COMPLIANCE CRASH TESTING OF THE TYPE 60K TERMINUS

STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
DIVISION OF RESEARCH AND INNOVATION
OFFICE OF SAFETY INNOVATION AND COOPERATIVE RESEARCH

Principal Investigator.......................................................... Rich Peter, P.E.
Current RSRG Chief .......................................................... Robert Meline, P.E.
Report Prepared by ...................................................... John Jewell, P.E. and David Whitesel, P.E.
Research Performed by ................................................. Roadside Safety Research Group (RSRG)
STATE OF CALIFORNIA

DEPARTMENT OF TRANSPORTATION
DIVISION OF RESEARCH AND INNOVATION
OFFICE OF SAFETY INNOVATION AND COOPERATIVE RESEARCH

COMPLIANCE CRASH TESTING
OF THE TYPE 60K TERMINUS

Principal Investigator ................................................ Rich Peter, P.E. (retired)
Current RSRG Chief ................................................ Robert Meline, P.E.
Report Prepared by .............................. John Jewell, P.E. and David Whitesel, P.E.
Research Performed by .............................. Roadside Safety Research Group

Robert Meline, P.E.
Chief
Roadside Safety Research Group

John Jewell, P.E.
Senior Transportation Engineer
Roadside Safety Research Group

David Whitesel, P.E.
Transportation Engineer
Roadside Safety Research Group
Crash testing for compliance with NCHRP Report 350 was performed on a Type 60K terminus. The Type 60K terminus was comprised of Type 60K portable concrete barrier (TL-3 approved) anchored to Type 60 concrete barrier at one end but free at the other. The Type 60K is a concrete barrier made up of 4-m long segments, which are connected together by pins. The barrier is freestanding and has a profile to match the Caltrans Type 60 median barrier. 9 segments (approximately 36 m) were pinned together with restraining stakes placed against the back edges of the last two segments of the barrier. For testing purposes, it was not necessary to anchor one end to Type 60 concrete barrier.

One crash test was performed under Report 350 Test Level 3 with a 2000-kg pickup truck. The results of the test were within the limits of the Report 350 guidelines.

The Type 60K Terminus is recommended for approval on California highways requiring a down-stream end treatment to the Type 60k barrier with the following limitations: First, there must be a need to be able to remove the barrier. Second, because a blunt end is exposed, it may not used in locations where a reverse hit is possible. Third, because it is restrained from lateral movement in one direction only, it can not be placed where impact can occur on the unrestrained side.

Key Words: 60K, Terminus, K-rail, Barriers, Crash Test, Single-slope, Concrete, Vehicle Impact Test

Security Classification: Unclassified

DISTRIBUTION STATEMENT: No Restrictions. This document is available through the National Technical Information Service, Springfield, VA 22161
NOTICE

The contents of this report reflect the views of Roadside Safety Research Group, which is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State of California or the Federal Highway Administration. This report does not constitute a standard specification or regulation.

Neither the State of California nor the United States Government endorses products or manufacturers. Trade or manufacturers' names appear herein only because they are considered essential to the object of this document.
## SI CONVERSION FACTORS

<table>
<thead>
<tr>
<th>To Convert From</th>
<th>To</th>
<th>Multiply By</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ACCELERATION</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>m/s²</td>
<td>ft/s²</td>
<td>3.281</td>
</tr>
<tr>
<td><strong>AREA</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>m²</td>
<td>ft²</td>
<td>10.76</td>
</tr>
<tr>
<td><strong>ENERGY</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Joule (J)</td>
<td>ft.lbf</td>
<td>0.7376</td>
</tr>
<tr>
<td><strong>FORCE</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Newton (N)</td>
<td>lbf</td>
<td>0.2248</td>
</tr>
<tr>
<td><strong>LENGTH</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>m</td>
<td>ft</td>
<td>3.281</td>
</tr>
<tr>
<td>m</td>
<td>in</td>
<td>39.37</td>
</tr>
<tr>
<td>cm</td>
<td>in</td>
<td>0.3937</td>
</tr>
<tr>
<td>mm</td>
<td>in</td>
<td>0.03937</td>
</tr>
<tr>
<td><strong>MASS</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>kg</td>
<td>lbm</td>
<td>2.205</td>
</tr>
<tr>
<td><strong>PRESSURE OR STRESS</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>kPa</td>
<td>psi</td>
<td>0.1450</td>
</tr>
<tr>
<td><strong>VELOCITY</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>km/h</td>
<td>mph</td>
<td>0.6214</td>
</tr>
<tr>
<td>m/s</td>
<td>ft/s</td>
<td>3.281</td>
</tr>
<tr>
<td>km/h</td>
<td>ft/s</td>
<td>0.9113</td>
</tr>
</tbody>
</table>
ACKNOWLEDGMENTS

This work was accomplished in cooperation with the United States Department of Transportation, Federal Highway Administration.

Special appreciation is due to the following staff members of Caltrans' Materials Engineering and Testing Services and the Office of Research for their enthusiastic and competent help on this project:

Mike O’Keeffe, Mike White, Erin McCrory and Larry Moore, test preparation, data reduction, vehicle preparation, and film processing; Dave Bengal, Independent Camera Operator; Bob Cullen, Eric Jacobson and Ed Ung electronic instrumentation; and Bill Poroshin, machine shop services.

Other persons from Caltrans who made important contributions include: Nahed Abdin, Engineering Services - Office of Structures, technical consultation; Ellis Hirst, Traffic Operations; Don Tateishi, Headquarters Photo Section; and Joy Pinne, Structures Construction.
# TABLE OF CONTENTS

TECHNICAL REPORT STANDARD TITLE PAGE .......................................................................................................................... I

NOTICE ...................................................................................................................................................................................................... II

SI CONVERSION FACTORS .............................................................................................................................................................................. III

ACKNOWLEDGMENTS........................................................................................................................................................................................ IV

TABLE OF CONTENTS .................................................................................................................................................................................. V

LIST OF FIGURES ........................................................................................................................................................................................................ VI

1. INTRODUCTION ..................................................................................................................................................................................................... 1
   1.1. Problem ........................................................................................................................................................................................................... 1
   1.2. Objective ........................................................................................................................................................................................................ 1
   1.3. Background .................................................................................................................................................................................................... 2
   1.4. Literature Search ..................................................................................................................................................................................... 2
   1.5. Scope ............................................................................................................................................................................................................... 3

2. TECHNICAL DISCUSSION .............................................................................................................................................................................. 4
   2.1. Test Conditions - Crash Tests ................................................................................................................................................................. 4
       2.1.1. Test Facilities .......................................................................................................................................................................................... 4
       2.1.2. Test Barrier .......................................................................................................................................................................................... 4
       2.1.3. Construction ....................................................................................................................................................................................... 4
       2.1.4. Test Vehicle ....................................................................................................................................................................................... 7
       2.1.5. Data Acquisition System ............................................................................................................................................................... 9
   2.2. Test Results - Crash Tests ................................................................................................................................................................. 9
       2.2.1. Impact Description - Test 601 ............................................................................................................................................................. 10
       2.2.2. Vehicle Damage - Test 601 ............................................................................................................................................................. 10
       2.2.3. Barrier Damage - Test 601 ............................................................................................................................................................. 12
   2.3. Discussion of Test Results - Crash Tests ............................................................................................................................................. 17
       2.3.1. General - Evaluation Methods ...................................................................................................................................................... 17
       2.3.2. Structural Adequacy ...................................................................................................................................................................... 17
       2.3.3. Occupant Risk .............................................................................................................................................................................. 17
       2.3.4. Vehicle Trajectory ...................................................................................................................................................................... 17

3. CONCLUSION ................................................................................................................................................................................................... 19

4. RECOMMENDATIONS .................................................................................................................................................................................. 20

5. IMPLEMENTATION ..................................................................................................................................................................................... 21

6. APPENDIX ...................................................................................................................................................................................................... 22
   6.1. Test Vehicle Equipment ............................................................................................................................................................................ 22
   6.2. Test Vehicle Guidance System ............................................................................................................................................................. 25
   6.3. Photo - Instrumentation ........................................................................................................................................................................ 25
   6.4. Electronic Instrumentation and Data .................................................................................................................................................. 28

7. REFERENCES ....................................................................................................................................................................................................... 35
LIST OF FIGURES

FIGURE 1-1 – EXAMPLE USE OF TYPE 60K TERMINUS ...................................................................................................1
FIGURE 2-1 – BARRIER PLACEMENT ............................................................................................................................ 5
FIGURE 2-2 – STAKE INSTALLATION ............................................................................................................................ 5
FIGURE 2-3 – BARRIER ALIGNMENT ............................................................................................................................ 6
FIGURE 2-4 – BACKSIDE OF COMPLETED BARRIER WITH STAKES ..................................................................................6
FIGURE 2-5 – FRONT OF TEST VEHICLE PRIOR TO IMPACT ........................................................................................ 7
FIGURE 2-6 – RIGHT SIDE OF TEST VEHICLE PRIOR TO IMPACT ................................................................................ 8
FIGURE 2-7 – FRONT RIGHT CORNER OF TEST VEHICLE PRIOR TO IMPACT ................................................................. 8
FIGURE 2-8 – INTENDED IMPACT POINT ..................................................................................................................... 10
FIGURE 2-9 – FRONT WHEEL OF TEST VEHICLE POST-IMPACT .................................................................................... 11
FIGURE 2-10 – FRONT RIGHT CORNER OF TEST VEHICLE POST-IMPACT ..................................................................... 11
FIGURE 2-11 – REAR RIGHT SIDE OF TEST VEHICLE POST-IMPACT ........................................................................... 12
FIGURE 2-12 – PERMANENT DEFLECTION DRAWING ................................................................................................ 12
FIGURE 2-13 – BARRIER DAMAGE NEAR THE IMPACT POINT ........................................................................................ 13
FIGURE 2-14 – PERMANENT DEFLECTION ................................................................................................................... 14
FIGURE 2-15 – BACKSIDE OF JOINT 8-9 SHOWING MINOR CONCRETE SPALLING AND BENT PIN (MISLABELED) ..........14
FIGURE 2-16 – CLOSE-UP OF BENT PIN AT JOINT 8-9 .................................................................................................. 15
FIGURE 2-17 – TEST 601 DATA SUMMARY SHEET ........................................................................................................ 16
FIGURE 6-1 – CAMERA LOCATIONS ............................................................................................................................ 26
FIGURE 6-2 – EVENT SWITCH LAYOUT ........................................................................................................................ 27
FIGURE 6-3 – VEHICLE ACCELEROMETER SIGN CONVENTION .................................................................................... 29
FIGURE 6-4 – TEST 601 VEHICLE ACCELERATIONS -VS- TIME .................................................................................... 29
FIGURE 6-5 – TEST 601 VEHICLE LONGITUDINAL ACCELERATION, VELOCITY AND DISTANCE -VS- TIME .........30
FIGURE 6-6 – TEST 601 VEHICLE LATERAL ACCELERATION, VELOCITY AND DISTANCE -VS- TIME ......31
FIGURE 6-7 – TEST 601 VEHICLE ROLL, PITCH AND YAW -VS- TIME ........................................................................ 32
FIGURE 6-8 – TYPE 60 STANDARD PLAN ..................................................................................................................... 33
# LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table 1-1</td>
<td>Target Impact Conditions</td>
<td>3</td>
</tr>
<tr>
<td>Table 2-1</td>
<td>Test Vehicle Information</td>
<td>7</td>
</tr>
<tr>
<td>Table 2-2</td>
<td>Test 601 Assessment Summary</td>
<td>18</td>
</tr>
<tr>
<td>Table 2-3</td>
<td>Vehicle Trajectories and Speeds</td>
<td>18</td>
</tr>
<tr>
<td>Table 6-1</td>
<td>Test 601 Vehicle Dimensions</td>
<td>24</td>
</tr>
<tr>
<td>Table 6-2</td>
<td>Typical Camera Type and Locations</td>
<td>25</td>
</tr>
<tr>
<td>Table 6-3</td>
<td>Accelerometer Specifications</td>
<td>29</td>
</tr>
</tbody>
</table>
1. INTRODUCTION

1.1. Problem

The California Department of Transportation (Caltrans) recently approved a new portable concrete barrier, the Type 60k, for use in semi-permanent applications. Type 60K installations are normally secured at their ends by pinned connections to permanent Type 60 concrete median barriers. This serves to prevent any significant lateral movement of the segments during redirecitive vehicle impacts under TL-3 conditions. However, recent developments have led to a need for terminating a run of Type 60K barrier segments without attaching the end segment to a permanent concrete barrier. An example of such a configuration is shown in the drawing below.

![Figure 1-1 – Example Use of Type 60K Terminus](image)

If the end segments are allowed to shift freely when struck by a vehicle, “pocketing” may occur that increases the likelihood of serious injury to vehicle occupants. Any restraint system that is used to prevent excessive shifting of the end segments during impact will need to be easily removed on occasions when the portable barrier segments have to be relocated (e.g., to detour traffic). A solution to this problem must be developed.

1.2. Objective

This research project involves conducting compliance tests of a terminus design for the Type 60K concrete barrier to determine whether it meets National Cooperative Highway Research Program (NCHRP) Report 350 criteria. The proposed terminus consists of two segments of Type 60K barrier at the downstream end of a barrier that are secured from lateral movement with
steel stakes. Two 1-m long stakes would be driven into the AC paving directly behind and in contact with each of the two segments. An impact location for the crash test will be selected to give the highest chance of failure through either pocketing or overturning of the barrier.

1.3. Background

In August 2001, Caltrans received Federal Highway Administration (FHWA) acceptance for using the Type 60K barrier on the National Highway System. The Type 60K is a concrete barrier made up of 4-m long segments, which are connected together by pins. The barrier is freestanding and has a profile to match the Caltrans Type 60 median barrier.

The Type 60K was initially developed to span a 40-m detour gap between two ends of Type 60 median barrier. In this configuration, both ends of every Type 60K segment were restrained. After developing the Type 60K for this purpose another need developed. Under certain conditions, it is necessary to place an arrow board or other obstacle in the median and protect it by a temporary barrier that can be completely removed in the event of a detour (see Figure 1-1). A Type 60K barrier appeared to be the best choice in this instance, but one end of the barrier would have to be terminated without attaching it to a rigid median barrier. There was concern on the part of FHWA and Caltrans engineers that the rail would not perform as intended if impacted by an errant vehicle. Although staking appeared to present a solution, the same individuals concluded that such staking could not automatically be assumed crashworthy. Testing would be necessary to verify the crashworthiness of the “60k Terminus”.

1.4. Literature Search

No literature was conducted because this product was based on newly developed barrier, the Type 60K.
1.5. Scope

Only one test was performed and evaluated in accordance with NCHRP Report 350. The testing matrix established for this project is shown in Table 1-1.

Table 1-1 – Target Impact Conditions

<table>
<thead>
<tr>
<th>Test Number</th>
<th>Barrier Type</th>
<th>Mass of Test Vehicle (kg)</th>
<th>Speed (km/h)</th>
<th>Angle (deg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>601</td>
<td>60K Terminus</td>
<td>2000</td>
<td>100</td>
<td>25</td>
</tr>
</tbody>
</table>
2. TECHNICAL DISCUSSION

2.1. Test Conditions - Crash Tests

2.1.1. Test Facilities

This crash test was conducted at the Caltrans Dynamic Test Facility in West Sacramento, California. The test area is a large, flat, asphalt concrete surface.

2.1.2. Test Barrier

2.1.2.1. Design

The primary design considerations for the 60K Terminus were:

1) Compliance with NCHRP Report 350 TL-3.

2) Minimum lateral movement during impact.

3) Ease of installation and removal.

4) Use of the Type 60K segments.

The simplest design was to have a freestanding downstream end of a run of Type 60K barrier as the terminus. To help minimize the lateral deflection of the terminus, 25-mm x 1000-mm steel stakes would be embedded in the pavement behind each of the last two segments.

2.1.3. Construction

A total of nine segments of Type 60K barrier were used to construct the barrier. The barriers were put in place via a 10-kip, side-shifting forklift. 31.8-mm x 760-mm pins were used to connect the segments to each other.
Segments 8 and 9 were the only segments that were laterally restrained through the use of 25-mm X 1000-mm stakes. The stakes were placed 425 mm from the joints of each of the ends of segments 8 and 9 for a total of 4 stakes. Both a jackhammer with a stake-driver and a sledge hammer were used to drive the stakes. The top 100 mm of each was left above grade.
The final test condition of the barrier appeared smooth and flat on the impact side.

![Figure 2-3 – Barrier Alignment](image)

The backside of the barrier was also smooth except for the 4 stakes that had been placed for lateral restraint.

![Figure 2-4 – Backside of Completed Barrier with Stakes](image)
2.1.4. Test Vehicle

The test vehicle complied with NCHRP Report 350 criteria. The vehicle was in good condition, free of major body damage and was not missing any structural parts. It had standard equipment and a front-mounted engine (see Table 6-1). The vehicle inertial mass was within recommended limits (see Table 2-1). Pictures of the test vehicle prior to impact are included in Figure 2-5 through Figure 2-7.

Table 2-1 – Test Vehicle Information

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Vehicle</th>
<th>Ballast (kg)</th>
<th>Test Inertial (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>601</td>
<td>1994 Chevrolet 2500</td>
<td>73</td>
<td>1960</td>
</tr>
</tbody>
</table>

Figure 2-5 – Front of Test Vehicle Prior to Impact
Figure 2-6 – Right Side of Test Vehicle prior to Impact

Figure 2-7 – Front Right Corner of Test Vehicle prior to Impact
The vehicle was self-powered. A speed-control device limited acceleration once the impact speed had been reached. Remote braking was possible at any time during the test through a radio-controlled transmitter/receiver. The vehicle was steered by a guide arm connecting the front left wheel. The guide arm, in turn, was connected to guidance rail that was fixed to the ground. A short distance before the point of impact, the vehicle was released from the guidance rail and the ignition was turned off. A detailed description of the test vehicle equipment and guidance systems is contained in Sections 6.1 and 6.2 of the Appendix.

2.1.5. Data Acquisition System

The test was documented through the use of still cameras, video cameras, high-speed film cameras, and two transient data recorders.

The impact phase of the crash test was recorded with seven high-speed, 16-mm movie cameras, one normal-speed 16-mm movie camera, one Beta format video camera, two 35-mm still cameras and one 35-mm sequence camera. The test vehicle and the barrier were photographed before and after impact with a normal-speed 16-mm movie camera, a Beta format video camera and a color 35-mm camera. A film report of this project will be assembled using edited portions of the film coverage.

The test vehicle included two sets of orthogonal accelerometers mounted at the center of gravity. Rate gyro transducers were also placed at the centers of gravity to measure the rates of roll, pitch and yaw. The data were used in calculating the occupant impact velocities, ridedown accelerations, and maximum vehicle rotation.

Two digital transient data recorders (TDRs), GMH Engineering’s Data Brick model II, were used to record electronic data during the tests. The digital data were analyzed using a desktop computer and DADiSP version 4.1 analysis software.

2.2. Test Results - Crash Tests

A film report with edited footage from all tests has been compiled and is available for viewing.
2.2.1. Impact Description - Test 601

The vehicle impact speed and angle were 100.3 km/h and 24.0 degrees, respectively. Impact occurred at approximately 1000 mm upstream of the joint 8-9 (i.e., the joint between segments 8 and 9). (See Figure 2-8 for an illustration of the intended impact point.) The maximum joint deflection occurred at joint 8-9 at 0.346 seconds after impact. There were no visible signs of snagging and the vehicle was smoothly redirected. The vehicle hood overrode barrier, penetrating the barrier face by approximately 300 mm. The brakes were applied 0.73 seconds after impact.

![Figure 2-8 – Intended Impact Point](image)

2.2.2. Vehicle Damage - Test 601

Most of the damage to the vehicle was on the front half of the right side. The right third of the bumper was pushed back into the front right wheel well. The front tire was torn, but still on the rim. The wheel was pushed back about 450 mm. The right side of the bed was dented near the cab and near the taillight.
Figure 2-9 – Front Wheel of Test Vehicle Post-Impact

Figure 2-10 – Front Right Corner of Test Vehicle Post-Impact
2.2.3. **Barrier Damage - Test 601**

Damage to the barrier was limited to barrier deflection, bending of the connecting pins and bending to the lateral retention stakes. Barrier deflections are shown in Figure 2-12. There was only minor scraping on the face of the barrier. Barrier damage is shown in Figure 2-13 through Figure 2-16.

<table>
<thead>
<tr>
<th>Joint</th>
<th>7a</th>
<th>7b</th>
<th>8a</th>
<th>8b</th>
<th>9a</th>
<th>9b</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lateral Deflection (mm)</td>
<td>0</td>
<td>5</td>
<td>15</td>
<td>555</td>
<td>565</td>
<td>1060</td>
</tr>
</tbody>
</table>

Figure 2-12 – Permanent Deflection Drawing
Repair to the barrier would require replacing the pins and realigning the last few barrier segments with new lateral retention stakes where necessary.

Figure 2-13 – Barrier Damage near the Impact Point
Figure 2-14 – Permanent Deflection

Figure 2-15 – Backside of Joint 8-9 showing Minor Concrete Spalling and Bent Pin (mislabeled)
Figure 2-16 – Close-up of Bent Pin at Joint 8-9
Figure 2-17 – Test 601 Data Summary Sheet

Impact Sequence Drawing

General Information
Test Agency: California DOT
Test Number: 601
Test Date: April 23, 2002

Test Article
Name: 60K Terminus
Installation Length: 36.0 m
Description: 9 segments of 60K barrier, on an AC base with 4 25-mm by 1000-mm stakes on the last two barriers

Test Vehicle
Model: 1994 Chevy 2500 PU
Inertial Mass: 1960 kg

Impact Conditions
Velocity: 100.3 km/h
Angle: 24.0°
Impact Severity: 125.8 kJ

Exit Conditions
Velocity: 80.3 km/h
Angle: 9 degrees

Test Dummy
Type: NA
Weight / Restraint: NA
Position: NA

Post-Impact Vehicular Behavior
Maximum Roll Angle: 26.88°
Maximum Pitch Angle: 8.70°

Test Data
Vehicle Exterior:
VDS (2): RFQ-3, FR-2
CDC (3): 02RFEW5
Vehicle Interior
O.C.D.I. (1): RF0001000

Occupant Risk Values

<table>
<thead>
<tr>
<th>Longitudinal</th>
<th>Lateral</th>
</tr>
</thead>
<tbody>
<tr>
<td>Occupant Impact Velocity</td>
<td>4.75 m/s</td>
</tr>
<tr>
<td>Ridedown Acceleration</td>
<td>-7.35 g</td>
</tr>
</tbody>
</table>

Barrier Damage
Barrier damage was limited to deflection and bent connecting pins. There was only minor scraping on the face of the barrier. Repair to the barrier would require replacing the pins and realigning the last few barrier segments with new lateral retention stakes where necessary.
2.3. Discussion of Test Results - Crash Tests

2.3.1. General - Evaluation Methods

NCHRP Report 350 stipulates that crash test performance be assessed according to three evaluation factors: 1) Structural Adequacy, 2) Occupant Risk, and 3) Vehicle Trajectory.

The structural adequacies, occupant risks, and vehicle trajectories associated with this barrier design were evaluated in comparison with Tables 3.1 and 5.1 of NCHRP Report 350.

2.3.2. Structural Adequacy

The structural adequacy of the 60K Terminus was acceptable. The lateral retaining takes prevented the impacted segments from rotating back too far and exposing the leading ends of the downstream segments. As a result, snagging was not an issue and the vehicle was smoothly redirected. During the time of contact between the test vehicle and the barrier there were minor amounts of scraping and spalling. The maximum permanent lateral deflection was 1060 mm and was not considered to be excessive. A detailed assessment summary of structural adequacy is shown in Table 2-2.

2.3.3. Occupant Risk

The occupant risk of the 60K Terminus was also acceptable. None of the tests indicated potential for material from the barrier to penetrate the occupant compartment of the vehicles. Please refer to Table 2-2 for a detailed assessment summary of occupant risk.

2.3.4. Vehicle Trajectory

The post-impact vehicle trajectory was also acceptable. All of the calculated occupant ridedown accelerations and occupant impact velocities were within the “preferred” range. Please refer to Table 2-2 for a detailed assessment summary of vehicle trajectory.
Table 2-2 – Test 601 Assessment Summary

<table>
<thead>
<tr>
<th>Evaluation Criteria</th>
<th>Test Results</th>
<th>Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Structural Adequacy</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A. Test article should contain and redirect the</td>
<td>The vehicle was smoothly redirected</td>
<td>pass</td>
</tr>
<tr>
<td>vehicle; the vehicle should not penetrate,</td>
<td></td>
<td></td>
</tr>
<tr>
<td>underride, or override the installation although</td>
<td></td>
<td></td>
</tr>
<tr>
<td>controlled lateral deflection of the article is</td>
<td></td>
<td></td>
</tr>
<tr>
<td>acceptable.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Occupant Risk</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D. Detached elements, fragments or other debris</td>
<td>There was no significant debris from either the vehicle or the barrier.</td>
<td>pass</td>
</tr>
<tr>
<td>from the test article should not penetrate or</td>
<td></td>
<td></td>
</tr>
<tr>
<td>show potential for penetrating the occupant</td>
<td></td>
<td></td>
</tr>
<tr>
<td>compartment, or present an undue hazard to other</td>
<td></td>
<td></td>
</tr>
<tr>
<td>traffic, pedestrians, or personnel in a work</td>
<td></td>
<td></td>
</tr>
<tr>
<td>zone. Deformation of, or intrusions into, the</td>
<td></td>
<td></td>
</tr>
<tr>
<td>occupant compartment that could cause serious</td>
<td></td>
<td></td>
</tr>
<tr>
<td>injuries should not be permitted.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F. The vehicle should remain upright during and</td>
<td>The maximum roll and pitch of the vehicle were well within acceptable</td>
<td>pass</td>
</tr>
<tr>
<td>after collision although moderate roll, pitching</td>
<td>limits</td>
<td></td>
</tr>
<tr>
<td>and yawing are acceptable.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Vehicle Trajectory</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>K. After collision it is preferable that the</td>
<td>The vehicle trajectory was would not have brought the vehicle back into</td>
<td>pass</td>
</tr>
<tr>
<td>vehicle’s trajectory not intrude into adjacent</td>
<td>traffic.</td>
<td></td>
</tr>
<tr>
<td>traffic lanes.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L. The occupant impact velocity in the</td>
<td>Long. Occ. Impact Vel. = 4.75 m/s</td>
<td>Pass</td>
</tr>
<tr>
<td>longitudinal direction should not exceed 12 m/</td>
<td>Long. Occ. Ridedown = -7.35 g</td>
<td></td>
</tr>
<tr>
<td>sec and the occupant ridedown acceleration in</td>
<td></td>
<td></td>
</tr>
<tr>
<td>the longitudinal direction should not exceed 20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>g.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M. The exit angle from the test article</td>
<td>Exit angle 9 degrees, or 38% of impact angle</td>
<td>Pass</td>
</tr>
<tr>
<td>preferably should be less that 60 percent of</td>
<td></td>
<td></td>
</tr>
<tr>
<td>the test impact angle, measured at time of</td>
<td></td>
<td></td>
</tr>
<tr>
<td>vehicle loss of contact with test device.”</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2-3 – Vehicle Trajectories and Speeds

<table>
<thead>
<tr>
<th>Test Number</th>
<th>Impact Angle [deg]</th>
<th>60% of Impact Angle [deg]</th>
<th>Exit Angle [deg]</th>
<th>Impact Speed, $V_i$ [km/h]</th>
<th>Exit Speed, $V_e$ [km/h]</th>
<th>Speed Change $V_i - V_e$ [km/h]</th>
</tr>
</thead>
<tbody>
<tr>
<td>601</td>
<td>24.0</td>
<td>37.5</td>
<td>9</td>
<td>100.3</td>
<td>80.3</td>
<td>20</td>
</tr>
</tbody>
</table>
3. CONCLUSION

In Test 601 all of the barrier structural adequacy, occupant risk, and vehicle trajectory criteria, as outlined in NCHRP Report 350, were within acceptable limits. The exit angles were small enough that the vehicle would not impose undue risks to other motorists. No debris was scattered in such a way that it would create hazards to other motorists.

The vehicle weight, impact speed, and impact angle were all within Report 350 limits for Test 3-11. However, the Impact Severity was 125.8 kJ, which is below the Report 350 limit of 127.3 kJ (138.1 kJ – 10.8 kJ). Because none of the other evaluation criteria outlined above were near failure, the low Impact Severity was not considered to be a cause for a retest.

Depending on the application of the Type 60K Terminus, repairs may have to be made quickly to avoid safety concerns for other vehicles impacting the same location.

Based on the testing of the Type 60K Terminus, the following conclusions can be drawn:

1. The Type 60K Terminus can successfully contain and redirect a 1960-kg pickup truck impacting at 24° and 100.3 km/h.

4. **RECOMMENDATIONS**

The Type 60K Terminus is recommended for approval on California highways requiring a down-stream end treatment to the Type 60k barrier with the following limitations:

1. First, there must be a need to be able to remove the barrier. Otherwise a more permanent anchor to the 60k should be used (i.e. Type 60 median barrier)

2. Second, it may not be used in locations where a reverse hit is possible.

3. Third, it can not be placed where impact can occur on the unrestrained side since the restraining stakes will not offer any lateral support when the 60k terminus is hit from the staked side.
5. IMPLEMENTATION

The Traffic Operations Program, in cooperation with Engineering Services will be responsible for the preparation of standard plans and specifications for the 60K Terminus, with technical support from the Roadside Safety Research Group with the Division of Research and Innovation.
6. APPENDIX

6.1. Test Vehicle Equipment
The test vehicles were modified as follows for the crash tests:

• The gas tanks on the test vehicle was disconnected from the fuel supply line and drained. A 12-liter safety gas tank was installed in the truck bed and connected to the fuel supply line. The stock fuel tank had gaseous CO₂ added to purge fuel vapors.

• A 12-volt deep cycle gel cell battery powered the transient data recorders, the solenoid-valve braking/accelerator system, rate gyros, and the electronic control box.

• A 4800-kPa CO₂ system, actuated by a solenoid valve, controlled remote braking after impact and emergency braking if necessary. Part of this system was a pneumatic ram that was attached to the brake pedal. The operating pressure for the ram was adjusted through a pressure regulator during a series of trial runs prior to the actual test. Adjustments were made to assure the shortest stopping distance without locking up the wheels. When activated, the brakes would apply in less than 100 milliseconds.

• The remote brakes were controlled via a radio link transmitter at a console trailer. When the brakes were applied by remote control from the console trailer, the ignition was automatically rendered inoperable by removing power to the coil.

• An accelerator switch was located on the rear of the vehicle. The switch opened an electric solenoid, which in turn released compressed CO₂ from a reservoir into a pneumatic ram that had been attached to the accelerator pedal. The CO₂ pressure for the accelerator ram was regulated to the same pressure of the remote braking system with a valve to adjust CO₂ flow rate.

• An electronic speed control box, connected in-line with the primary winding of the coil, was used to regulate the speed of the test vehicle based on the signal from a speed sensor output
from the vehicle transmission. This device was calibrated prior to all tests by conducting a series of trial runs through a speed trap comprised of two tape switches set a specified distance apart and a digital timer.

- A microswitch was mounted below the front bumper and connected to the ignition system. A trip plate on the ground near the impact point triggered the switch when the car passed over it. The switch would open the ignition circuit and shut off the vehicle’s engine prior to impact.

Table 6-1 gives specific information regarding vehicle dimensions and weights for Test 601.
Table 6-1 – Test 601 Vehicle Dimensions

DATE: 4/23/02  TEST NO: 601  VIN NO: 1GFC244R2263338  MAKE: Chevy
TIRE INFLATION PRESSURE: 55 (PSI)

MASS DISTRIBUTION (kg)

<table>
<thead>
<tr>
<th></th>
<th>LF</th>
<th>RF</th>
<th>LR</th>
<th>RR</th>
</tr>
</thead>
<tbody>
<tr>
<td>547.0</td>
<td>539.0</td>
<td>438.0</td>
<td>436.0</td>
<td></td>
</tr>
</tbody>
</table>

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST: There was a small dent in the driver’s side door.

ENGINE TYPE: Gas V8
ENGINE CID: 305
TRANSMISSION TYPE: X AUTO
OPTIONAL EQUIPMENT: AC
DUMMY DATA:
TYPE: NA
MASS: NA
SEAT POSITION: NA

GEOMETRY (mm)

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>J</th>
<th>K</th>
<th>L</th>
<th>M</th>
<th>N</th>
<th>O</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>1900</td>
<td>940</td>
<td>3340</td>
<td>1770</td>
<td>1300</td>
<td>5580</td>
<td>1489</td>
<td>na</td>
<td>90</td>
<td>1010</td>
<td>600</td>
<td>90</td>
<td>450</td>
<td>1570</td>
<td>1610</td>
<td>730</td>
</tr>
</tbody>
</table>

MASS - (kg)

<table>
<thead>
<tr>
<th></th>
<th>CURB</th>
<th>TEST INERTIAL</th>
<th>GROSS STATIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1</td>
<td>1075.0</td>
<td>1086.0</td>
<td>1086.0</td>
</tr>
<tr>
<td>M2</td>
<td>753.0</td>
<td>874.0</td>
<td>874.0</td>
</tr>
<tr>
<td>MT</td>
<td>1828.0</td>
<td>1960.0</td>
<td>1960.0</td>
</tr>
</tbody>
</table>
6.2. Test Vehicle Guidance System

A rail guidance system directed the vehicle into the barrier. The guidance rail, anchored at 3.8-m intervals along its length, was used to guide a mechanical arm that was attached to the front right wheel of the vehicle. A 10-mm nylon rope was used to trigger the release mechanism on the guidance arm, thereby releasing the vehicle from the guidance system before impact.

6.3. Photo - Instrumentation

Several high-speed movie cameras recorded the impact during the crash test. The types of cameras and their locations are shown in Table 6-2 and Figure 6-1.

All of these cameras were mounted on tripods except the three that were mounted on a 10.7-m high tower directly over the impact point on the test barrier. A video camera and a 16-mm film camera were turned on by hand and used to obtain pan shots during the test. Switches on a console trailer near the impact area remotely triggered all other cameras. Both the test vehicle and test barrier were photographed before and after impact with a normal-speed, 16-mm movie camera, a beta video camera and a color still camera. A film report of this project has been assembled using edited portions of the crash testing coverage.

<table>
<thead>
<tr>
<th>Camera Label</th>
<th>Film Size (mm)</th>
<th>Camera Type</th>
<th>Rate: (fr./sec.)</th>
<th>Typical Coordinates, m</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1</td>
<td>16</td>
<td>LOCAM 1</td>
<td>5.4</td>
<td>X: 5.4 Y: 2.4 Z: 1.4</td>
</tr>
<tr>
<td>L2</td>
<td>16</td>
<td>LOCAM 2</td>
<td>0.0</td>
<td>X: 0 Y: 0 Z: 9.1</td>
</tr>
<tr>
<td>L3</td>
<td>16</td>
<td>LOCAM 3</td>
<td>33.4</td>
<td>X: -0.61 Y: -26.3 Z: 4.5</td>
</tr>
<tr>
<td>L4</td>
<td>16</td>
<td>LOCAM 4</td>
<td>-0.61</td>
<td>X: 0 Y: 0 Z: 9.1</td>
</tr>
<tr>
<td>L5</td>
<td>16</td>
<td>LOCAM 5</td>
<td>-80.9</td>
<td>X: -80.9 Y: -0.8 Z: 1.4</td>
</tr>
<tr>
<td>L6</td>
<td>16</td>
<td>LOCAM 6</td>
<td>0.61</td>
<td>X: 0 Y: 0 Z: 9.1</td>
</tr>
<tr>
<td>L8</td>
<td>16</td>
<td>LOCAM 8</td>
<td>405.1</td>
<td>X: 1.6 Y: -26.0 Z: 1.4</td>
</tr>
<tr>
<td>V</td>
<td>1.27</td>
<td>SONY BETACAM</td>
<td>30</td>
<td>X: -2.4 Y: -26.3 Z: 4.5</td>
</tr>
<tr>
<td>H</td>
<td>35</td>
<td>HULCHER</td>
<td>40</td>
<td>X: -1.1 Y: -26.8 Z: 4.5</td>
</tr>
</tbody>
</table>

Note: Camera location measurements were approximated and are typical for all crash tests involved in this report.

*X, Y and Z distances are relative to the impact point.
The following are the pretest procedures that were required to enable film data reduction to be performed using a Visual Instrumentation Corporation Model 1214A film motion analyzer:

1) Butterfly targets were attached to the top and sides of each test vehicle. The targets were located on the vehicle at intervals of 0.5 and 1.0 meters. The targets established scale factors and horizontal and vertical alignment. The test barrier was stenciled with segment numbers on the front of the barrier.

2) Flashbulbs, mounted on the test vehicle, were electronically triggered to establish 1) initial vehicle-to-barrier contact, and 2) the time of the application of the vehicle brakes. The impact flashbulbs begin to glow immediately upon activation, but have a delay of several milliseconds before lighting up to full intensity.

3) Five tape switches, placed at 4-m intervals, were attached to the ground near the barrier and were perpendicular to the path of the test vehicle. Flashbulbs were activated sequentially when the tires of the test vehicle rolled over the tape switches. The flashbulb stand was placed in view of the cameras. The flashbulbs were used to correlate the cameras with the impact events and to calculate the impact speed independent of the electronic speed trap. The tape switch layout is shown in Figure 6-2.

4) High-speed cameras had timing light generators that exposed red timing pips on the film at a rate of 100 per second. The pips were used to determine camera frame rates.
Figure 6-2 – Event Switch Layout
6.4. **Electronic Instrumentation and Data**

Transducer data were recorded on two separate GMH Engineering, Data Brick Model II, digital transient data recorders (TDRs) that were mounted in the vehicle. The transducers mounted on the vehicle include two sets of accelerometers and one set of rate gyros at the center of gravity. The TDR data were reduced using a desktop personal computer running DADiSP 4.1.

Accelerometer specifications are shown in Table 6-3. The vehicle accelerometer sign convention used throughout this report is the same as that described in NCHRP Report 350 and is shown in Figure 6-3.

A rigid stand with three retro-reflective 90° polarizing tape strips was placed on the ground near the test barrier and alongside the path of the test vehicle (see Figure 6-2). The strips were spaced at carefully measured intervals of 1 m. The test vehicle had an onboard optical sensor, which produced sequential impulses or "event blips" that were recorded concurrently with the accelerometer signals on a TDR, serving as "event markers". The impact velocity of the vehicle could be determined from these sensor impulses and timing cycles and the known distance between the tape strips. A pressure sensitive tape switch on the front bumper of the vehicle closed at the instant of impact and triggered two events: 1) an “event marker” was added to the recorded data, and 2) a flashbulb mounted on the top of the vehicle was activated. The final event recorded to the TDR was from a brake pressure sensor attached to the CO₂ system. Two other pressure sensitive tape switches, connected to a speed trap, were placed 4 m apart just upstream of the test barrier specifically to establish the impact speed of the test vehicle.

The data curves are shown in Figure 6-4 through Figure 6-7 and include the accelerometer and rate gyro records from the test vehicles. They also show the velocity and displacement curves for the longitudinal and lateral components. These plots were needed to calculate the occupant impact velocities defined in NCHRP Report 350. All data were analyzed using software written by DADiSP 4.1 and modified by Caltrans.
Table 6-3 – Accelerometer Specifications

<table>
<thead>
<tr>
<th>TYPE</th>
<th>LOCATION</th>
<th>RANGE</th>
<th>ORIENTATION</th>
<th>TEST NUMBER</th>
</tr>
</thead>
<tbody>
<tr>
<td>STATHAM</td>
<td>VEHICLE C.G.</td>
<td>100 G</td>
<td>LONGITUDINAL</td>
<td>601</td>
</tr>
<tr>
<td>STATHAM</td>
<td>VEHICLE C.G.</td>
<td>100 G</td>
<td>LATERAL</td>
<td>601</td>
</tr>
<tr>
<td>STATHAM</td>
<td>VEHICLE C.G.</td>
<td>50 G</td>
<td>VERTICAL</td>
<td>601</td>
</tr>
<tr>
<td>HUMPHREY</td>
<td>VEHICLE C.G.</td>
<td>180 DEG/SEC</td>
<td>ROLL</td>
<td>601</td>
</tr>
<tr>
<td>HUMPHREY</td>
<td>VEHICLE C.G.</td>
<td>90 DEG/SEC</td>
<td>PITCH</td>
<td>601</td>
</tr>
<tr>
<td>HUMPHREY</td>
<td>VEHICLE C.G.</td>
<td>180 DEG/SEC</td>
<td>YAW</td>
<td>601</td>
</tr>
<tr>
<td>ENDEVCO</td>
<td>VEHICLE C.G.</td>
<td>200 G</td>
<td>LONGITUDINAL</td>
<td>601</td>
</tr>
<tr>
<td>ENDEVCO</td>
<td>VEHICLE C.G.</td>
<td>200 G</td>
<td>LATERAL</td>
<td>601</td>
</tr>
<tr>
<td>ENDEVCO</td>
<td>VEHICLE C.G.</td>
<td>200 G</td>
<td>VERTICAL</td>
<td>601</td>
</tr>
</tbody>
</table>

Figure 6-3 – Vehicle Accelerometer Sign Convention
Figure 6-4 – Test 601 Vehicle Accelerations Vs Time
Figure 6-5 – Test 601 Vehicle Longitudinal Acceleration, Velocity and Distance Vs Time
Figure 6-6 – Test 601 Vehicle Lateral Acceleration, Velocity and Distance -Vs- Time
Figure 6-7 – Test 601 Vehicle Roll, Pitch and Yaw -Vs- Time
Figure 6-8 – Type 60 Standard Plan
7. REFERENCES


