Performance Level 2 Tests on the Missouri 30-in. New Jersey Safety-Shape Bridge Rail

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Safety-shape bridge rails are substandard if they are less than 32 in. high, according to Section 2.7.1.2.2 of the AASHTO *Standard Specifications for Highway Bridges*. However, a substandard bridge rail may remain in operation if it passes a safety performance evaluation by full-scale crash testing. Therefore, Nebraska and Kansas pooled their efforts with Missouri to determine whether a 32-in. standard New Jersey safety-shape bridge rail would still provide a satisfactory safety performance if a 2-in. overlay were placed on the adjacent bridge deck. To evaluate the performance of this bridge rail, the Midwest Roadside Safety Facility conducted three full-scale vehicle crash tests on the Missouri 30-in. New Jersey safety-shape bridge rail. Test MS30-1 was conducted with an 18,011-lb single-unit straight truck at 16.1 degrees at 52.5 mph. Test MS30-2 was conducted with a 1,759-lb small automobile at 20.0 degrees at 62.5 mph. Test MS30-3 was conducted with a 5,460-lb pickup truck at 20.0 degrees at 63.5 mph. The test procedures were conducted and reported in accordance with the requirements in NCHRP Report 230. The tests were evaluated in accordance with the PL-2 safety criteria in the AASHTO *Guide Specifications for Bridge Railings*. The safety performance of the Missouri 30-in. New Jersey safety-shape bridge rail was found to be satisfactory according to the AASHTO PL-2 safety criteria.

FHWA currently considers a concrete safety-shape bridge rail substandard if it does not conform to a 32-in. minimum vertical height as stated in Section 2.7.1.2.2 of the AASHTO *Standard Specifications for Highway Bridges* (*1*), which states, "Concrete parapets designed with sloping faces intended to allow vehicles to ride up them under low angle contacts shall be at least 2 feet 8 inches in height." Therefore, a problem would be encountered when bridge decks with an attached 32-in. bridge rail required a 2-in. overlay.

In the past, when an overlay was to be placed on the roadway surface of a bridge deck, FHWA required that the bridge rail be modified so that it would remain in compliance with current specifications (i.e., increase the height of the bridge rail by retrofitting). However, the unmodified bridge rail may remain in operation if the bridge rail passes a safety performance evaluation by full-scale crash testing.

The Missouri Highway and Transportation Department and other highway departments across the Midwest have existing 32-in. standard New Jersey safety-shape bridge rails on decks that need to be resurfaced with a 2-in. concrete overlay. Therefore, Nebraska and Kansas pooled their efforts with Missouri to determine if a 32-in. standard New Jersey safety-shape bridge rail could have a 2-in. overlay placed on the adjacent bridge deck and still provide a satisfactory safety performance.

A safety performance evaluation was conducted on a 30-in. New Jersey safety-shape bridge rail according to test procedures in NCHRP Report 230 (*2*) and the PL-2 performance level evaluation criteria of AASHTO (*1*).

BRIDGE-RAIL DESIGN DETAILS

The installation consisted of a concrete New Jersey safety-shape bridge rail with an overall height of 30 in. and an overall length of 100 ft. The bridge-rail design details are shown in Figure 1, and photographs of the installation before impact

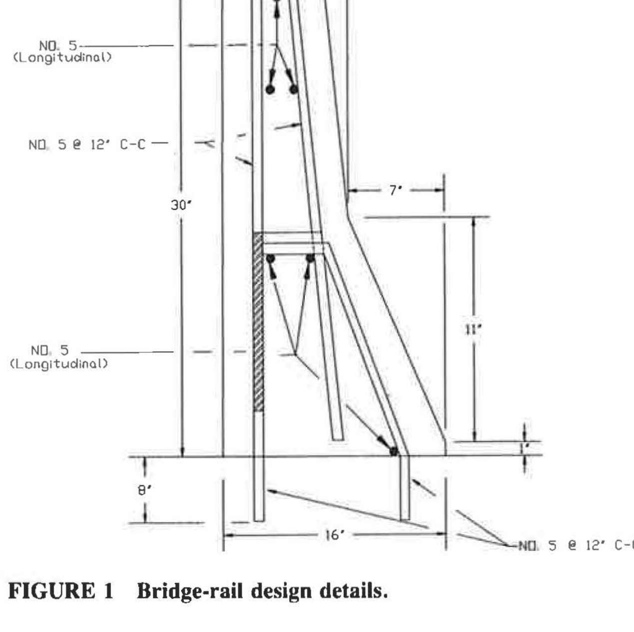

FIGURE 1 Bridge-rail design details.

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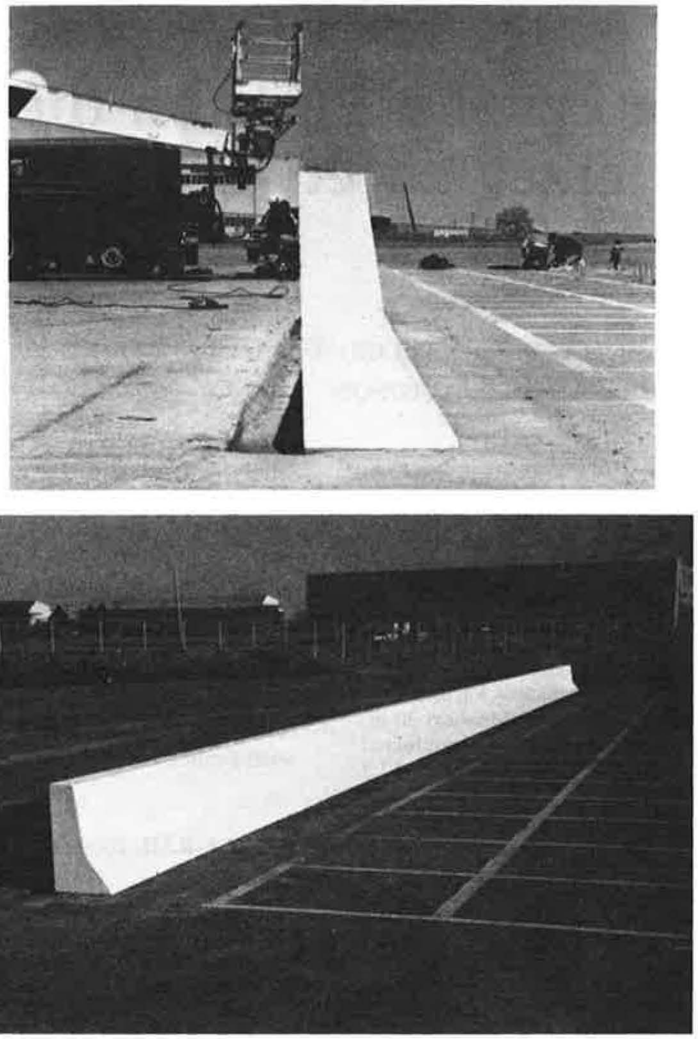


FIGURE 2 Missouri 30-in. New Jersey safety-shape bridge rail.

are shown in Figure 2. The 30-in. bridge rail was constructed by reducing the lower vertical face from 3 in. to 1 in. This construction procedure was accomplished by recessing standard 32-in. steel forms 2 in. below the existing concrete surface. The base width of the installation was 16.0 in., and the top width was 7.0 in.

The bridge rail was not constructed with a simulated concrete bridge deck because only the change in geometry caused by the reduced height was in question. Therefore, the bridge rail was attached to the existing concrete apron with two rows of No. 5 bent rebar spaced at 12-in. centers. The bars were rigidly attached to the apron with an epoxy grout adhesive and embedded 8 in. into the concrete apron surface. The reinforcement details are shown in Figure 1. Grade 60 reinforcing bars were used in all locations. The concrete compressive strength was approximately 6,000 psi.

TEST PARAMETERS

Three full-scale vehicle crash tests were conducted on the Missouri 30-in. New Jersey safety-shape bridge rail to satisfy the AASHTO (*1*) PL-2 performance level. The test vehicles are shown in Figure 3.

Test MS30-1 was conducted with a 18,011-lb single-unit truck at 16.1 degrees, 52.5 mph, and 35 ft from the upstream end. A detailed description of the ballasting procedure used for this test is shown in the test report (*3*). Test MS30-2 was conducted with a 1,759-lb small automobile at 20.0 degrees, 62.5 mph, and 30 ft from the upstream end. Test MS30-3 was conducted with a 5,460-lb pickup truck at 20 degrees, 63.5 mph, and 25 ft from the upstream end.

PERFORMANCE EVALUATION CRITERIA

The safety performance objective of a bridge rail is to reduce the number of deaths of and injuries to occupants of errant vehicles and to protect lives and property on, adjacent to, or below a bridge (*1*). In order to prevent or reduce the severity of such accidents, special attention should be given to four major areas: (a) railing strength to resist impact forces, (b) effective railing height, (c) shape of the face of the railing, and (d) deflection characteristics of the railing (*4*).

FIGURE 3 Test vehicles (*from top*): MS30-1, MS30-2, and MS30-3.

The major concerns about this installation were the reduced height and the change in the shape of the bridge rail face for an AASHTO PL-2 performance level. The other two items listed were not as critical because the tests were performed to evaluate the effects of the geometry change only. The rail must have adequate height in order to prevent vehicles from rolling over the railing. In the case of the small car and the pickup truck the rail must also prevent the vehicle from rolling onto its side away from the railing after redirection.

The performance evaluation criteria used to evaluate the three crash tests were taken from the AASHTO guide (*1*). The test conditions for the required test matrix are presented in Table 1. The safety performance of the bridge rail was evaluated according to three major factors: structural adequacy, occupant risk, and vehicle trajectory after collision. These three evaluation criteria are defined and explained in NCHRP Report 230. The vehicle damage was assessed by the traffic accident scale (TAD) (*5*) and the vehicle damage index (VDI) (*6*).

TEST RESULTS

Test MS30-1

After the initial impact with the bridge rail (35 ft from the upstream end), the right front corner crushed inward, causing the right front fender to ride along the top of the rail. At 0.15 sec after impact, the cab began to ride up the rail, rolling in a counterclockwise direction. At 0.30 sec, the front axle broke away from the frame on the right side and rotated inward underneath the truck. At this time, the cab had a roll angle of approximately 30 degrees counterclockwise, and the box remained level with the bridge rail. The front of the truck extended over the top as it traveled longitudinally along the bridge rail, leaving the front axle assembly on the traffic side of the rail.

At 0.42 sec, the cab began to rotate in the opposite direction (clockwise), with a clockwise yaw motion occurring simultaneously. The box began its clockwise roll motion at the same time. The combined effects of both the clockwise roll and yaw motions caused the rear end to uplift. This yaw motion

TABLE 1 Crash Test Conditions and Evaluation Criteria

Guidelines	Performance Level	Appurtenance	Test Vehicle	Impact Conditions		Evaluation Criteria[1]	
				Speed (mph)	Angle (deg)	Required	Desirable
AASHTO	PL-2	Bridge Rail	Small Automobile	60	20	3.a,b,c,d,g	3. e,f,h
AASHTO	PL-2	Bridge Rail	Pickup Truck	60	20	3. a,b,c,d	3. e,f,g,h
AASHTO	PL-2	Bridge Rail	Medium Single Unit Truck	50	15	3. a,b,c	3. d,e,f,h

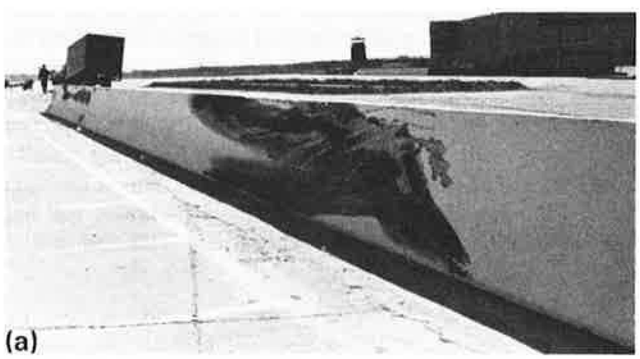
[1] - Evaluation criteria explained elsewhere (1).

continued for the remaining length of the rail. During the clockwise roll motion, the cab became level at 0.54 sec, and continued in a clockwise roll motion. At 0.66 sec, the cab and box were rolling in the same direction toward the rail.

At 1.0 sec after impact the entire vehicle (cab and box) had a continuing clockwise roll motion. Coinciding with this roll was positive yawing motion. At 1.04 sec the roll motion of the cab was constant (i.e., the roll angle was not increasing). At approximately 1.10 sec the cab began a sudden redirection in roll motion. This time also signified the front of the cab reaching the end of the rail. At 1.16 sec, as the vehicle exited the bridge rail, the cab was experiencing counterclockwise roll, and the same positive yaw motion continued until 1.40 sec, which was the approximate time that the entire vehicle was free of the bridge rail.

A significant portion of the vehicle had extended over the bridge rail, although there was no physical evidence that the truck touched down behind the bridge rail. It is the authors' opinion that the vehicle would have still been contained had the installation length been longer because the vehicle had obtained a near stable position before reaching the end of the rail, and the positive yaw motion of the vehicle may have kept the vehicle from traveling over the rail. The vehicle may have come to rest on the rail or could have fallen back down onto the roadway.

The vehicle came to rest approximately 183 ft downstream from impact. The vehicle remained upright both during and after the collision. The vehicle trajectory after impact indicated no intrusion into the adjacent traffic lanes. The maximum vehicle rebound distance was 18 ft.



(a)

(b)

FIGURE 4 Damage to (*a*) bridge rail and (*b*) test vehicle, Test MS30-1.

Bridge rail damage is shown in Figure 4(*a*). Concrete spalling occurred at the point of impact as a result of the right front wheel crushing into the bridge rail. Spalling also occurred along the top of the rail as a result of the undercarriage of the vehicle sliding along the top of the rail. No visible lateral movement of the rail occurred as a result of the collision. Tire marks were visible on the face of the rail for a length of about 17 ft after impact.

Vehicle damage is shown in Figure 4(*b*). Most of the damage occurred to the undercarriage. The front axle assembly was disengaged from its original position. The right rear wheels were damaged, and the drive shaft was separated from the transmission. There was no intrusion or deformation of the occupant compartment.

The longitudinal occupant impact velocity (OIV) was determined to be 11.1 fps, and the lateral OIV was 9.7 fps. The highest 0.010-sec average occupant ridedown decelerations were 2.1 *g* (longitudinal) and 3.0 *g* (lateral). The results of the occupant risk, determined from accelerometer data, are summarized in Figure 5 and Table 2.

A summary of the test and sequential photographs are shown in Figure 5. Additional sequential photographs are shown in Figure 6. The performance of the bridge rail was determined to be satisfactory for this test.

Test MS30-2

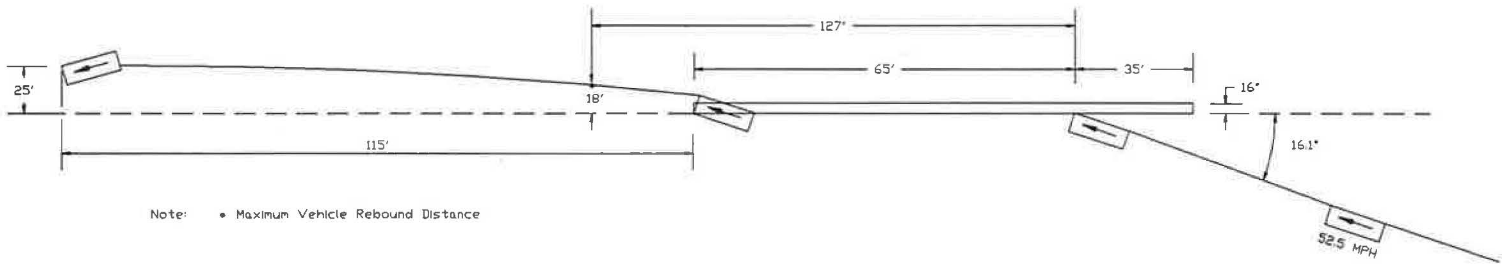
After the initial impact with the bridge rail (30 ft from the upstream end), the right front corner crushed inward, causing the corner of the hood to extend over the top of the rail. Following the initial impact, a counterclockwise rolling motion away from the bridge rail occurred. The vehicle became parallel with the bridge rail 0.15 sec after impact and exited at 0.28 sec, which was approximately 20 ft from impact. The continued counterclockwise roll caused the vehicle to become completely airborne at 0.31 sec. It was airborne until the left front wheel touched down at 0.60 sec. The touchdown signified the maximum roll angle; this angle could not be measured, however, because of technical difficulties with the downstream camera. The touchdown also caused the vehicle to roll clockwise toward the rail. The vehicle became level at 0.94 sec. It came to rest approximately 230 ft downstream from impact. The vehicle remained upright both during and after the collision, although moderate roll motion occurred during the test. Vehicle trajectory after impact indicated minimal intrusion into the adjacent traffic lanes. The maximum vehicle rebound distance was 9.5 ft.

The minor bridge rail damage is shown in Figure 7(*a*). The marks on the bridge rail indicated that the vehicle was in contact for approximately 12 ft. No visible lateral movement of the bridge rail occurred.

Vehicle damage is shown in Figure 7(*b*). The damage was mainly to the right front corner, consisting of wheel, bumper, fender, and axle damage. Slight buckling of the roof was also apparent. No intrusion or deformation of the occupant compartment occurred.

The longitudinal OIV was determined to be 11.9 fps, and the lateral OIV was 26.5 fps. The highest occupant ridedown decelerations were 5.5 *g* (longitudinal) and 9.0 *g* (lateral). The results of the occupant risk, determined from film anal-

Impact | 0.55 sec | 1.09 sec | 1.64 sec | 2.19 sec



· Test Number	MS30-1
· Date	4/15/91
· Installation	30 in. N.J. Safety Shape
· Total Length	100 ft
· Concrete Bridge Rail	
Material	Ne.Special Mix (47-B)
Length	100 ft
Weight	340 lb/ft
Area	2.27 ft^2
Height	30 in.
Lower Vertical Face	1 in.
Middle Inclined Surface	
Length	10 in.
Inclination	55 deg
Upper Inclined Surface	
Length	19 in.
Inclination	84 deg
Base Width	16 in.
Top Width	7 in.

· Vehicle Model	1986 Ford F-700
· Vehicle Weight	
Test Inertia	18,011 lb
Gross Static	18,011 lb
· Vehicle Impact Speed	52.5 mph
· Vehicle Exit Speed	NA
· Vehicle Impact Angle	16.1 deg
· Vehicle Exit Angle	NA
· Vehicle Snagging	None
· Effective Coef. of Friction	NA
· Vehicle Stability	Marginal
· Occupant Impact Velocity	
Longitudinal	11.1 fps
Lateral	9.7 fps
· Occupant Ridedown Deceleration	
Longitudinal	2.1 g's
Lateral	3.0 g's
· Vehicle Damage	
TAD	1-RFQ-3
VDI	01RFWS1
· Vehicle Rebound Distance	18 ft
Bridge Rail Damage	Minor Spalling

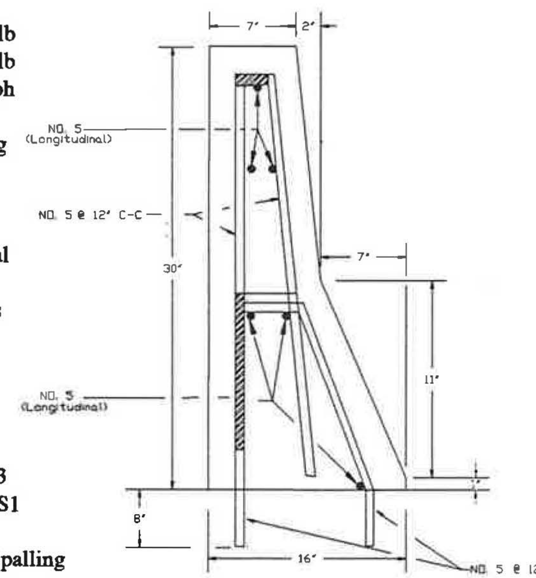


FIGURE 5 Summary and sequential photographs, Test MS30-1.

TABLE 2 Summary of Test Results

Test Item	Test MS30-1	Test MS30-2	Test MS30-3
Vehicle Weight (lb.)	18,011	1,759	5,460
Vehicle Impact Speed (mph)	52.5	62.5	63.5
Vehicle Exit Speed (mph)	NA	55.0	49.0
Vehicle Impact Angle (deg)	16.1	20.0	20.0
Vehicle Exit Angle (deg)	NA	6.6	6.0
Effective Coefficient of Friction	NA	0.11	0.37
Vehicle Rebound Distance (ft)	18.0	9.5	2.5
Vehicle Damage (TAD)	1-RFQ-3	1-RFQ-4	1-RFQ-4
Vehicle Damage (VDI)	01RFWS1	01RFES1	01RFES2
Occupant Impact Velocity (fps)			
Longitudinal	11.1	11.9	16.6
Lateral	9.7	26.5	14.3
Occupant Ridedown Decelerations (g's)			
Longitudinal	2.1	5.5	6.0
Lateral	3.0	9.0	6.6
Did Snagging Occur?	No	No	No

NA = Not Available

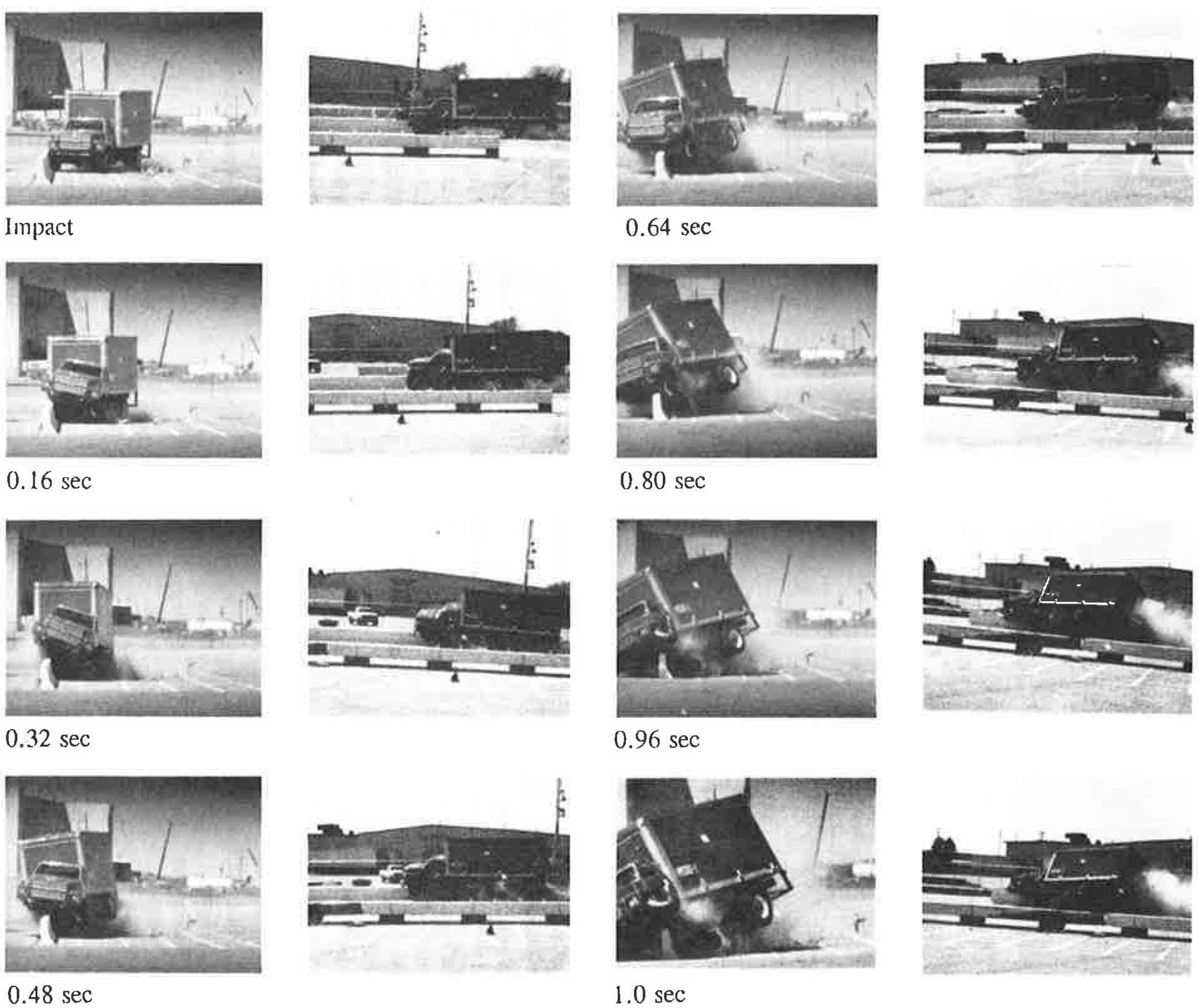
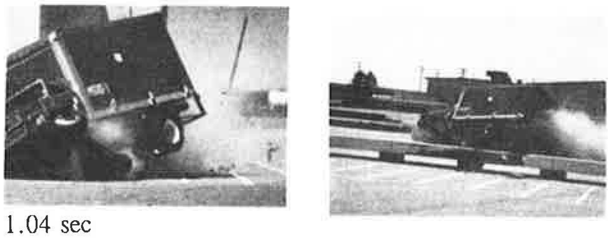
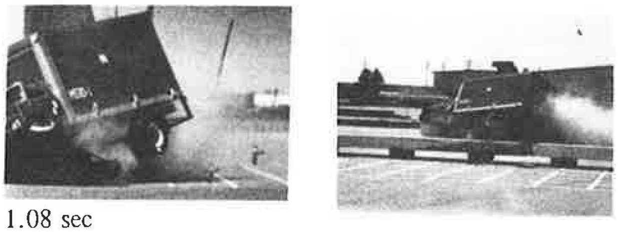


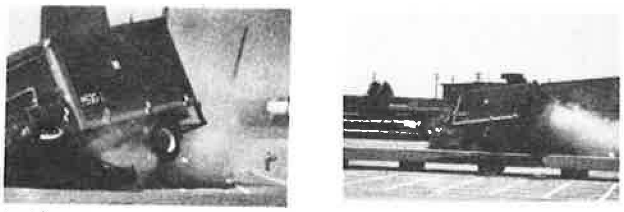
FIGURE 6 Parallel time sequential photographs, Test MS30-1 (***continued on next page***).



1.04 sec



1.08 sec



1.12 sec

1.16 sec

FIGURE 6 ***(continued).***

FIGURE 7 Damage to (*a*) bridge rail and (*b*) test vehicle, Test MS30-2.

ysis, are summarized in Figure 8, and Table 2. Because of technical difficulties in obtaining accelerometer data, the occupant risk values were determined from film analysis.

A summary of the test and sequential photographs are shown in Figure 8. Additional sequential photographs are shown in Figure 9. The performance of the bridge rail was determined to be satisfactory for this test.

Test MS30-3

After the initial impact with the bridge rail (25 ft from the upstream end), the right front corner of the truck was crushed inward. This maximum crushing distance was approximately 2 ft. At 0.13 sec after impact, the right front wheel began to climb up the rail. A parallel position with the bridge rail was obtained at 0.19 sec.

As the vehicle came out of the parallel position with the rail, the front wheels became airborne. At 0.49 sec, the left front wheel touched down, causing the vehicle to skid away from the rail. At 0.91 sec, the vehicle regained a parallel position with the bridge rail, having a lateral offset of approximately 5 ft. The vehicle came to rest approximately 203 ft downstream from the impact. The vehicle remained upright during and after the collision. The vehicle trajectory after impact indicated minimal intrusion into the adjacent traffic lanes. The maximum vehicle rebound distance was 5 ft.

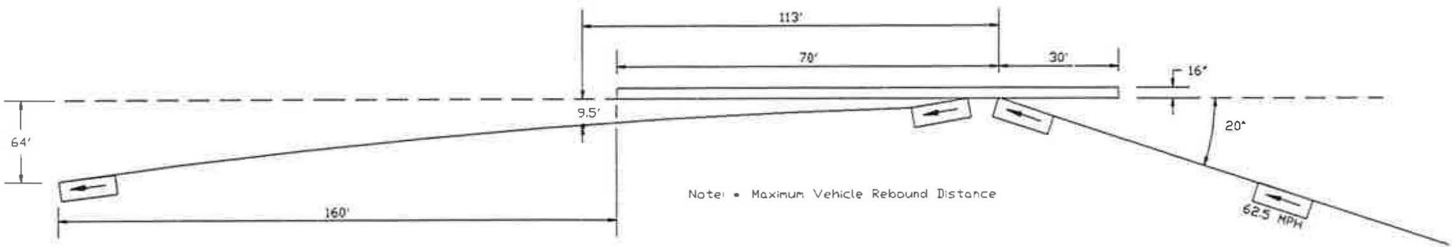
Bridge rail damage is shown in Figure 10(*a*). Damage was minimal. Tire marks and scrapes accounted for the majority of the damage. The marks on the rail were approximately 12 ft long. No visible lateral movement of the bridge rail occurred as a result of the collision.

Vehicle damage is shown in Figure 10(*b*). The damage was mainly to the right front corner of the vehicle. The passenger side door and rear wheel were also slightly damaged. The lower right corner of the windshield was also broken. There was no intrusion or deformation of the occupant compartment.

The longitudinal OIV was determined to be 16.6 fps and the lateral OIV was 14.2 fps. The highest 0.010-sec average occupant ridedown decelerations were 6.0 *g* (longitudinal) and 6.6 *g* (lateral). The results of the occupant risk, determined from accelerometer data, are summarized in Figure 11 and Table 2.

A summary of the test and sequential photographs are shown in Figure 11. Additional sequential photographs are shown

Impact | 0.31 sec | 0.63 sec | 0.94 sec | 1.25 sec



Test Number	MS30-2
Date	5/1/91
Installation	30 in. N.J. Safety Shape
Total Length	100 ft
Concrete Bridge Rail	
Material	Ne.Special Mix (47-B)
Length	100 ft
Weight	340 lb/ft
Area	2.27 ft^2
Height	30 in.
Lower Vertical Face	1 in.
Middle Inclined Surface	
Length	10 in.
Inclination	55 deg
Upper Inclined Surface	
Length	19 in.
Inclination	84 deg
Base Width	16 in.
Top Width	7 in.

Vehicle Model	1984 Dodge Colt
Vehicle Weight	
Test Inertia	1,759 lb
Gross Static	1,759 lb
Vehicle Impact Speed	62.5 mph
Vehicle Exit Speed	55.0
Vehicle Impact Angle	20.0 deg
Vehicle Exit Angle	6.6 deg
Vehicle Snagging	None
Effective Coef. of Friction	0.11
Vehicle Stability	Marginal
Occupant Impact Velocity	
Longitudinal	11.9 fps
Lateral	26.5 fps
Occupant Ridedown Deceleration	
Longitudinal	5.5 g's
Lateral	9.0 g's
Vehicle Damage	
TAD	1-RFQ-4
VDI	01RFES1
Vehicle Rebound Distance	9.5 ft
Bridge Rail Damage	Minor Spalling

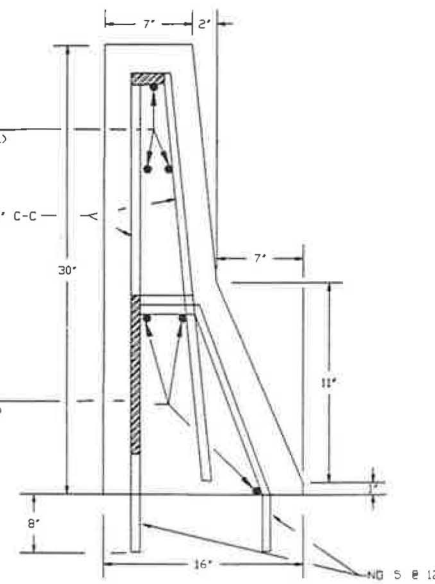


FIGURE 8 Summary and sequential photographs, Test MS30-2.

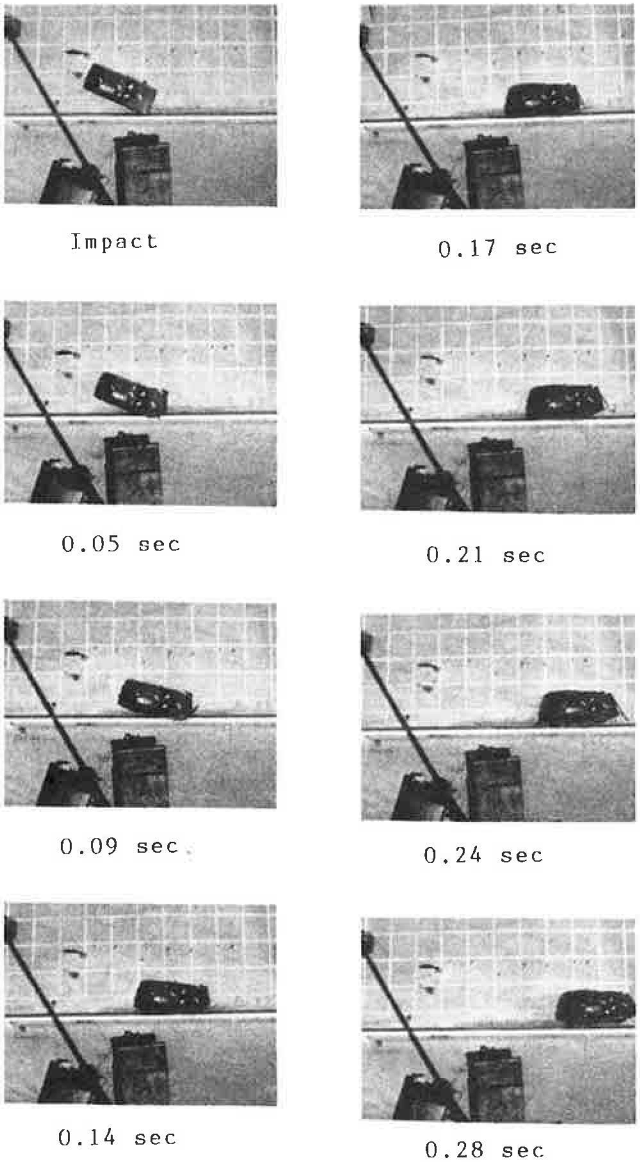


FIGURE 9 Overhead time sequential photographs, Test MS30-2.

in Figure 12. The performance of the bridge rail was determined to be satisfactory for this test.

CONCLUSIONS

The PL-2 performance level tests on the 30-in. New Jersey safety-shape bridge rail proved to be satisfactory according to the safety performance criteria given by AASHTO (*1*). The results of all three tests are summarized and presented in Table 2. The analysis of the tests revealed the following:

1. The bridge rail contained the vehicles without any visible lateral deflection, although a significant portion of the vehicle did protrude over the top of the bridge rail in Test MS30-1.
2. No detached elements or fragments penetrated the occupant compartments, and their integrity was maintained.

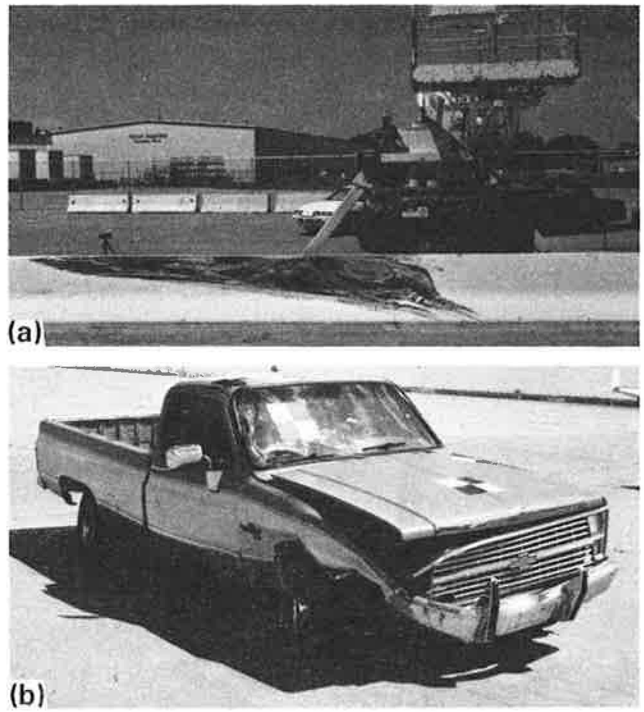


FIGURE 10 Damage to (*a*) bridge rail and (*b*) test vehicle, Test MS30-3.

3. The vehicles remained upright both during and after impact, although moderate roll did occur in Test MS30-2.
4. The redirection capability of the bridge rail was determined to be satisfactory.
5. The occupant ridedown decelerations were determined to be satisfactory.
6. The OIVs were determined to be satisfactory, although the OIV for Test MS30-2 was 5 percent greater than the design limit but less than the threshold.
7. The vehicles' exit angles and rebound distances were determined to be satisfactory.

DISCUSSION OF RESULTS

Current practice in state highway departments is to use concrete safety-shape bridge rails with either the standard New Jersey safety shape or the F shape. The standard New Jersey safety shape consists of a 32-in. concrete parapet with a 3-in. lower vertical face. The height above the roadway surface to the slope break point is 13 in. The F shape consists of a 32-in.-high concrete parapet with a 3-in. lower vertical face and a slope break point of 10 in. The Missouri 30-in. New Jersey safety shape consists of a concrete parapet with a 1-in. lower vertical face, and a slope break point of 11 in., which is similar to that of the F shape. This has been shown to reduce vehicle roll. These three bridge rails are shown in Figure 13.

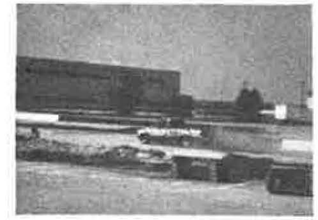
Past research results have shown that if the slope break point is higher than 13 in., the chances of vehicle rollover are increased, particularly for compact and subcompact automobiles (*7*). An example of this is the earlier General Motors

Impact

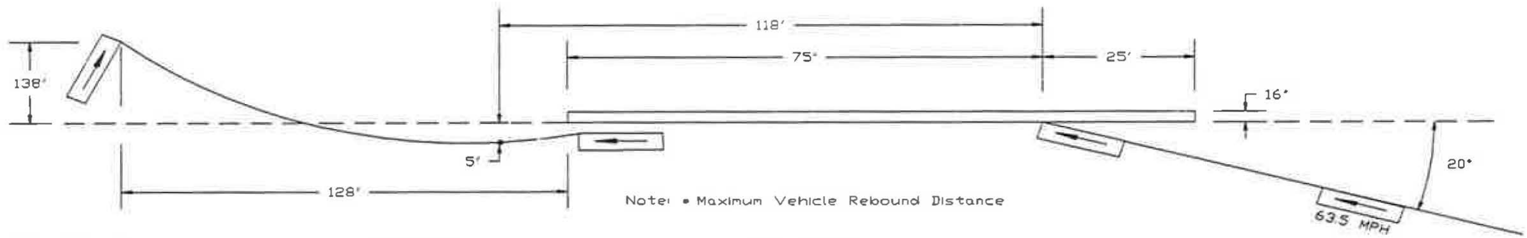
0.40 sec

0.78 sec

1.17 sec



1.52 sec



· Test Number	MS30-3
· Date	6/14/91
· Installation	30 in. N.J. Safety Shape
· Total Length	100 ft
· Concrete Bridge Rail	
Material	Ne.Special Mix (47-B)
Length	100 ft
Weight	340 lb/ft
Area	2.27 ft^2
Height	30 in.
Lower Vertical Face	1 in.
Middle Inclined Surface	
Length	10 in.
Inclination	55 deg
Upper Inclined Surface	
Length	19 in.
Inclination	84 deg
Base Width	16 in.
Top Width	7 in.

· Vehicle Model	1984 Chevy Silverado
· Vehicle Weight	
Test Inertia	5,460 lb
Gross Static	5,460 lb
· Vehicle Impact Speed	63.5 mph
· Vehicle Exit Speed	49.1 mph
· Vehicle Impact Angle	20.0 deg
· Vehicle Exit Angle	6.0 deg
· Vehicle Snagging	None
· Effective Coef. of Friction	0.37
· Vehicle Stability	Satisfactory
· Occupant Impact Velocity	
Longitudinal	16.6 fps
Lateral	14.2 fps
· Occupant Ridedown Deceleration	
Longitudinal	6.0 g's
Lateral	6.6 g's
· Vehicle Damage	
TAD	1-RFQ-4
VDI	01RFES2
· Vehicle Rebound Distance	5 ft
· Bridge Rail Damage	Minor Spalling

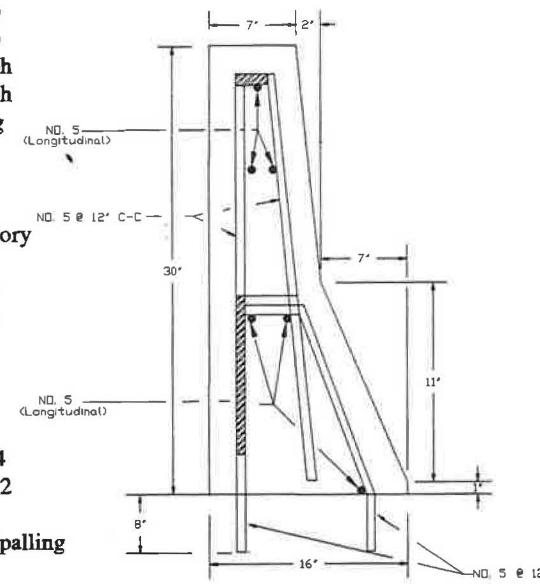


FIGURE 11 Summary and sequential photographs, Test MS30-3.

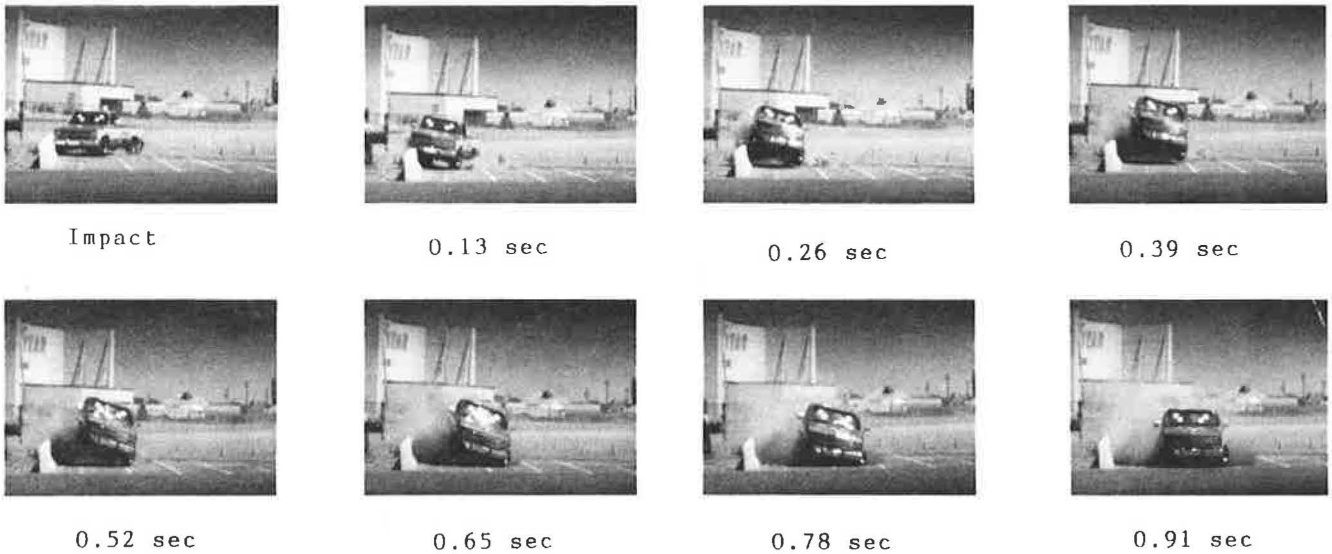


FIGURE 12 Parallel time sequential photographs, Test MS30-3.

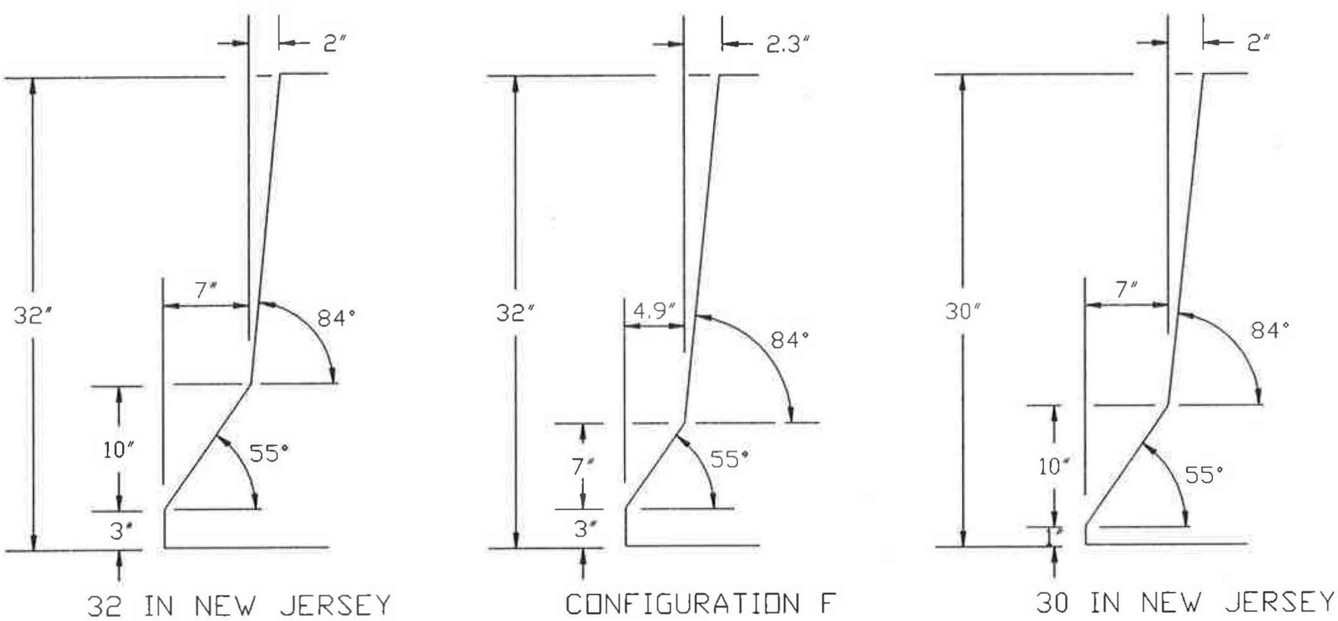


FIGURE 13 Geometric properties of safety-shape bridge rails.

shape, having a slope break point 15 in. above the roadway surface. This system is no longer recommended for use.

To help establish the validity of the 30-in. safety-shape bridge rail, a comparison of safety performance evaluations is presented against other AASHTO PL-2 safety-shape bridge rails (*8,9*). The tests were conducted on the 32-in. standard New Jersey safety-shape bridge rail and the 32-in. F-shape bridge rail. The comparison is shown in Table 3. It was evident that the safety performance results for these shapes and the 30-in. New Jersey safety shape provided similar results. One difference was that the 18,000-lb vehicle test on the 32-in. New Jersey safety shape (Test 7069-12) (*8*) resulted in vehicle rollover, whereas the 18,000-lb tests on the F safety shape (Test 7069-4) (*9*) and the 30-in. New Jersey safety shape (Test MS30-1) (*3*) did not result in vehicle rollovers. This may be explained by the differences in the geometry of the bridge railings, the make and model of the trucks, or even the location of impact.

From the four AASHTO PL-2 bridge railings reported in *Transportation Research Record 1258* (*8*), it was stated that test results indicate that a 32-in. vertical height would be a preferred minimum height. This statement was based upon the fact that only 32-in. bridge railings were tested. However, the authors did recognize that some innovative designs of a lesser height might be able to function in a suitable manner, but must be subjected to full-scale crash testing in order to prove their satisfactory performance. The adequacy of the 30-in. bridge rail was verified by full-scale crash testing. It was

TABLE 3 Comparison of PL-2 Bridge Rail Test Results

TEST ITEMS	TEST INSTALLATION AND TESTING FACILITY								
	32 in. New Jersey Safety Shape (Texas Transportation Institute) (8)			32 in. F-Shape (Texas Transportation Institute) (8)			30 in. New Jersey Safety Shape (Midwest Roadside Safety Facility) (3)		
	Tests Number and Dates			Test Numbers and Dates			Test Numbers and Dates		
	7069-12	3115-3[1]	7069-14	7069-11	7069-3	7069-4	MS30-1	MS30-2	MS30-3
	6/22/88	4/29/81	8/11/88	3/30/88	7/28/87	7/30/87	4/15/91	5/1/91	6/14/91
Vehicle (Year & Model)	1982 GMC SU Truck	1974 Honda	1981 Chevy PU	1982 Ford 7000 SUT	1980 Honda	1981 Chevy PU	1986 Ford F-700 SUT	1984 Dodge Colt	1984 Chevy PU
Vehicle Weight (Gross Static) lb.	18,000	1,968	5,724	18,000	1,966	5,780	18,011	1,759	5,460
Vehicle Impact Speed (mph)	51.6	61.3	57.7	52.1	60.1	65.4	52.5	62.5	63.5
Vehicle Impact Angle (deg)	15.5	20	20.6	14.8	21.4	20.4	16.1	20.0	20.0
Vehicle Exit Speed (mph)	NA	NA	35.8	NA	53.0	56.9	NA	55.0	49.0
Vehicle Exit Angle (deg)	2.0	7.0	.09	0.0	6.2	7.4	NA	6.6	6.0
Effective Coefficient of Friction	NA	NA	0.83	0.12	0.33	0.31	NA	0.11	0.37
Occupant Impact Velocity (fps)									
Longitudinal	13.4	NA	17.8	5.7	19.0	12.5	11.1	11.9	16.6
Lateral	10.2	NA	18.7	8.2	23.7	24.1	9.7	26.5	14.2
Occupant Ridedown Decelerations (g's)									
Longitudinal	3.0	4.4[2]	5.1	1.3	2.1	1.2	2.1	5.5	6.0
Lateral	4.9	10.6[2]	9.2	5.4	4.9	5.9	3.0	9.0	6.6

NA - Not Available
SUT - Single Unit Truck
PU - Pickup
[1] - Testing Performed at Dynamic Science, Inc. (9)
[2] - Maximum Deceleration (50 msec avg.)

the judgment of the authors that the 30-in. standard New Jersey safety-shape bridge rail met the AASHTO PL-2 performance level evaluation criteria. However this does not justify the reduction of heights for standard New Jersey or F-shape bridge railings. To do so would give up a margin of safety for little cost savings and would reduce the potential for safe performance after future overlays.

ACKNOWLEDGMENTS

This study was conducted under a cooperative program between the Midwest Roadside Safety Facility (MwRSF), the Missouri Department of Transportation, the Nebraska Department of Transportation, the Kansas Department of Transportation, the Midwest Transportation Center, and the University of Nebraska Center for Infrastructure Research. The crash tests were conducted by personnel at MwRSF under the direction of the late E. R. Post, to whom this paper is dedicated. This study was one of the last projects in which he was an active participant before his death.

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