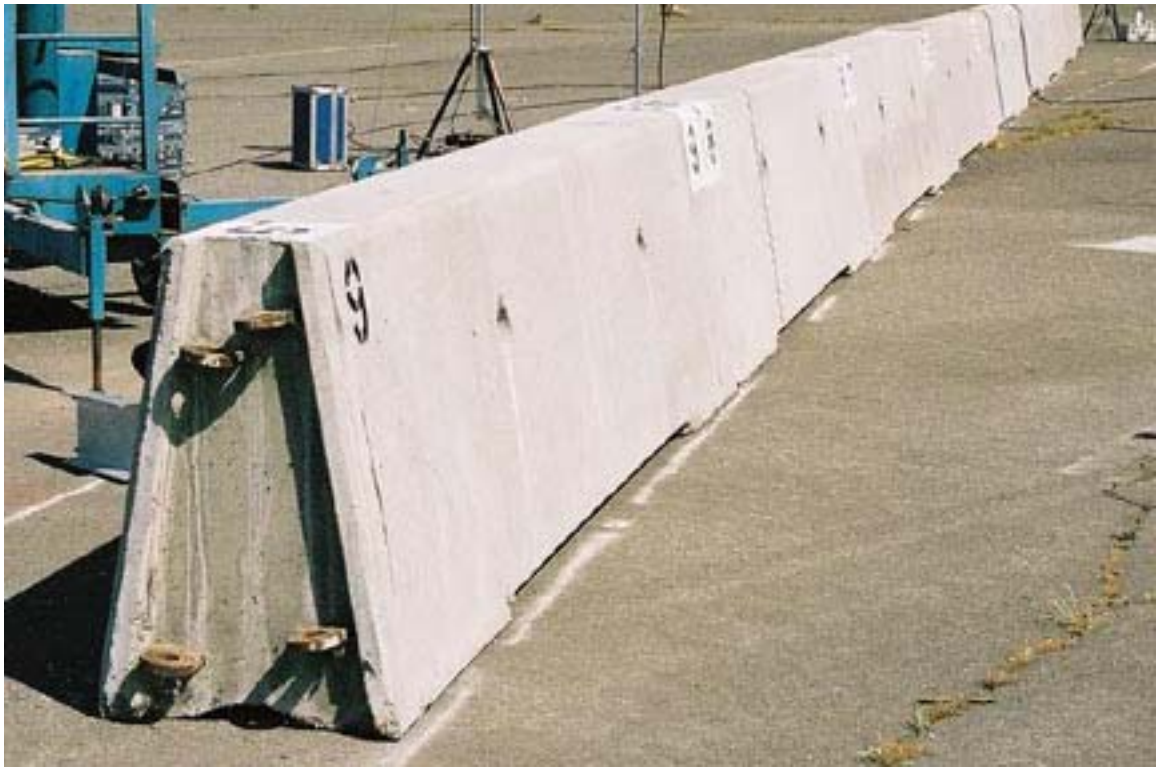
COMPLIANCE CRASH TESTING OF THE TYPE 60K TERMINUS



STATE OF CALIFORNIA

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

Principal Investigator ..... Rich Peter, P.E.

Current RSRG Chief ..... Robert Meline, P.E.

Report Prepared by .....John Jewell, P.E. and David Whitesel, P.E.

Research Performed by ..... Roadside Safety Research Group (RSRG)

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TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO. **FHWA/CA08-0287**	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
4. TITLE AND SUBTITLE COMPLIANCE CRASH TESTING OF A TYPE 60K TERMINUS		5. REPORT DATE December 2008 6. PERFORMING ORGANIZATION CODE FHWA/CA08-0287
7. AUTHOR(S) John Jewell, Rich Peter, David Whitesel		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Roadside Safety Research Group California Department of Transportation 5900 Folsom Blvd., Sacramento, CA. 95819		10. WORK UNIT NO. 11. CONTRACT OR GRANT NO. CA08-0287
12. SPONSORING AGENCY NAME AND ADDRESS California Department of Transportation 5900 Folsom Blvd., Sacramento CA. 95819		13. TYPE OF REPORT & PERIOD COVERED **Final** 14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

This project was performed in cooperation with the US Department of Transportation, Federal Highway Administration, under the research project titled "COMPLIANCE CRASH TESTING OF THE TYPE 60K TERMINUS".

16. ABSTRACT

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

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

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

17. KEY WORDS 60K, Terminus, K-rail, Barriers, Crash Test, Single-slope, Concrete, Vehicle Impact Test		18. DISTRIBUTION STATEMENT No Restrictions. This document is available through the National Technical Information Service, Springfield, VA 22161	
19. SECURITY CLASSIF. (OF THIS REPORT) Unclassified	20. SECURITY CLASSIF. (OF THIS PAGE) Unclassified	21. NO. OF PAGES 46	22. PRICE

NOTICE

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SI CONVERSION FACTORS

To Convert From	To	Multiply By
	ACCELERATION	
m/s^2	ft/s^2	3.281
	AREA	
m^2	ft^2	10.76
	ENERGY	
Joule (J)	$ft.lb_f$	0.7376
	FORCE	
Newton (N)	lb_f	0.2248
	LENGTH	
m	ft	3.281
m	in	39.37
cm	in	0.3937
mm	in	0.03937
	MASS	
kg	lb_m	2.205
	PRESSURE OR STRESS	
kPa	psi	0.1450
	VELOCITY	
km/h	mph	0.6214
m/s	ft/s	3.281
km/h	ft/s	0.9113

ACKNOWLEDGMENTS

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

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

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

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

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1. INTRODUCTION

1.1. Problem

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

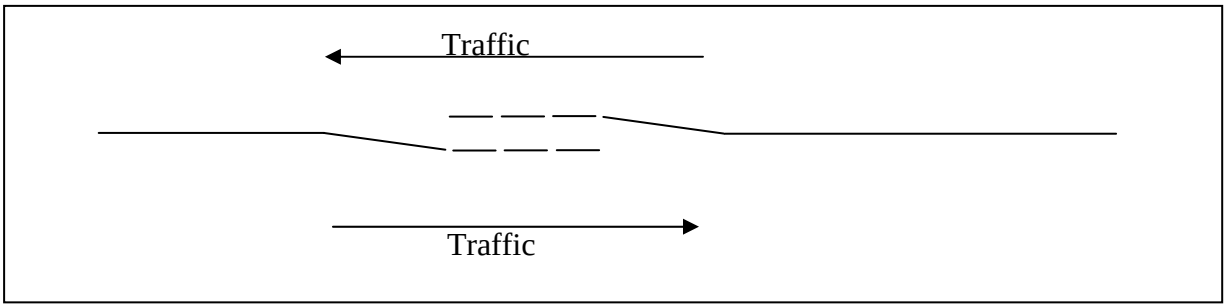


Figure 1-1 – Example Use of Type 60K Terminus

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

1.2. Objective

This research project involves conducting compliance tests of a terminus design for the Type 60K concrete barrier to determine whether it meets National Cooperative Highway Research Program (NCHRP) Report 350 [(1)] criteria. The proposed terminus consists of two segments of Type 60K barrier at the downstream end of a barrier that are secured from lateral movement with

steel stakes. Two 1-m long stakes would be driven into the AC paving directly behind and in contact with each of the two segments. An impact location for the crash test will be selected to give the highest chance of failure through either pocketing or overturning of the barrier.

1.3. Background

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

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

1.4. Literature Search

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

1.5. Scope

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

Table 1-1 – Target Impact Conditions

Test Number	Barrier Type	Mass of Test Vehicle (kg)	Speed (km/h)	Angle (deg)
601	60K Terminus	2000	100	25

2. TECHNICAL DISCUSSION

2.1. Test Conditions - Crash Tests

2.1.1. Test Facilities

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

2.1.2. Test Barrier

2.1.2.1. Design

The primary design considerations for the 60K Terminus were:

1) Compliance with NCHRP Report 350 TL-3.

2) Minimum lateral movement during impact.

3) Ease of installation and removal.

4) Use of the Type 60K segments.

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

2.1.3. Construction

A total of nine segments of Type 60K barrier were used to construct the barrier. The barriers were put in place via a 10-kip, side-shifting forklift. 31.8-mm x 760-mm pins were used to connect the segments to each other.

Figure 2-1 – Barrier Placement

Segments 8 and 9 were the only segments that were laterally restrained through the use of 25-mm X 1000-mm stakes. The stakes were placed 425 mm from the joints of each of the ends of segments 8 and 9 for a total of 4 stakes. Both a jackhammer with a stake-driver and a sledge hammer were used to drive the stakes. The top 100 mm of each was left above grade.

Figure 2-2 – Stake Installation

The final test condition of the barrier appeared smooth and flat on the impact side.

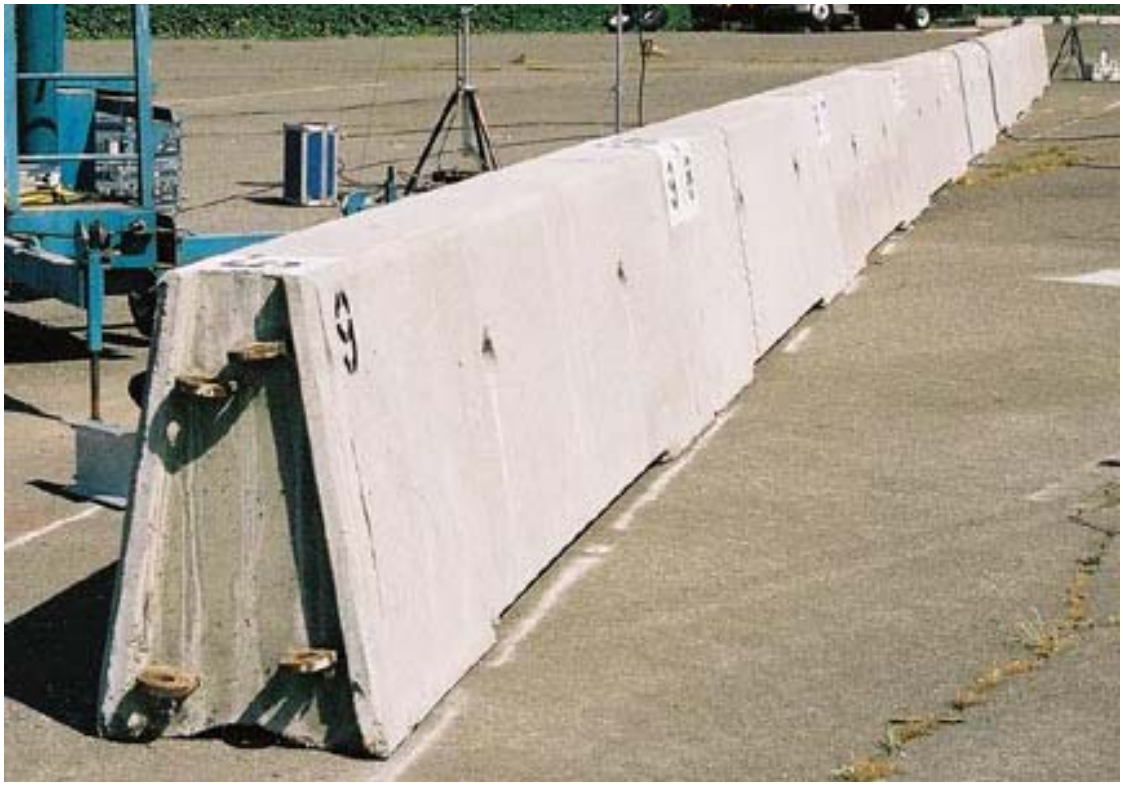


Figure 2-3 – Barrier Alignment

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

Figure 2-4 – Backside of Completed Barrier with Stakes

2.1.4. Test Vehicle

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

Table 2-1 – Test Vehicle Information

Test No.	Vehicle	Ballast (kg)	Test Inertial (kg)
601	1994 Chevrolet 2500	73	1960

Figure 2-5 – Front of Test Vehicle Prior to Impact

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

Figure 2-7 – Front Right Corner of Test Vehicle prior to Impact

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

2.1.5. Data Acquisition System

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

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

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

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

2.2. Test Results - Crash Tests

A film report with edited footage from all tests has been compiled and is available for viewing.

2.2.1. Impact Description - Test 601

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

Figure 2-8 – Intended Impact Point

2.2.2. Vehicle Damage - Test 601

Most of the damage to the vehicle was on the front half of the right side. The right third of the bumper was pushed back into the front right wheel well. The front tire was torn, but still on the rim. The wheel was pushed back about 450 mm. The right side of the bed was dented near the cab and near the taillight.

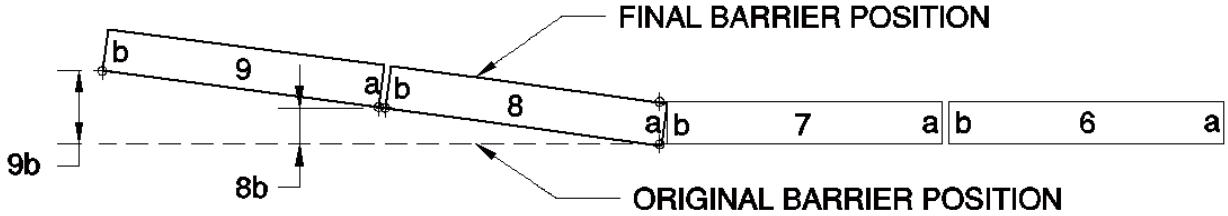
Figure 2-9 – Front Wheel of Test Vehicle Post-Impact

Figure 2-10 – Front Right Corner of Test Vehicle Post-Impact

Figure 2-11 – Rear Right Side of Test Vehicle Post-Impact

2.2.3. Barrier Damage - Test 601

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



Joint	7a	7b	8a	8b	9a	9b
Lateral Deflection (mm)	0	5	15	555	565	1060

Figure 2-12 – Permanent Deflection Drawing

Repair to the barrier would require replacing the pins and realigning the last few barrier segments with new lateral retention stakes where necessary.

Figure 2-13 – Barrier Damage near the Impact Point

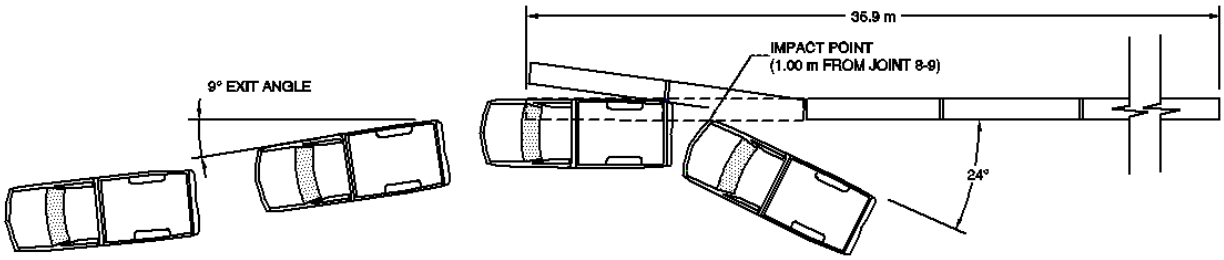
Figure 2-14 – Permanent Deflection

Figure 2-15 – Backside of Joint 8-9 showing Minor Concrete Spalling and Bent Pin (mislabeled)

Figure 2-16 – Close-up of Bent Pin at Joint 8-9

Figure 2-17 – Test 601 Data Summary Sheet

Impact Sequence Drawing



General Information

Test Agency	California DOT
Test Number	601
Test Date	April 23, 2002

Test Article

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

Test Vehicle

Model	1994 Chevy 2500 PU
Inertial Mass	1960 kg

Impact Conditions

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

Exit Conditions

Velocity	80.3 km/h
Angle	9 degrees

Test Dummy

Type	NA
Weight / Restraint	NA
Position	NA

Post-Impact Vehicular Behavior

Maximum Roll Angle	26.88º
Maximum Pitch Angle	8.70º
Maximum Yaw Angle	-39.99º

Test Data

Vehicle Exterior:

VDS [2]	RFQ-3, FR-2
CDC [3]	02RFEW5

Vehicle Interior

O.C.D.I.[1]	RF0001000

Occupant Risk Values	*Longitudinal*	*Lateral*
Occupant Impact Velocity	4.75 m/s	-6.40 m/s
Ridedown Acceleration	-7.35 g	12.85 g

Barrier Damage

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

2.3. Discussion of Test Results - Crash Tests

2.3.1. General - Evaluation Methods

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

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

2.3.2. Structural Adequacy

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

2.3.3. Occupant Risk

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

2.3.4. Vehicle Trajectory

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

Table 2-2 – Test 601 Assessment Summary

Test No. 601
Date April 23, 2002
Test agency California Dept. of Transportation

Evaluation Criteria	Test Results	Assessment
Structural Adequacy		
A. Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the article is acceptable.	The vehicle was smoothly redirected	pass
Occupant Risk		
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.	There was no significant debris from either the vehicle or the barrier.	pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The maximum roll and pitch of the vehicle were well within acceptable limits	pass
Vehicle Trajectory		
K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	The vehicle trajectory was would not have brought the vehicle back into traffic .	pass
L. The occupant impact velocity in the longitudinal direction should not exceed 12 m/sec and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 *g*.	Long. Occ. Impact Vel. = 4.75 m/s Long. Occ. Ridedown = -7.35 *g*	Pass
M. The exit angle from the test article preferably should be less that 60 percent of the test impact angle, measured at time of vehicle loss of contact with test device."	Exit angle 9 degrees, or 38% of impact angle	Pass

Table 2-3 – Vehicle Trajectories and Speeds

Test Number	Impact Angle [deg]	60% of Impact Angle [deg]	Exit Angle [deg]	Impact Speed, V_i [km/h]	Exit Speed, V_e [km/h]	Speed Change V_i - V_e [km/h]
601	24.0	37.5	9	100.3	80.3	20

3. CONCLUSION

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

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

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

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

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

2. The Type 90 meets the criteria set in the National Cooperative Highway Research Program's Report 350 "Recommended Procedures for the Safety Performance Evaluation of Highway Features" under Test Level 3 for longitudinal barriers.

4. RECOMMENDATIONS

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

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

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

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

5. IMPLEMENTATION

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

6. APPENDIX

6.1. Test Vehicle Equipment

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

- The gas tanks on the test vehicle was disconnected from the fuel supply line and drained. A 12-liter safety gas tank was installed in the truck bed and connected to the fuel supply line. The stock fuel tank had gaseous CO_2 added to purge fuel vapors.

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

- A 4800-kPa CO_2 system, actuated by a solenoid valve, controlled remote braking after impact and emergency braking if necessary. Part of this system was a pneumatic ram that was attached to the brake pedal. The operating pressure for the ram was adjusted through a pressure regulator during a series of trial runs prior to the actual test. Adjustments were made to assure the shortest stopping distance without locking up the wheels. When activated, the brakes would apply in less than 100 milliseconds.

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

- An accelerator switch was located on the rear of the vehicle. The switch opened an electric solenoid, which in turn released compressed 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 with a valve to adjust CO_2 flow rate.

- An electronic speed control box, connected in-line with the primary winding of the coil, was used to regulate the speed of the test vehicle based on the signal from a speed sensor output

from the vehicle transmission. This device was calibrated prior to all tests by conducting a series of trial runs through a speed trap comprised of two tape switches set a specified distance apart and a digital timer.

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

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

Table 6-1 – Test 601 Vehicle Dimensions

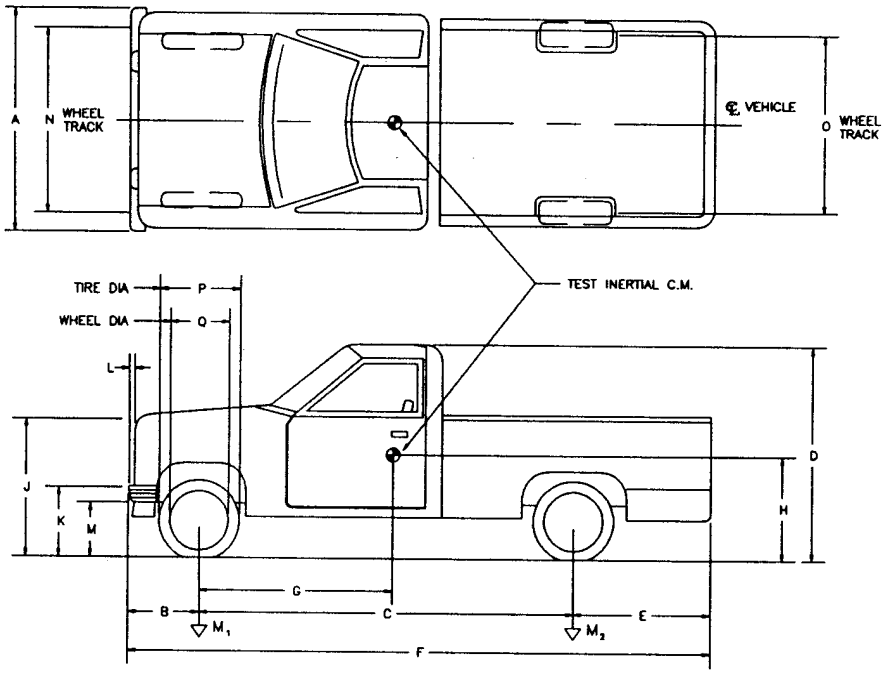
DATE: 4/23/02 **TEST NO:** 601 **VIN NO:** 1GCFC2444R2263338 **MAKE:** Chevy

MODEL: 2500 Pick-Up **YEAR:** 1994 **ODOMETER:** 24637.4 (MI) **TIRE SIZE:** LT255/75R16

TIRE INFLATION PRESSURE: 55 (PSI)

MASS DISTRIBUTION (kg) **LF** 547.0 **RF** 539.0 **LR** 438.0 **RR** 436.0

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



ENGINE TYPE: Gas V8

ENGINE CID: 305

TRANSMISSION TYPE:

X **AUTO**

_____ **MANUAL**

OPTIONAL EQUIPMENT:

AC

DUMMY DATA:

TYPE: NA

MASS: NA

SEAT POSITION: NA

GEOMETRY (mm)

A 1900	**D** 1770	**G** 1489	**K** 600	**N** 1570	**Q** 440
B 940	**E** 1300	**H** na	**L** 90	**O** 1610	
C 3340	**F** 5580	**J** 1010	**M** 450	**P** 730	

MASS - (kg)	**CURB**	**TEST INERTIAL**	**GROSS STATIC**
M1	1075.0	1086.0	1086.0
M2	753.0	874.0	874.0
MT	1828.0	1960.0	1960.0

6.2. Test Vehicle Guidance System

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

6.3. Photo - Instrumentation

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

All of these cameras were mounted on tripods except the three that were mounted on a 10.7-m high tower directly over the impact point on the test barrier.

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

Table 6-2 – Typical Camera Type and Locations

Typical Coordinates, m						
Camera Label	Film Size (mm)	Camera Type	Rate: (fr./sec.)	Test 601		
				X*	Y*	Z*
L1	16	LOCAM 1		5.4	2.4	1.4
L2	16	LOCAM 2	404.8	0	0	9.1
L3	16	LOCAM 3	400	33.4	-0.21	1.4
L4	16	LOCAM 4	400	-0.61	0	9.1
L5	16	LOCAM 5	400	-80.9	-.08	1.4
L6	16	LOCAM 6	400	0.61	0	9.1
L8	16	LOCAM 8	405.1	1.6	-26.0	1.4
V	1.27	SONY BETACAM	30	-2.4	-26.3	4.5
H	35	HULCHER	40	-1.1	-26.8	4.5

Note: Camera location measurements were approximated and are typical for all crash tests involved in this report.
*X, Y and Z distances are relative to the impact point.

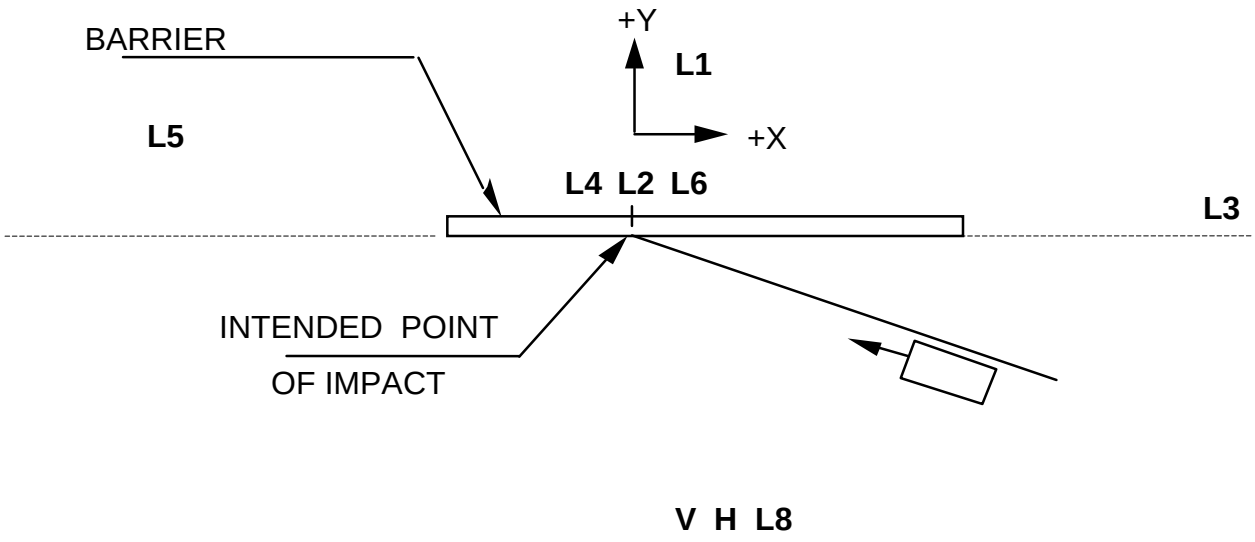


Figure 6-1 – Camera Locations

The following are the pretest procedures that were required to enable film data reduction to be performed using a Visual Instrumentation Corporation Model 1214A film motion analyzer:

1) Butterfly targets were attached to the top and sides of each test vehicle. The targets were located on the vehicle at intervals of 0.5 and 1.0 meters. The targets established scale factors and horizontal and vertical alignment. The test barrier was stenciled with segment numbers on the front of the barrier.
2) Flashbulbs, mounted on the test vehicle, were electronically triggered to establish 1) initial vehicle-to-barrier contact, and 2) the time of the application of the vehicle brakes. The impact flashbulbs begin to glow immediately upon activation, but have a delay of several milliseconds before lighting up to full intensity.
3) Five tape switches, placed at 4-m intervals, were attached to the ground near the barrier and were perpendicular to the path of the test vehicle. Flashbulbs were activated sequentially when the tires of the test vehicle rolled over the tape switches. The flashbulb stand was placed in view of the cameras. The flashbulbs were used to correlate the cameras with the impact events and to calculate the impact speed independent of the electronic speed trap. The tape switch layout is shown in Figure 6-2.
4) High-speed cameras had timing light generators that exposed red timing pips on the film at a rate of 100 per second. The pips were used to determine camera frame rates.

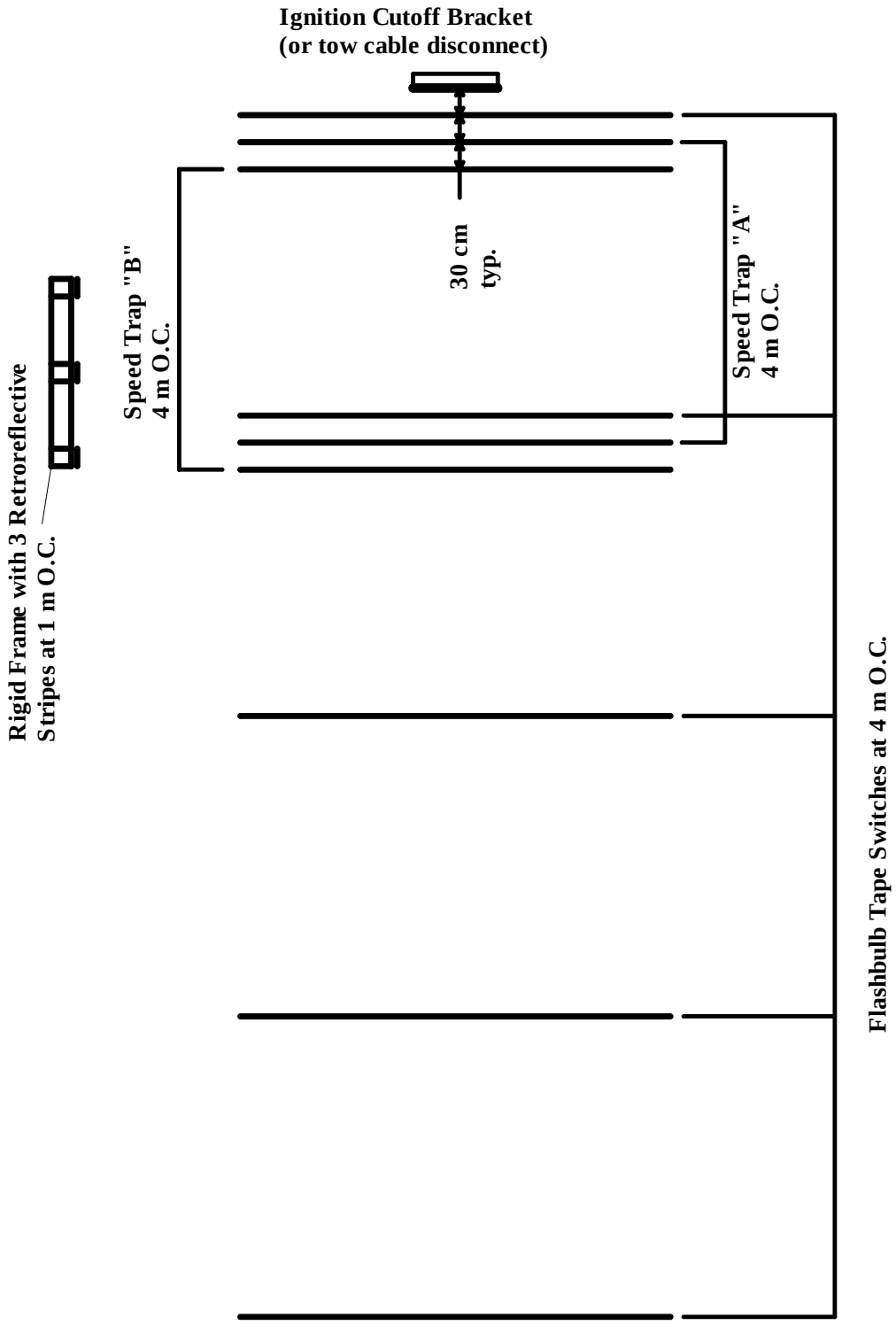


Figure 6-2 – Event Switch Layout

6.4. Electronic Instrumentation and Data

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

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

A rigid stand with three retro-reflective 90° polarizing tape strips was placed on the ground near the test barrier and alongside the path of the test vehicle (see Figure 6-2). The strips were spaced at carefully measured intervals of 1 m. The test vehicle had an onboard optical sensor, which produced sequential impulses or "event blips" that were recorded concurrently with the accelerometer signals on a TDR, serving as "event markers". The impact velocity of the vehicle could be determined from these sensor impulses and timing cycles and the known distance between the tape strips. A pressure sensitive tape switch on the front bumper of the vehicle closed at the instant of impact and triggered two events: 1) an “event marker” was added to the recorded data, and 2) a flashbulb mounted on the top of the vehicle was activated. The final event recorded to the TDR was from a brake pressure sensor attached to the CO_2 system. Two other pressure sensitive tape switches, connected to a speed trap, were placed 4 m apart just upstream of the test barrier specifically to establish the impact speed of the test vehicle.

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

Table 6-3 – Accelerometer Specifications

TYPE	LOCATION	RANGE	ORIENTATION	TEST NUMBER
STATHAM	VEHICLE C.G.	100 G	LONGITUDINAL	601
STATHAM	VEHICLE C.G.	100 G	LATERAL	601
STATHAM	VEHICLE C.G.	50 G	VERTICAL	601
HUMPHREY	VEHICLE C.G.	180 DEG/SEC	ROLL	601
HUMPHREY	VEHICLE C.G.	90 DEG/SEC	PITCH	601
HUMPHREY	VEHICLE C.G.	180 DEG/SEC	YAW	601
ENDEVCO	VEHICLE C.G.	200 G	LONGITUDINAL	601
ENDEVCO	VEHICLE C.G.	200 G	LATERAL	601
ENDEVCO	VEHICLE C.G.	200 G	VERTICAL	601

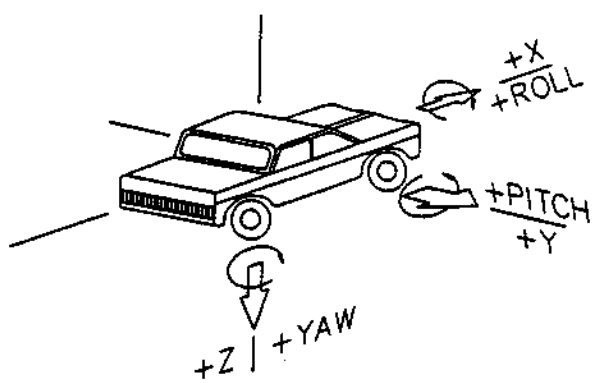


Figure 6-3 – Vehicle Accelerometer Sign Convention

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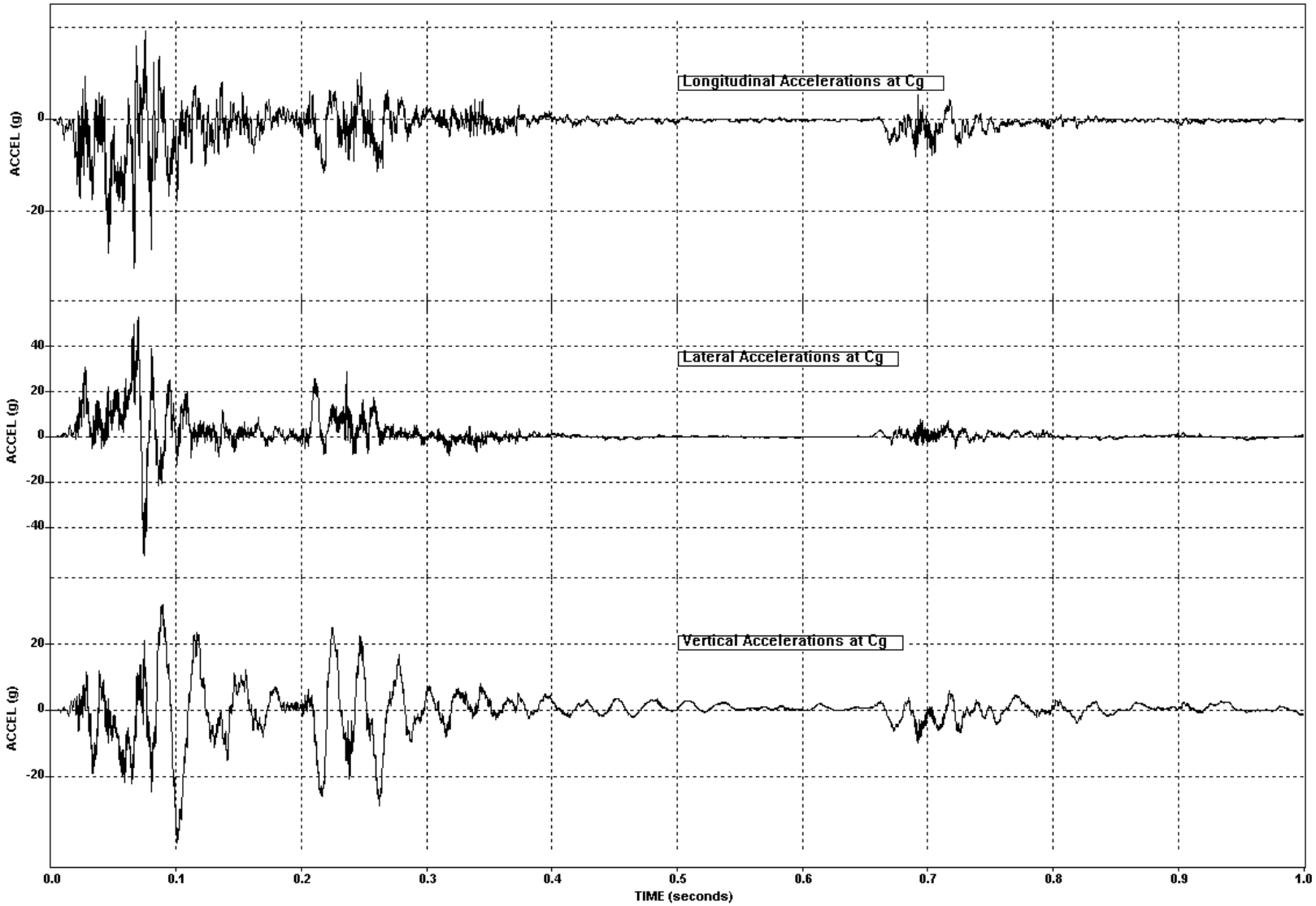

Figure 6-4 – Test 601 Vehicle Accelerations -Vs- Time

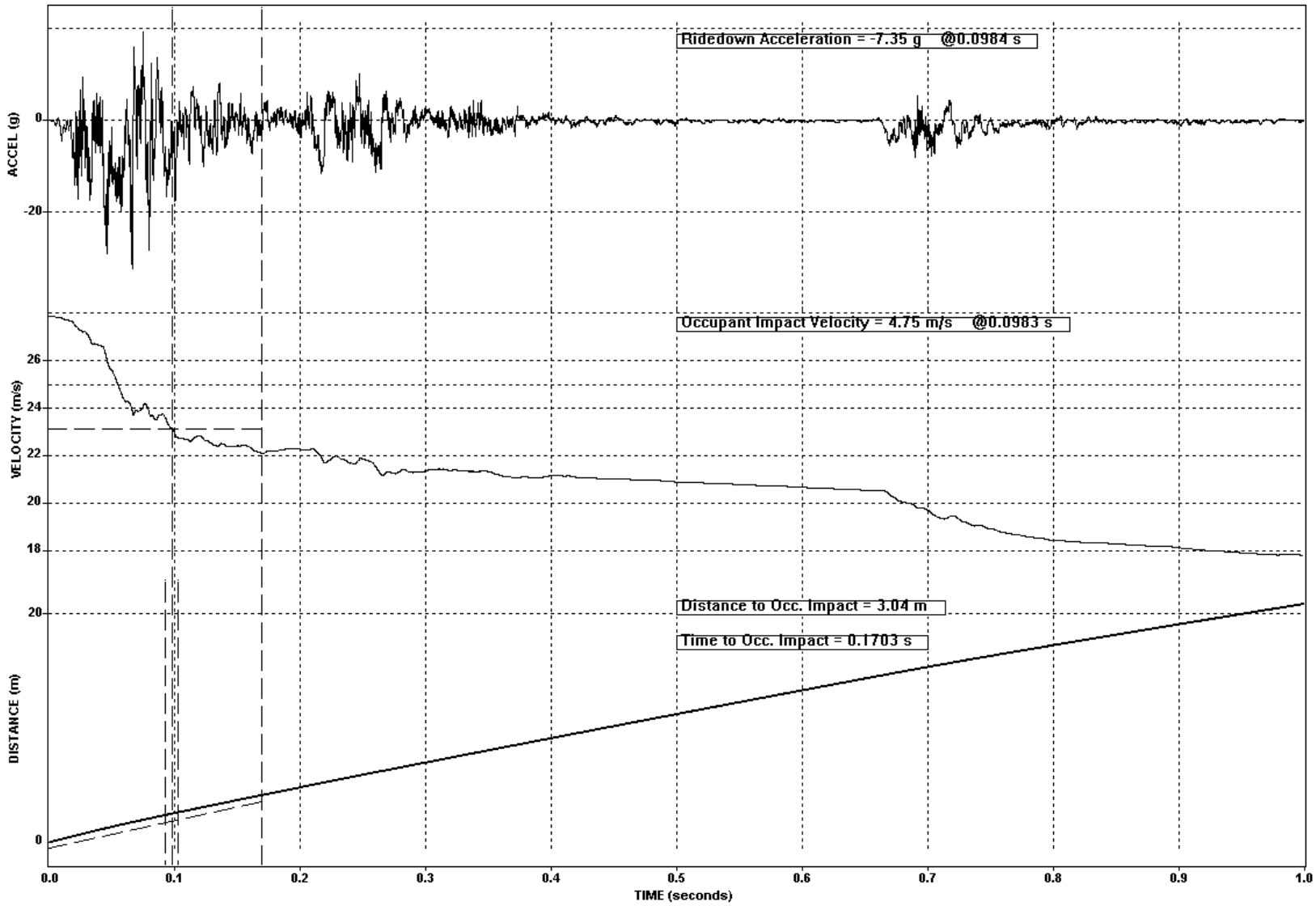

Figure 6-5 – Test 601 Vehicle Longitudinal Acceleration, Velocity and Distance -Vs- Time

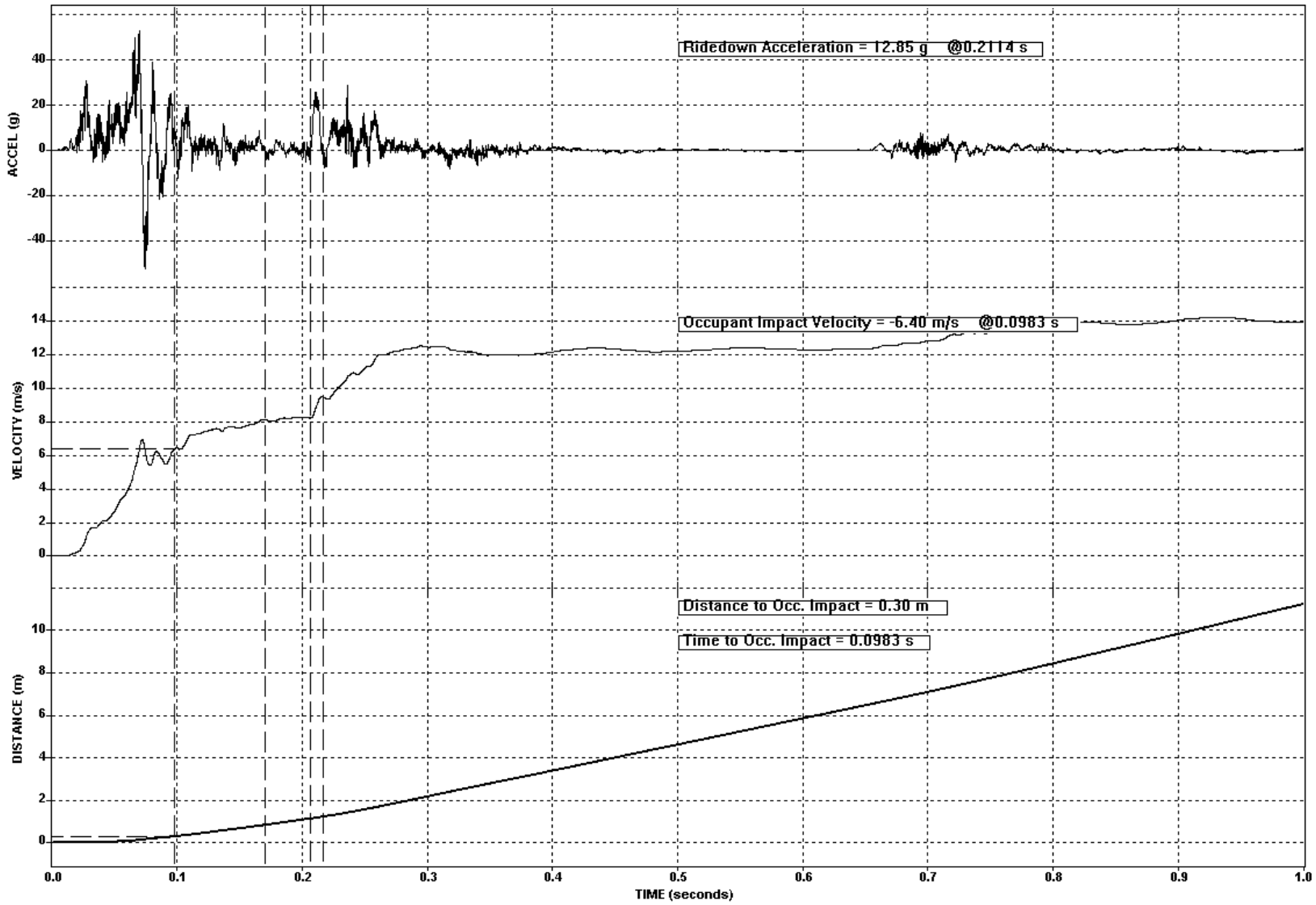

Figure 6-6 – Test 601 Vehicle Lateral Acceleration, Velocity and Distance -Vs- Time

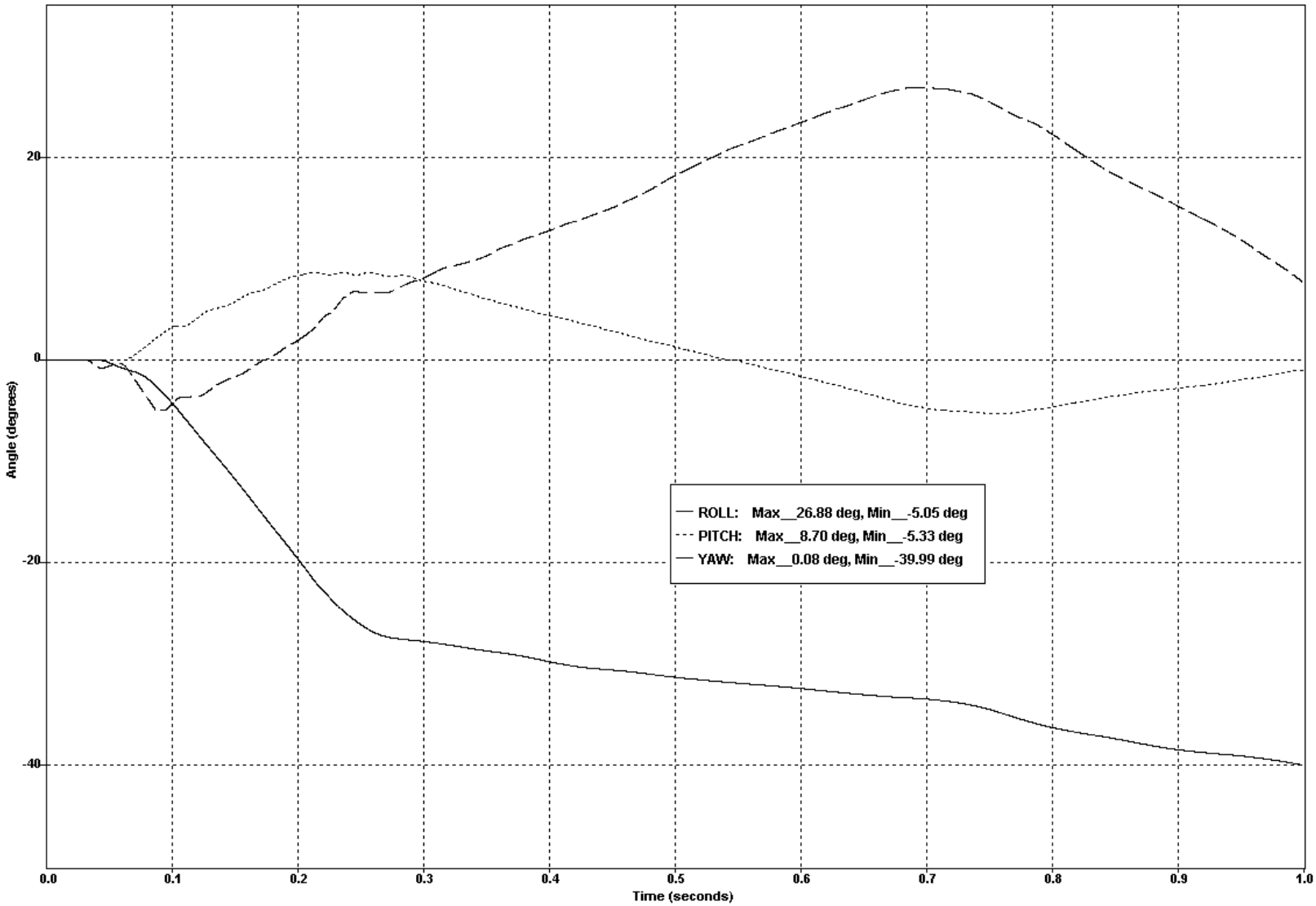

Figure 6-7 – Test 601 Vehicle Roll, Pitch and Yaw -Vs- Time

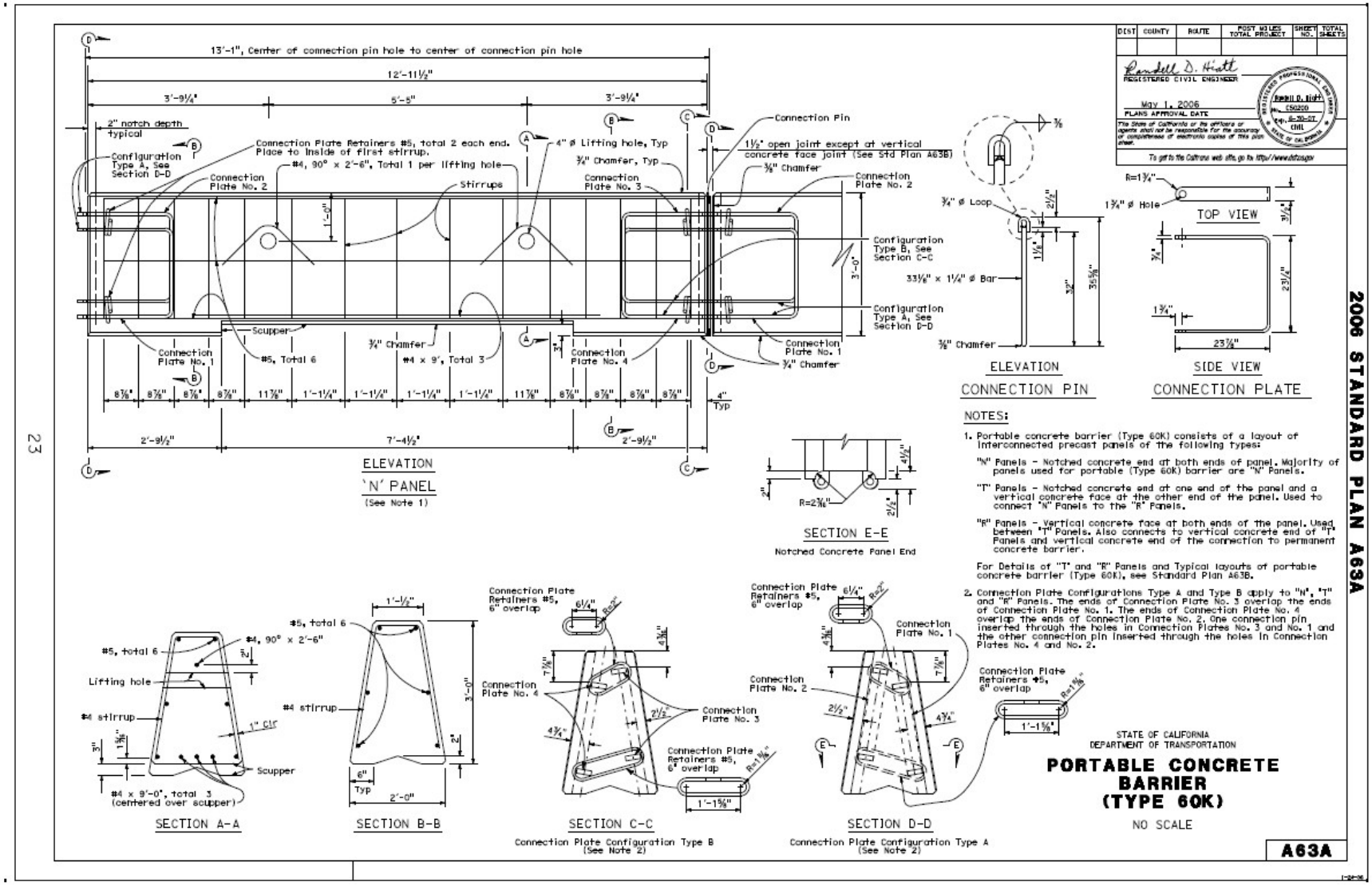

Figure 6-8 – Type 60 Standard Plan

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7. REFERENCES

1. “Recommended Procedures for the Safety Performance Evaluation of Highway Features”, Transportation Research Board, National Cooperative Highway Research Program Report 350, 1993.

2. “Vehicle Damage Scale for Traffic Accident Investigators”, Traffic Accident Data Project, National Safety Council, 1968.

3. “Collision Deformation Classification” - SAE J224 MAR80, SAE Recommended Practices, 1980.

4 Jewell, John, et al., "Compliance Crash Testing Of The Type 60k Concrete Barrier Used In Semi-Permanent Installations ", California Department of Transportation, August 2001.