Crash Tests of a Retrofit Thrie Beam Bridge Rail and Transition

DORAN L. GLAUZ, ROGER L. STOUGHTON, AND J. JAY FOLSOM

Two crash tests each were performed on a Thrie beam bridge rail and on the adjoining transition section to the approach guardrail. The bridge rail was designed (a) as a retrofit to replace the rail portion of an inadequate bridge rail supported on W6X15.5 steel posts at 6 ft 3-in. spacing, or (b) as a completely new barrier installed using resin capsule anchors to attach the posts to the edge of an existing bridge deck. The transition uses the same rail element, a 10-gauge Thrie beam, supported on standard wood posts. The tests performed approximated those required for a PL-1 bridge rail outlined in the 1989 American Association of State Highway and Transportation Officials *Guide Specifications for Bridge Railings*. The bridge rail was struck by a 5,400-lb pickup truck at 44.9 mph at an angle of 21 degrees and a 1,830-lb car at 48.7 mph at an angle of 18¼ degrees. The transition was hit by a 5,400-lb pickup truck at a speed of 44.7 mph at an angle of 18 degrees and a 1,930-lb car at 49.1 mph at an angle of 20¾ degrees. The crash tests satisfied the requirements for structural adequacy, occupant risk, and vehicle trajectory in *National Cooperative Highway Research Program Report 230* as well as the evaluation criteria in the American Association of State Highway and Transportation Officials guide specification.

There are many old bridge rails in service that do not meet modern standards of crashworthiness. These are mostly on narrow bridges on rural low-volume roads that have low speed limits. One common type in California, with more than 1,000 now in service, is a W-section metal beam and steel post bridge rail (Figure 1). This railing was crash tested in 1959 with a 4,000-lb vehicle/55 mph/30 degrees test condition (*1*). The concrete deck failed at the post connection, the rail pocketed and deflected 50 in., and the car was trapped and stood up almost on end. If there had been no earth support beyond the simulated deck, the vehicle would have continued through the rail and off the deck.

On federally funded local projects to upgrade old bridges, the Federal Highway Administration (FHWA) has required that bridge rails be replaced or retrofitted with designs that have been crash tested successfully under *National Cooperative Highway Research Program Report 230* (*2*) and the American Association of State Highway and Transportation Officials (AASHTO) *Guide Specifications for Bridge Railings* (*3*). The recently published AASHTO guide specifications for the first time provide for crash testing of "Performance Level One (PL1)" rails. PL1 rails are intended for local roads.

The Caltrans designers wanted a retrofit bridge rail design that would meet PL1 crash test requirements, that would eliminate deficiencies in the old design, and that would be simple and inexpensive to install.

California Department of Transportation, P.O. Box 19128, 5900 Folsom Boulevard, Sacramento, California 95819.

SCOPE OF RESEARCH

Two crash tests were performed on a Thrie beam bridge rail and on a transition to that rail. The tests followed the AASHTO *Guide Specifications for Bridge Railings* (*3*) for a performance level one bridge rail. The tests were conducted and evaluated using the criteria in *National Cooperative Highway Research Program Report 230* (*2*) and the AASHTO guide specifications (*3*). Intended impact conditions are shown in Table 1.

BRIDGE RAIL AND TRANSITION DESIGN

The Thrie beam bridge rail consisted of a 10-gauge Thrie beam rail blocked out and mounted with a top-of-rail height of 32 in. on W 6 × 15.5 steel posts (Figure 2). The designers favored a strong conservative rail and replaced the old 12-gauge W-section rail with a 10-gauge Thrie beam. This would limit rail deflection in impacts and keep vehicles from traveling many inches over the edge of the deck. The use of the Thrie beam raised the top of the rail height from 27 in. to 32 in. A rail height of 27 in. was set many years ago for passenger cars. In recent years, increased numbers of vans, pickup trucks, and other passenger vehicles with centers of gravity that are 6 or more in. higher than passenger cars travel the highways. The Thrie beam, with a height of 20 in., should accommodate a wider range of vehicle heights better than the old 12¼-in. W-section rail. Steel blockouts were used to (a) extend the

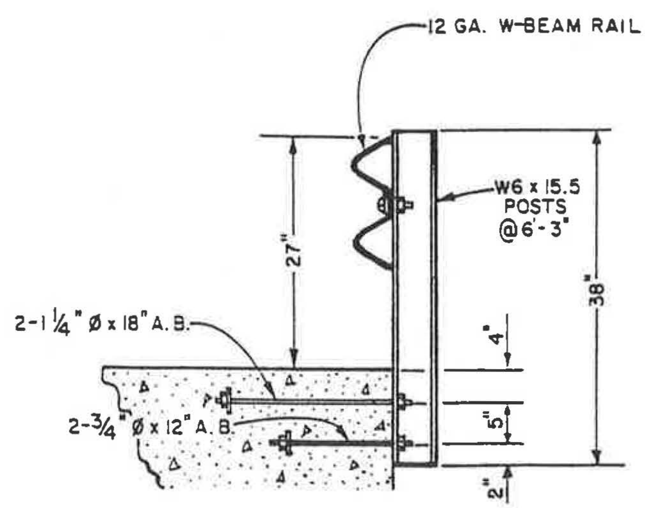


FIGURE 1 Metal bridge rail, 1959.

TABLE 1 TEST VEHICLES: IMPACT CONDITIONS

Test #	Target Weight (lbs)	Target Speed (mph)	Target Angle (deg)	Make	Model	Year	Weight (lbs)	Seat Belt?
473	5400	45	20	Chevrolet	Pick up	1983	5400	no
474	1800	50	20	Chevrolet	Spectrum	1986	1770	no
475	5400	45	20	Chevrolet	Pick up	1983	5400	yes
476	1800	50	20	Chevrolet	Spectrum	1987	1930	no

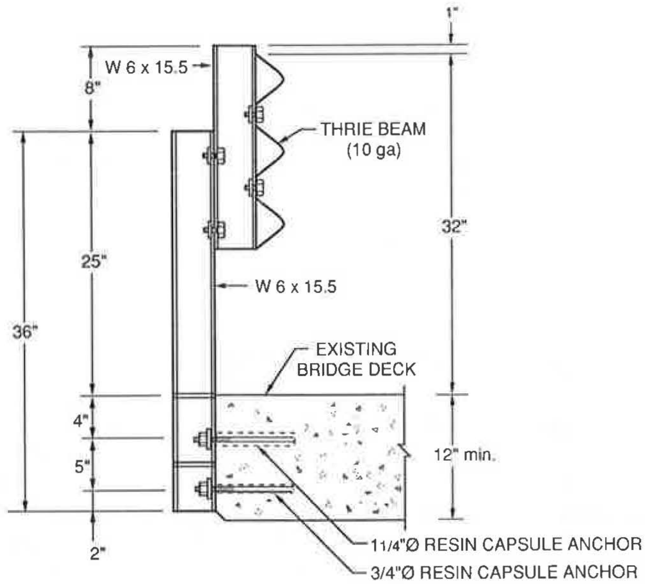


FIGURE 2 Thrie beam bridge rail cross section.

effective height of the post so that the Thrie beam could be used on the existing short posts, and (b) set the rail away from the posts to minimize the potential of snagging vehicles on the posts during impacts. Stiffener plates were welded to the posts at deck level to ensure good bending strength. (Alternate post designs will be tested statically in a follow-on project to try to eliminate the stiffeners.) Many existing bridge rails have inadequate post anchor bolts. Chipping out the deck so that new anchor bolts could be embedded would be costly. Therefore, resin anchor capsules with A307 threaded rod were installed in drilled holes in the simulated deck for the test barrier. If these proved strong enough, the concrete edge of the deck would not need to be replaced in retrofit jobs. A standard backup plate was mounted between the rail and steel block at posts in which there was no splice. The rail elements were mounted to the blocks with two ⅝-in. button head bolts. The blocks were mounted to the posts with two ⅝-in. hex head bolts.

The bridge approach transition is a 10-gauge Thrie beam, 12 ft 6 in. long supported on three 6-ft-long 6 × 8-in. Douglas fir posts and blocks and one bridge rail post (Figure 3). The posts nearest to the bridge rail are spaced at 3 ft 1½ in. and the third post is 6 ft 3 in. from the second. The approach transition is then connected to a standard metal beam guardrail using a standard W-beam to the Thrie beam transition piece. The guardrail is terminated with a breakaway cable terminal (Figure 4). The total minimum length of the transition, guardrail, and terminal is 50 ft. The terminal end is laid out on a 37.5-ft parabola with a 4-ft offset.

The tested bridge rail was 74 ft 9 in. long supported by 13 posts at 6 ft 3 in. on center. The third space (between Posts 3 and 4) was 6 ft to avoid existing anchor bolts used in the previous tests. The posts were mounted to the side of a simulated bridge deck using resin capsule anchors. Holes for the anchors were drilled with diamond core drills. Transition and terminal posts were set in strong soil.

Test Vehicles

All vehicles used in these tests were in good condition and free of any major body damage or missing parts. They had front-mounted engines and automatic transmissions. The vehicle models and weights are shown in Table 1. The trucks were ballasted to 5,400 lb with 50-lb steel plates mounted on the truck bed using 1-in.-diameter bolts. The small cars had front wheel drive. The vehicles were self powered in all tests.

Test Dummy

For each test an anthropomorphic dummy, 50th percentile American male, 165 lb, was placed in the driver's seat. It was

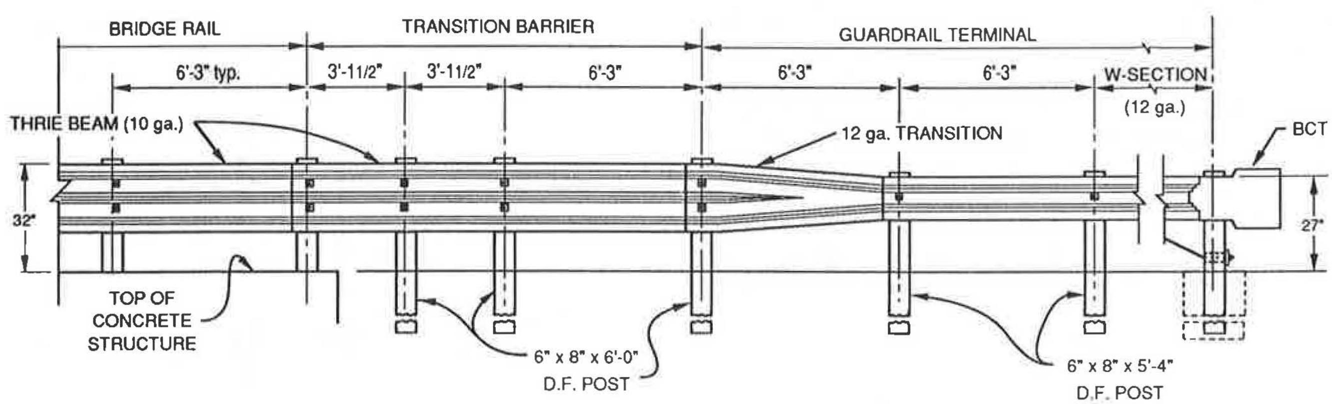


FIGURE 3 Bridge rail and transition elevation.

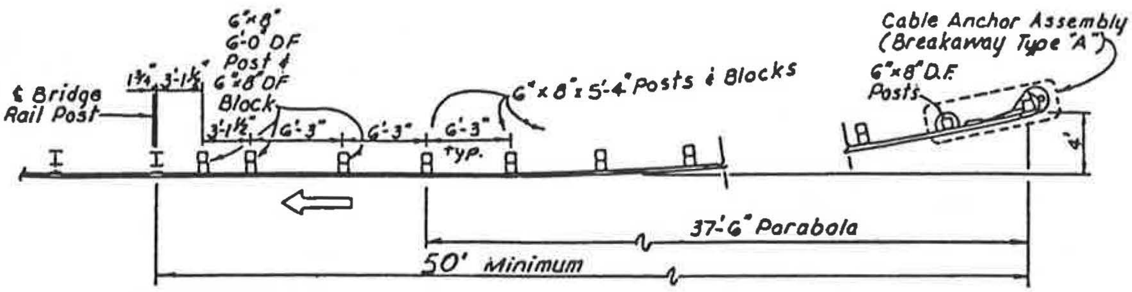


FIGURE 4 Approach guardrail layout (no scale).

unrestrained except in test 475. A set of three mutually perpendicular accelerometers was installed in the dummy's head.

Test Instrumentation

Test vehicles were instrumented with two sets of three accelerometers (independently recorded) and rate gyros near the center of gravity of the vehicle. Potentiometers were attached to the top of posts in the impact area. They measured the dynamic deflection of the posts during impact. Several high-speed cameras were used to record the impact.

TEST RESULTS

Test 473

Test Description

The right front bumper of the test vehicle struck the bridge rail near the midpoint between Posts 4 and 5 at a speed of 44.9 mph at an impact angle of 21 degrees. Vehicle contact with the Thrie beam began 2.7 ft downstream from Post 4 and continued for a length of about 16 ft (Figure 5). The vehicle was smoothly redirected, without exhibiting any tendency for the front wheel to snag on a post or wedge under the rail, and lost contact with the barrier at an exit angle of 6¼ degrees. The maximum roll was 10 degrees. The vehicle stopped on a safety berm about 140 ft downstream from impact and 37 ft in front of the face of the rail. It was lightly damaged (Figure 6).

Bridge Rail Damage

Post and rail damage were limited to the impact area. The permanent lateral deflection of the rail measured at the posts ranged from ⅛- to 9⁄16-in. deflection in a smooth long curve between Posts 2 and 9 (Figure 7). The displacements of each of the posts is shown in Table 2. The maximum dynamic lateral movement was 10.9 in.

On Posts 4, 5 ,6, and 7, the washers at the top mounting studs that attached the posts to the deck were pulled into the holes in the posts as the post flange was pushed around the nuts. The web was buckled at the bottom of Posts 4, 5, 6, and 7 (Figure 8). At Posts 5 and 6, the flange fractured at the upper mounting stud holes.

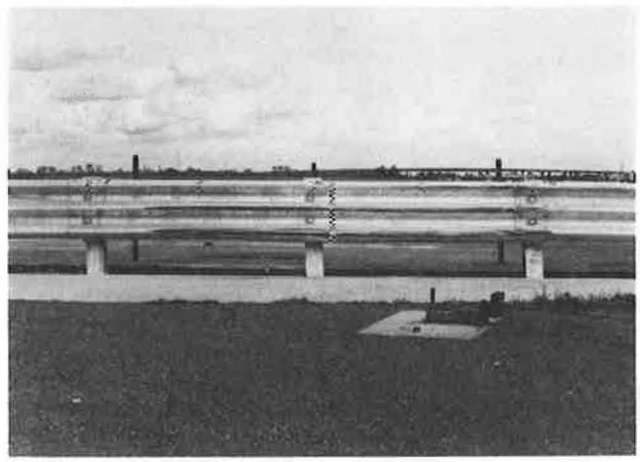


FIGURE 5 Vehicle contact marks, Test 473.

FIGURE 6 Vehicle after Test 473.

Dummy Response

During the collision, the unrestrained dummy was thrown to the right. Its shoulder hit the right door, and bent the top of the door outward. The dummy's final position was lying on its back across the passenger floor area with its legs wedged under the steering wheel.

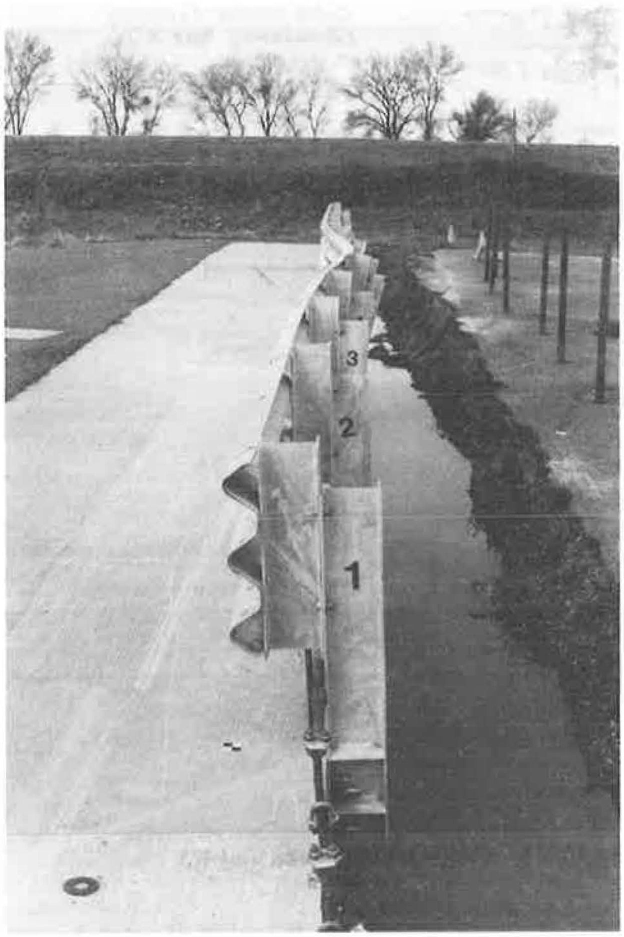
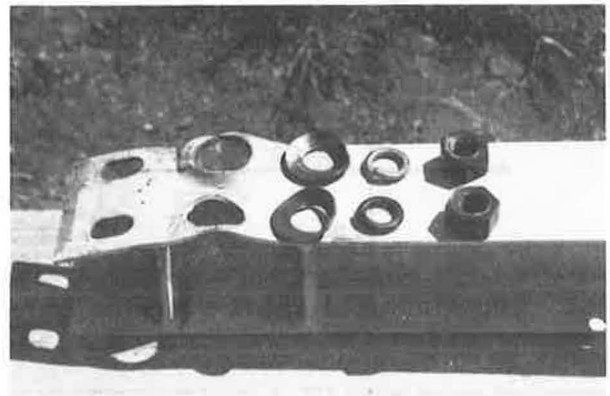


FIGURE 7 Rail damage: bent rail, bent posts, Test 473.

TABLE 2 POST DEFLECTIONS (in.)

Post	Test 473	Test 474
3	1/8	
4	3-9/16	1/16
5	9-1/16	7/16
6	8-5/16	1-7/16
7	2-1/2	1-5/16
8	1/8	5/16
9	1/4	0



(a)

(b)

FIGURE 8 Post 6 was severely bent after Test 473.

Test 474

Test Description

The right front bumper of the test vehicle struck the bridge rail upstream from Post 6 at a speed of 48.7 mph at an angle of 18 degrees. Vehicle contact with the Thrie beam began 1.0 ft upstream from Post 6 and continued for a length of 7.0 ft (Figure 9). The vehicle was smoothly redirected, without exhibiting any tendency to snag on a post or wedge under the rail, and lost contact with the barrier at an angle of 5 degrees. The exit speed of the vehicle was about 39 mph. The maximum roll was about −1.3 degrees. The remote brakes were activated approximately 0.4 sec before impact. The final location of the vehicle was about 127 ft downstream from impact and 10 ft in front of the rail (Figure 10). The right front cover of the vehicle was moderately damaged (Figure 11).

Bridge Rail Damage

The post and rail damage were limited to the impact area. The permanent lateral displacement of the rail measured at

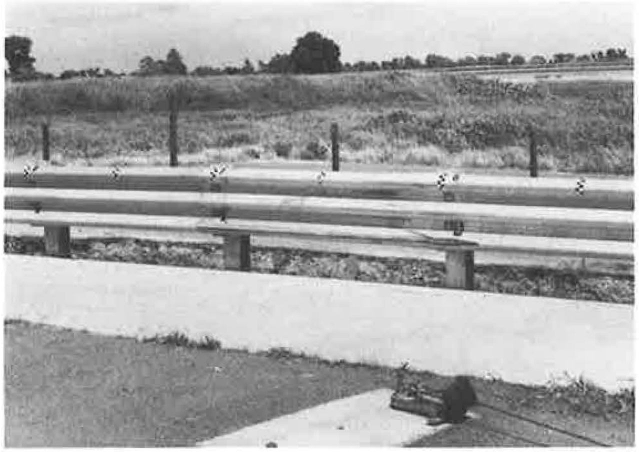


FIGURE 9 Vehicle contact marks, Test 474.

FIGURE 11 Damage to front of vehicle, Test 474.

the posts ranged from 1⁄16 to 17⁄16 in. (Figure 10). The displacements of each of the posts is shown in Table 2. The maximum dynamic barrier deflection was 3.8 in.

Dummy Response

During the collision, the unrestrained dummy was thrown to the right side of the vehicle. Its shoulder hit the inside of the right door, bending it outwards. Its head was outside the vehicle, sliding along the top of the rail while the vehicle was in contact with the rail. The dummy's head hit the block at Post 8, tearing the skin of the head. The dummy's final position was lying on its side with its upper body across the passenger side of the vehicle and its feet wedged underneath the driver's seat.

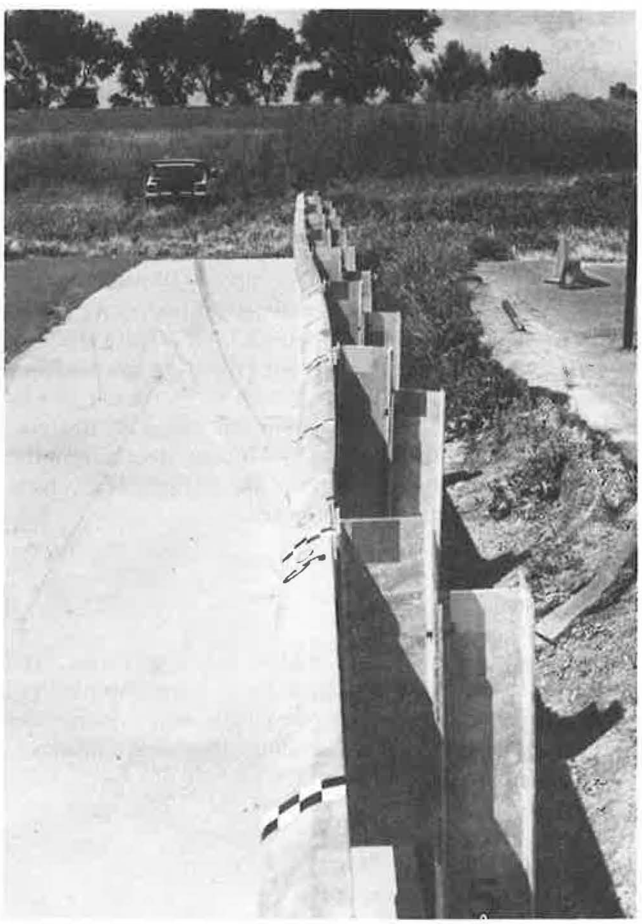


FIGURE 10 Rail damage: bent rail, bent posts, Test 474.

Test 475

Test Description

The right front bumper of the test vehicle struck the bridge approach transition near the midpoint between Posts 2 and 3 of the transition at a speed of 44.1 mph at an impact angle of 18 degrees. Vehicle contact with the transition began 3.1 ft downstream from Post 3 and continued for a distance of about 10 ft (Figure 12). The vehicle was smoothly redirected without exhibiting any tendency to snag or pocket and lost contact with the barrier at an exit angle of 4¼ degrees. The maximum roll was −2¾ degrees. The final location of the pickup truck was 140 ft downstream from impact and 37 ft in front of the bridge rail face (Figure 13). The vehicle was lightly damaged (Figure 14).

FIGURE 12 Vehicle contact marks, Test 475.

FIGURE 13 Rail damage: displaced posts, bent rail, broken post, Test 475.

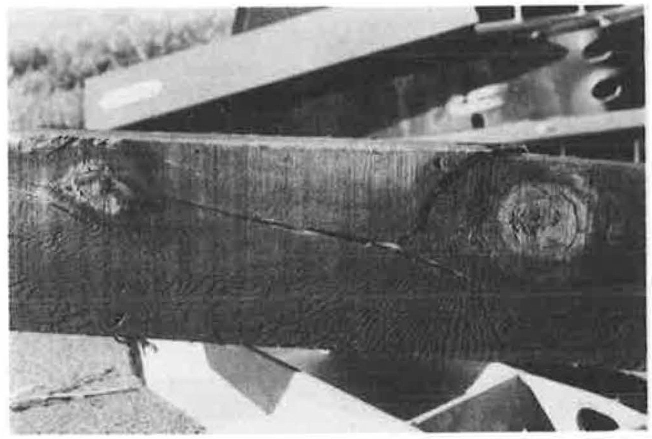


FIGURE 15 Rail damage, Test 475.

FIGURE 14 Vehicle after Test 475.

Barrier Damage

Post and rail damage was limited to the impact area. Damage consisted of a slight bend in the transition rail, displacement of posts, and one broken post (Figure 15). Post 3 was broken about 15 in. below ground level at a knot.

The permanent lateral deflection, measured at the posts, ranged from 1/16 to 4⅜ in. The displacements of each of the posts is shown in Table 3. The maximum displacement was 5⅛ in. between Posts 2 and 3. The maximum dynamic lateral movement was 9.6 in. at Post 3. The total length of vehicle contact was about 15 ft. The approach transition was permanently bent and the Thrie beam–W-beam transition was damaged; both were replaced.

Dummy Response

During impact, the unrestrained dummy was thrown to the right side of the vehicle. The dummy's final position was lying on its side with its upper body across the passenger side and its legs wedged under the steering wheel.

TABLE 3 POST DEFLECTIONS (in.)

Post	Test 475	Test 476
1	2 7/8	-3/8
2	4 3/8	13/16
3	3 3/4	1/2
4	1 1/16	1/16
5	3/8	-1/4
6	1/16	1/16

Test 476

Test Description

The right front bumper of the test vehicle struck the bridge approach transition near the midpoint between Posts 2 and 3 of the transition at a speed of 49.4 mph at an angle of 20¾ degrees. Vehicle contact with the rail began 3.3 ft downstream of Post 3 and continued for a length of 7.4 ft (Figure 16). The car was smoothly redirected without exhibiting any tendency to snag or pocket and lost contact with the barrier at an exit angle of 4¾ degrees. The maximum roll was +2¾ degrees. The final location of the car was 118 ft downstream from the impact point and 58.5 ft in front of the barrier. The vehicle was moderately damaged (Figure 17).

Barrier Damage

Post and rail damage was limited to the impact area. The barrier damage consisted of a slight bend of the transition rail and displacement of posts. Displacements were nominal and are tabulated in Table 3. The maximum dynamic lateral movement was 6.3 in. at Post 2.

Dummy Response

During collision, the unrestrained dummy was forcefully thrown to the right side of the vehicle and pushed the door outward.

FIGURE 16 Vehicle contact marks, Test 476.

FIGURE 17 Vehicle after Test 476.

The dummy's final position was lying on its side with its upper body across the passenger side with its legs wedged under the steering wheel.

Static Post Tests

A series of static tests on W6 × 15.5 steel posts were conducted. There were five tests, each on a different bridge rail post design. Post designs for Tests *A* through *E* are shown in Figure 18.

The purpose of the tests was to evaluate the effect of eliminating the web stiffeners at the base of the post and alternate post-strengthening schemes. Test *A* used a post as crash tested, Test *B* used the preferred alternate strengthening scheme, and Test *C* used an unstrengthened post. Tests *D* and *E* were additional alternate strengthening schemes. The test device consisted of a load frame anchored to the simulated bridge deck, a 75-ton hydraulic jack, a load cell, two linearly variable differential transformers (LVDTs), and a bearing plate. Load was applied 26 in. above the deck surface; the LVDTs measured displacement 4½ in. above the deck (Figure 19).

The test results are summarized in Table 4. Typically the web at the base of the post would buckle upon failure (Figure 20*a*, *b*, and *c*). In Tests *A* and *B* the web stiffeners and sandwich plates added sufficient strength so that the top anchor bolts pulled out. Total deformation of test Post *A* was less than two of the posts in Crash Test 473 (Figure 21).

DISCUSSION

Structural Adequacy

In Tests 473 and 475, a 5,400-lb pickup truck tested the structural adequacy of the bridge rail and the transition. The barriers were not penetrated or vaulted and there were no detached barrier elements; thus the design is adequate for the tested conditions. The bending of the bridge rail post with the partial pull through of the nuts and washers at the flange (Figure 8) indicate that the system is being significantly stressed by the impact. There was not much reserve strength to handle more severe impacts. The 10-gauge rail was effective in distributing impact loads among several posts. Vehicle contact in Test 473 was between Posts 4 and 7, and there was bending of Posts 3 through 9.

The transition tested appears to be of about the same stiffness as the bridge rail, evidenced by the dynamic deflections. The smaller magnitude of the residual deflection in the transition illustrates the greater resilience of the soil-wood post support as compared with the steel post. It is noteworthy that the transition performed well even though one post broke below grade. (The post fractured because of a flaw in the structure of the wood, a large knot through the 8-in. faces, that was near the allowable limit for that type of defect.)

Occupant Risk

Tests 474 and 476, small car, were to evaluate occupant risk factors. Occupant risk factors were also calculated for the other tests. The occupant impact velocities and ridedown accelerations were below those required by the AASHTO *Guide Specifications for Bridge Railings* (*3*) (Table 5). The vehicles in all tests remained upright and exhibited no tendency to roll over—all roll angles were less than 10 degrees. There was no evidence of the vehicles snagging or pocketing on the bridge rail or transition. Tire marks were observed on the ground about 3 in. from the face of posts and there was no evidence of any vehicle contact with posts.

The effective coefficient of friction (μ) for each test was calculated. It ranged from 0.07 to 0.22, within the good range per the AASHTO *Guide Specifications for Bridge Railings* (*3*).

Vehicle Trajectory

The post impact trajectory of the vehicles followed the same general pattern in each test; the vehicle moved away from the barrier in a straight line or slight curve (Figure 22). The exit angle for each test was low (4 to 6¼ degrees), well below 60 percent of the impact angle.

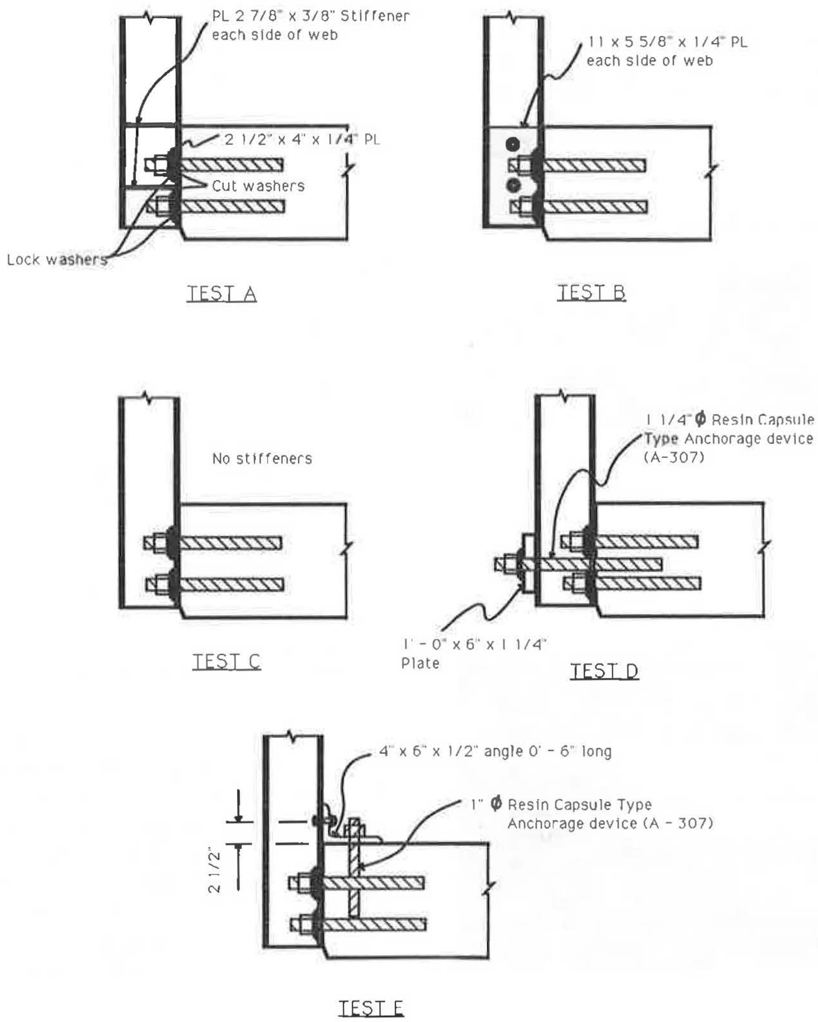


FIGURE 18 Static tested post designs.

The Guide Specification evaluation criterion "*h*" indicates that the vehicle should be no more than 20 ft from the face of the barrier after having traveled 100 ft. Measurements were not taken after each test to determine if this criterion was met or not. If it is assumed that the vehicle path was straight after impact—generally not the case—the criterion can be derived

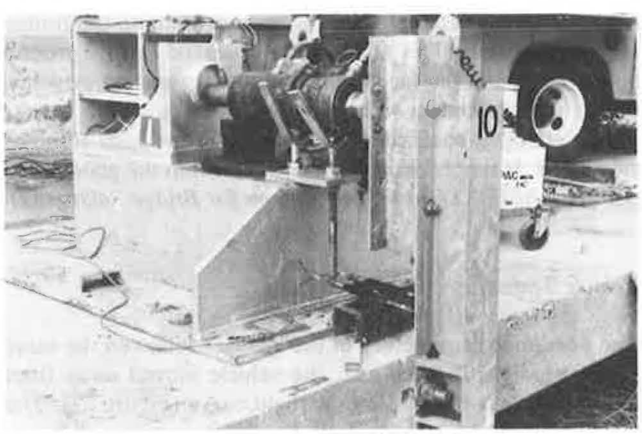


FIGURE 19 Static test setup.

TABLE 4 STATIC LOADS ON W 6 × 15.5 POSTS

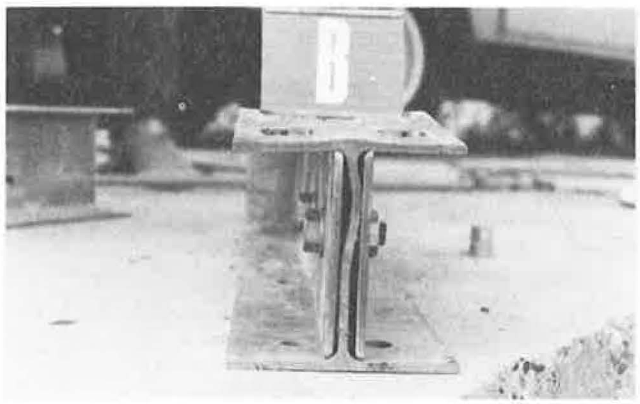
Test	Maximum Load(KIP)	Failure Mode
A	7.7	Anchor bolts pulled out and concrete spalled
B	7.7	Anchor bolts pulled out and concrete spalled
C	6.6	Web Buckled
D	7.7	Web Buckled
E	8.7	Concrete supporting bracket spalled

that "*h*" was not met. There was not enough information available to determine this.

Rail Installation and Maintenance

There were no problems encountered during the installation of the bridge rail, although it is possible that there could be problems on an actual bridge. Large resin capsule anchors, ¼ in. and 1 in., require a considerable force to set the threaded rod to the proper depth before the resin sets. The shape of

(a)



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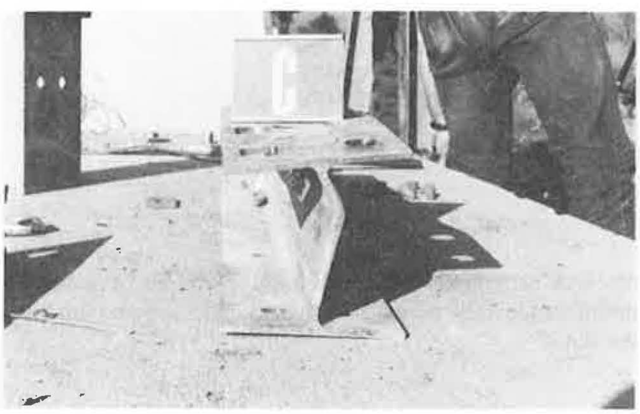

(c)

FIGURE 20 Bottom end of three posts after static tests.

the trench behind the simulated bridge deck facilitated applying that force; on an actual deck some other provision must be made to support workers. Installation of the posts and rail elements was similarly eased by being able to stand behind the rail on the ground. Rail installation was slightly more difficult than a structural tube rail because of the large number of fasteners at the rail splices.

After Test 473, the seven bent posts and three rail elements were replaced. Removal of Posts 5 and 6 was quite difficult; the holes and the post flanges were pushed around the washers

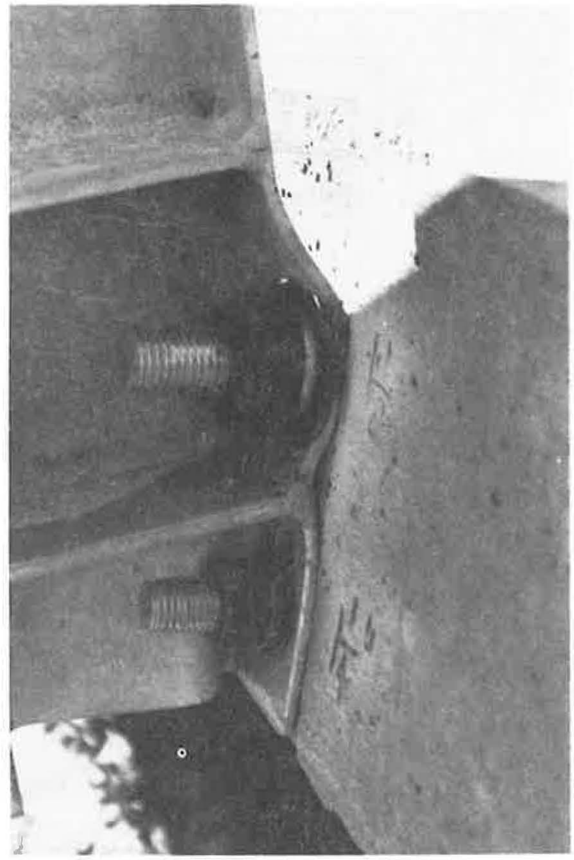

FIGURE 21 Buckled web contacted lower fastening nut on Post 6.

TABLE 5 VEHICLE KINEMATICS

Test #	Occ. Impact Velocity (fps) Long.	Lat	Ride down Acceleration (g) Long.	Lat.	Coeff. of Friction μ
473	7.7	n/a	n/a	n/a	0.07
474	13.2	-17.3	-0.6	-6.0	0.05
475	6.8	-17.5	-0.4	-10.3	0.12
476	11.6	-20.9	-1.4	-11.4	0.22

and nuts, making access to the top fasteners quite difficult. Also, the collapse of the web at the bottom of the post restricted the movement of one of the nuts (Figure 21). A cutting torch would be required to remove such a damaged post from a bridge deck with access only from the deck. The bridge approach transition was constructed and repaired by a guard rail maintenance crew by hand methods. No problems were encountered during installation or repair.

CONCLUSIONS

The following conclusions were drawn:

1. The Thrie beam bridge rail and transition design presented in this paper can successfully contain a 5,400-lb. ballasted pickup truck striking at a 20 degree angle at 45 mph.

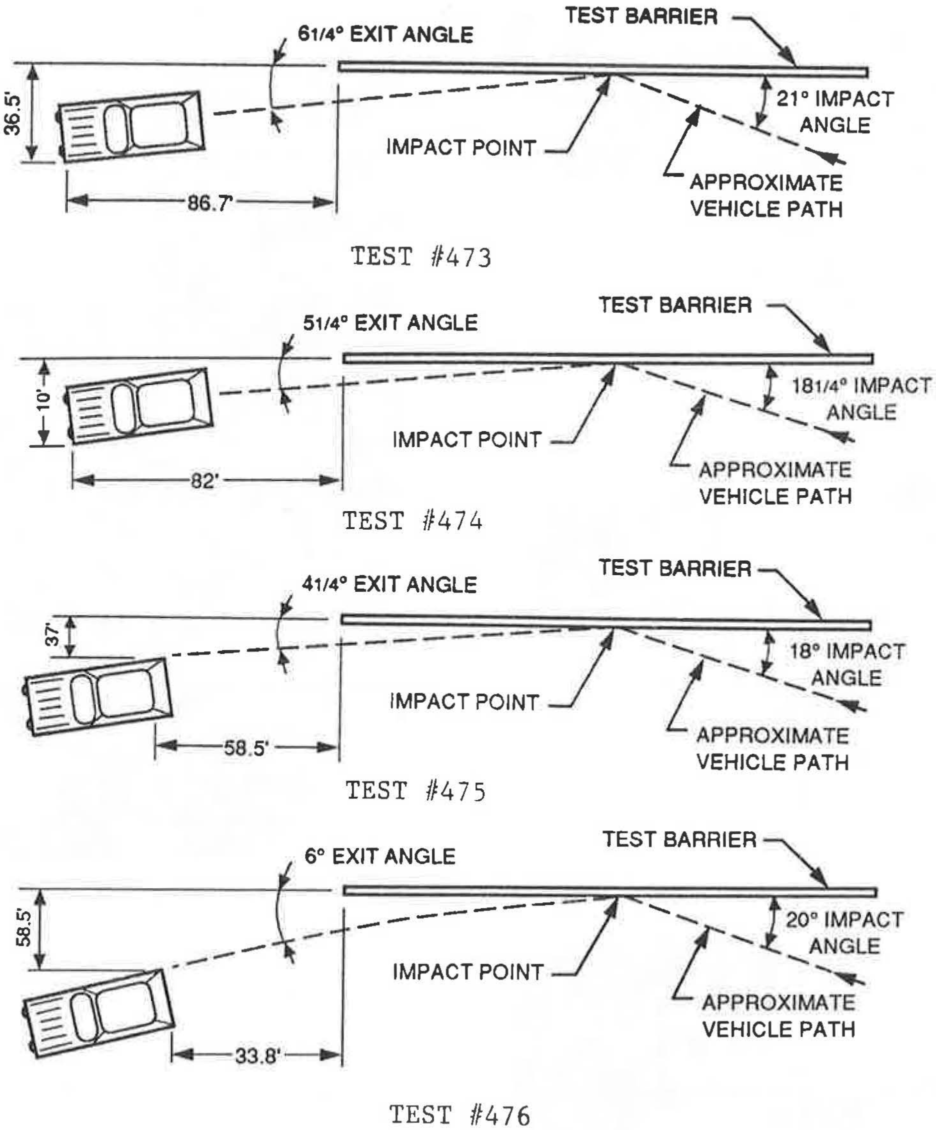

FIGURE 22 Vehicle trajectories.

2. The bridge rail and transition can smoothly redirect a small car and a pickup truck without any signs of undesirable behavior and without exceeding occupant risk evaluation guidelines.
3. Resin capsule anchors are adequate to withstand the impact loading on a W6×15.5 steel post when installed in reinforced concrete.
4. The Thrie beam bridge rail and transition designs essentially met the requirements for Performance Level 1 crash testing in the AASHTO *Guide Specifications for Bridge Railings* (*3*) and would be suitable for use as new or retrofit barriers on narrow, low-speed, low-volume local roads.
5. Some sort of post strengthening should be included on a Thrie beam bridge rail. Welded web stiffeners were crash tested; bolted-in sandwich plates would probably perform similarly at a lower cost.

ACKNOWLEDGMENTS

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