Velocity - fps [m/s]
- Forward (accel) . . . . . . -10.6 [-3.2]
- Lateral (accel) . . . . . -18.6 [-5.7]

Occupant Ridedown Accelerations - g's
- Forward (accel) . . . . -0.7
- Lateral (accel) 7.6

Maximum 50 msec Avg Accelerations - g's
- Longitudinal (accel) . . . . -5.0
- Lateral (accel) 8.5

Vehicle Damage
- TAD 01-FR-4
- VDI 01FREE6

TEST WB-1

Barrier Installation

The barrier evaluated in the test was a Glulam Prefabricated Bridge section. The barrier system consists of 18-ft (5.49 m) long by 7-ft (2.1 m) wide laminated wood bridge deck panels. The thickness of the deck panels used in this test was 10 in. (25.4 cm). For this test, 4 panels were used to construct a simulated bridge 72 ft (21.9 cm) in length. The panels were positioned and fastened to an existing reinforced concrete deck at the test site. The curb/scuppers, posts, and rail were attached to the deck according to the manufacturer's instructions. Figure 25 presents details supplied by the manufacturer of the system.

Test Purpose

The purpose of this test was to investigate the dynamic interactions of the small car with the bridge rail and curb. Goals for this test were: (1) the vehicle should be smoothly redirected without exhibiting any tendency to snag or pocket, (2) the vehicle should remain upright throughout the event, and (3) the vehicle after-collision trajectory should not present undue hazard to other traffic.

Test Vehicle

The vehicle used in the test was a 1982 Volkswagen Rabbit. Gross test weight, including the dummy and instrumentation was 1983-lb (900-kg).

Performance

Impact conditions were 59.2 m/h (95.3 km/h) and a 20-degree impact angle. As shown in figure 26, the vehicle impacted the barrier 29 in. (73.7 cm) downstream of Post 5. The vehicle remained in contact with the barrier for 12.5-ft [3.8-m] before redirection at a -12.0 degree angle. During the impact sequence the right front tire/wheel became engaged between the top of the curb and the bottom of the rail (see figure 27). Measurements of the tire/wheel path indicated a maximum of 5 in. (13 cm) of lateral engagement. Since the curb is 12 inches (30.4 cm) wide, there was no propensity for the wheel to snag on a post during impact. No significant pitch, roll, or yaw was noted during impact and redirection. The vehicle came to rest 140 ft (43 m) downstream of the impact point and 50 ft (15 m) out from the barrier plane. The vehicle brakes were applied at approximately 100 ft (30 m) after impact. Table 12 presents after impact vehicle trajectory. Maximum dynamic barrier deflection observed from the overhead data camera was 6.3 in (16.0 cm). Measurements of the barrier after the test, tabulated in table 13, showed a maximum of 1.5 in (3.8 cm) permanent deflection.

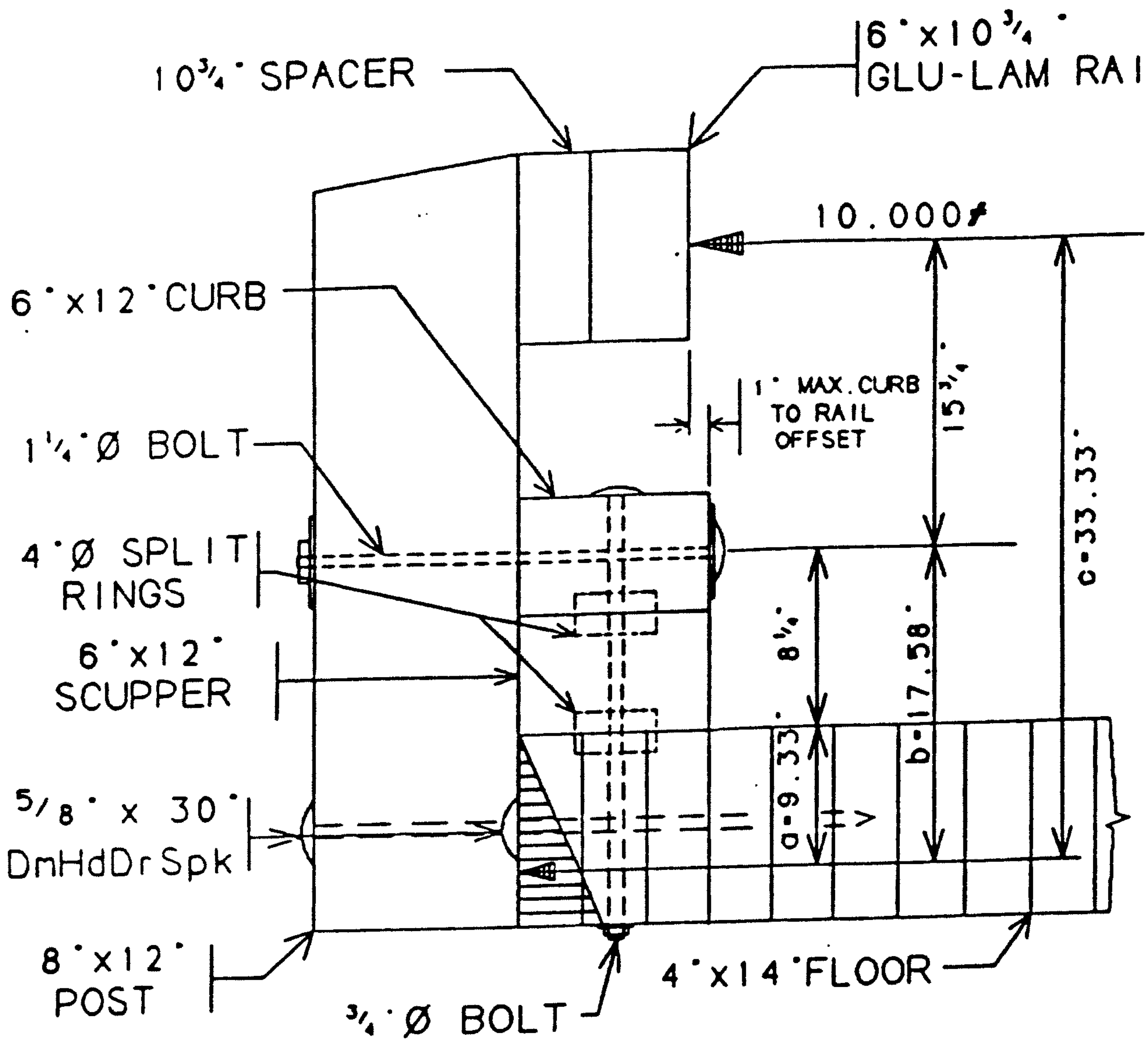
Maximum 50 m/s average accelerations from transducer data indicated 50 m/s averages of -5.0 g's (longitudinal) and 7.6 g's (lateral). Figure 28 presents a summary of test results. Vehicle kinetics from onboard transducers is tabulated in Table 14. Plots of vehicle accelerations are presented in Figure 29. Table 15 presents occupant risk data derived from the on-board transducers.

Barrier Damage

Damage to the barrier consisted of scuff marks and minor gouging on the rail and curb. Inspection of the barrier system revealed no fractured posts or beam members. Observation of the deck showed delamination between the second and third deck timbers in the impact area. The delamination of the deck occurred from the location of post 3 to post 9 with a maximum separation of 0.5 in (1.3 cm) on the top surface of the deck about 3 ft (0.9 m) downstream from post 6. Maximum separation observed on the bottom surface of the deck was 0.1-in (0.3 cm). Several drive spikes in the impact affected area of the deck showed evidence of minor "pullout."

Vehicle Damage

Damage to the vehicle consisted of sheet metal deformation of the hood, right front fender, side, and rear fender. The windshield was cracked from A-pillar deformation. Both right side tires were blown out during impact. Vehicle damage was considered commensurate with the severity of the impact. Vehicle damage measurements are contained in table 16.



	a	b	c
10"DECK	6.66"	14.91"	30.66"
12"DECK	8"	16.25"	32"

Figure 25. Barrier construction details, test WB-1.

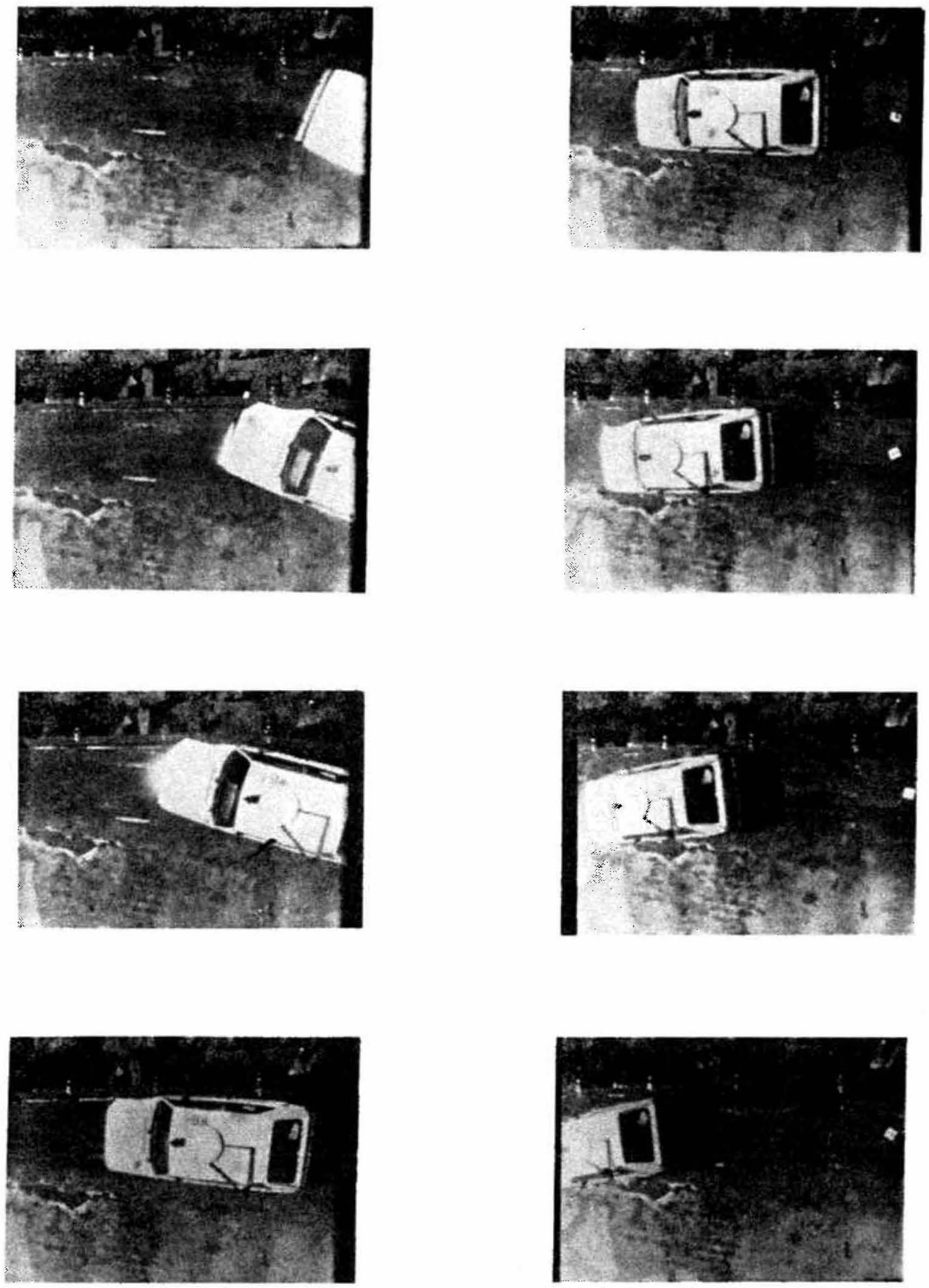


Figure 26. Sequential photographs during impact, test WB-1.

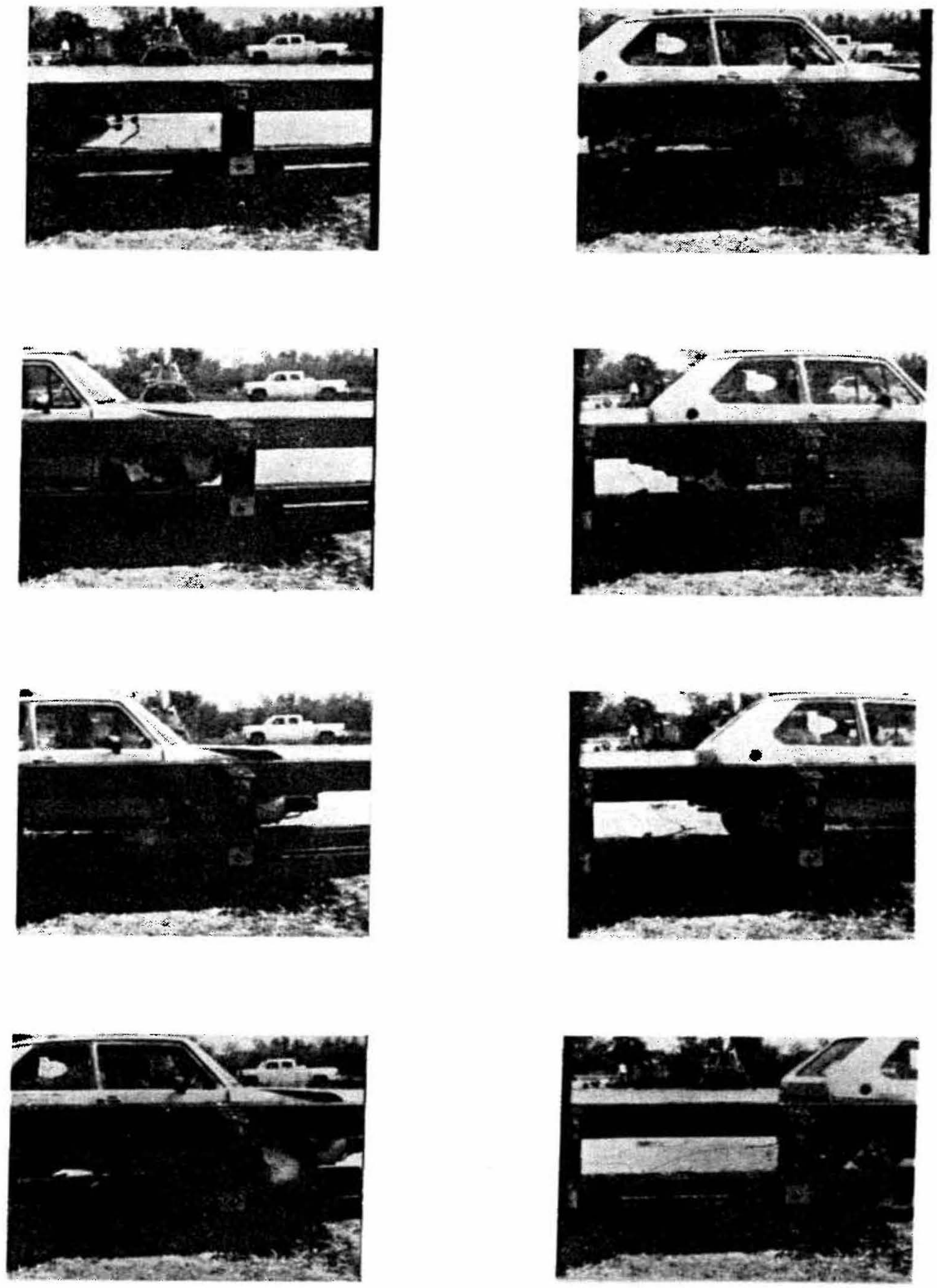
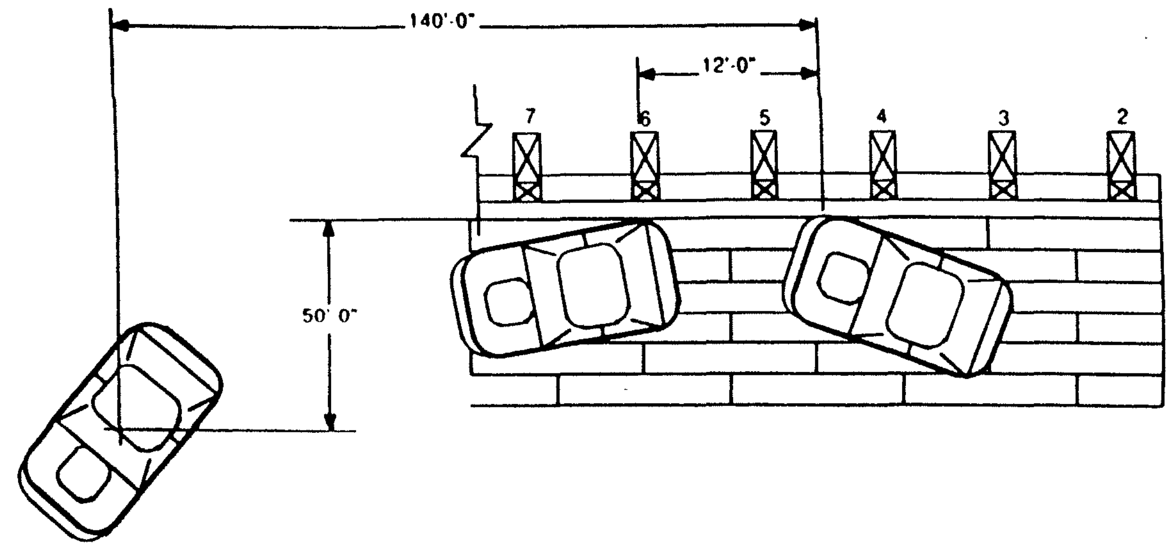


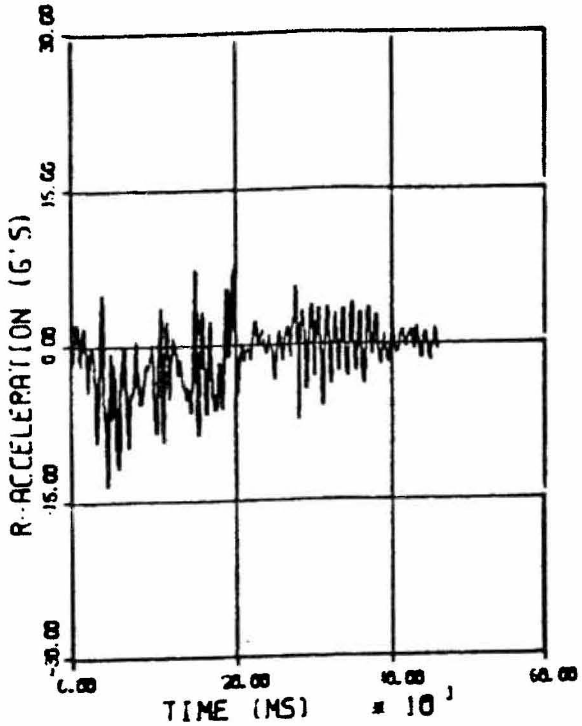
Figure 27. Sequential photographs as viewed from behind the rail, test WB-1.



Test No.	WB-1
Test Date	Sept. 21, 1988
Installation Length - ft [m]	72 [22]
Beam	
Member	6-in (15.2 cm) x10-3/4-in (27.3) laminated wood
Length - ft [m]	18.0 [5.5]
Maximum Deflections - in. [cm]	
Permanent	1.5 [3.8]
Dynamic	6.3 [16.0]
Post	
Details of the posts, blockouts, curb, and deck are included in figure 1.	
Vehicle	1982 V.W. Rabbit
Mass - lb [kg]	
Test Inertia	1818 [825]
Dummy	165 [75]
Gross Test Weight	1983 [900]
Speed - mi/h [km/h]	59.2 [95.3]

Angle - degrees	
Impact	20
Exit	-12.0
Occupant Impact Velocity - ft/s [m/s]	
Forward (accel)	-10.6 [-3.2]
Lateral (accel)	-18.6 [-5.7]
Occupant Ridedown Accelerations - g's	
Forward (accel)	-0.7
Lateral (accel)	7.6
Maximum 50 m/s Avg Accelerations - g's	
Longitudinal (accel)	-5.0
Lateral (accel)	8.5
Vehicle Damage	
TAD	01-FR-4
VDI	01FREE6

Figure 28. Summary of results, test WB-1.



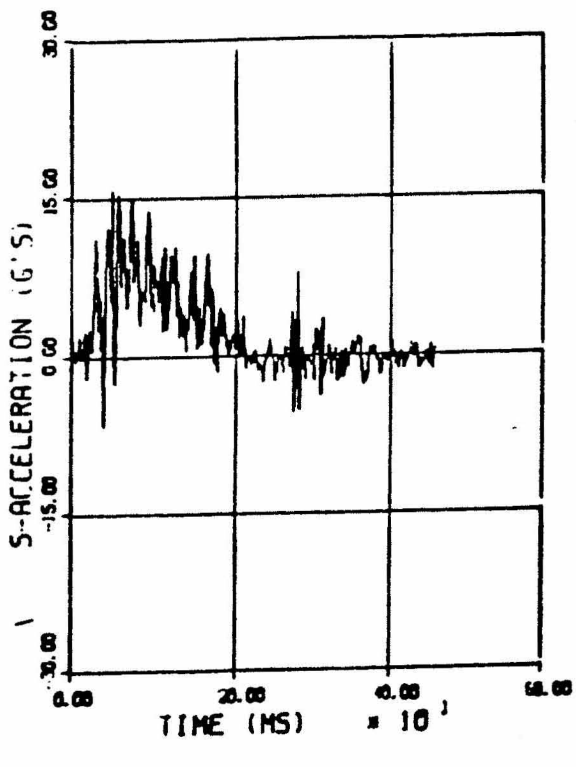


Figure 29. Vehicle acceleration plots, test WB-1.

Table 12. After impact vehicle trajectory, test WB-1.

Location[1]	Distance[2]
0	0
10	-0.2
20	1.5
30	3.3
40	5.2
50	9.0
60	10.5
70	12.8
80	16.1
90	19.8
100	24.5

[1]Distance measured in the downstream direction with 0 as the point of impact.

[2]Measured perpendicular to the barrier plane at the front tire on the impact side of the vehicle

Note: All dimensions are in feet. 1 ft = 0.305 m

Table 13. Permanent barrier deflections, test WB-1.

Post/Location	Deflection
3	0.3
4	0.4
5	0.5
6	0.8
7	1.5
8	1.3
9	0.8
10	0.4
11	0.2

Note: All dimensions are in inches. 1 ft = 2.54 m

Table 14. Vehicle kinetics data, test WB-1.

TEST ID ------- WB-1
TEST DATE ----- 09-21-88
VEHICLE CLASS - MINI
IMPACT SPEED -- 36.83 FPS

VEHICLE KINETICS SUMMARY
NOTE: VALUES ARE INSTANTANEOUS AT TIME

TIME	ACCEL.(G'S)		HEAD.ANG.	VELOCITY(FPS)		DISP.(F)	
(S)	LONG.	LAT.	DEG	LONG.	LAT.	X	Y
.000	-.30	-.88	20.00	86.83	.00	.00	.00
.010	-.97	1.14	19.96	86.85	-.05	.82	.30
.020	-3.04	-.19	19.93	86.76	.14	1.63	.59
.030	-4.71	11.21	20.00	86.15	1.18	2.44	.88
.040	-.47	-6.51	19.95	85.24	2.65	3.25	1.15
.050	-2.48	11.16	19.88	83.19	4.52	4.06	1.41
.060	-8.73	10.11	19.69	81.03	6.82	4.85	1.64
.070	-8.51	8.36	19.28	79.92	8.88	5.64	1.83
.080	.03	10.24	18.69	78.59	11.25	6.42	1.99
.090	-2.93	5.23	17.84	77.51	12.16	7.19	2.12
.100	-1.59	4.31	16.65	77.32	13.29	7.97	2.23
.110	1.72	9.46	15.17	76.71	13.63	8.75	2.31
.120	-4.60	5.69	13.18	76.27	12.84	9.52	2.37
.130	-2.81	5.09	10.80	76.32	12.09	10.29	2.41
.140	-5.22	.46	9.16	75.67	11.05	11.06	2.42
.150	5.16	8.04	7.54	74.78	10.31	11.82	2.43
.160	3.24	1.32	5.45	75.10	8.65	12.57	2.42
.170	1.27	6.34	3.51	74.90	7.92	13.33	2.39
.180	-1.87	4.03	1.69	73.86	6.24	14.07	2.36
.190	4.26	1.37	-.07	73.82	4.87	14.81	2.31
.200	-.30	.68	-1.61	74.88	3.24	15.55	2.26
.210	-1.08	3.67	-3.00	74.36	1.93	16.30	2.20
.220	-.30	-.74	-4.32	74.09	.28	17.04	2.14
.230	.20	-1.02	-5.54	74.37	-1.41	17.78	2.09
.240	-.82	-.19	-6.54	74.38	-3.07	18.52	2.03
.250	-3.04	-2.39	-7.49	74.01	-4.23	19.26	1.97
.260	-1.63	-.97	-8.39	73.83	-5.66	20.00	1.92
.270	-1.20	-.24	-9.30	73.83	-6.96	20.74	1.87
.280	1.95	.27	-10.28	74.34	-8.08	21.48	1.82
.290	-3.09	-1.38	-11.15	74.17	-9.21	22.22	1.76
.300	.43	-.38	-12.01	74.02	-10.57	22.97	1.71
.310	-1.87	-2.80	-12.78	74.10	-11.49	23.71	1.66
.320	.65	.73	-13.65	73.75	-12.77	24.46	1.61
.330	.60	-1.06	-14.48	73.52	-13.90	25.20	1.56
.340	1.27	-1.24	-15.31	73.41	-15.41	25.95	1.52
.350	3.13	.91	-16.14	73.23	-16.46	26.70	1.47
.360	2.62	1.51	-16.97	73.13	-17.17	27.45	1.43
.370	3.41	-1.66	-17.83	72.73	-18.82	28.20	1.38
.380	2.68	.50	-18.65	72.77	-19.81	28.95	1.34
.390	.71	-.15	-19.51	72.43	-21.13	29.70	1.29
.400	.93	-.16	-20.38	71.97	-22.36	30.45	1.25
.410	-.02	-.65	-21.19	71.69	-23.41	31.21	1.21
.420	-.08	-.15	-21.95	71.52	-24.52	31.96	1.17
.430	.09	-.28	-22.74	71.33	-25.53	32.72	1.13
.440	-1.20	-1.15	-23.52	70.99	-26.53	33.47	1.09
.450	-1.70	-.97	-24.30	70.57	-27.62	34.23	1.06

HIGHEST 50.0-MS AVG. ACCEL.

	G'S	TIME (SEC) START	END
LONG.	-5.03	.041	.091
LAT.	8.49	.046	.096

Table 15. Occupant risk data, test WB-1.

TEST ID ------- WB-1
TEST DATE ----- 09-21-88
VEHICLE CLASS - MINI
IMPACT SPEED -- 86.63 FPS

OCCUPANT RISK SUMMARY
NOTE: INSTANTANEOUS 10-MS AVERAGE ACCELERATIONS

TIME (S)	(----- VEHICLE ACCEL. (G'S) LONG.	LAT.	ANG.VEL (RAD/S) ------)	(----------- OCCUPANT VEL. (FPS) LONG.	LAT.	DISP. (F) LONG.	LAT. ----------)
.000	-.30	-.88	-.07	.00	.00	.00	.00
.010	.17	.57	-.02	.05	-.07	.00	.00
.020	-1.16	.91	.15	.36	-.51	.00	.00
.030	-4.15	6.04	.02	.79	-1.28	.01	-.01
.040	-2.81	2.63	.13	1.85	-2.96	.02	-.03
.050	-4.79	7.38	-.32	3.32	-4.41	.05	-.06
.060	-6.32	9.61	-.34	5.46	-6.99	.09	-.12
.070	-5.45	9.08	-.99	5.76	-8.90	.14	-.20
.080	-2.81	7.96	-1.28	6.71	-11.83	.21	-.31
.090	-3.30	8.34	-1.72	7.19	-13.51	.27	-.44
.100	-3.60	6.90	-2.39	6.46	-15.68	.33	-.69
.110	-2.64	6.89	-2.72	6.49	-17.86	.38	-.77
.120	-1.30	6.34*	-4.39	4.54	-18.12*	.41	-.96*
.130	-1.27	5.80	-3.66	4.90	-21.81	.41	-1.18
.140	-4.37	2.70	-2.49	6.57	-24.58	.43	-1.43
.150	-.96	5.28	-3.26	6.00	-25.34	.46	-1.69
.160	-1.82	3.15	-3.55	4.56	-26.43	.43	-1.96
.170	-2.47	5.06	-3.32	4.27	-28.73	.41	-2.26
.180	-4.13	2.26	-2.94	4.96	-30.19	.38	-2.56
.190	1.71	1.52	-2.83	4.25	-31.47	.34	-2.88
.200	.98	1.62	-2.54	2.72	-32.37	.30	-3.21
.210	-.70	.94	-2.46	2.54	-33.10	.24	-3.54
.220	.24	-.26	-2.29	2.22	-33.49	.18	-3.88
.230	.67	-.87	-1.90	1.65	-33.93	.11	-4.22
.240	-.15	-.22	-1.67	1.25	-33.90	.06	-4.56
.250	-1.39	-.73	-1.59	1.07	-34.12	-.02	-4.90
.260	.05	-.47	-1.60	.60	-33.88	-.09	-5.24
.270	.86	.53	-1.68	-.17	-33.69	-.17	-5.58
.280	.54	-.34	-1.37	-1.02	-34.22	-.28	-5.91
.290	-.43	-.41	-1.49	-1.69	-34.08	-.38	-6.26
.300	1.24	-.31	-1.47	-2.20	-33.86	-.50	-6.58
.310	-.79	-.03	-1.33	-2.73	-34.09	-.61	-6.91
.320	.17	-.33	-1.58	-3.43	-33.61	-.75	-7.24
.330	-.01	-.92	-1.34	-3.59	-33.81	-.89	-7.57
.340	.13	-.70	-1.50	-4.39	-33.15	-1.04	-7.89
.350	.63	.53	-1.46	-4.90	-33.19	-1.20	-8.20
.360	-.03	.04	-1.47	-5.57	-33.46	-1.37	-8.52
.370	.93	-1.16	-1.54	-6.05	-32.76	-1.56	-8.83
.380	.66	.18	-1.44	-6.75	-32.86	-1.75	-9.13
.390	-.49	-.83	-1.51	-7.32	-32.47	-1.96	-9.43
.400	.11	-.17	-1.44	-7.61	-32.33	-2.18	-9.72
.410	.12	-.44	-1.38	-8.06	-32.29	-2.40	-10.01
.420	.41	-.43	-1.38	-8.66	-32.03	-2.62	-10.30
.430	.57	.47	-1.34	-9.23	-31.97	-2.85	-10.58
.440	-.25	-.77	-1.38	-9.74	-31.78	-3.09	-10.86
.450	-.43	-.07	-1.33	-10.09	-31.59	-3.34	-11.14

OCCUP. RISK FACTORS	TIME (S)	VELOCITY (FPS)
>LONG. VEL. AFTER 2.0 FT. DISP. --	.460	-10.56
>LAT. VEL. AFTER 1.0 FT. DISP. --	.122	-18.60

MAX. ACCEL. AFTER OCCUPANT IMPACT	TIME(S)	ACC.(GS)
>LONG. ACCELERATION --	.460	-.69
>LAT. ACCELERATION --	.124	7.62

Table 16. Vehicle damage measurements, test WB-1.

	Before Test	After Test	Crush
L	52	52	Not Applicable
C-1	2.0	2.0	0.0
C-2	0.0	5.6	5.6
C-3	0.0	6.0	6.0
C-4	0.0	7.5	7.5
C-5	3.0	10.0	7.0
C-6	4.0	12.1	8.1

Maximum Crush of 12.0 at a location of 15.0 to the right of vehicle centerline.

Note: All dimensions are in inches. 1 in = 2.54 cm

APPENDIX D: SUMMARY OF RESULTS, TEST WB-2

Test No.	WB-2
Test Date	Sept. 27, 1988
Installation Length - ft [m]	72 [22]
Beam	
Member	6" x 10-3/4" laminated wood
Length - ft [m]	18.0 [5.5]
Maximum Deflections - in. [cm]	
Permanent	2.3 [5.8]
Dynamic	8.5 [21.6]
Post	
Details of the posts, blockouts, curb, and deck are included in Figure 1.	
Vehicle	1984 Ford F150 Pickup
Mass - lb [kg]	
Test Inertia	5254 [2383]
Dummy	165 [75]
Gross Test Weight	5419 [2458]
Speed - mph [km/h]	47.5 [76.4]
Angle - degrees	
Impact	20
Exit	-4.9
Occupant Impact Velocity - fps [m/s]	
Forward (accel)	8.1 [2.5]
Lateral (accel)	-17.2 [-5.2]
Occupant Ridedown Accelerations - g's	
Forward (accel)	-1.7
Lateral (accel)	6.9
Maximum 50 msec Avg Accelerations - g's	
Longitudinal (accel)	-3.2
Lateral (accel)	5.2
Vehicle Damage	
TAD	01-FR-4
VDI	01FREE6

TEST WB-2

Barrier Installation

The barrier evaluated in the test was a Glulam Prefabricated Bridge section. The barrier system consists of 18-ft (5.49 m) long by 7-ft (2.1 m) wide laminated wood bridge deck panels. The thickness of the deck panels used in this test was 10 in. (25.4 cm). For this test, four panels were used to construct a simulated bridge 72 ft (21.9 cm) in length. The panels were positioned and fastened to an existing reinforced concrete deck at the test site. The curb/scuppers, posts, and rail were attached to the deck according to the manufacturer's instructions. Figure 30 presents details of the system supplied by the manufacturer. The barrier was the same as that used in test WB-1. One deck panel with curb/rail was replaced in the impact area to ensure system integretry.

Test Purpose

The purpose of this test was to investigate the dynamic interactions of the pickup truck with the bridge rail and curb. Goals for this test were: (1) the vehicle must not penetrate or vault over the system, (2) the vehicle should remain upright throughout the event, and (3) the vehicle after-trajectory should not present undue hazard to other traffic.

Test Vehicle

The vehicle used in the test was a 1984 Ford F150 Pickup. Gross test weight, including the dummy and instrumentation was 5419-lb (2458 kg).

Performance

Impact conditions were 47.5 m/h (76.4 km/h) and a 20-degree impact angle. As shown in figure 31, the vehicle impacted the barrier midway between Post 5 and 6. The vehicle remained in contact with the barrier for 15.0-ft [4.6 m] before redirection at a -4.9 degree angle. The vehicle showed no tendancy to snag on the curb or posts during the impact sequence. No significant pitch, roll, or yaw was noted during impact and redirection. The vehicle came to rest 130 ft [40 m] downstream of the impact point and 48 feet [15 m] out from the barrier plane. The vehicle brakes were applied at approximately 100 feet [30 m] after impact. Table 17 presents after impact vehicle trajectory. Maximum dynamic barrier deflection observed from the overhead data camera was 8.5 inches [21.6 cm]. Measurements of the barrier after the test, tabulated in table 18, showed a maximum of 2.3-inches [5.8 cm] permanent deflection.

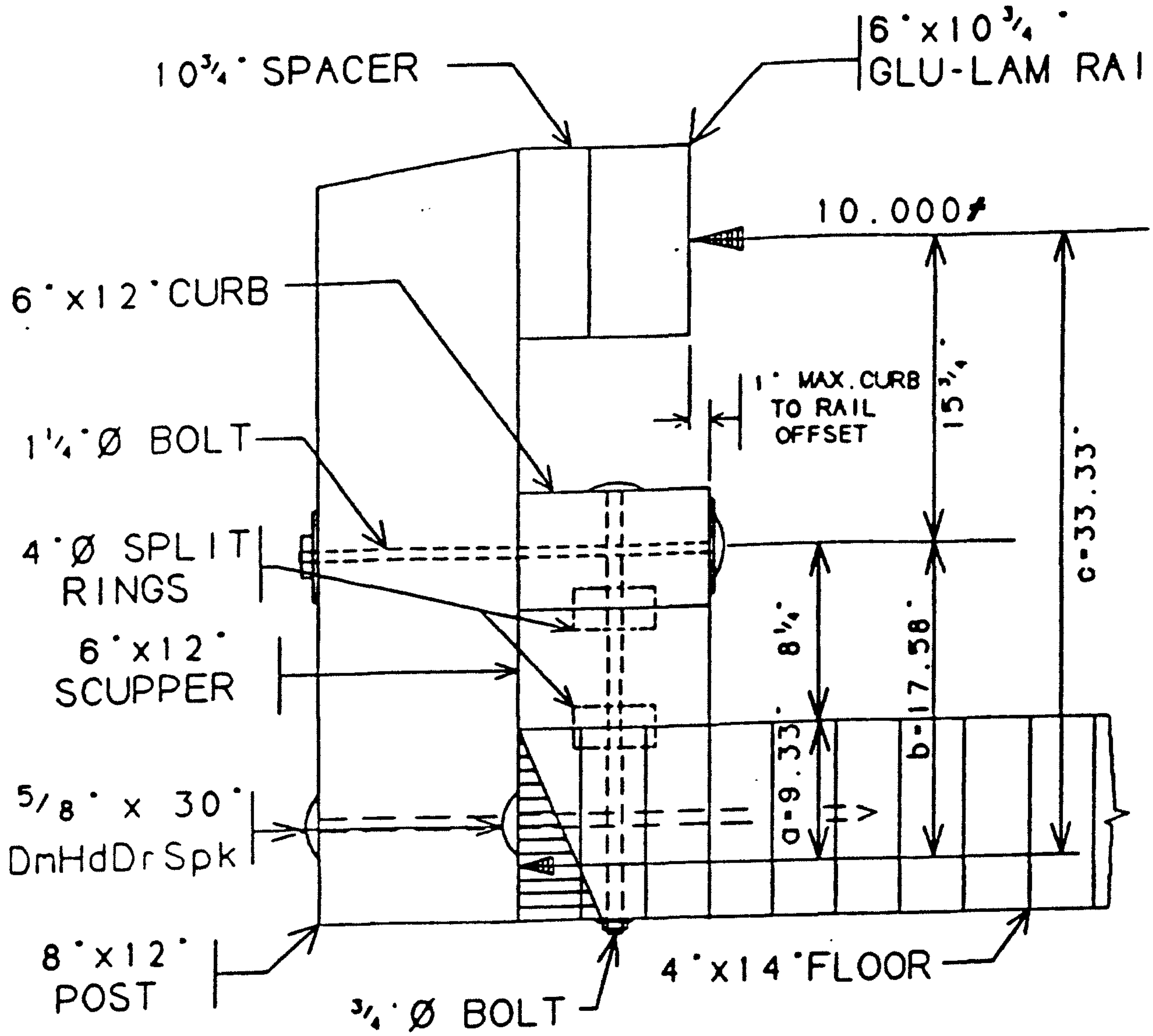
Maximum 50 m/s average accelerations from transducer data indicated 50 m/s averages of -3.2 g's (longitudinal) and 5.2 g's (lateral). Figure 33 presents a summary of test results. Vehicle kinetics from onboard transducers is tabulated in table 19. Plots of vehicle accelerations are presented in figure 34. Table 20 presents occupant risk data derived from the on-board transducers.

Barrier Damage

Damage to the barrier consisted of scuff marks and minor gouging on the rail and curb. Inspection of the barrier system revealed no fractured posts or beam members. Observation of the deck showed delamination between the second and third deck timbers in the impact area. The delamination of the deck occurred from the location of Post 3 to Post 9 with a maximum separation of 0.8 in. [2.0 cm] on the top surface of the deck about 3 ft [0.9 m] downstream from Post 6. Maximum separation observed on the bottom surface of the deck was 0.1 in. [0.3 cm]. Several drive spikes in the impact affected area of the deck showed evidence of minor "pullout."

Vehicle Damage

Damage to the vehicle consisted of sheet metal deformation of the right front fender, side, and rear fender. The windshield remained intact. The right front tire was blown out during impact. (Note: The tire remained on the wheel during redirection but became detached during subsequent vehicle retreivial from the run-out path.) Vehicle damage was considered commensurate with the severity of the impact. Vehicle damage measurements are contained in table 21.



	a	b	c
10"DECK	6.66"	14.91"	30.66"
12"DECK	8"	16.25"	32"

Figure 30. Barrier construction details, test WB-2.

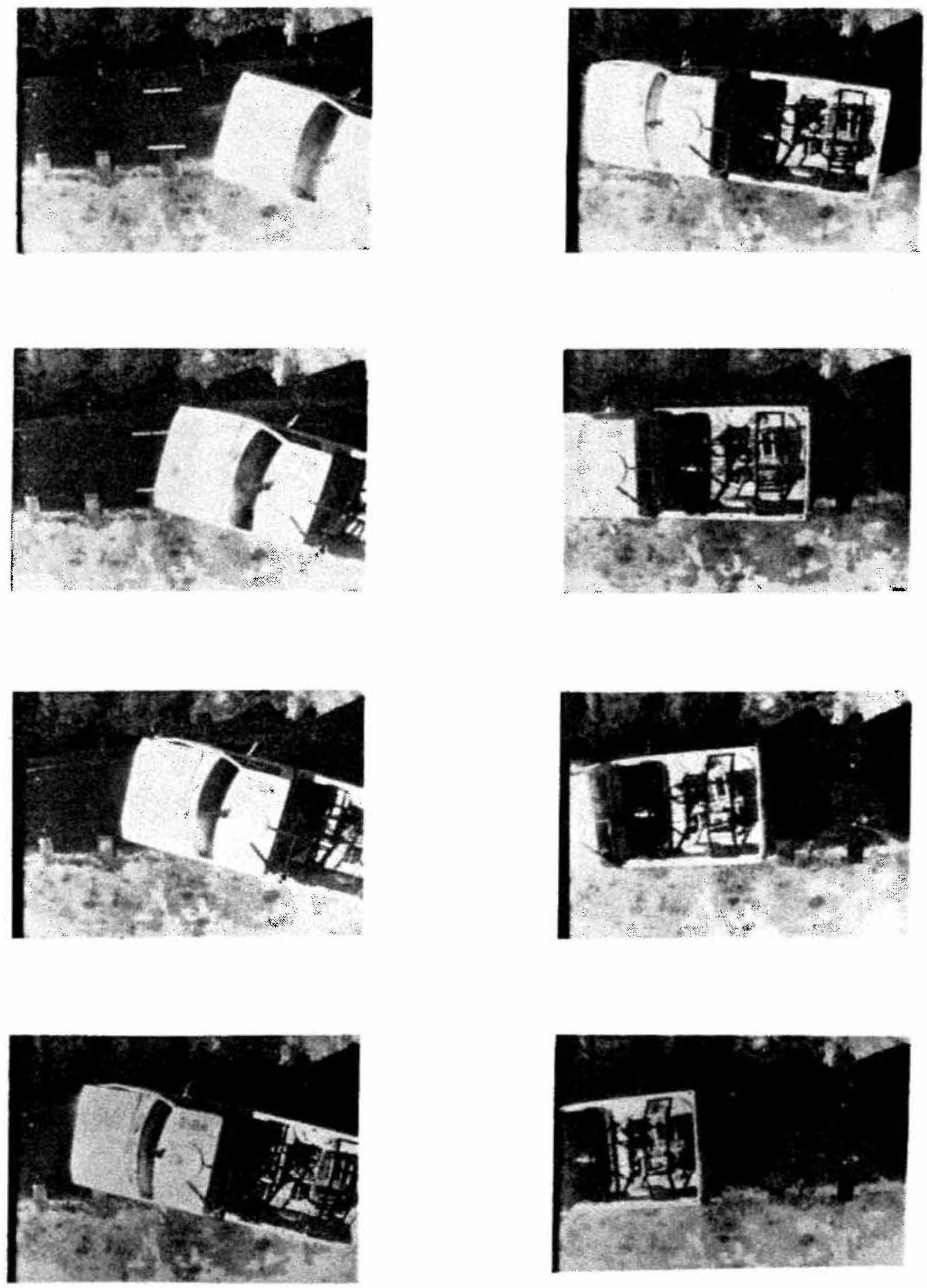


Figure 31. Sequential photographs during impact, test WB-2 (overhead view).

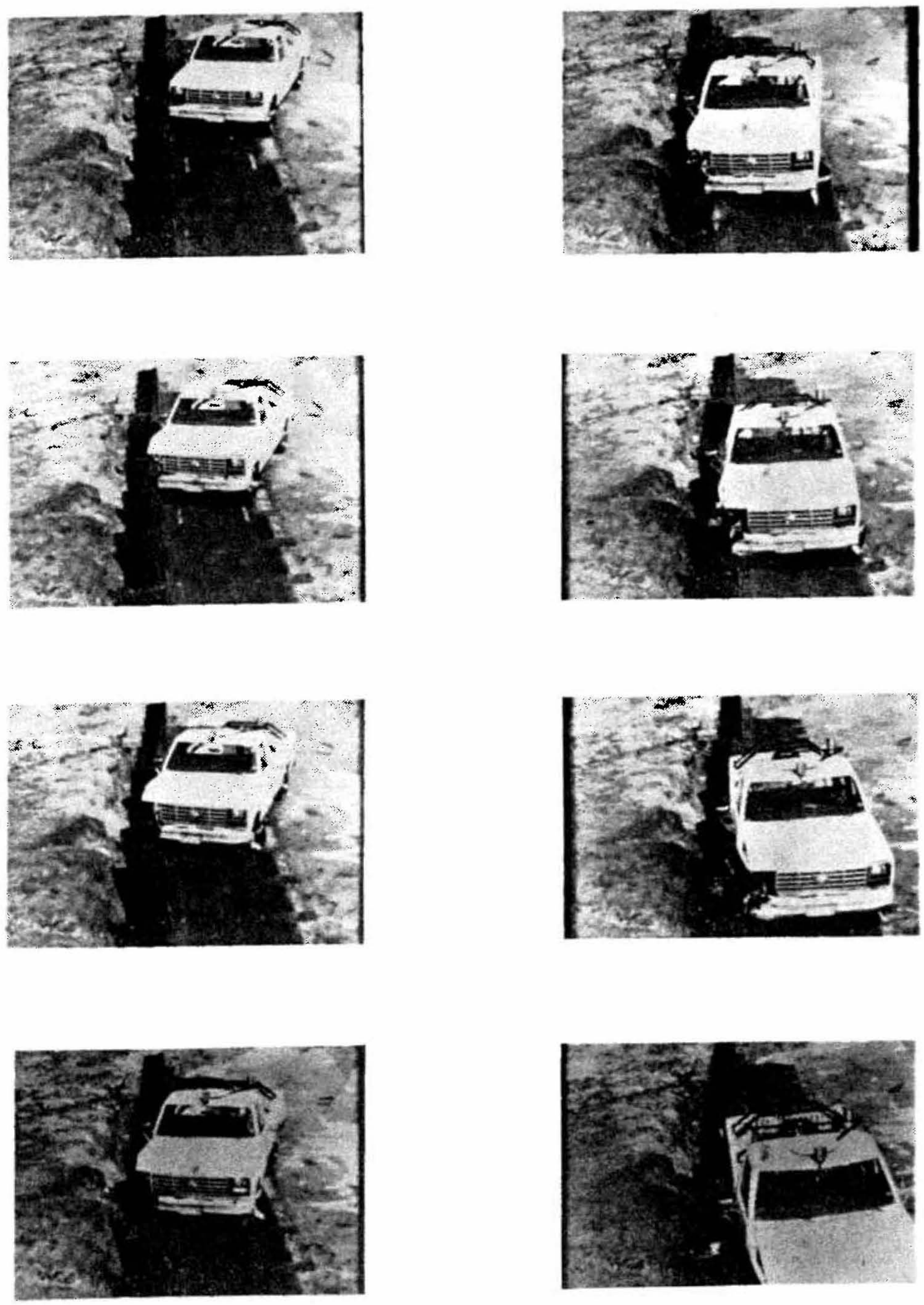


Figure 32. Sequential photographs, test WB-2 (view from downstream).

Table 17. After impact vehicle trajectory, test WB-2.

Location[1]	Distance[2]
0	0
10	-0.1
20	0.2
30	1.5
40	2.0
50	3.4
60	1.4
70	0.0
80	-3.0
90	-6.1
100	-11.2

[1]Distance measured in the downstream direction with 0 as the point of impact.

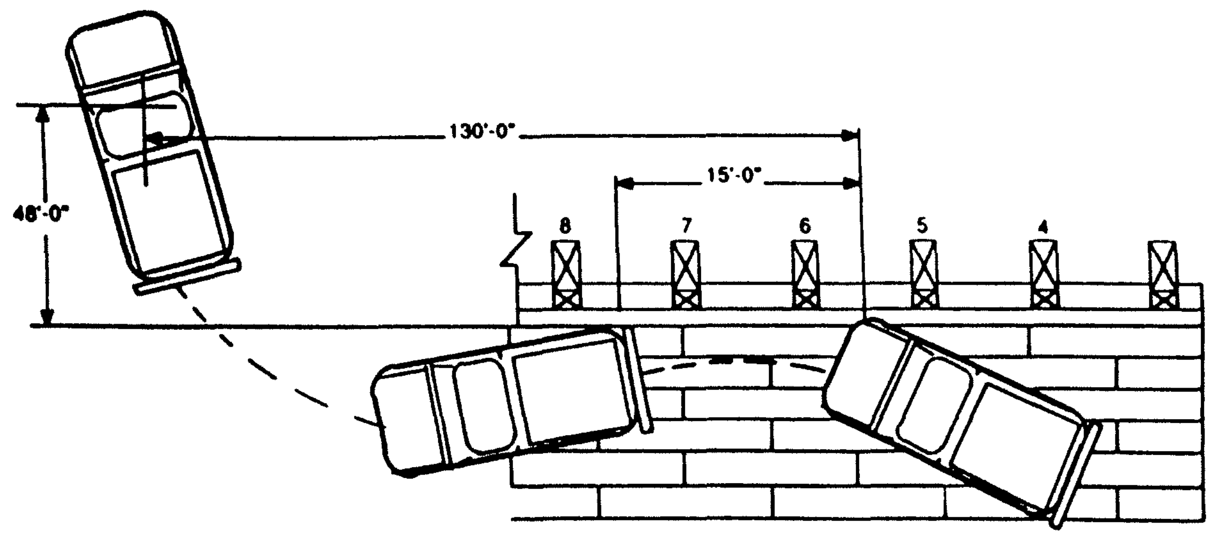
[2]Measured perpendicular to the barrier plane at the front tire on the impact side of the vehicle.

Note: All dimensions are in feet. 1 ft = 0.305 m

Table 18. Permanent barrier deflections, test WB-2.

Post/Location	Deflection
3	0.5
4	0.8
5	1.0
6	1.5
7	2.3
8	2.3
9	1.5
10	1.0
11	0.5

Note: All dimensions are in inches. 1 in = 2.54 cm



Test No.	WB-2
Test Date	Sept. 27, 1988
Installation Length - ft [m]	72 [22]
Beam	
Member	6-in (15.2 cm) x 10-3/4 -in (27.3 cm) laminated wood
Length - ft [m]	18.0 [5.5]
Maximum Deflections - in. [cm]	
Permanent	2.3 [5.8]
Dynamic	8.5 [21.6]
Post	
Details of the posts, blockouts, curb, and deck are included in figure 11.	
Vehicle	1984 Ford F150 Pickup
Mass - lb [kg]	
Test Inertia	5254 [2383]
Dummy	165 [75]
Gross Test Weight	5419 [2458]
Speed - mi/h [km/h]	47.5 [76.4]

Angle - degrees	
Impact	20
Exit	-4.9
Occupant Impact Velocity - ft/s [m/s]	
Forward (accel)	8.1 [2.5]
Lateral (accel)	-17.2 [-5.2]
Occupant Ridedown Accelerations - g's	
Forward (accel)	-1.7
Lateral (accel)	6.9
Maximum 50 m/s Avg Accelerations - g's	
Longitudinal (accel)	-3.2
Lateral (accel)	5.2
Vehicle Damage	
TAD	01-FR-4
VDI	01FREE6

Figure 33. Summary of results, test WB-2.

Table 19. Vehicle kinetics data, test WB-2.

TEST ID ------- WB-2
TEST DATE ----- 09-27-88
VEHICLE CLASS - OTHER
IMPACT SPEED -- 69.67 FPS

VEHICLE KINETICS SUMMARY
NOTE: VALUES ARE INSTANTANEOUS AT TIME

TIME (S)	ACCEL.(G'S) LONG.	ACCEL.(G'S) LAT.	HEAD.ANG. DEG	VELOCITY(FPS) LONG.	VELOCITY(FPS) LAT.	DISP.(F) X	DISP.(F) Y
.000	-.73	.47	20.00	69.67	.00	.00	.00
.010	-.01	.20	19.96	69.45	-.08	.65	.24
.020	-.62	-.08	19.90	69.31	-.17	1.31	.48
.030	-.17	-.08	19.84	69.23	-.26	1.96	.71
.040	.39	.43	19.78	69.27	-.22	2.61	.95
.050	.05	.57	19.76	69.40	-.09	3.26	1.19
.060	-.17	.38	19.74	69.31	-.08	3.91	1.42
.070	-.68	.61	19.72	69.30	-.01	4.56	1.66
.080	-2.24	2.92	19.71	68.74	.68	5.21	1.89
.090	.50	-.31	19.74	68.12	1.23	5.86	2.11
.100	.05	.57	19.87	67.75	1.66	6.50	2.32
.110	1.57	-7.48	19.92	67.18	1.04	7.14	2.54
.120	-1.74	5.08	19.85	66.64	1.50	7.78	2.76
.130	-.01	4.16	19.53	65.63	1.62	8.41	2.97
.140	1.40	-.03	18.99	64.69	1.75	9.03	3.17
.150	-11.20	.84	18.48	63.83	1.87	9.65	3.36
.160	1.29	5.40	17.86	63.72	2.91	10.26	3.53
.170	-5.21	7.20	17.22	62.99	3.85	10.88	3.69
.180	-.62	6.23	16.48	62.28	5.18	11.49	3.83
.190	-4.59	2.73	15.61	61.18	5.66	12.10	3.95
.200	-.12	2.82	14.65	60.24	6.02	12.70	4.05
.210	-3.25	5.13	13.55	59.46	6.32	13.30	4.14
.220	-4.54	3.93	12.38	58.36	6.16	13.88	4.21
.230	-.68	.11	11.12	57.68	5.99	14.47	4.27
.240	-.68	2.59	9.74	57.71	5.70	15.05	4.32
.250	-2.47	-4.92	8.27	57.80	4.89	15.62	4.35
.260	3.43	-2.91	6.87	57.52	4.86	16.20	4.38
.270	.05	12.31	5.37	57.38	4.90	16.78	4.39
.280	.84	1.17	3.92	57.23	4.24	17.35	4.39
.290	-2.02	-.49	2.67	57.12	3.25	17.93	4.38
.300	-.62	-13.47	1.52	56.12	1.11	18.49	4.38
.310	-4.03	-1.40	.44	55.61	-.98	19.05	4.39
.320	1.52	7.24	-.66	56.01	-2.03	19.61	4.41
.330	-1.46	8.99	-1.86	55.92	-1.98	20.17	4.42
.340	-.90	5.68	-2.82	56.38	-.98	20.73	4.41
.350	2.42	.75	-3.34	56.37	-.24	21.30	4.38
.360	-4.82	1.67	-3.72	55.82	1.01	21.85	4.34
.370	2.81	2.45	-4.00	55.37	1.82	22.41	4.29
.380	1.12	1.90	-4.16	55.95	2.00	22.96	4.23
.390	-1.96	-.12	-4.38	55.69	2.35	23.52	4.17
.400	-2.52	-.81	-4.66	56.27	2.19	24.07	4.10
.410	-.73	-.63	-4.94	54.94	2.14	24.61	4.03
.420	1.97	1.76	-5.05	55.08	2.26	25.16	3.96
.430	-.73	.80	-5.10	55.06	2.33	25.71	3.89
.440	-.17	-.12	-5.04	54.93	2.49	26.25	3.82
.450	1.12	-2.23	-4.98	55.13	2.29	26.80	3.75
.460	1.01	-.81	-4.90	55.29	2.05	27.35	3.68
.470	-1.63	-1.13	-4.92	55.19	1.84	27.90	3.61

HIGHEST 50.0-MS AVG. ACCEL.

	G'S	TIME (SEC) START	TIME (SEC) END
LONG.	-3.21	.180	.230
LAT.	5.23	.152	.202

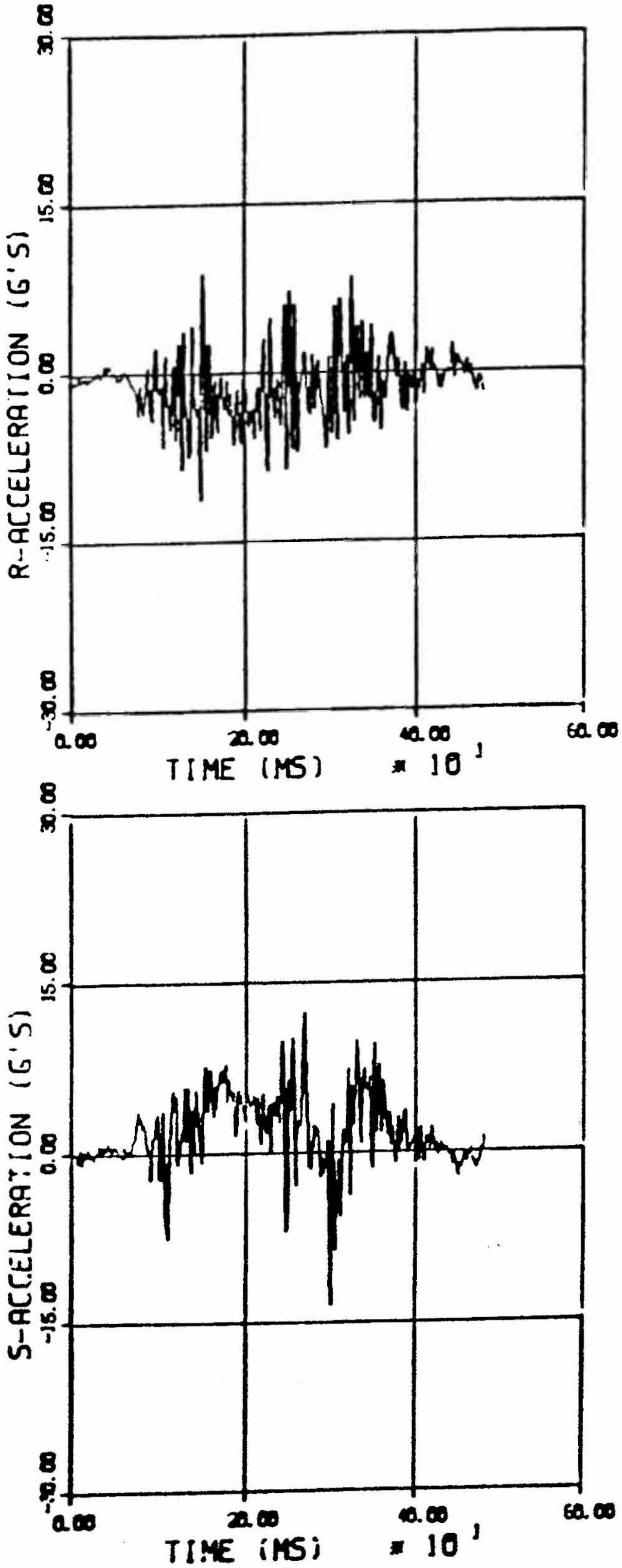


Figure 34. Vehicle acceleration plots, test WB-2.

Table 20. Occupant risk data, test WB-2.

TEST ID ------- WB-2
TEST DATE ----- 09-27-88
VEHICLE CLASS - OTHER
IMPACT SPEED -- 69.67 FPS

OCCUPANT RISK SUMMARY
NOTE: INSTANTANEOUS 10-MS AVERAGE ACCELERATIONS

	(----- VEHICLE	------)		(----------- OCCUPANT	-----------	-----------	)
TIME (S)	ACCEL. (G'S) LONG.	LAT.	ANG.VEL (RAD/S)	VEL. (FPS) LONG.	LAT.	DISP. (F) LONG.	LAT.
.000	-.73	.47	-.08	.00	.00	.00	.00
.010	-.52	-.17	-.06	.25	.04	.00	.00
.020	-.38	-.02	-.10	.33	.04	.00	.00
.030	-.04	.17	-.09	.42	.05	.01	.00
.040	.24	.38	-.05	.46	-.02	.01	.00
.050	.19	.39	-.05	.32	-.17	.02	.00
.060	-.18	.12	-.03	.44	-.20	.02	.00
.070	-.62	.80	-.02	.48	-.28	.02	.00
.080	-2.30	2.76	-.03	1.02	-.99	.03	-.01
.090	-2.03	.09	.15	1.93	-1.37	.05	-.02
.100	-.73	.99	.17	2.33	-1.64	.07	-.04
.110	-1.92	-2.42	.01	2.65	-1.07	.09	-.05
.120	-2.14	2.45	-.48	2.36	-1.98	.12	-.06
.130	-2.02	3.16	-.68	3.04	-2.64	.15	-.08
.140	-2.67	2.26	-.86	3.68	-3.57	.17	-.12
.150	-1.71	3.08	-.97	4.33	-4.39	.21	-.16
.160	-2.60	4.94	-1.24	3.97	-6.38	.25	-.22
.170	-2.44	6.35	-1.05	4.99	-7.97	.29	-.29
.180	-2.55	5.99	-1.38	5.10	-10.43	.34	-.39
.190	-3.76	4.00	-1.59	5.78	-12.13	.38	-.51
.200	-2.71	4.24	-1.81	6.24	-13.83	.43	-.64
.210	-4.06	4.20	-1.96	6.64	-15.56	.48	-.80
.220	-1.46	3.23	-2.12	7.27	-16.96*	.53	-.97*
.230	-1.74	2.93	-2.32	7.42	-18.46	.58	-1.16
.240	-2.54	5.27	-2.49	6.83	-19.95	.62	-1.37
.250	.69	.95	-2.34	6.66	-20.77	.65	-1.59
.260	-1.00	3.22*	-2.61	6.13	-22.62	.67	-1.83
.270	-.39	6.49	-2.61	5.83	-24.42	.68	-2.08
.280	-1.76	.85	-2.31	6.01	-25.25	.68	-2.35
.290	-1.69	-.82	-2.07	6.08	-25.54	.69	-2.62
.300	-3.23	-4.28	-1.99	6.79	-24.67	.70	-2.88
.310	1.95	-2.58	-1.77	7.23	-23.66	.71	-3.14
.320	-1.41	2.62	-1.99	6.01	-24.03	.71	-3.39
.330	1.75	6.01	-2.05	5.46	-25.51	.69	-3.65
.340	.15	5.12	-1.18	6.01	-26.92	.69	-3.93
.350	-1.08	3.70	-.39	7.10	-27.65	.71	-4.21
.360	-1.63	4.54	-.82	6.75	-29.65	.75	-4.50
.370	1.42	1.92	-.28	7.97	-30.37	.81	-4.80
.380	-.09	.91	-.29	7.30	-30.73	.37	-5.11
.390	-1.36	1.33	-.41	7.23	-31.42	.92	-5.43
.400	-1.40	.58	-.63	7.14	-31.73	.97	-5.75
.410	-.21	.46	-.40	7.72	-31.82	1.01	-6.07
.420	.82	.90	-.13	7.98	-31.86	1.08	-6.39
.430	-.84	.31	.21	8.53	-31.73	1.16	-6.71
.440	.46	-.22	.05	8.43	-31.94	1.25	-7.03
.460	.64	-1.22	.12	8.38	-31.62	1.34	-7.34
.460	.23	-.40	.12	8.26	-31.30	1.43	-7.65
.470	-.98	-1.00	-.09	7.98	-31.28	1.51	-7.97

OCCUP. RISK FACTORS	TIME (S)	VELOCITY (FPS)
>LONG. VEL. AFTER 2.0 FT. DISP. --	.480	8.11
>LAT. VEL. AFTER 1.0 FT. DISP. --	.221	-17.18

MAX. ACCEL. AFTER OCCUPANT IMPACT	TIME(S)	ACC.(GS)
>LONG. ACCELERATION --	.480	-1.74
>LAT. ACCELERATION --	.269	6.86

Table 21. Vehicle damage measurements, test WB-2.

	Before Test	After Test	Crush
L	58	58	Not Applicable
C-1	0.4	0.3	-0.1
C-2	0.8	3.3	+2.5
C-3	0.0	2.5	+2.5
C-4	0.0	4.0	+4.0
C-5	0.0	7.1	+7.1
C-6	1.5	11.5	+10.0

Maximum crush of 15.8 at a location of 25 to the right of vehicle centerline.

Note: All dimensions are in inches. 1 in = 2.54 cm

APPENDIX E: SUMMARY OF RESULTS, TEST KM-1

Test No. KM-1
Test Date . . . . Nov. 18, 1988
Installation Length - ft [m] . . . . . 69 [21]

Beam
  Member 9-by 10-in [25.4 cm by 22.8 cm] . . . . reinforced concrete
  Length - ft [m] . . . . 2 @ 24(7.3) and . . . . 1 @ 16(4.9)

Maximum Deflections - in. [cm]
  Permanent . . . . none
  Dynamic . . . . none

Post
  Details of the posts, blockouts, curb, and deck are included in figure 35.

Vehicle . . . . 1982 Honda Civic

Mass - lb [kg]
  Test Inertia . . . . 1825 [827]
  Dummy . . . . 165 [75]
  Gross Test Weight . . . . . 1990 [902]

Speed - mph [km/h] . . . . 51.0 [82.0]

Angle - degrees
  Impact 20.5
  Exit . . . . -3.7

Occupant Impact Velocity - ft/s [m/s]
  Forward (accel) . . 10.6 [3.2]/9.2 [2.8]
  Lateral (accel) -15.6 [-4.8]/-16.7 [-5.1]

Occupant Ridedown Accelerations - g's
  Forward (accel) . . . . -1.1
  Lateral (accel) 10.0

Maximum 50 msec Avg Accelerations - g's
  Longitudinal (accel) . . . . . . -2.8/-5.4
  Lateral (accel) 4.0/8.1

Vehicle Damage
  TAD 01-FR-4
  VDI 01FREE6

TEST KM-1

Barrier Installation

The barrier evaluated in the test was a Modified Kansas Corral bridge rail. The barrier system, which consisted of concrete posts, rails and a 6-in (15-cm) curb, was constructed on a simulated bridge deck. Total system length was 69 ft (21 m). Figure 35 presents details of the system tested.

Test Purpose

The purpose of this test was to investigate the dynamic interactions of the small car with the bridge rail and curb. Goals for this test were: (1) the vehicle should be smoothly redirected without exhibiting any tendency to snag or pocket, (2) the vehicle should remain upright throughout the event, and (3) the vehicle after-collision trajectory should not present undue hazard to other traffic.

Test Vehicle

The vehicle used in the test was a 1982 Honda Civic. Gross test weight, including the dummy and instrumentation was 1990 lb (902 kg).

Performance

Impact conditions were 51.0 m/h (82.0 km/h) and a 20.5-degree impact angle. As shown in figures 36 and 37, the vehicle impacted the barrier midway between posts 7 and 8. The vehicle remained in contact with the barrier for 13.8 ft (4.2 m) before redirection at a -3.7 degree angle. During the impact sequence the right front tire/wheel became engaged between the top of the curb and the bottom of the rail and the wheel hub contacted post 8. Although post 8 exhibited minor gouging, observation of the test film showed no significant snag potential. The vehicle remained stable during impact and redirection. The vehicle came to rest 150 ft [46 m] downstream of the impact point and 10.5 ft [3.2 m] out from the barrier plane. The vehicle brakes were not applied after impact. Table 22 presents after impact vehicle trajectory. The barrier did not deflect during impact.

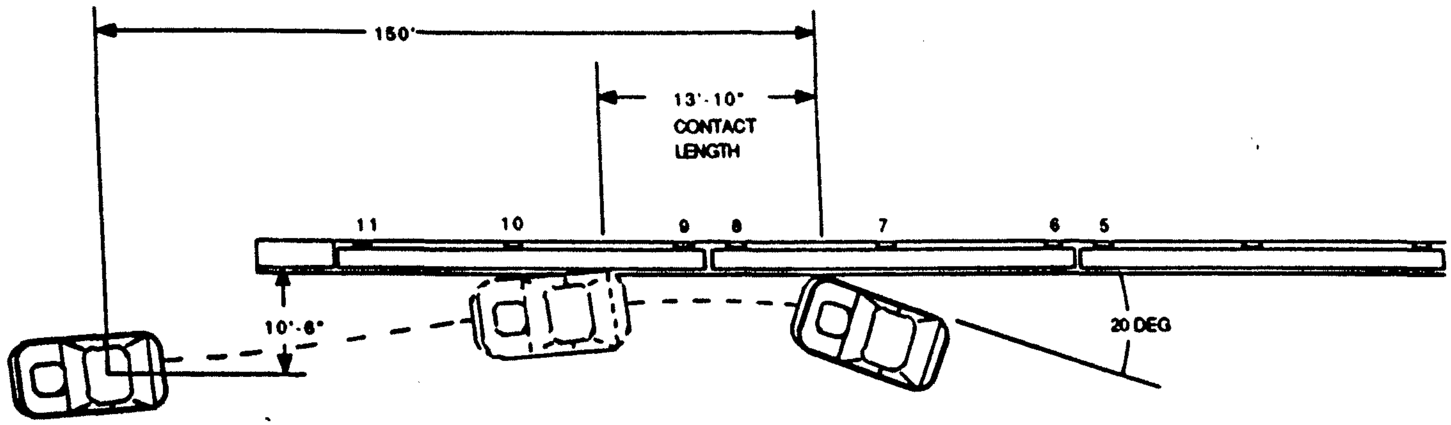
Film data indicated maximum 50 m/s averages of -2.8 g's (longitudinal) and 4.0 g's (lateral). Maximum 50 m/s average accelerations from transducer data indicated -5.4 g's (longitudinal) and 8.1 g's (lateral). Figure 38 presents a summary of test results. Vehicle kinetics from film and onboard transducers are tabulated in tables 23 and 24. Figure 38 contains photographs of vehicle and barrier damage. Plots of vehicle accelerations are presented in figure 39. Tables 25 and 26 present occupant risk data derived from film and the on-board transducers.

Barrier Damage

Damage to the barrier consisted of cosmetic scuff marks on the rail and curb. Minor gouging was noted on post 8. Inspection of the barrier system revealed no fractured posts or rail members. The barrier was considered as undamaged.

Vehicle Damage

Damage to the vehicle consisted of sheet metal deformation of the hood, right front fender, side, and rear fender. The right front tire was blown out during impact and the A-frame was displaced rearward to the fender well. Vehicle damage was considered commensurate with the severity of the impact. Vehicle damage measurements are contained in table 27.



Test No.	KM-1
Test Date	Nov, 18, 1988
Installation Length - ft [m]	69 [21]
Beam	
Member . . .	9-in (22.8 cm)x 10-in (25.4 cm) reinforced concrete
Length - ft [m]	2 @ 24 (7.3) and 1 @ 16 (4.9)
Maximum Deflections - in. [cm]	
Permanent	none
Dynamic	none
Post	
Details of the posts, blockouts, curb, and deck are included in figure 14.	
Vehicle	1982 Honda Civic
Mass - lb [kg]	
Test Inertia	1825 [827]
Dummy	165 [75]
Gross Test Weight	1990 [902]
Speed - mi/h [km/h]	51.0 [82.0]

Angle - degrees	
Impact	20.5
Exit	-3.7
Occupant Impact Velocity - ft/s [m/s]	
Forward (film/accel)	10.6 [3.2]/9.2 [2.8]
Lateral (film/accel)	-15.6 [-4.8]/-16.7 [-5.1]
Occupant Ridedown Accelerations - g's	
Forward (accel)	-1.1
Lateral (accel)	10.0
Maximum 50 m/s Avg Accelerations - g's	
Longitudinal (accel)	-2.8/-5.4
Lateral (accel)	4.0/8.1
Vehicle Damage	
TAD	01-FR-4
VDI	01FREE6

Figure 35. Summary of results, test KM-1.

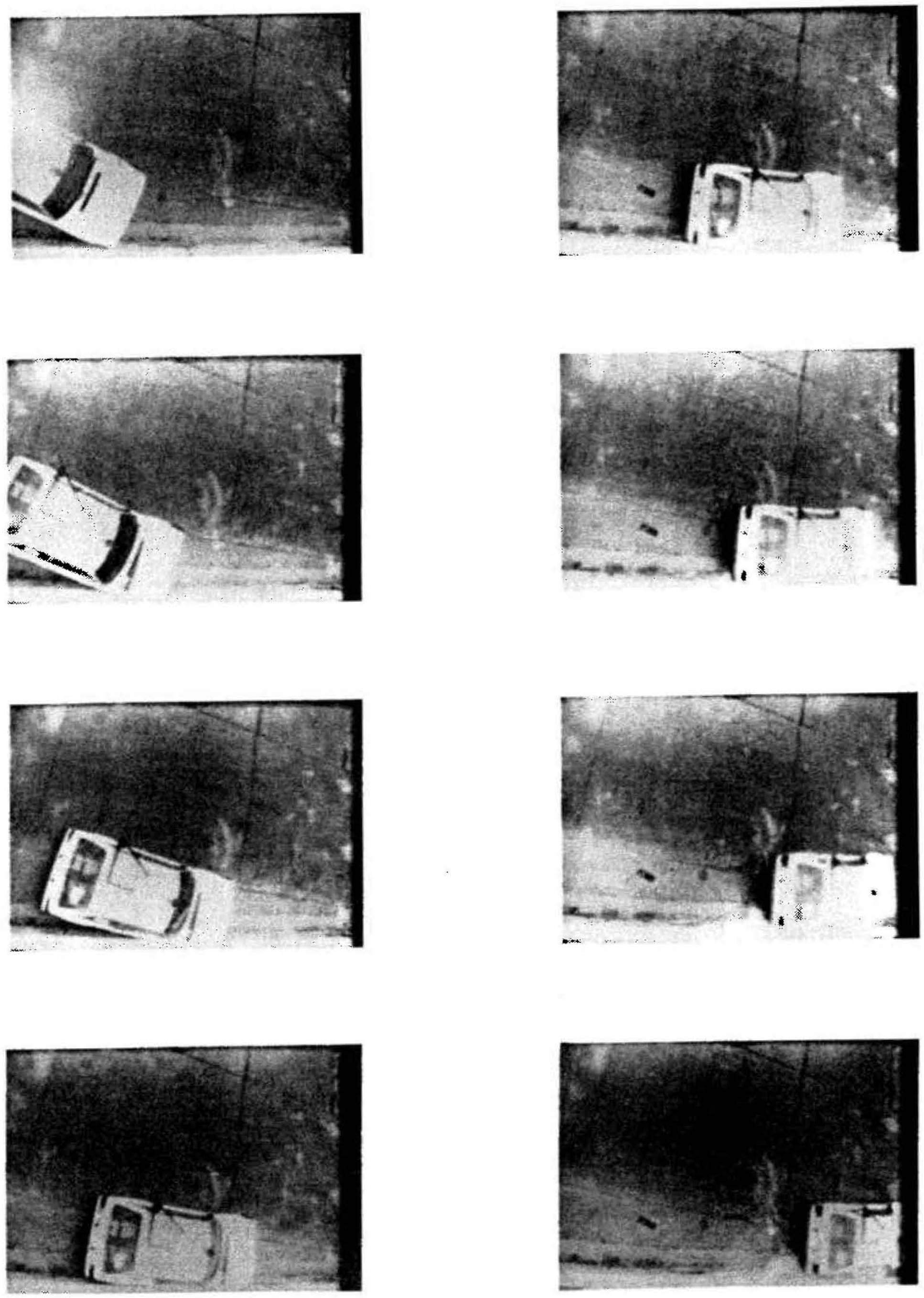


Figure 36. Sequential photographs during impact, test KM-1 (overhead view).

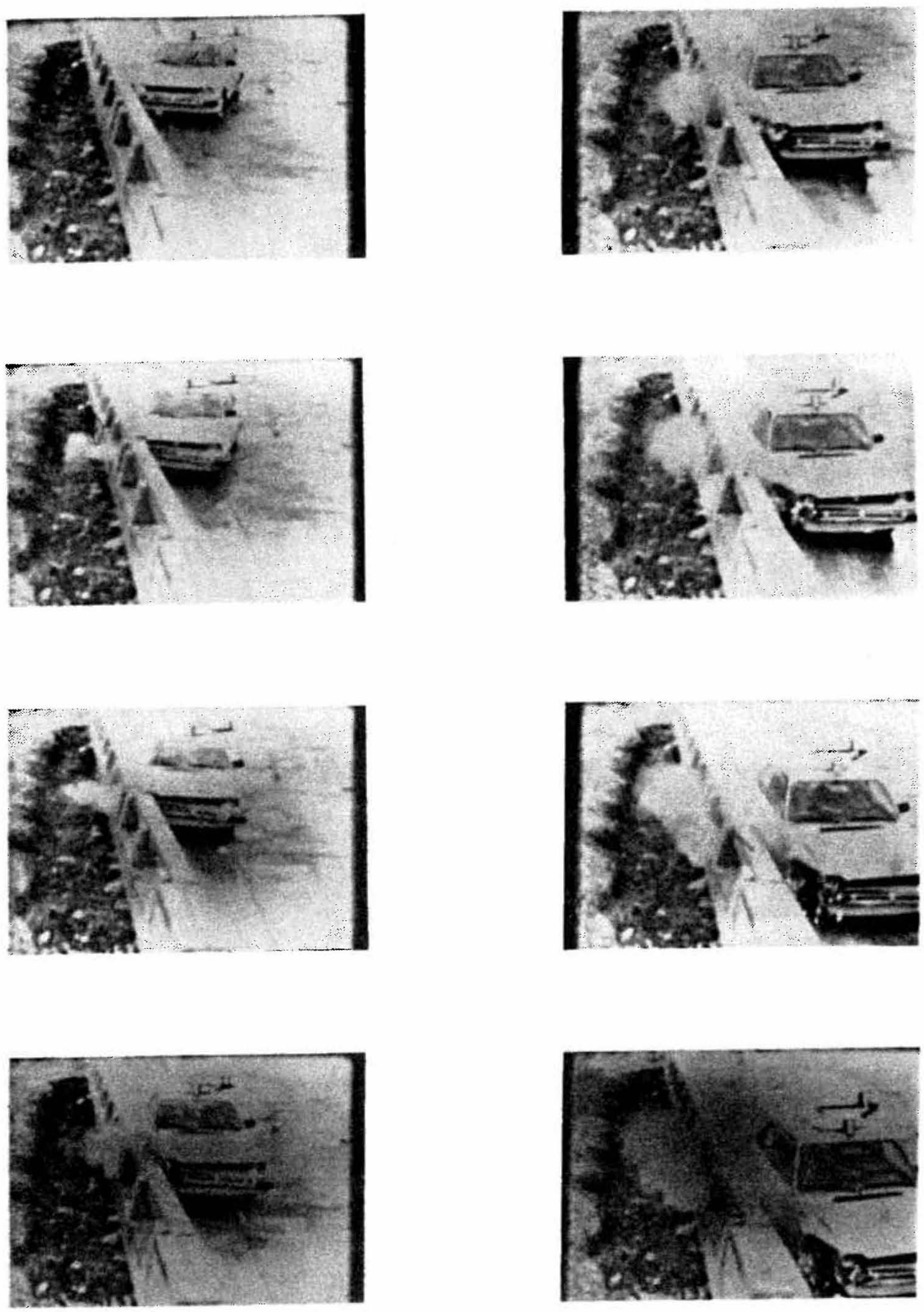
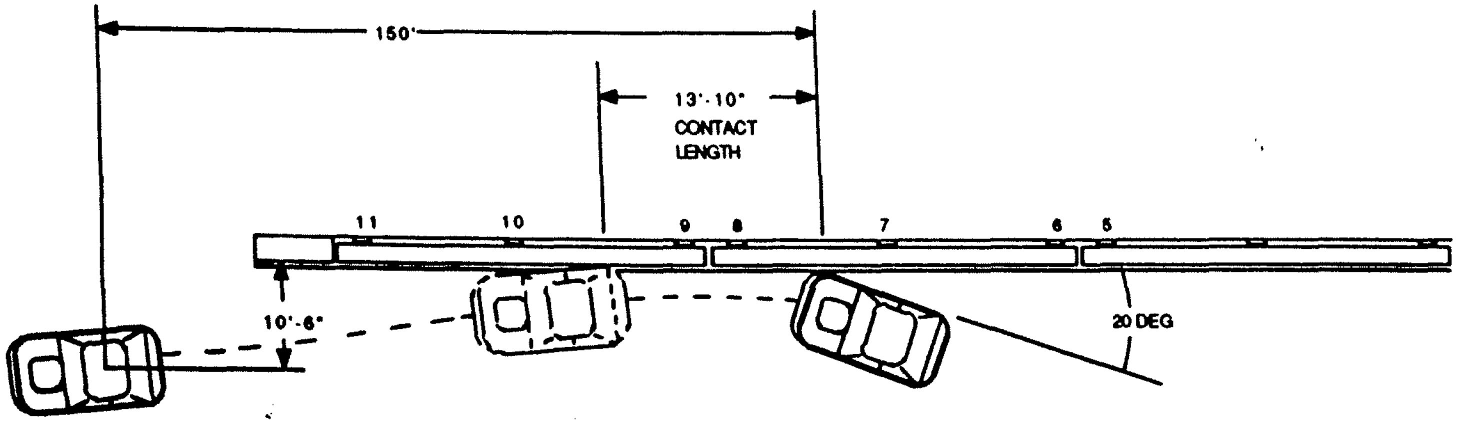


Figure 37. Sequential photographs, test KM-1 (view from downstream).



Test No. KM-1
Test Date . . . . Nov, 18, 1988
Installation Length - ft [m] . . . . 69 [21]
Beam
    Member . . . 9-in (22.8 cm)x 10-in (25.4 cm) reinforced concrete
    Length - ft [m] . . . . 2 @ 24 (7.3) and 1 @ 16 (4.9)

Maximum Deflections - in. [cm]
    Permanent . . . . none
    Dynamic . . . . none
Post
    Details of the posts, blockouts, curb, and deck are included in figure 14.

Vehicle . . . . 1982 Honda Civic

Mass - lb [kg]
    Test Inertia . . . . 1825 [827]
    Dummy . . . . 165 [75]
    Gross Test Weight . . . . 1990 [902]
Speed - mi/h [km/h] . . . . 51.0 [82.0]

Angle - degrees
    Impact 20.5
    Exit . . . . -3.7

Occupant Impact Velocity - ft/s [m/s]
    Forward (film/accel) . . . . 10.6 [3.2]/9.2 [2.8]
    Lateral (film/accel) . . . . -15.6 [-4.8]/-16.7 [-5.1]

Occupant Ridedown Accelerations - g's
    Forward (accel) . . . . -1.1
    Lateral (accel) 10.0

Maximum 50 m/s Avg Accelerations - g's
    Longitudinal (accel) . . . . -2.8/-5.4
    Lateral (accel) 4.0/8.1

Vehicle Damage
    TAD 01-FR-4
    VDI 01FREE6

Figure 38. Summary of results, test KM-1.

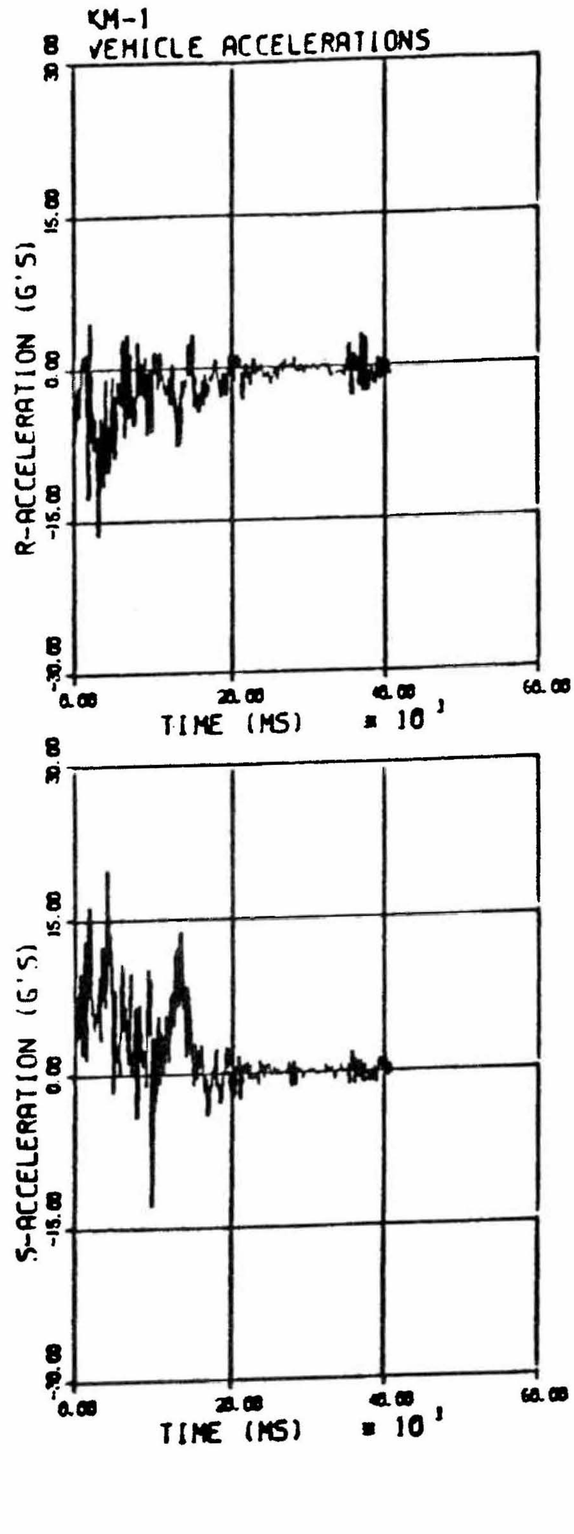


Figure 39. Vehicle acceleration plots, test KM-1.

Table 22. After impact vehicle trajectory, test KM-1.

Location[1]	Distance[2]
0	0
10	-0.2
20	0.8
30	1.5
40	2.3
50	3.2
60	4.0
70	4.8
80	5.6
90	6.3
100	6.9

[1]Distance measured in the downstream direction with 0 as the point of impact.

[2]Measured perpendicular to the barrier plane at the front tire on the impact side of the vehicle.

Note: All dimensions are in feet. 1 ft = 0.305 m

Table 23. Vehicle kinetics data (film), test KM-1.

VEHICLE KINETICS SUMMARY--FROM FILM ANALYSIS

TIME (S)	ACCEL. (G'S) LONG.	LAT.	HEADING ANG. (DEG)	VEL. (FPS) LONG.	LAT.	DISP. (F) X	Y
.000	-2.77	3.51	20.51	74.75	3.18	.99	-4.67
.010	-2.84	3.66	20.05	73.87	3.74	1.69	-4.45
.020	-2.87	3.78	19.49	72.99	4.21	2.40	-4.24
.030	-2.88	3.87	18.82	72.12	4.60	3.10	-4.04
.040	-2.85	3.93	18.06	71.26	4.91	3.79	-3.86
.050	-2.80	3.96	17.22	70.42	5.13	4.48	-3.69
.060	-2.74	3.97	16.29	69.61	5.28	5.17	-3.54
.070	-2.65	3.95	15.30	68.84	5.36	5.85	-3.40
.080	-2.55	3.90	14.25	68.10	5.37	6.53	-3.28
.090	-2.43	3.84	13.15	67.40	5.32	7.20	-3.17
.100	-2.31	3.75	12.02	66.74	5.21	7.86	-3.08
.110	-2.18	3.64	10.85	66.12	5.06	8.52	-3.00
.120	-2.05	3.52	9.67	65.54	4.85	9.18	-2.93
.130	-1.91	3.37	8.49	65.00	4.61	9.83	-2.87
.140	-1.78	3.21	7.30	64.50	4.33	10.48	-2.83
.150	-1.65	3.04	6.13	64.04	4.03	11.12	-2.79
.160	-1.53	2.86	4.98	63.60	3.70	11.76	-2.77
.170	-1.41	2.66	3.87	63.20	3.35	12.40	-2.76
.180	-1.30	2.45	2.79	62.82	2.99	13.03	-2.75
.190	-1.20	2.24	1.75	62.46	2.61	13.65	-2.76
.200	-1.11	2.03	.77	62.13	2.23	14.28	-2.77
.210	-1.02	1.81	-.15	61.82	1.86	14.90	-2.78
.220	-.94	1.59	-1.01	61.53	1.48	15.51	-2.81
.230	-.87	1.37	-1.80	61.26	1.11	16.13	-2.83
.240	-.81	1.16	-2.51	61.00	.76	16.74	-2.87
.250	-.75	.95	-3.15	60.76	.41	17.35	-2.90
.260	-.70	.75	-3.72	60.53	.09	17.95	-2.94
.270	-.65	.55	-4.21	60.31	-.22	18.55	-2.98
.280	-.60	.37	-4.62	60.11	-.51	19.15	-3.03
.290	-.55	.19	-4.96	59.92	-.77	19.75	-3.07
.300	-.51	.03	-5.22	59.74	-1.01	20.35	-3.11
.310	-.47	-.12	-5.42	59.58	-1.23	20.95	-3.16
.320	-.43	-.26	-5.54	59.43	-1.42	21.54	-3.20
.330	-.39	-.38	-5.60	59.30	-1.59	22.13	-3.24
.340	-.35	-.49	-5.61	59.18	-1.73	22.72	-3.29
.350	-.30	-.58	-5.56	59.08	-1.85	23.31	-3.32
.360	-.26	-.65	-5.46	58.99	-1.96	23.90	-3.36
.370	-.22	-.71	-5.33	58.92	-2.04	24.49	-3.40
.380	-.18	-.75	-5.16	58.86	-2.10	25.08	-3.43
.390	-.13	-.76	-4.97	58.82	-2.14	25.67	-3.46
.400	-.09	-.76	-4.76	58.79	-2.18	26.25	-3.49
.410	-.05	-.74	-4.54	58.78	-2.20	26.84	-3.52
.420	-.01	-.71	-4.32	58.77	-2.21	27.43	-3.54
.430	.03	-.65	-4.11	58.79	-2.21	28.02	-3.56
.440	.06	-.57	-3.91	58.81	-2.20	28.61	-3.58
.450	.10	-.47	-3.74	58.84	-2.19	29.19	-3.60
.460	.13	-.36	-3.59	58.88	-2.18	29.78	-3.61
.470	.15	-.23	-3.48	58.93	-2.16	30.37	-3.63
.480	.18	-.08	-3.41	58.99	-2.14	30.96	-3.64
.490	.20	.09	-3.39	59.05	-2.11	31.55	-3.66
.500	.21	.27	-3.42	59.11	-2.08	32.14	-3.67
.510	.23	.47	-3.49	59.18	-2.04	32.74	-3.68
.520	.24	.69	-3.63	59.25	-1.99	33.33	-3.70

HIGHEST 50-MS AVG.ACCEL.

	G-S	TIME (SEC) START	END
LONG.	-2.83	.0050	.0550
LAT.	3.96	.0350	.0850

Table 24. Vehicle kinetics data (transducer), test KM-1.

VEHICLE KINETICS SUMMARY
NOTE: VALUES ARE INSTANTANEOUS AT TIME

TIME (S)	ACCEL. (G'S) LONG.	ACCEL. (G'S) LAT.	HEAD. ANG. DEG	VELOCITY (FPS) LONG.	VELOCITY (FPS) LAT.	DISP. (F) X	DISP. (F) Y
.000	-3.58	-.09	20.51	74.75	3.18	.99	-4.67
.010	-.49	2.95	20.22	73.46	4.46	1.70	-4.45
.020	-2.82	10.36	19.77	72.48	6.98	2.40	-4.25
.030	-12.16	9.51	19.06	71.25	8.23	3.11	-4.08
.040	-.97	19.84	18.18	68.45	9.93	3.80	-3.94
.050	-4.61	5.86	17.00	67.00	11.63	4.48	-3.85
.060	-.14	8.05	15.55	65.94	11.47	5.15	-3.77
.070	-3.71	9.75	14.00	65.89	11.21	5.81	-3.71
.080	2.62	-.76	12.45	65.42	9.90	6.48	-3.67
.090	1.10	.52	10.91	65.45	9.12	7.14	-3.63
.100	-2.27	3.56	9.40	64.81	7.92	7.80	-3.60
.110	.48	1.12	7.98	65.05	6.51	8.45	-3.57
.120	-.90	5.93	6.59	64.75	5.59	9.10	-3.55
.130	-5.84	7.93	5.27	64.17	6.76	9.75	-3.54
.140	-1.65	1.73	4.14	62.91	8.18	10.39	-3.57
.150	1.79	-1.06	3.27	63.20	8.51	11.02	-3.61
.160	-2.48	2.83	2.48	62.50	7.95	11.65	-3.66
.170	-1.86	-2.70	1.76	61.93	6.92	12.28	-3.71
.180	.82	.09	1.20	61.75	6.22	12.90	-3.76
.190	-.49	.15	.68	61.40	5.29	13.51	-3.81
.200	.06	-1.98	.24	61.16	4.84	14.13	-3.86
.210	.82	-2.46	-.11	61.25	4.27	14.74	-3.90
.220	-.97	-.03	-.41	61.06	3.91	15.35	-3.94
.230	-.21	-.15	-.70	60.97	3.56	15.96	-3.99
.240	-.90	.03	-1.00	60.92	3.30	16.57	-4.03
.250	-1.65	-.09	-1.31	60.69	3.06	17.17	-4.07
.260	-.76	.15	-1.58	60.48	2.78	17.78	-4.12
.270	-.21	.03	-1.84	60.52	2.48	18.38	-4.16
.280	.96	.46	-2.07	60.52	2.26	18.99	-4.21
.290	-.21	-.58	-2.31	60.51	1.97	19.59	-4.25
.300	-.01	-.15	-2.53	60.46	1.72	20.19	-4.29
.310	-.14	-.27	-2.75	60.43	1.52	20.80	-4.34
.320	.82	-.21	-2.95	60.48	1.31	21.40	-4.38
.330	-.69	.33	-3.16	60.45	1.16	22.00	-4.43
.340	-.62	.33	-3.38	60.26	.89	22.61	-4.47
.350	.68	-.52	-3.57	60.14	.71	23.21	-4.52
.360	.48	-.82	-3.74	60.06	.59	23.81	-4.56
.370	2.27	-1.00	-3.90	60.08	.40	24.40	-4.61
.380	-1.24	-.15	-4.07	59.94	.10	25.00	-4.65
.390	.62	.82	-4.22	59.67	-.22	25.60	-4.69
.400	-.76	.88	-4.35	59.66	-.16	26.20	-4.73

HIGHEST 50.0-MS AVG. ACCEL.

	G'S	TIME (SEC) START	TIME (SEC) END
LONG.	-5.42	.016	.066
LAT.	8.13	.002	.052

Table 25. Occupant risk data (film), test KM-1.

OCCUPANT RISK SUMMARY -- FROM FILM ANALYSIS
NOTE: AVG. ACCEL. FOR PRIOR 0.010 SEC. CALCULATED
FROM VEHICLE VELOCITY CHANGE
RELATIVE VALUES-(OCCUPANT W.R.T. VEHICLE)

	(------- VEHICLE	--------	--------)	(-------- OCCUPANT		---------	---------)
TIME (S)	ACCEL. (G'S) LONG.	LAT.	ANG. VEL (RAD/S)	VEL. (FPS) LONG.	LAT.	DISP. (F) LONG.	LAT.
.000	-2.77	3.51	.36	.00	.00	.00	.00
.010	-2.84	3.66	.35	.65	-.94	.00	.00
.020	-2.87	3.78	.34	1.32	-1.95	.01	-.02
.030	-2.88	3.87	.33	1.99	-3.02	.03	-.04
.040	-2.85	3.93	.32	2.65	-4.15	.05	-.08
.050	-2.80	3.96	.30	3.28	-5.32	.08	-.13
.060	-2.74	3.97	.28	3.89	-6.54	.11	-.19
.070	-2.65	3.95	.27	4.46	-7.80	.15	-.26
.080	-2.55	3.90	.25	4.99	-9.08	.19	-.35
.090	-2.43	3.84	.23	5.47	-10.39	.24	-.45
.100	-2.31	3.75	.21	5.89	-11.70	.28	-.57
.110	-2.18	3.64	.19	6.27	-13.03	.33	-.70
.120	-2.05	3.52	.17	6.59	-14.34*	.38	-.84*
.130	-1.91	3.37*	.15	6.86	-15.64	.43	-1.00
.140	-1.78	3.21	.13	7.09	-16.92	.48	-1.17
.150	-1.65	3.04	.11	7.27	-18.16	.52	-1.36
.160	-1.53	2.86	.09	7.42	-19.36	.57	-1.56
.170	-1.41	2.66	.07	7.54	-20.51	.61	-1.77
.180	-1.30	2.45	.05	7.63	-21.61	.65	-1.99
.190	-1.20	2.24	.03	7.70	-22.65	.69	-2.22
.200	-1.11	2.03	.01	7.77	-23.62	.73	-2.47
.210	-1.02	1.81	.00	7.83	-24.52	.76	-2.72
.220	-.94	1.59	-.02	7.89	-25.35	.80	-2.98
.230	-.87	1.37	-.03	7.96	-26.10	.83	-3.25
.240	-.81	1.16	-.04	8.04	-26.78	.87	-3.52
.250	-.75	.95	-.06	8.14	-27.38	.91	-3.81
.260	-.70	.75	-.06	8.25	-27.90	.95	-4.09
.270	-.65	.55	-.07	8.39	-28.34	1.00	-4.38
.280	-.60	.37	-.08	8.54	-28.72	1.05	-4.67
.290	-.55	.19	-.09	8.72	-29.01	1.11	-4.97
.300	-.51	.03	-.09	8.91	-29.24	1.18	-5.26
.310	-.47	-.12	-.09	9.12	-29.40	1.25	-5.56
.320	-.43	-.26	-.10	9.34	-29.49	1.33	-5.86
.330	-.39	-.38	-.10	9.58	-29.52	1.42	-6.16
.340	-.35	-.49	-.10	9.81	-29.49	1.51	-6.45
.350	-.30	-.58	-.10	10.05	-29.41	1.62	-6.74
.360	-.26	-.65	-.10	10.29	-29.28	1.73	-7.03
.370	-.22	-.71	-.09	10.51	-29.11	1.85	-7.32
.380	-.18	-.75	-.09	10.72+	-28.90	1.98+	-7.61
.390	-.13	-.76	-.09	10.91	-28.67	2.11	-7.89
.400	-.09	-.76	-.08	11.08	-28.41	2.25	-8.17
.410	-.05	-.74	-.08	11.22	-28.13	2.40	-8.44
.420	-.01	-.71	-.08	11.32	-27.85	2.54	-8.71
.430	.03	-.65	-.07	11.40	-27.57	2.69	-8.98
.440	.06	-.57	-.07	11.43	-27.30	2.83	-9.24
.450	.10	-.47	-.07	11.43	-27.04	2.98	-9.51
.460	.13	-.36	-.06	11.39	-26.81	3.12	-9.77
.470	.15	-.23	-.06	11.32	-26.62	3.25	-10.03
.480	.18	-.08	-.06	11.20	-26.47	3.37	-10.29
.490	.20	.09	-.06	11.05	-26.37	3.49	-10.55
.500	.21+	.27	-.06	10.86	-26.33	3.59	-10.82

OCCUP. RISK FACTORS	TIME (S)	VELOCITY (FPS)
<LONG. VEL. AFTER 2.0 FT. DISP. --	.381	10.75
<LAT. VEL. AFTER 1.0 FT. DISP. --	.130	-15.64

Table 26. Occupant risk data (transducer), test KM-1.

OCCUPANT RISK SUMMARY
NOTE: INSTANTANEOUS 10-MS AVERAGE ACCELERATIONS

TIME (S)	VEHICLE ACCEL. (G'S) LONG.	VEHICLE ACCEL. (G'S) LAT.	VEHICLE ANG.VEL (RAD/S)	OCCUPANT VEL. (FPS) LONG.	OCCUPANT VEL. (FPS) LAT.	OCCUPANT DISP. (F) LONG.	OCCUPANT DISP. (F) LAT.
.000	-3.58	-.09	-.39	.00	.00	.00	.00
.010	-.90	6.86	-.63	1.00	-1.39	.01	-.01
.020	-4.19	8.98	-.96	1.59	-4.10	.02	-.03
.030	-8.83	7.16	-1.18	2.56	-6.04	.03	-.08
.040	-6.75	12.07	-1.77	4.63	-8.20	.07	-.15
.050	-5.33	4.35	-2.63	4.98	-10.45	.11	-.25
.060	-1.76	5.54	-2.49	6.14	-12.36	.16	-.37
.070	-1.11	3.13	-2.81	5.66	-13.75	.21	-.51
.080	-1.97	2.38	-2.70	6.08	-14.61	.25	-.66
.090	-1.66	2.77	-2.77	5.73	-15.75	.29	-.82
.100	-1.03	-.94	-2.69	6.18	-16.61*	.33	-.99*
.110	-.71	1.88	-2.28	6.14	-17.51	.36	-1.17
.120	-1.61	5.04	-2.37	5.97	-18.28	.39	-1.35
.130	-4.82	9.59*	-2.13	6.47	-21.42	.42	-1.56
.140	-1.11	6.40	-1.80	7.79	-24.67	.46	-1.80
.150	-.15	1.45	-1.38	7.73	-26.60	.51	-2.07
.160	-3.00	.79	-1.42	8.11	-26.99	.56	-2.34
.170	-1.64	-1.78	-1.03	8.91	-27.32	.61	-2.62
.180	-.41	-.21	-.94	8.98	-27.43	.67	-2.90
.190	-1.72	.05	-.88	9.20	-27.22	.74	-3.18
.200	-.01	-1.27	-.67	9.52	-27.57	.80	-3.46
.210	-.28	-.18	-.57	9.42	-27.55	.88	-3.74
.220	-.68	.29	-.46	9.62	-27.70	.95	-4.02
.230	.00	-.28	-.52	9.51	-27.64	1.03	-4.30
.240	-.46	.37	-.53	9.41	-27.74	1.10	-4.59
.250	-.77	.26	-.51	9.54	-27.90	1.17	-4.87
.260	-.29	-.04	-.46	9.69	-28.02	1.24	-5.15
.270	.08	.12	-.42	9.59	-28.08	1.31	-5.44
.280	-.07	-.25	-.41	9.48	-28.16	1.39	-5.73
.290	-.20	-.10	-.41	9.38	-28.16	1.45	-6.01
.300	-.05	.16	-.38	9.37	-28.23	1.52	-6.30
.310	-.05	-.01	-.37	9.31	-28.29	1.59	-6.59
.320	.29	.14	-.34	9.20	-28.38	1.66	-6.88
.330	-.49	-.05	-.38	9.08	-28.43	1.73	-7.17
.340	-.60	.05	-.36	9.19	-28.45	1.79	-7.46
.350	.11	-.05	-.31	9.28	-28.56	1.86	-7.75
.360	-.59	.15	-.30	9.28	-28.67	1.93	-8.04
.370	-.09	-.17	-.27	9.23+	-28.71	2.00+	-8.34
.380	-.45+	-.35	-.28	9.27	-28.59	2.06	-8.63
.390	-.56	.09	-.24	9.51	-28.51	2.13	-8.92
.400	-.36	.46	-.22	9.48	-28.74	2.21	-9.21

OCCUP. RISK FACTORS

		TIME (S)	VELOCITY (FPS)
>LONG. VEL. AFTER 2.0 FT. DISP.	--	.370	9.18
>LAT. VEL. AFTER 1.0 FT. DISP.	--	.101	-16.69

MAX. ACCEL. AFTER OCCUPANT IMPACT		TIME(S)	ACC.(GS)
>LONG. ACCELERATION	--	.383	-1.13
>LAT. ACCELERATION	--	.131	9.99

Table 27. Vehicle damage measurements, test KM-1.

	Before Test	After Test	Crush
L	48	48	Not Applicable
C-1	1.3	4.0	2.7
C-2	0.0	2.8	2.8
C-3	0.0	-0.8	+0.8
C-4	0.0	8.8	8.8
C-5	0.3	8.5	8.2
C-6	0.3	10.0	9.7

Maximum crush of 10.5 at a location of 22 to the right of vehicle centerline.

Note: All dimensions are in inches. 1 in = 2.54 cm

APPENDIX F: SUMMARY OF RESULTS, TEST KM-2

Test No. KM-2
Test Date . . . . Aug. 17, 1989
Installation Length - ft[m] . . . . 69 [21]

Beam
Member . . 9- by 10in. [25.4cm by 22.8cm]
Length - ft[m] . . . . . . 2 @ 24(7.3) and
. . . . 1 @ 16(4.9)

Maximum Deflections - in [cm]
Permanent . . . . none
Dynamic . . . . none

Post
Details of the posts, curb, and deck are included in figure 40.

Vehicle . . . . 1983 Ford F150 Pickup

Mass - lb [kg]
Test Inertia . . . . 5245 [2379]
Dummy . . . . 165 [75]
Gross Test Weight . . . . 5410 [2454]

Speed - mi/h [km/h] . . . . 46.6 [75.0]

Angles - degrees
Impact 20.0
Exit . . . . -2.4

Occupant Impact Velocity - ft/s [m/s]
Forward (film/accel) 2.3 [0.7]/7.2 [2.2]
Lateral (film/accel) . . . . -18.2 [5.5]/
. . . . -21.3.3 [-6.5]

Occupant Ridedown Accelerations - g's
Forward (accel) . . . . *
Lateral (accel) 9.7

Maximum 50 msec Avg Accelerations - g'
Longitudinal (film/accel) . . . -2.7/-3.4
Lateral (film/accel) 4.9/8.8

Vehicle Damage
TAD 01-FR-4
VDI 01FREE6

TEST KM-2

Barrier Installation

The barrier evaluated in the test was a Modified Kansas Corral bridge rail. The barrier system, which consisted of concrete posts, rails and a 6-in (15-cm) curb, was constructed on a simulated bridge deck. Total system length was 69 ft (21 m). Figure 40 presents details of the system tested.

Test Purpose

The purpose of this test was to investigate the dynamic interactions of the pickup truck with the bridge rail and curb. Goals for this test were: (1) the vehicle must not penetrate or vault over the system, (2) the vehicle should remain upright throughout the event, and (3) the vehicle after-collision trajectory should not present undue hazard to other traffic.

Test Vehicle

The vehicle used in the test was a 1984 Ford F150 Pickup. Gross test weight, including the dummy and instrumentation was 5419-lb (2458 kg).

Performance

Impact conditions were 46.6 m/h [74.9 km/h] and a 20.0-degree impact angle. As shown in figure 41, the vehicle impacted the barrier 0.8 ft [0.2 m] downstream of Post 7. The vehicle remained in contact with the barrier for 15.0 ft [4.6 m] before redirection at a -2.4 degree angle. The vehicle showed no tendency to snag on the curb or posts during the impact sequence. No significant pitch, roll, or yaw was noted during impact and redirection. The vehicle came to rest 190 ft [58 m] downstream of the impact point and 35 ft [11 m] out from the barrier plane. The vehicle brakes were applied at approximately 130 ft [40 m] after impact. Table 28 presents after impact vehicle trajectory. The barrier did not deflect during impact.

Film data indicated maximum 50 m/s averages of -2.7 g's (longitudinal) and 4.9 g's (lateral). Maximum 50 m/s average accelerations from transducer data indicated -3.4 g's (longitudinal) and 8.8 g's (lateral). Figure 43 presents a summary of test results. Vehicle kinetics from film and onboard transducers are listed in tables 29 and 30. Plots of vehicle accelerations are presented in figure 44. Tables 31 and 32 present occupant risk data derived from film and the on-board transducers.

Barrier Damage

Damage to the barrier consisted of cosmetic scuff marks on the rail and curb. Minor gouging from wheel contact was noted on the lower edge of the rail in the impact area. Inspection of the barrier system revealed no fractured posts or rail members. The barrier was considered as undamaged.

Vehicle Damage

Damage to the vehicle consisted of sheet metal deformation of the right front fender, side, and rear fender. The front bumper was deformed inward at the impact area. The right front tire was blown out during impact. Vehicle damage was considered commensurate with the severity of the impact. Vehicle damage measurements are contained in table 33.

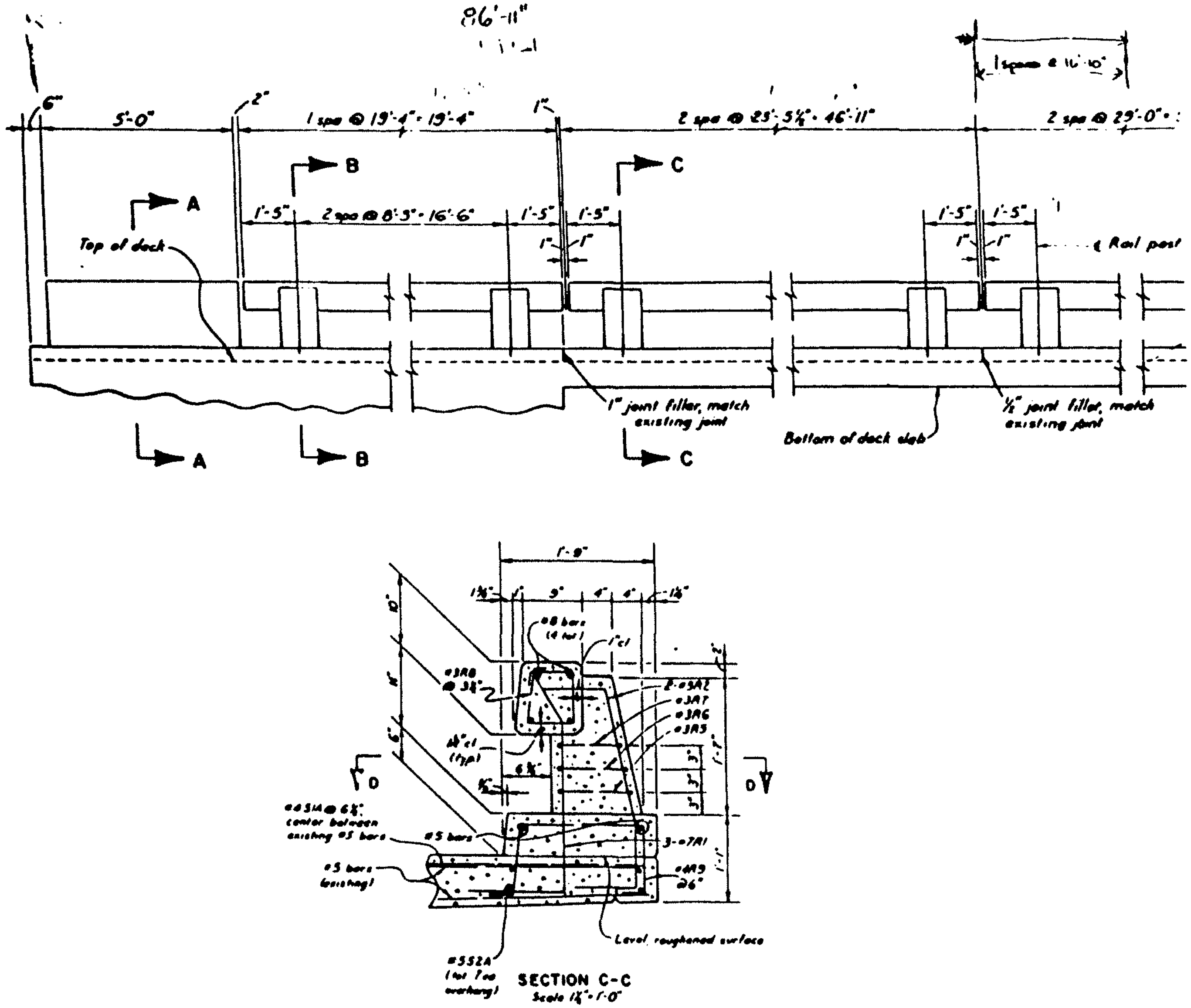


Figure 40. Barrier construction details, test KM-2.

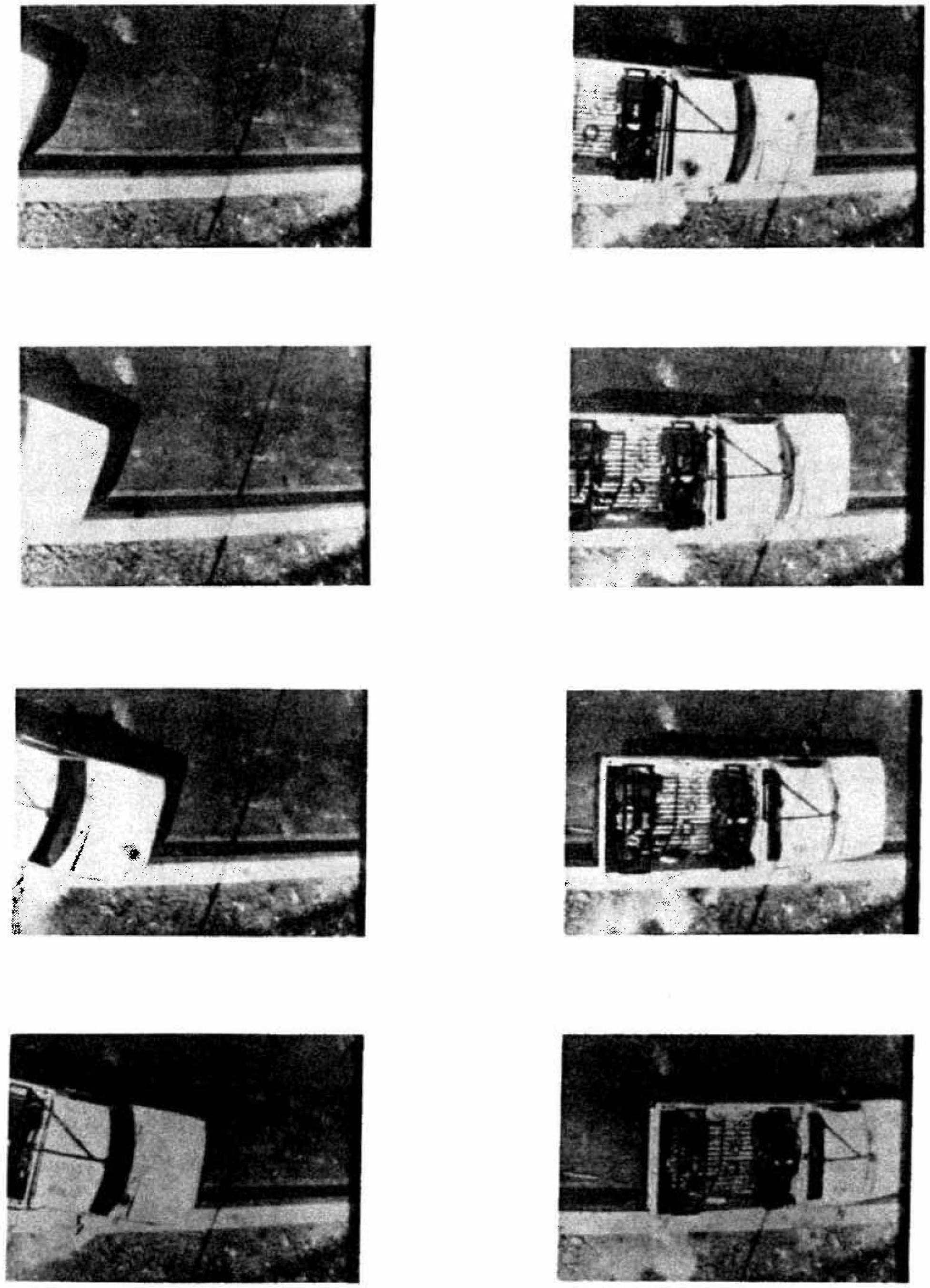


Figure 41. Sequential photographs during impact (overhead view), test KM-2.

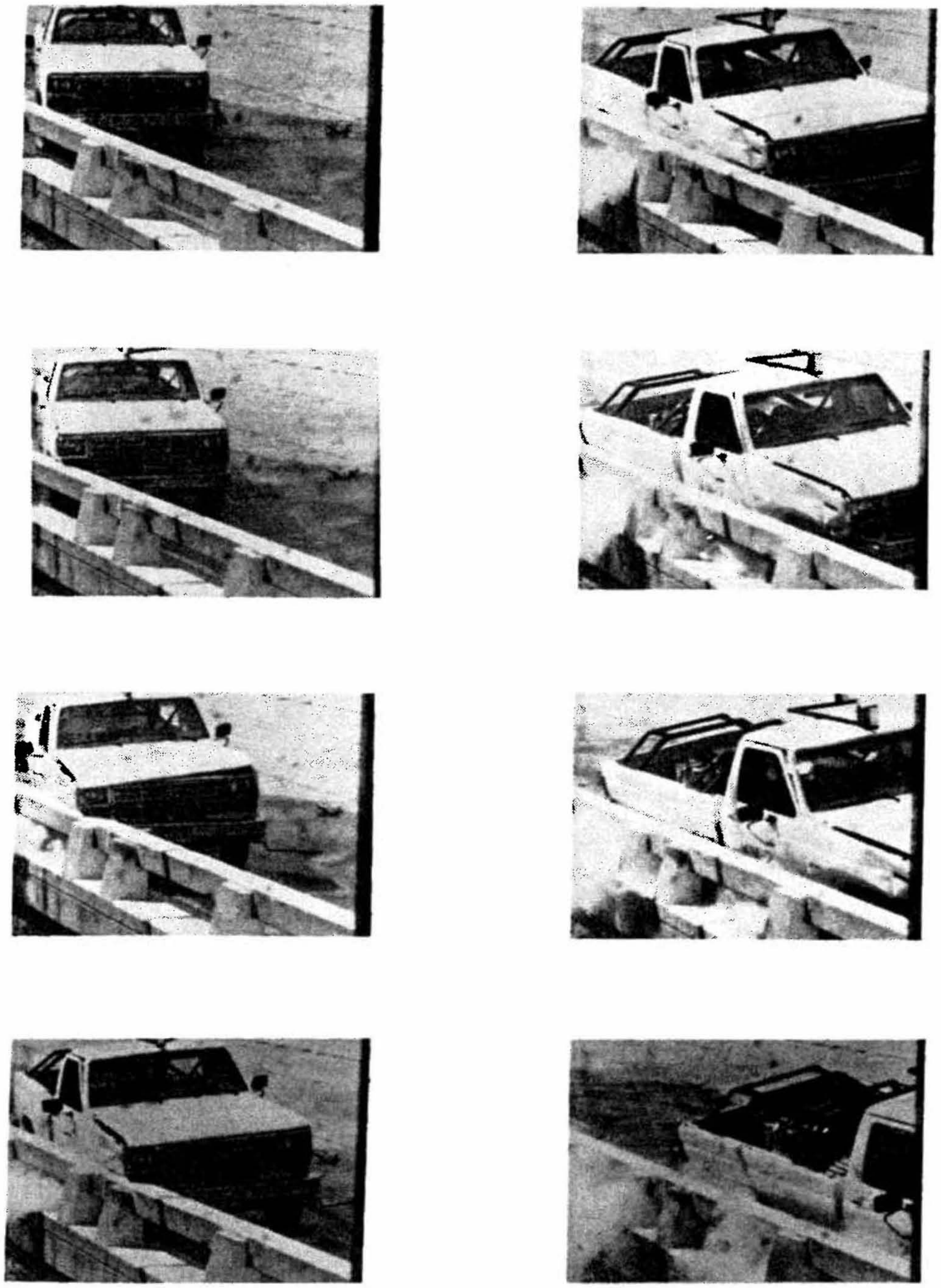
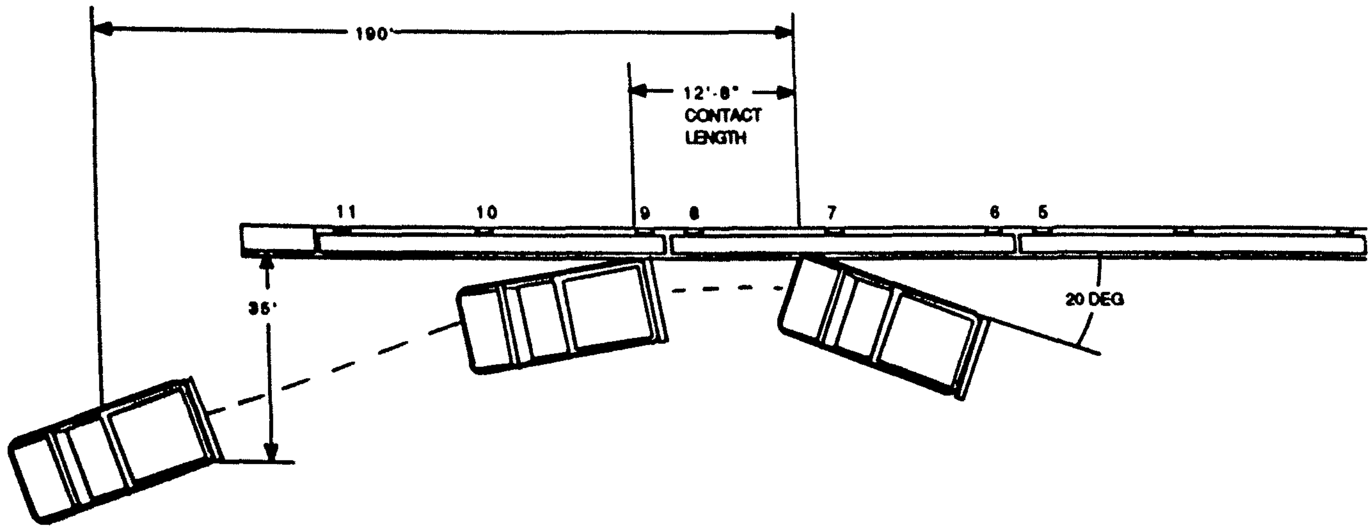


Figure 42. Sequential photographs during impact
as viewed from downstream, test KM-2.



Test No.	KM-2
Test Date	Aug. 17, 1989
Installation Length - ft (m)	69 (21)
Beam	
Member	9-in (22.8cm)x 10-in (25.4 cm) reinforced concrete
Length - ft (m)	2 @ 24 (7.3) and 1 @ 16 (4.9)
Maximum Deflections - in. (cm)	
Permanent	none
Dynamic	none
Post	
Details of the posts, blockouts, curb, and deck are included in figure 1.	
Vehicle	1983 Ford F150 Pickup
Mass - lb (kg)	
Test Inertia	5245 (2379)
Dummy	165 (75)
Gross Test Weight	5410 (2454)
Speed - mi/h (km/h)	46.6 (75.0)

Angle - degrees	
Impact	20
Exit	-2.4
Occupant Impact Velocity - fps (m/s)	
Forward (accel)	2.3 (0.7)/7.2 (2.2)
Lateral (accel)	-18.2 (-5.5)/-21.3 (-6.5)
Occupant Ridedown Accelerations - g's	
Forward (accel)	*
Lateral (accel)	9.7
Maximum 50 m/s Avg Accelerations - g's	
Longitudinal (film/accel)	-2.7/-3.4
Lateral (film/accel)	4.9/8.8
Vehicle Damage	
TAD	01-FR-4
VDI	01FREE6

Figure 43. Summary of results, test KM-2.

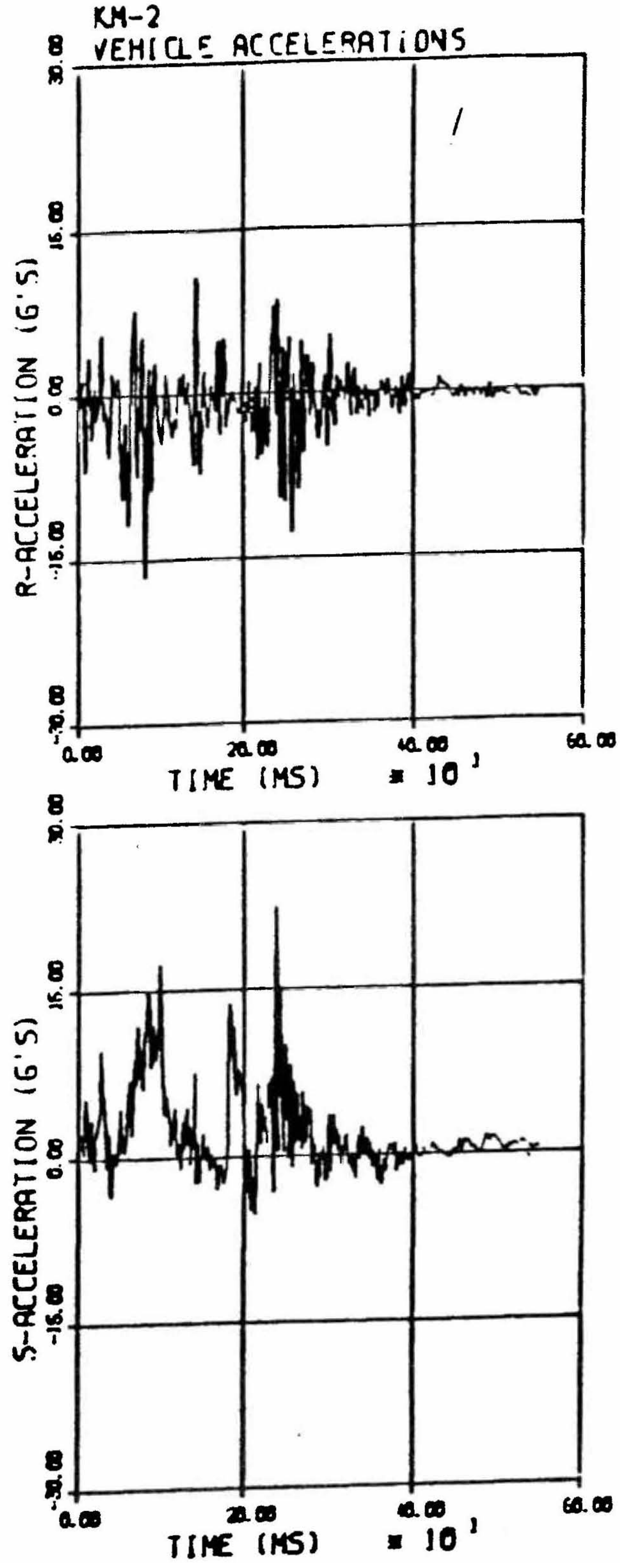


Figure 44. Vehicle acceleration plots, test KM-2.

Table 28. After impact vehicle trajectory, test KM-2.

Location[1]	Distance[2]
0	0
10	-0.3
20	1.0
30	2.3
40	2.4
50	3.3
60	4.3
70	5.2
80	6.3
90	7.5
100	8.8

[1]Distance measured in the downstream direction with 0 as the point of impact.

[2]Measured perpendicular to the barrier plane at the front tire on the impact side of the vehicle.

Note: All dimensions are in feet. 1 ft = 0.305 m

Table 29. Vehicle kinetics data (film), test KM-2.

TIME (S)	ACCEL. (G'S) LONG.	LAT.	HEADING ANG. (DEG)	VEL. (FPS) LONG.	LAT.	DISP. (F) X	Y
.000	-1.63	1.04	20.04	68.31	-2.00	-8.80	-4.90
.010	-1.62	1.72	20.03	67.79	-1.56	-8.17	-4.65
.020	-1.59	2.36	19.95	67.27	-1.01	-7.54	-4.41
.030	-1.57	2.94	19.77	66.76	-.36	-6.91	-4.18
.040	-1.53	3.46	19.50	66.26	.37	-6.29	-3.95
.050	-1.48	3.91	19.14	65.78	1.14	-5.66	-3.74
.060	-1.43	4.28	18.69	65.32	1.94	-5.04	-3.54
.070	-1.36	4.57	18.15	64.90	2.75	-4.41	-3.36
.080	-1.29	4.78	17.52	64.50	3.55	-3.79	-3.19
.090	-1.21	4.90	16.82	64.15	4.32	-3.16	-3.04
.100	-1.14	4.96	16.04	63.83	5.05	-2.53	-2.90
.110	-1.06	4.94	15.20	63.56	5.70	-1.90	-2.78
.120	-.98	4.85	14.30	63.33	6.29	-1.28	-2.68
.130	-.92	4.70	13.36	63.13	6.79	-.65	-2.59
.140	-.86	4.49	12.38	62.96	7.19	-.02	-2.52
.150	-.81	4.24	11.38	62.82	7.50	.61	-2.46
.160	-.77	3.95	10.37	62.70	7.71	1.24	-2.42
.170	-.75	3.63	9.35	62.60	7.82	1.88	-2.39
.180	-.74	3.29	8.33	62.49	7.83	2.51	-2.37
.190	-.74	2.94	7.34	62.39	7.74	3.13	-2.36
.200	-.76	2.58	6.36	62.28	7.57	3.76	-2.36
.210	-.78	2.22	5.42	62.15	7.32	4.39	-2.37
.220	-.81	1.86	4.53	62.01	7.00	5.01	-2.39
.230	-.84	1.53	3.68	61.85	6.63	5.64	-2.42
.240	-.87	1.21	2.88	61.66	6.21	6.26	-2.44
.250	-.90	.92	2.14	61.46	5.76	6.87	-2.48
.260	-.92	.65	1.46	61.23	5.28	7.49	-2.51
.270	-.93	.42	.85	60.99	4.80	8.10	-2.55
.280	-.93	.22	.29	60.73	4.32	8.71	-2.59
.290	-.92	.07	-.19	60.46	3.85	9.32	-2.63
.300	-.90	-.06	-.62	60.20	3.40	9.92	-2.67
.310	-.86	-.14	-.98	59.93	2.99	10.52	-2.71
.320	-.81	-.18	-1.29	59.68	2.61	11.12	-2.75
.330	-.75	-.19	-1.54	59.44	2.29	11.71	-2.79
.340	-.67	-.15	-1.75	59.22	2.02	12.30	-2.83
.350	-.58	-.09	-1.92	59.02	1.81	12.89	-2.87
.360	-.49	.01	-2.05	58.85	1.66	13.48	-2.91
.370	-.40	.14	-2.15	58.71	1.58	14.07	-2.94
.380	-.30	.29	-2.23	58.60	1.56	14.65	-2.98
.390	-.21	.45	-2.30	58.52	1.61	15.24	-3.02
.400	-.13	.64	-2.36	58.47	1.72	15.82	-3.06
.410	-.05	.83	-2.43	58.44	1.89	16.41	-3.10
.420	.01	1.02	-2.50	58.44	2.11	16.99	-3.15
.430	.05	1.21	-2.59	58.46	2.38	17.57	-3.20
.440	.08	1.39	-2.71	58.48	2.68	18.16	-3.25
.450	.08	1.55	-2.84	58.52	3.02	18.74	-3.31
.460	.06	1.69	-3.01	58.55	3.37	19.32	-3.37
.470	.00	1.80	-3.21	58.57	3.73	19.90	-3.43
.480	-.07	1.87	-3.45	58.58	4.08	20.49	-3.51
.490	-.18	1.90	-3.72	58.55	4.41	21.07	-3.59
.500	-.32	1.88	-4.02	58.50	4.71	21.65	-3.67
.510	-.49	1.82	-4.36	58.40	4.96	22.23	-3.76
.520	-.69	1.70	-4.72	58.24	5.16	22.81	-3.86
.530	-.92	1.53	-5.10	58.01	5.30	23.38	-3.96
.540	-1.16	1.31	-5.50	57.72	5.35	23.95	-4.07
.550	-1.42	1.03	-5.90	57.34	5.33	24.52	-4.18
.560	-1.70	.71	-6.30	56.87	5.21	25.08	-4.29
.570	-1.97	.33	-6.68	56.32	5.00	25.64	-4.41
.580	-2.23	-.09	-7.04	55.67	4.69	26.19	-4.52
.590	-2.46	-.55	-7.35	54.94	4.29	26.73	-4.63
.600	-2.64	-1.04	-7.62	54.14	3.78	27.27	-4.75
.610	-2.75	-1.55	-7.83	53.28	3.17	27.79	-4.85
.620	-2.76	-2.06	-7.96	52.40	2.46	28.31	-4.95
.630	-2.64	-2.57	-8.01	51.53	1.67	28.83	-5.05
.640	-2.35	-3.04	-7.97	50.72	.80	29.33	-5.13
.650	-1.87	-3.46	-7.84	50.03	-.13	29.83	-5.20
.660	-1.14	-3.78	-7.62	49.55	-1.11	30.32	-5.26
.670	-.12	-3.98	-7.31	49.34	-2.10	30.81	-5.31
.680	1.24	-4.00	-6.93	49.53	-3.06	31.31	-5.35
.690	2.98	-3.79	-6.50	50.23	-3.94	31.81	-5.37

HIGHEST 50-MS AVG.ACCEL.

	G-S	TIME (SEC) START	END
LONG.	-2.65	.5950	.6450
LAT.	4.89	.0850	.1350

Table 30. Vehicle kinetics data (transducer), test KM-2.

VEHICLE KINETICS SUMMARY
NOTE: VALUES ARE INSTANTANEOUS AT TIME

TIME (S)	ACCEL.(G'S) LONG.	ACCEL.(G'S) LAT.	HEAD.ANG. DEG	VELOCITY(FPS) LONG.	VELOCITY(FPS) LAT.	DISP.(F) X	DISP.(F) Y
.000	.79	.81	20.04	68.31	-2.00	-8.80	-4.90
.010	-5.44	3.99	20.05	67.81	-1.34	-8.17	-4.65
.020	.82	-.80	20.11	67.59	-.91	-7.53	-4.41
.030	-1.63	5.64	20.10	67.83	.45	-6.90	-4.17
.040	1.11	-1.19	19.94	66.91	.63	-6.26	-3.95
.050	.04	3.14	19.66	67.23	.42	-5.63	-3.72
.060	-10.66	6.03	19.17	65.33	.59	-5.00	-3.51
.070	.45	9.93	18.47	64.95	1.79	-4.39	-3.31
.080	-7.39	11.35	17.70	64.42	3.86	-3.77	-3.14
.090	-7.32	11.08	16.90	62.20	6.75	-3.15	-3.00
.100	-3.05	8.75	16.08	62.03	9.59	-2.53	-2.90
.110	-.25	3.04	15.10	61.79	10.25	-1.91	-2.83
.120	-2.73	.22	13.97	61.13	9.68	-1.29	-2.78
.130	-.91	4.36	12.77	61.40	8.83	-.67	-2.72
.140	-6.35	7.54	11.51	61.10	8.23	-.05	-2.68
.150	-2.10	2.12	10.23	60.98	7.06	.56	-2.64
.160	-.91	-.70	8.91	60.89	5.68	1.18	-2.60
.170	3.47	-.76	7.50	61.32	3.89	1.79	-2.56
.180	-2.51	1.11	6.04	61.49	1.91	2.40	-2.52
.190	-.25	5.54	4.60	61.21	3.43	3.01	-2.49
.200	.64	3.24	3.39	61.09	4.08	3.62	-2.48
.210	-2.57	-4.04	2.29	60.92	2.37	4.23	-2.49
.220	2.74	1.21	1.28	60.19	1.25	4.84	-2.48
.230	-4.18	6.52	.30	59.43	1.32	5.44	-2.49
.240	-1.98	14.43	-.57	59.85	2.67	6.03	-2.50
.250	-6.07	9.97	-1.18	59.73	4.19	6.63	-2.55
.260	-7.23	5.37	-1.53	58.49	5.23	7.22	-2.61
.270	4.73	1.89	-1.78	57.76	5.89	7.80	-2.68
.280	-1.63	3.08	-1.99	57.89	6.74	8.38	-2.76
.290	-3.20	.19	-2.16	57.53	6.53	8.95	-2.85
.300	-4.08	1.17	-2.31	57.20	6.19	9.52	-2.94
.310	-2.92	2.22	-2.42	56.90	6.59	10.09	-3.03
.320	-.12	1.57	-2.47	56.96	6.78	10.66	-3.12
.330	.10	-1.39	-2.45	56.94	6.91	11.22	-3.21
.340	-1.28	2.45	-2.41	56.88	6.89	11.79	-3.30
.350	-.91	.94	-2.37	56.58	7.12	12.35	-3.40
.360	-1.13	.42	-2.35	56.40	6.95	12.92	-3.49
.370	.10	.42	-2.32	56.37	6.61	13.48	-3.58
.380	.38	-.30	-2.31	56.31	6.81	14.04	-3.67
.390	-.75	-.14	-2.27	56.22	6.66	14.60	-3.76
.400	-1.00	.29	-2.25	56.17	6.67	15.15	-3.85
.410	.01	-.27	-2.24	55.98	6.73	15.71	-3.94
.420	.01	.02	-2.26	55.93	6.76	16.27	-4.03
.430	.79	.16	-2.28	55.89	6.92	16.82	-4.12
.440	.29	-.37	-2.27	56.09	6.93	17.38	-4.21
.450	-.12	-.11	-2.25	56.02	6.94	17.94	-4.30
.460	-.50	1.07	-2.22	55.96	7.17	18.50	-4.39
.470	-.62	.45	-2.18	55.84	7.50	19.05	-4.49
.480	-.62	.29	-2.12	55.73	7.64	19.61	-4.58
.490	.38	1.21	-2.07	55.66	8.04	20.16	-4.68
.500	-.50	1.07	-2.00	55.54	8.54	20.71	-4.79
.510	-.62	.42	-1.92	55.43	8.79	21.26	-4.89
.520	-.03	.78	-1.83	55.24	9.11	21.81	-5.00
.530	-.50	1.21	-1.74	55.12	9.49	22.36	-5.11
.540	.13	.19	-1.65	54.96	9.80	22.91	-5.22

HIGHEST 50.0-MS AVG. ACCEL.

	G'S	TIME (SEC) START	TIME (SEC) END
LONG.	-3.42	.051	.101
LAT.	8.82	.059	.109

Table 31. Occupant risk data (film), test KM-2.

OCCUPANT RISK SUMMARY -- FROM FILM ANALYSIS
NOTE: AVG. ACCEL. FOR PRIOR 0.010 SEC. CALCULATED
FROM VEHICLE VELOCITY CHANGE
RELATIVE VALUES-(OCCUPANT W.R.T. VEHICLE)

TIME (S)	(------- VEHICLE --------) ACCEL. (G'S) LONG.	LAT.	ANG. VEL (RAD/S)	(-------- OCCUPANT ---------) VEL. (FPS) LONG.	LAT.	DISP. (F) LONG.	LAT.
.000	-1.63	1.04	.35	.00	.00	.00	.00
.010	-1.62	1.72	.35	.35	-.61	.00	.00
.020	-1.59	2.36	.35	.68	-1.44	.01	-.01
.030	-1.57	2.94	.35	.99	-2.48	.02	-.03
.040	-1.53	3.46	.34	1.27	-3.71	.03	-.06
.050	-1.48	3.91	.33	1.53	-5.10	.04	-.11
.060	-1.43	4.28	.33	1.76	-6.63	.06	-.17
.070	-1.36	4.57	.32	1.96	-8.26	.07	-.24
.080	-1.29	4.78	.31	2.12	-9.98	.09	-.33
.090	-1.21	4.90	.29	2.25	-11.74	.11	-.44
.100	-1.14	4.96	.28	2.33	-13.52	.12	-.57
.110	-1.06	4.94	.27	2.36	-15.30	.14	-.72
.120	-.98	4.85	.25	2.36	-17.05*	.15	-.88*
.130	-.92	4.70*	.23	2.31	-18.74	.16	-1.06
.140	-.86	4.49	.22	2.23	-20.35	.16	-1.26
.150	-.81	4.24	.20	2.12	-21.88	.16	-1.47
.160	-.77	3.95	.18	2.00	-23.29	.15	-1.70
.170	-.75	3.63	.16	1.85	-24.59	.14	-1.95
.180	-.74	3.29	.15	1.71	-25.75	.12	-2.20
.190	-.74	2.94	.13	1.57	-26.78	.09	-2.46
.200	-.76	2.58	.11	1.45	-27.67	.06	-2.74
.210	-.78	2.22	.09	1.35	-28.42	.03	-3.02
.220	-.81	1.86	.08	1.28	-29.03	-.01	-3.31
.230	-.84	1.53	.06	1.24	-29.52	-.05	-3.60
.240	-.87	1.21	.05	1.25	-29.89	-.08	-3.90
.250	-.90	.92	.04	1.30	-30.15	-.12	-4.19
.260	-.92	.65	.03	1.38	-30.30	-.16	-4.49
.270	-.93	.42	.01	1.51	-30.38	-.20	-4.80
.280	-.93	.22	.01	1.67	-30.37	-.23	-5.10
.290	-.92	.07	.00	1.86	-30.31	-.26	-5.40
.300	-.90	-.06	-.01	2.07	-30.21	-.28	-5.70
.310	-.86	-.14	-.02	2.29	-30.08	-.29	-6.00
.320	-.81	-.18	-.02	2.52	-29.93	-.30	-6.30
.330	-.75	-.19	-.03	2.75	-29.78	-.30	-6.60
.340	-.67	-.15	-.03	2.97	-29.65	-.30	-6.89
.350	-.58	-.09	-.03	3.17	-29.54	-.29	-7.19
.360	-.49	.01	-.04	3.35	-29.47	-.27	-7.48
.370	-.40	.14	-.04	3.49	-29.45	-.25	-7.77
.380	-.30	.29	-.04	3.60	-29.49	-.23	-8.07
.390	-.21	.45	-.04	3.67	-29.59	-.20	-8.36
.400	-.13	.64	-.04	3.69	-29.77	-.18	-8.66
.410	-.05	.83	-.04	3.67	-30.02	-.15	-8.96
.420	.01	1.02	-.04	3.61	-30.35	-.12	-9.26
.430	.05	1.21	-.05	3.52	-30.75	-.10	-9.57
.440	.08	1.39	-.05	3.38	-31.23	-.09	-9.88
.450	.08	1.55	-.05	3.22	-31.77	-.08	-10.19
.460	.06	1.69	-.05	3.03	-32.36	-.08	-10.51
.470	.00	1.80	-.06	2.84	-33.01	-.09	-10.84
.480	-.07	1.87	-.06	2.64	-33.68	-.10	-11.17
.490	-.18	1.90	-.06	2.44	-34.37	-.13	-11.51
.500	-.32	1.88	-.07	2.27+	-35.07	-.17+	-11.86

OCCUP. RISK FACTORS	TIME (S)	VELOCITY (FPS)
<LONG. VEL. AFTER 2.0 FT. DISP. --	.500	2.27
<LAT. VEL. AFTER 1.0 FT. DISP. --	.127	-18.15

Table 32. Occupant risk data (transducer), test KM-2.

OCCUPANT RISK SUMMARY
NOTE: INSTANTANEOUS 10-MS AVERAGE ACCELERATIONS

TIME (S)	VEHICLE ACCEL. (G'S) LONG.	VEHICLE ACCEL. (G'S) LAT.	VEHICLE ANG.VEL (RAD/S)	OCCUPANT VEL. (FPS) LONG.	OCCUPANT VEL. (FPS) LAT.	OCCUPANT DISP. (F) LONG.	OCCUPANT DISP. (F) LAT.
.000	.79	.81	-.01	.00	.00	.00	.00
.010	-1.09	2.03	.04	.56	-.60	.00	.00
.020	-1.20	1.59	.08	.84	-.90	.01	-.01
.030	.06	4.43	-.15	.30	-2.54	.02	-.03
.040	-1.46	-.35	-.34	.98	-3.14	.02	-.06
.050	-2.66	1.58	-.68	.22	-3.66	.03	-.09
.060	-6.58	3.78	-1.00	1.70	-4.78	.03	-.13
.070	.31	8.36	-1.36	1.59	-7.24	.05	-.19
.080	-4.58	10.46	-1.36	2.07	-10.22	.07	-.28
.090	-1.70	10.51	-1.37	4.19	-14.09	.10	-.40
.100	-2.55	9.67	-1.60	3.99	-18.16	.14	-.57
.110	-.94	3.14	-1.84	3.81	-20.26	.16	-.76
.120	-1.42	1.15	-2.07	4.01	-21.30*	.19	-.97*
.130	.42	2.43	-2.19	3.38	-22.02	.20	-1.19
.140	-.23	1.85	-2.19	3.43	-22.90	.20	-1.42
.150	-1.94	.10	-2.22	3.22	-23.27	.20	-1.66
.160	-.94	-.36	-2.40	2.76	-23.63	.19	-1.90
.170	.25	-1.35	-2.51	1.80	-23.60	.16	-2.14
.180	-.07	4.30*	-2.54	1.14	-23.35	.12	-2.38
.190	-.57	7.84	-2.27	1.27	-26.20	.07	-2.63
.200	-.62	2.04	-2.00	1.29	-27.92	.02	-2.90
.210	-1.42	-2.81	-1.87	1.20	-27.27	-.02	-3.18
.220	-2.33	3.23	-1.75	1.67	-27.16	-.06	-3.45
.230	-2.06	4.41	-1.64	2.15	-28.19	-.11	-3.72
.240	2.55	8.30	-1.31	1.76	-30.12	-.14	-4.01
.250	-2.39	4.51	-.79	2.25	-31.69	-.17	-4.32
.260	-2.77	4.30	-.57	3.61	-32.85	-.17	-4.64
.270	-2.68	2.47	-.38	4.45	-33.58	-.15	-4.97
.280	.80	2.20	-.29	4.34	-34.55	-.12	-5.31
.290	-2.13	-.64	-.30	4.60	-34.53	-.10	-5.65
.300	.01	.04	-.24	4.93	-34.29	-.06	-6.00
.310	-.92	1.71	-.16	5.28	-34.72	-.02	-6.34
.320	.39	.68	-.03	5.36	-34.81	.02	-6.69
.330	.09	-.78	.07	5.51	-34.80	.08	-7.04
.340	-.96	.70	.05	5.56	-34.76	.14	-7.39
.350	-.48	.18	.04	5.88	-34.96	.20	-7.74
.360	-.57	-1.28	.05	6.07	-34.76	.26	-8.08
.370	.25	-.06	.03	6.09	-34.42	.33	-8.43
.380	-.70	-.08	.04	6.17	-34.59	.39	-8.77
.390	-.28	-.20	.05	6.29	-34.38	.46	-9.12
.400	-.21	.15	.05	6.35	-34.37	.53	-9.46
.410	-.37	.05	-.01	6.47	-34.49	.59	-9.81
.420	-.27	.34	-.05	6.46	-34.58	.65	-10.15
.430	.49	.28	-.01	6.54	-34.72	.72	-10.50
.440	.25	-.12	.04	6.40	-34.67	.78	-10.85
.450	-.42	.31	.04	6.49	-34.65	.85	-11.19
.460	-.25	.94	.05	6.58	-34.83	.92	-11.54
.470	-.30	.56	.08	6.76	-35.08	1.00	-11.89
.480	-.24	.48	.11	6.92	-35.13	1.08	-12.24
.490	-.37	1.38	.08	6.99	-35.50	1.16	-12.59
.500	-.19	1.03	.14	7.21	-35.87	1.24	-12.95

OCCUP. RISK FACTORS	TIME (S)	VELOCITY (FPS)
>LONG. VEL. AFTER 2.0 FT. DISP. --	.500	7.21
>LAT. VEL. AFTER 1.0 FT. DISP. --	.121	-21.31

MAX. ACCEL. AFTER OCCUPANT IMPACT	TIME(S)	ACC.(GS)
>LAT. ACCELERATION --	.186	9.65

Table 33. Vehicle damage measurements, test KM-2.

	Before Test	After Test	Crush
L	56	56	Not Applicable
C-1	2.0	3.8	1.8
C-2	1.0	5.5	4.5
C-3	0.0	4.0	4.0
C-4	0.0	3.5	3.5
C-5	1.0	15.6	14.6
C-6	2.0	14.0	12.0

Maximum crush of 16.0 at a location of 25.0 to the right of vehicle centerline.

Note: All dimensions are in inches. 1 in = 2.54 cm

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