DEVELOPMENT OF STAKING CONFIGURATIONS
FOR K-RAIL

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This project was performed in cooperation with the US Department of Transportation, Federal Highway Administration, under the research project titled “DEVELOPMENT OF STAKING CONFIGURATIONS FOR K-RAIL.”

Full-scale crash testing was conducted on various staking configurations for pre-cast concrete barrier (California K-raill). The staking configurations tested were developed in effort to optimize cost and worker safety. Testing was conducted in accordance with NCHRP Report 350. The tested barriers consisted of twelve or thirteen concrete segments, each 6045 mm (20 ft) in length. The segments were placed on 125-mm (5-in) AC pavement and connected together with 31.8 x 660 - mm (1.25 x 26 in) pins. Each segment was secured to the ground using 25 x 610-mm (24-in) stakes either uncapped or capped. The tests were performed at the Caltrans Dynamic Test Facility in West Sacramento, California.

A total of six crash tests were conducted under Report 350 Test Level 3-11. Two testing groups were established: K-rail as a median barrier and K-rail adjacent to an excavation. Each group was tested under three staking configurations. One test from the median barrier group and two tests from the excavation group were within the limits of Report 350 Test Level 3-11.

It is recommended that staked K-rail be approved for use on California State highways when the following conditions are present:

1. When K-rail is placed as a semi-permanent median barrier with less than 610 mm (2 ft) from the edge of travel way in both directions, use four capped stakes per section every other section.
2. When K-rail is placed less than 610 mm (2 ft) from the edge of an excavation, use two capped stakes per section along the traffic side. The distance between the K-rail and excavation must be a minimum of 75 mm (3 in).

K-rail, Type K, Type 50, Temporary Barriers, Safety Shape Barrier, Crash Test, Staking, Stake, New Jersey Shape, Temporary Railing, Tie-down, Anchored Barrier

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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.
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1. INTRODUCTION

1.1. Problem

The current policy for the staking of K-rail is not consistent with the current understanding of how K-rail reacts during vehicular impacts. Efforts to develop a new policy for staking K-rail during construction have been met with concern over cost-effectiveness and crashworthiness issues. A new configuration for staked K-rail that passes NCHRP Report 350 guidelines [1] must be developed to provide the safest alternative for the traveling public and construction personnel with minimal deployment cost.

1.2. Objective

This research project focuses on developing a cost-effective staking configuration for K-rail, which meets NCHRP Report 350 Test Level 3 for longitudinal barriers and the needs of Caltrans’ Traffic Operations and Construction. Traffic Operations requested a staking configuration to use when K-rail is placed as a median barrier in narrow medians. Construction requested a configuration that meets two criteria: place K-rail near the edge of an excavation and minimize the distance between the K-rail and the excavation. In addition, both groups requested that the staking configurations minimize barrier movement, pavement damage, and worker exposure.

1.3. Background and Significance of Work

Caltrans’ current standard for portable concrete barrier is K-rail. This barrier may be used in long-term installations when properly installed [2]. K-rail evolved from the Type 50 (“New Jersey shape”) median barrier, which has been approved for use in California and other states since the mid-1960s. By 1971, substantial interest was expressed in California and other states to develop a movable barrier that could be used in work zones. In 1972, Caltrans ran a series of crash tests on K-rail. The test results led to the approval of K-rail for use as a temporary barrier in California. The K-rail that has become the standard consists of 6.1-m (20-ft) long sections with pin and loop connections, each weighing approximately 3630 kg (8000 lbs).

In 1999, Caltrans tested fully staked K-rail for temporary installations, and the results showed that fully staked K-rail greatly reduced lateral barrier movement [3]. Traffic Operations issued a Policy Directive on 1/18/2002 that required K-rail to be staked when it was placed near the edge of travel way and/or near the edge of an excavation. However, the policy was rescinded on 3/15/2002 due to the increased traffic exposure for construction workers during stake installation, damage to the pavement, and increased cost of traffic control.

This research project was established to address the concerns listed above. The results of this research will lead to new policy that outlines the minimum guidelines for temporary K-rail installations.

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a Metric units are used for measurements taken for NCHRP Report 350 evaluation criteria. Dual units (Metric followed by U.S. Customary) are used for measurements related to the test article.
1.4. Literature Search

A search for information about staked K-rail consisted of information contained in past crash test reports by Caltrans and other agencies. Information was found in:

- Dynamic Tests of Prestressed Concrete Median Barrier Type 50, Series XXVI, CA-HY-MR-6588-1-73-06 [4]
- Crash Test Results for the Idaho 6095-mm Concrete Barrier [5]

1.5. Scope

A total of six tests were performed and evaluated in accordance to NCHRP Report 350. The first three tests evaluated K-rail when placed as a semi-permanent median barrier and the last three evaluated K-rail when place adjacent to an excavation. The testing matrix established for this project is shown in Table 1-1 on the proceeding page.
Table 1-1. Target Impact Conditions

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<td>100 (62.1)</td>
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<td>672</td>
<td>4 uncapped stakes per section, every other section.</td>
<td>2000 (4410)</td>
<td>100 (62.1)</td>
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<tr>
<td>673</td>
<td>4 capped stakes per section, every other section.</td>
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<tr>
<td>674</td>
<td>4 capped stakes per section, every other section with the barrier offset by 152mm (6 in) from the excavation’s edge.</td>
<td>2000 (4410)</td>
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<td>675</td>
<td>2 capped stakes per section, traffic side with the barrier offset by 76mm (3 in) from the excavation’s edge.</td>
<td>2000 (4410)</td>
<td>100 (62.1)</td>
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<tr>
<td>676</td>
<td>1 capped stake per section, traffic side, upstream relative to traffic with the barrier offset by 76mm (3 in) from the excavation’s edge.</td>
<td>2000 (4410)</td>
<td>100 (62.1)</td>
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2. TECHNICAL DISCUSSION

2.1. Test Conditions – Crash Tests

2.1.1. Test Facilities

All of the crash tests were conducted at the Caltrans Dynamic Test Facility in West Sacramento, California. The test area is a large, flat, asphalt concrete surface containing 2 overlays (Figure 2-1). Each overlay measured approximately 51 mm (2 in) thick. There were no obstructions near or within the testing area.

Figure 2-1. Asphalt Concrete Thickness
2.1.2. Test Article Design

2.1.2.1. K-rail

The K-rail was purchased new at Concrete Products in Tracy, CA. The K-rail was manufactured to Caltrans’ Standard Plans and Specifications. Members of the Roadside Safety and Research Group visited the plant to inspect the K-rail. They evaluated the construction process, collected concrete samples for testing, measured the concrete temperature, performed a slump test, and checked the rebar placement (Figure 2-2).

Sampling cylinders were prepared for later testing of the compressive strength of the concrete. Three cylinders were sent for testing to the concrete testing section at the Caltrans Transportation Laboratory. The 28-day average compressive strength was found to be 29,160 kPa (4230 psi). The results from all tests and inspections met or exceeded Caltrans’ 2004 Standard Specifications. The 2004 K-rail Standard Plan is located in Section 7.5 of the Appendix.

Figure 2-2. K-rail Rebar Placement
2.1.2.2. Stakes

2.1.2.2.1. Stake Description

The stakes originally selected were 610-mm (24-in) long, #25M (#8) deformed rebar of ASTM A615 Grade 60 material (Figure 2-3). These parameters were selected for the following reasons:

1. Deformed bar (vs. smooth bar) to increase the uplift resistance.
2. 610-mm (24-in) length allows for quick installation. A longer length would consume more installation time, and thus, would increase worker exposure. Additionally, a longer stake would not provide a significant amount of lateral resistance.
3. #25M (#8) rebar is the largest size that will fit through a K-rail staking slot. It provides greater to lateral displacement than smaller sizes.
4. ASTM A615 Grade 60 deformed rebar is a common material.

For conservative results, the uncapped stakes were driven down until their heads were flush with the K-rail slot’s horizontal surface. More details about the stakes and installation process are located in Sections 7.5 and 7.6.

Starting with Test 673, the stake design was modified to have a cap (Figure 2-4). This addition provided uplift resistance and prevented the K-rail from slipping over the stake when impacted. The uplift resistance was important since, without caps, the K-rail would rotate about the stakes opposite the impact side. The vehicle would then travel up the face of the barrier and be launched onto the top of the barrier.

The stake design changed to 610-mm (24-in) long, #25M (#8) deformed rebar of ASTM A706 Grade 60 material with a 70-mm (2.75-in) diameter by 13-mm (0.5-in) thick washer welded approximately 25 mm (1 in) below the top surface. Points were added to the stakes for Tests 674 – 676 for quicker installation. More information about stakes and the installation process is located in Sections 7.5 and 7.6.
2.1.2.3. Stake Configurations

Two types of staking configurations were developed. The first configuration type is used when K-rail is placed as a temporary median barrier. The second configuration type is used when K-rail is placed adjacent to an excavation during construction.

2.1.2.3.1. Median Configurations (Tests 671-673)

The median configurations are symmetrically designed relative to the traffic flow. The configurations are shown in top section of Figure 2-5.

The staking configuration for Test 671 incorporated two uncapped stakes per barrier. The stakes were placed in opposing corners in the slot that was upstream relative to the traffic’s flow. The critical impact point (CIP) was located 305 mm upstream from a joint to maximize the potential for vehicle roll and the barrier displacement.

The staking configuration for Test 672 incorporated four uncapped stakes in every other barrier. As in Test 671, the critical impact point was located 305 mm upstream from a joint on a staked section to maximize the vehicle’s roll and the barrier’s displacement.

The staking configuration for Test 673 incorporated four capped stakes in every other barrier. It was noted after Tests 671 and 672 that the uncapped stakes provided no uplift resistance for the barrier. Also, once the barrier lifted above the stake’s top edge, the stake provided no lateral resistance. Therefore, the configuration for Test 673 is the same as it was for Test 672, but capped stakes replaced uncapped stakes. Again, the critical impact point was located 305 mm upstream from a joint on a staked section to maximize the vehicle roll and the barrier displacement.

2.1.2.3.2. Adjacent to an Excavation Configurations (Tests 674-676)

The adjacent-to-an-excavation configurations were designed to establish guidelines for the minimum distance between the K-rail and an excavation and to minimize the lateral barrier movement. The excavation was approximately 610 mm deep. The configurations are shown in lower section of Figure 2-5.

The staking configuration for Test 674 incorporated four capped stakes in every other barrier. Since this configuration had a favorable result for Test 673, it was the first choice for the adjacent-to-an-excavation testing series. The barrier was placed 150 mm from the edge of the excavation. The critical impact point was located 914 mm upstream from a joint on a non-staked barrier segment to evaluate for potential vehicle snagging and to maximize the barrier displacement.

The staking configuration for Test 675 incorporated two capped stakes per barrier on the traffic side. It was noted from previous tests that the stakes that were located opposite of the impact side created a pivot point when the barrier was impacted. The pivot point would cause the barrier to rollback, which led to vehicle roll. The barrier was placed 75 mm from the edge of the excavation versus at the edge to account for varying edge conditions. The critical impact point was located 914 mm upstream from a joint to evaluate for potential vehicle snagging and to maximize the barrier displacement.

The staking configuration for Test 676 incorporated one capped stake per barrier in the traffic side’s upstream slot. It was designed to further reduce installation costs, pavement damage, and worker exposure. The barrier was placed 75 mm from the edge of the excavation
versus at the edge to account for varying edge conditions. The critical impact point was located 305 mm upstream from a joint to maximize the barrier’s displacement.

Figure 2-5. Staking Configurations Layout
2.1.3. Test Vehicles

Most test vehicles complied with NCHRP Report 350 Test Designation 3-11 guidelines. One vehicle was below the recommended test inertial mass\(^b\). For all tests, the vehicles were ¾-ton pickups in good condition, free of major body damage and not missing any structural parts. All of the vehicles had front-mounted engines and standard equipment.

Table 2-1. Test Vehicle Masses

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Vehicle</th>
<th>Year Manufactured</th>
<th>Test Inertial Kg (lbm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>671</td>
<td>GMC Sierra 2500</td>
<td>1992</td>
<td>1986.7 (4379.9)</td>
</tr>
<tr>
<td>672</td>
<td>GMC Sierra 2500</td>
<td>1993</td>
<td>1987.4 (4381.5)</td>
</tr>
<tr>
<td>673</td>
<td>Chevrolet 2500</td>
<td>1997</td>
<td>2016.3 (4445.2)</td>
</tr>
<tr>
<td>674</td>
<td>GMC Cheyenne</td>
<td>1989</td>
<td>1929.7(^b) (4254.3)</td>
</tr>
<tr>
<td>675</td>
<td>Chevrolet Silverado</td>
<td>1994</td>
<td>2005.9 (4422.2)</td>
</tr>
<tr>
<td>676</td>
<td>Chevrolet Silverado</td>
<td>1988</td>
<td>1981.0 (4367.4)</td>
</tr>
</tbody>
</table>

The test vehicles were self-powered and used a speed control device to limit acceleration once the impact speed had been reached. Remote braking was possible at any time during all tests via a radio-linked, remote-controlled braking setup. A short distance before the point of impact, remote braking was activated.

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\(^b\) The test inertial mass was less than the recommended test inertial mass range (2000 +/- 45 kg). The same conclusion for this test would have been made with a vehicle that was within the recommended test inertial mass range.

\(^c\) NCHRP Report 350 recommends that test vehicles be less than six years old at the time of testing. Although all of the vehicles were older than the recommended age limit, the body style of the 2500 pickup was the same from 1988 – 1998. In 1999 and 2000 the older body style was still available for new purchase.
impact each vehicle was released from the guidance rail and the ignition system was deactivated.
A detailed description of the test vehicle equipment and guidance system is contained in Sections
7.1 and 7.2 (located in the Appendix).

2.1.4. Data Acquisition System

All tests were recorded with high-speed digital video cameras, one normal speed digital video camera, and one digital SLR camera. The test vehicles and test articles were photographed before and after impact with a digital video camera and a digital SLR camera. A film report of this project was assembled using edited portions of the digital film and camera coverage. More detailed information on the cameras is located in Section 7.3.

Two sets of orthogonal accelerometers were mounted in the center of gravity of each vehicle. One set of rate gyro transducers was placed 191 mm (7.5 in) behind the set of accelerometers (along the X-axis) to measure the roll, pitch, and yaw rates. These data were used in calculating the occupant impact velocities, ridedown accelerations, and maximum vehicle rotation. More information on instrumentation is located in Section 7.7.1.

Two separate digital transient data recorders, manufactured by GMH Engineering (Model II), were used to record electronic data during all tests. The digital data were analyzed with custom DADiSP workbooks using a personal computer. The test data is located in the Appendix.

2.2. Test Results – Crash Tests

2.2.1. Test 671 – Median Layout: 2 Uncapped Stakes per Barrier

2.2.1.1. Impact Description/Vehicle Behavior

The intended impact angle of 25° and impact location on the vehicle’s left-front corner was set by the placement of the guide rail (Figure 2-7). Film analysis indicated that the actual impact angle was 28.3°, and the actual impact location was 93 mm upstream from the intended Critical Impact Point (CIP). The impact speed of 101.4 km/h (63.0 mph) was obtained by averaging the output from two independent speed traps located just upstream from the impact point. This speed was confirmed via film analysis. Upon impact the vehicle’s left front corner was crushed while the barrier rocked back and shifted laterally away from the impact. The vehicle rode upwards on the barrier during impact and stayed in contact for 3.2 m (10.5 ft). Approximately 0.29 s after impact the left rear tire lost contact with the barrier, and the vehicle was in the air. The vehicle rolled to the right (positive), and its right front tire landed on the ground 14.1 m (46.3 ft) from the CIP and 0.61 s after the initial impact. The vehicle’s undercarriage landed on top of the barrier 19.1 m (62.7 ft) from the CIP and 1.12 s after the initial impact. The vehicle remained in contact with the top of the barrier until reaching the end of the last segment, at which point it dropped to the ground. The brakes were applied 1.22 s after the initial impact as indicated by the data recorder’s event channel. The vehicle came to rest 76 m (250 ft) from the CIP. Figure 2-6 through Figure 2-16 show the pre-test and post-test condition of the test vehicle and test article. Sequence photographs of the impact for Test 671 are shown as Figure 2-17 on the data summary sheet on page 17.

The longitudinal occupant impact velocity was 5.25 m/s (17.2 ft/s), which was below the allowable maximum of 12 m/s (39 ft/s) specified in NCHRP Report 350. The longitudinal
occupant ridedown acceleration, 3.96 g, was below the allowed maximum of 20 g. Test results are summarized in Table 2-2 on page 59.

Figure 2-6. Test 671 - Side View of Vehicle Pre-Impact

Figure 2-7. Test 671 - Vehicle at Impact Location Pre-Impact
Figure 2-8. Test 671 - Close-up view of Vehicle at Impact Location Pre-Impact

Figure 2-9. Test 671 - Barrier Pre-Impact
2.2.1.2. **Barrier Damage**

The barrier underwent some permanent displacement as seen in the figure below (segments that did not have any measurable movement are not shown).

![Figure 2-10. Test 671 - Barrier Static Displacements [mm]](image)

The pin and loop connection between sections 5 & 6, 6 & 7 (nearest to the impact point) and 7 & 8 bent and caused spalling at the joint. Sections 6 through 12 had scuffmarks. Sections 10 and 11 had minor scarping on the top, which occurred when the vehicle rode on top of the barrier. The upstream stake in Section 6 & both stakes in Section 7 were bent. The staked, upstream slot in Section 6 had spalling. The maximum lateral static displacement was 370 mm (14.6 in), and the maximum lateral dynamic displacement was 389 mm (15.3 in) at the toe. Static measurements were taken with a tape measure and dynamic measurements were obtained via film analysis. After impact, segments 6 and 7 maintained a backward lean due to obstructions under the K-rail.

![Figure 2-11. Test 671 - Downstream View of Barrier Post-Impact](image)
Figure 2-12. Test 671 - Impact Location Post-Impact

Figure 2-13. Test 671 - Section 6 Upstream Stake Post-Impact
2.2.1.3. Vehicle Damage

The initial impact damaged the left front corner of the vehicle. The left front quarter panel and bumper were crushed. The floorboard intruded into the occupant compartment by 2.5 cm (1 in). The floorboard deformation area was approximately 140 cm$^2$ (0.15 ft$^2$) and was located at the left front corner. The tire partially slipped off of the rim. The secondary impact occurred when the vehicle contacted the ground while it was rolling. The right front quarter panel and bumper were damaged. The hub guidance assembly was slightly damaged.

Figure 2-14. Test 671 - Side View of Vehicle Post-Impact
Figure 2-15. Test 671 – Front-left View of Vehicle Post-Impact

Figure 2-16. Test 671 - Front-right View of Vehicle Post-Impact
2.2.1.4. Test 671 Data Summary Sheet

Figure 2-17. Test 671 - Impact sequence and diagram

General Information
Testing Agency........California DOT
Test Number ..............671
Test Date .................June 9, 2005

Test Article
Type..............Semi-permanent K-rail in a median
barrier configuration
Staking Configuration.........................
2 uncapped stakes in opposite corners,
upstream relative to the traffic flow.
Installation Length.....73.1 m (239.8 ft)
Element Length .........6.1 m (20 ft)
Element Height..........0.8 m (32 in)
Element Weight.........3540 kg (7805.7 lb)

Test Vehicle
Type..................Production Model
Designation..............2000P
Model ....................1992 GMC Sierra
Mass: Curb .................1984.9 kg (4375.9 lbm)
Test Inertial .........1986.7 kg (4380.0 lbm)

Impact Conditions
Impact Velocity ........101.4 km/h (63.0 mph)
Impact Angle .............28.3°

Exit Conditions
Exit Velocity ..............n/a
Exit Angle ................0°

Test Data
Occupant Impact Velocity
Long ....................5.25 m/s (17.2 ft/s)
Lat ....................-5.33 m/s (-17.5 ft/s)
Ridedown Acceleration
Long ....................3.96 g
Lat ....................-5.50 g
ASI ....................1.41
OCDI ....................LF0010000

Post-Impact Vehicular Behavior
(Data Analysis/Video Analysis)
Maximum Roll Angle..........33.93° / 63°
Maximum Pitch Angle ...........14.30° / 16°
Maximum Yaw Angle ..........24.22° / n/a

Test Article Deflections
Dynamic ..................389 mm (15.3 in)
Permanent .................370 mm (14.6 in)
2.2.2. Test 672 – Median Layout: 4 Uncapped Stakes per Every Other Barrier

2.2.2.1. Impact Description/Vehicle Behavior

The intended impact angle of 25° and impact location on the vehicle’s left-front corner was set by the placement of the guide rail (Figure 2-19). Film analysis indicated that the actual impact angle was 26.0°, and the actual impact location was 127 mm (5 in) upstream from the intended CIP. The impact speed of 99.1 km/h (61.6 mph) was obtained by averaging the output from two independent speed traps located just upstream from the impact point. This speed was confirmed via film analysis. Upon impact the vehicle’s left front corner was crushed. The vehicle rode upwards on the barrier during impact and stayed in contact for 3.0 m (9.8 ft). Approximately 0.29 s after impact the left rear tire lost contact with the barrier and the vehicle was in the air. The vehicle rolled to the right before its right front tire landed on the ground 13.3 m (43.6 ft) from the CIP and 0.59 s after the initial impact. The vehicle’s undercarriage landed on top of the barrier 23.8 m (78.1 ft) from the CIP and 1.23 s after the initial impact. The vehicle remained in contact with the top of the barrier until the end of the last segment was passed. The brakes were applied 0.82 s after the initial impact as indicated by the data recorder’s event channel. The vehicle came to rest 53 m (174 ft) from the CIP.

The longitudinal occupant impact velocity was 4.60 m/s (15.1 ft/s), which was above the allowable maximum of 12 m/s (39 ft/s) specified in NCHRP Report 350. The longitudinal occupant ridedown acceleration, -4.57 g, was below the allowed maximum of 20 g. Test results are summarized in Table 2-3 on page 60.

Figure 2-18 through Figure 2-29 show pre-test and post-test condition of the test vehicle and test article. Sequence photographs of the impact for Test 672 are shown as Figure 2-30 on the data summary sheet on page 25.
Figure 2-19. Test 672 - Vehicle at Impact Location Pre-Impact

Figure 2-20. Test 672 - Close-up View of Vehicle at Impact Location
Figure 2-21. Test 672 - Barrier Pre-Impact

Figure 2-22. Test 672 - Stake #6B Pre-Impact
2.2.2.2. **Barrier Damage**

The barrier underwent some permanent displacement as seen in the figure below.

![Figure 2-23. Test 672 - Barrier Static Displacements [mm]](image)

The pin and loop connection between sections 5 & 6, 6 & 7 (nearest to the impact point) and 7 & 8 bent and caused spalling at the joint. Some stakes in Section 6 were bent and the slots they were in had spalling. Sections 6 and 7 had scuffmarks from the impact. Sections 10 through 12 had minor scrapping on the top, which occurred when the vehicle rode on top of the barrier. Section 7 underwent the most movement with a maximum lateral static displacement of 205 mm (8.1 in) and maximum lateral dynamic displacement of 256 mm (10 in) at the toe. Static measurements were taken with a tape measure and dynamic measurements were obtained via film analysis.

![Figure 2-24. Test 672 - Downstream View of Barrier Post-Impact](image)
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2.2.2.3. Vehicle Damage

The initial impact damaged the left front corner of the vehicle. The left front quarter panel and bumper were crushed. Both rims on the left side were bent. The secondary impact occurred when the right side of the vehicle contacted the ground and rode along the top of the barrier. The right front quarter panel and bumper were damaged. The vehicle’s left mid-section was damaged when it landed on top of the barrier. The hub guidance assembly was slightly damaged.
Figure 2-29. Test 672 - Front-left View of Vehicle Post-Impact
2 TECHNICAL DISCUSSION

2.2.2.4. Test 672 Data Summary Sheet

**General Information**
- **Testing Agency**: California DOT
- **Test Number**: 672
- **Test Date**: June 23, 2005

**Test Article**
- **Type**: Semi-permanent K-rail in a median barrier configuration
- **Staking Configuration**: 4 uncapped stakes per section, every other element.
- **Installation Length**: 73.1 m (239.8 ft)
- **Elements Length**: 6.1 m (20 ft)
- **Elements Height**: 0.8 m (32 in)
- **Elements Weight**: 3540 kg (7805.7 lb)

**Test Vehicle**
- **Type**: Production Model
- **Designation**: 2000P
- **Model**: 1993 GMC Sierra
- **Mass: Curb**: 1967.6 kg (4337.8 lbm)
- **Test Inertial**: 1987.4 kg (4381.5 lbm)

**Impact Conditions**
- **Impact Velocity**: 99.1 km/h (61.6 mph)
- **Impact Angle**: 26.0°

**Exit Conditions**
- **Exit Velocity**: n/a
- **Exit Angle**: 0°

**Test Data**
- **Occupant Impact Velocity**
  - Long: 4.60 m/s (15.1 ft/s)
  - Lat: 7.91 m/s (25.9 ft/s)
- **Ridedown Acceleration**
  - Long: -4.57 g
  - Lat: -6.78 g
- **ASI**: 1.50
- **OCDI**: LF0011000

**Post-Impact Vehicular Behavior**
- **Maximum Roll Angle**: 56.66°/65°
- **Maximum Pitch Angle**: 14.28°/14°
- **Maximum Yaw Angle**: 35.34°/---

**Test Article Deflections**
- **Dynamic**: 256 mm (8.1 in)
- **Permanent**: 205 mm (10.1 in)

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*Figure 2-30. Test 672 - Impact sequence and diagram*
2.2.3. Test 673 - Median Layout: 4 Capped Stakes per Every Other Barrier

2.2.3.1. Impact Description/Vehicle Behavior

The intended impact angle of 25° and impact location on the vehicle’s left-front corner was set by the placement of the guide rail (Figure 2-32). Film analysis indicated that the actual impact angle was 26.2°, and the actual impact location was 112 mm (4.4 in) upstream from the intended CIP. The impact speed of 100.8 km/h (62.6 mph) was obtained by averaging the output from two independent speed traps located just upstream from the impact point. This speed was confirmed via film analysis. Upon impact the vehicle’s left front corner was crushed. The vehicle rode upwards on the barrier during impact and stayed in contact for 4.0 m (13 ft). Approximately 0.31 s after impact the left rear tire lost contact with the barrier and the vehicle was in the air. The vehicle pitched forward (negative) and its right front tire landed on the ground 13.0 m (42.7 ft) from the CIP and 0.64 s after the initial impact. The brakes were applied 1.87 s after the initial impact as indicated by the data recorder’s event channel. The vehicle had a secondary impact at its left front corner with a barrier protecting the downstream camera. The vehicle came to rest 82 m (269 ft) from the CIP.

The longitudinal occupant impact velocity was 5.31 m/s (17.4 ft/s), which was above the allowable maximum of 12 m/s (39 ft/s) specified in NCHRP Report 350. The longitudinal occupant ridedown acceleration, 4.51 g, was below the allowed maximum of 20 g. Test results are summarized in Table 2-4 on page 61.

Figure 2-31 through Figure 2-42 show the pre-test and post-test condition of the test vehicle and test article. Sequence photographs of the impact for Test 673 are shown as Figure 2-43 on the data summary sheet on page 33.

![Figure 2-31. Test 673 - Side View of Vehicle Pre-Impact](image-url)
Figure 2-32. Test 673 - Vehicle at Impact Location Pre-Impact

Figure 2-33. Test 673 - Close-up View of Vehicle at Impact Location Pre-Impact
Figure 2-34. Test 673 - Barrier Pre-Impact

Figure 2-35. Test 673 - Stake #6B Pre-Impact
2.2.3.2. **Barrier Damage**

The barrier underwent some permanent displacement as seen in the figure below.

![Figure 2-36. Test 673 - Barrier Static Displacements [mm]](image)

The pin and loop connection between sections 6 & 7 (nearest to the impact point) and 7 & 8 bent and caused spalling at the joint. Section 6 had a large, vertical crack on the impact side near the impact point. Sections 6 and 7 had scuffmarks from the initial impact. Some of the stakes lifted due to the barrier rotation. The maximum lateral static displacement was 163 mm (6.4 in) with a maximum lateral dynamic displacement of 200 mm (7.9 in) at the toe. Static measurements were taken with a tape measure, and dynamic measurements were obtained via film analysis.

![Figure 2-37. Test 673 - Downstream View of Barrier Post-Impact](image)
Figure 2-38. Test 673 - Impact Point Post-Impact

Figure 2-39. Test 673 - Stake #6B Post-Impact
2.2.3.3. **Vehicle Damage**

The initial impact damaged the left front corner of the vehicle. The left front quarter panel and bumper were crushed. A secondary impact occurred when the vehicle impacted a barrier protecting a camera. The impact was located at the left front corner again and further damaged the area. The hood was crushed inwards and the left front tire and rim were damaged. The maximum floorboard intruded\(^d\) into the occupant compartment by 3 cm (1.2 in). The floorboard deformation area was approximately 3275 cm\(^2\) (3.5 ft\(^2\)) and was located at the left front corner.

For Test 673, the vehicle impacted a K-rail section that had greater lateral and uplift resistance from the stakes than previous tests (due to the number of stakes and the caps); thus, Test 673’s vehicle was damaged more than previous tests.

![Test 673 - Side View of Vehicle Post-Impact](image)

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\(^d\) The floorboard deformation was greater for this test than the previous test since the vehicle impacted a fully staked section of K-rail. Upon impact, some of the vehicle’s kinetic energy is absorbed by the barrier (causing the barrier to typically move) and reduces damage to the vehicle. For this project, the amount of energy transferred to the barrier was dependent on:

1. Lateral resistance from the stakes
2. Uplift resistance along the impact side from the stakes

When the resistances in items 1 and 2 are increased, the kinetic energy absorbed by the barrier is reduced, and barrier displacement is decreased.
Figure 2-41. Test 673 - Front-left View of Vehicle Post-Impact

Figure 2-42. Test 673 - Barrier Involved with Secondary Impact
2.2.3.4. Test 673 Data Summary Sheet

Figure 2-43. Test 673 - Impact sequence and diagram

General Information
- Testing Agency: California DOT
- Test Number: 673
- Test Date: August 24, 2005

Test Article
- Type: Semi-permanent K-rail in a median barrier configuration
- Staking Configuration: K-rail as a temporary median divider with 4 capped stakes per section, every other section
- Installation Length: 79.2 m (259.8 ft)
- Element Length: 6.1 m (20 ft)
- Element Height: 0.8 m (32 in)
- Element Weight: 3540 kg (7805.7 lb)

Test Vehicle
- Type: Production Model
- Designation: 2000P
- Model: 1997 Chevy 2500
- Mass: Curb: 1951.2 kg (4301.7 kg)
  Test Inertial: 2016.3 kg (4445.2 kg)

Impact Conditions
- Impact Velocity: 100.8 km/h (62.6 mph)
- Impact Angle: 26.2°

Exit Conditions
- Exit Velocity: 84 km/h (52 mph)
- Exit Angle: >5°

Test Data
- Occupant Impact Velocity
  Long: 5.31 m/s (17.4 ft/s)
  Lat: 7.25 m/s (23.8 ft/s)
- Ridedown Acceleration
  Long: 4.51 g
  Lat: 11.21 g
- ASI: 1.73
- OCDI: LF0011001

Post-Impact Vehicular Behavior
(Data Analysis/Video Analysis)
- Maximum Roll Angle: 33.26°/39°
- Maximum Pitch Angle: 19.48°/30°
- Maximum Yaw Angle: 65.80°/n/a

Test Article Deflections
- Dynamic: 207 mm (8.1 in)
- Permanent: 163 mm (6.4 in)
2.2.4. Test 674 – Excavation Layout: 4 Capped Stakes per Every Other Barrier

2.2.4.1. Impact Description/Vehicle Behavior

The intended impact angle of 25° and impact location on the vehicle’s right-front corner was set by the placement of the guide rail (Figure 2-45). Film analysis indicated that the actual impact angle was 26.5°, and the actual impact location was 130 mm (5.1 in) upstream from the intended CIP, resulting in an impact point 783 mm (30.8 in) upstream from a joint. The impact speed of 98.9 km/h (61.4 mph) was obtained by averaging the output from two independent speed traps located just upstream from the impact point. This speed was confirmed via film analysis. Upon impact the vehicle’s right front corner was crushed. The vehicle rode upwards on the barrier face during impact and stayed in contact for 4.5 m (15 ft). Approximately 0.37 s after impact the right rear tire lost contact with the barrier and the vehicle was in the air. The vehicle pitched forward and its left front tire landed on the ground 13.0 m (42.7 ft) from the CIP and 0.59 s after the initial impact. The brakes were applied 1.30 s after the initial impact as indicated by the data recorder’s event channel. The vehicle came to rest 51 m (170 ft) from the CIP.

The longitudinal occupant impact velocity was -3.80 m/s (-12.5 ft/s), which was below the allowable maximum of 12 m/s (39 ft/s) specified in NCHRP Report 350. The longitudinal occupant ridedown acceleration, -5.66 g, was below the allowed maximum of 20 g. Test results are summarized in Table 2-5 on page 62.

Figure 2-44 through Figure 2-57 show the pre-test and post-test condition of the test vehicle and test article. Sequence photographs of the impact for Test 674 are shown in Figure 2-58 on the data summary sheet.

Figure 2-44. Test 674 - Side View of Vehicle Pre-Impact
Figure 2-45. Test 674 - Vehicle at Impact Location Pre-Impact

Figure 2-46. Test 674 - Close-up View of Vehicle at Impact Location
2.2.4.2. **Barrier Damage**

The barrier underwent some permanent displacement as shown in the figure below.
The pin and loop connection between sections 7 & 8 (nearest to the impact point) and 8 & 9 bent and caused spalling at the joint. Section 8 had spalling at the upstream, impact-side slot due to the stake bending. The upstream, excavation-side stake in Section 8 broke through the AC. The maximum lateral static displacement was 670 mm (26.3 in). Static measurements were taken with a tape measure. Due to the angle between the vehicle targets and the camera, the dynamic displacement could not be accurately measured.
Figure 2-51. Test 674 - Impact Point Post-Impact

Figure 2-52. Test 674 – Upstream, Impact-side Stake in Section 8 Post-Impact
Figure 2-53. Test 674 - Back of Barrier Post-Impact

Figure 2-54. Test 674 - Damaged Pavement from Rear Stake
2 TECHNICAL DISCUSSION

2.2.4.3. Vehicle Damage

The impact damaged the right front corner of the vehicle. The right front quarter panel and bumper were crushed. Both front tires were damaged. The body on the right side had minor body damage from scraping against the barrier. The bottom of the tailgate detached from the bed and was held in place by the upper hinges.
Figure 2-57. Test 674 - Front-right View of Vehicle Post-Impact
2.2.4.4. Test 674 Data Summary Sheet

**Figure 2-58. Test 674 - Impact sequence and diagram**

### General Information
- **Testing Agency:** California DOT
- **Test Number:** 674
- **Test Date:** October 5, 2005

#### Test Article
- **Type:** Longitudinal Barrier / Temporary Barrier, with excavation 152 mm behind back of K-rail
- **Staking Configuration:** 4 capped stakes per section, every other section.
- **Installation Length:** 79.2 m (259.8 ft)
- **Element Length:** 6.1 m (20 ft)
- **Element Height:** 0.8 m (32 in)
- **Element Weight:** 3540 kg (7805.7 lb)

#### Test Vehicle
- **Type:** Production Model
- **Designation:** 2000P
- **Model:** 1989 GMC Cheyenne
- **Mass:**
  - Curb: 1901.8 kg (4192.7 lbm)
  - Test Inertial: 1929.7 kg (4254.3 lbm)

### Impact Conditions
- **Impact Velocity:** 98.9 km/h (61.4 mph)
- **Impact Angle:** 26.5°

### Exit Conditions
- **Exit Velocity:** 86 km/h (53 mph)
- **Exit Angle:** 5°

### Test Data
- **Occupant Impact Velocity**
  - Long: -3.80 m/s (-12.5 ft/s)
  - Lat: -9.55 m/s (-31.3 ft/s)
- **Ridedown Acceleration**
  - Long: -5.66 g
  - Lat: 8.74 g
- **ASI:** 2.11
- **OCDI:** RF0001000

#### Post-Impact Vehicular Behavior
(Data Analysis/Video Analysis)
- **Maximum Roll Angle:** -29.71°/-10°
- **Maximum Pitch Angle:** -27.80°/25°
- **Maximum Yaw Angle:** 46.96°/---

#### Test Article Deflections
- **Dynamic:** n/a
- **Permanent:** 670 mm (26.4 in)
2.2.5. Test 675 – Excavation Layout: 2 Capped Stakes per Barrier on Traffic Side

2.2.5.1. Impact Description/Vehicle Behavior

The intended impact angle of 25° and impact location on the vehicle’s right-front corner was set by the placement of the guide rail (Figure 2-60). Film analysis indicated that the actual impact angle was 26.4°, and the actual impact location was 170 mm (6.7 in) downstream from the intended CIP. The impact speed of 100.6 km/h (62.5 mph) was obtained by averaging the output from two independent speed traps located just upstream from the impact point. This speed was confirmed via film analysis. Upon impact the vehicle’s right front corner was crushed. The vehicle rode upward on the barrier during impact and stayed in contact for 4.5 m (14 ft). Approximately 0.29 s after impact the right rear tire lost contact with the barrier and the vehicle was in the air. The vehicle rolled to the left and its left front tire landed on the ground 12.9 m (42.3 ft) from the CIP and 0.58 s after the initial impact. The brakes were applied 1.17 s after the initial impact as indicated by video analysis using the brake flash. The vehicle came to rest 61 m (200 ft) from the CIP.

The longitudinal occupant impact velocity was 4.66 m/s (15.3 ft/s), which was above the allowable maximum of 12 m/s (39 ft/s) specified in NCHRP Report 350. The longitudinal occupant ridedown acceleration, -3.68 g, was below the allowed maximum of 20 g. Test results are summarized in Table 2-6 on page 63.

Figure 2-59 through Figure 2-70 show the pre-test and post-test condition of the test vehicle and test article. Sequence photographs of the impact for Test 675 are shown as Figure 2-71 on the data summary sheet on page 49.
Figure 2-60. Test 675 - Vehicle at Impact Location Pre-Impact

Figure 2-61. Test 675 - Close-up View of Vehicle at Impact Location
2.2.5.2. **Barrier Damage**

The barrier underwent some permanent displacement as seen in the figure below.

![Figure 2-62. Test 675 - Barrier Pre-Impact](image)

The pin and loop connection between sections 5 & 6 (nearest to the impact point) and 6 & 7 bent and caused spalling at the joint. The slots located in the upstream end of Section 5 and downstream end of Section 6 had spalling. Sections 5 and 6 had scuffmarks on the surface from the impact. The barriers’ maximum lateral static displacement was 350 mm (13.8 in) and the maximum lateral dynamic displacement was 350 mm (13.8 in) at the toe. The barrier extended over the excavation by approximately 280 mm (11.0 in). Static measurements were taken with a tape measure, and dynamic measurements were obtained via film analysis.
Figure 2-64. Test 675 - Downstream View of Barrier Post-Impact

Figure 2-65. Test 675 - Barrier over Excavation
2.2.5.3. Vehicle Damage

The impact damaged the right front corner of the vehicle. The right front quarter panel and bumper were crushed. The tire slipped off the rim. The suspension and steering assemblies were damaged. The tie rod sheered off the spindle. The hub guidance assembly was slightly damaged.
Figure 2-69. Test 675 - Side View of Vehicle Post-Impact

Figure 2-70. Test 675 - Front-right View of Vehicle Post-Impact
2.2.5.4. Test 675 Data Summary Sheet

![Image of Test Sequence]

**General Information**
- **Testing Agency**: California DOT
- **Test Number**: 675
- **Test Date**: October 25, 2005

**Test Article**
- **Type**: Longitudinal Barrier / Temporary Barrier with excavation 76 mm behind back of K-rail
- **Staking Configuration**: 2 capped stakes per section, traffic side.
- **Installation Length**: 73.2 m (239.8 ft)
- **Element Length**: 6.1 m (20 ft)
- **Element Height**: 0.8 m (32 in)
- **Element Weight**: 3540 kg (7805.7 lb)

**Test Vehicle**
- **Type**: Production Model 2000P
- **Designation**: 1994 Chevy Silverado
- **Mass**: Curb: 1970.9 kg (4345.1 lbm), Test Inertial: 2005.9 kg (4422.2 lbm)

**Impact Conditions**
- **Impact Velocity**: 100.6 km/h (62.5 mph)
- **Impact Angle**: 26.4°

**Exit Conditions**
- **Exit Velocity**: 84 km/h (52.2 mph)
- **Exit Angle**: 12°

**Test Data**
- **Occupant Impact Velocity**
  - Long: 4.66 m/s (15.3 ft/s)
  - Lat: -5.86 m/s (-19.2 ft/s)
- **Ridedown Acceleration**
  - Long: -3.68 g
  - Lat: 7.10 g
- **ASI**: 1.32
- **OCDI**: RF0001000

**Post-Impact Vehicular Behavior**
- **Maximum Roll Angle**: -56.92°/-64°
- **Maximum Pitch Angle**: 16.78°/11°
- **Maximum Yaw Angle**: ---

**Test Article Deflections**
- Dynamic: 350 mm (13.8 in)
- Permanent: 350 mm (13.8 in)
2.2.6. Test 676 – 1 Capped Stake per Barrier

2.2.6.1. Impact Description/Vehicle Behavior

The intended impact angle of 25° and impact location on the vehicle’s right-front corner was set by the placement of the guide rail (Figure 2-73). Film analysis indicated that the actual impact angle was 25.1° and the actual impact location was 12 mm (0.5 in) downstream from the intended CIP. The impact speed of 101.8 km/h (63.3 mph) was obtained by averaging the output from two independent speed traps located just upstream from the impact point. This speed was confirmed via film analysis. Upon impact the vehicle’s right front corner was crushed. The vehicle rode upwards on the barrier during impact and stayed in contact for 3.4 m (11 ft). Approximately 0.29 s after impact the right rear tire lost contact with the barrier and the vehicle was in the air. The vehicle rolled to its left and its left front tire landed on the ground and barrier simultaneously 13.7 m (44.9 ft) from the CIP and 0.63 s after the initial impact. The rear of the vehicle’s undercarriage landed on top of the barrier 48.7 m (160 ft) from the CIP. The vehicle remained in contact with the top of the barrier almost to the end. Approximately 1 m (3 ft) before the barrier’s end, the vehicle separated from the barrier and proceeded to rollover. Since the event channel was damaged and the vehicle rolled out of the camera’s view, the brake application time is not available. The vehicle came to rest 64 m (210 ft) from the CIP.

The longitudinal occupant impact velocity was 3.63 m/s (11.9 ft/s), which was below the allowable maximum of 12 m/s (39 ft/s) specified in NCHRP Report 350. The longitudinal occupant ridedown acceleration, -3.86 g, was below the allowed maximum of 20 g. Test results are summarized in Table 2-7 on page 64.

Figure 2-72 through

Figure 2-80 show the pre-test and post-test condition of the test vehicle and test article. Sequence photographs of the impact for Test 676 are shown in Figure 2-82 on the data summary sheet.
Figure 2-72. Test 676 - Side View of Vehicle Pre-Impact

Figure 2-73. Test 676 - Vehicle at Impact Location Pre-Impact
Figure 2-74. Test 676 - Close-up View of Vehicle at Impact Location

Figure 2-75. Test 676 - Barrier Pre-Impact
2.2.6.2. **Barrier Damage**

The barrier underwent some permanent displacement as seen in the figure below.

The pin and loop connections between sections 5 & 6 (nearest to the impact point) and 6 & 7 were bent and caused spalling at the joint. Section 5 had spalling at the stake location. Sections 5 and 6 had scuffmarks from the impact. Sections 9 through 12 had minor scrapping on the top, which occurred when the vehicle rode on top of the barrier.

The maximum lateral static displacement was 505 mm (20.0 in). Due to the angle between the vehicle targets and the camera, the dynamic displacement could not be accurately measured.
2.2.6.3. Vehicle Damage

The initial impact damaged the right front corner of the vehicle. The right front quarter panel and bumper were crushed inwards. The right front tire and right side rims were damaged. The right body panel was crushed when the vehicle rode on top of the barrier. The windshield was damaged during the rollover, but remained in place. The rear window shattered.
Figure 2-80. Test 676 - Vehicle Post-Impact Front View

Figure 2-81. Test 676 - Vehicle Post-Impact Side View
2 TECHNICAL DISCUSSION

2.2.6.4. Test 676 Data Summary Sheet

![Image of Test 676 - Impact sequence and diagram]

**General Information**
- Testing Agency: California DOT
- Test Number: 676
- Test Date: May 16, 2006

**Test Article**
- Type: Longitudinal Barrier / Temporary Barrier with excavation 76 mm behind back of K-rail
- Staking Configuration: 1 capped stake per section, traffic side, upstream relative to traffic.
- Installation Length: 73.1 m (239.8 ft)
- Element Length: 6.1 m (20 ft)
- Height Length: 0.8 m (32 in)
- Weight Length: 3540 kg (7805.7 lb)

**Test Vehicle**
- Type: Production Model
- Designation: 2000P
- Model: 1988 Chevy Silverado
- Mass: Curb: 1923.5 kg (4240.6 lbm)
- Test Inertial: 1981.0 kg (4367.4 lbm)

**Impact Conditions**
- Impact Velocity: 101.8 km/h (63.3 mph)
- Impact Angle: 25.1°

**Exit Conditions**
- Exit Velocity: n/a
- Exit Angle: 0°

**Test Data**
- Occupant Impact Velocity
  - Long: 3.63 m/s (11.9 ft/s)
  - Lat: -5.96 m/s (-19.6 ft/s)
- Ridedown Acceleration
  - Long: -3.86 g
  - Lat: 5.35 g
- ASI: 1.16
- OCDI: RF0011010

**Post-Impact Vehicular Behavior**
- (Data Analysis/Video Analysis)
  - Maximum Roll Angle: -57.41°/-55°
  - Maximum Pitch Angle: 14.10°/25°
  - Maximum Yaw Angle: -52.45°/n/a

**Test Article Deflections**
- Dynamic: n/a mm
- Permanent: 505 mm (20.0 in)
2.3. Discussion of Test Results

NCHRP Report 350 stipulates that crash test performance is assessed according to three evaluation factors: 1) Structural Adequacy, 2) Occupant Risk, and 3) Vehicle Trajectory. These evaluation factors are further defined by evaluation criteria and are shown for each test designation in Table 5.1 of NCHRP Report 350. The NCHRP Report 350 Test Designation is 3-11 (2000P vehicle) for all tests conducted during this research.

2.3.1. Structural Adequacy

2.3.1.1. Median Barrier Configurations

Of the three tests conducted in the median barrier configuration, only Test 673 demonstrated acceptable structural adequacy. Tests 671 and 672 failed to safely redirect the test vehicle, demonstrating an inadequate structural integrity.

Test 671, with each K-rail element being held in position by two uncapped stakes in a staggered configuration, resulted in launching the vehicle up, over, and onto the top of the barrier. This was an unstable result, which could have led to a rollover or impact with oncoming traffic.

Test 672, with four uncapped stakes in every other K-rail element, yielded the same result as Test 671. The K-rail element leaned back and lifted off of the uncapped stake, resulting in a vehicle riding up the face and resting on the top of the barrier.

Test 673, with four capped stakes in every other K-rail element, resulted in one cracked K-rail element, a permanent lateral displacement of 163 mm (604 in), and some damage to the K-rail interconnects at the impact point. However, the damage to the barrier was not unexpected and the vehicle stability was much better in this test than it had been in the previous two. The vehicle did not vault onto the top of the barrier. The structural adequacy was acceptable for test configuration 673.

2.3.1.2. Adjacent to Excavation Configurations

Since this configuration involves an excavation, the K-rail Staking Committee added an additional criterion for evaluation in the Structural Adequacy category. The Committee asked that the lateral penetration of the K-rail into the excavation be kept to a minimum and that the Committee review the test results. Based on the additional Structural Adequacy Criteria, the configuration in Test 675 demonstrated acceptable structural adequacy, while the configurations in tests 674 and 676 did not.

Tests 674 (which was the same configuration as 673 except with the excavation), resulted in an acceptable redirection of the test vehicle but produced excessive penetration of the barrier into the excavation, posing an unacceptable risk to workers. Additionally, the failure of the AC pavement behind the rear stakes would require additional exposure of workers during pavement repair efforts at a later date.

Test 675, with capped stakes placed in every stake hole on the traffic-side of the K-rail but none on the excavation side, resulted in minimal lateral deflation and good vehicle redirection. There was no damage to the pavement. The review by the Committee resulted in the assessment that the 280 mm (11 in) of overlap into the excavation was acceptable. The structural adequacy of configuration 675 is acceptable.
Test 676, with a single capped stake on the downstream traffic side of each K-rail, resulted in excessive barrier movement and a rollover of the test vehicle. This test was a clear failure of the Structural Adequacy criteria.

A detailed assessment summary of structural adequacy for each test is shown in Table 2-2 through Table 2-7.

2.3.2. Occupant Risk

2.3.2.1. Median Barrier Configurations
All three of the median configuration tests passed the criteria for occupant risk. However, it should be noted that tests 671 and 672 resulted in the test vehicles straddling the barrier, which could result in secondary impacts and greater occupant risk. The occupant deformations were considered acceptable for all of the median configuration tests.

2.3.2.2. Adjacent to Excavation Configurations
Of the three tests conducted on excavation configurations, only test 675 concluded with acceptable results. The other configurations presented undue hazards to either the vehicle occupants or the work zone personnel.

Although Test 674 resulted in acceptable conditions for the vehicle occupants, there were undue hazards to the work zone personnel. Failure of the AC to hold the rear stake caused a large chunk of the AC to break loose and fall into the excavation. Additionally, the barrier penetrated 670 mm (26 in) into the excavation. The Committee considered the pavement failure and the deflection as unacceptable to the work zone safety.

Test 675 resulted in acceptable occupant risk. There was lateral deflection of barrier. However, the AC did not fail and the barrier deflection was acceptable to the Committee.

Test 676 failed several criterion of the Occupant Risk. There was excessive barrier penetration into the work zone. After impact the vehicle slid along the top of the barrier, presenting addition risk to the work zone. After losing contact with the barrier the vehicle rolled over.

A detailed assessment summary of occupant risk for each test is shown in Table 2-2 through Table 2-7.

2.3.3. Vehicle Trajectory

2.3.3.1. Median Barrier Configurations
The vehicle trajectory was considered marginal for tests 671 and 672 because the vehicle ended up straddling the barrier. Test 673 was considered to have acceptable post-impact trajectory.

2.3.3.2. Adjacent to Excavation Configurations
Test 674 and Test 675 had acceptable vehicle trajectory. The vehicle for Test 674, however, ended with a high degree of yaw toward the barrier shortly after impact.

The vehicle trajectory for Test 676 was not acceptable due to the rollover.

A detailed assessment summary of vehicle trajectory for each test is shown in Table 2-2 through Table 2-7.
### Table 2-2. Test 671 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. The Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection on the test article is acceptable.</td>
<td>Vehicle landed on top of the barrier and intruded into opposing traffic.</td>
<td>Fail</td>
</tr>
<tr>
<td><strong>Occupant Risk</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformation of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.</td>
<td>There were minor penetrations into the passenger compartment. Deformation was well within Report 350 guidelines.</td>
<td>Pass</td>
</tr>
<tr>
<td>F. The vehicle should remain upright during and after collision although moderate roll, pitching, and yawing are acceptable.</td>
<td>Vehicle remained upright and stable throughout the test and had a moderate roll.</td>
<td>Pass</td>
</tr>
<tr>
<td><strong>Vehicle Trajectory</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>K. After collision it is preferable that the vehicle’s trajectory not intrude into adjacent traffic lanes.</td>
<td>The vehicle straddled the barrier, but maintained a relatively straight course after exiting the barrier.</td>
<td>Marginal Pass</td>
</tr>
<tr>
<td>L. The occupant impact velocity in the longitudinal direction should not exceed 12 m/s and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 G’s.</td>
<td>Long. Occ. Impact Vel. = 5.25 m/s Long. Occ. Ridedown = 3.96 g</td>
<td>Pass</td>
</tr>
<tr>
<td>M. The exit angle from the test article preferably should be less than 60% of the test impact angle, measured at time of the vehicle loss contact with the test article.</td>
<td>The vehicle remained within the preferred limit.</td>
<td>Pass</td>
</tr>
</tbody>
</table>
Table 2-3. Test 672 Assessment Summary

<table>
<thead>
<tr>
<th>Evaluation Criteria</th>
<th>Test Results</th>
<th>Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structural Adequacy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A.</td>
<td>Vehicle landed on top of the barrier and intruded into opposing traffic.</td>
<td>Fail</td>
</tr>
<tr>
<td>Occupant Risk</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D.</td>
<td>There were minor penetrations into the passenger compartment. Deformation was well within Report 350 guidelines.</td>
<td>Pass</td>
</tr>
<tr>
<td>F.</td>
<td>Vehicle remained upright and stable throughout the test and had a moderate roll.</td>
<td>Pass</td>
</tr>
<tr>
<td>Vehicle Trajectory</td>
<td></td>
<td></td>
</tr>
<tr>
<td>K.</td>
<td>The vehicle straddled the barrier, but maintained a relatively straight course after exiting the barrier.</td>
<td>Marginal Pass</td>
</tr>
<tr>
<td>L.</td>
<td>Long. Occ. Impact Vel. = 4.60 m/s Long. Occ. Ridedown = -4.57 g</td>
<td>Pass</td>
</tr>
<tr>
<td>M.</td>
<td>The vehicle remained within the preferred limit.</td>
<td>Pass</td>
</tr>
</tbody>
</table>
## Table 2-4. Test 673 Assessment Summary

<table>
<thead>
<tr>
<th>Test No.</th>
<th>673 — Temporary Railing (Type K) with 2000P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date</td>
<td>August 24, 2005</td>
</tr>
<tr>
<td>Test agency</td>
<td>California Dept. of Transportation</td>
</tr>
</tbody>
</table>

<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.</td>
<td>Vehicle contained and redirected.</td>
<td>Pass</td>
</tr>
<tr>
<td>D.</td>
<td>There were minor penetrations into the passenger compartment. Deformation was well within Report 350 guidelines.</td>
<td>Pass</td>
</tr>
<tr>
<td>F.</td>
<td>Vehicle remained upright and stable throughout the test.</td>
<td>Pass</td>
</tr>
<tr>
<td><strong>Occupant Risk</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F.</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Vehicle Trajectory</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>K.</td>
<td>The vehicle maintained a relatively straight course after exiting the barrier.</td>
<td>Pass</td>
</tr>
<tr>
<td>L.</td>
<td>Long. Occ. Impact Vel. = 5.25 m/s</td>
<td>Pass</td>
</tr>
<tr>
<td>M.</td>
<td>The vehicle remained within the preferred limit.</td>
<td>Pass</td>
</tr>
</tbody>
</table>
Table 2-5. Test 674 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. The Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection on the test article is acceptable</td>
<td>Although the vehicle was contained and redirected, the AC supporting the rear stakes failed, resulting in an uncontrolled lateral deflection of the barrier.</td>
<td>Failure</td>
</tr>
<tr>
<td><strong>Occupant Risk</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformation of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.</td>
<td>There were minor penetrations into the passenger compartment. Deformation was well within Report 350 guidelines. However, the level of lateral translation of the barrier and debris from the filing AC posed an undue risk the work zone personnel.</td>
<td>Maginal Failure</td>
</tr>
<tr>
<td>F. The vehicle should remain upright during and after collision although moderate roll, pitching, and yawing are acceptable.</td>
<td>Vehicle remained upright and stable throughout the test.</td>
<td>Pass</td>
</tr>
<tr>
<td><strong>Vehicle Trajectory</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>K. After collision it is preferable that the vehicle’s trajectory not intrude into adjacent traffic lanes.</td>
<td>The vehicle maintained a relatively straight course after exiting the barrier.</td>
<td>Pass</td>
</tr>
<tr>
<td>L. The occupant impact velocity in the longitudinal direction should not exceed 12 m/s and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 G’s.</td>
<td>Long. Occ. Impact Vel. = 3.80 m/s Long. Occ. Ridedown = -5.66 g</td>
<td>Pass</td>
</tr>
<tr>
<td>M. The exit angle from the test article preferably should be less than 60% of the test impact angle, measured at time of the vehicle loss contact with the test article.</td>
<td>The vehicle remained within the preferred limit.</td>
<td>Pass</td>
</tr>
</tbody>
</table>
## 2 TECHNICAL DISCUSSION

### Table 2-6. Test 675 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.</td>
<td>The Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection on the test article is acceptable</td>
<td>Vehicle contained and redirected.</td>
</tr>
<tr>
<td><strong>Occupant Risk</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D.</td>
<td>Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformation of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.</td>
<td>There were minor penetrations into the passenger compartment. Deformation was well within Report 350 guidelines.</td>
</tr>
<tr>
<td>F.</td>
<td>The vehicle should remain upright during and after collision although moderate roll, pitching, and yawing are acceptable.</td>
<td>Vehicle remained upright and stable throughout the test and had a moderate roll.</td>
</tr>
<tr>
<td><strong>Vehicle Trajectory</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>K.</td>
<td>After collision it is preferable that the vehicle’s trajectory not intrude into adjacent traffic lanes.</td>
<td>The vehicle maintained a relatively straight course after exiting the barrier.</td>
</tr>
</tbody>
</table>
| L.                  | The occupant impact velocity in the longitudinal direction should not exceed 12 m/s and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 G’s. | Long. Occ. Impact Vel. = 4.66 m/s  
Long. Occ. Ridedown = -3.68 g | Pass |
<p>| M.                  | The exit angle from the test article preferably should be less than 60% of the test impact angle, measured at time of the vehicle loss contact with the test article. | The vehicle remained within the preferred limit. | Pass |</p>
<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. The Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection on the test article is acceptable</td>
<td>Vehicle rode on top of the barrier and intruded into construction zone.</td>
<td>Fail</td>
</tr>
<tr>
<td><strong>Occupant Risk</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformation of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.</td>
<td>There were minor penetrations into the passenger compartment. Deformation was well within Report 350 guidelines. However, the level of lateral translation of the barrier posed added risk the work zone personnel.</td>
<td>Marginal Pass</td>
</tr>
<tr>
<td>F. The vehicle should remain upright during and after collision although moderate roll, pitching, and yawing are acceptable.</td>
<td>Vehicle rolled-over after losing contact with the barrier.</td>
<td>Fail</td>
</tr>
<tr>
<td><strong>Vehicle Trajectory</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>K. After collision it is preferable that the vehicle’s trajectory not intrude into adjacent traffic lanes.</td>
<td>The vehicle did not maintain a relatively straight course after exiting the barrier.</td>
<td>Fail</td>
</tr>
<tr>
<td>L. The occupant impact velocity in the longitudinal direction should not exceed 12 m/s and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 G’s.</td>
<td>Long. Occ. Impact Vel. = 3.63 m/s Long. Occ. Ridedown = -3.86 g</td>
<td>Pass</td>
</tr>
<tr>
<td>M. The exit angle from the test article preferably should be less than 60% of the test impact angle, measured at time of the vehicle loss contact with the test article.</td>
<td>The vehicle remained within the preferred limit.</td>
<td>Pass</td>
</tr>
</tbody>
</table>
### Table 2-8. Vehicle Trajectory, Speed and Impact Severity

<table>
<thead>
<tr>
<th>Test Number</th>
<th>Impact Angle</th>
<th>60% of Impact Angle</th>
<th>Exit Angle</th>
<th>Impact Speed, $V_i$</th>
<th>Exit Speed, $V_e$</th>
<th>Speed Change $V_i - V_e$</th>
<th>Impact Severity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Units</td>
<td>deg</td>
<td>deg</td>
<td>deg</td>
<td>$km/h$ (mph)</td>
<td>$km/h$ (mph)</td>
<td>$km/h$ (mph)</td>
<td>$kJ$ (ft.lbf)</td>
</tr>
<tr>
<td>671</td>
<td>28.3</td>
<td>17.0</td>
<td>0*</td>
<td>101.4 (63.1)</td>
<td>NA</td>
<td>NA</td>
<td>177.1 (130600)</td>
</tr>
<tr>
<td>672</td>
<td>26.0</td>
<td>15.6</td>
<td>0*</td>
<td>99.1 (61.6)</td>
<td>NA</td>
<td>NA</td>
<td>144.7 (106700)</td>
</tr>
<tr>
<td>673</td>
<td>26.2</td>
<td>15.7</td>
<td>5</td>
<td>100.8 (62.6)</td>
<td>84 (52)</td>
<td>16</td>
<td>154.1 (113700)</td>
</tr>
<tr>
<td>674</td>
<td>26.5</td>
<td>15.9</td>
<td>3</td>
<td>98.9 (61.5)</td>
<td>86 (53)</td>
<td>13</td>
<td>145.0 (107000)</td>
</tr>
<tr>
<td>675</td>
<td>26.4</td>
<td>15.8</td>
<td>12</td>
<td>100.6 (62.5)</td>
<td>84 (52)</td>
<td>17</td>
<td>154.8 (114200)</td>
</tr>
<tr>
<td>676</td>
<td>25.1</td>
<td>15.1</td>
<td>0*</td>
<td>101.8 (63.3)</td>
<td>NA</td>
<td>NA</td>
<td>142.5 (105100)</td>
</tr>
</tbody>
</table>

* Vehicle rode on top of the barrier until the last section.

### Table 2-9. Tolerances for Impact Angle, Velocity and Severity

<table>
<thead>
<tr>
<th>Impact Angle - deg</th>
<th>Nominal</th>
<th>Negative Tolerance</th>
<th>Positive Tolerance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impact Velocity - km/h (mph)</td>
<td>100 (62.1)</td>
<td>96 (60)</td>
<td>104 (65)</td>
</tr>
<tr>
<td>Impact Severity – Kj (ft.lbf)</td>
<td>138.1 (102000)</td>
<td>127.3 (94000)</td>
<td>149.4 (110000)</td>
</tr>
</tbody>
</table>
3. CONCLUSIONS

Based on the testing of the K-rail as described in this report, the following conclusions can be drawn:

1. The staking configurations in Tests 671 and 672 resulted in the test vehicles overriding the barrier into opposing traffic and are unacceptable as longitudinal TL-3 median barrier configurations. It was concluded that additional testing would have to balance the need for minimal lateral deflection with minimal barrier leaning. The front of the barrier would have to be kept down.

2. The staking configuration in Test 673 successfully contained and redirected a 2000-kg (4410-lbm) pickup truck impacting at 25° and 100 km/h (62.1 mph) and is a good staking configuration for use in TL-3 median applications.

3. Although the staking configuration in Test 674 successfully contained and redirected a 2000-kg (4410-lbm) pickup truck impacting at 25° and 100 km/h (62.1 mph), damage to the pavement and the high lateral deflection make this configuration a danger to work zone personnel. Therefore this configuration is unacceptable for use adjacent to an excavation.

4. The staking configuration in Test 675 placed stakes only on the traffic side of the barrier to maximize the amount of ground resistance behind the stake and to minimize the amount of barrier lean. This configuration successfully contained and redirected a 2000-kg (4410-lbm) pickup truck impacting at 25° and 100 km/h (62.1 mph) and is a good staking configuration for use in TL-3 applications where placing K-rail adjacent to an excavation is necessary.

5. The staking configuration in Test 676 resulted in the vehicle overriding the barrier and rolling over. This configuration is unacceptable in a TL-3 application. After Test 676, it was concluded that the least number of capped stakes that could be used to safely restrain K-rail is two stakes per segment.

6. Damage to installations of K-rail in crashes similar to the tests conducted for this project will result in small to moderate amounts of scraping and spalling of the rail and deformation to the connection loops and pins.

7. Damage to the asphalt concrete from the stakes was minimal before and after impact with the exception of Test 674. The hole in the asphalt concrete after a stake was removed measured approximately 25 mm x 380 mm (1 in x 15 in).

8. Capped stakes provided uplift resistance and greater lateral resistance than uncapped stakes.

9. The K-rail stakes on the side opposite of impact, while adding shear strength, also create a pivot point upon impact. However, stakes within 305 mm (12 in) of the excavation tear out and add little shear strength as in test 674.
4. RECOMMENDATIONS

Based on the conclusions, the following are recommended:

1. When K-rail is placed as a semi-permanent median barrier on low and high-speed highways with less than 610 mm (24 in) from the edge of travel way, using four capped stakes per every other segment is an acceptable option where the first and last segments are staked.

2. When K-rail is placed between 75 and 610 mm (3 and 24 in) from the edge of an excavation on low and high-speed highways, use two capped stakes per segment along the traffic side.

3. Placing K-rail less than 75 mm (3 in) from an excavation is not recommended even with staking.

4. The minimum recommended depth for the asphalt concrete supporting staked K-rail is 100 mm (4 in).

5. The staking of K-rail is not recommended for permanent installations due to concern for decreasing performance of the stakes over time.

6. The stakes should be capped in a manor similar to what was used in this testing.
5. IMPLEMENTATION

The Caltrans Division of Traffic Operations and Construction will be responsible for creating and distributing a policy memo dictating the appropriate staking configuration for any future K-rail installations.
6. REFERENCES


7. APPENDIX

7.1. Test Vehicle

7.1.1. Equipment

The test vehicles were modified as follows for the crash tests:

- The gas tanks on the test vehicles were disconnected from the fuel supply line and drained. A 12-liter (3.2-gal) safety gas tank was installed in the truck bed or rear cargo area and connected to the fuel supply line. The stock fuel tanks had dry ice or gaseous CO$_2$ added to purge fuel vapors.
- One 12-volt, deep-cycle, gel cell motorcycle storage battery was mounted in the vehicle. The battery operated the solenoid-valve braking/accelerator system, rate gyros, and the electronic control box. Two additional 12-volt, deep-cycle, gel cell battery powered the transient data recorder.
- A 1700-kPa (250-psi) CO$_2$ system, actuated by a solenoid valve, controlled remote braking after impact and emergency braking if necessary. This system included 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 could be applied in less than 100 milliseconds.
- The remote brakes were controlled via a radio link transmitter. When the brakes were applied by remote control from the console trailer, the ignition was also automatically rendered inoperable by removing power to the coil.
- For all self-propelled vehicle tests, an accelerator switch was located on the rear of the vehicle. The switch opened an electric solenoid, which in turn released compressed CO$_2$ from a reservoir into a pneumatic ram that had been attached to the accelerator pedal. The CO$_2$ pressure for the accelerator ram was regulated to the same pressure of the remote braking system. The speed at which the ram extended was adjusted via a needle valve.
- For all self-propelled vehicle tests a speed control device, 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. When the speed control device was not compatible with the vehicle, a series of tests were performed to acquire the distance for the vehicle to reach a specified speed. During the tests, a driver would immediately press the accelerator pedal to the floorboard to simulate the pneumatic ram. The vehicle would start at a set distance from the tape switches. Depending on the speed result, the vehicle would be shifted closer or further away from the tape switches. After the vehicle reached the specified speed from a location three consecutive times, the starting distance was determined for the actual test.
- For all self-propelled vehicle tests a micro switch 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 as the car passed over it. The switch would open the ignition circuit and shut off the vehicle’s engine prior to impact.
7.1.2. Vehicle Parameters

Table 7-1 through Table 7-6 gives specific information regarding vehicle dimensions and weights for Tests 671 through 676.

Table 7-1. Test 671 Vehicle Dimensions

<table>
<thead>
<tr>
<th>VEHICLE DIMENSIONS</th>
<th>Test #: 671</th>
</tr>
</thead>
<tbody>
<tr>
<td>DATE: 04-04-04</td>
<td>TEST NO: 671</td>
</tr>
<tr>
<td>MODEL: 2500 SIERRA</td>
<td>VIN: 1GTF24K2NE532112</td>
</tr>
<tr>
<td>YEAR: 1992</td>
<td>MAKE: GMC</td>
</tr>
<tr>
<td>TIRE INFLATION PRESSURE (psig): NOT RECORDED</td>
<td>TIRE SIZE: LT 225/75R16</td>
</tr>
<tr>
<td>MASS DISTRIBUTION (kg): LF 543.8 RF 551.3 LR 437.1 RR 454.5</td>
<td></td>
</tr>
<tr>
<td>DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST: none</td>
<td></td>
</tr>
</tbody>
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ENGINE TYPE: V8
ENGINE CID: 350
TRANSMISSION TYPE: X AUTO MANU | MANUAL
OPTIONAL EQUIPMENT: none
DUMMY DATA: TYPE: N/A
MASS: N/A
SEAT POSITION: N/A

GEOMETRY (mm):
<table>
<thead>
<tr>
<th>A</th>
<th>1900</th>
<th>D</th>
<th>1790</th>
<th>G</th>
<th>1497</th>
<th>K</th>
<th>632</th>
<th>N</th>
<th>1558</th>
<th>Q</th>
<th>445</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>900</td>
<td>E</td>
<td>1330</td>
<td>H</td>
<td></td>
<td>L</td>
<td>77</td>
<td>O</td>
<td>1612</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>3335</td>
<td>F</td>
<td>5560</td>
<td>J</td>
<td>1045</td>
<td>M</td>
<td></td>
<td>P</td>
<td>745</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

MASS (kg) | CURB | TEST INERTIAL | GROSS STATIC
---- | ------ | -------------- | --------------
M1 | 1110.2 | 1095.1 | 1095.1 |
M2 | 874.7 | 891.6 | 891.6 |
MT | 1984.9 | 1986.7 | 1986.7 |
Table 7-2. Test 672 Vehicle Dimensions

**VEHICLE DIMENSIONS**

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<tr>
<th>DATE:</th>
<th>06-14-05</th>
<th>TEST NO:</th>
<th>672</th>
<th>VIN:</th>
<th>1GTF2C4K5P2550390</th>
<th>MAKE:</th>
<th>GMC</th>
</tr>
</thead>
<tbody>
<tr>
<td>MODEL:</td>
<td>2500 SIERRA</td>
<td>YEAR:</td>
<td>1993</td>
<td>ODOMETER:</td>
<td>157414 mi</td>
<td>TIRE SIZE:</td>
<td>LT 225/75R16</td>
</tr>
<tr>
<td>TIRE INFLATION PRESSURE (psig):</td>
<td>FRONT 31-33</td>
<td>REAR 42-45</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MASS DISTRIBUTION (kg):</td>
<td>LF 554.5</td>
<td>RF 547.6</td>
<td>LR 443.1</td>
<td>RR 442.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:</td>
<td>none</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**GEOMETRY (mm):**

| A | 1915 |
| B | 927  |
| C | 3345 |

| D | 1785 |
| E | 1360 |
| F | 5610 |

| G | 1488 |
| H | 1030 |
| J | 1030 |

| K | 605  |
| L | 100  |
| M | 395  |

| N | 1580 |
| O | 1620 |

| P | 760  |

| Q | 443  |

**MASS (kg):**

<table>
<thead>
<tr>
<th>MASS (kg)</th>
<th>CURB</th>
<th>TEST INERTIAL</th>
<th>GROSS STATIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1</td>
<td>1108.3</td>
<td>1102.1</td>
<td>1102.1</td>
</tr>
<tr>
<td>M2</td>
<td>859.3</td>
<td>885.25</td>
<td>885.25</td>
</tr>
<tr>
<td>MT</td>
<td>1967.6</td>
<td>1987.4</td>
<td>1987.4</td>
</tr>
</tbody>
</table>

**ENGINE TYPE:** V8

**ENGINE CID:** 350

**TRANSMISSION TYPE:**

| AUTOMATIC | MANUAL |

**OPTIONAL EQUIPMENT:** none

**DUMMY DATA:**

<table>
<thead>
<tr>
<th>TYPE:</th>
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</tr>
</thead>
<tbody>
<tr>
<td>MASS:</td>
<td>N/A</td>
</tr>
<tr>
<td>SEAT POSITION:</td>
<td>N/A</td>
</tr>
</tbody>
</table>

[Diagram of vehicle geometry and dimensions]
Table 7-3. Test 673 Vehicle Dimensions

**VEHICLE DIMENSIONS**

**DATE:** 08-08-05  **TEST NO:** 673  **VIN:** 1GCFC24MIVZ136702  **MAKE:** CHEVY  
**MODEL:** 2500  **YEAR:** 1997  **ODOMETER:** 131456 mi  **TIRE SIZE:** LT 245/75R16  
**TIRE INFLATION PRESSURE (psig):** 50  
**MASS DISTRIBUTION (kg):** LF 589.3  RF 558.4  LR 425.9  RR 442.5  
**DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:** none

**GEOMETRY (mm):**

<table>
<thead>
<tr>
<th></th>
<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>
<th>Q</th>
<th>R</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1900</td>
<td>910</td>
<td>1760</td>
<td>1250</td>
<td>5550</td>
<td>990</td>
<td>1489</td>
<td>95</td>
<td>410</td>
<td>1555</td>
<td>630</td>
<td>410</td>
<td>1610</td>
<td>1760</td>
<td>630</td>
<td>95</td>
<td>410</td>
<td>440</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>1138.6</td>
<td>1147.9</td>
<td>1147.9</td>
</tr>
<tr>
<td>M2</td>
<td>812.6</td>
<td>868.4</td>
<td>868.4</td>
</tr>
<tr>
<td>MT</td>
<td>1951.2</td>
<td>2016.3</td>
<td>2016.3</td>
</tr>
</tbody>
</table>

**ENGINE TYPE:** V8  
**ENGINE CID:** 350  
**TRANSMISSION TYPE:** X AUTO  
**OPTIONAL EQUIPMENT:** none  
**DUMMY DATA:** TYPE: N/A  
**SEAT POSITION:** N/A
### Table 7-4. Test 674 Vehicle Dimensions

**VEHICLE DIMENSIONS**

<table>
<thead>
<tr>
<th>DATE</th>
<th>09-16-05</th>
<th>TEST NO.</th>
<th>674</th>
<th>VIN:</th>
<th>1GCFC24HAKE227696</th>
<th>MAKE: GMC</th>
</tr>
</thead>
<tbody>
<tr>
<td>MODEL:</td>
<td>CHEYENNE</td>
<td>YEAR:</td>
<td>1989</td>
<td>ODOMETER:</td>
<td>104344 mi</td>
<td>TIRE SIZE: LT 225/75R16</td>
</tr>
<tr>
<td>TIRE INFLATION PRESSURE (psig):</td>
<td>50</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MASS DISTRIBUTION (kg):</td>
<td></td>
<td></td>
<td></td>
<td>LF 560.2</td>
<td>RF 528.5</td>
<td>LR 420.1</td>
</tr>
<tr>
<td>DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST:</td>
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<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
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**VEHICLE GEOMETRY (mm):**

<table>
<thead>
<tr>
<th>A</th>
<th>3880</th>
<th>D</th>
<th>1760</th>
<th>G</th>
<th>1460.2</th>
<th>K</th>
<th>590</th>
<th>N</th>
<th>1575</th>
<th>Q</th>
<th>.440</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
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<td>E</td>
<td>1275</td>
<td>H</td>
<td>L</td>
<td>90</td>
<td>O</td>
<td>1615</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>3350</td>
<td>F</td>
<td>5530</td>
<td>J</td>
<td>965</td>
<td>M</td>
<td>375</td>
<td>P</td>
<td>720</td>
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</table>

**MASS (kg):**

<table>
<thead>
<tr>
<th>M1</th>
<th>CURB</th>
<th>TEST INERTIAL</th>
<th>GROSS STATIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1094.5</td>
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<td>1088.6</td>
<td></td>
</tr>
<tr>
<td>807.3</td>
<td>841.1</td>
<td>841.1</td>
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</tr>
<tr>
<td>1901.8</td>
<td>1929.7</td>
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</tbody>
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**ENGINE TYPE:** V8

**ENGINE CID:** 305

**TRANSMISSION TYPE:** X AUTO

**OPTIONAL EQUIPMENT:** none

**DUMMY DATA:**

<table>
<thead>
<tr>
<th>TYPE</th>
<th>MASS</th>
<th>SEAT POSITION</th>
</tr>
</thead>
<tbody>
<tr>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>
Table 7-5. Test 675 Vehicle Dimensions

**VEHICLE DIMENSIONS**

DATE: 10-18-05  TEST NO: 675  VIN: 1GCGC24K2RE107690  MAKE: CHEVROLET
MODEL: SILVERADO  YEAR: 1994  ODOMETER: 119490 mi  TIRE SIZE: LT 245/75R16
TIRE INFLATION PRESSURE (psig): 45
MASS DISTRIBUTION (kg): LF 566  RF 544.3  LR 447.8  RR 447.8
DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST: none

**ENGINE TYPE:** V8  
**ENGINE CID:** 350  
**TRANSMISSION TYPE:** X AUTO MANUAL  
**OPTIONAL EQUIPMENT:** none  
**DUMMY DATA:**  
TYPE: N/A  
MASS: N/A  
SEAT POSITION: N/A

**GEOMETRY (mm):**

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<tr>
<th>A</th>
<th>1880</th>
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<th>1800</th>
<th>G</th>
<th>1495.8</th>
<th>K</th>
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<td>B</td>
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<td>110</td>
<td>L</td>
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<td>O</td>
<td>1620</td>
<td></td>
<td></td>
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<td>C</td>
<td>3350</td>
<td>F</td>
<td>5480</td>
<td>J</td>
<td>1100</td>
<td>M</td>
<td>420</td>
<td>P</td>
<td>755</td>
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**MASS (kg):**

<table>
<thead>
<tr>
<th>M1</th>
<th>1118.1</th>
<th>M2</th>
<th>852.8</th>
<th>MT</th>
<th>1970.9</th>
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<tbody>
<tr>
<td></td>
<td>CURB</td>
<td>TEST INERTIAL</td>
<td>GROSS STATIC</td>
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<tr>
<td></td>
<td>1110.3</td>
<td>1110.3</td>
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75
Table 7-6. Test 676 Vehicle Dimensions

**VEHICLE DIMENSIONS**

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<th>MODEL:</th>
<th>YEAR:</th>
<th>ODOMETER:</th>
<th>MAKE:</th>
<th>TIRE INFLATION PRESSURE (psig):</th>
<th>50</th>
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<tbody>
<tr>
<td>MASS DISTRIBUTION (kg):</td>
<td>LF 554.5</td>
<td>RF 542.4</td>
<td>LR 443.6</td>
<td>RR 440.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TIRE SIZE:</td>
<td>LT 245/75R16</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>MAKE:</td>
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<td></td>
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<tr>
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<td></td>
</tr>
<tr>
<td>MASS DISTRIBUTION (kg):</td>
<td>LF 554.5</td>
<td>RF 542.4</td>
<td>LR 443.6</td>
<td>RR 440.6</td>
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<td>TRANSMISSION TYPE:</td>
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<td></td>
<td></td>
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<td>OPTIONAL EQUIPMENT:</td>
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<td></td>
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<tr>
<td>DUMMY DATA:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MASS:</td>
<td>N/A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SEAT POSITION:</td>
<td>N/A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**GEOMETRY (mm):**

| A 1860 | D 1780 | G 1493.3 | K 625 | N 1830 | Q 440 |
| B 845  | E 1310 | H 85     | L 85  | O 1595 |       |
| C 3345 | F 5500 | J 1045   | M 405 | P 770  |       |

**MASS (kg):**

| M1 1095.2 | M2 837.3 | MT 1932.5 | GROSS STATIC |
| M1 1096.8 | M2 884.2 | MT 1981.0 | |
| M1 1096.8 | M2 884.2 | MT 1981.0 | |
7.2. **Guidance System**

A rail guidance system directed all vehicles into the test articles. The guidance rail, anchored at 3.8-m (12-ft) intervals along its length, was used to guide a mechanical arm that was attached to the vehicle’s front wheel (Figure 7-1). A 10-mm (0.4-in) nylon rope was used to trigger the release mechanism on the guidance arm, thereby releasing the vehicle from the guidance system before impact.

![Figure 7-1. Guidance System](image-url)
7.3. Photo Instrumentation

Several high-speed digital cameras recorded the impact during the crash tests. Figure 7-2 shows a diagram of the camera locations. The types of cameras used are shown in Table 7-7 and their locations are shown in Table 7-8 and Table 7-9.

All of these cameras were mounted on tripods except the three that were mounted on a 10.7-m (35.1-ft) high tower directly over the impact location.

A video camera and a digital SLR camera were turned on by hand and used to obtain pan shots during the test. A switch on a console trailer near the impact area remotely triggered the other cameras. The test vehicle and test article were photographed before and after impact with digital video camera and a digital SLR camera. A film report of this project has been assembled using edited portions of the crash testing coverage.

Figure 7-2. Typical Camera Locations and Labels

<table>
<thead>
<tr>
<th>Camera Location</th>
<th>Figure 7-2 Label</th>
<th>Camera</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upstream</td>
<td>A</td>
<td>Weinberger SpeedCam Visario 1500</td>
</tr>
<tr>
<td>Downstream</td>
<td>B</td>
<td>Weinberger SpeedCam Visario 1500</td>
</tr>
<tr>
<td>Across</td>
<td>C</td>
<td>Weinberger SpeedCam Visario 1500</td>
</tr>
<tr>
<td>Behind</td>
<td>D</td>
<td>Weinberger SpeedCam Visario 1500</td>
</tr>
<tr>
<td>Upstream Overhead</td>
<td>E</td>
<td>Weinberger SpeedCam Visario 1500</td>
</tr>
<tr>
<td>Center Overhead</td>
<td>F</td>
<td>Weinberger SpeedCam Visario 1500</td>
</tr>
<tr>
<td>Downstream Overhead</td>
<td>G</td>
<td>Weinberger SpeedCam Visario 1500</td>
</tr>
<tr>
<td>Pan Digital Camera</td>
<td>H</td>
<td>Canon XL-1</td>
</tr>
<tr>
<td>Digital SLR Camera</td>
<td>J</td>
<td>Nikon D2X</td>
</tr>
<tr>
<td>Ground Camera</td>
<td>K</td>
<td>Weinberger SpeedCam Visario 1500</td>
</tr>
<tr>
<td>Ground Pan Camera</td>
<td>L</td>
<td>Canon XL-1</td>
</tr>
</tbody>
</table>
Table 7-8. Camera Locations for Test 671 through Test 673  
(Relative to the Critical Impact Point)

<table>
<thead>
<tr>
<th>Camera Location</th>
<th>Figure 7-2 Label</th>
<th>Test #671</th>
<th></th>
<th>Test #672</th>
<th></th>
<th>Test #673</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>x</td>
<td>y</td>
<td>z</td>
<td>x</td>
<td>y</td>
<td>z</td>
</tr>
<tr>
<td>Upstream</td>
<td>A</td>
<td>-35.7 mm</td>
<td>-330 mm</td>
<td>1 m</td>
<td>-36.6 m</td>
<td>0 m</td>
<td>1 m</td>
</tr>
<tr>
<td>Downstream</td>
<td>B</td>
<td>65.2 m</td>
<td>145 mm</td>
<td>1 m</td>
<td>75.3 m</td>
<td>0 m</td>
<td>1 m</td>
</tr>
<tr>
<td>Across</td>
<td>C</td>
<td>-2.6 m</td>
<td>-19.4 m</td>
<td>1 m</td>
<td>-711 mm</td>
<td>-17.3 m</td>
<td>1 m</td>
</tr>
<tr>
<td>Behind</td>
<td>D</td>
<td>22.5 m</td>
<td>9.8 m</td>
<td>1 m</td>
<td>28.8 m</td>
<td>10.7 m</td>
<td>1 m</td>
</tr>
<tr>
<td>Upstream Overhead</td>
<td>E</td>
<td>-457 mm</td>
<td>0 m</td>
<td>9.1 m</td>
<td>-457 mm</td>
<td>0 mm</td>
<td>9.1 m</td>
</tr>
<tr>
<td>Center Overhead</td>
<td>F</td>
<td>0 mm</td>
<td>0 mm</td>
<td>9.1 m</td>
<td>0 mm</td>
<td>0 mm</td>
<td>9.1 m</td>
</tr>
<tr>
<td>Downstream Overhead</td>
<td>G</td>
<td>457 mm</td>
<td>0 mm</td>
<td>9.1 m</td>
<td>457 mm</td>
<td>0 mm</td>
<td>9.1 m</td>
</tr>
<tr>
<td>Pan Digital Camera</td>
<td>H</td>
<td>-2.5 m</td>
<td>-21.6 m</td>
<td>5 m</td>
<td>3.5 m</td>
<td>-20.4 m</td>
<td>5 m</td>
</tr>
<tr>
<td>Digital SLR Camera</td>
<td>J</td>
<td>-1575 mm</td>
<td>-21.6 m</td>
<td>5 m</td>
<td>4.5 m</td>
<td>-20.4 m</td>
<td>5 m</td>
</tr>
<tr>
<td>Ground Camera</td>
<td>K</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-3.8 m</td>
<td>2 m</td>
<td>-</td>
</tr>
<tr>
<td>Ground Pan Camera</td>
<td>L</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
Table 7-9. Camera Locations for Test 674 through Test 676
(Relative to the Critical Impact Point)

<table>
<thead>
<tr>
<th>Camera Location</th>
<th>Figure 7-2 Label</th>
<th>Test #674</th>
<th>Test #675</th>
<th>Test #676</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>x</td>
<td>y</td>
<td>z</td>
</tr>
<tr>
<td>Upstream</td>
<td>A</td>
<td>-42.4 m</td>
<td>0 m</td>
<td>1 m</td>
</tr>
<tr>
<td>Downstream</td>
<td>B</td>
<td>85 m</td>
<td>0 m</td>
<td>1 m</td>
</tr>
<tr>
<td>Across</td>
<td>C</td>
<td>-1092 mm</td>
<td>-14.7 m</td>
<td>1 m</td>
</tr>
<tr>
<td>Behind</td>
<td>D</td>
<td>28.3 m</td>
<td>10.7 m</td>
<td>1 m</td>
</tr>
<tr>
<td>Upstream Overhead</td>
<td>E</td>
<td>-457 mm</td>
<td>0 mm</td>
<td>9.1 m</td>
</tr>
<tr>
<td>Center Overhead</td>
<td>F</td>
<td>0 mm</td>
<td>0 mm</td>
<td>9.1 m</td>
</tr>
<tr>
<td>Downstream Overhead</td>
<td>G</td>
<td>457 mm</td>
<td>0 mm</td>
<td>9.1 m</td>
</tr>
<tr>
<td>Pan Digital Camera</td>
<td>H</td>
<td>4.5 m</td>
<td>-15.7 m</td>
<td>5 m</td>
</tr>
<tr>
<td>Digital SLR Camera</td>
<td>J</td>
<td>6.3 m</td>
<td>-15.8 m</td>
<td>5 m</td>
</tr>
<tr>
<td>Ground Camera</td>
<td>K</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Ground Pan Camera</td>
<td>L</td>
<td>2 m</td>
<td>-14.8 m</td>
<td>305 mm</td>
</tr>
</tbody>
</table>

Locations not recorded
7.4. Video Analysis

Visual Fusion, video analysis software, was used to verify the impact speed and to obtain the impact angle, exit angle, exit speed, brake application time, and the maximum yaw, pitch, and roll angles.

The following are the pretest procedures that are completed to enable film data analysis:

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 (1.64 and 3.28 ft). The targets established scale factors and horizontal and vertical alignment.

2. Flashbulbs, mounted on the test vehicle, were electronically triggered to establish 1) initial vehicle-to-article 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.
7.5. Detailed Drawings of Test Article

Figure 7-3. K-rail Standard Plan (2004)
Figure 7-4. Typical Uncapped Stake Installation Layout
Figure 7-5. Typical Capped Stake Installation Layout
Figure 7-6. Capped Stake Dimensions [mm]
7.6. Test Article Installation

The K-rail barrier was placed on a surveyed line using a forklift with lifting hooks. The pins were placed in the pin-and-loop connection by hand. The barrier was not pull tight to maintain some of the slack in the joints. Holes in the asphalt concrete were drilled by using the K-rail stake holes as guides for a roto-hammer and 7/8-in drill bit. The stakes were installed in the pre-drilled holes using a 60-lb (27-kg) jackhammer with a stake-driving attachment. They were driven in until the head of the stakes cleared the barrier face to prevent wheel snagging (Figure 7-4 and Figure 7-10).

Figure 7-7. Stake Installation

Figure 7-8. Forklift Carrying K-rail

Figure 7-9. Installed Uncapped Stake

Figure 7-10. Installed Capped Stake
7.7. Electronic Instrumentation and Data

7.7.1. Instrumentation

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

Beginning at Test 674, a new set of gyros was installed. The previous set of gyros had malfunctioned and could not be repaired. The gyro and accelerometer specifications are shown in Table 7-10. The vehicle accelerometer and gyro sign convention used throughout this report is the same as that described in NCHRP Report 350 and is shown in Figure 7-12.

A rigid stand with three retro-reflective 90° polarizing tape strips was placed on the ground near the test article and alongside the path of the test vehicle (Figure 7-11). The strips were spaced at carefully measured intervals of 1.000-m (3.281-ft). The test vehicle had an onboard optical sensor that produced sequential impulses or “event blips” that were recorded concurrently with the accelerometer signals on the 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. Two other pressure-sensitive tape switches, connected to a speed trap, were placed 4.000-m (13.124-ft) apart just upstream of the test article specifically to establish the impact speed of the test vehicle. The layout for all of the pressure-sensitive tape switches is shown in Figure 7-11.

The data curves are shown in Figure 7-13 through Figure 7-42 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 velocity defined in NCHRP Report 350. All data were analyzed using software written by DADiSP and modified by Caltrans.

![Figure 7-11. Instrumentation Layout](image-url)
Table 7-10. Accelerometer and Gyro Specifications

<table>
<thead>
<tr>
<th>MANUFACTURER</th>
<th>LOCATION</th>
<th>RANGE</th>
<th>ORIENTATION</th>
<th>TEST NUMBER</th>
</tr>
</thead>
<tbody>
<tr>
<td>Endevco</td>
<td>Vehicle’s C.G.</td>
<td>100 G</td>
<td>Longitudinal (primary)</td>
<td>ALL</td>
</tr>
<tr>
<td>Endevco</td>
<td>Vehicle’s C.G.</td>
<td>100 G</td>
<td>Lateral (primary)</td>
<td>ALL</td>
</tr>
<tr>
<td>Endevco</td>
<td>Vehicle’s C.G.</td>
<td>100 G</td>
<td>Vertical (primary)</td>
<td>ALL</td>
</tr>
<tr>
<td>Endevco</td>
<td>Vehicle’s C.G.</td>
<td>100 G</td>
<td>Longitudinal (secondary)</td>
<td>ALL</td>
</tr>
<tr>
<td>Endevco</td>
<td>Vehicle’s C.G.</td>
<td>100 G</td>
<td>Lateral (secondary)</td>
<td>ALL</td>
</tr>
<tr>
<td>Endevco</td>
<td>Vehicle’s C.G.</td>
<td>100 G</td>
<td>Vertical (secondary)</td>
<td>ALL</td>
</tr>
<tr>
<td>Humphrey</td>
<td>191 mm (7.5-in)</td>
<td>180 DEG/SEC</td>
<td>Roll</td>
<td>671, 672, 673</td>
</tr>
<tr>
<td>Humphrey</td>
<td>behind the C.G.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Humphrey</td>
<td>(along the X-axis)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Humphrey</td>
<td>90 DEG/SEC</td>
<td></td>
<td>Pitch</td>
<td>671, 672, 673</td>
</tr>
<tr>
<td>Humphrey</td>
<td>180 DEG/SEC</td>
<td></td>
<td>Yaw</td>
<td>671, 672, 673</td>
</tr>
<tr>
<td>BEI Systron Donner Inertial</td>
<td>191 mm (7.5-in)</td>
<td>500 deg/sec</td>
<td>Roll</td>
<td>674, 675, 676</td>
</tr>
<tr>
<td>BEI Systron Donner Inertial</td>
<td>behind the C.G.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BEI Systron Donner Inertial</td>
<td>(along the X-axis)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BEI Systron Donner Inertial</td>
<td>500 deg/sec</td>
<td></td>
<td>Pitch</td>
<td>674, 675, 676</td>
</tr>
<tr>
<td>BEI Systron Donner Inertial</td>
<td>191 mm (7.5-in)</td>
<td></td>
<td>Yaw</td>
<td>674, 675, 676</td>
</tr>
<tr>
<td>BEI Systron Donner Inertial</td>
<td>behind the C.G.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BEI Systron Donner Inertial</td>
<td>(along the X-axis)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
7.7.2. Data

Figure 7-13 through Figure 7-42 show the data for Tests 671 through 676.
Figure 7-13. Test 671 Vehicle Accelerations Vs Time
Figure 7-14. Test 671 Vehicle Longitudinal Acceleration, Velocity, and Distance Vs Time
Figure 7-15. Test 671 Vehicle Lateral Acceleration, Velocity, and Distance Vs Time
Figure 7-16. Test 671 Acceleration Severity Index Vs Time

Acceleration Severity Index (ASI) = 1.41 @ 0.0618 s
Figure 7-17. Test 671 Vehicle Roll, Pitch, and Yaw Vs Time
Figure 7-18. Test 672 Vehicle Accelerations Vs Time
Figure 7-19. Test 672 Vehicle Longitudinal Acceleration, Velocity, and Distance Vs Time
Figure 7-20. Test 672 Vehicle Lateral Acceleration, Velocity, and Distance Vs Time
Figure 7-21. Test 672 Vehicle Roll, Pitch, and Yaw Vs Time
Figure 7-22. Test 672 Acceleration Severity Index Vs Time
Figure 7-23. Test 673 Vehicle Accelerations Vs Time
Figure 7-24. Test 673 Vehicle Longitudinal Acceleration, Velocity, and Distance Vs Time
Figure 7-25. Test 673 Vehicle Lateral Acceleration, Velocity, and Distance Vs Time
Figure 7-26. Test 673 Vehicle Roll, Pitch, and Yaw Vs Time
Figure 7-27. Test 673 Acceleration Severity Index Vs Time

Acceleration Severity Index (ASI) = 1.73 @ 0.0557 s
Figure 7-28. Test 674 Vehicle Longitudinal Acceleration, Velocity, and Distance Vs Time
Figure 7-29. Test 674 Vehicle Accelerations Vs Time
Figure 7-30. Test 674 Vehicle Lateral Acceleration, Velocity, and Distance Vs Time
Figure 7-31. Test 674 Vehicle Roll, Pitch, and Yaw Vs Time
Figure 7-32. Test 674 Acceleration Severity Index Vs Time

Acceleration Severity Index (ASI) = 2.11 @0.0447 s
Figure 7-33. Test 675 Acceleration Severity Index Vs Time
Figure 7-34. Test 675 Vehicle Roll, Pitch, and Yaw Vs Time
Figure 7-35. Test 675 Vehicle Accelerations Vs Time
Figure 7-36. Test 675 Vehicle Lateral Acceleration, Velocity, and Distance Vs Time
Figure 7-37. Test 675 Vehicle Longitudinal Acceleration, Velocity, and Distance Vs Time
Figure 7-38. Test 676 Vehicle Accelerations Vs Time
Figure 7-39. Test 676 Vehicle Longitudinal Acceleration, Velocity, and Distance Vs Time
Figure 7-40. Test 676 Vehicle Lateral Acceleration, Velocity, and Distance Vs Time
Figure 7-41. Test 676 Vehicle Roll, Pitch, and Yaw Vs Time
Figure 7-42. Test 676 Acceleration Severity Index Vs Time