B-17

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SUBJECT

Single Slope Concrete Median Barrier

TO	MESSAGE/COMMENT	FROM/DATE
Safety Program Engineers HEO-01 thru 10	Enclosed are selected portions of a report describing a concrete barrier developed and tested for the Texas Department of Highways and Public Transportation. Its performance is at least equal to the standard concrete safety shape and its increased height and single-sloped face may offer some advantages as noted in the report. We consider this median barrier to be innovative in term of Section 1058 of the ISTEA and it may be used as such on Federal-aid projects if requested by a State Highway agency. Geometric and Roadside Design Acceptance Letter B-17	Richard Powers for S.I. Sillan HNG-14 2/11/92

Revised 3-1-8

TEXAS TRANSPORTATION INSTITUTE

DEVELOPMENT OF A SINGLE SLOPE CONCRETE MEDIAN BARRIER

By

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H. S. Perera and Wanda Campise

REPORT NO. 9429C-1

TEXAS TRANSPORTATION INSTITUTE
THE TEXAS A&M UNIVERSITY SYSTEM
COLLEGE STATION, TEXAS

STATE DEPARTMENT OF HIGHWAYS
AND PUBLIC TRANSPORTATION

INTRODUCTION

Over the past several years, New Jersey concrete median barriers (CMB) have gained widespread acceptance. Further, other types of longitudinal barriers employing the New Jersey shape, including bridge rails and portable barriers, have become very popular. Full scale crash tests have shown that New Jersey longitudinal barriers are capable of smoothly redirecting the standard vehicle tests specified in NCHRP 230 (1) including both the strength and stability tests.

While, the use of the New Jersey CMB has been successful, there are disadvantages with its use. One of the biggest disadvantages is that the profile of the New Jersey shape varies with height above grade. This means that if the roadway is resurfaced, both the height of the barrier and the shape of the barrier will be substantially changed. It may be that the performance of the New Jersey safety shape is not negatively affected by the addition of a few inches of pavement overlay. However, as the thickness of the overlay is increased, the performance of the New Jersey CMB will eventually become unsatisfactory if only because of the reduction of the overall height of the barrier. Therefore, it has become fairly standard practice to reset the New Jersey longitudinal barriers as the pavement height is increased in the overlaying process. This process is both expensive and time consuming.

The purpose of the research presented in this report was to develop a new CMB shape whose performance is not impaired by the application of several inches of pavement overlays. Further, a major effort was made to develop the geometry of the new CMB so that its effect on impacting vehicles is as good as or better than the effect of the New Jersey CMB.

The new barrier shape selected consists of a barrier face with a single slope. This shape was suggested by engineers with the Texas State Department of Highways and Public Transportation (SDHPT). Because the barrier face has a single, constant slope, its performance is not affected by overlaying the adjacent pavement. Rather, the additional pavement overlay serves to anchor the barrier more securely at its base. The performance of the single slope CMB is controlled by its height and slope.

The new single slope CMB can be used in either a temporary or a permanent application. The performance of the new CMB was documented in a series of three crash tests. The first test was conducted to verify that the performance of the barrier is acceptable in a temporary application. The second two tests were accomplished to establish the performance of the barrier in a permanent application as prescribed in NCHRP 230 (1).

The remainder of this report is divided into three major sections. The next section presents a description of the newly developed single slope CMB. This is followed by a section on the full scale testing of the single slope CMB. The final section presents conclusions and recommendations for the use of the single slope CMB.

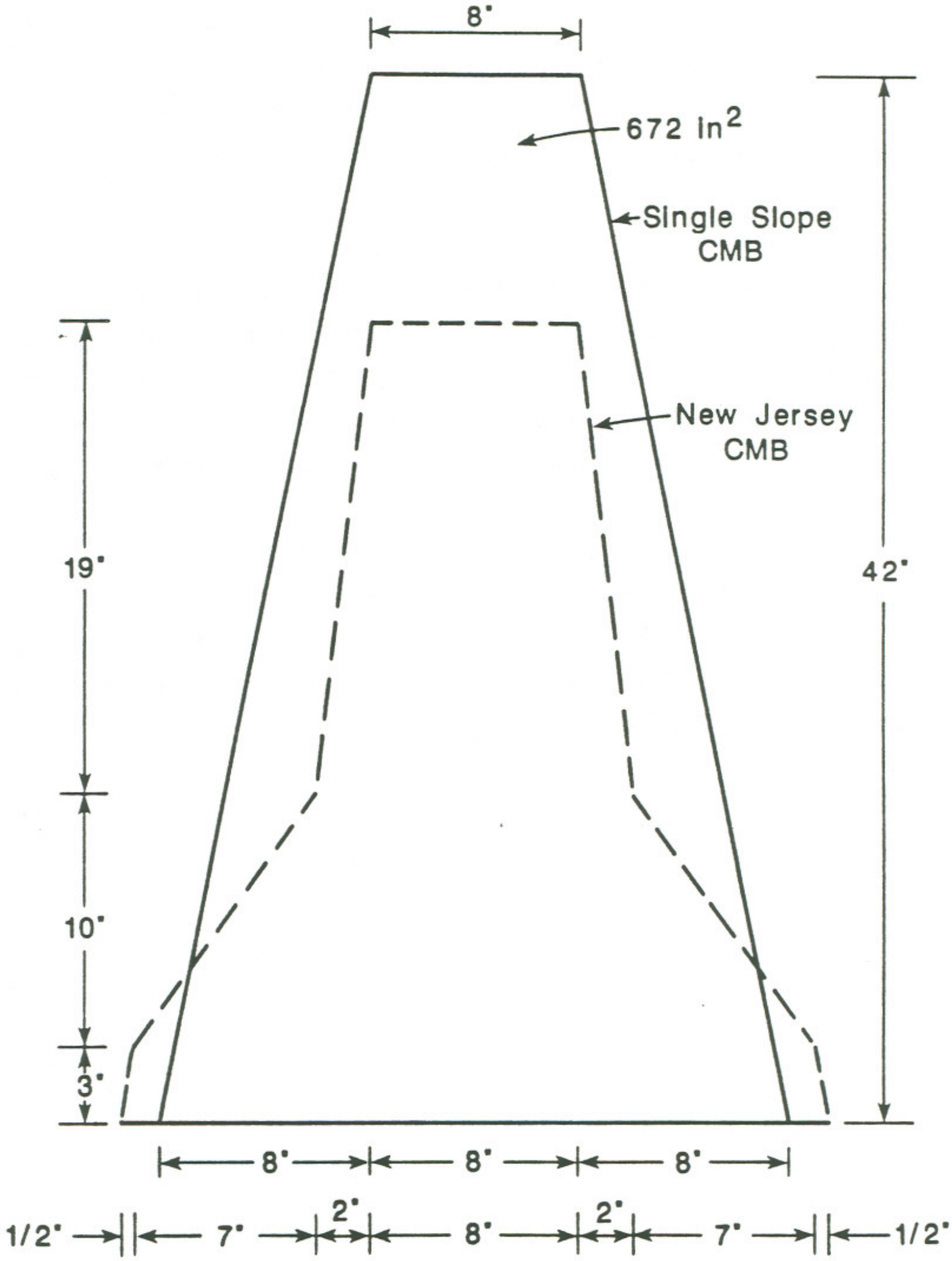


Figure 4. Comparison of Single Slope and New Jersey CMB's.

FULL SCALE CRASH TESTS

Three full-scale crash tests were conducted on the single slope CMB to evaluate its performance with respect to structural adequacy, occupant risk, and vehicle exit trajectory. The first test involved a 4,500 lb (2,043 kg) full-size automobile which impacted the single slope CMB in the temporary configuration. The second and third tests involved a 4,500 lb (2,043 kg) full-size automobile and a 1,800 lb (817 kg) subcompact automobile, respectively. The vehicles in the second and third tests impacted the single slope CMB in the permanent configuration.

The full-scale crash tests were conducted using four 30 ft (9.1 m) single slope CMB segments connected together to form a 120 ft (36.4 m) longitudinal barrier. The four 30 ft (9.1 m) barrier segments in the temporary barrier configuration were positioned on an existing conrete surface at the TTI test track. These barrier segments were joined with the angle splice connection without the reinforcing bar grid. The single slope CMB in the temporary configuration was not attached to the roadway surface in anyway. This installation represents a typical temporary installation.

The four 30 ft (9.1 m) barrier segments in the permanent barrier configuration were positioned on a specially prepared subbase consisting of 2 in (5.1 cm) of type D hot mix asphalt which was placed on top of 4 in (10.2 cm) of compacted crushed limestone. The subbase was specially prepared for this project in an area which is immediately adjacent to the concrete test track. The subbase area was approximately 125 ft (37.9 m) long and 8 ft (2.4 m) wide as shown in Figure 7. The four barrier segments were alligned on the subbase such that the impact surface of the barrier was set back approximately 1 ft (.3 m) from the front of the subbase as shown in Figure 7. Then, the reinforcing bar grids were put into the slots at the ends of the barrier segments. Next, another 1 in (2.54 cm) of type D hot mix asphalt was added to the subbase in front of the barrier and behind the barrier. This final application of asphalt resulted in a 1 ft

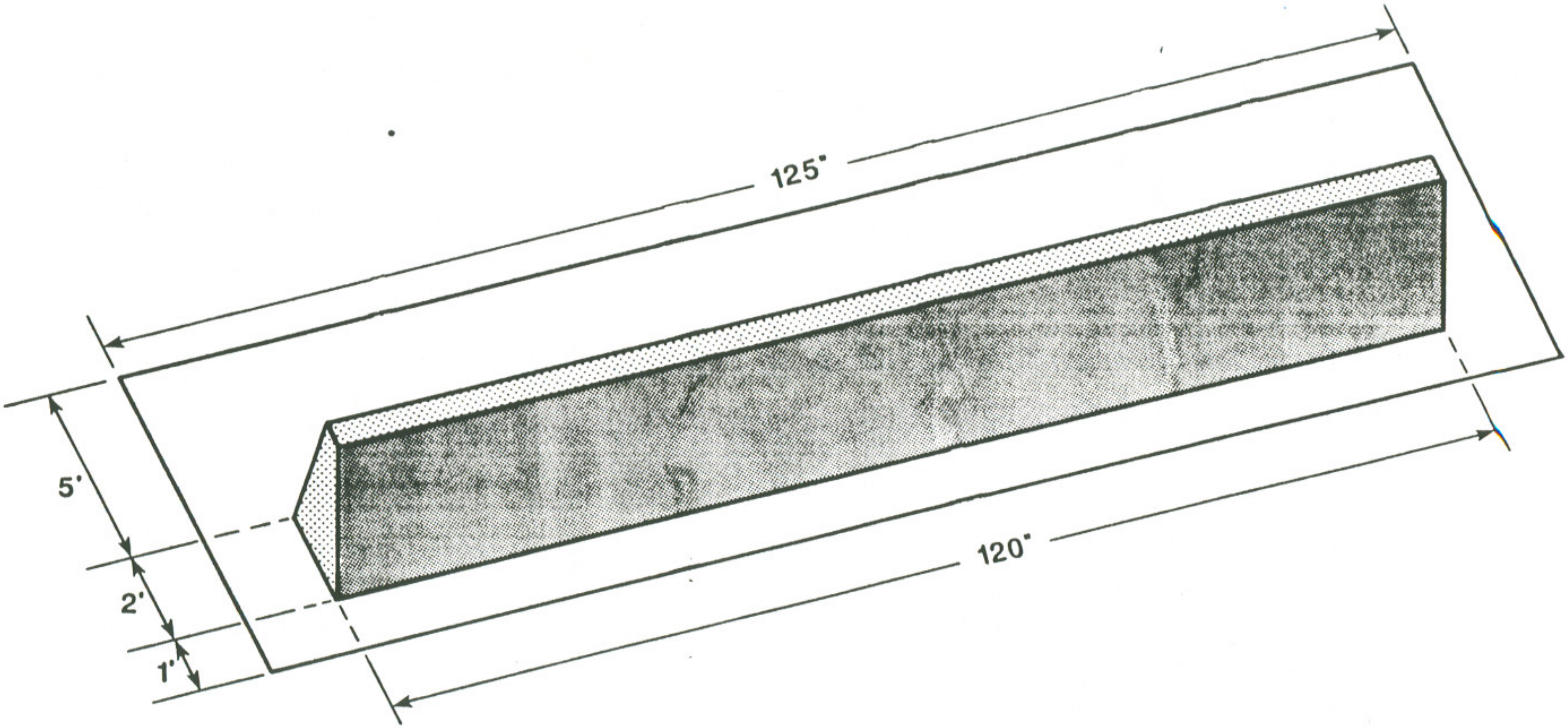


Figure 7. Permanent Single Slope CMB Installation.

(.3 m) wide addition of asphalt on the impact side of the barrier and a 5 ft (1.5 m) wide addition of asphalt on the opposite side of the barrier as shown in Figure 7. Finally, the barrier slots, the gap between the barrier segment ends, and the angle splice insets on the ends of the barrier were all grouted with a mixture of one part sand and two parts cement. The grout was applied so that the 120 ft (36.4 m) barrier had the appearance of a continuous barrier. The use of the angle splice connection in the permanent configuration is optional and it was not used in the permanent installation described in this report.

In all three of the full-scale crash tests, the vehicle impacted the 120 ft (36.4 m) long longitudinal barrier at a point approximately 5 ft (1.5 m) upstream of the middle barrier segment joint. This impact location was chosen to provide the most critical impact situation with respect to both strength and snagging. Test statistics for the three crash tests are summarized in Table 1. Sequential photographs of the tests are presented in Appendix B. Accelerometer traces and plots of roll, pitch, and yaw are presenteed in Appendix C.

Results From Test 9429C-1

In this test, a 1980 Cadillac Sedan DeVille was directed into the single slope CMB deployed in a temporary configuration. Figures 8 and 9 show the vehicle prior to the impact. The vehicle was propelled into the barrier using a reverse tow and guidance system. Figure 10 presents the temporary barrier prior to the impact. The test inertia mass of the vehicle was 4,500 (2,043 kg). The height to the lower edge of the vehicle bumper was 12.5 in (31.8 cm) and it was 21.0 in (53.3 cm) to the top of the bumper. Other dimensions and information on the test vehicle are presented in Figure 11. The vehicle was free-wheeling and unrestrained just prior to the impact.

The speed of the vehicle at impact was 60.3 mi/h (97.0 km/h) and the

Table 1. Summary of crash test results

Test No.	9429C-1	9429C-2	9429C-3
Vehicle Weight, lb (kg)	4500(2043)	1800(817)	4500(2043)
Impact Speed, mi/h (km/hr)	60.3(97.0)	60.7(97.7)	63.1(101.5)
Impact Angle, degrees	15.2	19.9	26.5
Exit Angle, degrees	0.5	4.3	8.5
Displacement, in (cm)	7.0(17.8)	0.0(0.0)	0.0(0.0)
Occupant Impact Velocity ft/s (m/s)			
Longitudinal	14.4(4.4)	15.7(4.8)	22.1(6.7)
Lateral	17.6(5.4)	27.7(8.4)	28.9(8.8)
Occupant Ridedown Acceleration g's			
Longitudinal	-2.5	-2.3	-4.2
Lateral	-7.7	-9.2	-10.7
Vehicle Damage Classification			
TAD	11LFQ4	11LFQ5	11LFQ5
CDC	11FLEK2& 11LFEW3	11LFEW3	11LFAW3

angle of impact was 15.2 degrees. The vehicle impacted the barrier approximately 55 ft (16.8 m) from the upstream end of the barrier. The left front wheel of the vehicle made contact with the barrier at approximately 0.029 seconds after impact and shortly thereafter the tire began to ride up the face of the barrier. The vehicle began to redirect at 0.049 seconds. At about 0.160 seconds, the rear of the vehicle struck the barrier and by 0.173 seconds the vehicle was travelling parallel to the barrier at a speed of 51.9 mi/h (83.5 km/h). The vehicle lost contact with the barrier at 0.462 seconds travelling at a velocity of 51.3 mi/h (82.5 km/h) and with an angle of 0.5 degrees away from the barrier. The brakes were then applied and the vehicle yawed in a counter-clockwise direction and subsequently came to rest 240 ft (73 m) from the point of impact. Sequential photographs of the impact are shown in Figure 33 in Appendix B.

As shown in Figures 12 and 13, the barrier received only minimal cosmetic damage. There were tire marks on the face of the barrier to a maximum height of 31 in (79 cm). The bumper scraped the barrier at a height of 42 in (107 cm). The vehicle was in contact with the barrier for 17 ft (5.2 m). The maximum lateral movement of the barrier was 7 in (17.8 cm) at the middle joint of the barrier.

The vehicle sustained moderate damage to the left side as shown in Figures 14 and 15. Maximum crush at the left front corner at bumper height was 12.0 in (30.7 cm). The left front rim was bent and the tire damaged. There was damage to the hood, grill, bumper, left front quarter panel, the left front and rear doors, the left rear quarter panel and the rear bumper.

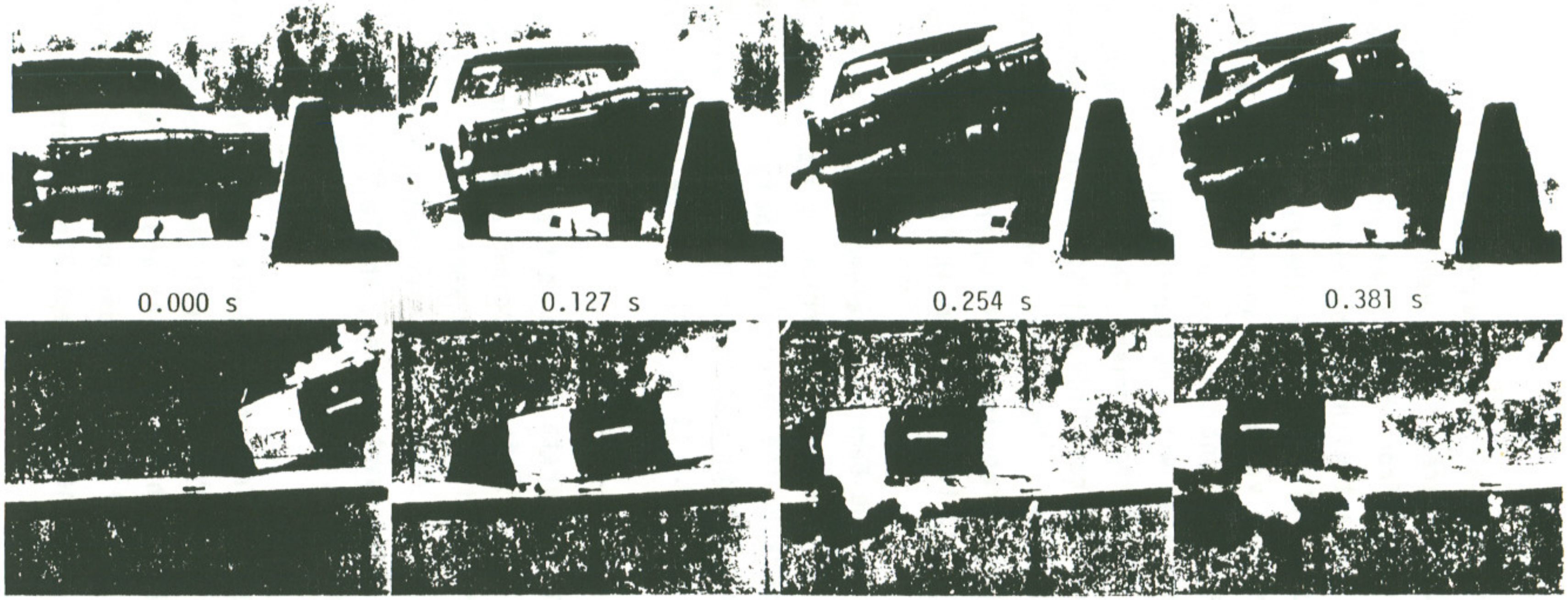
As stated previously the impact speed was 60.3 mi/h (97.0 km/h) and the angle of impact was 15.2 degrees. The vehicle lost contact with the barrier travelling at 51.3 mi/h (82.5 km/h) and 0.5 degrees. NCHRP 230 describes occupant risk evaluation criteria and places limits on these for acceptable performance for tests conducted with 1,800 lb (817 kg) vehicles (1). These limits do not apply to tests conducted with 4,500 lb (2,043 kg) vehicles but were computed and reported for information only. The occupant impact velocity was 14.4 ft/s (4.4 m/s) in the longitudinal direction and 17.6 ft/s (65.4 m/s) in the lateral direction. The highest 0.010 second occupant ridedown accelerations were -2.5 g (longitudinal) and -7.7 g (lateral). These data and other pertinent information from the test are summarized in Figure 16.

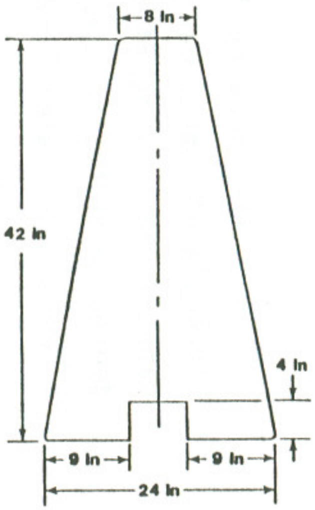
Vehicular angular displacements are displayed in Figure 36 of Appendix B. Vehicular accelerations versus time traces filtered at 300 Hz are presented in Figures 37 through 39 in Appendix C. These data were further analyzed to obtain the 0.050 second average accelerations. The maximum 0.050 second average accelerations measured near the vehicle center-of-gravity were -3.3 g (longitudinal) and -6.8 g (lateral).

These test results show that the barrier contained and smoothly redirected the test vehicle with little lateral movement of the barrier. There was no intrusion into the occupant compartment and minimal deformation of the occupant compartment. The vehicle remained upright and relatively stable during the collision. The vehicle trajectory at loss of contact indicates minimum intrusion into the adjacent traffic lanes.

Results From Test 9429C-2

In this test, a 1980 Honda Civic was directed into the single slope barrier deployed in a permanent configuration using a reverse tow and guidance system. Figure 17 presents the vehicle prior to the impact. Figures 18 and 19 show the single slope CMB in the permanent configuration prior to the impact. The test inertia mass of the vehicle was 1,800 lb (817 kg). The height to the lower edge of the vehicle bumper was 13.5 in (34.3 cm) and it was 18.5 in (47.0 cm) to the top of the bumper. Other dimensions and information on the test vehicle are given in Figure 20. The vehicle was free wheeling and unrestrained just prior to impact.





Test No.	9429C-1
Date	11/22/88
Test Installation . .	Single Slope Concrete Barrier
Installation Length. .	120 ft (36.6 m)
Vehicle	1980 Cadillac Sedan DeVille
Vehicle Weight	
Test Inertia	4,500 lb (2,043 kg)
Vehicle Damage Classification	
TAD	11LFQ4
CDC	11FLEK2 & 11LFEW3
Maximum Vehicle Crush.	12.0 in (30.5 cm)
Max. Barrier Movement.	7.0 in (17.8 cm)

Impact Speed. . .	60.3 mi/h (97.0 km/h)
Impact Angle. . .	15.2 deg
Exit Speed. . . .	51.3 (82.5 km/h)
Exit Trajectory .	0.5 deg
Vehicle Accelerations (Max. 0.050-sec Avg)	
Longitudinal. .	-3.3 g
Lateral	-6.8 g
Occupant Impact Velocity	
Longitudinal. .	14.4 ft/s (4.4 m/s)
Lateral	17.6 ft/s (5.4 m/s)
Occupant Ridedown Accelerations	
Longitudinal. .	-2.5 g
Lateral	-7.7 g

Figure 16. Summary of results for test 9429C-1.

The speed of the vehicle at impact was 60.7 mi/h (97.7 km/h) and the angle of impact was 19.9 degrees. The vehicle impacted the barrier approximately 55 ft (16.7 m) from the upstream end of the barrier. The left front wheel made contact with the barrier at approximately 0.016 seconds after impact and shortly thereafter the tire began to be pushed up the face of the barrier. The vehicle began to redirect at 0.034 seconds and at 0.076 seconds the left front tire aired out. By 0.129 seconds, the vehicle was travelling parallel with the barrier and at about 0.134 seconds the rear of the vehicle struck the barrier. The vehicle lost contact with the barrier at 0.273 seconds travelling at 52.1 mi/h (83.8 km/h) and 4.3 degrees away from the barrier. The brakes were then applied and the vehicle subsequently came to rest 160 ft (49 m) from the point of impact. Sequential photographs of this test are shown in Figure 34 of Appendix B.

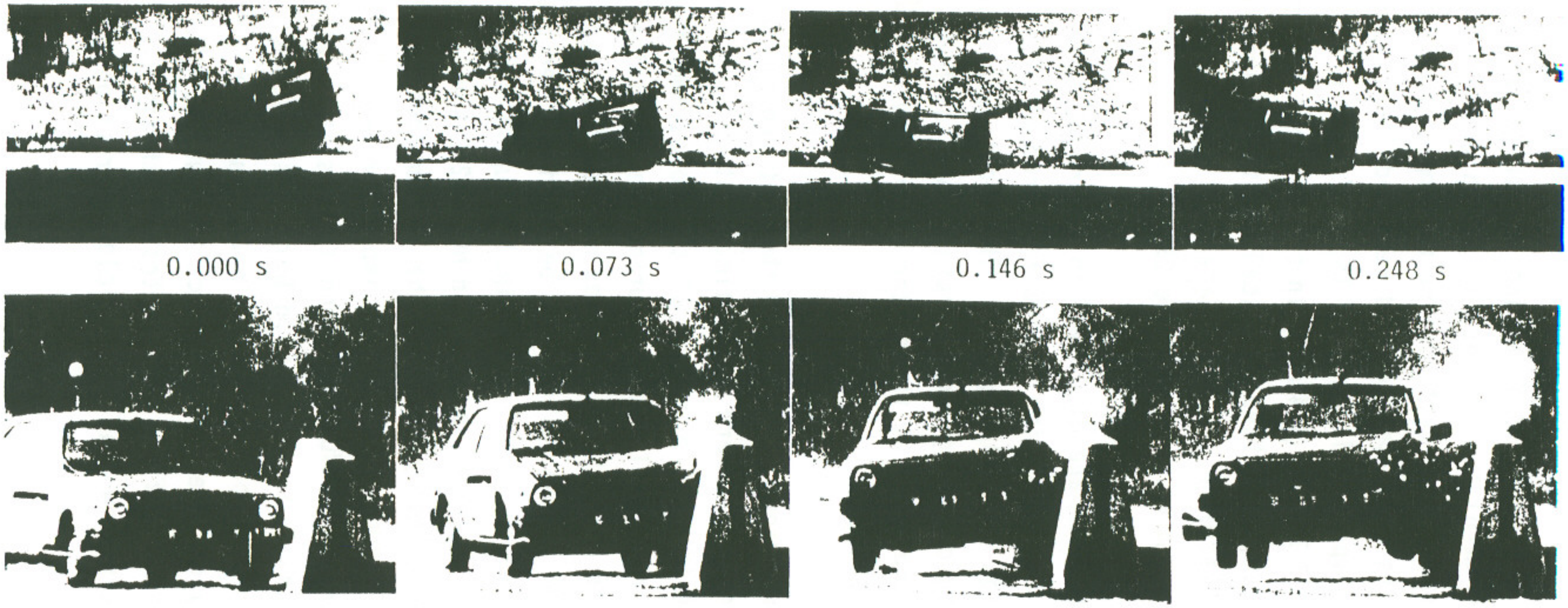
As shown in Figure 21, the barrier received minimal cosmetic damage. There were tire marks on the face of the barrier to a maximum height of 24 in (61 cm). The bumper scraped the barrier at a height of 30 in (776 cm) and there were sheet metal scrapings at 35 in (89 cm). The vehicle was in contact with the barrier for 9.5 ft (2.9 m). There was no discernable movement of the barrier.

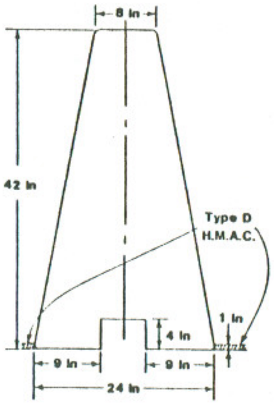
The vehicle sustained moderate damage to the left side as shown in Figure 22. Maximum crush at the left front corner at bumper height was 7.0 in (17.8 cm). The left front and rear struts were damaged, the left front rim was bent, and the tire was damaged. There was damage to the hood, grill, front bumper, left front quarter panel, the left door, the left rear quarter panel and the rear bumper.

As stated previously, the impact speed was 60.7 mi/h (97.7 km/h) and the angle of impact was 19.9 degrees. The vehicle lost contact with the barrier travelling at 52.1 mi/h (83.8 km/ h) and with an angle of 4.3 degrees with the barrier. NCHRP 230 describes occupant risk evaluation criteria and places limits on these for acceptable performance for tests conducted with 1,800 lb (817 kg) vehicles impacting longitudinal barriers with a speeds of 60 mph (96 km/h) and angles of 15 degrees (1). These limits do not apply to this particular test because the impact angle was 20 degrees. However, these limits were computed and reported for information purposes only. The occupant impact velocity was 15.7 ft/s (4.8 m/s) in the longitudinal direction and 27.7 ft/s (8.4 m/s) in the lateral direction. The highest 0.010 second occupant ridedown accelerations were -2.3 g (longitudinal) and -9.2 g (lateral). These data and other pertinent information from the test are summarized in Figure 23.

Vehicle angular displacements are displayed in Figure 40 in Appendix B. Vehicular accelerations versus time traces filtered at 300 Hz are presented in Figures 41 through 43 in Appendix B. These data were further analyzed to obtain 0.050 second average accelerations versus time. The maximum 0.050 second averages measured at the center-of-gravity were -6.5 g (longitudinal) and -15.3 g (lateral).

The barrier contained and smoothly redirected the test vehicle with no lateral movement of the barrier. There was minimal intrusion into the occupant compartment and minimal deformation of the compartment. The vehicle remained upright and relatively stable during the collision. The vehicle trajectory at the loss of contact indicates minimum intrusion into adjacent traffic lanes with the change in velocity being within recommended NCHRP limits for a 15 degree impact. The longitudinal occupant/compartment impact velocity was within the limit recommended in NCHRP 230 for 15 degree impacts. The lateral impact velocity exceeded the recommended NCHRP 230 limit for 15 degree impacts. However, the lateral impact velocity was less than the limiting value presented in NCHRP 230 and is consistent with the performance of other vehicles impacting rigid barriers under similar conditions (6,7). It should also be noted that new impact performance standards are currently being considered to replace the current NCHRP 230 criteria (8). Finally, comparisons of the current tests with similar tests conducted on New Jersey barriers show that the vehicle redirection with the





Test No. 9429C-2
Date 12/05/88
Test Installation . . Single Slope Concrete Barrier
Installation Length. . 120 ft (36.6 m)
Vehicle . . . . 1980 Honda Civic
Vehicle Weight
  Test Inertia . . . . . 1,800 lb (817 kg)
Vehicle Damage Classification
  TAD 11LFQ5
  CDC 11LFEW3
Maximum Vehicle Crush. 7.0 in (17.8 cm)

Impact Speed. . . 60.7 mi/h (97.7 km/h)
Impact Angle. . . 19.9 deg
Exit Speed. . . . 52.1 (83.8 km/h)
Exit Trajectory . 4.3 deg
Vehicle Accelerations
  (Max. 0.050-sec Avg)
  Longitudinal. . -6.5 g
  Lateral . . . . -15.3 g
Occupant Impact Velocity
  Longitudinal. . 15.7 ft/s (4.8 m/s)
  Lateral . . . . 27.7 ft/s (8.4 m/s)
Occupant Ridedown Accelerations
  Longitudinal. . -2.3 g
  Lateral . . . . -9.2 g

Figure 23. Summary of results for test 9429C-2.

new single slope barier is more stable than similar impacts with the New Jersey shape barriers.

Results From Test 9429C-3

This test involved the impact of a 1979 Caddilac Sedan deVille as shown in Figure 24. The vehicle was directed into the barrier using a reverse tow and guidance system. Figure 25 presents the single slope barrier prior to the impact. The barrier shown in Figure 25 is the same barrier used in the previous test with paint added for cosmetic purposes. The test inertia mass of the vehicle was 4,500 lb (2,043 kg). The height to the lower edge of the vehicle bumper was 12.0 in (30.5 cm) and it was 23.0 in (58.4 cm) to the top of the bumper. Other dimensions and information on the test vehicle are presented in Figure 26. The vehicle was free-wheeling and unrestrained just prior to impact.

The speed of the vehicle at impact was 63.1 mi/h (101.5 km/h) and the angle of impact was 26.5 degrees. The vehicle impacted the barrier approximately 54 ft (16.5 m) from the upstream end of the barrier. The left front wheel made contact with the barrier at approximately 0.024 seconds after impact and shortly thereafter the tire began to be pushed up the face of the barrier. The vehicle began to redirect at 0.034 seconds and at about 0.171 seconds the rear of the vehicle struck the barrier. The left side of the vehicle became airborne at 0.188 seconds. By 0.198 seconds the vehicle was travelling parallel with the barrier at a speed of 53.2 mi/h (85.6 km/h). The vehicle became completely airborne at 0.295 seconds. While still airborne, the vehicle lost contact with the barrier at 0.360 seconds travelling at 51.8 mi/h (83.3 km/h) and 8.5 degrees away from the barrier. The right front tire touched ground at 0.726 seconds after impact. The brakes were then applied and the vehicle subsequently came to rest 165 ft (50 m) from the point of impact. Sequential photographs of this test are presented in Figure 35 in Appendix B.

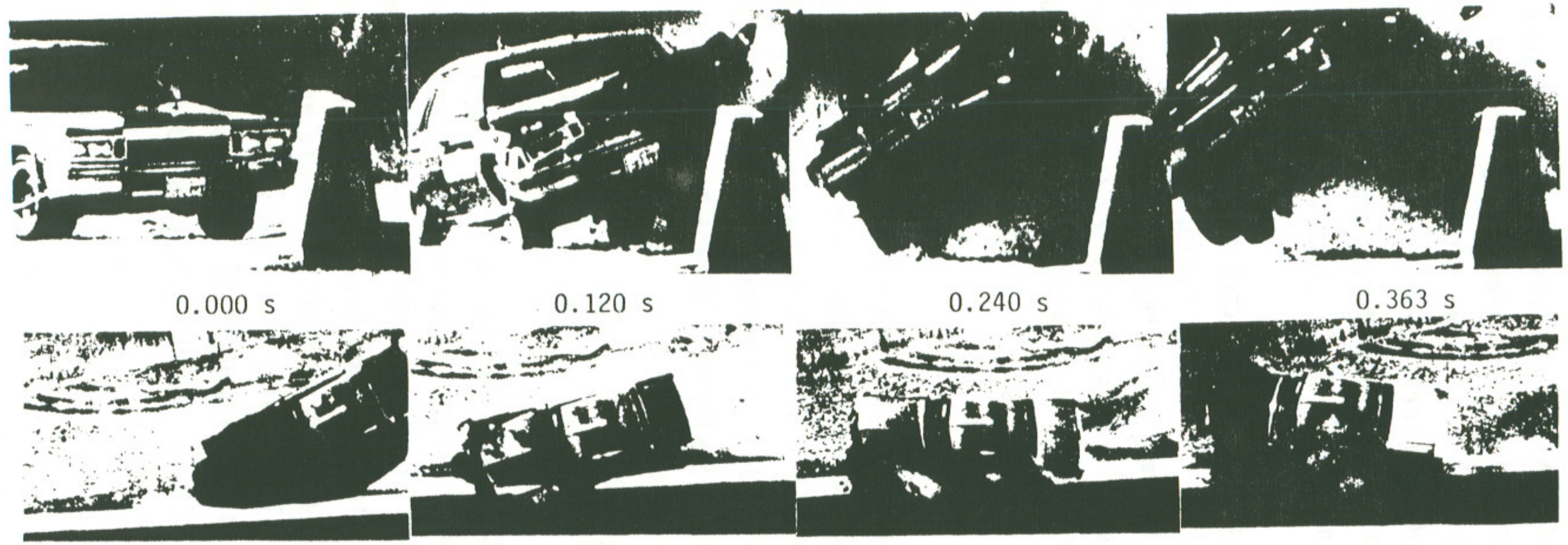
As shown in Figure 27, the barrier received minimal cosmetic damage. There were tire marks on the face of the barrier to a maximum height of 34 in (86 cm). The bumper scraped the barrier at a height of 40 in (102 cm) and there were sheet metal scrapings to the top of the barrier. Examinations of the high speed movies and direct measurements of the markings on the barrier show that center of the automobile wheel hub rose to a height of 26-30 in (66-76 cm) before losing contact with the barrier. The vehicle was in contact with the barrier for 13 ft (4 m). There was no discernable movement of the barrier.

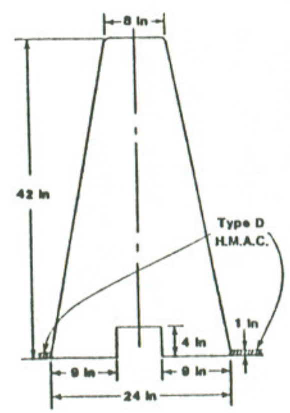
The vehicle sustained severe damage to the left side as shown in Figures 28 and 29. Maximum crush at the left front corner at bumper height was 12.0 in (30.5 cm). The floorpan and subframe were bent and the left side of the rear axle was damaged. The left front rim was bent and the tire was damaged. There was damage to the hood, grill, radiator and fan, front bumper, left front quarter panel, the left front and rear doors, the left rear quarter panel, and the rear bumper. The right front quarter panel was bent when the front of the vehicle shifted to the right about 5 in (13 cm).

As stated previously, the impact speed was 63.1 mi/h (101.5 km/h) and the angle of impact was 26.5 degrees. The vehicle lost contact with the barrier travelling at 51.8 mi/h (83.3 km/h) and 8.5 degrees. NCHRP 230 describes occupant risk criteria and places limits on these for acceptable performance for tests involving 1,800 lb (817 kg) impacting at 15 degrees with a velocity of 60 mph (96 km/h) (1). These limits do not apply to tests conducted at 25 degree impact angles but were computed and reported for information only. Occupant impact velocity was 22.1 ft/s (6.7 m/s) in the longitudinal direction and 28.9 ft/s (8.8 m/s) in the lateral direction. The highest 0.010 second occupant ridedown accelerations were -4.2 g (longitudinal) and -10.7 g (lateral). These data and other pertinent information from the test are summarized in Figure 30.

report.

Another advantage of the new single slope barrier is that the redirection of the 1,800 lb (817 kg) vehicle appeared to be much more stable than analogous redirections observed with the New Jersey CMB (6). While further study is required to make a definitive statement on this matter it is believed that the new single slope CMB will result in fewer rollover crashes than occur with the New Jersey CMB. This is particularly





Test No.	9429C-3	Impact Speed. . .	63.1 mi/h (101.5 km/h)
Date	12/12/88	Impact Angle. . .	26.5 deg
Test Installation . .	Single Slope Concrete Barrier	Exit Speed. . . .	51.8 (83.3 km/h)
		Exit Trajectory .	8.5 deg
Installation Length. .	120 ft (36.6 m)	Vehicle Accelerations (Max. 0.050-sec Avg)	
Vehicle	1979 Cadillac Sedan deVille	Longitudinal. .	-6.4 g
Vehicle Weight		Lateral	-13.1 g
Test Inertia	4,500 lb (2,043 kg)	Occupant Impact Velocity	
Vehicle Damage Classification		Longitudinal. .	22.1 ft/s (6.7 m/s)
TAD	11LFQ5	Lateral	28.9 ft/s (8.8 m/s)
CDC	11LFAW3	Occupant Ridedown Accelerations	
Maximum Vehicle Crush.	12.0 in (30.5 cm)	Longitudinal. .	-4.2 g
		Lateral	-10.7 g

Figure 30. Summary of results for test 9429C-3.

true with nontracking, high angle, low velocity impacts of small vehicles.

A total of three full-scale tests were conducted on the new single slope CMB. The first test involved a 4,500 lb (2043 kg) impacting the new barrier in a temporary configuration. The second and third tests involved an 1,800 lb (817 kg) automobile and a 4,500 lb (2043 kg) automobile. In all cases the vehicles were smoothly redirected with no snagging. Results from these tests were within acceptable limits for roll, pitch, yaw, acceleration as described in NCHRP 230 (1). As such the new single slope CMB is recommended for immediate use.