Wyoming Tube-Type Bridge Rail and Box-Beam Guardrail Transition

KING K. MAK, ROGER P. BLIGH, AND DAVID H. POPE

The results of testing and evaluation of the current Wyoming steel tube-type bridge railing system and the development, testing, and evaluation of a box-beam guardrail transition for use with this bridge railing system are presented. The crash test results indicate that both the bridge railing and the box-beam guardrail transition retrofit design satisfy the guidelines set forth in *NCHRP Report 230*. The steel tube-type bridge railing is currently on the approved list of bridge railings for use on Federal-Aid projects. The box-beam guardrail transition is currently under review by FHWA for approval. The key advantages of this steel tube-type bridge railing are that it is aesthetically pleasing and that it allows the traveling public views of surrounding areas from the bridge deck. Its initial and maintenance costs are competitive. This type of railing does not present problems with drifting snow or clearing snow from roadways, commonly associated with concrete barriers. These problems are what prompted the development of the transition treatment so that the box-beam guardrail could be used in conjunction with the steel tube-type bridge rail.

The Wyoming steel tube-type bridge railing system has been used in the state since the early 1960s with only minor changes over the years. It is a low-profile, streamlined rail that is aesthetically pleasing and allows the traveling public views of surrounding areas from the bridge deck. The rail is versatile and has minimal maintenance costs. Replacement rail posts, rails, and hardware can be stockpiled, both by fabricators and in highway department maintenance yards, to expedite repairs to damaged rails. Experience indicates that the rail has performed well in the field. There has never been any penetration or vaulting over the rail, even when struck by tractor-semitrailers.

The rail's installed cost is competitive with the concrete alternatives installed on a limited basis throughout the state. One major problem encountered with concrete-type bridge railings, because of their closed nature, is that of drifting snow and clearing snow from roadways. The open nature of the structural steel, tube-type bridge railing does not present this problem. This bridge railing remains popular throughout the state.

The Wyoming State Highway Department contracted with Texas Transportation Institute (TTI) to crash test and evaluate this steel tube-type bridge railing (*1*) and, in a follow-up study (*2*), to develop a transition treatment from a box-beam guardrail to the steel tube-type bridge railing. The results of these two studies are presented.

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WYOMING TUBE-TYPE BRIDGE RAIL

Description of Bridge Rail and Installation

The Wyoming bridge rail consists of fabricated posts spaced 9 ft 3 in. apart with two TS 6 × 2 × 0.25 tube-type beams. The structural steel components of the bridge rail conform to the requirements of ASTM A 500 or ASTM A 501. The metal rail sits on top of a 6-in.-high curb for a total height of 29 in. above the pavement surface. The face of the curb was flush with the traffic face of the rails. The 77-ft bridge rail was installed on a simulated bridge deck of the same length, which was designed and constructed in accordance with standard bridge specifications used by the Wyoming State Highway Department. Photographs of the installation are shown in Figure 1.

Crash Testing and Evaluation

Two crash tests were conducted to evaluate the Wyoming bridge rail system:

1. Test S13—1,800-lb vehicle striking the bridge rail at 60 mph and 20 degrees.
2. Test 10—4,500-lb vehicle striking the bridge rail at 60 mph and 25 degrees.

A decision was made by the Wyoming Highway Department, after consultation with FHWA, to use Test S13 instead of Test 12 (1,800-lb passenger car striking the bridge rail at 60 mph and 15 degrees) as the small-car test. The rationale was that the 20-degree impact angle is a more severe test and provides a better assessment in terms of wheel snagging.

The crash test and data analysis procedures were generally in accordance with guidelines presented in *NCHRP Report 230* (*3*). The test vehicles were instrumented with three rate transducers to measure roll, pitch, and yaw rates and with a triaxial accelerometer near the vehicle center of gravity to measure acceleration levels. An uninstrumented 50-percentile male dummy was placed in the driver's seat for the 1,800-lb car test, but not for the 4,500-lb car test.

Test 1 (0368-1)

A 1979 Honda Civic struck the railing at 61.1 mph and 20.0 degrees. The point of impact was the center of the splice for the top rail, approximately 38 ft downstream from the begin-

FIGURE 1 Wyoming tube-type bridge rail.

ning of the bridge railing. The vehicle was smoothly redirected and exited from the rail at a speed of 49.7 mph and at an exit angle of 7.1 degrees. The vehicle was in contact with the rail for a total of 8.1 ft.

The rail sustained minor damage, as shown in Figure 2. The permanent residual deformation was 0.25 in. vertically and laterally for both the top and bottom rails. The only repair necessary after the test was to loosen the bolts attaching the rail elements to two posts and realign the rail elements.

The vehicle sustained moderate damage, considering the severity of the impact. As shown in Figure 2, the damage consisted primarily of sheet metal crushing along the front left side of the vehicle. Maximum crush was 7.0 in. at the left front corner of the vehicle. There was also damage to the left front strut assembly and tire rim. In addition, the left door became ajar and the window glass was broken.

Sequential photographs and a summary of the test results and other information pertinent to this test are given in Figure 3. The maximum 0.050-sec average acceleration experienced by the vehicle was $-8.0\ g$ in the longitudinal direction and $-16.5\ g$ in the lateral direction. Occupant impact velocities were 20.9 ft/sec and 30.9 ft/sec in the longitudinal and lateral directions, respectively. The highest 0.010-sec occupant ride-down accelerations were $-2.7\ g$ (longitudinal) and $-10.1\ g$ (lateral).

The lateral occupant impact velocity of 30.9 ft/sec was marginally higher than the limit of 30 ft/sec according to the guidelines on occupant risk criteria in *NCHRP Report 230*. However, once the occupant impact velocity is adjusted to account for the higher vehicle impact speed of 61.1 mph, it falls within the limit at 29.8 ft/sec. A comparison was made

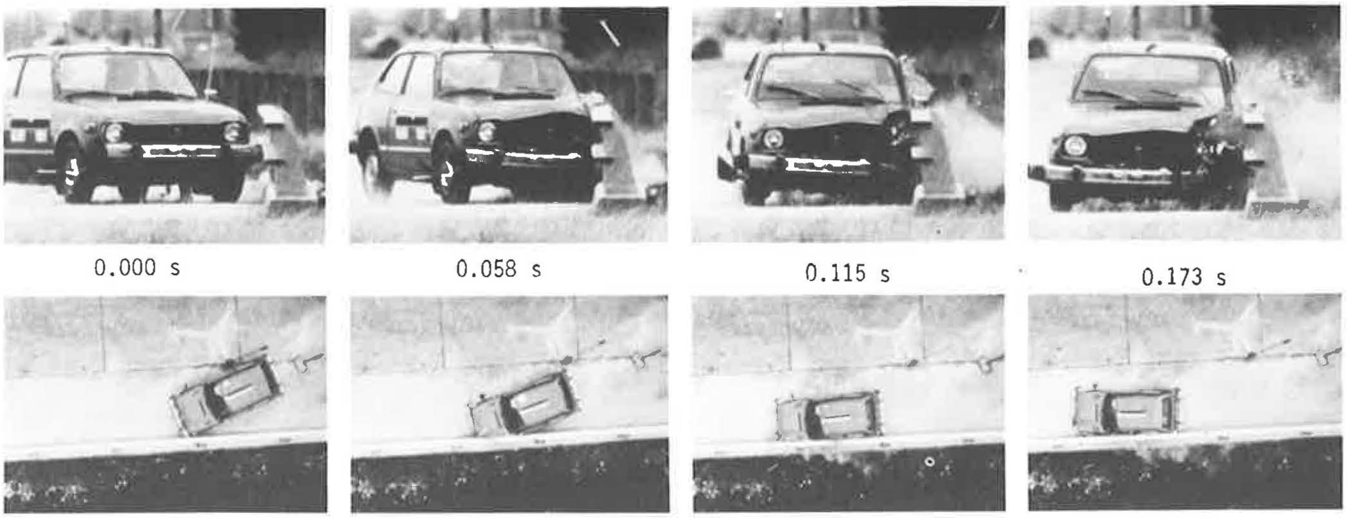
FIGURE 2 Barrier and vehicle damage after Test 0368-1.

with other bridge rails recently crash tested at TTI. For tests involving 1,800-lb passenger cars striking the bridge rails at 60 mph and 20 degrees, the lateral occupant impact velocities ranged from 23.7 to 30.3 ft/sec. Although the Wyoming tube-type bridge rail is at the high end of the spectrum, its performance is not considered to be significantly different from that of the other bridge rails. Given the rigid nature of bridge rails and the severe impact angle of 20 degrees, a relatively high lateral occupant impact velocity is to be expected.

The occupant risk criteria are not applicable to any of the four crash tests reported in this paper, in accordance with *NCHRP Report 230* requirements. The results are reported for information purposes only.

Test 2 (0368-2)

A 1979 Cadillac Sedan de Ville struck the railing at 63.3 mph and 25.0 degrees. The point of impact was midway between the posts for the span containing the splice for the top rail, approximately 40 ft downstream from the beginning of the rail. Although the deflated front tire and deformed sheet metal of the vehicle contacted the first post downstream from the impact point, the vehicle was smoothly redirected. The vehicle exited from the rail at a speed of 45.9 mph and an exit angle of 4.6 degrees. The vehicle was in contact with the rail for a total of 10.6 ft.



Test No	0368-1
Date.	02/09/88
Test Installation	Wyoming Tube-Type Bridge Rail
Length of Installation. . . .	77 ft (23.5 m)
Vehicle	1979 Honda Civic
Vehicle Weight	
Test Inertia.	1,800 lb (816 kg)
Gross Static.	1,968 lb (893 kg)
Vehicle Damage Classification	
TAD	11LFQ5
CDC	11FLES2 & 11LFES3
Maximum Vehicle Crush	7.0 in (17.8 cm)
Max. Perm. Rail Deformation .	0.25 (0.64 cm)

Impact Speed	61.1 mi/h (98.3 km/h)
Impact Angle	20.0 degrees
Exit Speed	49.7 mi/h (80.0 km/h)
Exit Angle	7.1 degrees
Vehicle Accelerations (Max. 0.050-sec Avg)	
Longitudinal	- 8.0 g
Lateral	-16.5 g
Occupant Impact Velocity	
Longitudinal	20.89 ft/s (6.4 m/s)
Lateral	30.89 ft/s (9.4 m/s)
Occupant Ridedown Accelerations	
Longitudinal	- 2.7 g
Lateral	-10.1 g

FIGURE 3 Summary of results for Test 0368-1.

The rail sustained minor damage, as shown in Figure 4. The permanent residual deformation was 1.25 in. vertically and 0.75 in. laterally for the bottom rail and approximately 0.50 in. both vertically and laterally for the top rail. Diagonal stress cracks were found on the concrete bridge deck around the post immediately downstream from the point of impact, and a small piece of concrete was broken off behind the post.

The vehicle sustained light to moderate damage, as shown in Figure 4. The front end of the car was shifted to the right and the subframe was bent. Maximum crush was 18.0 in. at the left front corner of the vehicle. The primary and secondary hood latches of the vehicle were disengaged by the impact, and part of the hood slid across the top of the top rail element.

Sequential photographs and a summary of the test results and other information pertinent to this test are given in Figure 5. The maximum 0.050-sec average accelerations experienced by the vehicle were -9.6 *g* in the longitudinal direction and -14.7 *g* in the lateral direction. Occupant impact velocities were 25.1 ft/sec and 29.5 ft/sec in the longitudinal and lateral directions, respectively. The highest 0.010-sec occupant ridedown accelerations were -5.8 *g* (longitudinal) and -12.2 *g* (lateral). Although not required for the evaluation of a transition test, the occupant impact velocities and ridedown accelerations were all within the acceptable limits.

The vehicle velocity change of 17.4 mph was higher than the limit of 15 mph recommended in *NCHRP Report 230*. However, because the exit angle of 4.6 degrees was substantially less than 60 percent of the impact angle and the vehicle trajectory indicated a minimal potential for intrusion into the adjacent traffic lanes, the 15 mph criterion was not considered applicable.

Summary

Results of the two crash tests indicate that the Wyoming steel tube-type bridge railing generally meets the guidelines set forth in *NCHRP Report 230*. The rail contained and smoothly redirected the vehicles with little lateral movement of the barrier. The vehicles sustained light to moderate damage with minimal deformation and intrusion into the occupant compartment. The vehicle trajectories at loss of contact with the rail indicate minimum potential for intrusion into the adjacent traffic lanes. The vehicles remained upright and stable during the initial test periods and after leaving the rail. This bridge railing is approved for use on Federal-Aid projects.

BOX-BEAM GUARDRAIL TRANSITION

As discussed in the previous section, the tube-type bridge rail was found to be in compliance with guidelines set forth in *NCHRP Report 230*. However, the exposed end of this bridge railing, like any rigid bridge railing, can present a serious

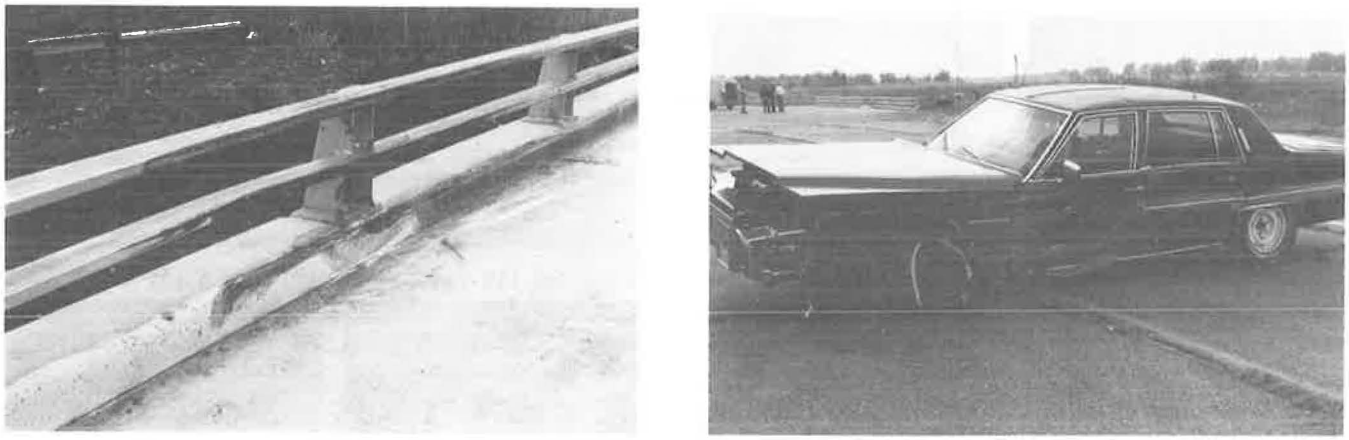
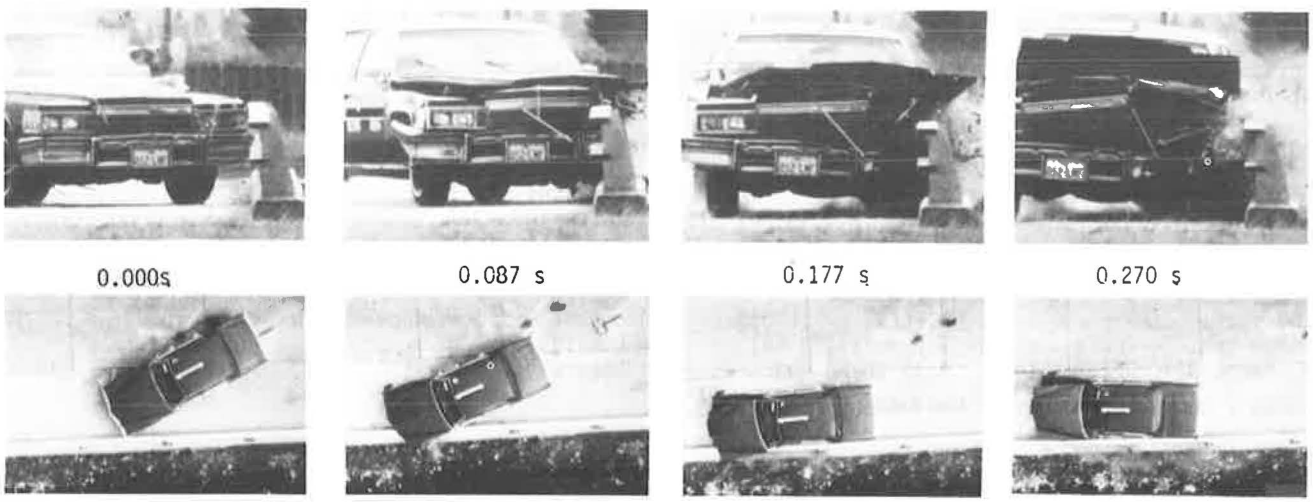


FIGURE 4 Barrier and vehicle damage after Test 0368-2.



Test No	0368-2
Date.	02/10/88
Test Installation	Wyoming Tube-Type Bridge Rail
Length of Installation. . . .	77 ft (23.5 m)
Vehicle	1979 Cadillac Sedan Deville
Vehicle Weight	
Test Inertia.	4,510 lb (2,045.7 kg)
Vehicle Damage Classification	
TAD	11LFQ6
CDC	11FLEK3 & 11LYES4
Maximum Vehicle Crush	18.0 in (45.7 cm)
Max. Perm. Rail Deformation .	1/25 (3.2 cm)

Impact Speed	63.3 mi/h (101.9 km/h)
Impact Angle	25.0 degrees
Exit Speed	45.9 mi/h (73.9 km/h)
Exit Angle	4.6 degrees
Vehicle Accelerations (Max. 0.050-sec Avg)	
Longitudinal	- 9.6 g
Lateral	-14.7 g
Occupant Impact Velocity	
Longitudinal	25.1 ft/s (7.7 m/s)
Lateral	29.5 ft/s (9.0 m/s)
Occupant Ridedown Accelerations	
Longitudinal	- 5.8 g
Lateral	-12.2 g

FIGURE 5 Summary of results for Test 0368-2.

safety hazard if improperly treated. In most instances, an approach roadside barrier is used to shield the exposed bridge railing end and to prevent errant vehicles from getting behind the railing and encountering underlying hazards. These approach guardrails are typically much more flexible than the bridge railings and can deflect sufficiently to allow an errant vehicle to strike or snag on the end of the rigid bridge railing. A transition section is therefore warranted whenever there is a significant change in lateral strength from the approach guardrail to the bridge rail.

A limited number of studies have addressed the transition problem and, consequently, few standards exist. In recent years, however, several acceptable guardrail-to-bridge-railing transition designs have been developed and tested (*4–6*). Although these designs have exhibited good impact performance, most of this research has focused on developing a transition from a strong-post W-beam guardrail to a rigid concrete parapet. Little, if any, analysis has been conducted on developing a transition from a weak-post box-beam guardrail to a steel tube-type bridge railing such as that used by Wyoming and other states.

Transition Development

The relatively high degree of flexibility of the box-beam guardrail (deflections of 5 to 6 ft are not uncommon for severe impacts) makes significant modifications necessary in developing a transition to a rigid bridge railing. The required increase in lateral barrier strength can be achieved by varying several key design parameters. These parameters include guardrail beam strength, post size or strength, and post spacing.

The major features of the basic transition design included a continuation of the lower TS 6 × 2 × 0.25 steel tube from the bridge rail onto the transition treatment and the use of stronger W 6 × 9 steel posts at a reduced post spacing near the bridge rail end. Computer simulation techniques were used to model this basic design and to evaluate various design alternatives, such as the number and spacing of the heavier posts.

Computer Simulation

The Barrier VII computer simulation model (*7*) was chosen for use in developing the new transition design. Despite its two-dimensional nature, the Barrier VII program has been successfully used to simulate impacts with a variety of flexible barriers, including transitions from flexible to rigid barriers (*4–6*). The program has been shown to be capable of accurately predicting barrier response under severe impact conditions. Further, for impacts into barriers on flat terrain, such as that found on the approach to a bridge, vehicle vaulting and underride are of little concern.

All simulations for this study involved impacts with a 4,500-lb vehicle traveling 60 mph at an angle of 25 degrees. This impact condition simulated Test 30 of *NCHRP Report 230*, which is the recommended test for evaluating the performance of a transition. This test examines the structural adequacy of the transition as well as the propensity for the more flexible barrier to deflect and allow a vehicle to snag on the end of the stiffer barrier.

The purpose of the computer simulations was to evaluate the effect of post size and spacing on barrier performance. The systems were compared on the basis of maximum dynamic barrier deflection and the extent of wheel contact estimated on the guardrail posts and bridge rail end. Because of the large deflections associated with their use, the weak S 3 × 5.7 posts had to be replaced in the transition region. Use of a stronger W 6 × 9 post was investigated for two different post spacings, 4 ft and 2 ft, near the bridge end. These post spacings were selected because Wyoming's current transition to the steel tube-type bridge railing uses a 4-ft post spacing. Thus, both of these spacings would provide for a simplified retrofit operation, which was considered an important factor in the transition development.

Table 1 summarizes the simulation results obtained when using W 6 × 9 steel posts with different post spacing. As indicated in Table 1, Barrier VII predicted various degrees of wheel contact for the two alternatives. Computer simulation models, such as Barrier VII, cannot simulate tire-post interactions, but they can be used to predict when wheel contact might occur. The extent of wheel contact is inferred from post deflections and wheel positions during the impact event.

Because tire-post interactions cannot be accurately simulated, it is difficult to determine how a vehicle's wheel will behave after such contact has occurred. Depending on the type and degree of contact, the tire may simply roll around or over the post, be pushed back into the wheel well, or rotate about the ball joint. The behavior of the wheel after initial contact will determine the extent of contact on subsequent posts. Wheel contact with the steel guardrail post, in itself, does not necessarily represent a severe safety hazard. By design, the box-beam guardrail readily detaches from its supporting posts. This leaves the steel posts unrestrained at the top and allows them to deform more readily on wheel contact. Furthermore, some wheel contact can be viewed as beneficial to vehicle stability and trajectory. When a wheel is damaged, the vehicle tends to remain adjacent to the barrier, thereby lending stability to the vehicle and preventing it from exiting into adjacent traffic lanes at a high angle. Thus, the design alternatives were evaluated not solely on whether or not post contact occurred, but also on the amount of contact predicted.

Numerous simulations were also made to analyze the behavior of the secondary transition from the standard box-beam guardrail to the transition section with the lower rail extended. The extension of the lower rail aids in the smooth transition of lateral stiffness from a weak-post box-beam guardrail to the strong-post transition treatment. Simulations also indicated that a 9-in. spacer or blockout should be used behind the guardrail post where the lower rail was terminated. This

TABLE 1 BARRIER VII RESULTS FOR TRANSITION USING W 6 × 9 STEEL POSTS WITH DIFFERENT POST SPACINGS

Post Spacing (ft)	Maximum Barrier Deflection (in)	Extent of Wheel Contact: Post 2* Contact (in)	Post 2* Rotation (deg)	Post 1 Contact (in)	Post 1 Rotation (deg)	Bridge Rail End Contact (in)	Bridge Rail End Rotation (deg)
4	12.3	NA	NA	4.0	12	-2.0	0
2	9.3	2.9	7	3.5	8.5	-4.5	0

* Intermediate post for 2-foot post spacing design

reduces the potential for snagging on the end of the lower tube when the barrier is struck upstream of the transition. Details of the final design are described below.

Final Design Selection

As indicated in Table 1, use of the 2-ft post spacing increases the lateral strength of the transition and thereby reduces the dynamic deflection of the rail by approximately 3 in. By decreasing the deflection, the probability of wheel contact on the rigid bridge rail post is reduced. On the other hand, use of the 2-ft post spacing introduces more posts into the vehicle's path and, therefore, the amount of significant wheel contact on the W 6 × 9 steel posts is increased. Post rotations are reduced because of the decrease in rail deflection, so the predicted snagging for this design has the potential for being more severe than that predicted for the 4-ft post spacing design. In addition, the 2-ft post spacing has the potential for collecting drifting snow and hindering snow-clearing operations. Taking into account the simulation results and the considerations mentioned, it did not appear that the closer post spacing was warranted. Thus, the 4-ft post spacing was selected for testing in the final design.

The final transition design uses two different rail elements. The upper TS 6 × 6 × 3/16 box beam is mounted at a height of 29 in. and is attached to the upper bridge rail element with a special tapered sleeve. The lower TS 6 × 2 × 0.25 steel tube is mounted at a height of 17 in. and is carried off the bridge a distance of 36 ft, at which point it is flared away from the roadway behind a guardrail post. A C 9 × 13.5 spacer is used to block out the lower rail from the post when it is terminated. Three standard S 3 × 5.7 posts extend into the transition at the standard post spacing of 6 ft 0 in. before switching to the heavier W 6 × 9 posts. The first space with the heavier posts remains at 6 ft 0 in., after which the spacing is reduced to 4 ft 0 in. near the bridge end. The end of the curb on the bridge deck is tapered back away from the roadway to help reduce the potential for wheel snagging.

Photographs of the test installation are shown in Figure 6.

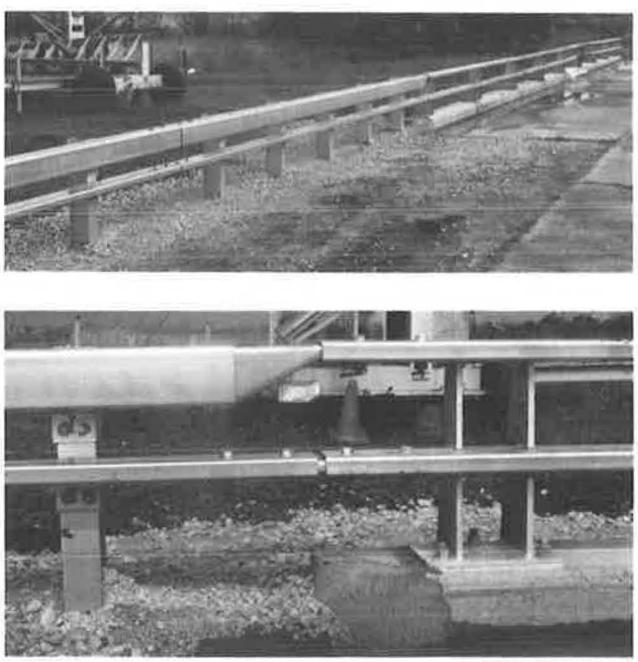


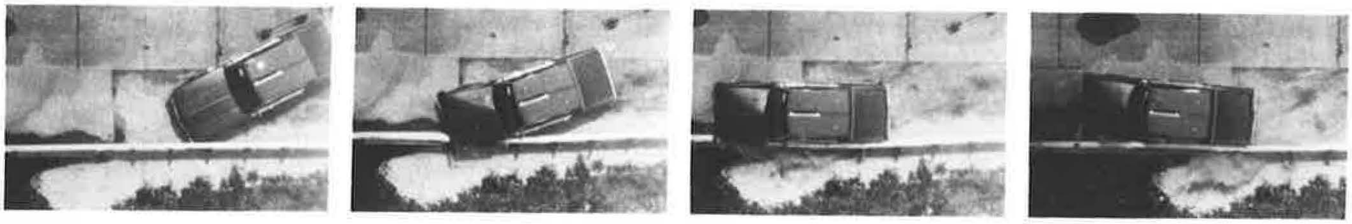
FIGURE 6 Wyoming bridge rail transition.

Crash Testing and Evaluation

According to *NCHRP Report 230* guidelines, one crash test (Test 30) is recommended for the evaluation of a transition installation. The test involves a 4,500-lb full-size automobile striking 15 ft (or at the most critical point) upstream of the second and more laterally stiff system at a speed of 60 mph and at an angle of 25 degrees. However, because of the design of this transition treatment, there are two transition points, one from the flexible weak-post box-beam guardrail to the semirigid transition treatment and the second from the semirigid transition treatment to the rigid bridge railing. Two full-scale crash tests were thus conducted, one for each of the two transition points.

Simulation runs using the Barrier VII program were conducted to determine the most critical point of impact for each of the two transition points. For the transition from the transition treatment to the bridge railing, the most critical impact point was determined to be approximately 9½ ft upstream from the first bridge rail post, or midspan of Posts 2 and 3 of the transition treatment. For the transition from the box-beam to the transition treatment, a distance of 15 ft upstream from the beginning of the transition treatment was found to be

FIGURE 7 Barrier and vehicle damage after Test 0382-1.



0.000 s 0.099 s 0.199 s 0.298 s

Test No.	0382-1
Date	07/11/89
Test Installation.	Wyoming Bridge Rail Transition
Installation Length . . .	168.3 ft (51.3 m)
Vehicle.	1980 Oldsmobile Ninety-Eight
Vehicle Weight	
Test Inertia	4,500 lb (2,043 kg)
Vehicle damage Classification	
TAD.	11LFQ-4 & 11LD-2
CDC.	11FLEK2 & 11LFES
Maximum Vehicle Crush. . .	12.0 in (30.5 cm)
Maximum Dynamic Rail Deflection.	12.0 in (30.5 cm)

Impact Speed	62.8 mi/h (101.1 km/h)
Impact Angle.	25.5 deg
Exit Speed.	44.4 (71.4 km/h)
Exit Trajectory	9.7 deg
Vehicle Accelerations (Max. 0.050-sec Avg)	
Longitudinal.	-8.4 g
Lateral	-12.6 g
Occupant Impact Velocity	
Longitudinal.	28.0 ft/s (8.5 m/s)
Lateral	27.7 ft/s (8.4 m/s)
Occupant Ridedown Accelerations	
Longitudinal.	-6.1 g
Lateral	-14.2 g

FIGURE 8 Summary of results for Test 0382-1.

most critical. As it turned out, this point corresponded to a rail splice connection for the box beam.

Test 3 (0382-1)

A 1980 Oldsmobile Ninety-Eight struck the transition installation 9½ ft upstream of the first bridge rail post at 62.8 mph and 25.5 degrees. The vehicle was smoothly redirected, although the front of the vehicle did partially strike the first bridge rail post (i.e., the post immediately downstream of the transition). The vehicle exited the installation at a speed of 44.4 mph and an exit angle of 9.7 degrees.

The transition installation and bridge railing sustained moderate damage, as shown in Figure 7. The first post in the transition (i.e., Post 1 immediately upstream of the bridge railing end) became completely detached from the upper and lower rails and was displaced a maximum of 4.0 in. rearward and 7.0 in. laterally. Maximum permanent rail deformation was 5.0 in. for the upper rail at the first transition post and 4.8 in. for the lower rail at the second post in the transition. The maximum dynamic rail deflection was 12 in. Maximum displacement at the first bridge rail post was 3.8 in.

Damage to the vehicle is shown in Figure 7. The damaged areas included the left side of the vehicle and the left front tire and rim. The left front wheel was pushed rearward a total of 9.5 in., causing the floor of the passenger compartment to be deformed slightly. The maximum crush was 12.0 in. at the front left corner of the vehicle.

Sequential photographs and a summary of the test results and other information pertinent to this test are given in Figure 8. The maximum 0.050-sec average accelerations experienced by the vehicle were -8.4 *g* in the longitudinal direction and -12.6 *g* in the lateral direction. Occupant impact velocity was 28.0 ft/sec in the longitudinal direction and 27.7 ft/sec in lateral direction. The maximum 0.010-sec occupant ridedown accelerations were -6.1 *g* (longitudinal) and -14.2 *g* (lateral). Although not required for the evaluation of a transition test, the occupant impact velocities and ridedown accelerations were all within the maximum acceptable limits.

The vehicle velocity change of 18.4 mph was higher than the limit of 15 mph recommended in *NCHRP Report 230*. However, because the exit angle of 9.7 degrees was substantially less than 60 percent of the impact angle and the vehicle trajectory indicated a minimal potential for intrusion into the adjacent traffic lanes, the 15-mph criterion was not considered applicable.

Test 4 (0382-2)

A 1981 Oldsmobile Ninety-Eight struck the box-beam guardrail 15 ft upstream from the beginning of the transition treatment at 61.3 mph and 27.2 degrees. The vehicle was smoothly redirected. As is typical of a flexible weak-post barrier system, the top box-beam rail separated from the posts at the clip angles on impact, and the vehicle contacted the posts and pushed them down. As the front of the vehicle approached the end of the lower rail attached behind the ninth post in the transition, the lower rail detached from its posts, allowing the vehicle to push it down and ride over it. As the vehicle proceeded down the rail, the lower rail continued to separate from the posts at the clip angles. The vehicle exited the rail traveling at 40.5 mph at a shallow angle.

The box-beam guardrail and transition treatment sustained only minor damage, as shown in Figure 9. The first seven posts downstream from the point of impact (Posts 5 through 9 of the transition treatment and Posts 10 and 11 of the box-beam guardrail) were bent over and separated from the upper and lower rails. The next four posts (Posts 1 through 4 of the

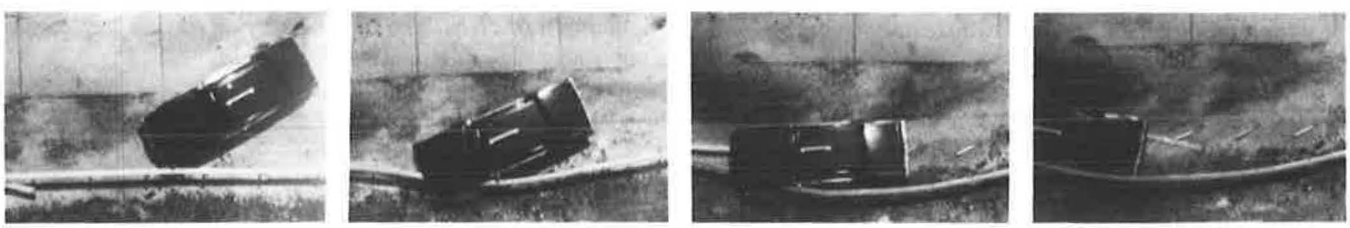
FIGURE 9 Barrier and vehicle damage after Test 0382-2.

transition) remained upright, and the upper rail remained attached to these posts. Post 6 of the transition was completely pulled out from the soil. Maximum dynamic rail deflection was 5.8 ft at the eighth post of the transition. The vehicle remained in contact with the guardrail and transition treatment for a distance of approximately 62 ft.

The vehicle sustained only minor damage, as indicated in Figure 9. The damage was confined to the left side of the vehicle and the left front tire and rim. The maximum crush was 12.5 in. at the front left corner of the vehicle. Although slightly damaged, the left front wheel was not displaced rearward.

Sequential photographs and a summary of the test results and other information pertinent to this test are given in Figure 10. The maximum 0.050-sec average accelerations experienced by the vehicle were $-4.4\,g$ in the longitudinal direction and $-4.8\,g$ in the lateral direction. Occupant impact velocity was 21.1 ft/sec in the longitudinal direction and 16.3 ft/sec in the lateral direction. The maximum 0.010-sec occupant ridedown accelerations were $-8.0\,g$ (longitudinal) and $-8.1\,g$ (lateral). Although not required for the evaluation of a transition test, the occupant impact velocities and ridedown accelerations were all within the maximum acceptable limits.

The vehicle velocity change of 20.8 mph was higher than the limit of 15 mph recommended in *NCHRP Report 230*. However, the exit angle was very shallow and substantially less than 60 percent of the impact angle, and the vehicle trajectory indicated a minimal potential for intrusion into the adjacent traffic lanes. The 15 mph criterion was therefore not considered applicable.



0.000 s　0.170 s　0.340 s　0.510 s

Test No.	0382-2
Date	07/12/89
Test Installation.	Wyoming Bridge Rail Transition
Installation Length. . . .	168.3 ft (51.3 m)
Vehicle.	1981 Oldsmobile Ninety-Eight
Vehicle Weight	
Test Inertia	4,500 lb (2,043 kg)
Vehicle damage Classification	
TAD.	11LFQ-4 & 11LD-2
CDC.	11FLEK2 & 11LFES1
Maximum Vehicle Crush. . .	12.5 in (31.8 cm)
Maximum Dynamic Rail Deflection.	5.8 ft (1.8 m)

Impact Speed	61.3 mi/h (98.6 km/h)
Impact Angle.	27.2 deg
Exit Speed.	N/A
Exit Trajectory	N/A
Vehicle Accelerations (Max. 0.050-sec Avg)	
Longitudinal.	-4.4 g
Lateral	-4.8 g
Occupant Impact Velocity	
Longitudinal.	21.1 ft/s (6.4 m/s)
Lateral	16.3 ft/s (5.0 m/s)
Occupant Ridedown Accelerations	
Longitudinal.	-8.0 g
Lateral	-8.1 g

FIGURE 10 Summary of results for Test 0382-2.

TABLE 2 SUMMARY OF CRASH TEST RESULTS AND EVALUATION CRITERIA

Evaluation Factors		Evaluation Criteria	Bridge Rail Test 1	Bridge Rail Test 2	Transition Test 3	Transition Test 4
Structural Adequacy	A.	Test article shall smoothly redirect the vehicle; the vehicle shall not penetrate or go over the installation although controlled lateral deflection of the test article is acceptable.	Yes	Yes	Yes	Yes
	D.	Detached elements, fragments or other debris from the test article shall not penetrate or show potential for penetrating the passenger compartment or present undue hazard to other traffic.	Yes	Yes	Yes	Yes
Occupant Risk	E.	The vehicle shall remain upright during and after collision although moderate roll, pitching and yawing are acceptable. Integrity of the passenger compartment must be maintained with essentially no deformation or intrusion.	Yes	Yes	Yes	Yes
	F.	Impact velocity of hypothetical front seat passenger against vehicle interior, calculated from vehicle accelerations and 24 in. forward and 12 in. lateral displacements, shall be less than:				
		Occupant Impact Velocity:				
		Longitudinal: Limit - 40 fps, Desirable - 30 fps	20.9	25.1	28.0	21.1
		Lateral: Limit - 30 fps, Desirable - 20 fps	30.9*	29.5	27.7	16.3
		and vehicle highest 10 ms average accelerations subsequent to instant of hypothetical passenger impact should be less than:				
		Occupant Ridedown Accelerations:				
		Longitudinal: Limit - 20 g's, Desirable - 15 g's	- 2.7	- 5.8	- 6.1	- 8.0
		Lateral Limit - 20 g's, Desirable - 15 g's	-10.1	-12.2	-14.2	- 8.1
Vehicle Trajectory	H.	After collision, the vehicle trajectory and final stopping distance shall intrude a minimum distance, if at all, into adjacent traffic lanes.	Yes	Yes	Yes	Yes
	I.	In test where the vehicle is judged to be redirected into or stopped while in adjacent traffic lanes, vehicle speed change during test article collision should be less than 15 mph and the exit angle from the test article should be less than 60 percent of test impact angle, both measured at time of vehicle loss of contact with test device.				
		Vehicle Speed Change: Limit - 15 mph	11.4	17.4**	18.4**	20.8**
		Exit Angle: Less than 60 Percent of Impact Angle (12° for 20° impact angle and 15° for 25° impact angle)	7.1	4.6	9.7	N/A***

* The 30.9 fps lateral occupant impact velocity was marginally higher than the limit of 30 fps. However, once the occupant impact velocity is adjusted to account for the higher vehicle impact speed of 61.1 mph, it would fall within the limit at 29.8 fps.

** The limit of 15 mph speed change is considered as not applicable if the vehicle exit angle is less than 60 percent of the impact angle and the vehicle trajectory does not pose any potential hazard to vehicles in adjacent traffic lanes.

*** The vehicle exit angle was not available since the vehicle was out of the overhead camera's view at the point of exit. However, review of other camera angles indicated that the exit angle would be less than 60 percent of the impact angle.

Summary of Results of Crash Tests

Results of the two crash tests indicate that the Wyoming transition treatment from a standard box-beam guardrail to the steel tube-type bridge rail generally meets with the guidelines set forth in *NCHRP Report 230*. The rail contained and smoothly redirected the vehicle in both crash tests. There was minimal deformation or intrusion into the vehicle occupant compartment. The vehicle exit angle and trajectory indicated minimal potential for intrusion into adjacent traffic lanes. In addition, the vehicle remained upright and stable during the initial test period and after exiting the rail installation.

SUMMARY

The results of testing and evaluation of the current Wyoming steel tube-type bridge railing system and the development, testing, and evaluation of a box-beam guardrail transition for use with this bridge railing system were presented. The crash test results, as summarized in Table 2, indicate that both the bridge railing and the box-beam transition generally satisfy the guidelines set forth in *NCHRP Report 230*. The steel tube-type bridge railing is currently on the approved list of bridge railings for use on Federal-Aid projects. The box-beam guardrail transition is currently under review by FHWA for approval.

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