COMPLIANCE CRASH TESTING OF THE TYPE 60K CONCRETE BARRIER USED IN SEMI-PERMANENT INSTALLATIONS

FINAL REPORT # FHWA/CA/TL-2001/08

STATE OF CALIFORNIA

DEPARTMENT OF TRANSPORTATION

ENGINEERING SERVICES

MATERIALS ENGINEERING AND TESTING SERVICES

Supervised by .... Phil Stolarski, P.E.

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

Report Prepared by .... John Jewell, P.E.

Research Performed by .... Roadside Safety Technology Section

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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 CONCRETE BARRIER USED IN SEMI-PERMANENT INSTALLATIONS".

16. ABSTRACT

Three segmented, concrete barriers were built and crash tested in compliance with NCHRP Report 350. Each barrier was designed to match the single-slope profile of the California Type 60 median barrier. Of the three designs tested, only the third meets the NCHRP 350 guidelines.

The first and second designs (designated 60K-v1 and 60K-v2) consisted of 3.138-m long concrete segments joined by pin-and-loop connections. Each of these designs exhibited a high potential for snagging between segments as demonstrated in their respective crash tests.

The third design (designated 60K-v3), consisting of 4-m long segments with pin-and-plate connections, demonstrated smooth redirection with minimal snagging potential. This design was tested with one 2000-kg pickup and two 820-kg cars.

Design 60K-v3 is recommended for operational use as a semi-permanent barrier.

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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

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1. INTRODUCTION

1.1. Problem

The Federal Highway Administration (FHWA) has established a number of deadlines by which roadside safety features used on the National Highway System will have to comply with the crash testing criteria embodied in the National Cooperative Highway Research Program (NCHRP) Report 350[(1)]. Two deadlines are applicable to the use of portable barriers. Such barriers installed in work zones on a temporary basis on or after October 1, 2002 must meet the Report 350 criteria. Similarly, portable barrier used in permanent or semi-permanent installations must meet the Report 350 criteria if installed on or after October 1, 1998.

District 2 had a need for portable, semi-permanent median barrier and unaware of the FHWA requirements for compliance with NCHRP Report 350 criteria, the district designed such a barrier and had it built without first ensuring that it met the criteria. This barrier, the Type 60K, was placed in two separate configurations, one with a Portland cement concrete (PCC) foundation and another with an asphalt concrete (AC) base. The FHWA may withhold federal funding on highway construction projects utilizing roadside safety features that do not comply with the Administration's requirements to meet NCHRP Report 350 criteria. However, FHWA representatives have been working with Caltrans to avoid this situation. Caltrans staff have stated their intent to conduct the necessary crash testing of the Type 60K barrier as soon as practicable to demonstrate compliance with the applicable criteria. Following successful testing and FHWA acceptance, the Type 60K could continue to be used in District 2 and installed anywhere else it is needed on the state highway system.

1.2. Objective

It was the objective of this research project to conduct compliance testing of the Type 60K portable semi-permanent barrier to determine whether it meets NCHRP Report 350 criteria. Since District 2 developed two configurations for placement of the Type 60K barrier for semi-permanent applications, two sets of crash tests were necessary. In the event of a failure of one or both of these configurations to meet the Report 350 criteria, provisions were made to modify the designs and re-test the barrier to verify compliance.

1.3. Background

In February 1998, the FHWA issued a letter of acceptance for the Type 60 concrete median barrier (CMB), a single-slope design developed by Caltrans. The Type 60 is a slip-formed longitudinal barrier that has replaced the older Type 50 CMB as a standard barrier on California highways. A District 2 project on Interstate 5 near Dunsmuir, California included over 10 km of Type 60 CMB. Several sections of this median barrier were redesigned as portable segments (the Type 60K) so these sections could be temporarily removed for traffic control purposes if conditions so warranted.

The design of the Type 60K barrier shares some of the features of the standard California K–rail. Both are segmented to allow removal, have lifting holes and scuppers for positioning, and use pin and loop connections between the segments. Both designs are 610 mm wide at the base, but at 3138 mm, the Type 60K segments are one-half the length of the standard K-rail segments.

The Type 60K has a single-slope profile (9.1 degrees from the vertical) while the K-rail incorporates the Type 50 CMB (“safety-shape”) profile. There are also significant differences in the manner in which the two designs are restrained from lateral movement. For semi-permanent applications, K-rail is staked to the ground with four 1-m long stakes through the vertical holes along each face. The 60K is staked down in one of two ways:

1) The segments placed on AC use 32-mm diameter, 1330-mm long pins in the pin-and-loop connections, with each pin being driven into the ground approximately 150 mm.

2) The segments placed on a concrete base use the same 32-mm x 1330-mm pins in the pin-and-loop connections described above. However, instead of being driven into the ground, the pins drop into 50-mm diameter sleeves that are cast into the concrete base. In addition, the concrete base features a 30-mm deep trough in which the segments are placed.

Both of these methods for restraining the 60K barrier are currently used in District 2. Method 1 is the less expensive of the two, but method 2 offers more lateral restraint than method 1. The Type 60K barrier had not been crash tested in either of the specified restraint configurations prior to installation.

1.4. Literature Search

A search for information about construction barrier and semi-permanent barrier was conducted using three separate sources. The first source was Charles McDevitt, with the Federal Highway Administration's (FHWA) Design Concepts Research Division in McLean, Virginia. The second source was the database of reports held by the Roadside Safety Technology Branch within Caltrans Materials Engineering and Testing Services. The third location was the Caltrans Library within Caltrans Headquarters (The Caltrans library also ran searches into the NTIS, Compendex and TRIS databases.)

Each of the sources produced information on design history. Conversations with the FHWA staff revealed current research direction within the United States.

1.5. Scope

A total of six tests were 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)
562	60K on PCC (60K-v1)	2000	100	25
564	60K on AC (60K-v2)	2000	100	25
565	60K-v3	2000	100	25
566	60K-v3	820	100	20
567$^{\tau}$	60K-v3	820	100	20
$^{\tau}$ Test 567 was a retest of test 566.				

2. TECHNICAL DISCUSSION

2.1. Test Conditions - Crash Tests

2.1.1. Test Facilities

Each of the crash tests was conducted at the Caltrans Dynamic Test Facility in West Sacramento, California. The test area is a large, flat, asphalt concrete surface. There were no obstructions nearby except for a 2 m-high earth berm 40 meters downstream from the barrier in tests 562 and 564.

2.1.2. Test Barrier

2.1.2.1. Design

The primary design considerations for the development of a semi-permanent barrier were:

1) Compliance with NCHRP Report 350 TL-3.

2) Minimum lateral movement during impact.

3) Ease of installation and removal.

Two designs were developed prior to the initiation of this research project. The third design was developed in response to the results of the crash tests of the first two designs. All three designs were based on a single-slope profile, contained reinforcing steel and used pin-and-loop or pin-and-plate connectors to hold the precast segments together.

Design 1 – 60K-v1

The design for the 60K-v1 is shown in Figure 6-20, located in the Appendix.

The first design (designated 60K-v1) consisted of concrete barrier segments 3138-mm long and 910-mm tall installed on a PCC footing. The barrier profile was designed to match the Type 60 median barrier (1999 California Standard Plan A76A). The face of the barrier was sloped at 9.1° off the vertical and each segment was 610-mm wide at the base. The purpose of the footing was to minize the lateral deflection.

Segments were designed with pin-and-loop connections. For ease of installation, the loops were designed to be larger at one end of each barrier segment than at the other. The loops on one end had a 22-mm radius and the loops on the other end had a 50-mm radius.

The PPC base featured a 30-mm deep trough into which the 60k segments were placed. The trough was designed to limit the lateral deflection to +/-30 mm. The edges of the trough were reinforced with 50-mm angle iron. The base also featured steel-sleeved holes, 50-mm in diameter and 150-mm deep, at 3138-mm intervals down the center of the base. The barrier segments were situated such that each pin connecting two segments also extended down into the steel-sleeved holes in the PCC base.

The test barrier included a PCC base long enough to support sixteen segments of 60K barrier. These segments were placed in the trough in the base and connected with fifteen pins. An extra pin was placed in the loops and base holes on each of the outside ends of the first and last segments.

Design 2 – 60K-v2

The design for the 60K-v2 is shown in Figure 6-20, located in the Appendix.

The 60K on AC was a modification of the first design (60k-v1). The barrier segments were pinned together using a single 32-mm pin at each joint. In order to limit the barrier deflection during vehicular impacts, the pins were designed to penetrate the asphalt concrete by 150 mm.

The test design consisted of placing and connecting sixteen segments of the Type 60K-v1,2 on an AC surface. The design did not allow for the segments to be pulled tight to take up slack in the pin-and loop connectors.

Design 3 – 60K-v3

The design for the 60K-v3 is shown in Figure 6-21 through Figure 25, located in the Appendix.

After looking at the crash testing results from the first two designs, a third design was developed. This design was longer, used a two-pin connection at each joint, and featured a tighter joint connection using steel plates instead of loops.

The 60k-v3 segments were increased in length to 4 meters, corresponding closely to the weight of a single segment of construction barrier currently used in California (a New Jersey profile precast barrier with 6096-mm segments, also known as K-rail (See Caltrans 1999 Standard Plan T3)).

The segments were designed with only one scupper. The elimination of the center support, standard on k-rail and incorporated in Designs 1 and 2, would help to minimize the chance that a segment could high-center on a section of pavement. This would also help to make the segments more resistant to rotation about their centers, increasing the barrier's rotational stiffness.

When placing the 60K-v3 barrier for testing, the segments were not pulled tight to take up slack in the pin-and loop connections. Additionally, there was no positive connection to the pavement.

2.1.3. Construction

2.1.4. 60K-v1

Eighteen of the 3.138-m long Type 60K-v1 segments were fabricated at a precast plant and shipped to the Caltrans Dynamic Test Facility. A concrete footing was placed according to design details at the end of this report. A hole was cut in the AC paving to allow for the placement of the 230-mm deep, 1010-mm wide PCC footing. Concrete and reinforcing steel were placed and steel sleeves were inserted at the proper intervals to allow the connecting pins to engage the footing.

Sixteen segments were used in the construction of the 60K-v1 barrier. The segments were placed on the footing after the concrete had cured for at least 28 days. The connecting pins used to join the individual segments were placed as the individual segments were positioned. The total length of the barrier was 50.2 m.

2.1.5. 60K-v2

The segments from the first version were interchangeable with the Type 60K-v2. Sixteen segments were placed on a 50-mm AC pad and joined together with one connecting pin at each joint. The tips of the connecting pins were then pounded through the AC until the bottoms of the pinheads were flush with the top loops of the 60K-v2 segments. The connecting pins used to join the individual segments were placed as the individual segments were positioned. The total length of the barrier was 50.2 m.

2.1.6. 60K-v3

Thirteen of the 4-m long 60K-v3 segments were fabricated at a precast plant and shipped to the Caltrans Dynamic Test Facility. The segments were placed on a 50-mm AC pad and joined together with two connecting pins at each joint. Due to the tight tolerance at the joints, connecting the Type 60K-v3 segments together did require a little more effort than connection of the Type 60K-v1 or v2 segments*. The connecting pins used to join the individual segments were placed as the segments were positioned. Twelve segments were used in the construction of the 60K-v3 test barrier. The total length of the barrier was 48.0 m.

2.1.7. Test Vehicles

The test vehicles complied with NCHRP Report 350 criteria. For all of the tests, the vehicles were in good condition, free of major body damage and were not missing structural parts. All of the vehicles had standard equipment and front-mounted engines (see Table 6-1 through Table 6-5). The vehicle inertial masses were within recommended limits (see Table 2-1).

Table 2-1 - Test Vehicle Information

Test No.	Vehicle	Ballast (kg)	Test Inertial (kg)
562	1990 Chevrolet 2500	0	1962
564	1988 Chevrolet 2500	0	2018
565	1996 Chevrolet 2500	0	2186
566	1993 Geo Metro	0	816.5
567	1994 Geo Metro	0	837

* Higher quality control during the manufacture of the segments and chamfering the tips on the pins could increase the speed and efficiency of placing the 60K-v3 segments.

The pickups were self-powered; A speed-control device limited acceleration once the impact speed had been reached. The small cars were connected by a steel cable to a tow vehicle and towed to impact speed. Remote braking was possible at any time during the test through a tetherline connected to the rear of each vehicle. The vehicles were steered by a guide arm connecting a front wheel to a guidance rail that was fixed to the ground. A short distance before the point of impact, each vehicle was released from the guidance rail and the ignition was turned off (for the Geo, the tow cable was released from the undercarriage). 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

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

The impact phase of each 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 with and one 35-mm sequence camera. The test vehicles 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 was assembled using edited portions of the film coverage.

Each test vehicle included two sets of orthogonal accelerometers mounted at the center of gravity. An additional set of orthogonal accelerometers was mounted 600 mm behind the center of gravity in the small car tests. 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.

An anthropomorphic dummy was used in 820-kg vehicle tests to obtain dummy motion data, but was not instrumented. The dummy, a Hybrid III built to conform to Federal Motor Vehicle Safety Standards by the Humanoid Systems Division, Humanetics, Inc., simulated a 50th percentile American male weighing 75 kg. The dummy was placed in the passenger's seat and was restrained with a lap and shoulder belt.

A digital transient data recorder (TDR), Pacific Instruments model 5600, was used to record electronic data during the tests. The digital data were analyzed using a desktop computer.

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 562

The vehicle impact speed and angle were 99.7 km/h and 25.8 degrees, respectively. Impact occurred 100 mm upstream of the joint 8-9 (i.e., the joint between segments 8 and 9). The front right corner of the pickup was crushed as it slid along segments 8 and 9, forcing the vehicle to align parallel to the barrier. There was moderate snagging on the leading edge of segment 9.

While in contact with segment 9, the pickup's front rose about 400 mm and the vehicle rolled to the right. The hood of the vehicle crossed over the top of the barrier, extending 300 mm beyond the face. At 0.25 seconds after impact, the vehicle was parallel to segment 9. As the vehicle approached segment 10, the upper face of segment 9 rotated 150 mm behind the upper face of segment 10. This allowed the vehicle to heavily snag the opening at joint 9-10.

As the vehicle reached the front of segment 11, it became parallel to the ground. The vehicle rose to a maximum height of 1.5 m between segments 11 and 12. When the vehicle made contact with the ground, it pitched forward and rolled slightly to the right. Contact with the ground occurred 0.75 seconds after impact when the vehicle was adjacent to segment 14. The impact redirected the vehicle, forcing its rear away from the barrier.

When the vehicle started tracking again, it was pointed back toward the barrier. However, because the barrier ended 25 m downstream of impact, the vehicle was directed behind the barrier.

2.2.2. Vehicle Damage - Test 562

Most of the damage to the vehicle was on the front half of the right side (Figure 2-1). 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 door was severely jammed and its sheet metal covering was ripped along its lower third (Figure 2-2).

The back half of the vehicle also received some damage. The portion of the bed separating the rear tire and the cab was crushed and rippled. The rear right tire was blown and the rim was bent. The wheel did not sustain any permanent longitudinal displacement.

The floor deformation at the center of the front passenger side of the vehicle was about 115 mm. At the firewall, the maximum floor deformation was 135 mm.

Figure 2-1 – Test 562. Overall damage to the vehicle

Figure 2-2 – Test 562. Damage to the vehicle door

2.2.3. Barrier Damage - Test 562

The barrier did not have any significant permanent deflection and appeared, at first glance, to be in good condition after the impact. After closer examination, however, it was noted that the backside of each of the segments that shifted was spalled along the bottom edge. The steel angle that lined the sides of the trough was littered with concrete that had been cut by the angle. The leading edges of two of the segments sustained minor spalling. Two of the connecting pins were bent enough that they had to be cut before the barrier could be disassembled.

Figure 2-3 shows the spalled concrete at the base of segment 8, one joint upstream of impact. The steel angle lining the sides of the trough acted to cut the barrier along the backside of the segments that were laterally deflected.

Figure 2-3 – Test 562. Segment 8 at Joint 7-8

Illustrating the snagging potential of the Type 60K-v1, Figure 2-4 shows the scuff marks on the end face of segment 10 where the vehicle penetrated the barrier face.

Figure 2-4 - Test 562. Segments 9 and 10

Figure 2-5 - Test 562 Data Summary Sheet

t = 0.000 t = 0.256 t = 0.511 t = 0.767

t = 1.022 t = 1.278 t = 1.534 t = 1.789

General Information:
- Test Agency ---------- California DOT
- Test Number --------- 562
- Test Date -------------- February 17, 1999

Test Article:
- Name ------------------- Type 60K-v1
- Installation Length--- 50.2 m
- Description------------ 16 segments of 60K barrier, on a concrete base pinned with 32–mm connecting pins

Test Vehicle:
- Model ------------------ 1990 Chevy 2500 PU
- Inertial Mass ---------- 1962.5 kg

Impact Conditions:
- Velocity --------------- 99.7 km/h
- Angle ------------------ 25.8°

Exit Conditions:
- Velocity --------------- **61** km/h
- Angle ------------------ **0** degrees

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

Vehicle Exterior:
- VDS[1] -------------------- RD-6, FR-5, RFQ-5
- CDC[2] -------------------- 02RYEW8

Vehicle Interior:
- O.C.D.I. ----------------- RF0011000

Barrier Damage: ----------- There was no damage to the concrete trough. Several of the segments spalled along the bottom edges.

Occupant Risk Values	*Longitudinal*	*Lateral*
Occupant Impact Velocity	5.0 m/s	6.6 m/s
Ridedown Acceleration	17.3 g	19.1 g

2.2.4. Impact Description - Test 564

The vehicle impact speed and angle were 99.2 km/h and 25 degrees respectively. The vehicle remained upright and relatively under control. The test was characterized by moderate lateral deflections with multiple snag points developing.

The impact occurred 1 meter upstream of the joint between segments 8 and 9. The upper face of segment 8 rotated back 100 mm before the front of the vehicle reached segment 9, causing the front right fender panel to snag on the leading edge of segment 9 and causing the front right tire to blow. As the vehicle continued to push on segment 9, the barrier moved laterally to the right. Joint 8-9 slid back 720 mm.

As the front of the vehicle approached segment 10, joint 9-10 started to open and the vehicle started to yaw to the left. When the front of the vehicle reached joint 9-10 the vehicle snagged a second time, penetrating the joint by 160 mm. As the front of the vehicle met joint 10-11, the rear of the vehicle slid into segment 9, forcing the yaw to stop.

When the rear of the vehicle reached joint 9-10, several events occurred. The back bumper and frame snagged the joint. The rear end kicked up and away from the barrier. The drive shaft pulled out of the transmission. The speed and angle of the vehicle as it lost contact with the barrier were about 73 km/h and 10 degrees, respectively.

The vehicle continued to yaw heavily to the right as it lost contact with the barrier. When the vehicle made full contact with the ground again, it was facing the barrier. The vehicle continued to yaw to the right until it had turned 180 degrees. The vehicle then rolled backward until coming to a stop.

The system used for the collection of onboard acceleration data failed during test 564.

2.2.5. Vehicle Damage - Test 564

Vehicle damage was extensive. The right front wheel, hub and spindle assemblies were sheared from the suspension. The right A-arm was bent back and twisted. The right side of the front bumper was pushed back approximately 510 mm (see Figure 2-6). The right front fender and inner fender were pushed in and back against the engine. The right frame rail was bent into the engine and the engine was tilted up on the right side. The radiator, transmission cooler, battery box and battery received extensive damage.

Transmission oil, coolant and battery acid leaked out of the vehicle. The right side of the hood received minor damage and the windshield was fractured on the right side. The right door was pushed back into its frame. The right door buckled outward approximately 140 mm, jamming the door closed and breaking the door glass.

The right rear of the vehicle also received extensive damage (see Figure 2-7). The right side of the bed was dented the full length and the whole bed was shifted to the left on the frame. The rear axle broke loose from the suspension, and was pushed back approximately 600 mm. The axle housing bent and the differential housing broke. Both of the right side tires were flat and ruptured with extensive damage to both wheels.

The left rear side of the vehicle received minor damage. The tailgate and left door were operational.

The passenger compartment received extensive damage, especially to the right side. The dash was pushed back 100 mm. The sheet metal in the floor was torn and the floor pan was buckled up and folded over in multiple places. The left side of the floor received minor rippling and bending. The floor deformation at the center of the front passenger side of the vehicle was about 100 mm, with about 65 mm at the firewall.

Figure 2-6 – Test 564. Damage to the front of the vehicle

Figure 2-7 – Test 564. Damage to the side of the vehicle

2.2.6. Barrier Damage - Test 564

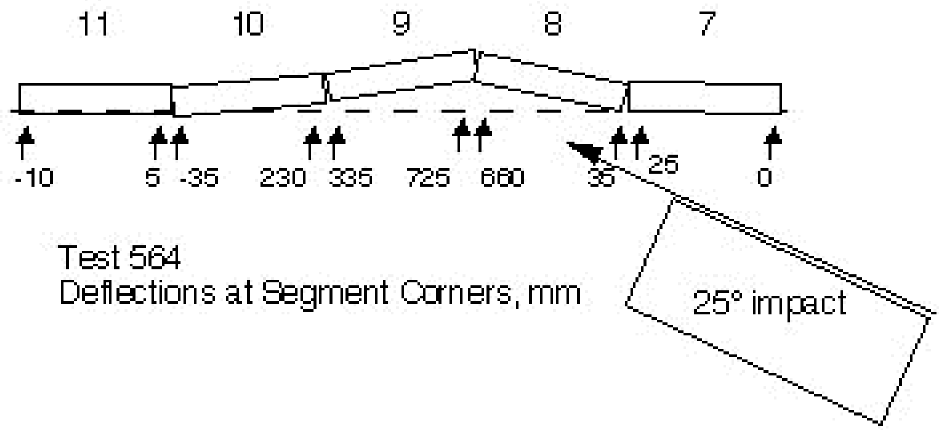


Figure 2-8 – Test 564. Barrier deflections

Damage to the barrier was limited to barrier deflection, two of the connection pins being pulled out of the pavement, and some minor concrete spalling. The maximum, permanent barrier deflection was 725 mm at the joint between segments 8 and 9 (see Figure 2-8). The barrier deflections led to the pins at joints 8-9 and 9-10 being pulled out of the pavement. Concrete spalling was limited to the leading edges of segments 8 and 10 where the vehicle snagged the barrier. All of the barrier segments were reusable.

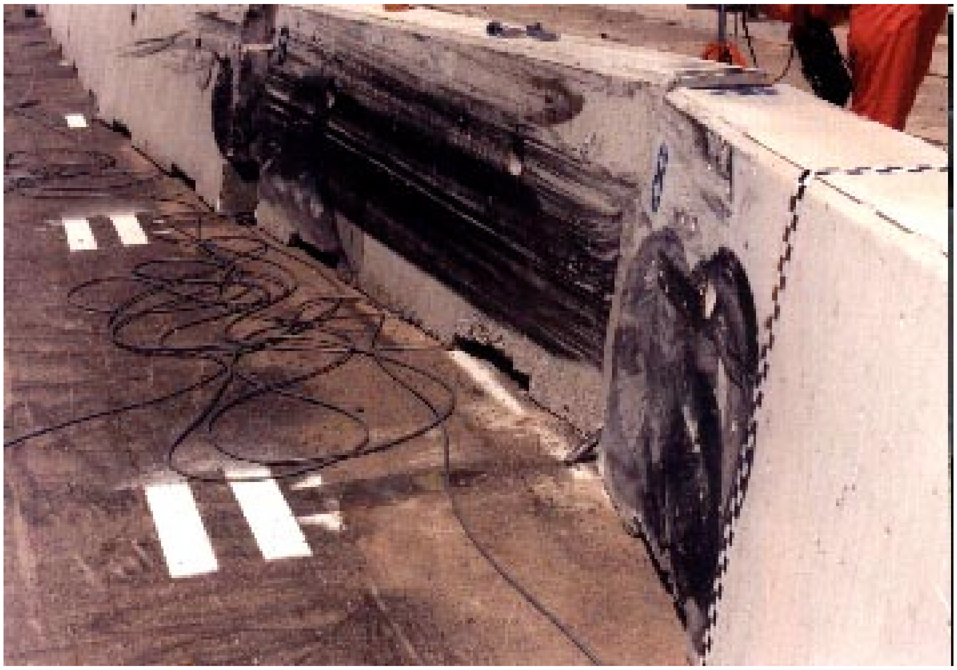


Figure 2-9 – Test 564. Deflection and tire marks

Figure 2-10 – Test 564. Snag at joint 9-10

Figure 2-11 - Test 564 Data Summary Sheet

t = 0.000 t = 0.395 t = 0.790 t = 1.185

t = 1.580 t = 1.975 t = 2.370 t = 2.765

General Information:
- Test Agency ---------- California DOT
- Test Number ---------- 564
- Test Date ---------- April 28, 1999

Test Article:
- Name ---------- 60k-v2
- Installation Length ---------- 50.2 m
- Description ---------- 16 segments of 60K barrier, pinned with 32–mm pins pounded 150 mm into the AC.

Test Vehicle:
- Model ---------- 1988 Chevy 2500 PU
- Inertial Mass ---------- 2018.0 kg

Impact Conditions:
- Velocity ---------- 99.2 km/h
- Angle ---------- 25°

Exit Conditions:
- Velocity ---------- 73 km/h
- Angle ---------- 10 degrees

Test Dummy:
- Type ---------- NA
- Weight / Restraint ---------- NA
- Position ---------- Front Right

Vehicle Exterior:
- VDS[1] ---------- FR-6, RD-6, RFQ-5
- CDC[2] ---------- 02RFEW8

Vehicle Interior:
- OCDI ---------- RF1012110

Barrier Damage: ---------- Minor concrete spalling, moderate lateral displacement, and bent connecting pins.

Occupant Risk Values	*Longitudinal*	*Lateral*
Occupant Impact Velocity	NA	NA
Ridedown Acceleration	NA	NA

2.2.7. Impact Description - Test 565

The vehicle impact speed and angle were 98.7 km/h and 25 degrees, respectively. The vehicle remained upright and stable. There were moderate lateral deflections of the barrier, with minimal snag points developing. The vehicle made contact with three barrier segments.

The impact occurred at joint 6-7. The barrier was pushed back 650 to 750 mm as the vehicle slid along the barrier face. As the front of the vehicle reached the midpoint of segment 7, the hood rode over the top of the barrier, extending 360 mm past the barrier face.

As the front of the vehicle reached the end of segment 7, the front wheels started to lift off the ground. The rear wheels lifted off the ground as the back end made contact with the center of segment 7. The rear right wheel separated from the vehicle as it made contact with the barrier. The vehicle rose to a maximum of 540 mm off the ground, but remained level.

The vehicle was completely redirected while in contact with segment 8. The maximum opening in the face at joint 7-8 did not exceed 25 mm. However, there was minimal spalling of segment 8 as the front of the vehicle reach joint 7-8. The front right tire made contact with the ground as the vehicle approached segment 10. The exit speed and angle were 80 km/h and 10 degrees, respectively.

2.2.8. Vehicle Damage - Test 565

Most of the damage to the vehicle was confined to the front right corner, with additional damage along the impacting side of the vehicle (see Figure 2-12 and Figure 2-13). The front right tire was torn, but still on the vehicle. The corner panel and the far right side of the bumper were crushed. The tie-rod was severely bent. The hood was partly raised, but still latched. There were scuff-marks along the rear right side of the vehicle. The right rear wheel separated at the seam, allowing the tire and rim to detach from the vehicle. The engine was still functional.

The occupant compartment sustained some minor crumpling on the right side floorboard measuring 25 mm at the center of the passenger side and 110 mm at the firewall. The right door was jammed closed. The windshield was not cracked.

Figure 2-12 – Test 565. Impacted corner of vehicle

Figure 2-13 – Test 565. Damage to the back right of the vehicle

2.2.9. Barrier Damage - Test 565

The barrier shifted a maximum of 750 mm at the impacted joint during impact.

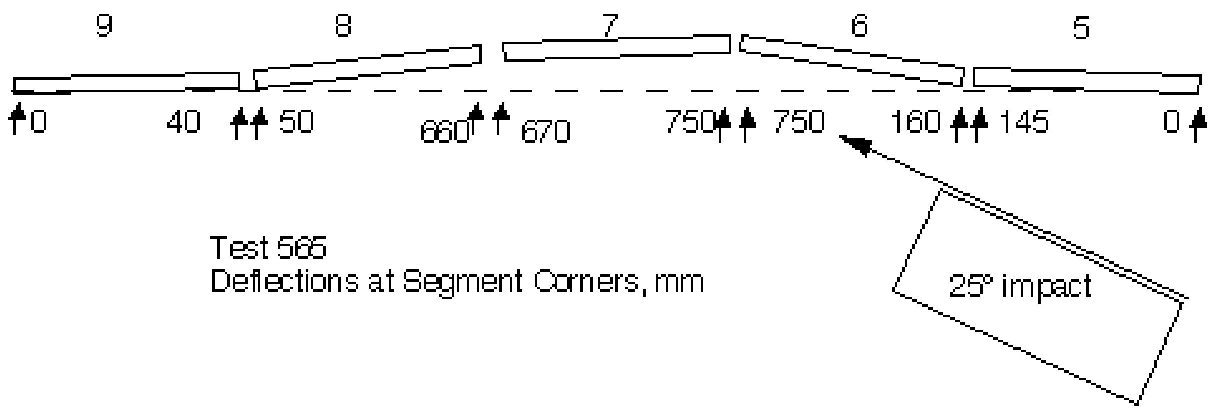


Figure 2-14 – Test 565. Barrier deflections

Damage to the barrier was limited to shifted segments, minor concrete spalling, bent connecting pins, and scuffing of the concrete face. Out of the 12 segments making up this barrier, only segments 1, 2, and 12 did not move. Segments 5,6,7,8, and 9 had measurable lateral deflections. The spalling concrete occurred at joint 6-7 where the concrete is the thinnest. The connecting pins nearest the impact were bent, six of which had to be cut. All of the barrier segments were reusable.

Figure 2-15 – Test 565. Lateral deflections

Figure 2-16 – Test 565. Tire marks

Figure 2-17 - Test 565 Data Summary Sheet

t = 0.000 t = 0.140 t = 0.280 t = 0.419

t = 0.559 t = 0.699 t = 0.839 t = 0.978

General Information:
- Test Agency: California DOT
- Test Number: 565
- Test Date: August 19, 2000

Test Article:
- Name: Type 60K-v3
- Installation Length: 48.0 m
- Description: twelve 4.00-m segments pinned together on AC

Test Vehicle:
- Model: 1996 Chevy 2500
- Inertial Mass: 2186 kg

Impact Conditions:
- Velocity: 98.7 km/h
- Angle: 25°

Exit Conditions:
- Velocity: **80** km/h
- Angle: **10** degrees

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

Vehicle Exterior:
- VDS[3]: FR-3, RF-2, RFQ-2
- CDC[4]: 02RFEW4

Vehicle Interior:
- O.C.D.I.: RF0010000

Barrier Damage: Minor concrete spalling, moderate lateral displacement, and bent connecting pins.

Occupant Risk Values	*Longitudinal*	*Lateral*
Occupant Impact Velocity	4.3 m/s	5.8 m/s
Ridedown Acceleration	-5.6 g	-12.2 g

2.2.10. Impact Description - Test 566

The vehicle impact speed and angle were 99.8 km/h and 18 degrees, receptively. Due to a problem with the guidance system, the vehicle was forced into a slight leftward turn. The leftward turn resulted in a smaller impact angle than was intended. The vehicle missed the impact point by 0.65 m, and induced a slight roll to the right just before impact. The vehicle remained upright and stable. The test consisted of low lateral barrier deflections and no snag points developing. The vehicle made contact with only one barrier segment.

Impact occurred 535 mm downstream of joint 7-8. The vehicle started to yaw to the left during the initial contact with the barrier. As the front of the vehicle approached segment 9, it lifted off the ground and the rear of the vehicle made contact with segment 8. The vehicle maintained sliding contact with segment 8 while the rear wheels lost contact with the ground. The vehicle leveled off at an altitude of 0.3 m as the front of the vehicle reached the midpoint of segment 9. At that point, it lost contact with the barrier completely.

The exit speed and angle were 96 km/h and 11 degrees, respectively. About 15 degrees of roll had occurred before the vehicle made contact with the pavement. The vehicle then tracked correctly until coming to a rest.

The maximum 10-ms lateral acceleration was -21.7g. This figure was inexplicably high, and didn't correlate with the vehicle damage (Section 2.2.11) or any observed impact phenomena. No instrumentation, data storage, or processing errors were discovered.

2.2.11. Vehicle Damage - Test 566

Most of the vehicle damage was limited to the front right corner of the vehicle. The corner panel was crushed and the hood had been buckled. The front right wheel was turned inward. The steering mechanism was damaged but the steering wheel could still turn the wheels. The tire was still inflated. The hubcap was missing from the front right wheel.

The rear right fender panel also received some minor damage. The flare on the rear wheel well was flattened and hubcap was scraped. The bumper also received some minor scraping. There was no visible structural damage to the rear of the vehicle.

There was no discernable floorboard deformation.

Figure 2-18 – Test 566. Vehicle damage to the impacted corner

2.2.12. Barrier Damage - Test 566

The barrier shifted a maximum of 100 mm during impact.

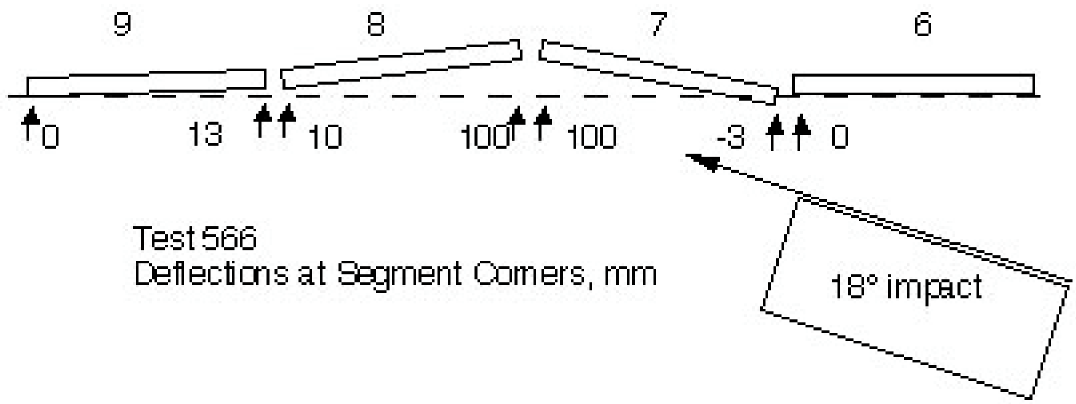


Figure 2-19 – Test 566. Barrier deflections

Impact occurred on segment 8, 535 mm downstream from joint 7-8. Damage was limited to scuffing on the face of segment 8 only. Although the connecting pins were slightly snug, they could be pulled out using a pry bar.

Figure 2-20 - Test 566 Data Summary Sheet

t = 0.000 | t = 0.177 | t = 0.355 | t = 0.532

t = 0.709 | t = 0.887 | t = 1.064 | t = 1.241

General Information:
- Test Agency ---------- California DOT
- Test Number ---------- 566
- Test Date ---------- August 2, 2000

Test Article:
- Name ---------- Type 60K-v3
- Installation Length ---------- 48.0 m
- Description ---------- twelve 4.00-m segments pinned together on AC

Test Vehicle:
- Model ---------- 1993 Geo Metro
- Inertial Mass ---------- 816.5 kg

Impact Conditions:
- Velocity ---------- 99.7 km/h
- Angle ---------- 18°

Exit Conditions:
- Velocity ---------- 96 km/h
- Angle ---------- 11 degrees

Test Dummy:
- Type ---------- Hybrid III
- Weight / Restraint ---------- 74.8 kg / belted
- Position ---------- Front Right

Vehicle Exterior:
- VDS[5] ---------- FR-4, RFQ-4, RD-3
- CDC[6] ---------- 02RFEW5

Vehicle Interior:
- O.C.D.I. ---------- RF0000000

Barrier Damage: ---------- There was minor latteral movement and scuffing.

Occupant Risk Values	*Longitudinal*	*Lateral*
Occupant Impact Velocity	2.94 m/s	5.77 m/s
Ridedown Acceleration	-2.18 g	-21.7 g

2.2.13. Impact Description - Test 567

Test 567 was conducted as a repeat of Test 566 because the impact angle in Test 566 was too low. Moreover, the lateral ridedown acceleration for Test 566 was unexplainably high.

The vehicle impact speed and angle were 101 km/h and 20 degrees respectively. The vehicle remained upright and stable. Lateral barrier deflections were moderate and no snagging was evident. The vehicle made contact with two barrier segments.

Impact occurred 100 mm upstream of joint 7-8. The initial impact forced the 7-8 joint back 100 mm. The vehicle was forced to the left, causing it to yaw until the rear of the vehicle came into contact with segment 8. The impacting rear end pushed the 7-8 joint back another 160 mm.

The vehicle slid along segment 8 and rose about 0.5 m. The maximum height was achieved 0.35 seconds after impact. The maximum roll of 25 degrees occurred at 0.5 seconds. The exit speed and angle were 91.4 km/h and 11 degrees, respectively. The vehicle tracked smoothly after impact until coming to rest. Lateral and longitudinal ridedown acceleration and occupant impact velocity were within NCHRP Report 350 limits.

2.2.14. Vehicle Damage - Test 567

The damage to the test vehicle was similar to the vehicle damage in test 566. Most of the damage was limited to the front right corner of the vehicle. The corner panel was crushed and the hood had a small dent. The right 300 mm of the front bumper was pushed back 150 mm into the wheel well. The front right wheel was turned inward more severely than in test 566 and the hubcap was lost. The steering mechanism was damaged but the steering wheel could still turn the wheels. The tire was still inflated.

The rear right fender panel also received some minor damage. The flare on the rear wheel well was flattened and hub cab was lost. The bumper also received some minor scraping. There was no visible structural damage to the rear of the vehicle.

As in Test 566, there was no discernable floorboard deformation.

Figure 2-21 - Test 567. Damage to the impacted corner of the vehicle

2.2.15. Barrier Damage - Test 567

The barrier shifted a maximum of 260 mm during impact.

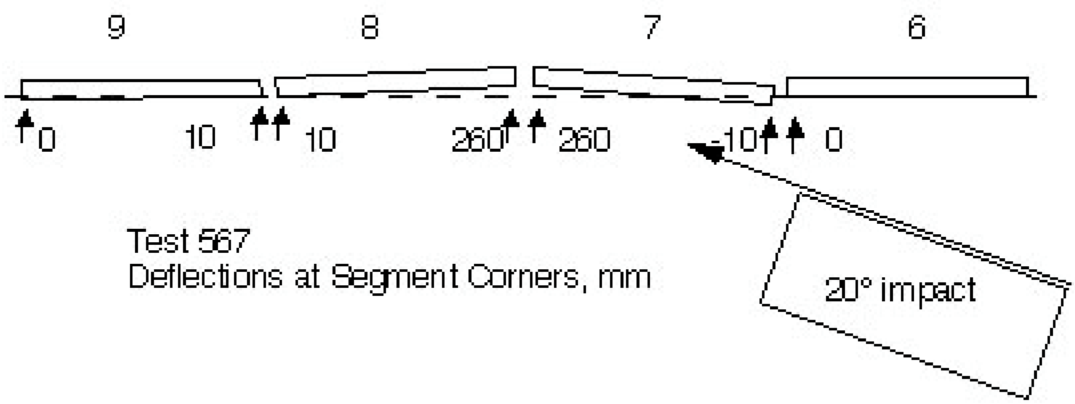


Figure 2-22 - Test 566. Barrier deflections

Impact occurred on segment 7, 100 mm upstream from joint 7-8. Segments 7 and 8 received some scuffing during contact with the test vehicle. Segment 8 received some minor spalling at its leading edge. As in Test 566, the connecting pins were slightly snug, but could be pulled out using a pry bar.

Figure 2-23 – Test 567. Scuffing and lateral deflection of barrier

Figure 2-24 - Test 567 Data Summary Sheet

t = 0.000 t = 0.0.180 t = 0.360 t = 0.540

t = 0.720 t = 900 t = 1.080 t = 1.260

General Information:
- Test Agency: California DOT
- Test Number: 567
- Test Date: October 24, 2000

Test Article:
- Name: Type 60K-v3
- Installation Length: 48.0 m
- Description: twelve 4.00-m segments pinned together on AC

Test Vehicle:
- Model: 1994 Geo Metro
- Inertial Mass: 837.0 kg

Impact Conditions:
- Velocity: 101.0 km/h
- Angle: 20°

Exit Conditions:
- Velocity: **91.4** km/h
- Angle: **11** degrees

Test Dummy:
- Type: Hybrid III
- Weight / Restraint: 74.8 kg / belted
- Position: Front Right

Vehicle Exterior:
- VDS[7]: RFQ-3, FR-2, RD-1
- CDC[8]: 02RFEW5

Vehicle Interior:
- O.C.D.I.: RF0001100

Barrier Damage: Some lateral movement and scuffing.

Occupant Risk Values	*Longitudinal*	*Lateral*
Occupant Impact Velocity	4.82 m/s	6.7 m/s
Ridedown Acceleration	-2.9 g	-15.4 g

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 the three barrier designs were evaluated in comparison with Tables 3.1 and 5.1 of NCHRP Report 350.

Structural Adequacy

60K-v1: The structural adequacy of the 60K-v1 was unacceptable. Test 562 showed that the pin and loop connections between the segments were so loose that impacted segments rotated back and exposed the leading ends of the downstream segments. The test vehicle subsequently snagged at the joints. During the time of contact between the test vehicle and the barrier there were minor amounts of scraping and spalling.

60K-v2: The structural adequacy of the 60K-v2 was also unacceptable. Test 564 showed that the differential rotation of the barrier segments and consequential vehicle snagging at the barrier joints was even more pronounced than in the test of 60K-v1. During the time of contact between the test vehicles and the barriers there were minor amounts of scraping and spalling.

60K-v3: The structural adequacy of the 60K-v3 was acceptable. There was no significant differential rotation between segments due to the much more secure segment connections. The lateral movement of the rail during these tests was acceptable. During the time of contact between the test vehicles and the barriers there were minor amounts of scraping and spalling.

A detailed assessment summary of structural adequacy is shown in Table 2-2 through Table 2-6.

Occupant Risk

60K-v1: The occupant risk of the 60K-v1 was problematic. Although the occupant compartment of test vehicle 562 did not experience major deformation or intrusion, the high degree vehicle of climb and pitch could have contributed to a rollover.

60K-v2: The occupant risk of the 60K-v2 was unacceptable. As in the testing for the 60K-v1, the occupant compartment did not sustain any major deformation. However, the severe snagging of the front right wheel imposed significant risk to the occupants.

60K-v3: The occupant risk of the 60K-v3 was acceptable. In each of the tests there were no signs of snagging or pocketing with the barrier. There were no signs of spalling concrete penetrating the occupant compartment of the vehicles. All of the calculated occupant ridedown accelerations and occupant velocities were well within limits (with the exception of test 566, which was repeated due to questionable readings from the accelerometers).

Please refer to Table 2-2 through Table 2-6 for a detailed assessment summary of occupant risk.

Vehicle Trajectory

60K-v1: Post-impact trajectory for the first design was acceptable. The exit angle was near zero degrees for the only test conducted. The vehicle demonstrated a clear redirection back into the barrier.

60K-v2: Post-impact trajectory for the second design was not acceptable. Though the exit angle was only 10 degrees for the single test, it should be understood that the snagging caused the rear of the vehicle to rise up and push out into the traffic. This imparted high degrees of yaw to the vehicle forcing it into an uncontrolled trajectory backward and into traffic.

60K-v3: Post-impact trajectory for the third design was acceptable. The three tests conducted on the barrier demonstrated that the barrier redirects impacting vehicles smoothly away from the barrier. Each of the vehicles remained stable and upright as they exited the impact zone.

The detailed assessment summaries of the vehicle trajectories may be seen in Table 2-2 through Table 2-6.

Table 2-2 - Test 562 Assessment Summary

Test No. 562
Date March 17, 1999
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 contained and redirected. However, excessive snagging was a problem due to the 150-mm lateral opening created as the top of the barrier segments rotated back.	marginal
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 were no penetrations into the passenger compartment. Deformation was within Report 350 guidelines. The maximum floorboard deformation was 135 mm	pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle remained upright and stable throughout the test. However, the pitch and the yaw of the vehicle were high.	marginal
Vehicle Trajectory		
K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	After impact the vehicle was redirected back into the barrier	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. = 5.01 m/s Long. Occ. Ridedown = 17.3 *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 0 degrees, or 0% of impact angle	pass

Table 2-3 - Test 564 Assessment Summary

Test No. 564
Date April 28, 1999
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 contained and redirected. However, severe multiple snag points developed during impact, causing extensive damage to the vehicle.	Fail
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 were no penetrations into the passenger compartment. Deformation was well within Report 350 guidelines. The maximum Floorboard deformation was 100 mm.	pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle remained upright but experienced a high degree of yaw after losing contact with the barrier.	marginal
Vehicle Trajectory		
K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	The vehicle redirected back into the barrier.	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*.	Due to failure of the data onboard acquisition system, neither the occupant impact velocity nor the ridedown could be calculated.	----
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 10 degrees, or 40% of impact angle	pass

Table 2-4 - Test 565 Assessment Summary

Test No. 565
Date July 19, 2000
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 contained and 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 were no penetrations into the passenger compartment. Deformation was well within Report 350 guidelines.	pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	The vehicle remained upright and stable throughout the test.	pass
Vehicle Trajectory		
K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	The vehicle maintained a relatively straight course after exiting the barrier.	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. = 4.3 m/s Long. Occ. Ridedown = -5.6*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 10 degrees, or 40% of impact angle	pass

Table 2-5 - Test 566 Assessment Summary

Test No. 566
Date August 2, 2000
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 contained and 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.	Only minimal amounts of scuffing were created during impact. There was no significant debris from the vehicle.	pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable	The maximum roll, pitch and yaw were 29.46, -15.26, and –27.19°, respectively. These are all acceptable.	pass
H. Occupant impact velocities (see Appendix A, Section A5.3 for calculation procedure) should satisfy the following: Occupant Impact Velocity Limits (m/s) Component / Preferred / Maximum Longitudinal and lateral / 9 / 12	Occupant impact velocities were within acceptable range. Long. Occ. Impact Vel. = 2.94 m/s Lat. Occ. Impact Vel. = 5.77 m/s	pass
I. Occupant Ridedown Accelerations (see Appendix A, Section A5.3 for calculation procedure) should satisfy the following: Occupant Ridedown Acceleration Limits (*g*) Component / Preferred / Maximum Longitudinal and lateral / 15 / 20	Long. Ridedown Acc. = -2.18 *g* Lat. Ridedown Acc. = -21.7 *g*	fail
Vehicle Trajectory		
K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes	The vehicle maintained a relatively straight course after exiting the barrier.	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 11 degrees, or 55% of impact angle	pass

Table 2-6 - Test 567 Assessment Summary

Test No. 567
Date October 24, 2000
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 contained and 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.	Only moderate amounts of spalling were created during impact. There was no significant debris from the vehicle. There was no discernable floorboard deformation.	pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable	The maximum roll, pitch and yaw were 26.5, -5.25, and –24.85°, respectively. These are all acceptable.	pass
H. Occupant impact velocities (see Appendix A, Section A5.3 for calculation procedure) should satisfy the following: Occupant Impact Velocity Limits (m/s) Component / Preferred / Maximum Longitudinal and lateral / 9 / 12	Occupant impact velocities were within preferred range. Long. Occ. Impact Vel. = 4.82 m/s Lat. Occ. Impact Vel. = 6.7 m/s	pass
I. Occupant Ridedown Accelerations (see Appendix A, Section A5.3 for calculation procedure) should satisfy the following: Occupant Ridedown Acceleration Limits (*g*) Component / Preferred / Maximum Longitudinal and lateral / 15 / 20	Long. Ridedown Acc. = -2.9 *g* Lat. Ridedown Acc. = -15.4 *g*	pass
Vehicle Trajectory		
K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes	The vehicle maintained a relatively straight course after exiting the barrier.	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 11 degrees, or 55% of impact angle	pass

Table 2-7 - 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]
562	25.8	15.5	21	99.7	61	38.7
564	25.0	15.0	10	99.2	73	26.2
565	25.0	15.0	10	98.7	80	18.7
566	18.0	10.8	11	99.7	96	3.7
567	20.0	12.0	11	101.0	91	10.0

3. CONCLUSION

Based on the testing of the various versions of the Type 60K barrier, the following conclusions can be drawn:

1) The snagging potential of the barrier made the Type 60K-v1 highly undesirable as a moveable median barrier. In Test 562 the barrier opened at the joints, producing a high potential for snagging.

2) Although the vehicle in Test 564 remained upright during the test, serious snagging made the Type 60K-v2 unacceptable as a temporary barrier.

3) The Type 60K-v3 barrier can successfully contain and redirect a 2000-kg pickup truck impacting at 25° and 100 km/h. The occupant impact velocity and ridedown acceleration were within acceptable limits of NCHRP Report 350. The maximum lateral deflection of the barrier did not exceed 0.75 m. The floorboard deformation was 25 mm at the center of the vehicle. This deformation was judged too small to cause serious injury to the occupants in the vehicle.

4) The Type 60K-v3 barrier can smoothly and successfully redirect an 820-kg car impacting at 20° and 100 km/h. Barrier deflections were low (approximately 260 mm). The vehicle sustained very low longitudinal ridedown accelerations and only moderate lateral ridedown accelerations.

5) The Type 60K-v3 barrier meets the criteria set in the National Cooperative Highway Research Program's Report 350 "Recommendations for the Safety Performance Evaluation of Highway Safety Features" under Test Level 3 for longitudinal barriers.

4. RECOMMENDATIONS

1) Neither the 60k-v1 nor the 60k-v2 should be considered for use on the state highway system.

2) The type 60k-v3 is recommended for use as a semi-permanent barrier on the state highway system.

5. IMPLEMENTATION

The Traffic Operations Program, in cooperation with the Engineering Service Center, will be responsible for the preparation of standard plans and specifications for the 60K-v3, with technical support from Materials Engineering and Testing Services and the Office of Structures Construction.

6. APPENDIX

6.1. Test Vehicle 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. For tests involving the pickup trucks, a 12-L safety gas tank was installed and connected to the fuel supply line. In order to purge the gasoline and oxygen vapors from the fuel tank, gaseous CO_2 was pumped in. For Tests involving the small cars, a 12-L safety tank was not installed because the vehicle was towed to impact instead of self-powered.

One pair of 12-volt, wet cell, motorcycle storage batteries was mounted in the vehicle. The batteries operated the solenoid-valve braking/accelerator system, rate gyros and an electronic control box. A second 12-volt, deep cycle, gel cell battery powered the transient data recorder.

The remote brakes were controlled at a console trailer. A cable ran from the console trailer to an electronic instrumentation van. From there, the remote brake signal was carried on one channel of a multi-channel tether line that was connected to the test vehicle. Any loss of continuity in these cables would have activated the brakes automatically. Also, if the brakes were applied by remote control from the console trailer, removing power to the coil would automatically cut the ignition for the self-powered vehicle. 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, which 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.

For tests involving a small car, the speed of the test vehicle was regulated by the speed of a tow vehicle. The tow vehicle pulled a tow cable through a series of sheaves arranged to produce a 2:1 mechanical advantage. Vehicle speed control was attained by the use of an ignition cutout on the tow vehicle that had been configured for the correct speed.

For tests involving a pickup truck, an accelerator switch was located on the rear of the truck bed. Activating 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 as the remote braking system with a valve to adjust CO_2 flow rate. A speed control device, connected in-line with the ignition module signal to the coil, was used to regulate the speed of the test vehicle based on the signal from the vehicle transmission speed sensor. This device was calibrated prior to the test 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 truck passed over it. The switch opened the ignition circuit and shut off the vehicle's engine prior to impact.

Table 6-1 - Test 562 Vehicle Dimensions

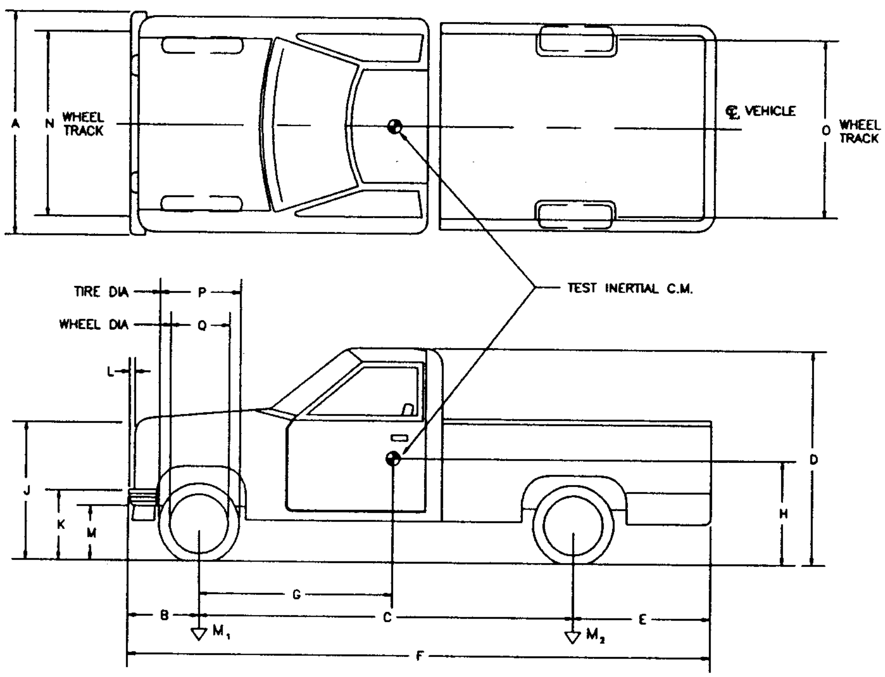
DATE: 3/17/99 **TEST NO:** 562 **VIN NO:** 1GCFC24H71Z256679 **MAKE:** Chevy

MODEL: 2500 Pick-Up **YEAR:** 1990 **ODOMETER:** 86139 (MI) **TIRE SIZE:** LT255/75R16

TIRE INFLATION PRESSURE: 60 (PSI)

MASS DISTRIBUTION (kg) **LF** 545.0 **RF** 536.0 **LR** 450.5 **RR** 429.5

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST: Right door, lower rear corner has a shallow dent. The right side of the bed has a long shallow dent in front of the rear wheel.



ENGINE TYPE: Gas V8

ENGINE CID: 350

TRANSMISSION TYPE:

X **AUTO**

___ **MANUAL**

OPTIONAL EQUIPMENT:

AC

DUMMY DATA:

TYPE: NA

MASS: NA

SEAT POSITION: NA

GEOMETRY (cm)

A	192.5	**D**	179.2	**G**	152.7	**K**	60.7	**N**	157.5	**Q**	44.4
B	92.1	**E**	135.5	**H**	na	**L**	8.0	**O**	162.0		
C	334.5	**F**	553.7	**J**	102.5	**M**	39.1	**P**	75.0		

MASS - (kg)	**CURB**	**TEST INERTIAL**	**GROSS STATIC**
M1	1084.5	1081.0	1081.0
M2	865.5	880.0	880.0
MT	1949.5	1962.0	1962.0

Table 6-2 - Test 564 Vehicle Dimensions

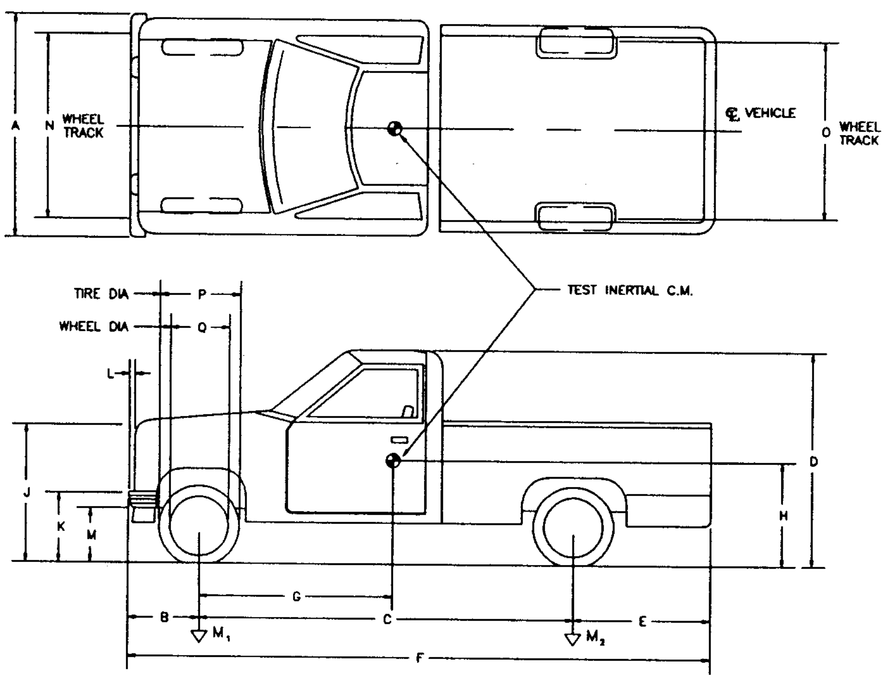
DATE: 4/28/99 **TEST NO:** 564 **VIN NO:** 2GCFC24KOJ1134229 **MAKE:** CHEVY

MODEL: 2500 Pick-Up **YEAR:** 1988 **ODOMETER:** 61048 (MI) **TIRE SIZE:** LT225/75R16

TIRE INFLATION PRESSURE: 60 (PSI)

MASS DISTRIBUTION (kg) **LF** 580 **RF** 559.5 **LR** 442.5 **RR** 436.0

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST: NONE



ENGINE TYPE: Gas V8

ENGINE CID: 350

TRANSMISSION TYPE :

X **AUTO**

____ **MANUAL**

OPTIONAL EQUIPMENT:

AC

Trailer hitch

DUMMY DATA:

TYPE: NA

MASS: NA

SEAT POSITION: NA

GEOMETRY (cm)

A	192.0	**D**	178.5	**G**	150.7	**K**	61.0	**N**	157.0	**Q**	44.5
B	90.0	**E**	131.0	**H**	na	**L**	9.5	**O**	161.5		
C	336.0	**F**	554.1	**J**	102.5	**M**	39.0	**P**	74.0		

MASS - (kg)	CURB	TEST INERTIAL	GROSS STATIC
M1	1138.0	1139.5	1139.5
M2	849.5	878.5	878.5
MT	1987.5	2018.0	2018.0

Table 6-3 - Test 565 Vehicle Dimensions

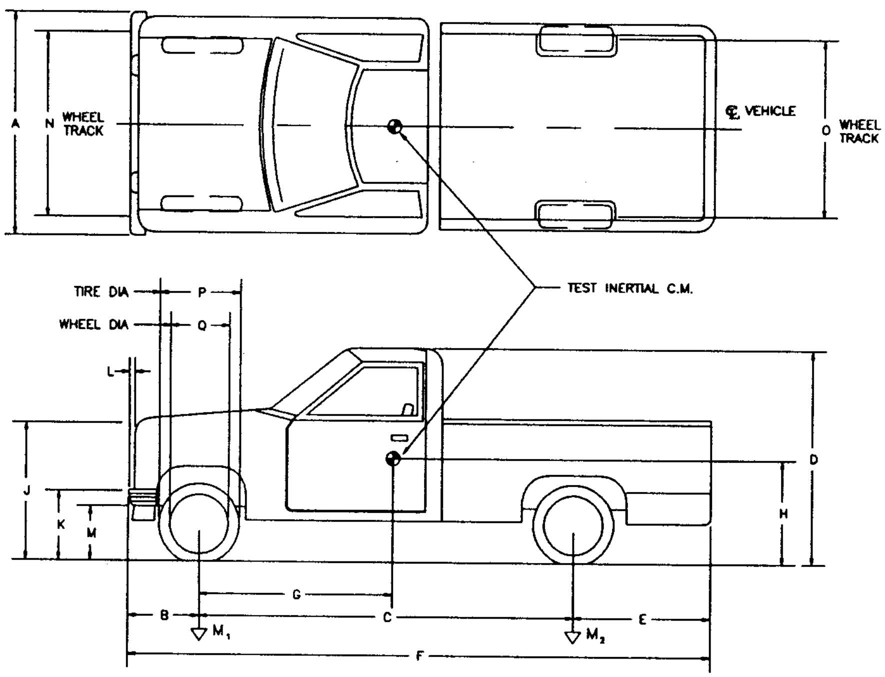
DATE: 7/19/00 **TEST NO:** 565 **VIN NO:** 1GCGC24R2VE148137 **MAKE:** CHEVY

MODEL: 2500 Pick-Up **YEAR:** 1996 **ODOMETER:** 124920 (MI) **TIRE SIZE:** LT245/75R16

TIRE INFLATION PRESSURE: 45 (PSI)

MASS DISTRIBUTION (kg) **LF** 604.0 **RF** 608.0 **LR** 467.0 **RR** 454.0

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST: The front wall of the bed was pushed forward at he top by 25 mm. The right rear stake pocket was dented at the top of the bed.



ENGINE TYPE: V8

ENGINE CID: 350

TRANSMISSION TYPE :

X AUTO

___ MANUAL

OPTIONAL EQUIPMENT:

AC

Receiver hitch

DUMMY DATA:

TYPE: NA

MASS: NA

SEAT POSITION: NA

GEOMETRY (cm)

A 198.0	D 183.5	G 144.6	K 65.4	N 160.0	Q 45.1
B 89.0	E 130.0	H na	L 9.3	O 163.0	
C 335.0	F 554.5	J 109.4	M 37.1	P 73.3	

MASS - (kg)	CURB	TEST INERTIAL	GROSS STATIC
M1	1212.0	1221.0	1221.0
M2	980.0	965.0	965.0
MT	2192.0	2186.0	2186.0

Table 6-4 - Test 566 Vehicle Dimensions

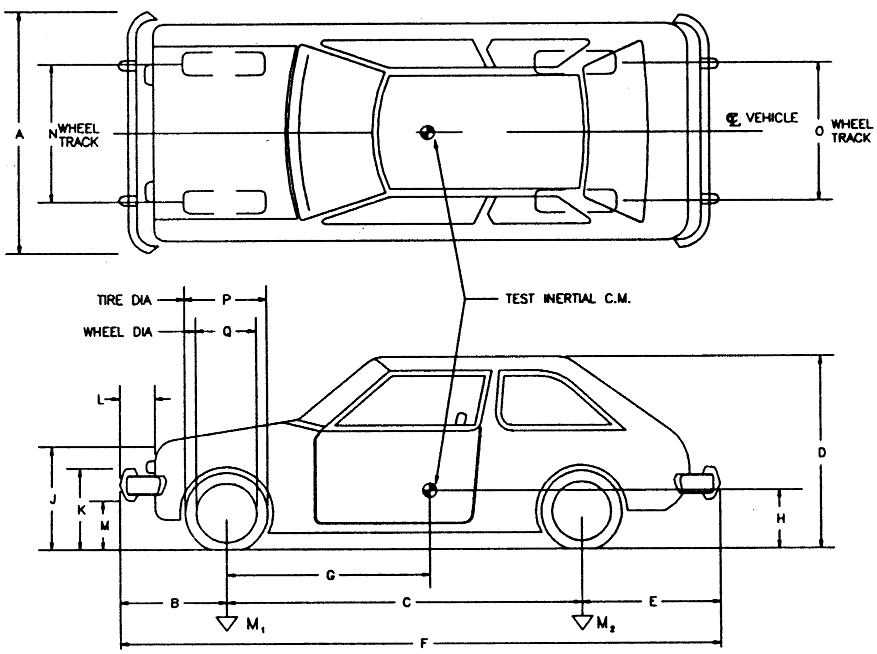
DATE: 8/2/00 **TEST NO:** 566 **VIN NO:** 2C1MR6465R6703457 **MAKE:** GEO

MODEL: METRO 5-DR **YEAR:** 1993 **ODOMETER:** 84580 (MI) **TIRE SIZE:** P145/80R12

TIRE INFLATION PRESSURE: 40 (PSI)

MASS DISTRIBUTION (kg) **LF** 238.5 **RF** 213.5 **LR** 186.0 **RR** 178.5

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST: NONE



ENGINE TYPE: IN-LINE 3 CYL.

ENGINE CID: 1.0 LITER

TRANSMISSION TYPE:

____ **AUTO**

X **MANUAL**

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: HYBRID III 50th %

MASS: 75 KG

SEAT POSITION: RIGHT FRONT

GEOMETRY (cm)

A	157.5	**D**	135.3	**G**	105.6	**K**	54.0	**N**	134.3	**Q**	34.0
B	80.1	**E**	70.2	**H**	NA	**L**	9.2	**O**	133.8		
C	236.5	**F**	385.5	**J**	69.8	**M**	21.6	**P**	50.7		

MASS - (kg)	CURB	TEST INERTIAL	GROSS STATIC
M1	446	452.0	494
M2	315	364.5	398
MT	761	816.5	892

Table 6-5 - Test 567 Vehicle Dimensions

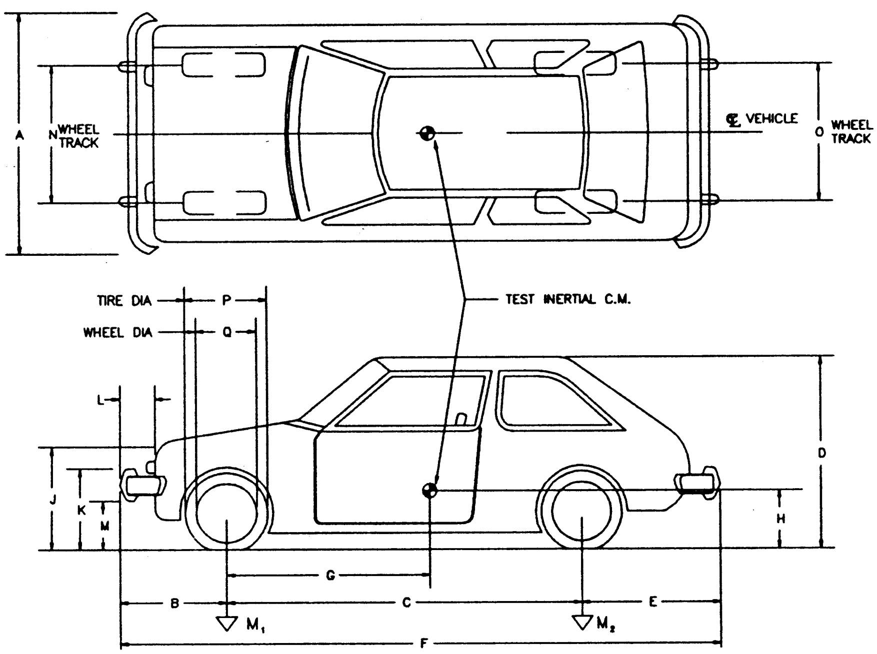
DATE: 10/4/00 **TEST NO:** 567 **VIN NO:** 2C1MR2468R6757246 **MAKE:** GEO

MODEL: METRO 3-DR **YEAR:** 1994 **ODOMETER:** 112084 (MI) **TIRE SIZE:** 155/80R12

TIRE INFLATION PRESSURE: 35 (PSI)

MASS DISTRIBUTION (kg) **LF** 254.5 **RF** 239.5 **LR** 180.5 **RR** 162.5

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST: NONE



ENGINE TYPE: IN-LINE 3 CYL.

ENGINE CID: 1.0 LITER

TRANSMISSION TYPE:

X AUTO

____ MANUAL

OPTIONAL EQUIPMENT:

Air conditioning

DUMMY DATA:

TYPE: HYBRID III 50th %

MASS: 75 KG

SEAT POSITION: RIGHT FRONT

GEOMETRY (cm)

A	158.5	D	133.5	G	93.2	K	52.7	N	134.6	Q	35.0
B	78.0	E	72.4	H	NA	L	9.0	O	134.0		
C	227.5	F	372.0	J	69.4	M	22.0	P	53.3		

MASS - (kg)	CURB	TEST INERTIAL	GROSS STATIC
M1	487.5	494.0	529.0
M2	282.0	343.0	383.0
MT	770.0	837.0	912.0

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, which was attached to the front left wheel of each of the test vehicles. A plate and lever were 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 tests. The types of cameras and their locations are shown in

Figure 6-1 and Table 6-6. All of these cameras were mounted on tripods except the three that were mounted on a 10.7-m tower and placed directly over the intended impact point of the test barrier.

A video camera and a 16-mm film camera were turned on by hand and used for panning during the test. Switches on a console trailer near the impact area remotely triggered all other cameras. Both the vehicle and barrier were photographed before and after impact with a normal-speed 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.

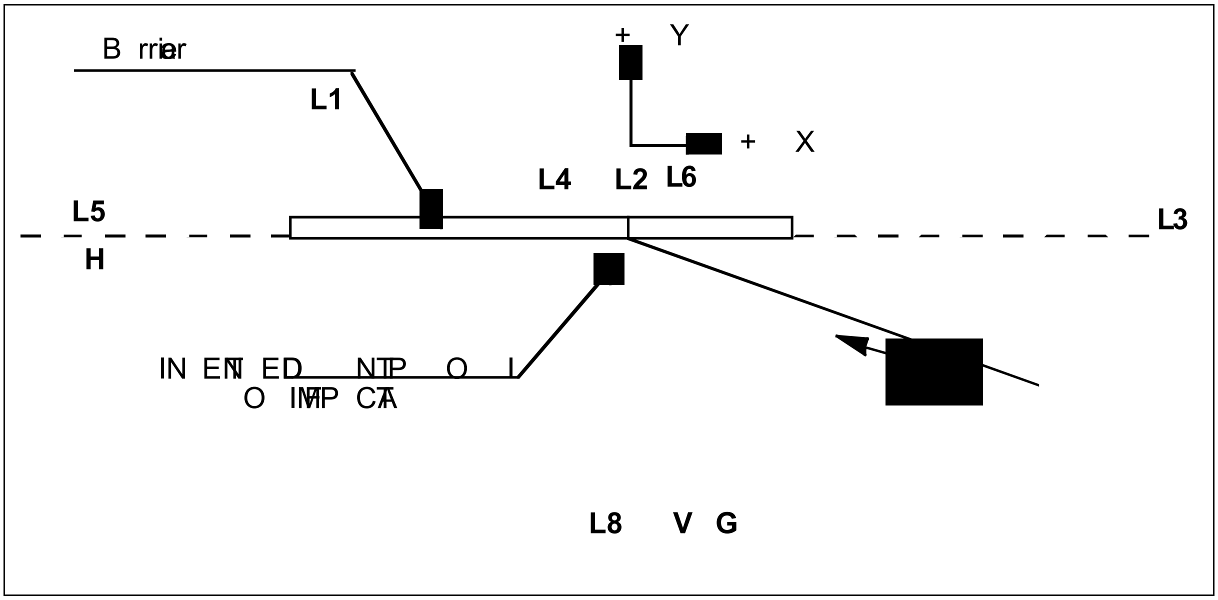


Figure 6-1 - Camera Locations

Typical Coordinates, m						
Camera Label	Film Size (mm)	Camera Type	Rate: (fr./sec.)	Typical Test X*	Y*	Z*
L1	16	LOCAM 1	400	-29.4 m	+9.7 m	1.5 m
L2	16	LOCAM 2	400	0	0	12 m
L3	16	LOCAM 3	400	+33.1 m	+.42 m	1.5 m
L4	16	LOCAM 4	400	-.6 m	0	12 m
L5	16	LOCAM 5	400	-76.2 m	-.7 m	3.5 m
L6	16	LOCAM 6	400	0	+.6 m	12 m
L8	16	LOCAM 8	400	+.1 m	-15.1 m	1.5 m
G	16	GISMO	64	-7.6 m	-17.2 m	6 m
V	1.27	SONY BETACAM	30	-3.0 m	-12.7 m	1.5 m
H	35	HULCHER	40	-75.5 m	-2.5 m	3.5 m

Note: Camera location measurements were surveyed after each test. For each test in this series the cameras were placed in nearly identical locations allowing the average location to be recorded in this table.
*X, Y and Z distances are relative to the impact point.

Table 6-6 – Typical Camera Type and Locations

The following are the pretest procedures that were required to enable film data reduction to be performed using a 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 305, 610 and 1219 mm (1, 2 and 4 feet.). The targets

established scale factors and horizontal and vertical alignment. The test barrier segments were targeted with stenciled numbers on each.

2) Flashbulbs, mounted on the test vehicle, were electronically triggered to establish 1) initial vehicle-to-barrier contact, and 2) the time of application for 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. Flash bulbs were activated sequentially when the tires of the test vehicle rolled over the tape switches. The flashbulb stand was placed in view of most of the cameras. The flashing bulbs were used to correlate the cameras with the impact events and to calculate the impact speed independently of the electronic speed trap. The tape switch layout is shown in Figure 6-2.

4) High-speed cameras had timing light generators which exposed red timing pips on the film at a rate of 100 per second. The pips were used to determine camera frame rates.

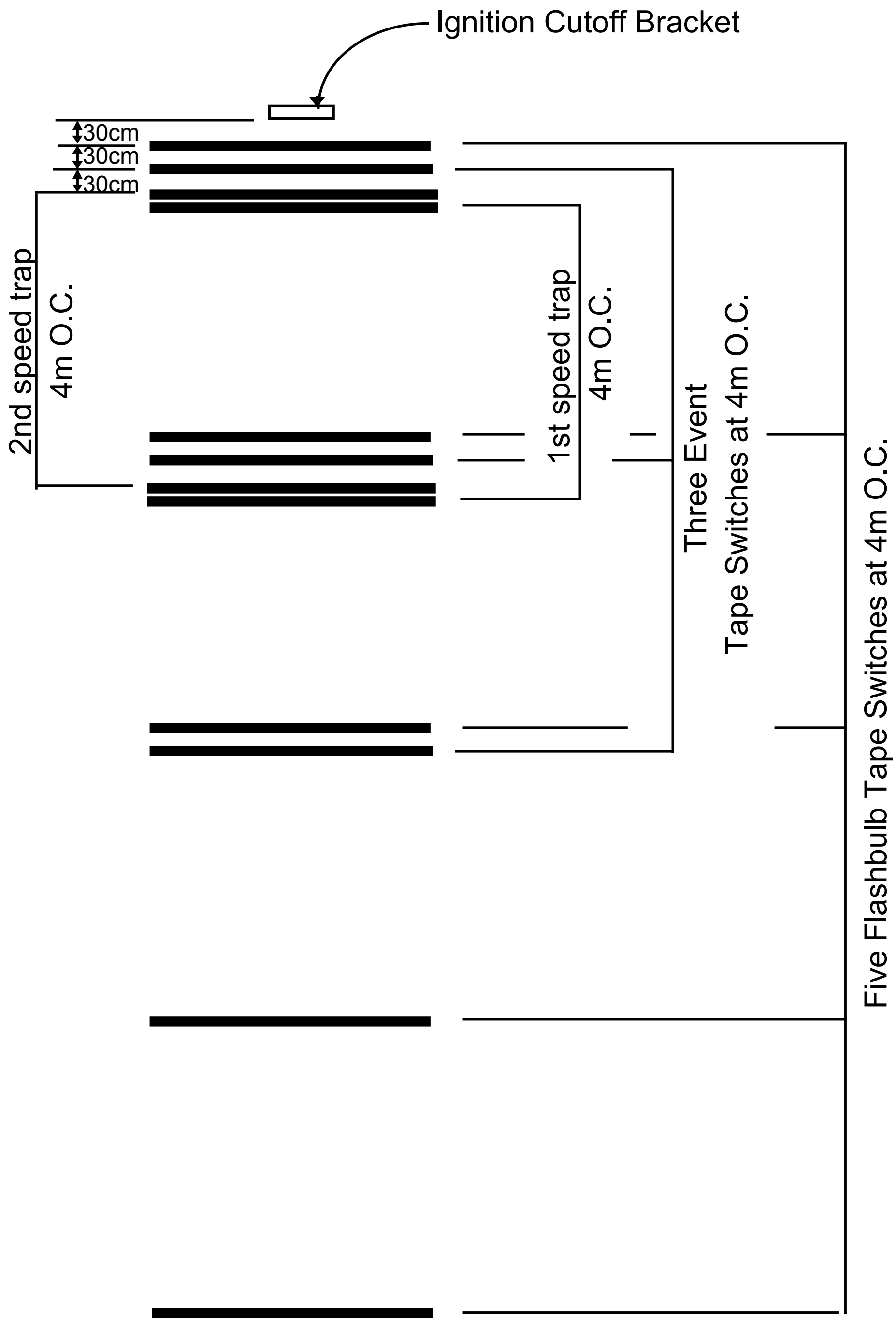


Figure 6-2 - Tape Switch Layout

6.3.1. Electronic Instrumentation and Data

Transducer data were recorded on a Pacific Instruments digital transient data recorder (TDR) model 5600, which was mounted in the vehicle. The transducers mounted on the test vehicles included two sets of accelerometers and one set of rate gyros at the center of gravity. The TDR data were reduced using a desktop computer.

Three pressure-activated tape switches were placed on the ground in front of the test barrier. They were spaced at carefully measured intervals of 4 m. When the test vehicle tires passed over them, the switches produced sequential impulses or "event blips" which were recorded concurrently with the accelerometer signals on the TDR, serving as "event markers". A 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 flash bulb mounted on the top of the vehicle was activated. The impact velocity of the vehicle could be determined from the tape switch impulses and timing cycles. Two other 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 vehicles. The tape switch layout for all tape switches is shown in Figure 6-2.

The data plots are shown in Figure 6-4 through Figure 6-19 and include the accelerometer and rate gyro records from the test vehicles. They also show the longitudinal velocity and displacement versus time. 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.

Table 6-7 - Accelerometer Specifications

TYPE	LOCATION	RANGE	ORIENTATION	TEST NUMBER
ENDEVCO	VEHICLE C.G.	100 G	LONGITUDINAL	551, 552
ENDEVCO	VEHICLE C.G.	100 G	LATERAL	551, 552
ENDEVCO	VEHICLE C.G.	100 G	VERTICAL	551, 552
HUMPHREY	VEHICLE C.G.	180 DEG/SEC	ROLL	551, 552
HUMPHREY	VEHICLE C.G.	90 DEG/SEC	PITCH	551, 552
HUMPHREY	VEHICLE C.G.	180 DEG/SEC	YAW	551, 552
ENDEVCO	VEHICLE C.G.	100 G	LONGITUDINAL	551, 552
ENDEVCO	VEHICLE C.G.	100 G	LATERAL	551, 552
ENDEVCO	VEHICLE C.G.	100 G	VERTICAL	551, 552

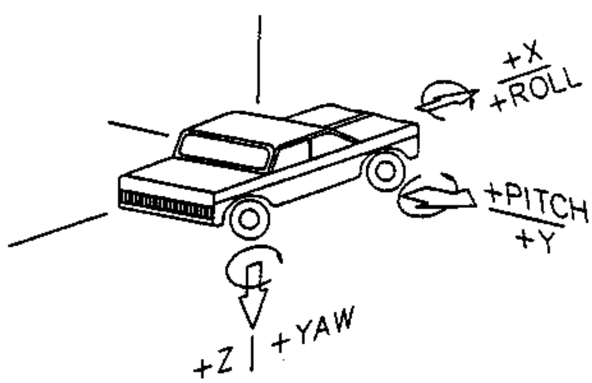


Figure 6-3 - Vehicle Accelerometer Sign Convention

Figure 6-4 - Test 562 Vehicle Longitudinal Acceleration, Velocity and Distance -Vs- Time

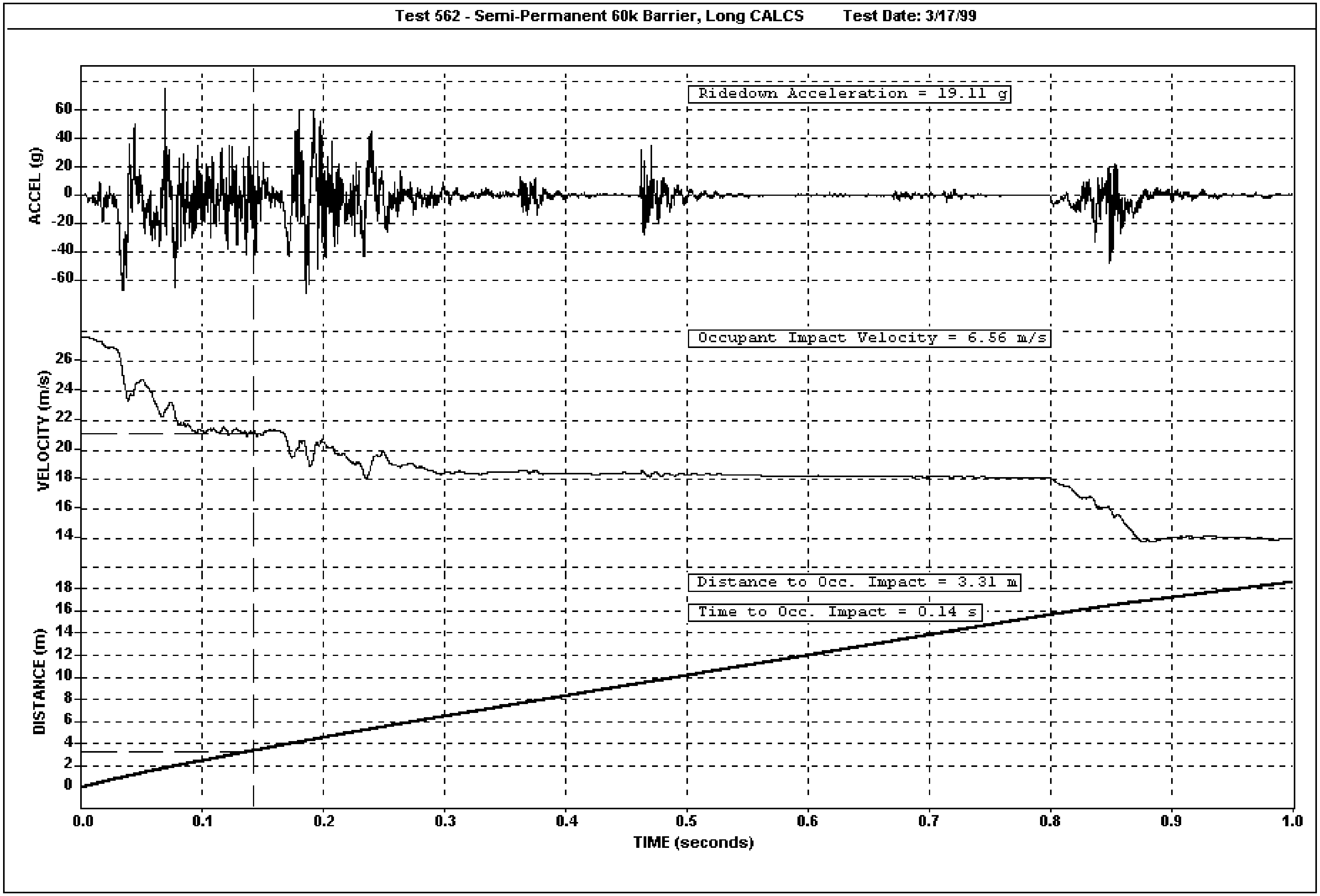


Figure 6-5 - Test 562 Vehicle Lateral Acceleration, Velocity and Distance -Vs- Time

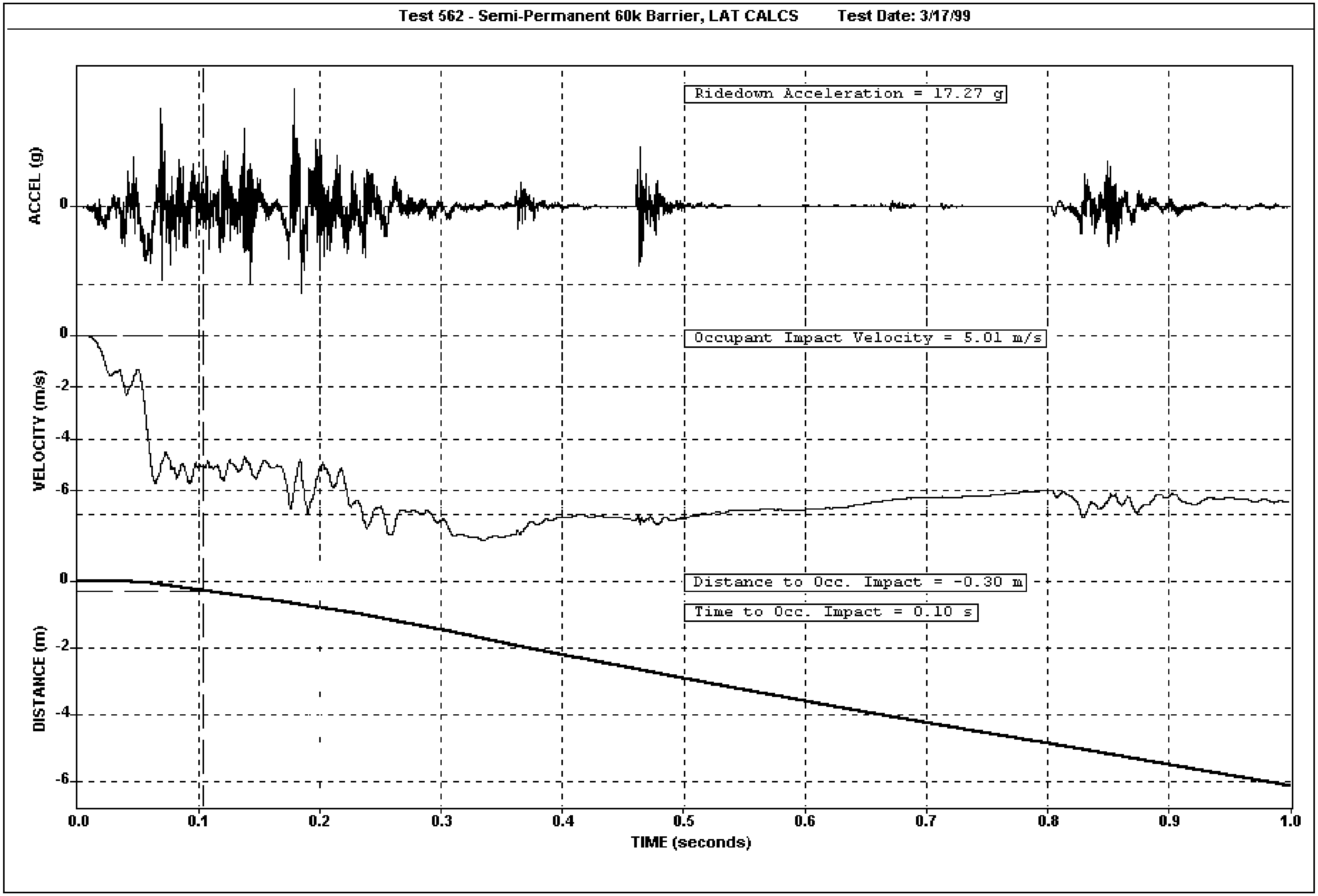
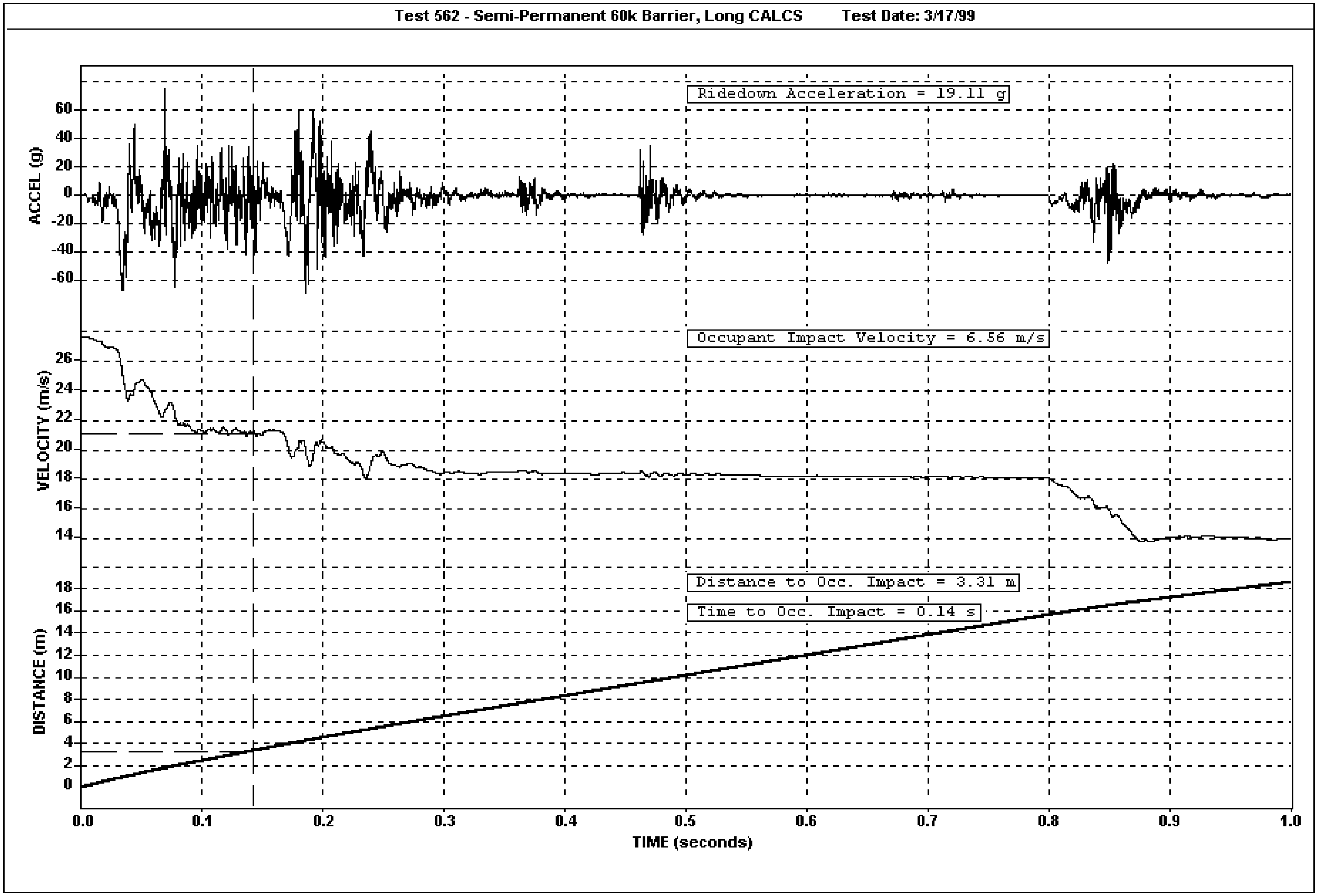


Figure 6-6 - Test 562 Vehicle Roll, Pitch and Yaw -Vs- Time



Test data recorder for Test 564 failed to collect data

Figure 6-7 - Test 564 Vehicle Accelerations -Vs- Time

na

Figure 6-8 - Test 564 Vehicle Longitudinal Acceleration, Velocity and Distance -Vs- Time

na

Figure 6-9 - Test 564 Vehicle Lateral Acceleration, Velocity and Distance -Vs- Time

na

Figure 6-10 - Test 564 Vehicle Roll, Pitch and Yaw -Vs- Time

na

Figure 6-11 - Test 565 Vehicle Longitudinal Acceleration, Velocity and Distance -Vs- Time

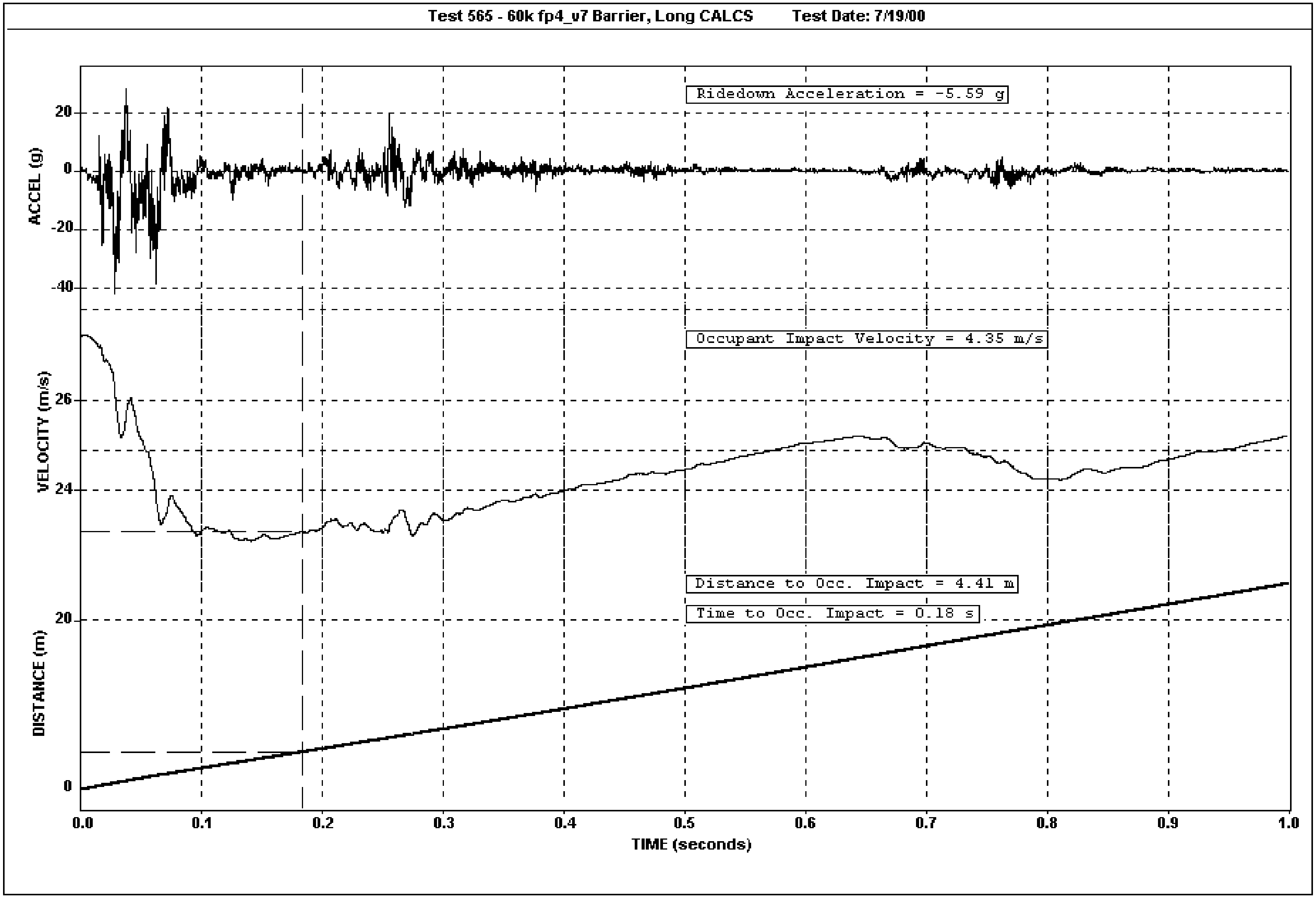


Figure 6-12 - Test 565 Vehicle Lateral Acceleration, Velocity and Distance -Vs- Time

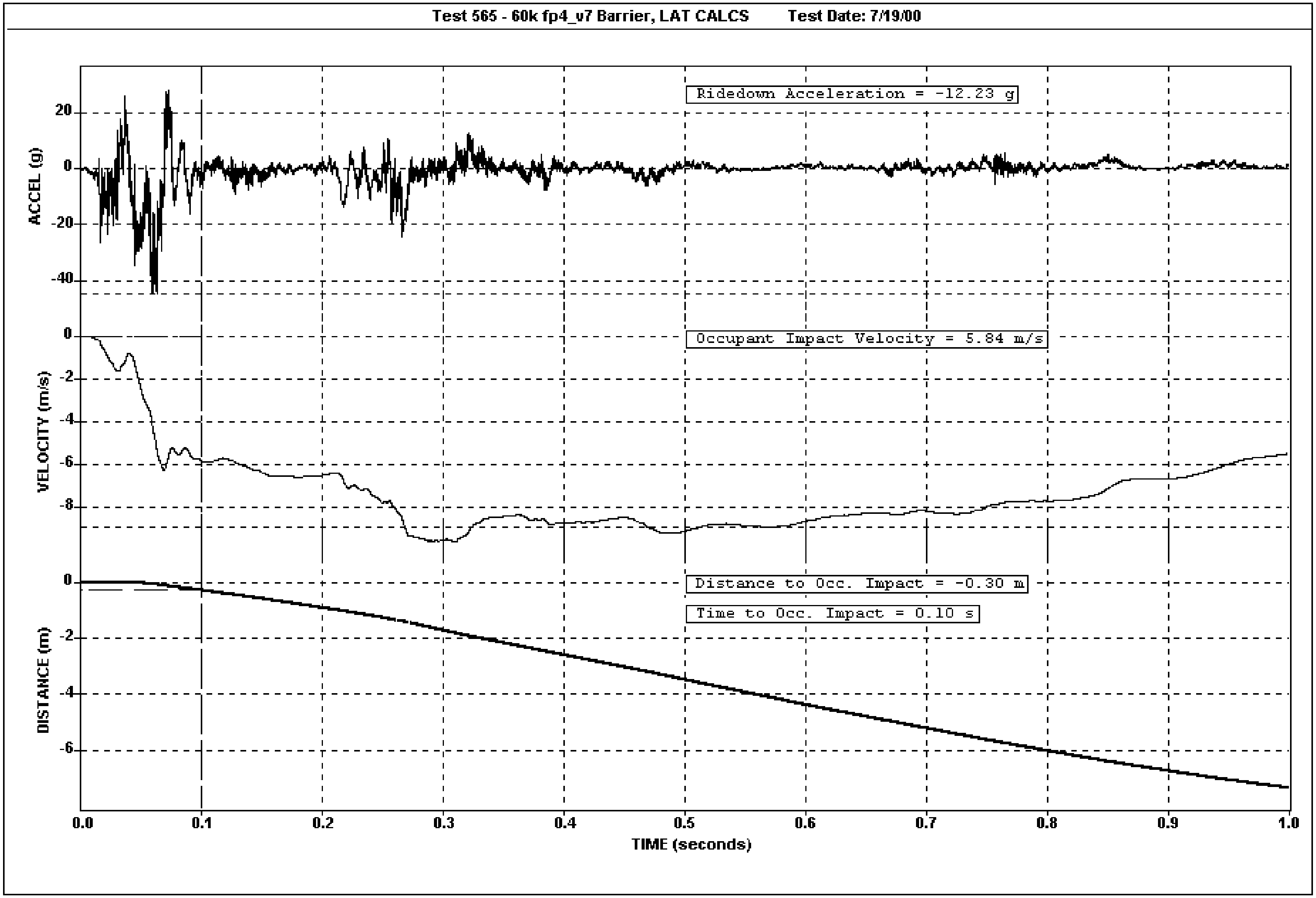


Figure 6-13 - Test 565 Vehicle Roll, Pitch and Yaw -Vs- Time

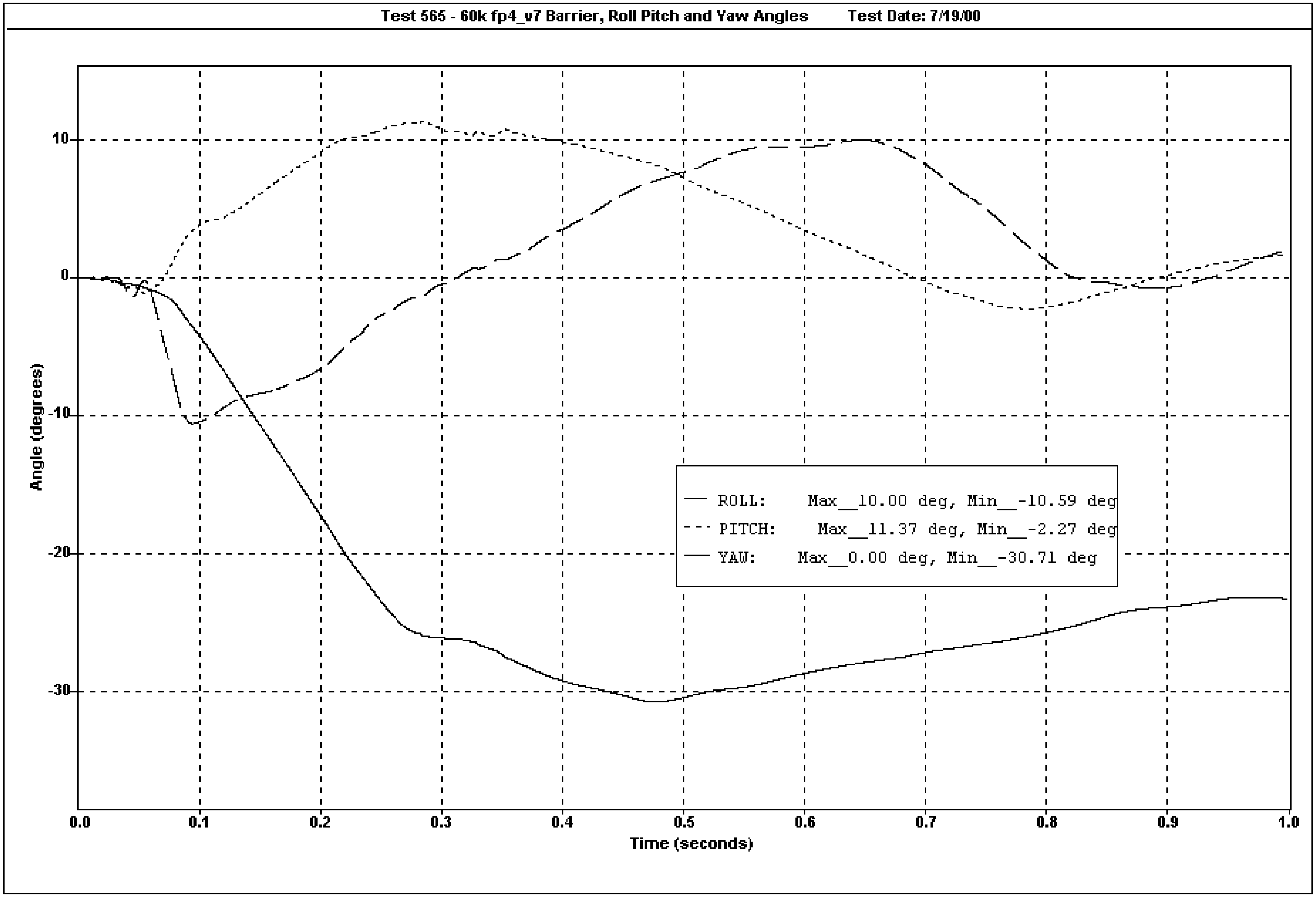


Figure 6-14 - Test 566 Vehicle Longitudinal Acceleration, Velocity and Distance -Vs- Time

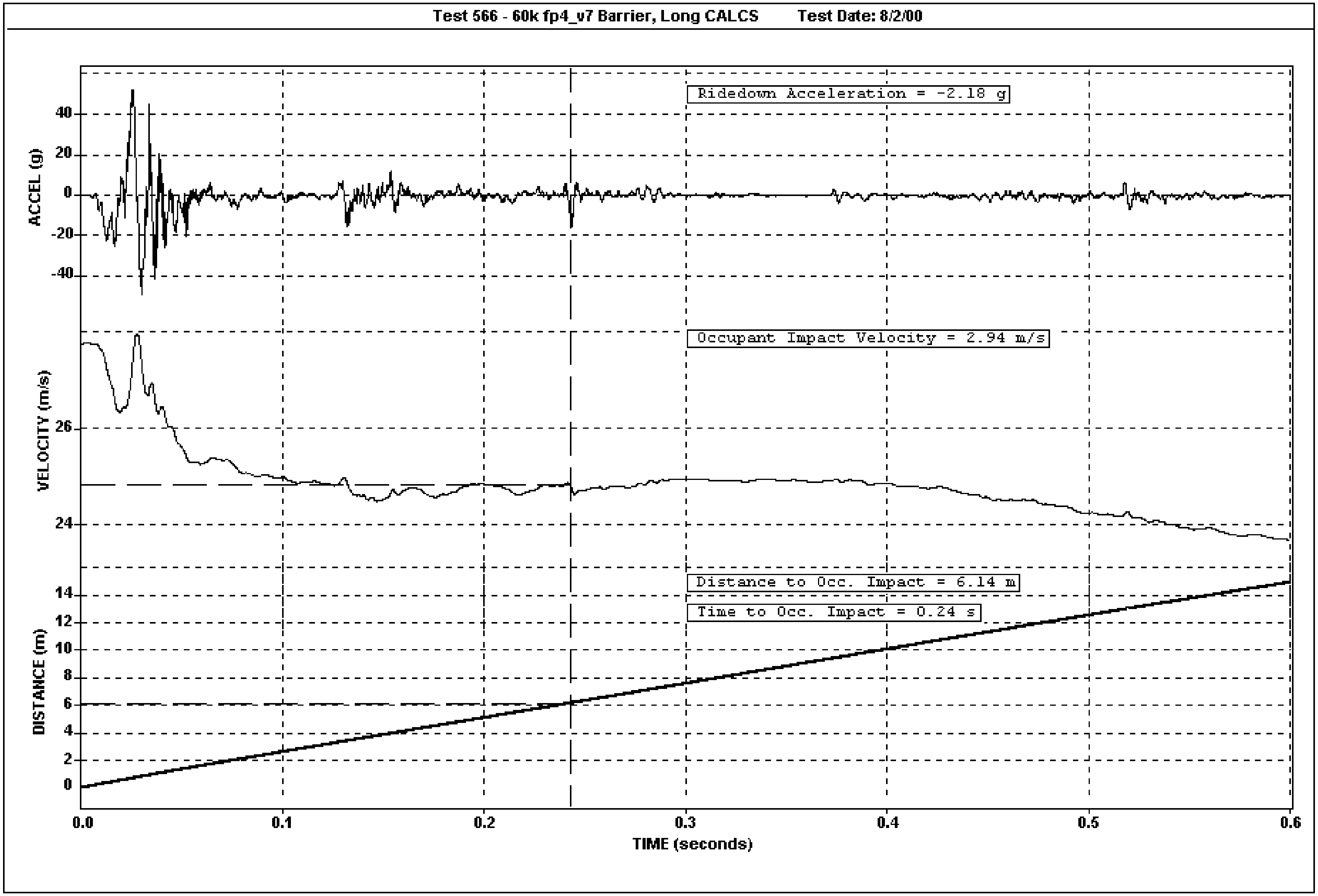


Figure 6-15 - Test 566 Vehicle Lateral Acceleration, Velocity and Distance -Vs- Time

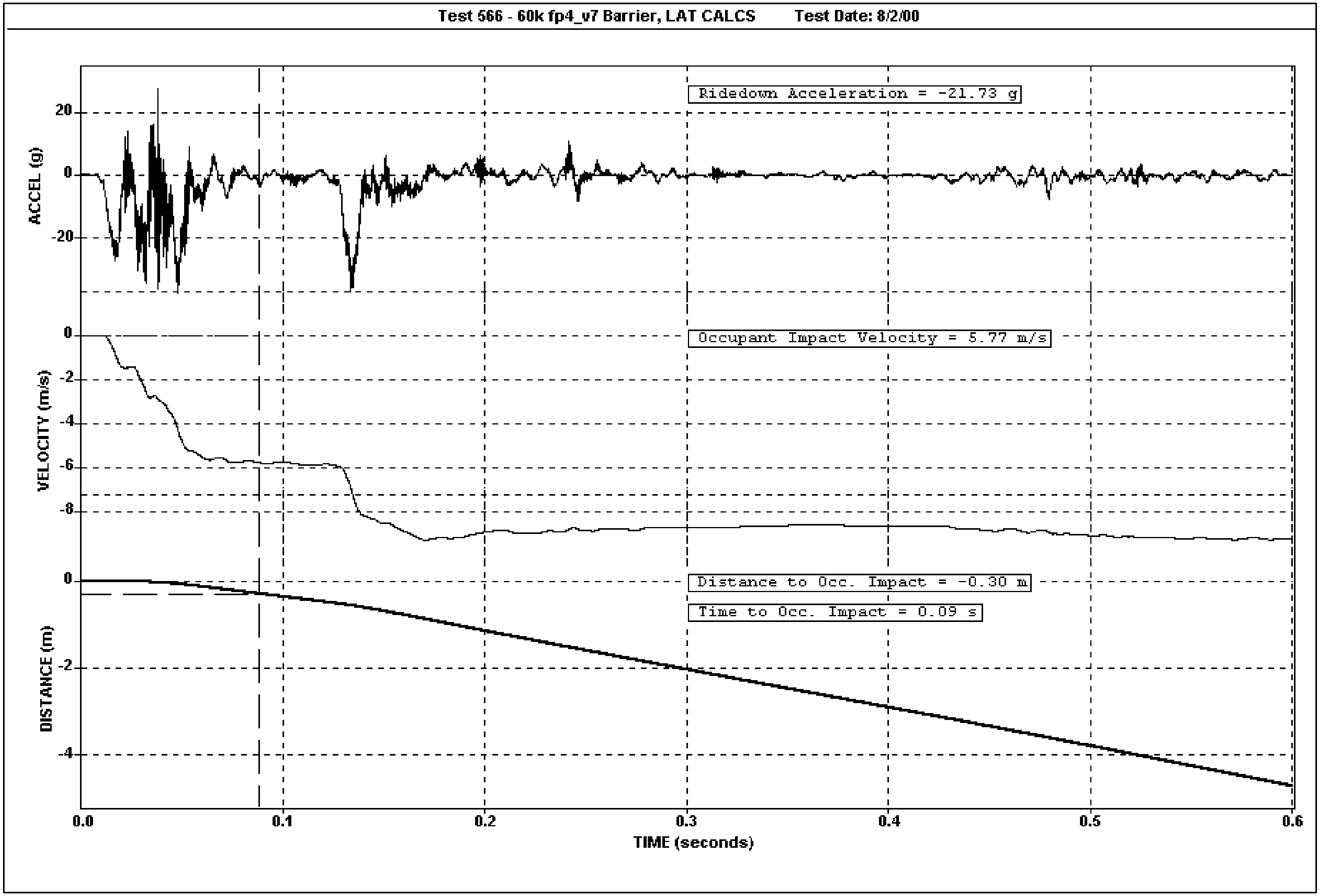


Figure 6-16 - Test 566 Vehicle Roll, Pitch and Yaw -Vs- Time

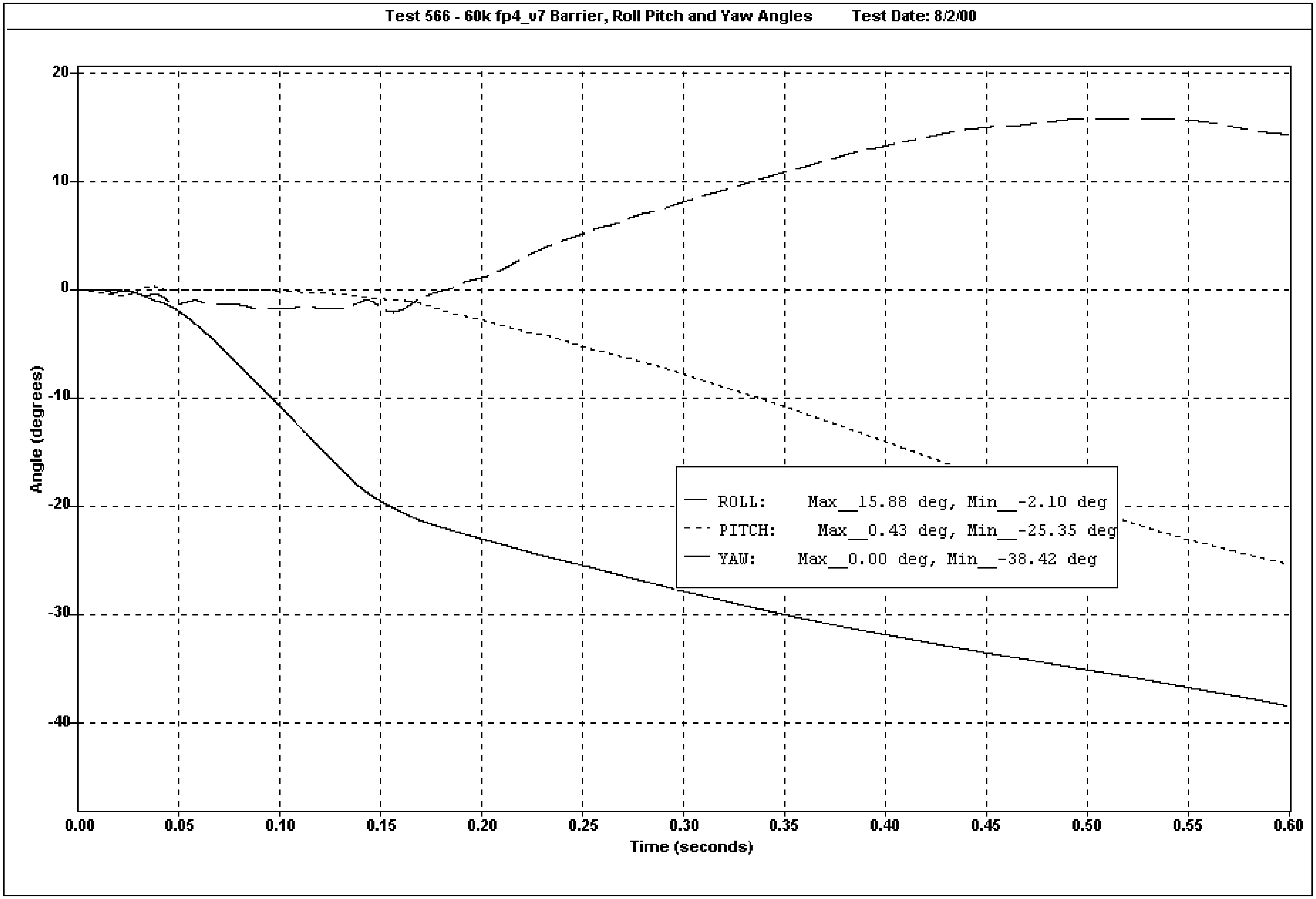


Figure 6-17 - Test 567 Vehicle Longitudinal Acceleration, Velocity and Distance -Vs- Time

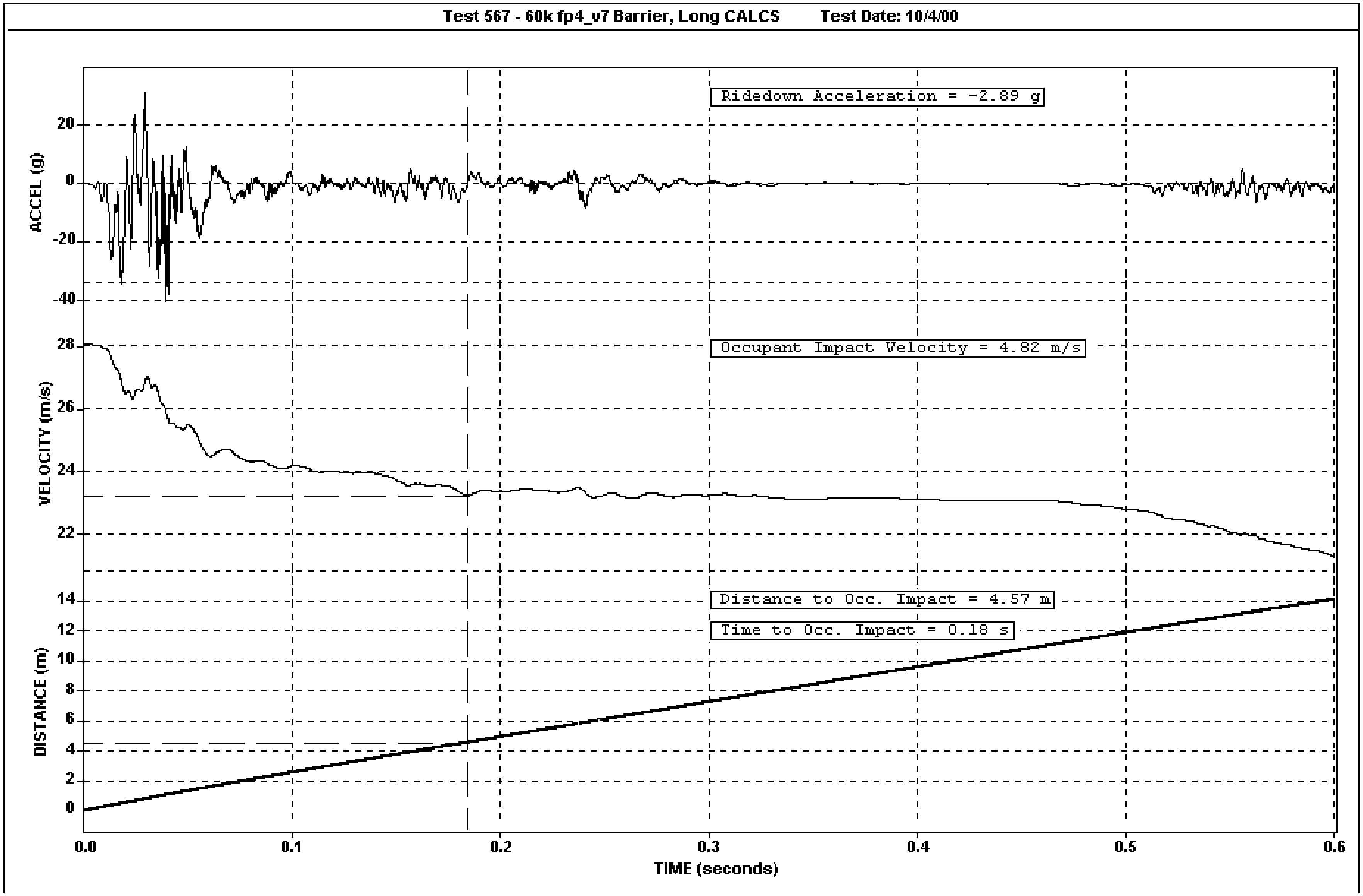


Figure 6-18 - Test 567 Vehicle Lateral Acceleration, Velocity and Distance -Vs- Time

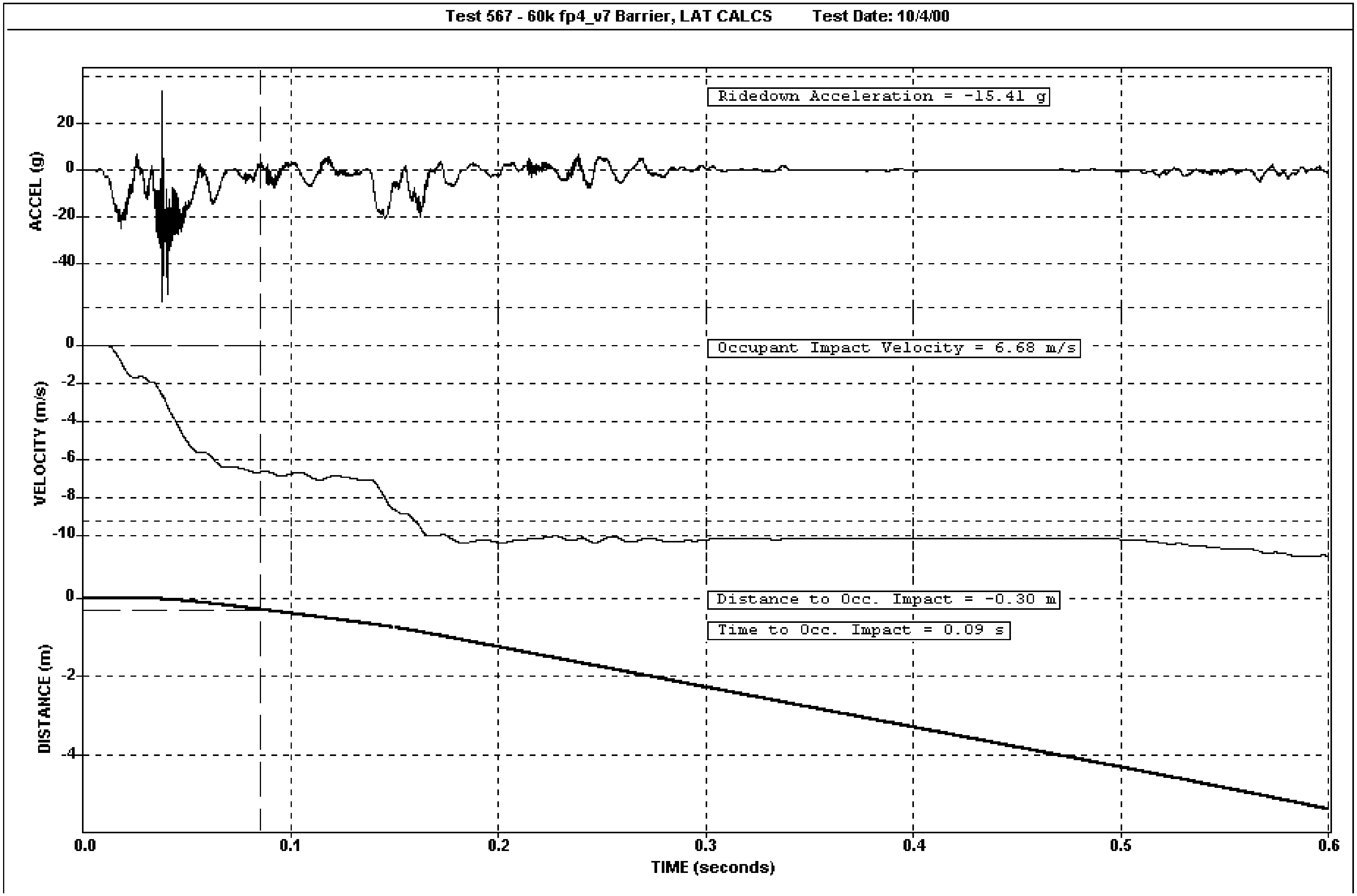
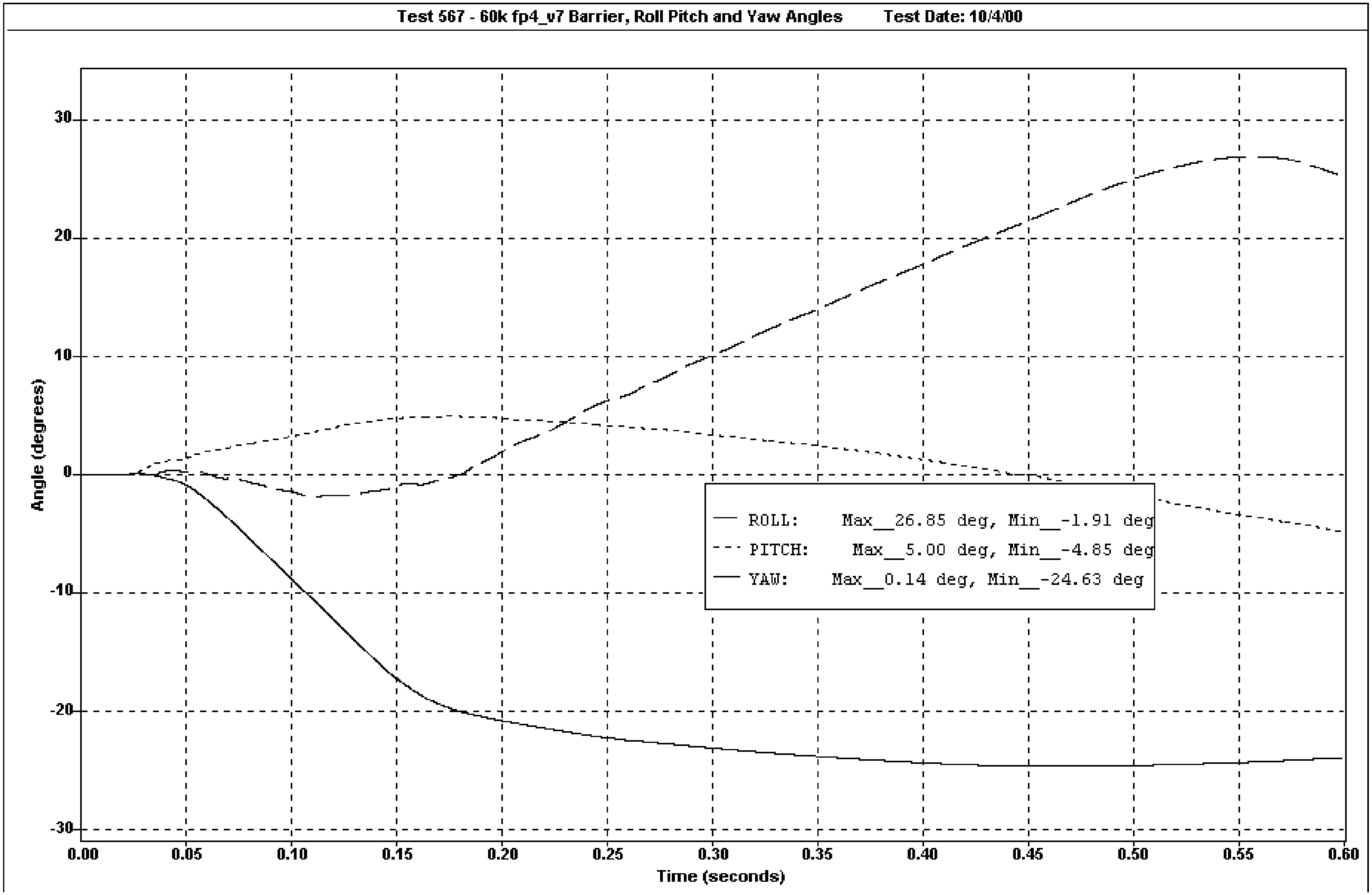


Figure 6-19 - Test 567 Vehicle Roll, Pitch and Yaw -Vs- Time



6.4. Detailed Drawing

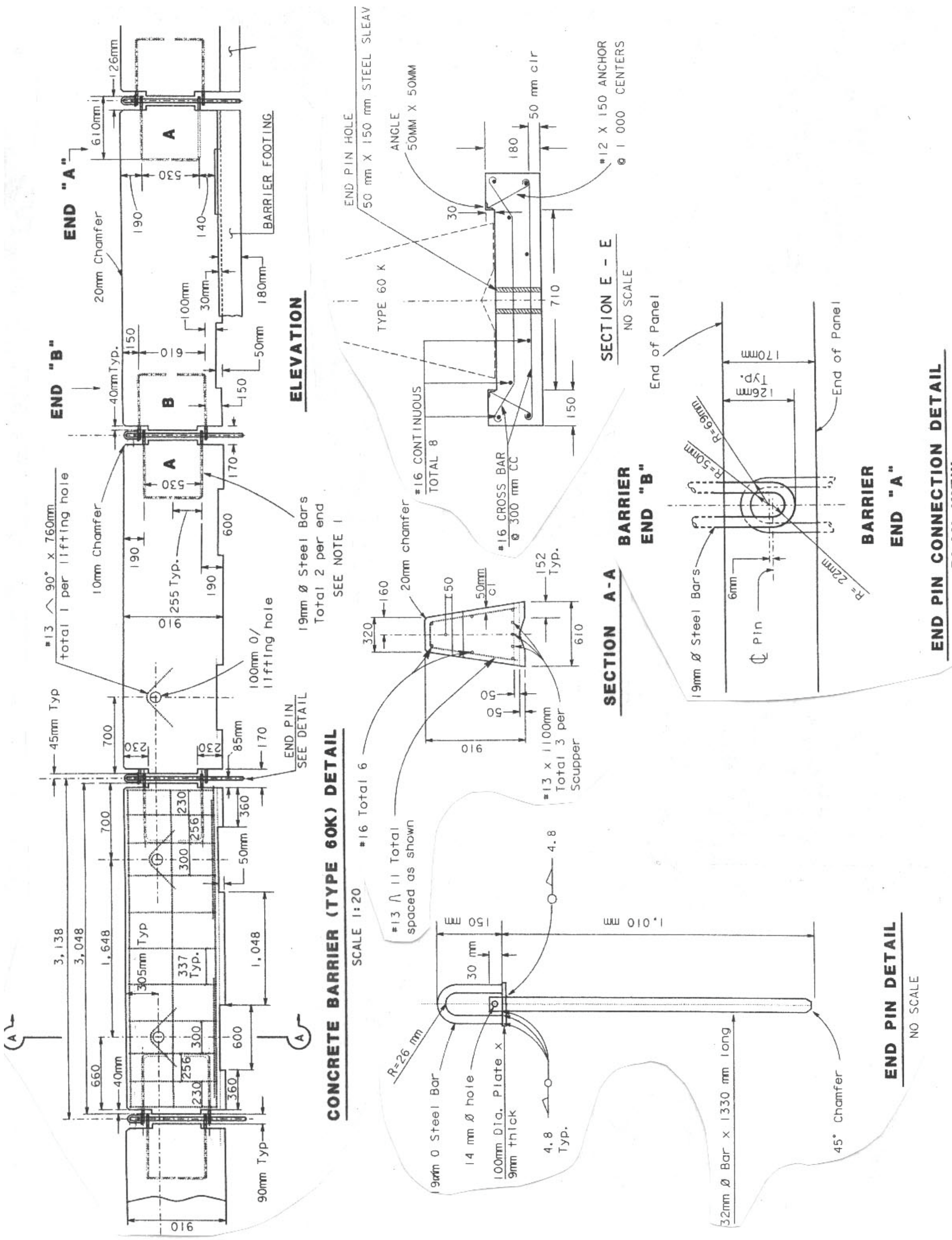


Figure 6-20 - Type 60K-v1, v2

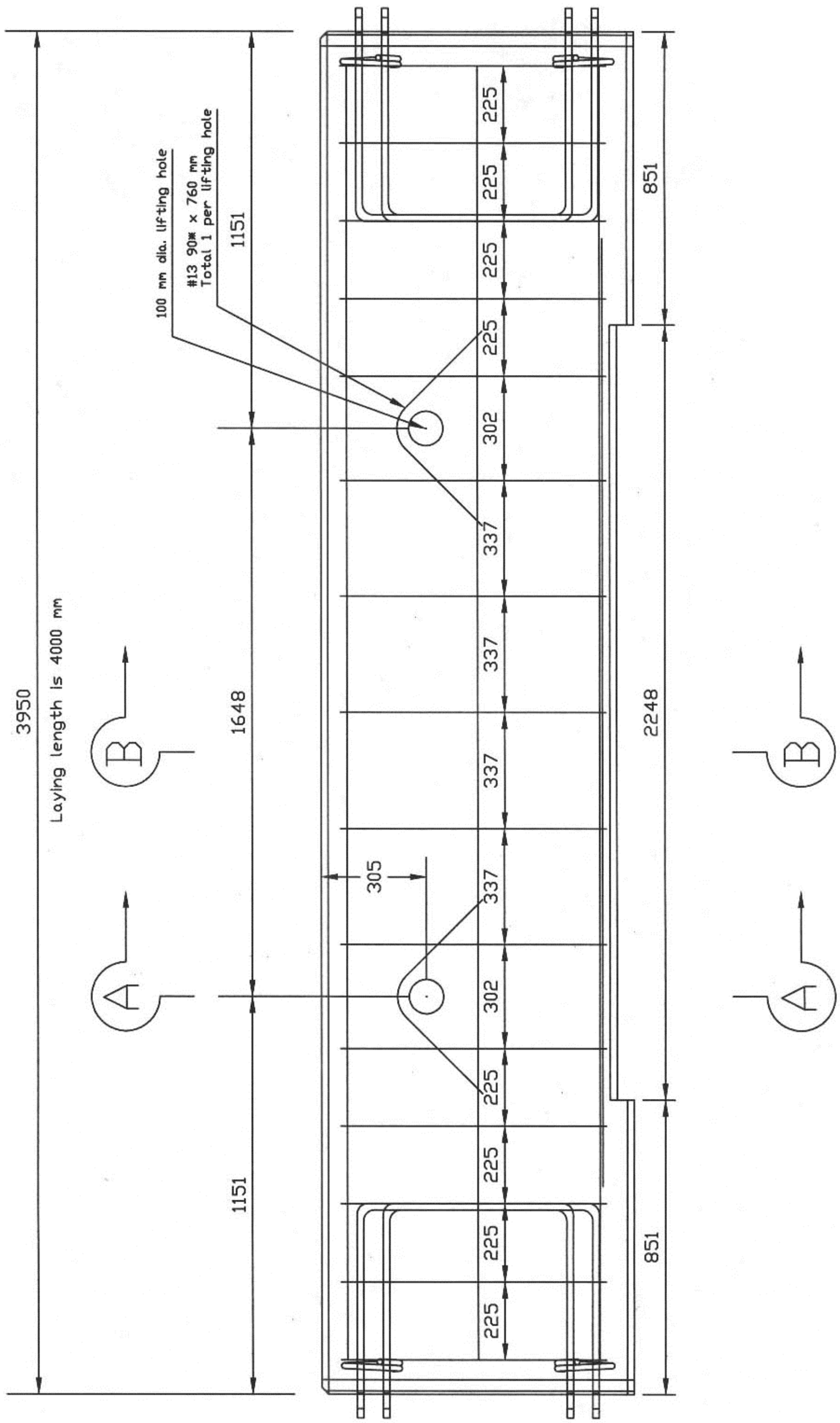


Figure 6-21 - Type 60k-v3 profile

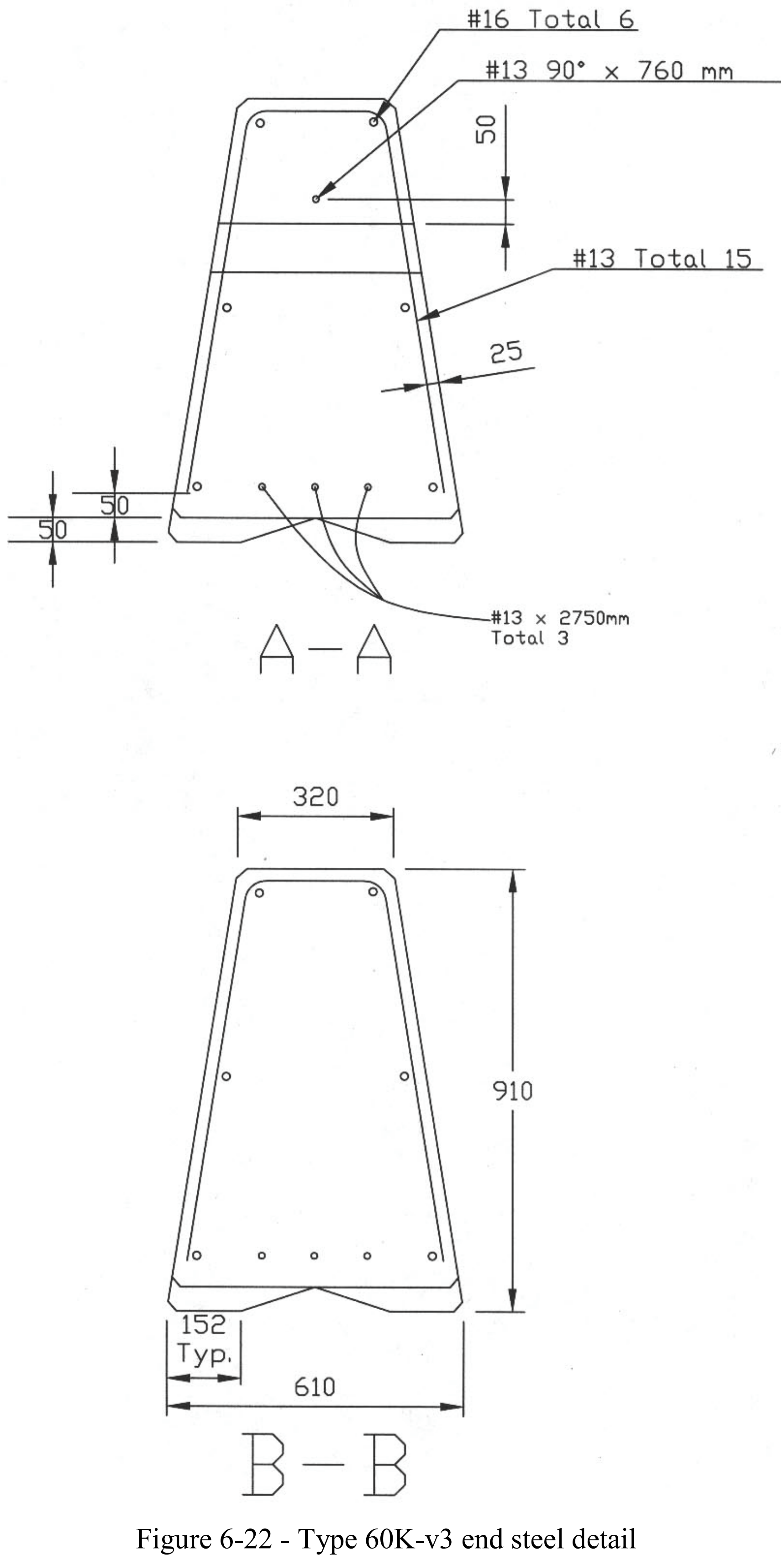


Figure 6-22 - Type 60K-v3 end steel detail

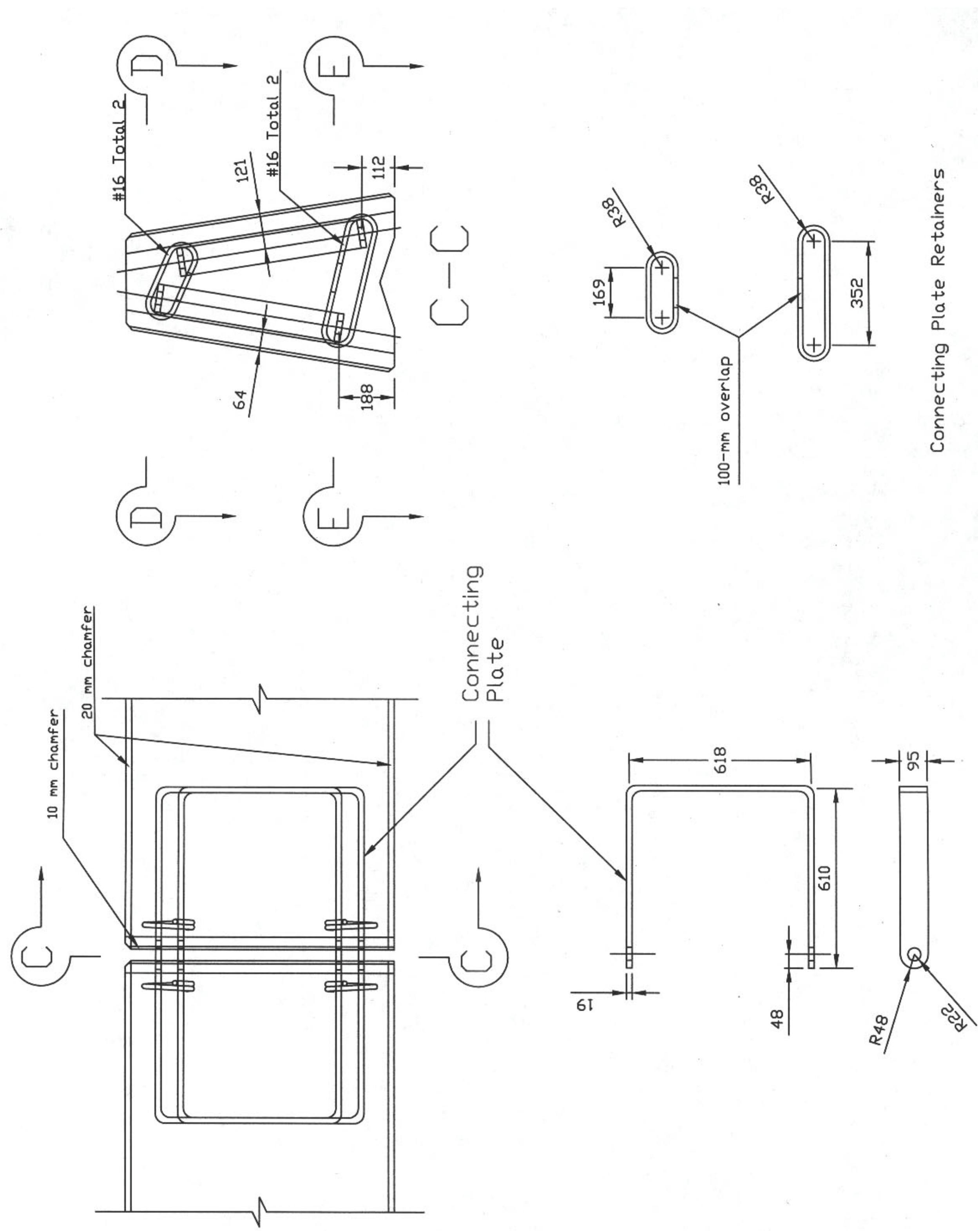


Figure 6-23 - Type 60K-v3 connection plate detail

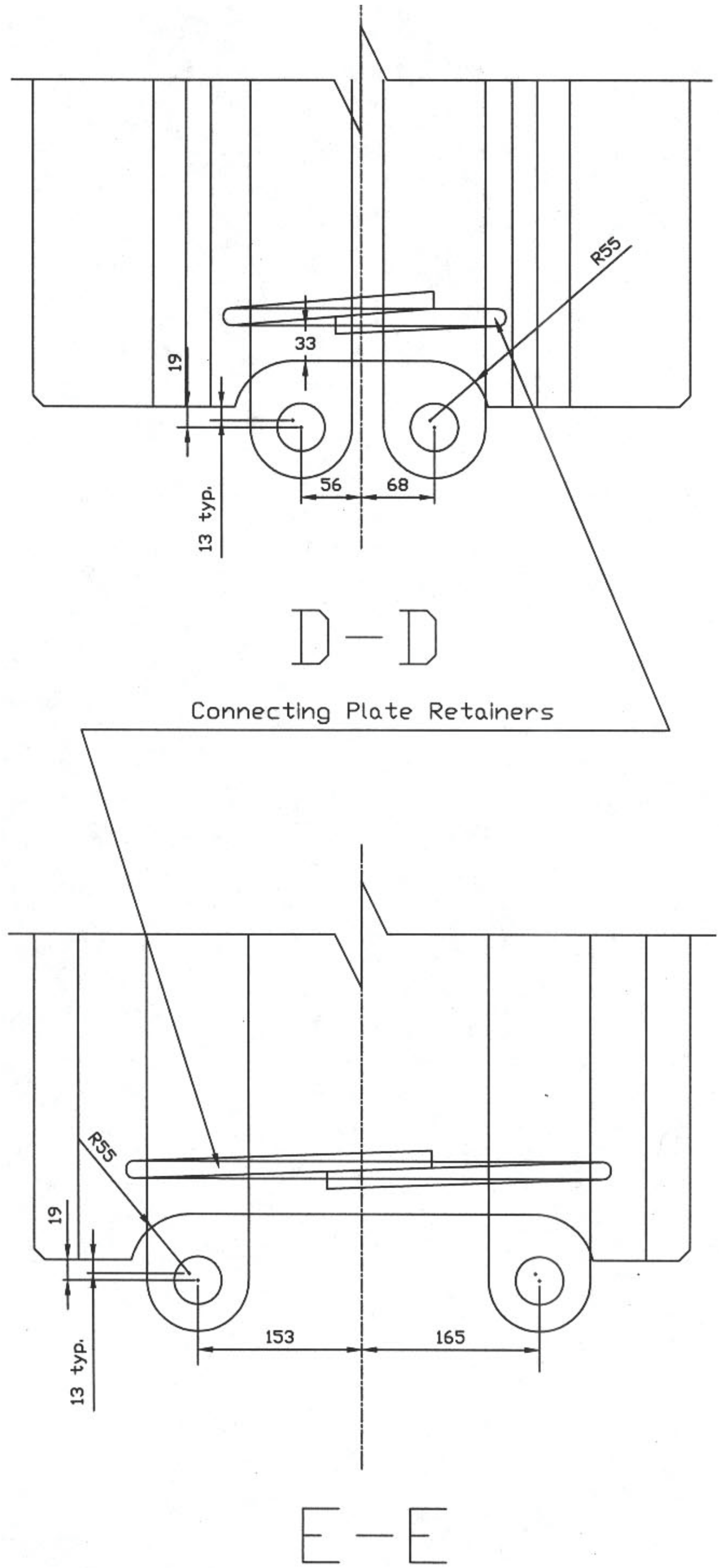


Figure 6-24 - Type 60K-v3 connection plate locations

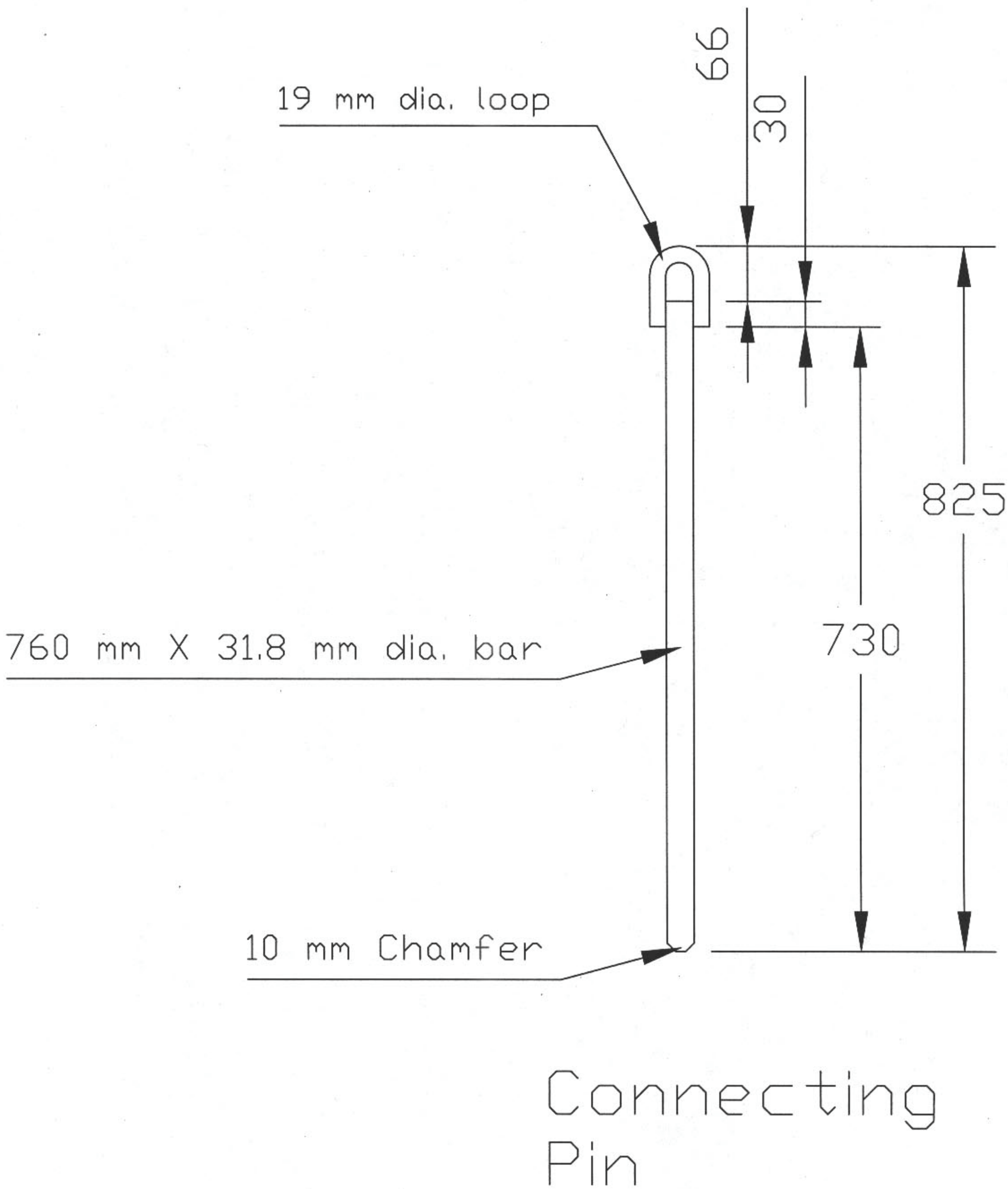


Figure 25 - Type 60K-v3 connection pin

7. REFERENCES

1 "Vehicle Damage Scale for Traffic Accident Investigators", Traffic Accident Data Project, National Safety Council, 1968.

2 "Collision Deformation Classification" - SAE J224 Mar80, SAE Recommended Practices, 1980.

3 "Vehicle Damage Scale for Traffic Accident Investigators", Traffic Accident Data Project, National Safety Council, 1968.

4 "Collision Deformation Classification" - SAE J224 Mar80, SAE Recommended Practices, 1980.

5 "Vehicle Damage Scale for Traffic Accident Investigators", Traffic Accident Data Project, National Safety Council, 1968.

6 "Collision Deformation Classification" - SAE J224 Mar80, SAE Recommended Practices, 1980.

7 "Vehicle Damage Scale for Traffic Accident Investigators", Traffic Accident Data Project, National Safety Council, 1968.

8 "Collision Deformation Classification" - SAE J224 Mar80, SAE Recommended Practices, 1980.