The upper concrete beam centered at 79.5 in. (202 cm) was designed so that the tank trailer would strike it and be prevented from overturning.

The cross-sectional area of this modified rail is approximately 7.6 ft^2 (0.7 m^2) as compared with approximately 2.6 ft^2 (0.2 m^2) for a standard Texas Type T5 traffic rail. The approximate cost of this modified rail would be about $125 per linear foot, whereas a standard Texas Type T5 traffic rail normally costs about $35 per linear foot.

SUMMARY AND CONCLUSIONS

A standard Texas Type T5 traffic rail concrete safety shape was modified by increasing its height and strength so that it could restrain and redirect an 80,000-lb tank-type truck or tractor-trailer. The height of the concrete parapet was increased to 48 in. A concrete beam element 16 in. wide and 21 in. deep was mounted on concrete posts on top of the concrete parapet to achieve a total rail height of 90 in. The concrete posts were 8 in. thick, 5 ft long, and 21 in. (53 cm) high with 5-ft (1.5-m) openings between the posts. The rail was constructed vertically on a 14-degree curve with the deck superelevated 0.055 ft/ft.

The crash test was conducted on this bridge rail with an 80,120-lb tank-type tractor-trailer impacting the rail at 51.4 mph and at an impact angle of 15 degrees. The vehicle was smoothly redirected.

This test has shown that a bridge rail can be built on a slightly modified Texas standard bridge deck to contain large tank-type tractor-trailer trucks and redirect them without rollover.

ACKNOWLEDGMENT

This research was conducted under a cooperative program between TTI, the Texas State Department of Highways and Public Transportation, and FHWA.

REFERENCES

1. T.J. Hirsch and A. Arnold. Bridge Rail to Restrain and Redirect 80,000 lb Trucks. Research Report 230-4F. Texas Transportation Institute, Texas A&M University, College Station, Nov. 1981.
2. T.J. Hirsch. Analytical Evaluation of Texas Bridge Rails to Contain Buses and Trucks. Research Report 230-2. Texas Transportation Institute, Texas A&M University, College Station, Aug. 1978.
3. T.J. Hirsch. Bridge Rail to Restrain and Redirect Buses. Research Report 230-3. Texas Transportation Institute, Texas A&M University, College Station, Feb. 1981.
4. J.S. Noel, C.E. Buth, and T.J. Hirsch. Loads on Bridge Railings. In Transportation Research Record 796, TRB, National Research Council, Washington, D.C., 1981, pp. 31-35.
5. T.J. Hirsch, J.J. Panak, and C.E. Buth. Tubular W-Beam Bridge Rail. Research Report 230-1. Texas Transportation Institute, Texas A&M University, College Station, Oct. 1978.
6. J.D. Michie. Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances. NCHRP Report 230. TRB, National Research Council, Washington, D.C., March 1981.

Roadside Barriers for Bridge-Pier Protection

JAMES E. BRYDEN and RICHARD G. PHILLIPS

ABSTRACT

Seven full-scale crash tests were conducted to evaluate a concrete bridge-pier protection barrier. This barrier consists of four concrete half-section safety-shape barriers placed in front of the pier and flaring back from the pavement edge. The end of the concrete barrier is protected by a 6 by 6-in. box-beam guiderail bolted to the concrete. The barrier was impacted at various points with either 1,800- or 4,500-lb sedans at 15 and 25 degrees and a speed of about 60 mph. The original design caused vehicles to roll over when the concrete barrier was impacted at 25 degrees near the first bridge pier. The design was modified by extending the box beam across the face of the barrier directly in front of the piers. This eliminated the rollover problem and strengthened the barrier, resulting in performance in compliance with the standards in NCHRP Report 230.

Unprotected concrete bridge piers located near the pavement edge pose a serious hazard to vehicles leaving the roadway at that point. This problem is especially serious on older expressways on which high traffic speeds and volumes occur and bridge piers are located only a few feet from the pavement edge. As part of the effort to upgrade highway safety, it frequently becomes desirable to reduce the hazard presented by these piers. Because their removal would generally be prohibitively expensive, the solution generally is to shield the piers against impact. Impact attenuators may be used effectively in some cases, but their high construction and maintenance costs frequently result in the selection of longitudinal barriers as a more cost-effective alternative. Where shoulder widths are adequate, a variety of flexible steel traffic barriers are available that effectively shield the bridge piers and provide a reasonable level of motorist protection (1). Unfortunately, piers are sometimes located so close to the pavement edge that a nonyielding barrier is needed to provide adequate protection without further reducing the already limited shoulder width.

PURPOSE AND SCOPE

One solution to this problem has been used extensively on the New York State Thruway and to a limited extent by the New York State Department of Transportation (NYSDOT). This design consists of a concrete safety-shape barrier half-section directly in front of the piers, flaring back from the pavement at a 1:8 rate just upstream of the piers. A 6 x 6 x 3/16-in. box-beam guiderail protects the exposed upstream end of the concrete barrier. The guiderail uses the standard NYSDOT terminal on its upstream end, and the downstream end is bolted flush to the face of the concrete barrier. Both the concrete safety shape (2) and box-beam guiderail (3) are tried and proved systems that have been shown to perform well when used separately. However, their combined use raises questions that can best be answered through full-scale crash tests. These tests would determine the impact severity, strength, and redirectional characteristics of this concrete pier-protection barrier.

METHODOLOGY AND BARRIER DESCRIPTION

Seven full-scale crash tests were conducted under this study following the guidelines in NCHRP Report 230 (4). Work was started in 1982, but a performance problem was identified that required design modifications and additional tests in 1983. Five were strength tests with target conditions of 4,500-lb vehicles at 60 mph and 25 degrees. The two remaining tests were to assess occupant risk, with target conditions of 1,800-lb vehicles at 60 mph and 15 degrees.

The barrier system consisted of four 15-ft half-section concrete barriers to which was fastened a 6 x 6 x 3/16-in. box-beam guiderail. Total length of the barrier system was 130.5 ft. The box beam was sup- ported by S3x5.7 steel posts at a height of 30 in. Post spacing in the impact area varied from 2 to 3 ft, and upstream post spacing was maintained at 6 ft. Figure 1 shows details of the barrier as it was erected for Tests 60 through 63. The simulated bridge piers for these four tests were 36-in.-diameter cast-in-place columns. These were situated on

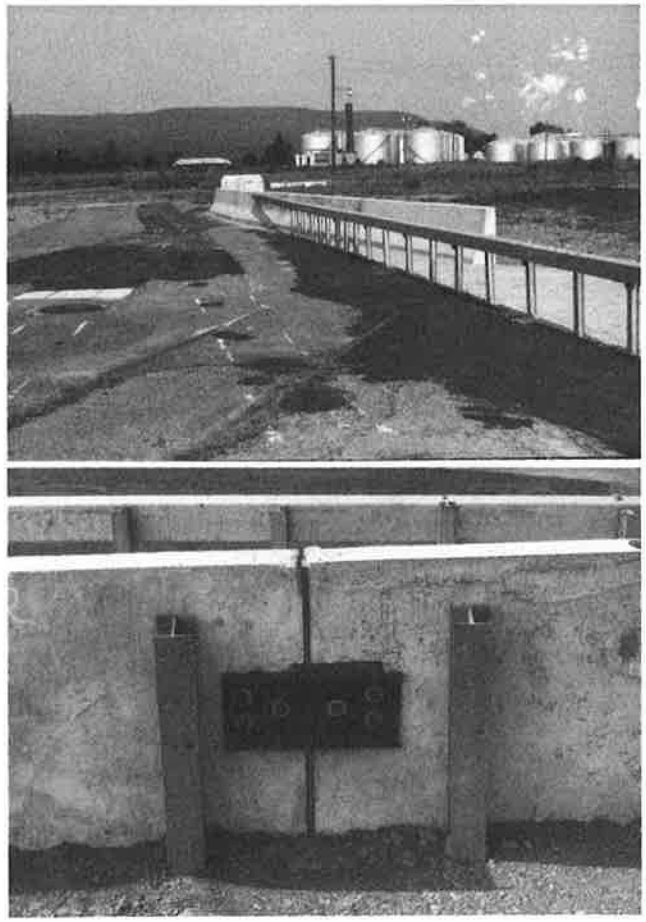

FIGURE 1 Pier-protection barrier for Tests 60 through 63 (above) included continuity connector and W6x9 backup posts for joint support (below).

4-ft-diameter concrete footings about 1 ft below grade.

For Tests 76 through 78 the columns were precast concrete culvert pipe 33 in. in diameter and 8 ft long. The pipes were placed on end with their bottoms about 1 ft below grade, and the excavation was carefully backfilled with compacted soil. The pipes were filled with soil to increase their mass. Changes to the barrier design for the final three tests (Figures 2 and 3) included (a) an earth backfill behind the concrete barrier in place of the heavy posts, (b) continuation of the box beam across Section A, and (c) addition of a 6-in. blockout between the concrete barrier and box beam at Section B.

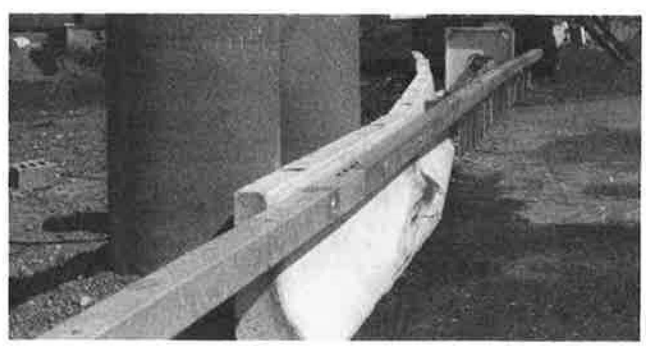

FIGURE 2 Pier-protection barrier for Tests 76 and 77: extending the box beam across Section A.

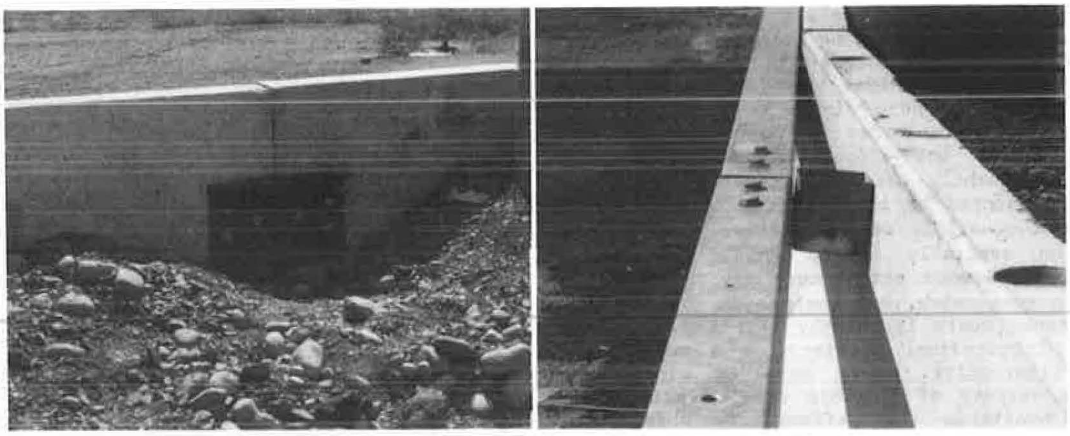

FIGURE 3 Pier-protection barrier for Tests 76 and 77: continuity connectors and earth fill (left), and a 6 by 6-in. blockout at Section B (right).

For all tests the concrete barrier was embedded 8 in. into the ground and continuity connectors were used between sections. The only problem involved with the installation of the barrier system was alignment of the W6x9 backup posts. These had to be driven before the concrete barriers could be positioned. Soil at the test site contained large cobbles in the granular material, which caused a few posts to be slightly misaligned. Hardwood shims filled any gaps resulting between the posts and the back of the concrete barrier. The steel backup posts thus were eliminated for the last three tests, because it appeared that the 6 x 6-in. box beam, combined with the continuity connectors and soil backfill, would provide adequate load transfer across the joints.

RESULTS

Results of the seven full-scale crash tests are summarized in Table 1. The purpose of Test 60 was to ensure that 4-ft clearance between the box beam and the end of the concrete barrier was sufficient to prevent the vehicle from striking the barrier. Standard design deflections for box-beam guiderail are 5 ft with 6-ft post spacing and 4 ft with 3-ft post spacing. Although it was anticipated that adequate deflection control would thus be provided by the 3-ft post spacing, this test was necessary to confirm it.

The 4,450-lb sedan impacted the box beam 55.5 ft downstream from its end (15 ft upstream from the end of the concrete barrier) at 55.7 mph and 25 degrees. Dynamic deflection was 2.6 ft, which confirmed that

TABLE 1 Test Results

Item	Test 60	Test 61	Test 62	Test 63	Test 76	Test 77	Test 78
Point of impact	Box-beam 55.5' downstream from end	Box-beam 12.2' upstream from box beam	Box-beam 12.2' upstream from box beam	Concrete barrier Section B	Box beam & concrete barrier; Section B	Box beam & concrete barrier; Section B	Box beam & concrete barrier; Section B
Barrier Length, ft	130.5	130.5	130.5	130.5	130.5	130.5	130.5
Vehicle Weight, lb	4450	1600	4500	4500	1800	4650	4500
Vehicle Speed, mph	55.7	59.0	54.3	57.1	58.3	61.2	63.7
Impact Angle, deg	25	14	29	26	20	29	30
Exit Angle, deg	9	4	7	9	11	12	9
Max. Roll, deg	-10	5	-9	-46	3	5	-180
Max. Pitch, deg	-2	0	4	-5	4	2	-5
Max. Yaw, deg	0	0	-117	70	0	0	0
Contact Distance, ft	27	21.2	15.6	12.7	12.4	14.9	6.7
Contact Time, ms	749	278	430	635	198	331	482
Deflection, ft							
Dynamic	2.6	.5	.25	N.A.	0	N.A.	N.A.
Permanent	1.7	0	.19	.21	0	.19	.17
Decelerations, g's							
50 ms avg.							
Longitudinal	3.2	4.6	11.1	12.9	10.4	5.9	9.0
Lateral	5.5	8.2	9.7	7.7	14.0	10.9	9.9
Max. Peak							
Longitudinal	9.4	10.2	25.5	34.9	21.1	10.9	-35.9
Lateral	16.1	15.0	20.5	27.6	27.2	17.5	-103.2
Occupant Ridedown							
Longitudinal	6.6	-1.1	6.3	-25.0	4.1	2.3	12.0
Lateral	8.6	8.0	9.3	9.7	6.4	7.8	10.6
Occupant Impact Velocity, fps							
Longitudinal (2.0 ft)	17.6	12.2	30.3	39.0	17.4	16.2	34.2
Lateral (1.0 ft)	16.6	19.9	23.6	19.3	26.5	26.0	23.0
Results and Comments	Good redirection	Good redirection	Good redirection	Vehicle rolled over; heavily damaged	Good redirection	Good redirection	Vehicle rolled over; heavily damaged

the 4-ft clearance was adequate. The vehicle attained a maximum pitch of only 2 degrees and a roll to the right of 10 degrees. (Positive roll is clockwise, positive pitch is nose down, and positive yaw is counterclockwise with respect to the driver's attitude.) Redirection was smooth with an exit angle of 9 degrees and a very slight curve to the right. Damage to the vehicle was moderate, and damage to the box beam was limited to 2 rail sections and 15 posts. Total contact distance was 27 ft. Peak 50-msec average decelerations were 3.2 g longitudinal and 5.5 g lateral. Occupant impact velocities were 17.6 ft/sec longitudinal and 16.6 ft/sec lateral, below those recommended by NCHRP Report 230 for 60-mph, 15-degree impacts. Figure 4 shows the vehicle and barrier after the test. From these results it appears that the barrier performs well at this point.

Test 61 was intended to evaluate barrier performance at the connection between the box beam and the concrete barrier. In addition to determining impact severity and postimpact trajectory, this test investigated the problem of wheel snagging between the bottom of the box beam and the concrete barrier. The 1,600-lb Subaru sedan impacted 12.2 ft upstream from the end of the box beam at 59.0 mph and 14 degrees. The vehicle redirected smoothly with an exit angle of only 4 degrees and followed a curved path to the right back toward the barrier. Virtually no pitch or yaw was observed, and maximum roll was only 5 degrees toward the barrier. Vehicle damage (Figure 5) resulting from the impact was light, although the vehicle was subsequently damaged in a secondary

FIGURE 4 Test vehicle and barrier after Test 60.

FIGURE 5 Test vehicle and barrier after Test 61.

impact with a chain-link-fence arrestor system. Minor sheet-metal snagging occurred on a hex-head bolt used to connect the box beam to the concrete barrier. Peak 50-msec average decelerations were 4.6 g longitudinal and 8.2 g lateral. Occupant impact velocities were 12.2 ft/sec longitudinal and 19.9 ft/sec lateral compared with NCHRP Report 230 recommended maximums of 30 and 20 ft/sec, respectively. This test was thus considered successful.

The impact point in Test 62 was the same as that in Test 61, but the test was designed to evaluate the strength of the barrier system at the connection point. The 4,500-lb Mercury sedan impacted at 54.3 mph and 29 degrees. The vehicle was smoothly redirected with a maximum roll of -9 degrees and maximum pitch of 4 degrees. Departure angle was 7 degrees, but the vehicle gradually curved to the right and yawed about 117 degrees to the right, coming to rest at an angle of 110 degrees along the barrier line. Damage to the vehicle was generally moderate, although the sheet metal on the right front door snagged on a box-beam connection bolt and was peeled off the car (Figure 6). Barrier damage included one bent rail section and two vertical cracks in Section B of the concrete barrier near the end of the box beam. Peak 50-msec decelerations were 11.1 g longitudinal and 9.7 g lateral. Occupant impact velocities were 30.3 ft/sec longitudinal and 23.6 ft/sec lateral. Although impact severity slightly exceeded recommended values for 15-degree impacts, it appeared reasonable for this 29-degree impact. The barrier was thus considered to meet strength and redirectional requirements at this point.

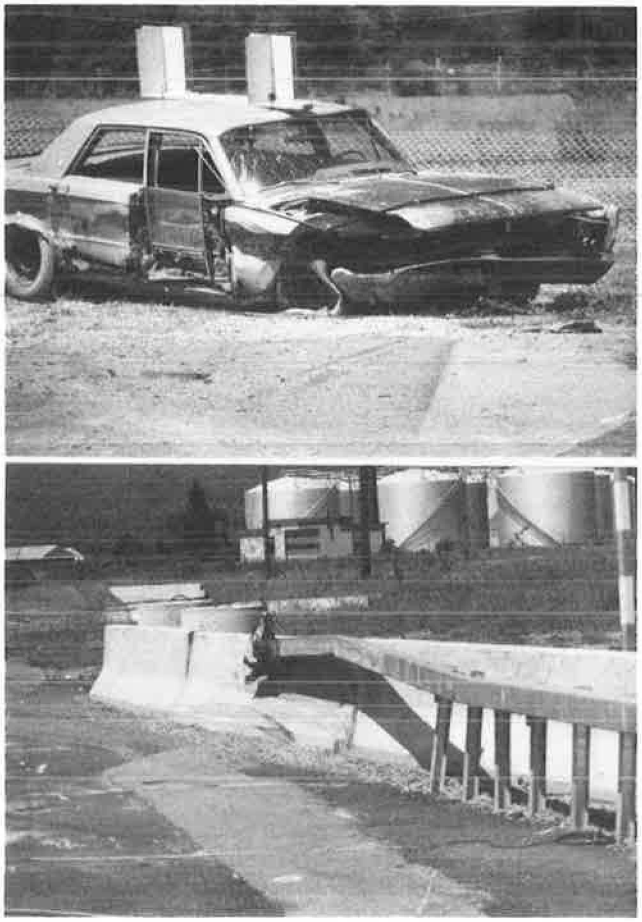

FIGURE 6 Test vehicle and barrier after Test 62.

FIGURE 7 Test vehicle and barrier after Test 63.

Test 63 was intended to test the strength of the connection between barrier Sections A and B, just upstream from the first bridge column. The 4,730-lb Ford station wagon impacts 7.7 ft upstream from the joint at 57.1 mph and 26 degrees. The vehicle quickly climbed to the top of the concrete barrier while rolling 46 degrees counterclockwise. Tire marks at the top of the 4-ft-high simulated bridge columns confirmed that the vehicle would have sustained solid impact with full-height columns. Film measurements showed that the car penetrated about 1.5 ft behind the back of the concrete barrier, or 2 ft behind the barrier face. On leaving the barrier, the vehicle yawed 70 degrees to the left while still rolling away from the barrier. It then rolled sharply toward the right, and on contact with the ground rolled over completely on the right front corner before coming to rest. Peak 50-msec decelerations were 12.9 g longitudinal and 7.7 g lateral, with corresponding occupant impact velocities of 39.0 and 19.3 ft/sec. The vehicle was extensively damaged during the initial impact and subsequent rollover. Damage to the barrier was also extensive, as seen in Figure 7; there were cracks through both Sections A and B and the continuity connector was nearly broken out of the barrier. This test thus indicated that joint strength is marginal for such severe impacts. More important, contact with the columns, high decelerations, and vehicle rollover all confirm that the concrete safety-shape barrier is inadequate for high-angle impacts, especially when fixed objects are located immediately behind the barrier. The vehicle and barrier after the test are shown in Figure 7.

Good performance had been obtained in Tests 61 and 62, where impact had occurred upstream of the end of the box beam. The primary difference between those two tests and Test 63 was that the box beam prevented the vehicle from climbing up the concrete barrier and attaining a very high roll angle. The barrier thus was modified for the 1983 tests by extending the box beam past the columns and bolting it to the face of Section A by using carriage bolts. For the remaining three tests, the height of the simulated bridge piers was increased to 7 ft. Continuity connectors were again attached between sections of concrete barrier, and a 2-ft earth backfill was used behind the barrier in place of the heavy posts used in the previous tests. Because protrusion of the base made it impossible to install posts in front of Section B, a 6-in. steel blockout was added to connect the box beam to the concrete barrier. An 8-in. carriage bolt connected the box-beam rail to the blockout from the front, and an 8 x 3/4-in. hex-head bolt connected the blockout to the concrete barrier.

Test 76 was intended to evaluate the modified design for wheel snag, impact severity, and redirection. The 1,800-lb Honda sedan impacted 4.3 ft upstream from the connection between Sections A and B at 58.3 mph and 20 degrees. Even at this relatively high impact angle, the car was smoothly redirected at an exit angle of 11 degrees, with no appreciable yaw. Maximum roll and pitch were +3 and +4 degrees,

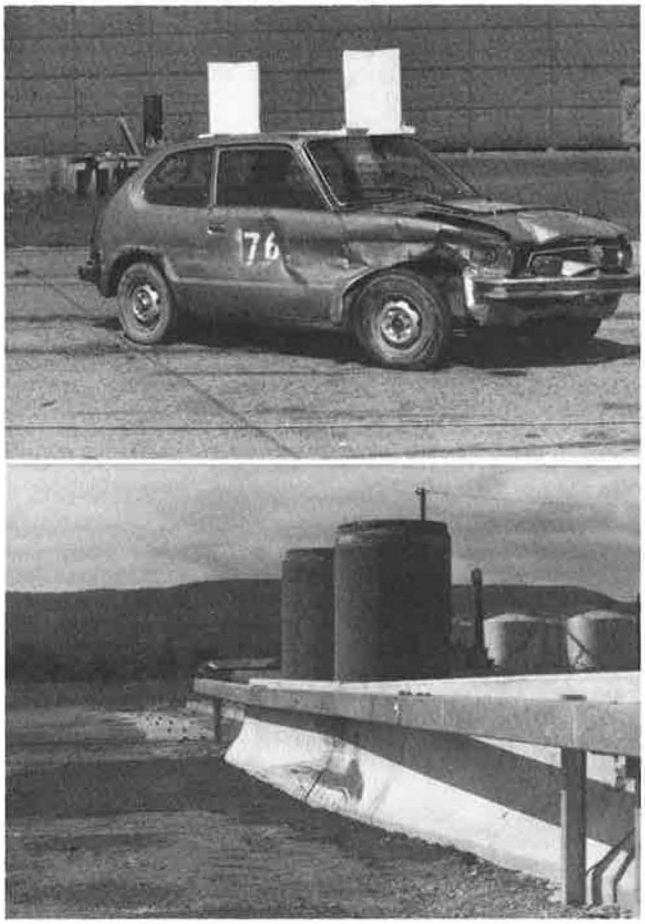

FIGURE 8 Test vehicle and barrier after Test 76.

FIGURE 9 Test vehicle and barrier after Test 77.

respectively. Peak 50-msec average decelerations were 10.4 *g* longitudinal and 14.0 *g* lateral. Occupant impact velocities were 17.4 ft/sec longitudinal and 26.5 ft/sec lateral, slightly exceeding the recommended lateral occupant impact velocity. However, considering the high impact angle, these results are not considered unacceptable. Vehicle damage was light in this test, and the barrier had virtually no damage (Figure 8).

Test 77 was a strength test with impact at the same point as that in Test 76. The 4,650-lb Lincoln sedan impacted at 61.2 mph and 29 degrees. The vehicle was smoothly redirected along a 12-degree exit path and curved slightly to the right. Roll and pitch were limited to +5 and +2 degrees, respectively. Peak 50-msec average decelerations were 5.9 *g* longitudinal and 10.9 *g* lateral, with corresponding occupant impact velocities of 16.2 and 26.0 ft/sec. Only moderate damage was sustained by the vehicle, and barrier damage was very light (Figure 9).

Tests 76 and 77 confirmed that extending the box beam along the top face of the concrete barrier reduced vehicle roll to a very low level and kept impact forces within tolerable levels. It also increased load transfer between adjoining sections of concrete barrier, greatly reducing barrier damage on severe impacts. It thus appears that the modified barrier provides an acceptable level of protection and will require very little postimpact repair.

Following completion of the two successful tests on the modified barrier, the box beam across Section A was removed and Test 63 was repeated. The objective of this test was to evaluate the severity of contact with the full-height columns. A continuity connector was again used between Sections A and B, but earth backfill was substituted for the backup posts used in Test 63.

The 4,500-lb Chevrolet sedan impacted 3.2 ft upstream from the joint between Sections A and B at 63.7 mph and 30 degrees. It immediately climbed all the way to the top of the barrier and rolled nearly 90 degrees counterclockwise. The vehicle impacted both columns above the top of the barrier and then continued to roll counterclockwise as it left the barrier. It rolled onto its roof and left the barrier on a 9-degree angle, sliding on its roof. The vehicle was severely damaged by the impact with the barrier and piers and the subsequent rollover (Figure 10). Peak 50-msec average decelerations were 9.0 *g* longitudinal and 9.9 *g* lateral, with corresponding occupant impact velocities of 34.2 and 23.0 ft/sec. In spite of the severe impact, the barrier experienced only light damage. The earth backfill used for this test was capable of absorbing severe loads without misalignment of the barrier, even without the box beam or 6x8.5 backup posts. Impact conditions in this test were somewhat more severe than the 60-mph, 25-degree intended impact. However, as shown in Test 63, contact with the columns and a similar vehicle trajectory would probably have resulted even at the lower speed and lesser angle.

DISCUSSION AND FINDINGS

On the basis of five successful full-scale tests, it appears that the box-beam concrete-barrier pier-pro-

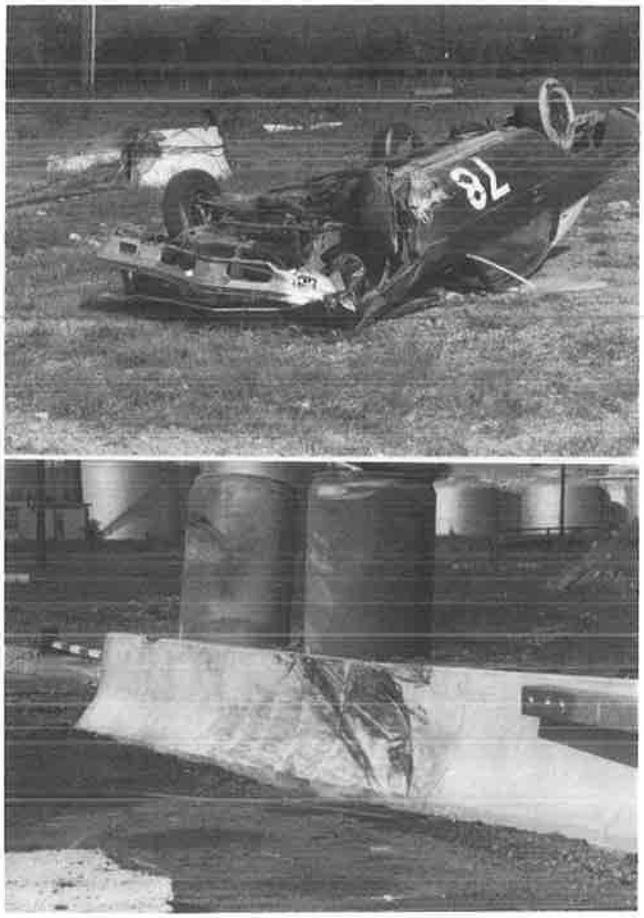

FIGURE 10 Test vehicle and barrier after Test 78.

tection system, as modified, meets the performance criteria of NCHRP Report 230. Structural adequacy was evaluated at three points along the barrier. Test 60 demonstrated that the 4-ft clearance between the box beam and the end of the concrete barrier was adequate. The connection of the box beam to the concrete barrier was also adequate, and continuing the box beam across the front of the bridge pier resulted in adequate strength and containment. Post-impact vehicle trajectories were satisfactory in all five tests. Occupant risk factors slightly exceeded the recommended value in one 1,800-lb vehicle test, but this was attributed to the high 20-degree impact angle. Occupant risk factors for the three large-car tests at 25-degree impact angles were close to or below recommended values for 15-degree tests. The box beam successfully held vehicle roll to a very low level. This may also have increased impact severity somewhat, because very little impact energy was absorbed in lifting the vehicle as normally occurs in concrete-barrier impacts.

The two large-vehicle tests on the concrete barrier in front of the bridge columns--without the box beam--provided strong evidence that this barrier does not provide safe performance for high-angle impacts. In each test, the vehicle climbed to the top of the concrete barrier, developed a very high roll angle, contacted the columns, and rolled over on leaving the barrier. At least a 2-ft clearance behind the barrier face appears necessary to prevent contact with the columns or other rigid objects. This type of behavior has been seen in previous concrete-barrier tests during high-angle impacts (5,6). However, this unsuitable behavior was eliminated by extending the box beam across the front of the piers. A comparison of vehicle redirection with and without the box beam is shown in Figure 11.

Strength of the connection between concrete-barrier sections was also evaluated. The backup posts and continuity connectors were not adequate to provide load transfer in severe impacts (4,500 lb, 60 mph, 25 degrees) and substantial damage to the barrier was experienced. However, with the box beam extended across the concrete barrier joint, adequate load transfer was provided by using the continuity connector and earth backfill. Although the continuity connector was nearly broken out of the barrier in Test 63, addition of the box beam and soil backfill greatly strengthened the system, and the anchorage system used for the connector was entirely adequate without the posts. In Test 78 adequate joint strength was provided by the connector and backfill without either the posts or box beam.

Based on these tests, the following conclusions can be stated:

1. The box-beam concrete-barrier pier-protection system appears to meet NCHRP Report 230 performance criteria when the box beam is extended across the front of the piers.
2. In impacts at 60 mph and 25 degrees, the concrete barrier alone was unable to prevent contact with bridge columns located immediately behind the barrier. At least 2 ft of clearance behind the barrier appears necessary to prevent contact.
3. The continuity connectors and W6x8.5 steel posts provided only marginal strength at the con-

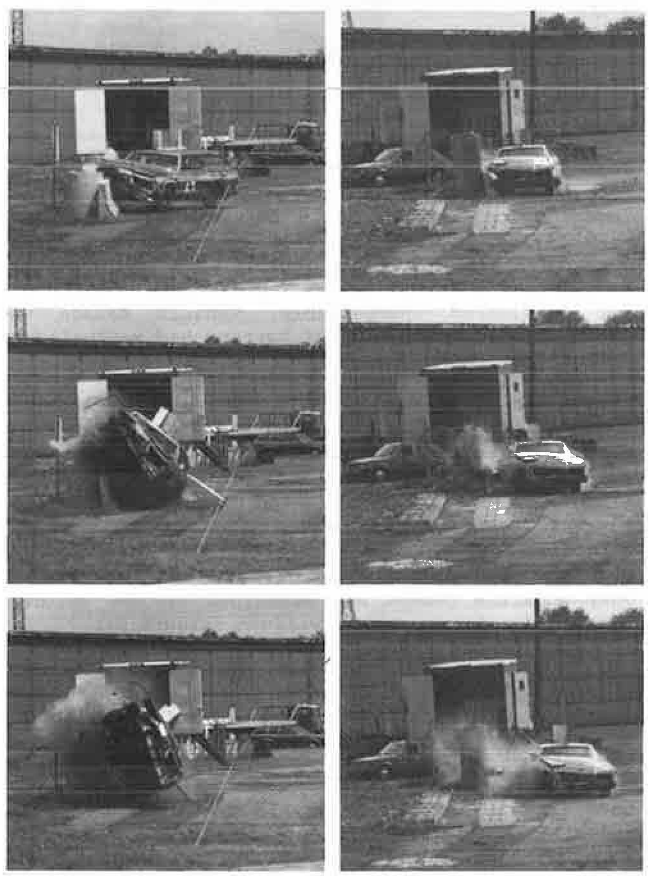

FIGURE 11 Vehicle redirection in Test 63 without box-beam (left) versus Test 77 with box beam (right).

crete barrier joints, because the joint was displaced several inches and the connector broken out by the large-sedan impact.

4. When the box beam was extended across the concrete barrier joint, the continuity connector and earth backfill provided adequate strength without the use of backup posts.

5. Use of carriage bolts instead of hex-head bolts to attach the box-beam rail to the concrete barrier reduced sheet-metal snagging.

6. The 4-ft clearance between the box-beam rail and the end of the concrete barrier is adequate.

For a full explanation of testing procedures, data analysis, and test results, the reader is referred to NYSDOT Research Report 117 (7).

ACKNOWLEDGMENTS

The research reported here was performed under the technical supervision of James E. Bryden. Full-scale tests were supervised by Richard G. Phillips, assisted by James W. Reilly, Jan S. Fortuniewicz, Wayne R. Shrome, Alan W. Rowley, and Robert P. Murray. David R. Kinerson and Wilfred J. Deschamps of the Special Projects Section performed instrumentation work for this project.

Assistance in installing the barriers for this project was provided by NYSDOT Schenectady County Residency under the direction of Edward J. Dannehy and the New York State Thruway Authority under the direction of John Heller. Their support is gratefully acknowledged. Technical assistance was also provided by employees of NYSDOT Facilities Design Division and Structures Design and Construction Division and of the New York State Thruway Authority.

Research reported in this paper was conducted in cooperation with FHWA, U.S. Department of Transportation.

REFERENCES

1. H.E. Ross. Guide to Selecting, Locating, and Designing Traffic Barriers. AASHTO, Washington, D.C., 1977.
2. M.E. Bronstad et al. Concrete Median Barrier Research, Vol. 2: Research Report. Report FHWA-RD-77-4. Southwest Research Institute, San Antonio, Tex., March 1976.
3. J.L. Whitmore, R.G. Picciocca, and W.A. Snyder. Testing of Highway Barriers and Other Safety Accessories. Research Report 38. Engineering Research and Development Bureau, New York State Department of Transportation, Albany, Dec. 1976.
4. J.D. Michie. Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances. NCHRP Report 230. TRB, National Research Council, Washington, D.C., March 1981.
5. K.C. Hahn and J.E. Bryden. Crash Tests of Construction-Zone Traffic Barriers. Research Report 82. Engineering Research and Development Bureau, New York State Department of Transportation, Albany, June 1980.
6. J.S. Fortuniewicz, R.G. Phillips, and J.E. Bryden. Crash Tests of Portable Concrete Median Barrier for Maintenance Zones. Research Report 102. Engineering Research and Development Bureau, New York State Department of Transportation, Albany, Dec. 1982.
7. Roadside Barriers for Bridge Pier Protection. Research Report 117. Engineering Research and Development Bureau, New York State Department of Transportation, Albany, Dec. 1984.

The Connecticut Impact-Attenuation System

JOHN F. CARNEY III, CHARLES E. DOUGAN, and MARTIN W. HARGRAVE

ABSTRACT

The development of a new crash cushion is described. This impact-attenuation device is composed of steel tubular members formed from straight plate sections, which are bolted together to form a cluster. This device is unique in that it will trap an errant vehicle under most impact conditions. The vehicle will be redirected back out into the roadway only when the impact location is so close to the rear of the system that it is impossible to obtain acceptable energy-dissipation and deceleration-trapping responses because of the proximity of the site hazard. No other attenuation system in use today possesses this capability. In addition, the Connecticut impact-attenuation system exhibits the following characteristics: (a) it satisfies the impact performance standards outlined in Transportation Research Circular 191 and NCHRP Report 230, (b) it is inexpensive to fabricate, (c) the energy-dissipating tubes can be refurbished after impact and reused, (d) there is no flying debris associated with the crash event, and (e) it is constructed of readily available materials.