Vehicle Crash Tests of Type 115 Barrier Rail Systems for Use on Secondary Highways

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A total of three vehicle crash tests were performed on a California Type 115 bridge rail. The Type 115 bridge-rail test barrier consisted of two steel tube rails (10 × 10 × 0.64 cm) supported from the edge of deck by steel W8×31-posts at 244-cm spacing. The height of the top rail was 76 cm. There were two impact tests on a Type 115 bridge rail and one on a Type 115 bridge-rail transition. Although it was planned to test the Type 115 bridge rail to Performance Level 2 (PL2) and it was tested with a 2450- and 810-kg vehicle at 95 km/hr and 20 degrees, the snagging of wheels in Tests 471 and 472 led to the recommendation that the Type 115 be used as a PL1 bridge rail for lower-speed narrow bridges where impact angles are expected to be less. The Type 115 bridge-rail transition, when tested with a 2450-kg vehicle, produced some moderate pocketing, but could easily be stiffened to lessen the pocketing problem. Otherwise, the transition met all test criteria.

California has used the Type 115 bridge rail (Figure 1) for a number of years on lower service level highways. Better visibility, more usable deck width on existing bridges, and local agency aesthetics were needed. The Type 115 railing consists of two 10 × 10-cm tube rails mounted on W8×31 posts. It was designed under old AASHTO bridge-rail specifications that only required an analysis using a 44.5-kPa static load applied to the rails, but no crash testing.

All old or new bridge-rail designs used to replace old railings or for new construction now must be crash tested to qualify for federal aid. The crash tests must use current test and evaluation guidelines according to *NCHRP Report 230* (*1*) and AASHTO *Guide Specifications for Bridge Railings* (2). Hence, to continue using the Type 115 railing, the California Department of Transportation (Caltrans) needed to conduct crash tests that would confirm compliance with current guidelines.

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. Recent FHWA policy allows PL1 rails to be used on California highway rehabilitation work that is federally funded. The California Type 18 (Figure 2) metal railing (tubular) has met current crash-test requirements but is much more costly and takes up more deck width than the older steel rail design, the Type 115 (Figure 1). Therefore, it was decided to quality the Type 115 rail for use by crash testing. The PL2 level of testing was selected to determine the limits of performance of the Type 115.

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SCOPE

Three crash tests were performed, two on Type 115 bridge rail and one on a transition to that rail. The bridge-rail test conditions followed the AASHTO *Guide Specifications for Bridge Railings* (*2*) for a PL2 bridge rail (except no 8200-kg truck test was planned). The transition barrier was tested at the PL1 level, a decision made after the first two bridge-rail tests had been analyzed. The tests were conducted and evaluated using the procedures and criteria in *NCHRP Report 230* (*1*) and also evaluated using the AASHTO guide specifications (2). Intended impact conditions are given in Table 1.

BRIDGE-RAIL AND TRANSITION DESIGN

The Type 115 metal-tube bridge railing has two 10 × 10 × 0.64-cm structural steel tube rail elements attached to W8×31 steel posts. Spaced 244 cm on center, the tube rails are attached directly to the posts with no block outs. Rail-to-deck clearance is 41 cm and the overall height is 76 cm. Two 10-cm high rail faces are exposed to traffic, and there are no energy-absorbing elements. The posts were attached to the edge of the bridge deck with high strength anchor bolts. The two top bolts were 3.2 cm in diameter and the two bottom bolts 2.5 cm in diameter.

Steel rails and posts were used to minimize the rail area obstructing the vision of motorists. Structural steel concentrates strength in a small area of material. The two tube rails were needed to provide a broad impact surface for vehicles of varying height. The top edge of the top tube rail is 76 cm above the deck; thus, it prevents vehicles with high centers of gravity from getting over the rail better than do 68.6-cm high barriers (the lowest height now generally allowed).

The W8×31 posts and anchor bolts embedded in the edge of the deck met the old AASHTO bridge-rail static load design requirement. The anchor bolts used for testing were previously used in the testing of the Type 18 bridge rail and were judged to be undamaged and acceptable for additional tests with the Type 115.

The concrete-simulated deck was a block of reinforced concrete 25.6 m long, 1.07 m wide, and 0.91 m deep with a cantilevered section the length of the deck that was 1.07 m wide and 0.30 m thick. At the time of the first test the compressive strength (f_c') of the concrete in the deck was 30.9

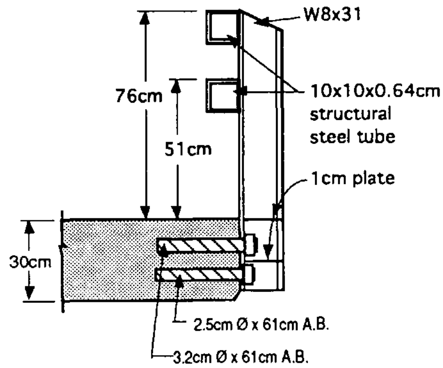


FIGURE 1 Type 115 bridge rail.

MPa. The cantilevered deck had steel reinforcement typical for a bridge deck, and all rebar conformed to ASTM A615, grade 60. The deck surface was flush with the surrounding asphalt-concrete pavement.

The transition from a thrie-beam guardrail to a Type 115 (Figure 3) bridge rail was accomplished through a 30 × 51 × 0.64-cm steel plate. A structural steel tube 30 cm long 10 × 10 × 0.64 cm was welded onto the plate. The flat side of the plate was bolted to the thrie beam. The side of the plate with the steel tube was fitted between the two tubes on the Type 115 and bolted to the post (Figure 4). The thrie beam was connected to a standard metal beam guardrail using a standard W-beam to thrie-beam transition piece. The guardrail was terminated with a breakaway cable terminal. The bridge rail was designed by the Caltrans Division of Structures.

CRASH TESTING

Test Vehicles

The test vehicles complied with *NCHRP Report 230* (*1*). For all tests, the vehicles were in good condition and free of major body damage and missing structural parts. All equipment on the vehicles was standard. The engines were front mounted. Ballast was used on Tests 472 and 477 only. Vehicle types used in the tests and their masses are shown in Table 2. The vehicles were self-powered in all tests.

Test Dummy

An anthropometric dummy with three accelerometers mounted in its head cavity was placed in the driver's seat of the test vehicle to obtain motion and acceleration data. The dummy was placed in the driver's seat and not restrained except in Test 472.

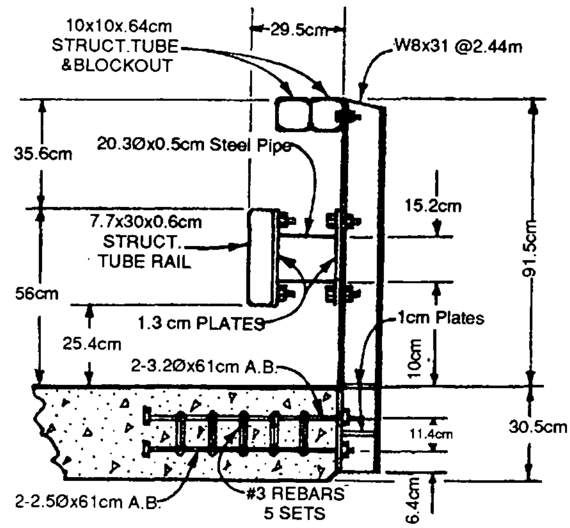


FIGURE 2 California Type 18.

Test Instrumentation

Six accelerometers were attached to the floor of the vehicle near the center of gravity to measure motion in the longitudinal, lateral, and vertical directions. Rate gyro transducers were also placed at this location to measure the pitch, roll, and yaw of the vehicle. The accelerometer data were used in calculating the occupant impact velocity.

CRASH TESTS RESULTS

Test 471

Impact Description

The vehicle weighed 810 kg and measured impact speed was 94.9 km/hr. The actual impact angle was 19.0 degrees (Figures 5 and 6*a*). The vehicle right side contacted the barrier face 38 cm downstream from Post 6. Contact continued for a distance of about 300 cm.

The right front tire contacted the lower rail face for about 61 cm starting at 37 cm downstream from Post 6 (Figure 6*b*). The right rear wheel touched the lower rail face for about 160 cm and left contact 42 cm downstream from Post 7 (Figure 6*c*). The right front alloy wheel was damaged on Post 7.

The right corner of the car bumper was slightly snagged and sliced off on Post 7 between the lower and upper rails. With the exception of the snagging wheel, the car was redirected smoothly. The vehicle remained upright throughout and after the collision. The exit angle and speed of the car

TABLE 1 Target Impact Conditions

Test No.	Barrier type	Mass (kgs)	Speed (kph)	Angle (deg)
471	115	810	95	20
472	115	2450	95	20
477	115 transition	2450	72	20

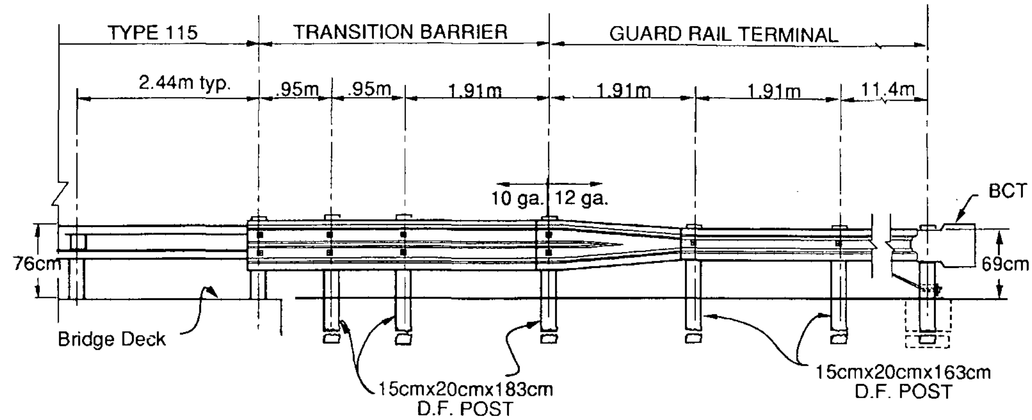


FIGURE 3 Type 115 transition.

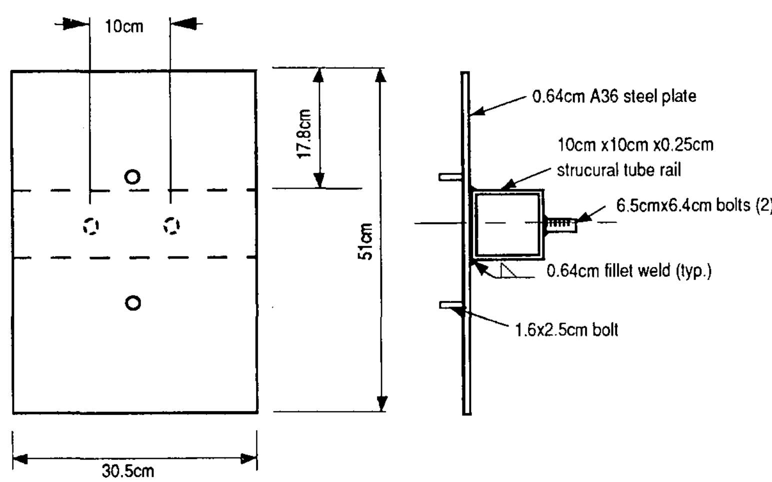


FIGURE 4 Thrie-beam to Type 115 transition piece.

were 5.0 degrees and 87.5 km/hr, respectively. The car stopped about 26 m downstream from the barrier after the brakes were applied.

Vehicle Damage

The test car was moderately damaged, with considerable crumpling of the right side body sheet metal but little frame damage (Figure 6*d*). The contact pattern extended from the right front corner for about 25 cm across the right side of the vehicle. The front frame members under the engine were bent on the right side. The windshield was cracked on the lower right corner. The right front fender was severely crushed by the penetration of the upper rail for a depth of about 18 cm. The right front door was jammed. Both front wheels were broken, and the tires were flattened and wheel movement was completely restricted.

TABLE 2 Test Vehicle Weights

Test No.	Vehicle	Ballast-(kg)	Mass-(kg)
471	1985 Isuzu 1-Mark	0	810
472	1985 Dodge Truck	562	2480
477	1985 Chevy Truck	230	2450

Barrier Damage

Barrier damage consisted of a slight bend of the rail and backward displacement of post tops in the impact area. The maximum dynamic lateral deflection was 4.45 cm at Post 7. The residual lateral displacement was 2.3 cm at the same post. The lateral displacement of post tops ranged between 1.9 and 1.4 cm. The maximum depth of car contact on the top of the upper rail was 3.7 cm at 57 cm upstream from Post 7.

The right front fender and each of the right tires contacted the barrier. The length of the right front fender contact with the top of the upper rail was 245 cm and ended 74 cm further downstream from the point where the rail lost contact with the car's right front fender. The tire marks of the right front wheel on the lower rail face were 51 cm high for a length of 61 cm. The right rear tire marks on the lower rail face were also 51 cm high for a length of 160 cm.

Dummy Response

During collision, the unrestrained dummy was thrown to the right. Its shoulder hit the right front door, bending it outward. The dummy's final position was on its back across the pas-

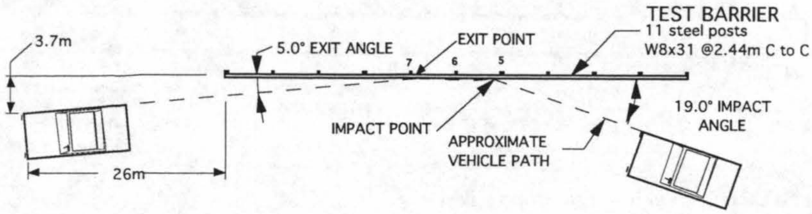


FIGURE 5 Vehicle trajectory, Test 471.

senger floor area with its legs wedged under the steering wheel. The dummy had a gash in its head, torn covering on the left foot, and torn coveralls.

Test 472

Impact Description

The vehicle weighed 2480 kg and speed at impact was 103 km/hr (Figures 7 and 8). The measured angle of impact was 21.0 degrees (Figure 8*a*). The right front corner of the truck bumper struck the lower rail face 17 cm downstream from the centerline of Post 5. The truck body's first contact with the upper rail was 37 cm upstream of the centerline of Post 5 (20 cm upstream of the bumper contact point).

The right front tire contacted the lower rail face at the centerline of Post 5 and remained in contact with the rail for about 494 cm. During impact, the right front tire contacted the top of the lower rail first at 10 cm downstream of Post 5 for a length of 43 cm and second at Post 6 for 20 cm. The truck's right front wheel snagged on Post 6 and was torn

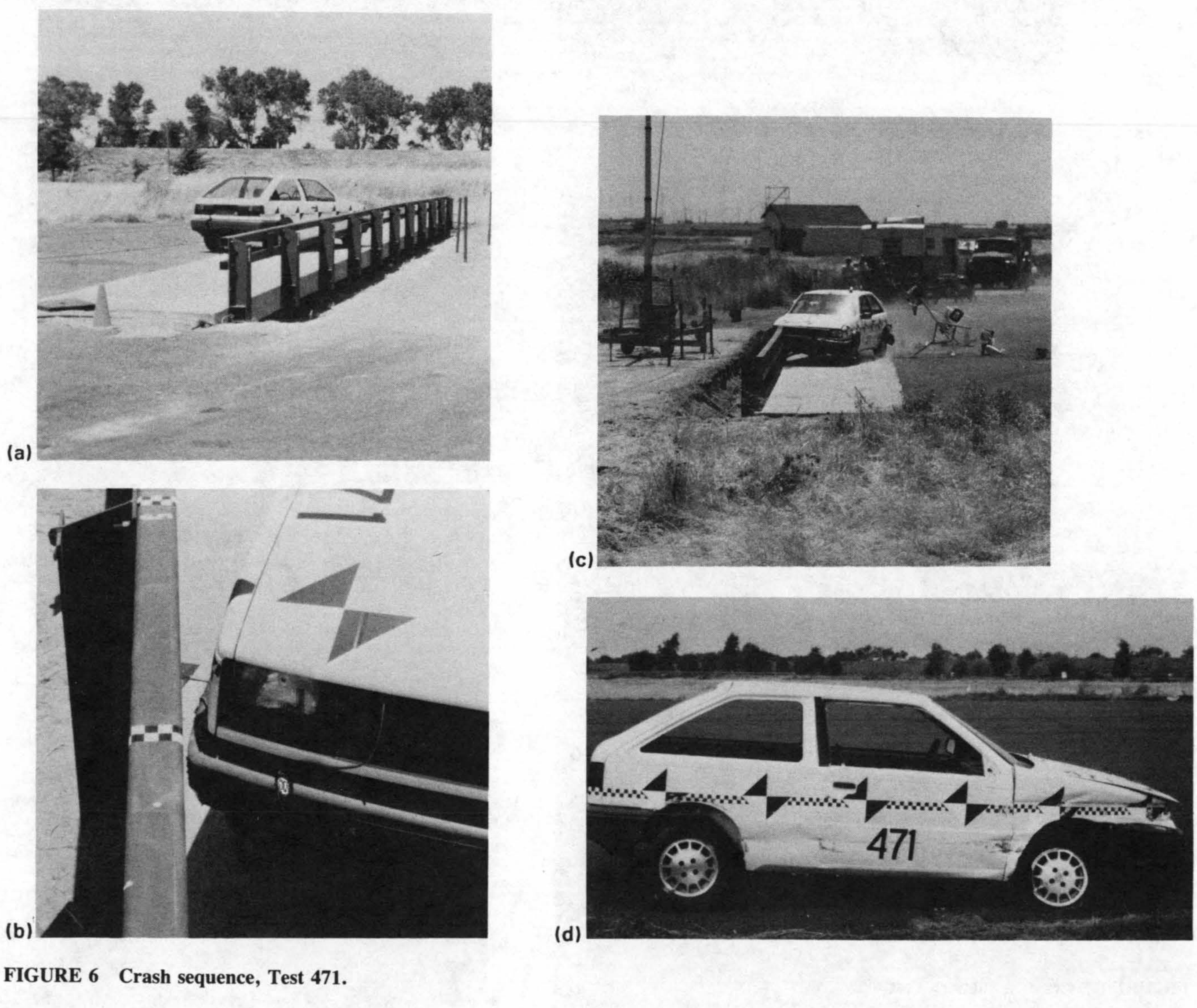


FIGURE 6 Crash sequence, Test 471.

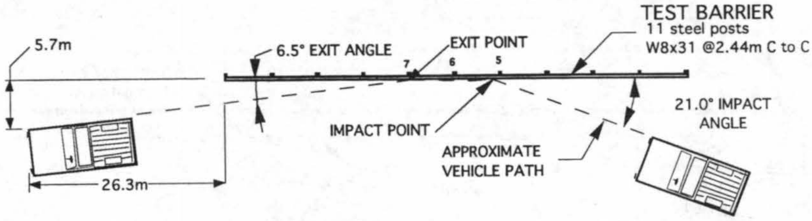


FIGURE 7 Vehicle Trajectory, Test 472.

FIGURE 8 Crash sequence, Test 472.

forcefully off the truck. The wheel rolled and tumbled alongside the redirected truck and came to rest behind it.

The right rear tire contact with the lower rail started 76 cm downstream of Post 5 and ended 6.3 cm downstream of Post 7. The contact with the upper rail started 120 cm upstream and ended 18 cm downstream of Post 7. The only post contact by the right rear tire was with Post 6.

The truck continued to turn to the left after it left the pavement (Figure 8*b*). The truck was redirected relatively smoothly and came to rest about 26.4 m downstream from Post 11. The exit angle and speed were 6.6 degrees and 77.4 km/hr, respectively.

Vehicle Damage

The vehicle sustained extensive damage to various areas (Figure 8*c*). The right front bumper was crushed and bent under the crushed right front fender. the right front wheel, including the suspension assembly, was torn from under the truck during impact. The right door was crushed and jammed. The floor on the right side was crushed and pushed up into the passenger compartment. The windshield was broken, partially popped out of its frame, and pushed to the right. The radiator was pushed back to the fan. The battery broke loose from the mounts. The right side of the truck bed was crushed for the entire length at rail height. The bed was twisted and pushed rearward, toward the right side of the truck. The right wheel well was crushed by the shifting of the ballast (a 540-kg steel plate broke free from mounting brackets during impact).

Barrier Damage

Post and rail damage were limited to the impact area. The upper rail separated at the splice 0.8 cm at the face and 2.0 cm at the back. The lower rail also separated at the splice 0.64 cm at the face and 0.5 cm at the back.

The lateral deflection of the upper rail, measured at the posts, ranged from 0.64 to 28.2 cm, in a smooth long curve between Posts 4 and 8 (Figure 8*d*). The maximum deflection was measured at Post 6. The lateral displacements at the top of the steel Posts 4, 5, 6, 7, and 8 were 12.1, 27.6, 40.3, 20.3, and 10.8 cm, respectively. The same posts experienced some bending ranging from 1.3 to 5.1 cm. The washers on the top studs of Posts 5 and 6 were pulled through the holes (Figure 8*e*). After impact, all posts remained attached to the bridge deck and the two rails remained attached to the posts.

Tire marks from the right front wheel on the upper rail face were about 76 cm high for a length of 110 cm between Posts 5 and 6. On the lower rail, marks from the same tire appeared for 260 cm. The same tire contacted the top of the lower rail for 43 cm downstream from Post 5 and for 20 cm downstream from Post 6.

The right rear tire marks on the upper rail face were 28 cm long 110 cm downstream from Post 5 and 140 cm long 120 cm downstream from Post 6. The right rear tire marks on the lower rail face were about 420 cm long, and started 76 cm downstream from Post 5.

Dummy's Response

During collision, the restrained dummy remained almost in its place. The dummy did not experience any damage as a result of the collision. The dummy's final position was in the driver seat.

Test 477

Impact Description

The height to the lower edge of the truck's bumper was 44.5 cm and it was 66.8 cm to the top of the bumper. The vehicle weighed 2450 kg and was freewheeling and unrestrained just before impact. The measured impact speed was 74.8 km/hr and the angle was 19.2 degrees (Figures 9 and 10).

The vehicle bumper contacted the middle ridge of the transition face 15 cm upstream from wood Post 3. Contact continued for a distance of about 381 cm. The right front tire contacted the thrie-beam corrugation at Post 3 and ended at Post 1. The right rear tire touched the lower ridge about 40 cm upstream from Post 2 for about 84 cm. The sheet metal body contact of the vehicle with the upper ridge of the rail began 44.5 cm upstream from Post 3 and ended 15 cm downstream from metal Post 1. The body contact of the vehicle with the middle and lower ridges was noted as discontinuous scratches that ended about 15 cm past steel Post 1.

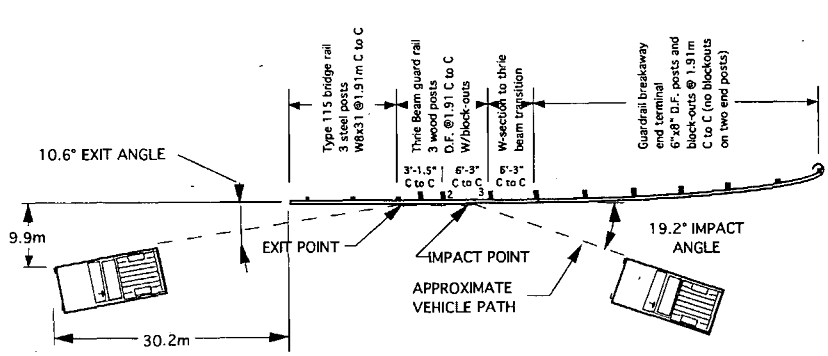
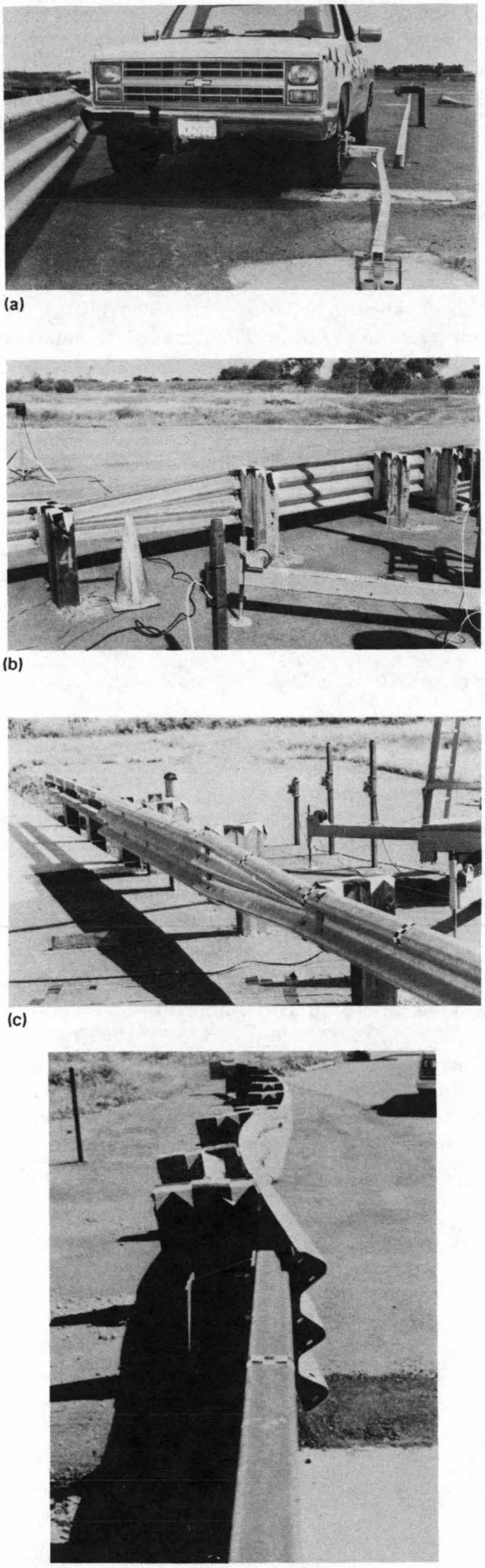


FIGURE 9 Vehicle trajectory, Test 477.



(a)

(b)

(c)

(d)

FIGURE 10 Crash sequence, Test 477.

The vehicle was redirected when pocketing occurred upstream from Post 1. It remained upright throughout and after the collision. The exit speed and angle were 59.2 km/hr and 10.6 degrees, respectively. The remote brakes were applied after impact. The vehicle went off the pavement and stopped on a berm. The final location of the vehicle was 40 m from the impact point and 11.7 m in front of the barrier.

Vehicle Damage

The vehicle was damaged, with severe crushing of the right front side and moderate impairment on both sides. The bumper was jammed, split at the right corner, and pushed to the left side (Figure 10*d*). The entire right side of the vehicle was scraped. The tires were intact but movement of the right front wheel was restricted because the front bumper was pushed against it. There was no intrusion into the passenger compartment.

Barrier Damage

Post and rail damage was limited to the impact area. The top of the wood posts 1, 2, 3, 4, and 5 had permanent lateral displacements that were 15, 25, 23, 8, and 2.5 cm, respectively, and dynamic lateral deflections of 20, 36, 33, 10, and 8 cm, respectively. Wood Posts 4 and 5 were deflected at ground level. The first steel post of the bridge rail (metal Post 1) had permanent and dynamic deflections of 1.3 and 3.8 cm, respectively.

The length of vehicle scratch on the upper ridge of the rail was 445 cm. The tire marks of the right rear wheel covered a length of 84 cm on the lower ridge starting 41 cm upstream from Wood Post 2.

Dummy Response

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

DISCUSSION OF CRASH-TEST RESULTS

Structural Adequacy

Tests 472 and 477, using the 2450-kg pickup trucks, tested the structural adequacy of the bridge rail and 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 indicated that posts were being stressed significantly when struck.

The small car had alloy (instead of steel) wheels, which may have lessened the deceleration during the wheel snagging. The pickup truck had its front wheel torn off completely. The value of μ calculated for Test 472 using the formula in the AASHTO guidelines was unacceptably high. Type 115 is recommended as a PL1 bridge rail for lower-speed narrow bridges where impact angles are expected to be less than the 20 degrees tested.

Occupant Risk

Each test required the test vehicle to remain upright with acceptable (low) levels of yaw, pitch, and roll. All the tests produced vehicle reactions that were acceptable within this criterion.

The AASHTO guidelines limit the occupant impact velocity in the lateral direction to 7.6 m/sec, in the longitudinal direction to 9.1 m/sec, and the ridedown acceleration in both directions to 15 *g*. Table 3 shows the test data as compared with NCHRP 230 criteria (*1*).

Vehicle Trajectory

NCHRP Report 230 (*1*) stresses that "trajectory evaluation for redirection type of tests is focused on the vehicle at the time it loses contact with the test article, and the subsequent part of the trajectory is not evaluated."

The exit angle for all tests was less than the recommended upper limit of 60 percent of the impact angle; hence, all tests passed the criterion. The speed reduction of 25.9 km/hr is greater than the recommended 24 km/hr maximum for Test 472, but the 1.8 km/hr difference is not significant enough to fail Test 472. The vehicle exit speeds and angles are shown in Table 4.

The Type 115 bridge rail and the thrie-beam transition to the bridge rail passed all the NCHRP 230 (*1*) and AASHTO guidelines (*2*) criteria (Table 5) except for a minor exceedance of the AASHTO guide specification criteria 3.f. in Test 472. This failure led us to classify the Type 115 as a PL 1 barrier.

RECOMMENDATIONS

The researchers propose to design a bridge rail similar to the Type 115 that will have three steel-tube rails instead of two to eliminate wheel snagging on the post. It is intended to crash test this design with passenger vehicles using PL2 test procedures and criteria.

It is also recommended that the possible modification of a terminal connector of the type shown in Figure 11 be used to establish a viable solution for vehicle impacts occurring at the transition connection, but coming from the opposing direction. This terminal connector is currently approved in California for use in transitions from thrie beam to the concrete safety shape. The researchers and bridge engineers involved in the design and testing of the transition will be reviewing this terminal connector design and other options to decide whether additional testing is warranted.

CONCLUSIONS

On the basis of the results of the two impact tests on the Type 115 bridge railing and the one impact test on the Type 115 bridge railing transition, the following conclusions can be drawn:

- The Type 115 bridge rail design presented here can successfully contain a 2450-kg ballasted pickup truck striking at a 20-degree angle at 97-km/hr. However, the snagging of a wheel on Test 472 disqualifies the Type 115 bridge rail for PL2. But, because of passing the AASHTO guide specification and NCHRP 230 criteria, and otherwise smooth redirection, the Type 115 bridge rail is acceptable for PL1 impact conditions.
- The Type 115 bridge rail can smoothly redirect a small car and a pickup truck without any signs of undesirable be-

TABLE 3 Occupant Risk Test Results Compared with NCHRP 230 Criteria

	Test 471	Test 472	Test 477
Vehicle Mass, kg	810	2480	2450
Vehicle Speed, kph	94.9	103.2	74.8
Vehicle Angle, degrees	19	21	19.2
Occupant Impact Velocity - Long. (m/s) (Threshold - 9.1 Limit - 12)	4.08	5.49	3.81
Occupant Impact Velocity - Lat. (m/s) (Threshold - 6.1, Limit - 9.1)	5.61	5.91	5.52
Ridedown Acceleration - Long. (g's) Threshold - 15, Limit - 20)	NA	-8.0	0.2
Ridedown Acceleration - Lat. (g's) Threshold - 15, Limit - 20)	-8.9	10.6	7.6
Maximum 50ms Avg. Accel. - Long (g's)	-5.7	-5.2	2.9
Maximum 50ms Avg. Accel. - Lat. (g's)	-8.3	7.7	5.9

TABLE 4 Vehicle Trajectories and Speeds

	Angles			Speeds		
Test Number	Impact Angle (deg)	60% of Impact Angle (deg)	Exit Angle (deg)	Impact Speed, V_i (kph)	Exit Speed, V_E (kph)	Speed Change $V_i - V_E$ (kph)
471	19.0	11.4	5.0	94.9	87.7	7.2
472	21.0	12.6	6.5	103	77.4	25.9
477	19.2	11.5	10.6	74.8	59.2	15.6

TABLE 5 Summary of Crash-Test Criteria

NCHRP 230	Test 471	Test 472	Test 477
Structural Adequacy			
A. Containment and smooth redirection	P *	P *	P
D. No debris hazard to traffic or passenger compartment	P	P	P
Occupant Risk			
E. Vehicle upright, moderate pitch, roll and yaw; no passenger compartment intrusion	P	P	P
F. Occupant Impact Velocity & Ridedown Acceleration criteria	P	P **	P **
Vehicle Trajectory			
H. Minimal intrusion in traffic lanes	P	P	P
I. Minimal speed change and exit angle	P	F ***	P
AASHTO Guidelines			
1. Tests per NCHRP 230 criteria; report max. loads that can be transmitted from bridge railing to bridge deck	P/NA †	P/NA †	
2. Within vehicle speed and angle tolerances	P	P	
3. a. Vehicle contained	P	P	
b. Vehicle/barrier debris was no undue hazard to passengers or traffic	P	P	
c. No intrusion of passenger compartment	P	P	
d. Vehicle remains upright	P	P	
e. Smooth vehicle redirection, yaw of rear of vehicle < 5°	P	P	
f. Smooth vehicle to barrier interaction, $\mu < 0.35$	P μ=0.067	F μ=0.517	
g. Occupant Impact Velocity and Ridedown Acceleration criteria	P	P	
h. Vehicle trajectory and exit angle	P	P	

* Smooth redirection despite wheel snagging.
** Not required to pass Criteria in these tests.
*** Exceeded change of velocity limit by only 1.8 kph.
† These loads have not been measured or calculated.
P = passed
F = failed

havior (except the wheel snagging) and without exceeding occupant risk evaluation guidelines.

• The Type 115 bridge-rail transition produced some pocketing, but can easily be stiffened to lessen the pocketing problem. It passed all criteria for transitions in NCHRP 230. After consideration of the transition design, however, it was concluded that there may be a problem with impacts in the reverse direction. Therefore, until further investigation can yield a reasonable level of safety in both directions, the transition design discussed in this paper should not be used where impacts can occur in the reverse direction.

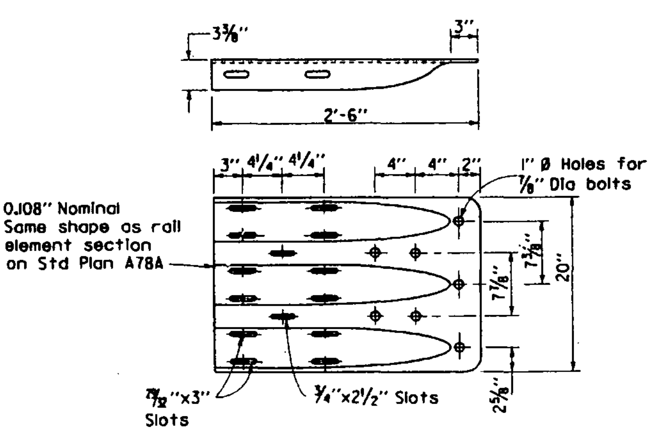


FIGURE 11 California standard plan A78B terminal connector.

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