Cable Median Barrier Retrofit Testing at FOIL

Background
Cable barriers are increasingly being used to contain and/or redirect vehicles that leave the roadways. These barriers redirect an encroaching vehicle as the cables elastically stretch and laterally deflect, thus minimizing the forces on the vehicle and its occupants relative to other types of barriers. Cable barriers are appropriate for locations where sufficient space is available to accommodate the larger lateral deflections that can occur. The growing use of cable barrier systems in highway medians can be attributed to their effectiveness in mitigating median crossings, their lower installation costs and time, adaptability to various roadside conditions, as well as a reduced impact severity for vehicle occupants. Various generic and proprietary cable barrier systems are available in various design configurations.

While cable median barriers have generally been found to perform very effectively, there have been reports of vehicles occasionally penetrating the cable median barriers and crossing into the opposing traffic lanes. This problem prompted research by the Federal Highway Administration (FHWA) to better understand the dynamics associated with vehicles moving at high speeds over sloped terrain and its influence on the effectiveness of vehicle-to-barrier interfaces [1]. In the initial stages of the research, analysis and testing was conducted to confirm the causes of observed under-ride problems and to validate the models developed. In the next phase, the research focused on studying vehicle trajectories when traversing sloped medians, assessing vehicle to barrier engagement, and developing retrofit options for existing cable median barrier installations. This technical summary presents four full-scale crash tests conducted under this study.

Approach
The National Crash Analysis Center (NCAC) at the George Washington University undertook computer analyses and conducted full-scale crash tests of cable median barriers to address various safety performance research questions. This research used finite element analysis to model and simulate vehicle-to-barrier impacts and vehicle dynamics analysis to track a vehicle’s yaw, pitch, and roll motions as it traverses sloped medians. Using these methods, the interface and strength performance of various cable median barrier designs and placement options were assessed. The cable median barrier retrofit designs developed were crash tested to confirm the broader analyses findings [1, 2, 3].

Testing Objectives
The overall objective of the full-scale crash tests was to validate the analyses of vehicle-to-barrier interface findings for a worst case scenario with the type of vehicle most frequently noted to under-ride. A series of four tests was conducted to assess the performance of proposed retrofit designs in both far- and near-side impacts as follows:

- Test 07002 – a far-side impact into a four-cable system to assess the vehicle-to-barrier interface at impact and examine the dynamics effects imposed by suspension compression.
- Test 07011 – a far-side impact into a one-cable system to assess the adequacy of single cable to redirect the vehicle.
- Test 07012 – a near-side impact into a four-cable system to assess its effectiveness in redirecting the vehicle when approaching from the near side.
- Test 07014 – a near-side impact similar to test 07012, but with a modified four-cable design.

Test Conditions
In all four crash tests, the cable barrier system was placed on a 4.9 m (16 ft) width median (measured from the shoulder break points) with 6H:1V side slopes. The median was V-shaped and symmetric. In all four tests, the cable barrier was located four feet from the center of the median. For the far-side hits, this meant that impacts were on the up-slope of the median. For near-side hits, impacts occurred on the down-slope.

The total length of the cable barrier installations (between the two end-anchors) was 140 m (460 ft).
The posts were spaced 4.9 m (16 ft) along the longitudinal direction of the barrier. The four cable heights were varied as noted in Figures 1 through 4. Standard cable-barrier components were used to construct the barrier in this test setup. They were installed and the cables were tensioned by an experienced guardrail and cable-barrier installation contractor. The cables used in the barriers were all 19 mm (0.75 in) in diameter, fabricated from 7 steel helical woven wires and finished with an outer coating of zinc. The minimum tensile strength specified was 111,250 N (25,000 lbs).

The cables were supported at the appropriate heights above ground by S75 X 8 rolled steel posts, 1,778 mm (70 in) in length, using hook bolts. The hook bolts opened up, to permit the cable to release from the post when a force ranging from 2,240 N (500 lbs) to 4,450 N (1,000 lbs) was applied normal to the longitudinal axis of the post. The posts were embedded into the ground 851 mm (33.5 in) and were spaced 4.9 m (16.0 ft) apart. Each cable end was anchored to the ground using a cable anchor attached to a large concrete block. After installation, each cable was tensioned with a turnbuckle adjacent to a spring assembly at one end of each cable. The spring assembly had a spring rate of 2,000 ± 222 N/mm (450 ± 4.5 lb/in). The turnbuckle had a minimum adjustment range of 152 mm (6 in). The tension in the cables was set based upon the ambient temperature. At a temperature of 18 degrees C (65 degrees F) the tension in each cable was set to approximately 4,450 N (1,000 lb).

Computer analysis followed by a full-scale crash test showed that the three cables used in standard generic, low tension, cable median barriers are not sufficient to safely redirect all vehicle types approaching at typical highway speeds and approach angles when installed on certain critical region in the sloped medians. This finding was based upon the assumption that a minimum of two cables is needed to engage the mid-size and large vehicles.

The test vehicle used for all tests was a Ford Crown Victoria, with a curb mass of about 1,725 kg (3,797 lb). Each vehicle was prepared for the test by draining all fluids, removing the battery, spare tire, and jack, and installing the on-board data acquisition equipment, battery pack, data sensors, and an automated emergency braking system. A full description of the test instrumentation is provided in the test report [3].

For all tests, the vehicle was propelled (towed) toward the barrier using the FOIL propulsion system. It was released from the tow system, such that it was freewheeling and unrestrained, 16 m (52.5 ft) prior to impact into the barrier. The tests were planned for vehicle impacts into the cable barrier at a speed of 100 km/h (62 mi/h) with an approach angle relative to the longitudinal axis of the barrier was 25 degrees.

Results
The testing followed the procedures prescribed in NCHRP Report 350, for test 3-11 (longitudinal barrier strength test) [4]. The exception was that the test vehicle was the Ford Crown Victoria sedan in lieu of the specified 2,000 kg (4,400 lb) pickup truck. This vehicle was selected because vehicles with size and sloped-front end design were found to be prone to under-ride cable barriers. Criteria from NCHRP Report 350 for Structural Adequacy, Occupant Risk, and Vehicle Trajectory were the primary evaluation measures as summarized in Table 3.

Four full-scale crash tests were conducted at the FHWA Federal Outdoor Impact Laboratory (FOIL) during 2007 (specific dates are noted in Table 1). A static view of the vehicle to barrier interface for each test is provided in Table 1. The relative position of the barrier in the median and the heights of the cables for each case are also listed in Table 1.

Table 2 provides a brief description of the impact event and outcomes from each test. The actual impact speed is noted and it was recorded that all impacts were at a 25 degree angle. These notes indicate that the vehicle was airborne as predicted by the computer analysis in all of the tests. The outcomes of tests 07002 and 070014 provide strong evidence that the option of adding a fourth cable represents a viable retrofit option. Test 07011 confirmed the assumption that a single, low-tension cable was not sufficient to restrain the vehicle. There was no evidence from this test, however, that the cable or other barrier components did not have adequate strength. The override in Test 07012 was determined to be the result of a higher “jump” of the vehicle than expected which allowed only the top cable to engage the vehicle. The raising of the cable heights for the subsequent test seemed to address that problem. It is not clear from the last test whether the positioning of the two top cables on the side of the post closest to the road had a significant influence. It was hypothesized that for near-side hits that were likely to be higher, that this would add the strength of post to the lateral resistance of the barrier (as opposed to one of the cable hook brackets).
Table 3 provides a summary of the NCHRP 350-type evaluation of the test results that was undertaken. Even though a mid-sized vehicle was used in these tests instead of the 2000P vehicle, the results from these tests coupled with previous tests, where a 2000P vehicle impacted similar system on flat terrain, gives a good indication of whether or not the barrier meets Report 350 Criteria. The test summaries for each test are provided in Figures 1 through 4. These provide sequential photos, diagrams of the crash event, data for the test set-up, and various metrics derived from the tests.

**Summary & Conclusions**

Full-scale crash tests were conducted as part of efforts to assess vehicle-to-cable barrier interaction when the system is installed on sloped medians and to develop some retrofit designs to mitigate these events. The resulting retrofit cable barrier design recommendations were based upon computer analysis of dynamics of vehicles as they traverse roadside slopes prior to interfacing a barrier. Such analyses have not typically been undertaken to determine optimal placement for a given barrier.

While various retrofit options were evaluated, the addition of a fourth cable was considered to have the greatest potential to address the under-ride problem without having to re-install the barrier system. The retrofit design tested is appropriate for a low tension, cable barrier on a 6H:1V sloped median when placed 1.2 m (4 ft) offset from the center of the median.

The test results indicated that the safety performance of generic cable median barriers can be improved by the addition of a fourth cable and lowering of the other cables. The testing showed this to be effective for both near- and far-side hits with a vehicle considered to be representative of those noted to be most susceptible to penetrating a cable median barrier. This change can be readily implemented in the field. The tests also confirmed assumptions about the number of cable needed to effectively engage a vehicle. The analyses suggested also that there is an underlying relationship between median barrier performance, the design of barrier, the median configuration, and its placements in the median.

**References**


**For More Information:**
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Table 1 - Summary of Barrier Design & Placement Details for Each Test

<table>
<thead>
<tr>
<th>Test</th>
<th>Date</th>
<th>Setup</th>
</tr>
</thead>
<tbody>
<tr>
<td>07002</td>
<td>1/19/07</td>
<td>![Image showing vehicle travel direction and 6H:1V slope diagram]</td>
</tr>
<tr>
<td>07011</td>
<td>5/10/07</td>
<td>![Image showing vehicle travel direction and 6H:1V slope diagram]</td>
</tr>
<tr>
<td>07012</td>
<td>6/28/07</td>
<td>![Image showing vehicle travel direction and 6H:1V slope diagram]</td>
</tr>
<tr>
<td>07014</td>
<td>10/03/07</td>
<td>![Image showing vehicle travel direction and 6H:1V slope diagram]</td>
</tr>
<tr>
<td>Test</td>
<td>Impact Description (all occurred at 25 degrees)</td>
<td>Outcome</td>
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<tr>
<td>--------</td>
<td>-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>07002</td>
<td>The test vehicle reached the shoulder break point at a speed of 98.2 km/h (61.4 mi/h) at time zero and went airborne until reaching the far-side slope at time 290 ms where the suspension was compressed. The vehicle continued up the far slope and reached the cable barrier at time 340 ms. The two lower cables engaged the vehicle and redirected it along the median with deflection of 4.0 m (13 ft). Moderate roll and pitch was observed. Vehicle yaw was over 200 degrees before coming to rest but remained stable.</td>
<td>The barrier successfully redirected and contained the test vehicle, and brought it to a stop in the center of the median after a far-side hit. The test vehicle remained upright during the entire collision event.</td>
</tr>
<tr>
<td>07011</td>
<td>The test vehicle reached the shoulder break point at a speed of 100.7 km/h (62.9 mi/h) at time zero and went airborne until reaching the far-side slope at time 290 ms where the suspension was compressed. The vehicle continued up the far slope and reached the cable barrier at time 340 ms. The single cable engages the vehicle and brings it parallel to the barrier at 870 ms with deflection of 6.1 m (20 ft). At 1.2s the cable slides under the vehicle and all contact is lost and the vehicle reaches 9.0 m (30 ft) of penetration. Moderate roll and pitch was observed.</td>
<td>The test vehicle was not successfully redirected by the single-cable barrier due to loss of contact with the single cable. The test vehicle remained upright during the entire impact event. The test vehicle came to its final resting position on the opposite side of the median in what would be considered on-coming traffic lanes.</td>
</tr>
<tr>
<td>07012</td>
<td>The test vehicle reached the shoulder break point at a speed of 100.8 km/h (63.0 mi/h) at time zero and went airborne until reaching the near-side barrier at time 130 ms. The vehicle remained airborne with all cables engaged, but the rotating tire causes 3 cables to disengage by time 220 ms. The upper cable disengages when the vehicle touches down at 1 s. The vehicle penetration was more than 5.50 m (18 ft) before it was brought to a stop. Moderate roll and pitch was observed. The vehicle yaw was about 19 deg.</td>
<td>The test showed that the barrier did not redirect the vehicle and did not prevent it from crossing through the median. The test vehicle remained upright during the entire impact event. The test vehicle was not successfully redirected despite engage of all cable for a short time and an extended engagement by one remaining cable until touching the ground after being airborne. The test vehicle came to its final resting position on the opposite side of the median and crossed beyond the on-coming traffic lanes.</td>
</tr>
<tr>
<td>07014</td>
<td>The test vehicle reached the shoulder break point at a speed of 99.2 km/h (62.0 mi/h) at time zero and goes airborne until reaching the near-side barrier at time 130 ms. The vehicle is partially airborne and contacts the top cable barrier. The second cable engages and brings the vehicle parallel to the barrier and at 950ms the vehicle impacts a downstream section of the barrier. The deflection was 4.0 m (13 ft). Moderate roll and pitch was observed. The vehicle yaw was about 47 deg.</td>
<td>This test (07014) is a repeat of the previous crash test (07012) with the upper-most cable raised 75 mm (3 in) and the one below it was raised 25 mm (1 in). The heights of the two lower cables were not changed. The test showed that the barrier successfully redirected the vehicle. The test vehicle remained upright during the entire impact event. The test vehicle came to its final resting position in the median.</td>
</tr>
</tbody>
</table>
Table 3 – Summary of Evaluation Results (Based upon NCHRP Report Test 3-11)

<table>
<thead>
<tr>
<th>Evaluation Criteria</th>
<th>Test 07002</th>
<th>Test 07011</th>
<th>Test 07012</th>
<th>Test 07014</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Structural Adequacy</strong></td>
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<tr>
<td>(A) - Test article should contain and redirect the vehicle; the vehicle should not penetrate, under-ride, or override the installation although controlled lateral deflection of the test article is acceptable.</td>
<td>The cable barrier redirected and contained the vehicle. The vehicle did not override or underside the barrier</td>
<td>The cable barrier failed to redirect and contained the vehicle. The vehicle overrode the barrier and crossed the median</td>
<td>The cable barrier did not prevent the vehicle from crossing the median.</td>
<td>The cable barrier redirected and contained the vehicle. The vehicle did not override or underside the barrier</td>
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<tr>
<td><strong>Occupant Risk</strong></td>
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<tr>
<td>(D) - Detached elements, fragments or other debris from the test article should not penetrate or show potential of penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a WZ. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.</td>
<td>No detached elements or debris was observed from the test. No deformation was observed in the occupant compartment</td>
<td>No detached elements or debris was observed from the test. No deformation was observed in the occupant compartment</td>
<td>No detached elements or debris was observed from the test. No deformation was observed in the occupant compartment</td>
<td>No detached elements or debris was observed from the test. No deformation was observed in the occupant compartment</td>
</tr>
<tr>
<td>(F) - The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable</td>
<td>The vehicle remained upright and stable during the impact. Minimal roll and pitch was observed. Vehicle yaw was over 200 degrees before coming to rest but remained stable</td>
<td>The vehicle remained upright and stable during the impact. Minimal roll and pitch was observed</td>
<td>The vehicle remained upright and stable during the impact. Minimal roll and pitch was observed. The vehicle yaw was about 19 deg.</td>
<td>The vehicle remained upright and stable during the impact. Minimal roll and pitch was observed. The vehicle yaw was about 7 deg.</td>
</tr>
<tr>
<td><strong>Vehicle Trajectory</strong></td>
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<tr>
<td>(K) - After collision it is preferable that the vehicle’s trajectory not intrude into adjacent traffic lanes.</td>
<td>The vehicle final rest position was at the center of the median and intruded into opposing traffic</td>
<td>The vehicle crossed the median and intruded into opposing traffic</td>
<td>The vehicle crossed the median and intruded into opposing traffic</td>
<td>The vehicle final rest position was at the center of the median.</td>
</tr>
<tr>
<td>(L) - The occupant impact velocity in the longitudinal direction should not exceed 12 m/sec and the occupant ride-down acceleration in the longitudinal direction should not exceed 20 G’s</td>
<td>The occupant impact velocity was 4.05 m/s and ride-down acceleration was 7.65 g.</td>
<td>The occupant impact velocity was 4.62 m/s and ride-down acceleration was 6.17 g.</td>
<td>The occupant impact velocity was 2.23 m/s and ride-down acceleration was 8.65 g.</td>
<td>The occupant impact velocity was 3.83 m/s and ride-down acceleration was 6.45 g.</td>
</tr>
<tr>
<td>(M) - The exit angle from the test article preferably should be less than 60 percent of the test impact angle, measured at time of vehicle loss of contact with the test device</td>
<td>The vehicle did not lose contact with the barrier during the impact</td>
<td>The angle when the vehicle lost contact with the barrier was 4 deg</td>
<td>The vehicle exit angle was about 6 deg</td>
<td>The vehicle did not lose contact with the barrier during the impact</td>
</tr>
</tbody>
</table>

*Criterion is preferable and not required.*
Figure 1: Summary of Test Results, Test 7002
**General Information**

- **Test Agency**: Federal Outdoor Impact Lab.
- **Test No.**: 07011
- **Date**: 05/10/2007

**Test Article**

- **Type**: Low tension cable barrier
- **Name or Mfg**: Generic
- **Installation length (m)**: 140
- **Size and/or dimension**: one cable system
- **and material of key elements**: 1.22 m offset from median center
- **Soil Type and Condition**: Standard, dry

**Test Vehicle**

- **Type**: Production
- **Designation**: Large Sedan
- **Model**: Ford Crown Victoria
- **Mass (kg)**:
  - Curb: 1778
  - Test Inertial: 1752
  - Dummy: 0
  - Gross Static: 1752

**Impact Conditions**

- **Speed (km/h)**: 100.7
- **Angle (deg)**: 25

**Exit Conditions**

- **Speed (km/h)**: 82
- **Angle (deg)**: 5

**Occupant Risk Values**

- **Impact Velocity (m/s)**
  - x-direction: 4.62
  - y-direction: 0.14
  - THIV (optional): N/A
  - Ridedown Accelerations (g's)
    - x-direction: 6.17
    - y-direction: 3.62
    - PHD (optional): N/A
    - ASI (optional): N/A
  - Max. 0.050-s Average (g's)
    - x-direction: 3.0
    - y-direction: 2.1
    - z-direction: 6.0

**Test Article Deflection (m)**

- **Dynamic**: 6.7
- **Permanent**: NA

**Vehicle Damage**

- Exterior
  - VDS: N/A
  - CDC: N/A
- Interior
  - OCDI: N/A
  - Maximum Exterior
    - Vehicle Crush (mm): N/A
  - Max. Occ. Compartment Deformation (mm): N/A

**Post-Impact Behavior**

- Max. Roll Angle (deg): 14
- Max. Pitch Angle (deg): 5
- Max. Yaw Angle (deg): 21

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**Figure 2: Summary of Test Results, Test 7011**
Figure 3: Summary of Results, Test 07012
**General Information**
- **Test Agency**: Federal Outdoor Impact Lab.
- **Test No.**: 07014
- **Date**: 10/03/2007

**Test Article**
- **Type**: Low tension cable barrier
- **Name or Mfg**: Generic
- **Installation length (m)**: 140 m
- **Size and/or dimension**: Four cable retrofit system and material of key elements: 1.22 m offset from median center

**Soil Type and Condition**
- **Type**: Standard, dry

**Test Vehicle**
- **Type**: Production
- **Designation**: Large Sedan
- **Model**: Ford Crown Victoria
- **Mass (kg)**: Curb: 1778, Test Inertial: 1748, Dummy: 0, Gross Static: 1748

**Impact Conditions**
- **Speed (km/h)**: 99.2
- **Angle (deg)**: 25

**Exit Conditions**
- **Speed (km/h)**: 0
- **Angle (deg)**: 0

**Occupant Risk Values**
- **THIV (optional)**
- **Ridedown Accelerations (g's)**
  - x-direction: 3.83
  - y-direction: 2.98
  - z-direction: 4.45
- **PHD (optional)**
- **ASI (optional)**
- **Max. 0.050-s Average (g's)**
  - x-direction: 2.5
  - y-direction: 5.0
  - z-direction: 3.2

**Vehicle Damage**
- **Exterior**: N/A
- **Interior**: N/A
- **Maximum Exterior Vehicle Cruch (mm)**: N/A
- **Max. Occ. Compartment Deformation (mm)**: Nill

**Post-Impact Behavior**
- **Max. Roll Angle (deg)**: 24
- **Max. Pitch Angle (deg)**: 3.5
- **Max. Yaw Angle (deg)**: 47

**Figure 4: Summary of Results, Test 07014**