Single-Slope Concrete Median Barrier

W. LYNN BEASON, H. E. ROSS, JR., H. S. PERERA, AND MARK MAREK

A single-slope concrete median barrier has been developed for use as either a permanent concrete median barrier or as a temporary barrier. It is designed to meet accepted criteria for the performance of longitudinal barriers and to be used in applications in which the New Jersey concrete median barrier would normally be employed. The primary advantage of the new barrier is that the pavement adjacent to it can be overlaid several times without changing the performance of the barrier. This should help to reduce the maintenance costs associated with its use. The performance of the new barrier is documented with the presentation of results from four full-scale crash tests. These tests were conducted with the new single-slope concrete median barrier deployed in both permanent and temporary configurations.

Over the past several years, the New Jersey concrete median barrier (CMB) has 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 the New Jersey longitudinal barrier is capable of meeting the requirements specified in National Cooperative Highway Research Program Report 250 (1), including both strength and stability requirements.

Although the use of the New Jersey CMB has been successful, there are disadvantages associated with its use. One of the biggest of these 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 face will be changed. As the thickness of the overlay is increased, the performance of the New Jersey CMB will become unsatisfactory, if only because of the reduction of the overall height of the barrier. Therefore, New Jersey CMBs must be reset as the pavement height is increased in the overlaying process. The resetting process is both expensive and time consuming.

The purpose of the research presented in this paper was to develop a new CMB shape, the performance of which would not be 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 vehicles striking it is equivalent to the effect of the New Jersey CMB under similar circumstances as determined through the use of computer simulations (2).

The new barrier has a single-slope face. This shape was suggested by engineers with the Texas State Department of Highways and Public Transportation (SDHPT) (2). Because the barrier face has a single, constant slope, the shape of the barrier face is not affected by overlaying the adjacent pavement. Rather, the additional pavement overlay serves to anchor the barrier more securely at its base, thus increasing its resistance to lateral impact forces. The new single-slope CMB can be used in both temporary and permanent applications. The performance of the single-slope CMB was examined in a series of four full-scale crash tests. The first test was conducted to verify that the performance of the barrier is acceptable in a temporary application. The second and third tests were conducted to establish the performance of the barrier in a permanent application. The fourth test was conducted to establish the performance of the single-slope CMB in an alternate temporary configuration.

The remainder of this paper is divided into three major sections. In the next section, a brief description of the newly developed single-slope CMB is presented. 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.

DEVELOPMENT OF THE SINGLE-SLOPE CMB

The objective of the research presented in this paper was to develop a single-slope CMB. The design of the single-slope CMB is based on the results of a series of computer simulations and engineering judgments, as discussed in the following paragraphs.

The initial geometric constraints were that the single-slope CMB should be 42 in. (106.7 cm) tall, with a flat top that is a minimum of 8 in. (20.3 cm) wide. In addition, it was required that the impact face of the single-slope CMB incorporate a constant slope.

It is known that a rigid barrier with a vertical face results in the minimum vehicle instability during impact. Vertical face rigid barriers have undergone extensive testing with a variety of different vehicles ranging from compact automobiles to tractor-trailers (3, 4). Computer simulations and practical experience suggest that as the angle of the barrier face (measured with respect to the vertical) is increased, vehicles striking it will be subjected to increasing instabilities. If the angle of the barrier face becomes large enough, the vehicle instabilities will lead to ramping or vehicle roll-over, or both.

Vehicles are clearly more stable during impacts with vertical, rigid barriers, but it is possible that a vehicle striking a tall, vertical barrier will be subjected to accelerations that are large enough to cause the heads of the occupants to be propelled through the vehicle side windows and against the barrier. This behavior has been observed in crash tests that incorporated anthropomorphic dummies. The angle of the barrier face was set so that an impacting vehicle will roll away from the barrier to prevent this phenomenon.

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Although the design of the single-slope barrier was not based solely on the results of computer simulations, such results were used to study the effect of the barrier slope on the vehicle redirection characteristics. The computer program used to evaluate the performance of the single-slope CMB was Highway-Vehicle-Object-Simulation-Model (HVOSM) (5). The version of HVOSM used in this study was the RD2 version, which incorporates modifications developed by researchers at the Texas Transportation Institute (TTI). The TTI modifications permit the structure of the vehicle to interact with a multi-faced rigid barrier. Studies of rigid New Jersey CMBs made with this modified version of HVOSM have been reasonably successful (6,7). Therefore, the RD2 version of HVOSM was used to study the effects of various barrier face angles on the performance of the single-slope CMB.

The performance of rigid longitudinal barriers is evaluated by the stability of the vehicle after impact and the severity of the occupant impact forces. The roll angle of the vehicle is an important measure of vehicle stability and occupant impact velocity is controlled to limit occupant impact forces. Large barrier face angles (measured from the vertical) increase the propensity for the vehicle to become unstable, whereas small angles increase occupant impact velocities. The objective of the computer simulation study was to provide critical input into the selection of a barrier face angle that results in vehicle roll angles and occupant impact velocities that are similar to those associated with the New Jersey CMB.

The HVOSM program was first used to simulate various barrier impacts involving a 4,500-lb (2,043-kg) automobile with a speed of 60 mph (96 km/h) and an impact angle of 25 degrees. The performance of a New Jersey CMB and a set of rigid single-slope CMBs with various barrier face angles was examined. The 42-in. (106.7-cm) high single-slope barriers, examined with the computer simulations, contained horizontal offsets of 0 in. (0 cm), 4 in. (10.2 cm), 8 in. (20.3 cm), and 12 in. (30.5). These geometries resulted in single-slope barriers with angles of 0, 5.4, 10.8, and 14 degrees measured from the vertical. Maximum roll angles and occupant impact velocities determined using the HVOSM program are presented in Table 1 for these conditions.

The HVOSM program was next used to simulate barrier impacts involving an 1,800-lb (817-kg) automobile with a speed of 60 mph (96 km/h) and an impact angle of 20 degrees. The maximum roll angles and the occupant impact velocities determined using the HVOSM program for this latter vehicle type are presented in Table 2.

The primary use of the data presented in Tables 1 and 2 was to provide a mechanism for relative comparisons of the performance of the different barriers. Computer simulations are not yet sophisticated enough so that a barrier design can be based solely on computer simulation data. Further, it would be naive to believe that the computer simulation results should agree precisely with full-scale crash test results.

Examinations of the simulation data contained in Tables 1 and 2 show that a single-slope CMB with a barrier face angle of 10.8 degrees results in an overall barrier-vehicle interaction that is reasonably similar to that achieved with the New Jersey CMB. Based on these data, engineering judgment, and the initial geometric constraints, it was determined that the single-slope CMB should have a base width of 24 in. (61 cm), a top width of 8 in. (20.3 cm), and a height of 42 in. (106.7 cm), as shown in Figure 1. This conclusion was reinforced by simplified approximate analyses and the collective judgment of the TTI research staff.

A comparison of the cross-section properties of the single-slope CMB and the New Jersey CMB is presented in Figure 2. The single-slope CMB is approximately 30 percent taller than the New Jersey CMB. The weight of the single-slope CMB is about 675 lb/ft (1,000 kg/m). This estimated weight is approximately 40 percent more than the New Jersey CMB. The weight increase is a result of the increased barrier height. The resistance to overturning provided by the dead weight of the single-slope CMB is approximately 20 percent more than that shown for the New Jersey CMB. Finally, the center of gravity of the single-slope CMB, which is approximately 18 in. (45.7 cm), is much closer to the center of gravity of typical automobiles than the center of gravity of the New Jersey CMB, which is approximately 11.5 in. (29.2 cm). All of these geometric factors combine to suggest that the single-slope CMB should display a better impact performance than the New Jersey CMB, particularly in the temporary configuration.

Construction details of the single-slope CMB are presented in Figure 3. It is recommended that the single-slope CMB be fabricated in 30 ft (9.1 m) lengths. Two steel pipes are embedded in the barrier segments approximately at the quarter points to facilitate handling of the barrier. The procedure for lifting the barrier involves the insertion of steel lifting bars through the steel pipes. Chains are then draped around the lifting bars.

<table>
<thead>
<tr>
<th>Barrier Type</th>
<th>Maximum Roll Angle</th>
<th>Occupant Impact Velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>degrees</td>
<td>ft/s (m/s) Longitudinal</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>New Jersey CMB</td>
<td>20</td>
<td>15.3 (5.0) 20.6 (6.3)</td>
</tr>
<tr>
<td>Vertical Single-Slope CMB</td>
<td>26</td>
<td>18.5 (5.6) 21.3 (6.5)</td>
</tr>
<tr>
<td>5.4 Degree Single-Slope CMB</td>
<td>26</td>
<td>17.4 (5.3) 22.7 (6.9)</td>
</tr>
<tr>
<td>10.8 Degree Single-Slope CMB</td>
<td>24</td>
<td>15.9 (4.8) 21.3 (6.5)</td>
</tr>
<tr>
<td>14 Degree Single-Slope CMB</td>
<td>38</td>
<td>13.7 (4.2) 20.1 (6.1)</td>
</tr>
</tbody>
</table>
TABLE 2  COMPUTER SIMULATION RESULTS FOR SUBCOMPACT AUTOMOBILE

<table>
<thead>
<tr>
<th>Barrier Type</th>
<th>Maximum Roll Angle degrees</th>
<th>Occupant Impact Velocity ft/s (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>New Jersey CMB</td>
<td>20</td>
<td>11.9 (3.6) 21.4 (6.5)</td>
</tr>
<tr>
<td>Vertical Single-Slope CMB</td>
<td>11</td>
<td>13.9 (4.2) 20.2 (6.2)</td>
</tr>
<tr>
<td>5.4 Degree Single-Slope CMB</td>
<td>16</td>
<td>15.8 (4.8) 22.4 (6.8)</td>
</tr>
<tr>
<td>10.8 Degree Single-Slope CMB</td>
<td>13</td>
<td>12.2 (3.7) 20.7 (6.3)</td>
</tr>
<tr>
<td>14 Degree Single-Slope CMB</td>
<td>31</td>
<td>11.8 (3.6) 20.5 (6.2)</td>
</tr>
</tbody>
</table>

and the barrier is moved with either two pieces of light lifting equipment or a single piece of heavy lifting equipment. In the current project the barrier segments were moved with two forklift machines with approximately the same ease as moving similar 30 ft (9.1 m) segments of the New Jersey CMB.

The ends of the single-slope CMB segments are equipped with provisions for two different types of connections. The first involves the use of external steel angles that are attached to the barrier segment ends with specially fabricated bolts, as shown in Figures 3 and 4. This angle-splice connection is for use with temporary connections and is not required when the barrier is installed in the permanent configuration.

The second connection detail involves a slot that is cast into both ends of the barrier segments, as shown in Figure 3. A permanent connection is made by inserting a reinforcing bar grid into the slots of both ends of mating barrier segments and filling the slots and the space between the barrier ends with grout. The permanent installation is completed by locking the barrier segment into place with a minimum of 1 in. (2.54 cm) of asphalt overlay placed next to both faces of the barrier.

An alternative temporary connection can be accomplished by inserting the reinforcing bar grid into the slots without using the grout. Although this temporary connection is not as strong as the angle-splice connection, it is adequate for temporary applications.

FULL-SCALE CRASH TESTS

Four full-scale crash tests were conducted to evaluate the performance of the single-slope CMB for structural adequacy, occupant risk, and vehicle exit trajectory. The first test involved a 4,500-lb (2,043-kg) full-size automobile that struck the single-slope CMB in the angle-splice temporary configuration. The second and third tests involved a 4,500-lb (2,043-kg) full-size automobile and an 1,800-lb (817-kg) subcompact
FIGURE 3 Construction details for single-slope CMB.
automobile, respectively. The vehicles in the second and third tests struck the single-slope CMB deployed in the permanent configuration. The fourth test involved a 4,500-lb (2,043-kg) full-size automobile that struck the single-slope CMB in the alternate temporary configuration.

A total of six 30-ft (9.1-m) single-slope barrier segments were fabricated for testing. The first three 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 fourth full-scale crash test was conducted using all six of the 30-ft (9.1-m) CMB segments for an overall length of 180 ft (54.6 m).

In all of the full-scale crash tests, the vehicle struck the longitudinal barrier at a point approximately 5 ft (1.5 m) upstream of the middle barrier segment joint. This impact point was chosen to provide the most critical impact situation for both strength and snagging.

Test results show that the single-slope CMB, in all configurations, contained and smoothly redirected the test vehicles with minimal lateral movement in the temporary configurations and no lateral movement in the permanent configuration. There were no intrusions into occupant compartments and there were minimal deformations of the occupant compartments. The vehicles remained upright and relatively stable during the collisions. The vehicle trajectories at loss of contact indicated minimal intrusions into the adjacent traffic lanes. Test statistics for the four crash tests are summarized in Table 3. Complete photographic and acceleration data are presented elsewhere (2). Brief descriptions of each test are provided in the following paragraphs.

**Test 1**

Test 1 involved testing the single-slope barrier deployed in a temporary configuration. In this test, the barrier segments

### TABLE 3 SUMMARY OF CRASH TEST RESULTS

<table>
<thead>
<tr>
<th>Test No.</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle Weight, lb (kg)</td>
<td>4500(2043)</td>
<td>1800(817)</td>
<td>4500(2043)</td>
<td>4500(2043)</td>
</tr>
<tr>
<td>Impact Speed, mi/h (km/hr)</td>
<td>60.3(97.0)</td>
<td>60.7(97.70)</td>
<td>63.1(101.5)</td>
<td>62.0(99.8)</td>
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<tr>
<td>Exit Angle, degrees</td>
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<td>4.3</td>
<td>8.5</td>
<td>3.5</td>
</tr>
<tr>
<td>Impact Angle, degrees</td>
<td>15.2</td>
<td>19.9</td>
<td>26.5</td>
<td>15.1</td>
</tr>
<tr>
<td>Displacement, in (cm)</td>
<td>7.0(17.8)</td>
<td>0.0(0.0)</td>
<td>0.0(0.0)</td>
<td>6.0(15.2)</td>
</tr>
<tr>
<td>Maximum Roll angle, degrees</td>
<td>12</td>
<td>6.3</td>
<td>32.5</td>
<td>17</td>
</tr>
<tr>
<td>Occupant Impact Velocity ft/s (m/s)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Longitudinal</td>
<td>14.4(4.4)</td>
<td>15.7(4.8)</td>
<td>22.1(6.7)</td>
<td>16.3(5.0)</td>
</tr>
<tr>
<td>Lateral</td>
<td>17.6(5.4)</td>
<td>27.7(8.4)</td>
<td>28.9(8.8)</td>
<td>18.4(5.6)</td>
</tr>
<tr>
<td>Occupant Ridedown Acceleration g's</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Longitudinal</td>
<td>-2.5</td>
<td>-2.3</td>
<td>-4.2</td>
<td>-3.2</td>
</tr>
<tr>
<td>Lateral</td>
<td>-7.7</td>
<td>-9.2</td>
<td>-10.7</td>
<td>-6.2</td>
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<tr>
<td>Vehicle Damage Classification</td>
<td>TAD</td>
<td>CDC</td>
<td></td>
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</tr>
<tr>
<td>11LFQ4</td>
<td>11LFQ5</td>
<td>11LFQ5</td>
<td>11LFQ4</td>
<td></td>
</tr>
<tr>
<td>11FLEX2&amp;</td>
<td>11LF EW3</td>
<td>11LF EW3</td>
<td>11FLEX2&amp;</td>
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<tr>
<td>11LF EW3</td>
<td></td>
<td></td>
<td>11LF EW1</td>
<td></td>
</tr>
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</table>
were joined together with the angle-splice temporary barrier connections. Because the angle-splice connections are reasonably stiff, it was determined that four barrier segments would adequately represent a continuous barrier installation. The barrier segments were positioned on an existing concrete surface at the TTI test track with no positive attachment to the roadway surface.

A 1980 Cadillac Sedan DeVille was directed into the single-slope CMB. The test inertia mass of the vehicle was 4,500 lb (2,043 kg). The speed of the vehicle at impact was 60.3 mph (97.0 km/hr) and the angle of impact was 15.2 degrees. These impact conditions are recommended in National Cooperative Highway Research Program Report 230 (1) for temporary barriers. The vehicle struck approximately 55 ft (16.8 m) from the upstream end of the barrier. The maximum roll angle of the vehicle was about 12 degrees. The barrier received minimal cosmetic damage, as shown in Figure 5. The maximum lateral movement of the barrier was 7 in. (17.8 cm). The vehicle sustained moderate damage to the left side, as shown in Figure 6.

National Cooperative Highway Research Program Report 230 (1) contains occupant impact velocity and occupant ride-down acceleration performance limits for tests involving 1,800-lb (817-kg) vehicles striking with angles of 15 degrees and velocities of 60 mph (96 km/hr). These limits do not apply to the current test; the values are presented for information only. The longitudinal and lateral occupant impact velocities were determined to be 14.4 ft/s (4.4 m/s) and 17.6 ft/s (5.4 m/s), respectively. The highest 0.010-sec occupant ride-down accelerations were determined to be -2.5 g (longitudinal) and -6.8 g (lateral). A detailed summary of these and other pertinent crash test data is presented in Figure 7.

Test 2

Test 2 involved testing the single-slope CMB deployed in a permanent configuration. In this test, the barrier segments were positioned on a subbase consisting of 2 in. (5.1 cm) of hot mix asphalt on top of 4 in. (10.2 cm) of compacted crushed limestone. The subbase area was approximately 125 ft (37.9 m) long and 8 ft (2.4 m) wide. Because the subbase provides continuous support for the barrier segments, it was judged that the performance of the barrier should be relatively independent of the barrier length. Therefore, it was determined

FIGURE 5 Single-slope barrier after Test 1.

FIGURE 6 Vehicle after Test 1.
that four barrier segments would adequately represent a con-
tinuous barrier installation.

The four barrier segments were aligned on the subbase so
that the impact surface of the barrier was set back approxi-
mately 1 ft (.3 m) from the front of the subbase. The rein-
forcing bar grids were then placed into the slots at the ends
of the barrier segments. Another 1 in. (2.54 cm) of hot-mix
asphalt was added to the subbase in front and behind the
barrier. This final application of asphalt resulted in a 1-ft (0.3-
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. 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. The grout was applied
so that the 120-ft (36.4-m) barrier had the appearance of a
continuous barrier.

A 1980 Honda Civic was directed into the single-slope CMB.
The test inertia mass of the vehicle was 1,800 lb (817 kg).
The speed of the vehicle at impact was 60.7 mph (97.7 km/
hr) and the angle of impact was 19.9 degrees. The vehicle
struck approximately 55 ft (16.7 m) from the upstream end
of the barrier. The maximum roll angle of the vehicle was
about 6.3 degrees. The barrier received minimal cosmetic
damage, as shown in Figure 8. There was no discernible move-
ment of the barrier. The vehicle sustained moderate damage
to the left side, as shown in Figure 9.

National Cooperative Highway Research Program Report
230 (f) contains occupant impact velocity and occupant ride-
down acceleration performance limits for tests involving 1,800-
lb (817-kg) vehicles striking with angles of 15 degrees and
velocities of 60 mph (96 km/hr). These limits do not apply to
the current test; the values are presented for information only.
The longitudinal and lateral occupant impact velocities were
determined to be 15.7 ft/s (4.8 m/s) and 27.7 ft/s (8.4 m/s),
respectively. The highest 0.010-sec occupant ridedown accel-
erations were determined to be −2.3 g (longitudinal) and
−9.2 g (lateral). A detailed summary of these and other
pertinent crash test data is presented in Figure 10.

Test 3

Test 3 involved testing the single-slope CMB deployed in a
permanent configuration. The same installation used in Test
2 already described was used in this test. The only repair
involved the application of paint to hide the vehicle and tire marks accrued during Test 2.

Test 3 involved the impact of a 1979 Cadillac Sedan De Ville. The vehicle struck approximately 54 ft (16.5 m) from the upstream end of the barrier. The speed of the vehicle at impact was 63.1 mph (101.5 km/hr) and the angle of impact was 26.5 degrees. There was no discernible movement of the barrier and it received only minimal cosmetic damage, as shown in Figure 11. Examination of the high-speed movies and direct measurements of the markings on the barrier showed that the center of the wheel hub rose to a height of 26 to 30 in. (66 to 76 cm) before losing contact with the barrier. This was the highest vehicle elevation achieved in the set of four crash tests. The maximum vehicle roll angle was about 32 degrees. The vehicle sustained severe damage to the left side, as shown in Figure 12.

National Cooperative Highway Research Program Report 230 (1) contains occupant impact velocity and occupant ride-down acceleration performance limits for tests involving 1,800-lb (817-kg) vehicles striking with angles of 15 degrees and velocities of 60 mph (96 km/hr). These limits do not apply to the current test; the values are presented for information only. The longitudinal and lateral occupant impact velocities were determined to be 22.1 ft/s (6.7 m/s) and 28.9 ft/s (8.8 m/s), respectively. The highest 0.010-sec occupant ride-down accelerations were determined to be -4.2 g (longitudinal) and -10.7 g (lateral). A detailed summary of these and other pertinent crash test data is presented in Figure 13.

It should be noted in evaluating the results of this test that both the velocity and the impact angle were higher than specified in National Cooperative Highway Research Program Report 230 (1). The following formula presented in that report allows the impact severity, $IS$, to be quantified in terms of the impact velocity, $V$, vehicle mass, $m$, and impact angle, $\phi$.

$$IS = \frac{1}{2} m v^2 (\sin \phi)^2$$

The impact severity calculated for the actual test conditions is approximately 25 percent greater than the intended impact severity. This deviation resulted in a much more severe impact than was required in National Cooperative Highway Research Program Report 230 (1). Results from HVOSM suggests that this deviation increased the roll angle by about 31 percent and the occupant impact velocities by about 5 percent. Despite the increased severity of this impact, the vehicle was smoothly redirected and remained upright throughout the test.

Test 4

Test 4 involved testing the single-slope CMB deployed in an alternate temporary configuration. In this test, the barrier
segments were joined together with the ungrouted reinforcing bar grid connection. Because this connection has no moment capacity, it was decided to use all six of the available barrier segments to represent a continuous barrier installation. However, it is believed that the two additional barrier segments had no effect on the outcome of the test. Four of the segments used in this test were the same barrier segments used in the permanent barrier configuration of Tests 2 and 3. The reinforcing bar grids that were grouted into the barriers in the permanent configuration were removed by drilling and chipping. The barrier segments were positioned on an existing concrete surface at the TTI test track, new rebar grids were slipped into place, and no grout was applied. There was no positive attachment to the roadway surface.

A 1981 Pontiac Bonneville was directed into the single-slope CMB. The test inertia mass of the vehicle was 4,500 lb (2,043 kg). The speed of the vehicle at impact was 62.0 mph (99.8 km/hr) and the angle of impact was 15.1 degrees. The vehicle struck approximately 85 ft (26.0 m) from the upstream end of the barrier. The maximum vehicle roll angle was about 17 degrees. The barrier received only minimal cosmetic damage, as shown in Figure 14. The maximum lateral displacement of the barrier was 6.0 in. (15.2 cm). The vehicle received moderate damage to the left side, as shown in Figure 15.

National Cooperative Highway Research Program Report 230 (J) contains occupant impact velocity and occupant ride-down acceleration performance limits for tests involving 1,800-lb (817-kg) vehicles striking with angles of 15 degrees and velocities of 60 mph (96 km/hr). These limits do not apply to the current test; the values are presented for information only. The longitudinal and lateral occupant impact velocities were determined to be 16.3 ft/s (5.0 m/s) and 18.4 ft/s (5.6 m/s), respectively. The highest 0.010-sec occupant ride-down accelerations were determined to be −3.2 g (longitudinal) and −6.2 g (lateral). A detailed summary of these and other pertinent crash test results is shown in Figure 16.

When the results of this test are compared with the results of Test 1, it can be observed that the permanent lateral displacements of the barriers are essentially the same. Computer simulations confirm that this observation is to be expected. However, the vehicle in Test 4 rolled almost 50 percent more than the vehicle in Test 1. The reason for the additional roll angle is that the ungrouted grid slot connection allows more torsional rotation of the barrier than the more rigid angle-
<table>
<thead>
<tr>
<th>Test No.</th>
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<th>Impact Speed..</th>
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<tr>
<td>Date</td>
<td>12/12/88</td>
<td>Impact Angle ..</td>
<td>26.5 deg</td>
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<td>Test Installation</td>
<td>Single Slope</td>
<td>Exit Speed ..</td>
<td>51.8 (83.3 km/h)</td>
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<tr>
<td>Installation Length</td>
<td>120 ft (36.6 m)</td>
<td>Exit Trajectory</td>
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</tr>
<tr>
<td>Vehicle</td>
<td>1979 Cadillac</td>
<td>Vehicle Accelerations</td>
<td>(Max. 0.050-sec Avg)</td>
</tr>
<tr>
<td>Weight</td>
<td>Sedan deVille</td>
<td>Longitudinal</td>
<td>-6.4 g</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lateral</td>
<td>-13.1 g</td>
</tr>
<tr>
<td>Inertia</td>
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<td></td>
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<td>-10.7 g</td>
</tr>
<tr>
<td>Crush</td>
<td>12.0 in (30.5 cm)</td>
<td>Maximum Vehicle Crush.</td>
<td>12.0 in (30.5 cm)</td>
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</table>
FIGURE 14 Single-slope barrier after Test 4.
splice connection. The added rotation of the barrier about its longitudinal axis increases the angle of the barrier face during the impact, resulting in increased vehicle roll.

The temporary connection used in Test 4 is considerably easier to deploy than the connection used in Test 1. In addition, both connections lead to a barrier installation that is capable of redirecting vehicles based on temporary design considerations.

CONCLUSIONS

A new single-slope CMB has been developed that can be used in both temporary and permanent applications. It was designed to redirect a 4,500-lb (2043-kg) automobile traveling at 60 mph (96.6 km/hr) with an impact angle of 25 degrees allowing only cosmetic damage when deployed in the permanent configuration. Further, it was designed to redirect a 4,500-lb (2043-kg) automobile traveling at 60 mph (96.6 km/hr) with an impact angle of 15 degrees when deployed in either of two different temporary configurations. It is highly probable that the new single-slope CMB will be able to successfully redirect more severe impacts involving heavier vehicles with higher centers of gravity.

The primary advantage of the new single-slope CMB is that it will not be necessary to reset the barrier each time the surrounding pavement is overlaid, as may be required with the New Jersey CMB. As stated in the previous section, the center of the wheel hub of the vehicle in the third test rose to a maximum height of no more than 30 in. (76 cm) before losing contact with the barrier. Experience suggests that the barrier would continue to redirect the vehicle as long as the contact height of the center of the wheel hub does not exceed the height of the barrier. Therefore, it is believed that the overall height of the barrier can be reduced to at least 30 in. (76 cm) by adjacent pavement overlays without significantly affecting the performance of the barrier for the test conditions presented in this paper. It is possible that the barrier would continue to perform satisfactorily at lower heights; however, it is not recommended for use at heights below 30 in. (76 cm) unless further tests are conducted.

Another advantage of the single-slope CMB is that the redirection of the 1,800-lb (817-kg) vehicle was very stable. Although 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 roll-over crashes than occur with the New Jersey CMB. This is particularly true with nontracking, high-angle, low-velocity impacts of small vehicles (8,9).

A total of four full-scale tests were conducted on the new single-slope CMB. The first test involved a 4,500-lb (2043-kg) automobile striking 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 striking the single-slope CMB in a permanent configuration. The fourth test involved a 4,500-lb (2043-kg) automobile striking the single-slope CMB in an alternate temporary configuration. In all cases, the vehicles were smoothly redirected with no snagging. Results from these tests were within acceptable performance limits described in National Cooperative Highway Research Program Report 230 (1), as applicable. As such, the new single-slope CMB is recommended for immediate use.

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FIGURE 16 Summary of results for Test 4.

REFERENCES


