CRASHWORTHINESS TESTING OF A PORTABLE MAINTENANCE WORK-ZONE BARRIER

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

Supervised by..Robert Meline, P.E.

Principal Investigator .... John Jewell, P.E.

Report Prepared by .... Christopher Caldwell

Research Performed by ....Roadside Safety Research Group

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16. ABSTRACT

Barrier and shadow vehicles generally provide Caltrans maintenance workers protection from errant vehicles entering the work zone from the upstream direction of traffic flow. This type of protection does not protect workers from vehicles entering the work zone laterally. In an effort to provide workers with positive lateral protection the portable maintenance work-zone barrier (PMWB) was developed. The PMWB is more commonly know as the Balsi Beam named in honor of a Caltrans maintenance worker who was injured by an errant vehicle while performing his duties.

The Balsi Beam consists of a modified tractor truck and trailer. The trailer has two telescoping box beams, one on each side, that connect the front and back of the trailer. To create a positive workspace, one of the beams rotates onto the other beam to create a double beam barrier. The trailer can then be extended to provide 9.1 m (30 ft) of protected workspace. The beams can both be rotated to protect either side of the trailer so that work can be done on median or shoulder areas. The portable barrier has the ability to be moved forward along the highway without any downtime for disassembly and reassembly. It was developed to be quick, easy, and safe to deploy at the work area.

There are not any specified testing criteria for this type of barrier. Therefore, the barrier was tested under NCHRP Report 350 test Level 2 for Longitudinal Barriers. Two crash tests were conducted, one with an 820-kg small car and one with a 2000-kg pickup truck. The results of the two tests were within the limits of the Report 350 guidelines. There was minor damage to the barrier and sheet metal from the impacting vehicle tended to accumulate at the overlapping joint of the barrier's box beams.

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NOTICE

English to Metric System (SI) of Measurement

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

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1 INTRODUCTION

1.1 Problem

Caltrans maintenance forces working adjacent to live traffic lanes are at risk of being injured or killed by vehicles that stray into the work zone. Barriers and shadow vehicles generally provide worker protection from errant vehicles entering the work zone longitudinally, from the upstream direction of traffic flow. However, they may not provide protection from lateral penetrations. From December 1990 to June 2001, errant vehicles entering work zones had struck 103 Caltrans employees on foot. Of this total 93 were injured and 10 were killed.

1.2 Objective

The objective of the testing presented in this report was to evaluate a newly developed portable maintenance work-zone barrier (PMWB) that will shield maintenance personnel from errant vehicles entering work zones. The portable barrier has the ability to be moved forward along the highway without any downtime for disassembly and reassembly. It was developed to be quick, easy, and safe to deploy at the work area. Since there are no set criteria for testing and evaluating this type of barrier it was decided that the barrier would be tested and evaluated to meet the requirements of the National Cooperative Highway Research Program (NCHRP) Report 350[1] TL-2 for longitudinal barriers, adhering to the test matrix below (see Table 1-1).

Table 1-1 TL-2 Test Matrix

Test Designation	Vehicle Designation	Nominal Speed (km/h)	Nominal Angle, θ (deg)
2-10	820C	70	20
2-11	2000P	70	25

1.3 Background

A comprehensive literature search was conducted to determine if any similar products have been developed. Only two systems were discovered, both developed by the Texas Transportation Institute (TTI) for use by the Texas Department of Transportation (TXDOT). Neither one was ever put into operation beyond the initial trial periods

In 1982 TTI developed a portable traffic barrier which consisted of five used station wagons closely connected by tow bars and protected on both sides by thrie beam rail elements[2] (Figure 1-1). The lead car towed the other four to the work zone. This train of vehicles formed a portable barrier 2.4 meters (94 inches) wide and 30.5 meters (100 feet) long that could shield maintenance personnel in an adjacent lane or shoulder. The trailing vehicle did not perform as an end treatment or crash cushion. It was successfully crash tested twice with a 2,041-kg (4,500-lb) sedan, impacting at 83.7 km/h (52 mph) with an angle of 7 degrees and at 77.2 km/h (48 mph) with an angle of 15 degrees. Texas DOT maintenance forces tried using the system but found it too cumbersome to deploy efficiently. The lead vehicle also suffered transmission failure during one of the trail deployments.

Figure 1-1 Used Car Barrier

In 1984 TTI made another attempt with a truck-mounted portable maintenance barrier[3] (Figure 1-2). This system consisted of a steel barrier connected between two 5 cubic yard dump trucks. The 13.4-m (44-ft) barrier was attached to hitch and support assemblies fixed to the sides and rear or front of the trucks. The barrier was towed behind one of the vehicles with a tow dolly and then assembled between the two trucks along the traffic side at the work location. It took two men 15 minutes to set up the barrier. This provided a 9.1-m (30-ft) work zone and 4.3-m (14-ft) buffer zone between the two trucks. The lead vehicle could tow the barrier and trailing vehicle in this configuration at 24.1 km/h (15 mph). It was successfully crash tested twice with a 2,041-kg (4,500-lb) sedan, impacting at 82.1 km/h (51 mph) with an angle of 7.3 degrees and at

80.5 km/h (50 mph) with an angle 15 degrees. It also passed a crash test with an 800.6-kg (1765-lb) vehicle impacting at 82.1 km/h (50 mph) with an angle of 14 degrees. Texas DOT used the system for several short-term maintenance operations, but found it too cumbersome to operate.

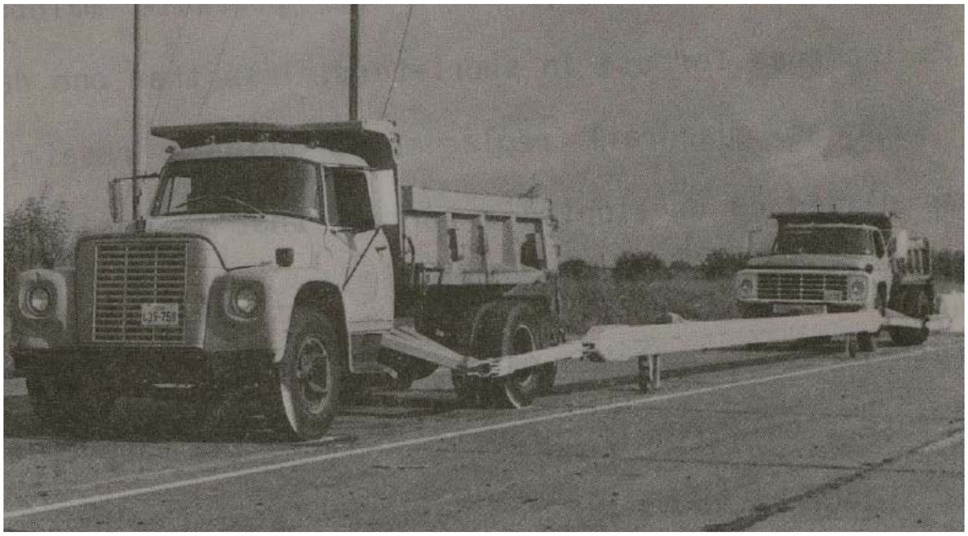

Figure 1-2 Truck-Mounted Portable Barrier

1.4 Scope

Two full-scale crash tests were performed and evaluated in accordance with NCHRP Report 350. Computer modeling was also performed with the intent of determining the crashworthiness of the PMWB during the design process (see Section 7.6 in the Appendix). Table 1-2 shows the test matrix developed for this project. The primary purpose of these tests was to determine the crashworthiness of a newly developed portable maintenance work-zone barrier as it pertains to longitudinal impacts under TL-2 conditions.

Table 1-2 Target Test Conditions

Test Number	Vehicle Mass Kg (lbm)	Nominal Speed km/h (mph)	Nominal Impact Angle, θ (deg)
641	820 (1810)	70 (43)	20
642	2000 (4410)	70 (43)	25

2 TECHNICAL DISCUSSION

2.1 Test Conditions – Crash Tests

2.1.1 Test Facilities

The crash tests were conducted at the Caltrans Dynamic Testing Facility in West Sacramento, California. The test area is a large, flat, asphalt concrete surface. There were no obstructions nearby that would affect either the impact or exit trajectories of the test vehicles.

2.1.2 Test Barrier

The Caltrans Portable Maintenance Work-Zone Barrier (PMWB) is commonly referred to as the Balsi Beam in honor of a Caltrans maintenance employee who was seriously injured while performing his assigned duties. The Balsi Beam consists of a modified tractor truck and trailer. The trailer has two telescoping box beams, one on each side, that connect the front and back of the trailer. To create a positive workspace, one of the beams rotates onto the other beam to create a double beam barrier. The trailer can then be extended to provide 9.1 m (30 ft) of protected workspace. The beams can both be rotated to protect either side of the trailer so that work can be done on median or shoulder areas. The trailer is controlled from inside the cab of the tractor truck.

Figure 2-1 Balsi Beam Deployment 1

Figure 2-2 Balsi Beam Deployment 2

Figure 2-3 Balsi Beam Deployment 3

Figure 2-4 Balsi Beam Deployment 4

Figure 2-5 Balsi Beam Deployment 5

Figure 2-6 Fully Deployed Balsi Beam

2.1.3 Test Vehicles

Both test vehicles complied with NCHRP Report 350. The vehicles were in good condition, free of major body damage and were not missing any structural parts. The vehicles had standard equipment and a front-mounted engine, for more details see Table 7-1 and Table 7-2. The Geo Metro used in test 641 had a 74.8-kg (156.1-lb) Male Hybrid III test dummy placed in the passenger side of the vehicle. The inertial mass of the Metro was 840 kg (1851.9 lbs) without the test dummy. The truck had 33.1 kg (73 lbs) added to the bed in order to meet the minimum weight for the test. This brought the inertial mass of the truck up to 1,962 kg (4325.5 lbs), which was within the recommended limits of NCHRP Report 350 (see Table 2-1).

Both vehicles were self-powered and a speed-control device limited the acceleration once the impact speed had been reached. Steering was controlled by means of a guidance rail anchored to the ground. Remote braking was possible at any time during the test via radio control. A short distance before the point of impact the vehicle was released from the guidance rail and the ignition system was deactivated. A detailed description of the test vehicle equipment and guidance system is contained in Appendices 7.1and 7.2.

Table 2-1 Test Vehicle Information

Test Number	Vehicle	Curb Mass kg (lbm)	Test Inertial kg (lbm)	Nominal Impact Severity kJ (ft-lbf)
641	1989 Geo Metro	790 (1740)	840 (1850)	18.6 (13700)
642	1994 Chevy 2500 Truck	1,821 (4015)	1,962 (4325)	66.2 (48800)

2.1.4 Data Acquisition System

The impact event of the crash was recorded with high-speed digital video cameras, one digital movie video camera, and one digital SLR camera. The test vehicles and the barrier were photographed before and after each impact with a digital movie camera and a digital SLR camera. A film report of this project was assembled using edited portions of the film coverage.

Two sets of orthogonal accelerometers were mounted in the vehicles at the center of gravity. One set of rate gyro transducers was placed 191 mm (7.5 in) behind the center of gravity (along the x-axis) to measure the roll, pitch, and yaw rates. The data collected by these devices were used to calculate the occupant impact velocities, ridedown accelerations, and maximum vehicle rotation.

Two separate digital transient data recorders (TDRs) manufactured by GMH Engineering (Model II) were used to record electronic data during the tests. The digital data was analyzed with custom DADiSP workbooks using a personal computer.

2.2 Test Results – Crash Tests

A description of the impact, vehicle damage, and barrier damage is given in this section. An edited video report detailing the testing of the PMWB was created as part of this research project and is available for viewing.

2.2.1 Test 641

2.2.1.1 Impact Description – Test 641

The vehicle was set to impact on the front passenger side 2.6 m (8.5 ft) upstream of the overlap of the two box beams. Film analysis shows that the vehicle actually impacted at 2.3 m (7.5 ft) upstream of the overlap. The impact angle was set at 20° by the placement of guide rail. Film analysis reveals that the impact angle was 21.5º at impact, which is 0.1º above the tolerance given in NCHRP Report 350. The impact speed of 70.9 km/h (44.1 mph) was obtained by averaging the speed recorded by two speed traps located just upstream from the impact point and the speed calculated from film analysis.

After the initial impact the vehicle was smoothly redirected until the front end hit the overlap of the two box beams at 122 ms after impact. At this point the sheet metal began to snag in the overlap. The snagged sheet metal accumulated at the overlap and pushed the passenger door inward at 174 ms after impact. The vehicle lost contact with the barrier at 264 ms. The exit angle was 0.9º and the exit velocity was 57.7 km/h (35.9 mph). The right front tire was damaged during the initial impact, causing the vehicle to steer back toward the tractor truck. Roughly 380 ms after the initial impact the vehicle hit the backside of front bumper on the tractor truck. At this point the vehicle yawed to the right about its right front corner by approximately 110º before coming to a rest.

2.2.1.2 Vehicle Damage – Test 641

The right front corner of the vehicle sustained minor damage from the initial impact with the barrier. The amount of damage increased as the vehicle impacted the point where the box beams overlap each other. The sheet metal over the right front tire was crumpled inward and the tire deflated. The sheet metal over the passenger door was completely pulled away and the internal portion of the door was pushed inward. The final impact with the bumper on the tractor truck pushed the right front bumper of the test vehicle backward. The right front tire was also pushed back in the wheel well. Inspection of the occupant compartment revealed that there had been little to no deformation to the floorboard and firewall.

2.2.1.3 Barrier Damage – Test 641

The barrier suffered minor scrapes and scratches from the impact with the vehicle. Sheet metal from the vehicle was lodged in-between the overlapping in the beams. During the impact with the vehicle, the barrier defected dynamically by 100 mm (3.94 in) and had a final static defection of 23-mm (0.91-in). The PMWB did not move from its initial location. The tractor truck had minor damage to the left side. The front bumper was push forward away from the truck slightly.

2.2.1.4 Dummy's Response – Test 641

The test dummy was strapped into the right front seat with both a lap and shoulder belt. The dummy's head never moved out of the passenger's side window. There was no contact between the dummy and the face of the barrier. The dummy remained upright and secure during the test. The final resting position of the dummy was leaning slightly to the left, but was still belted into the passenger's seat.

Figure 2-7 Impact Area Prior to Test 641

Figure 2-8 Impact Area Prior to Test 641

Figure 2-9 Test Vehicle 641 Prior to Test

Figure 2-10 Trailer Prior to Being Deployed for Test 641

Figure 2-11 Trailer in Barrier Mode for Test 641

Figure 2-12 Final Location of Test Vehicle 641

Figure 2-13 Impact Area After Test 641

Figure 2-14 Test Vehicle After Test 641

Figure 2-15 Test Vehicle After Test 641

Figure 2-16 Test Vehicle After Test 641

Figure 2-17 Barrier After Test 641

Figure 2-18 Barrier After Test 641

Figure 2-19 Final Resting Place of Test Dummy

2.2.1.5 Data Summary Sheet – Test 641

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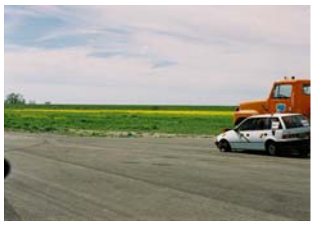

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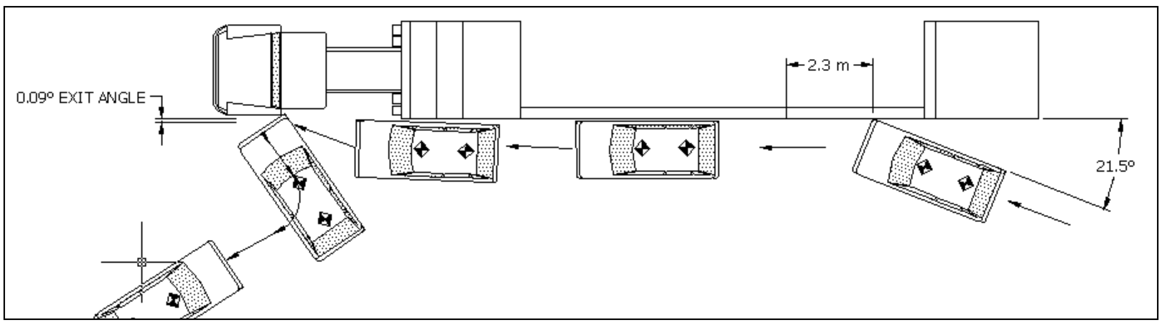

Figure 2-20 Test 641 Impact Sequence and Diagram

General Information

Testing Agency	California DOT
Test Number	641
Test Date	February 25, 2003

Test Article

Type	Portable Maintenance Work-Zone Barrier

Test Vehicle

Type	Geo
Designation	820C
Model	1989 Metro
Mass Curb	790 kg (1741.6 lbs)
Test Inertial	840 kg (1851.9 lbs)

Test Dummy

Type	Male Hybrid III
Weight	74.8 kg
Position	Right Front
Restraint	Lap and Shoulder Belt

Impact Conditions

Impact Velocity	70.9 km/h (44.1 mph)
Impact Angle	21.5°
Impact Severity	21.9 kJ

Exit Conditions

Exit Velocity	57.7 km/h (35.9 mph)
Exit Angle	2.5°

Test Article Deflection

Dynamic	100 mm (3.9 in)
Permanent	23 mm (0.9 in)

Post-Impact Vehicular Behavior

(*Data Analysis/Video Analysis*)

Maximum Roll Angle	-6.5°/-6.3°
Maximum Pitch Angle	-1.96°/-0.2°
Maximum Yaw Angle	-20.34°/-24.0°

Test Data

ASI	0.94
Vehicle Exterior:	
VDS[4,5]:	RFQ-5, RD-7
CDC[6]:	01RYES8
Vehicle Interior:	
O.C.D.I.[1]:	RF0000000

Occupant Risk Values	*Longitudinal*	*Lateral*
Occupant Impact Velocity	2.21 m/s	-4.20 m/s
Ridedown Acceleration	-4.62g	11.19g

Barrier Damage

The barrier had minor scratches from the impact. A piece of the Metro's sheet metal was lodged in the area where the box beams overlap. The tractor truck had minor damage to the front end due to a secondary impact with the vehicle.

2.2.2 Test 642

2.2.2.1 Impact Description – Test 642

The front passenger side of the vehicle was set to impact the barrier 0.7 m (2.3 ft) upstream of the overlap of the top beams. Film analysis showed that the vehicle actually impacted at 0.6 m (1.95 ft) upstream of the overlap. The Impact angle was set at 25° and film analysis revealed that the vehicle impacted at an angle of 25.2°. An impact speed of 69.6 km/h (43.2 mph) was obtained by averaging the speed recorded by two speed traps located just upstream from the impact point and the speed calculated from film analysis.

The initial impact with the barrier caused the right front corner of the vehicle to deform inward and the hood to overlap the front face of the barrier. 30 ms later the vehicle impacted the overlap of the two beams. The hood of the vehicle continued to override the top of the barrier but the sheet metal covering the right front wheel well snagged on the overlap and was pulled away from the vehicle. At 132 ms much of right front corner panel was accumulated at the beam overlap and had completely torn away from the vehicle. Also, the sheet metal from the passenger door had pulled away from the vehicle. The hood of the vehicle overlapped the front face of the barrier 387 mm (15.4 in) and did not penetrate the back face of the barrier. The vehicle lost contact with the barrier at 448 ms after the initial impact. At this point the vehicle exited at an angle of 1.5° and a velocity of 45.9 km/h (28.5 mph).

2.2.2.2 Vehicle Damage – Test 642

The right front corner of the vehicle sustained significant damage due to the impact with the box beam overlap. Only the lower control arm was still attached to the front wheel hub assembly. All of the sheet metal that covered the right corner of the vehicle was torn away. The battery was exposed and only supported by its wiring. The right half of the front bumper was folded backward. The top of the passenger door was bent outward and the steel metal was crumpled inward.

2.2.2.3 Barrier Damage – Test 642

The barrier appears to have suffered only minor damage and scraping. There was a large amount of the test vehicle's sheet metal lodged into the overlapping joint of the barrier's box beams.

During the impact with the vehicle, the barrier had a lateral dynamical deflection of 200 mm (7.87 in) and had a final static defection of 142 mm (5.59 in). Both the tractor truck and trailer were pushed away from the impact area (to the right/passenger side of the tractor truck and trailer). Figure 2-21 shows the amount of displacement of the tractor truck tires, trailer tires, and trailer brace.

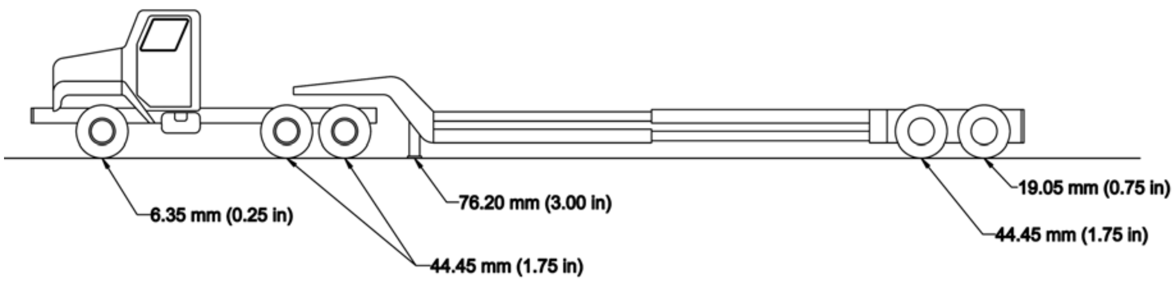

Figure 2-21 Later Displacement of the Tractor Truck and Trailer to Test 642

Figure 2-22 Impact Area Prior to Test 642

Figure 2-23 Close-up of Impact Area Prior to Test 642

Figure 2-24 Vehicle Prior to Test 642

Figure 2-25 Vehicle Prior to Test 642

Figure 2-26 Barrier Prior to Test 642

Figure 2-27 Vehicle After Test 642

Figure 2-28 Vehicle After Test 642

Figure 2-29 Barrier After Test 642

Figure 2-30 Barrier After Test 642

Figure 2-31 Close-up of the Vehicle's Sheet Metal in Test 642

Figure 2-32 Trailer Tire and Brace Displacement in Test 642

2.2.2.4. Data Summary Sheet – Test 642

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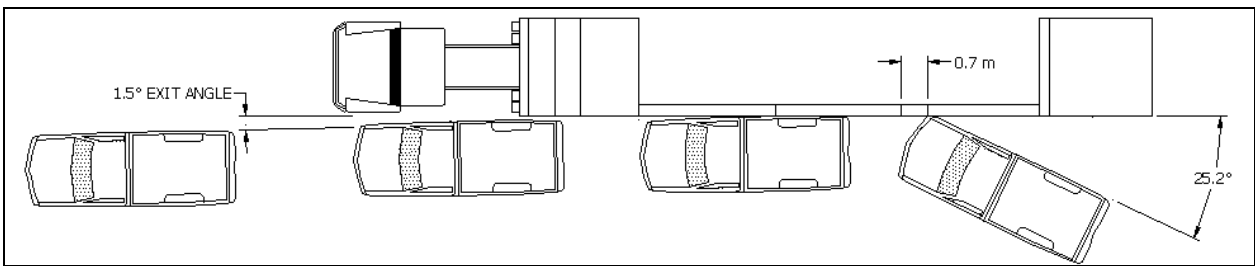


Figure 2-33 Test 642 Impact Sequence and Diagram

General Information

- Testing Agency: California DOT
- Test Number: 642
- Test Date: April 4, 2003

Test Article

- Type: Portable Maintenance Work-Zone Barrier

Test Vehicle

- Type: 2500 Pick-up Truck
- Designation: 2000P
- Model: 1994 Chevy
- Mass Curb: 1821 kg (4014.6 lbs)
  - Test Inertial: 1962 kg (4325.5 lbs)

Impact Conditions

- Impact Velocity: 69.6 km/h (43.2 mph)
- Impact Angle: 25.2°
- Impact Severity: 66.4 kJ

Exit Conditions

- Exit Velocity: 45.9 km/h (28.5 mph)
- Exit Angle: 1.5°

Test Article Deflection

- Dynamic: 200 mm (7.9 in)
- Permanent: 142 mm (5.6 in)

Post-Impact Vehicular Behavior

(*Data Analysis/Video Analysis*)

- Maximum Roll Angle: -5.32°/5.4°
- Maximum Pitch Angle: -3.48°/3.4°
- Maximum Yaw Angle: -32.14°/-26.7°

Test Data

- ASI: 1.03
- Vehicle Exterior:
  - VDS[4,5]: RFQ-7, RD-4
  - CDC[6]: 01RDES7
- Vehicle Interior:
  - O.C.D.I.[1]: RF0001010

Occupant Risk Values	*Longitudinal*	*Lateral*
Occupant Impact Velocity	6.08 m/s	-4.63 m/s
Ridedown Acceleration	-6.03g	-13.53g

Barrier Damage

The barrier suffered minor scratches caused by the vehicle. The tractor-trailer was pushed backwards slightly. A large section of sheet metal from the vehicle was wedged in-between the overlap in the box beams.

2.3 Discussion of Test Results

Each of the two tests conducted involved significant sheet metal damage. This was expected considering the reversed lap connection in the barrier elements for the top beam. The snagging of the sheet metal can probably be lessened if each of the beam elements were made to lap in the appropriate direction. However, this change would make a reverse hit even more damaging to the impacting vehicle.

The impact severity for Test 641 was above the tolerance suggested in NCHRP Report 350. In test 641 the vehicle's test inertial mass was 840 kg (1851.9 lbs). Combined with the impact speed and angle, the impact severity was calculated to be 21.9-kJ, which is 1.7-kJ above the positive tolerance listed in NCHRP Report 350. NCHRP Report 350 also states that if the impact severity exceeds the positive tolerance given the test does not have to be retested as long as the test meets the recommended evaluation criteria, see Table 2-3. With the increased mass the test vehicle 641 it is important to also evaluate the longitudinal and lateral accelerations more closely. Both the longitudinal and lateral accelerations were well within recommended limits. The accelerometer trace for Test 641 also indicated the impact with the tractor truck. The impact at this location is just as likely as a hit anywhere else on the barrier. However, since the main function of the PMWB is to protect the workers, and since the truck is just as vulnerable as it would be if it were only supporting a truck-mounted attenuator, the secondary impact with the cab is still in keeping with current practices for work zones.

Test 642 was conducted within the guidelines of NCHRP Report 350 and the results are discussed below.

2.3.1 General – Evaluation Methods

As stated earlier in this report, the testing conducted on the PMWB was chosen based on the NCHRP Report 350 Test Level 2 for longitudinal barriers, stipulates that crash test performance be assessed according to three evaluation factors: 1) Structural Adequacy, 2) Occupant Risk, and 3) Vehicle Trajectory. These evaluation factors are further defined by specific evaluation criteria and are shown for each test designation in Table 5.1 of NCHRP Report 350.

2.3.2 Structural Adequacy

The structural adequacy of the PMWB was acceptable. Both test vehicles were redirected and the barrier did not allow the vehicle to penetrate, underride, or override the barrier. Assessment summaries of the structural adequacy of the tests are given in TablesTable 2-3 andTable 2-4.

2.3.3 Occupant Risk

No detached elements, fragments, or other debris from the barrier would pose a risk to occupants or others. There was no significant occupant compartment deformation to either of the vehicles tested. The occupant impact velocities and ridedown accelerations were all within the specified limits for both tests. Please refer to Tables Table 2-3 and Table 2-4 for detailed assessment summaries of the occupant risk of the tests.

2.3.4 Vehicle Trajectory

The exit trajectory of the vehicle in test 641 led to a second impact with the tractor truck that transports and anchors the barrier. The data recorders recorded this second impact. Both the occupant impact velocities and ridedown accelerations were all within the specified limits. Refer to Figures 5-9 and 5-10 for plots of the velocities and accelerations of the second impact.

The exit angles of both tests were less than 60% of the initial impact angles. The exit trajectory of the vehicle in test 642 was acceptable. Table 2-2 gives more detail of the vehicles trajectories and speeds. See Table 2-3 and Table 2-4for the assessment summaries of the test vehicles trajectory evaluation.

Table 2-2 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)	Impact Severity (kJ)
641	21.5	12.9	0.9	70.9	57.7	13.2	21.9
642	25.2	15.1	1.5	69.6	45.9	23.7	66.4

Table 2-3 Test 641 Assessment Summary

Test No.	641
Date	February 25, 2003
Test Agency	California Department 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 form 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 injures should not be permitted.	There was no significant debris from the vehicle. There was no significant occupant compartment deformation.	Pass Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching, and yawing are acceptable.	The vehicle remained upright.	Pass
H. Occupant impact velocities (see Appendix A, Section A5.3 in NCHRP Report 350 for calculation procedure) should satisfy the following: Occupant Impact Velocity Limits (m/s) Component: Longitudinal and Lateral — Preferred: 9 — Maximum: 12	Long. Occ. Impt. Vel.= 2.21 m/s Lat. Occ. Impt. Vel.= -4.20 m/s	Pass Pass
I. Occupant ridedown accelerations (see Appendix A, Section A5.3 in NCHRP Report 350 for calculation procedure) should satisfy the following: Occupant Ridedown Acceleration Limits (g) Component: Longitudinal and Lateral — Preferred: 15 — Maximum: 20	Long. Occ. Rd. Acc. = -4.62 g Lat Occ. Rd. Acc. = 11.19 g	Pass Pass
Vehicle Trajectory		
K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	The vehicle did not intrude into adjacent traffic lanes.	Pass
M. The exit angle from the test article preferably should be less than 60 percent of the test impact angle, measured at time of vehicle loss of contact with test device.	The exit angle was 2.5º.	Pass

Table 2-4 Test 642 Assessment Summary

Test No.	642
Date	April 4, 2003
Test Agency	California Department 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 form 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 injures should not be permitted.			There was no significant debris from the vehicle. There was no significant occupant compartment deformation.	Pass Pass
F. The vehicle should remain upright during and after collision although moderate roll, pitching, and yawing are acceptable.			The vehicle remained upright.	Pass
H. Occupant impact velocities (see Appendix A, Section A5.3 in NCHRP Report 350 for calculation procedure) should satisfy the following:				
Occupant Impact Velocity Limits (m/s)				
Component	Preferred	Maximum	Long. Occ. Impt. Vel.= 6.08 m/s	Pass
Longitudinal and Lateral	9	12	Lat. Occ. Impt. Vel.= -4.63 m/s	Pass
I. Occupant ridedown accelerations (see Appendix A, Section A5.3 in NCHRP Report 350 for calculation procedure) should satisfy the following:				
Occupant Ridedown Acceleration Limits (g)				
Component	Preferred	Maximum		
Longitudinal and Lateral	15	20	Long. Occ. Rd. Acc. = -6.03 g Lat Occ. Rd. Acc. = -13.53 g	Pass Pass
Vehicle Trajectory				
K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.			The vehicle did not intrude into adjacent traffic lanes.	Pass
M. The exit angle from the test article preferably should be less than 60 percent of the test impact angle, measured at time of vehicle loss of contact with test device.			The exit angle was 1.5º	Pass

3 CONCLUSIONS

Based on the physical crash testing involved in this project the following conclusions can be drawn:

1. The Portable Maintenance Work-Zone Barrier (PMWB) can successfully contain and redirect an 820-kg small car impacting at 20º and 70 km/h. The occupant impact velocities, ridedown accelerations, and minor compartment deformation where still within the guidelines given in NCHRP Report 350.

2. The PMWB can successfully contain and redirect a 2000-kg pickup truck impacting at 25º and 70 km/h.

3. Damage to the PMWB in accidents similar to the tests conducted in this report will result in small to moderate amounts of scraping and gouging of the barrier's box beams. Varying amounts of vehicle sheet metal will accumulate at the overlapping joint of the box beams and will have to be removed before the barrier can be redeployed.

4. Although there are no specified testing criteria for this type of barrier, the PMWB 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 2 for Longitudinal Barriers.

In test 641 (small car) all of the barrier structural adequacy, occupant risk, and vehicle trajectory criteria, as outlined in NCHRP Report 350, were within acceptable limits. The exit angle was small enough and even with a secondary impact 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 remained upright throughout the test.

In test 642 (pickup truck) all of the barrier structural adequacy, occupant risk, and vehicle trajectory criteria, as outlined in NCHRP Report 350, were within acceptable limits. None of the detached pieces of the vehicle penetrated the passenger compartment of the test vehicle.

4 RECOMMENDATIONS

1. Based on the computer modeling and the limited full-scale crash testing, it is recommended that the PMWB (also known as the Balsi Beam) be approved for use in locations where appropriate. These locations should be evaluated to ensure that the potential for vehicle impacts to not exceed Test Level 2 conditions (i.e. under 70 km/h (43 mph).
2. It is also recommended that the PMWB be evaluated through field-testing under closely monitored conditions. This monitoring should be done to discern any potential problems in deployment and handling.
3. It is also recommended that the PMWB be outfitted with a truck-mounted attenuator (TMA) and followed with a shadow vehicle that also has a TMA. This is recommended because no testing was done on the PMWB to ensure that a rear hit on a deployed system will not collapse the system.

5 IMPLEMENTATION

The PMWB should be placed under joint control between the Division of Equipment and Maintenance Operations with oversight by Division of Research and Innovation until it is fully operational. Once fully operational, the PMWB should be under the control of the Maintenance Operations.

6 REFERENCES

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

2. D.L. Sicking, H.E. Ross Jr., D.L. Ivey and T.J. Hirsch. "A Portable Traffic Barrier for Work Zones", *Research Report 262-3*, Texas Transportation Institute, A&M University, College Station, May 1982.

3. W.L. Beason and H.E. Ross. "Development of a Truck-Mounted Portable Maintenance Barrier", *Research Report 262-5*, Texas Transportation Institute, A&M University, College Station, May 1984.

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

5. "Vehicle Damage Scale for Traffic Crash Investigators", Crash Records Bureau, Texas Department of Public Safety, 2006.

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

7 APPENDICES

7.1 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. A safety gas tank was installed in the truck bed of the Chevy and the back seat of the Metro. The safety tank was then connected to the fuel supply line. The stock fuel tanks had gaseous CO_2 added in order to purge the fuel vapors and eliminate oxygen.
- A 12-volt, gel-cell battery was mounted in the vehicles. The battery operated the solenoid-valve braking/accelerator system, powered the rate gyros and the electronic control box. A second pair of 12-volt, deep cycle gel-cell batteries powered the transient data recorders.
- A 2400-kPa (350-psi) CO_2 system, actuated by a solenoid valve, controlled remote braking after impact and could have been used for emergency braking if necessary. Part of this system includes 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 would apply in less than 100 milliseconds.
- The brakes were applied via radio control. When the remote activates the brakes, the ignition is automatically rendered inoperable by removing power to the coil. The braking system would also automatically engage in the event of a lost signal between the transmitter and the receiver.
- The vehicles were self-propelled and an accelerator switch was located on the driver side above the rear tire of both vehicles. 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. In order to keep the gas pedal from depressing too quickly, a valve was used to adjust CO_2 flow rate to the accelerator ram.
- A speed control device, connected in-line with the primary winding of the coil, was used to regulate the speed of the test vehicles 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 trials runs through a speed trap comprised of two tape-switches set at a specified distance apart and a digital timer.

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

Table 7-1 Test 641: Vehicle Specifications

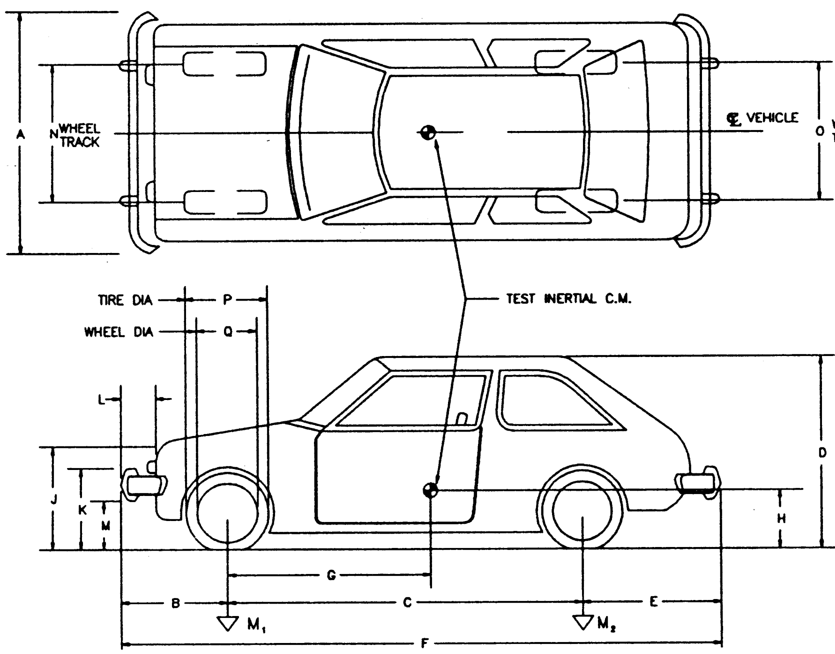
DATE: 03/10/2003 TEST NO.: 641 VIN: SG1MR6466LK742509 MAKE: GEO

MODEL: METRO YEAR: 1989 ODOMETER: 35163 mi TIRE SIZE: 155R12

TIRE INFLATION PRESSURE (psig): 35

MASS DISTRIBUTION (kg): LF: 254 RF: 239 LR: 150 RR: 147

DESCRIBE ANY DAMAGE TO VECHILE PRIOR TO TEST: None



ENGINE TYPE: 3cyl

ENGINE: 1000CC

TRANSMISSION TYPE:

● AUTO

MANUAL

OPTIONAL EQUIPMENT:
AIR CONDITIONER

DUMMY DATA:

TYPE: Male Hybrid III

MASS: 74.8 kg

SEAT POSITION: Right Front

GEOMETRY (mm)

A 1500	D 1370	G 937	K 510	N 1360	Q 330
B 730	E 660	H	L 90	O 1350	
C 2370	F 3760	J 670	M 390	P 540	

MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M1	493 kg	508 kg	557 kg
M2	297 kg	332 kg	358 kg
MT	790 kg	840 kg	915 kg

Table 7-2 Test 642: Vehicle Specifications

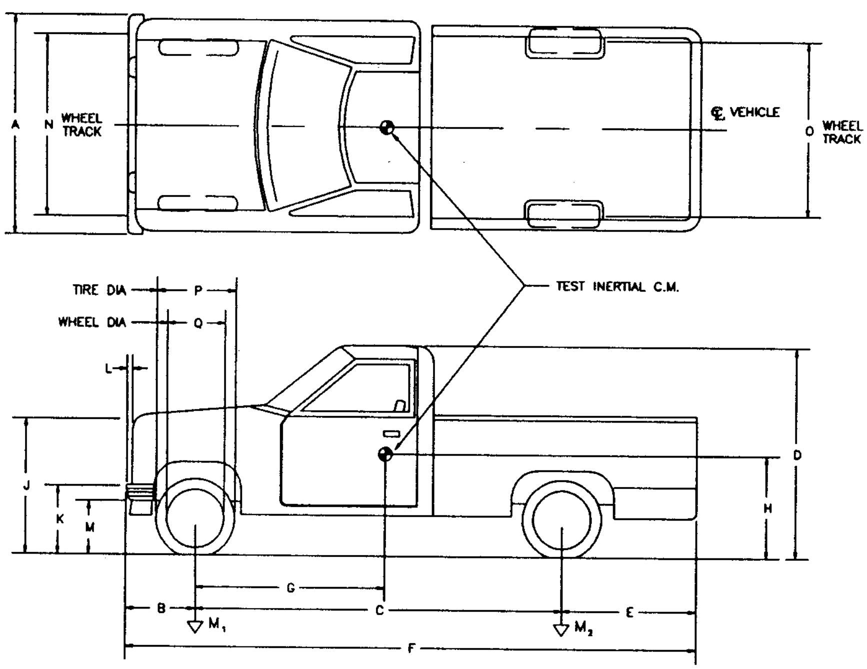
DATE: 03/20/2003 TEST NO.: 642 VIN: 1GCFC2443R2263122 MAKE: Chevy

MODEL: 2500 PU YEAR: 1994 ODOMETER: 18710 mi TIRE SIZE: LT225175R16

TIRE INFLATION PRESSURE (psig): 55

MASS DISTRIBUTION (kg): LF: 524 RF: 550 LR: 396 RR: 351

DESCRIBE ANY DAMAGE TO VECHILE PRIOR TO TEST: None



ENGINE TYPE: U8

ENGINE CID: 305

TRANSMISSION TYPE:

● AUTO

MANUAL

OPTIONAL EQUIPMENT:
AIR CONDITIONER

DUMMY DATA:

TYPE:

MASS:

SEAT POSITION:

GEOMETRY (mm)

A 1910	D 1780	G 1485	K 615	N 1585	Q 440
B 830	E 1330	H	L 80	O 1610	
C 3350	F 5510	J 1025	M 415	P 730	

MASS – (kg)	CURB	TEST INERTIAL	GROSS STATIC
M1	1074 kg	1092 kg	1092 kg
M2	747 kg	870 kg	870 kg
MT	1821 kg	1962 kg	1962 kg

7.2 Test Vehicle Guidance System

A rail guidance system directed the vehicles into the barrier. The guidance rail, anchored at 3.8 m (12.5 ft) intervals along its length, was used to guide a mechanical arm that is attached to the front driver side wheel of the each of the vehicles. A 10-mm (0.375-in) nylon rope was used to trigger the release mechanism on the guidance arm, thereby releasing the vehicle from the guidance system before impact, see Figure 7-1.

Figure 7-1 Vehicle Guidance System

7.3 Photo - Instrumentation

Several high-speed movie cameras recorded the impact during the crash tests. The types of cameras and their locations are shown in Table 7-3 and Figure 7-2. All of these cameras were mounted on tripods except the three that were mounted on a 10.7-m (35.1-ft) high tower directly over the impact location.

A manually operated video camera and digital SLR camera were used to pan through the movement of the vehicle during the test. A tape-switch inline with the vehicle's tire path near the impact area remotely triggered the high-speed digital cameras. Both vehicles and the barrier were photographed before and after impact with a digital video camera and a digital SLR camera. A video report of this project has been assembled using selected portions of the crash testing coverage.

Table 7-3 Typical Camera Type and Locations

Typical Coordinates								
Camera Label	Camera Type	Figures 5-2 & 5-3 Labels	Test 641			Test 642 (similar to 641)		
			X*	Y*	Z*	X*	Y*	Z*
V1 (Upstream)	Weinberger SpeedCam Visario 1500	A	28.3	0	1.4			
V2 (Downstream)	Weinberger SpeedCam Visario 1500	B	-29.8	0	1.4			
V3 (Across)	Weinberger SpeedCam Visario 1500	C	-5.1	-18.2	1.4			
Behind	NOT USED	D	--	--	--	--	--	--
V4 (Tower Upstream)	Weinberger SpeedCam Visario 1500	E	0.61	0	9.1			
V5 (Tower Center)	Weinberger SpeedCam Visario 1500	F	0	0	9.1			
V6 (Tower Downstream)	Weinberger SpeedCam Visario 1500	G	-0.61	0	9.1			
J (Pan Digital Camera)	Canon XL-1	H	-3.1	-18.4	4.5			
N (Digital SLR Camera)	Nikon D2X	I	-1.6	-18.4	4.5			
Note: *X, Y, and Z distances are relative to the impact point.								

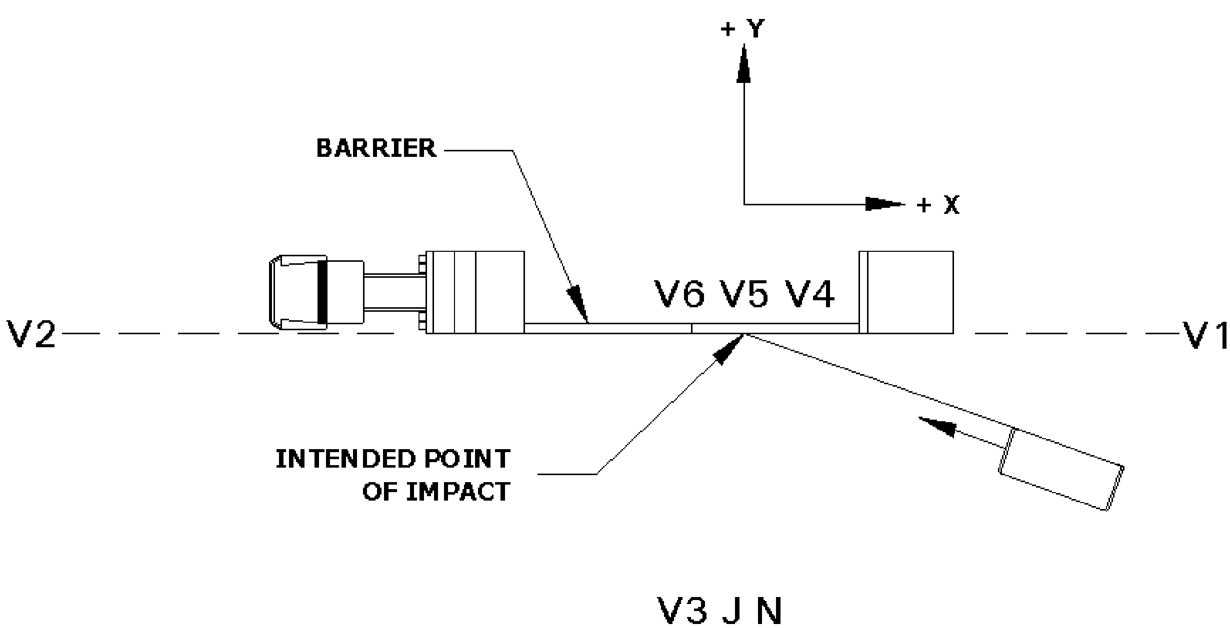


Figure 7-2 Camera Locations Test 641 (Not to Scale)

The following are the pretest procedures that were required to enable film data reproduction to be performed using film motion analyzer or video analysis software:

1) Quad targets were attached to the top and sides of the test vehicles. The targets were located on the vehicle at intervals of 0.5 m and 1.0 m (1.64 ft and 3.28 ft). The targets established scale factors and horizontal and vertical alignment.
2) Flashbulbs, mounted on the test vehicles, were electronically triggered to establish a) initial vehicle-to-article contact, and b) the time of the application of the vehicle brakes. The flashbulbs begin to glow immediately upon activation, but have a delay of several milliseconds before lighting up to full intensity.
3) High-speed digital video cameras were all time-coded through the use of a portable computer and were triggered as the test vehicle passed over a tape switch located on the vehicle path upstream of impact.

7.4 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 vehicles. The transducers mounted on the vehicles include two sets of accelerometers at the center of gravity and one set of rate gyros 191 mm (7.5 in) behind the C.G. (along the x-axis). The TDR data was reduced using a desktop personal computer running DADiSP 4.1.

Accelerometer and gyro specifications are shown in Table 7-4. The vehicle accelerometer sign convention used throughout this report is the same that is described in NCHRP Report 350 and is shown on Figure 7-3.

A rigid stand with three retro reflective 90º polarizing tape strips was placed on the ground near the test article and alongside the path of the test vehicles, Figure 7-4. The strips were spaced at carefully measured intervals of 1.0 m (3.28 ft). The test vehicles had an onboard optical sensor that produced sequential impulses or "event blips" that were recorded concurrently with the accelerometer signals on the TDR, serving as "event markers". The impact velocity of the vehicles could be determined form 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 vehicles 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 vehicles were activated. Two other pressure sensitive tape switches, connected to a speed trap, were placed 4.0 m (13.1 ft) apart just upstream of the test article specifically to establish the impact speed of the test vehicles. The layout for all of the pressure sensitive tape switches is shown in Figure 7-4.

The data curves are shown in Figure 7-5 through Figure 7-12 and include the accelerometer and rate gyro records from the test vehicles. They also show the velocity and displacement curves for the longitudinal and lateral components. These plots were needed to calculate the occupant impact velocity defined in NCHRP Report 350. All data were analyzed using software written by DADiSP and modified by Caltrans.

Table 7-4 Accelerometer Specification for Tests 641 and 642

TYPE	LOCATION	RANGE	ORIENTATION	TEST NUMBER
Endevco	Vehicle's C. G.	100 G	Longitudinal (primary)	641 & 642
Endevco	Vehicle's C. G.	100 G	Lateral (primary)	641 & 642
Endevco	Vehicle's C. G.	100 G	Vertical (primary)	641 & 642
Endevco	Vehicle's C. G.	100 G	Longitudinal (secondary)	641 & 642
Endevco	Vehicle's C. G.	100 G	Lateral (secondary)	641 & 642
Endevco	Vehicle's C. G.	100 G	Vertical (secondary)	641 & 642
Humphrey	191 mm (7.5-in) behind the C.G. (along the X-axis)	500 deg/s	Roll	641 & 642
Humphrey	191 mm (7.5-in) behind the C.G. (along the X-axis)	500 deg/s	Pitch	641 & 642
Humphrey	191 mm (7.5-in) behind the C.G. (along the X-axis)	500 deg/s	Yaw	641 & 642

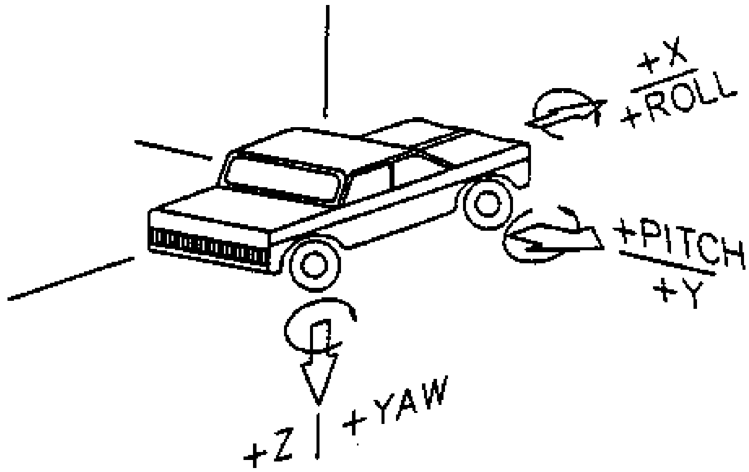


Figure 7-3 Vehicle Accelerometer Sign Convention

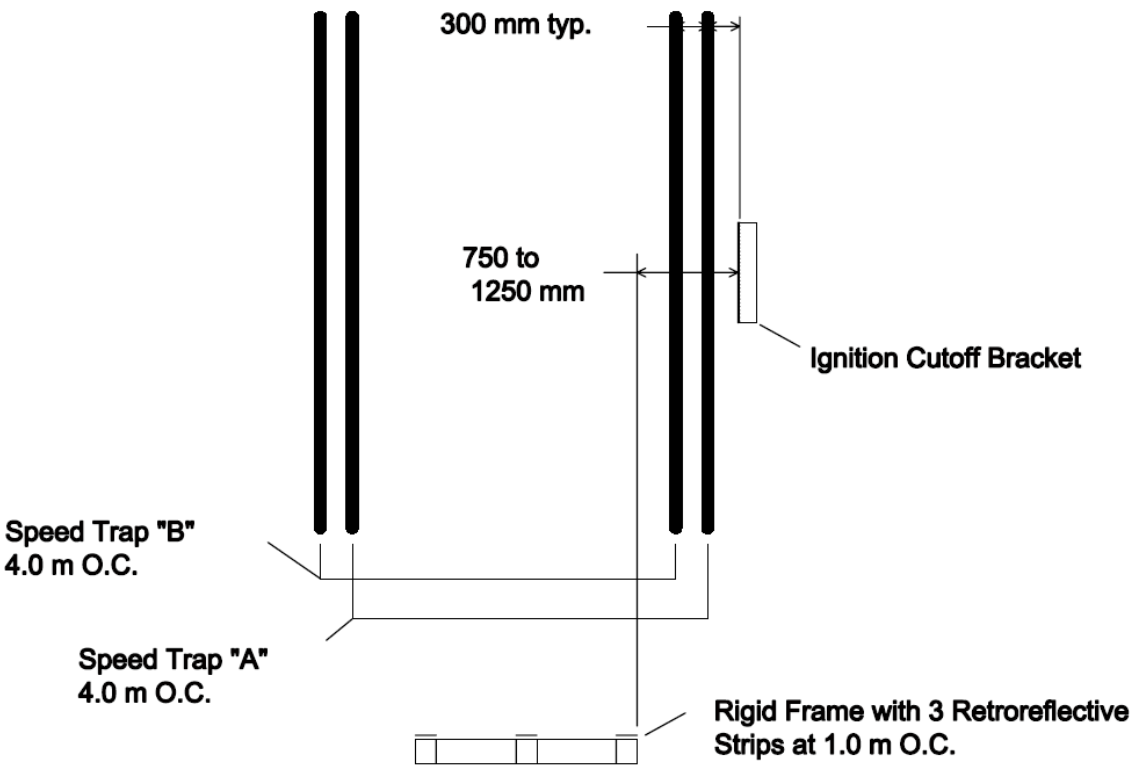


Figure 7-4 Event Switch Layout

7.5 Accelerometer and Rate Gyro Plots

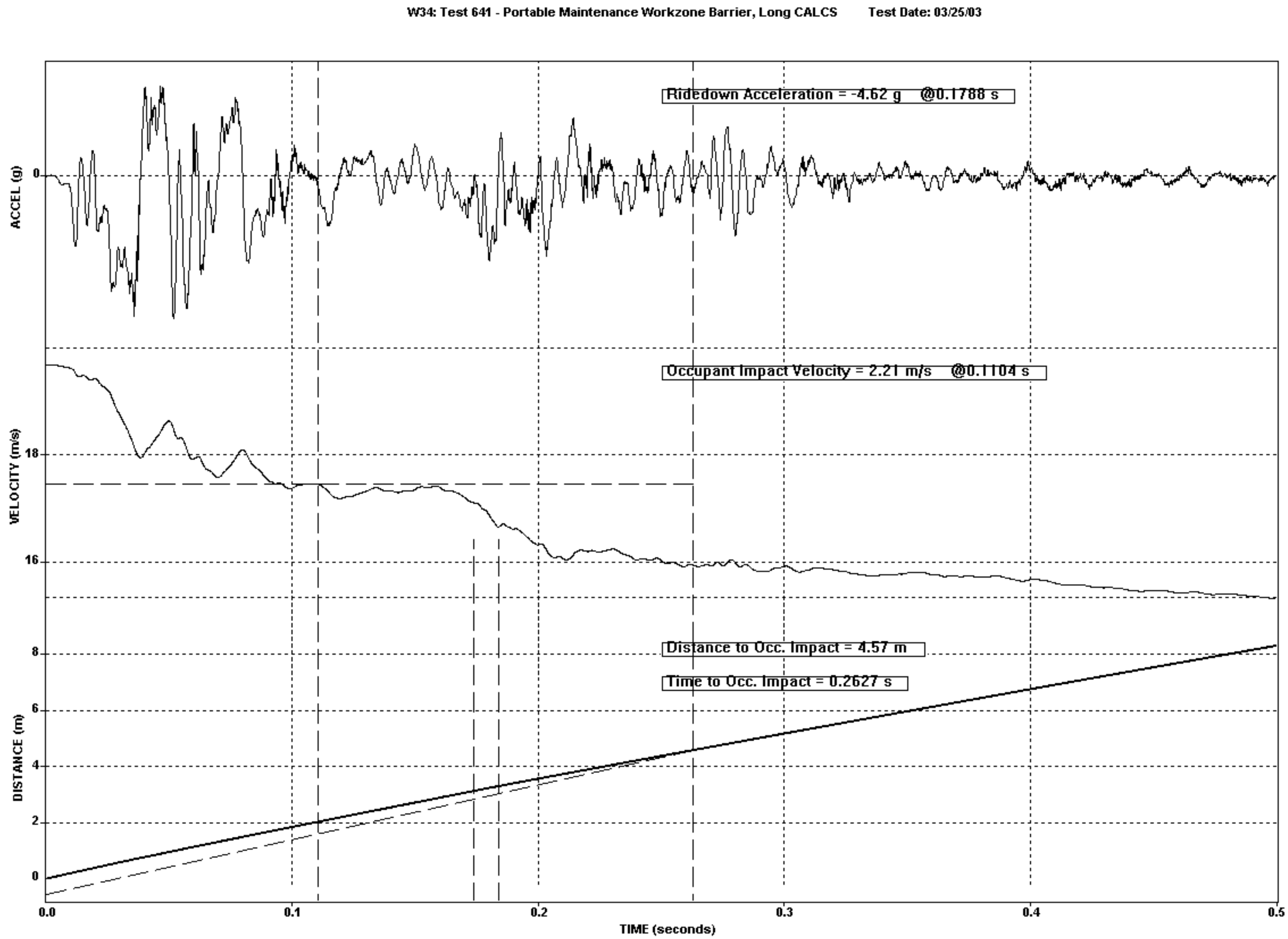


Figure 7-5 Test 641 Vehicle Longitudinal Acceleration, Velocity, and Distance -Vs- Time

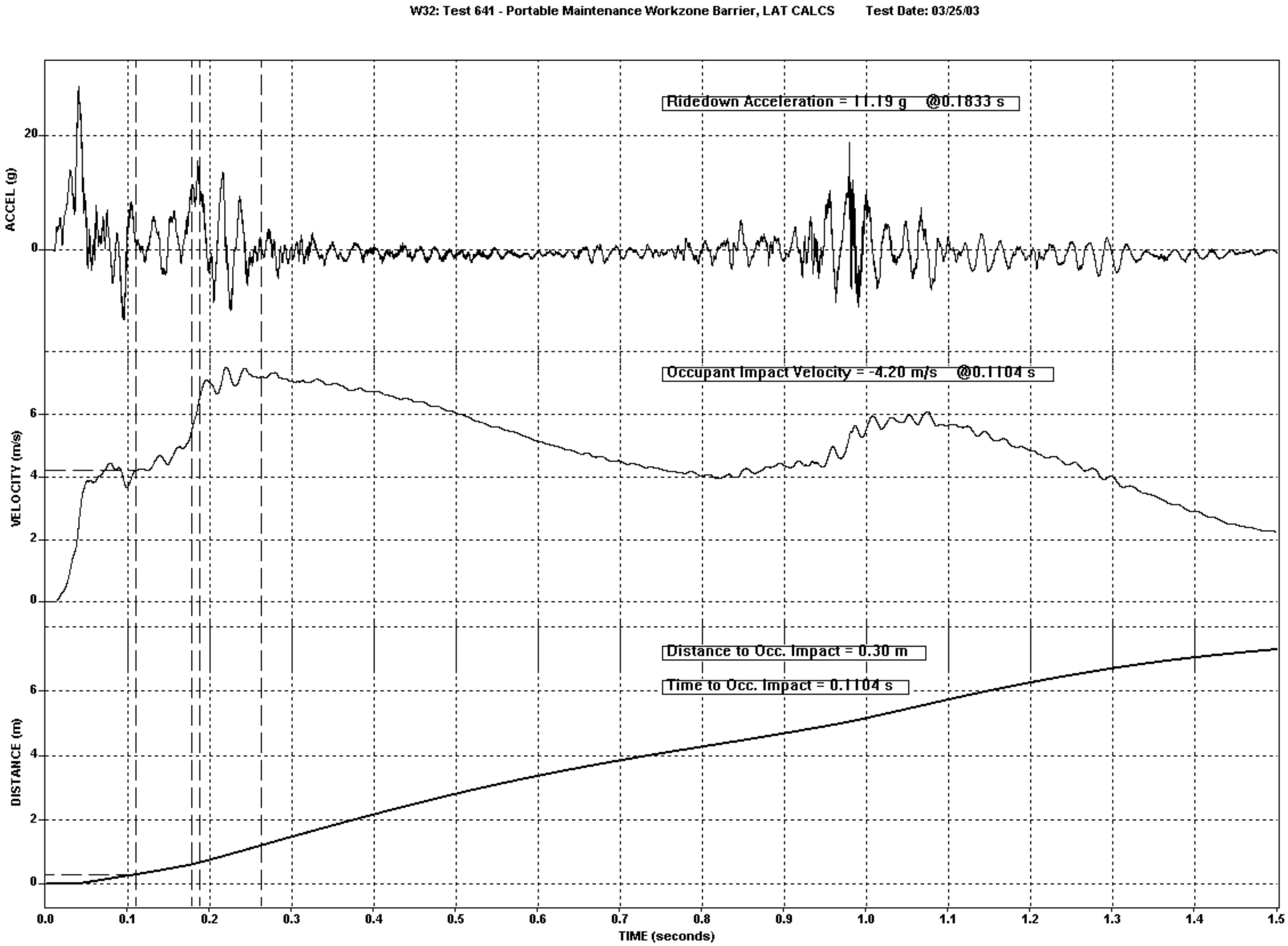


Figure 7-6 Test 641 Vehicle Lateral Acceleration, Velocity, and Distance -Vs- Time

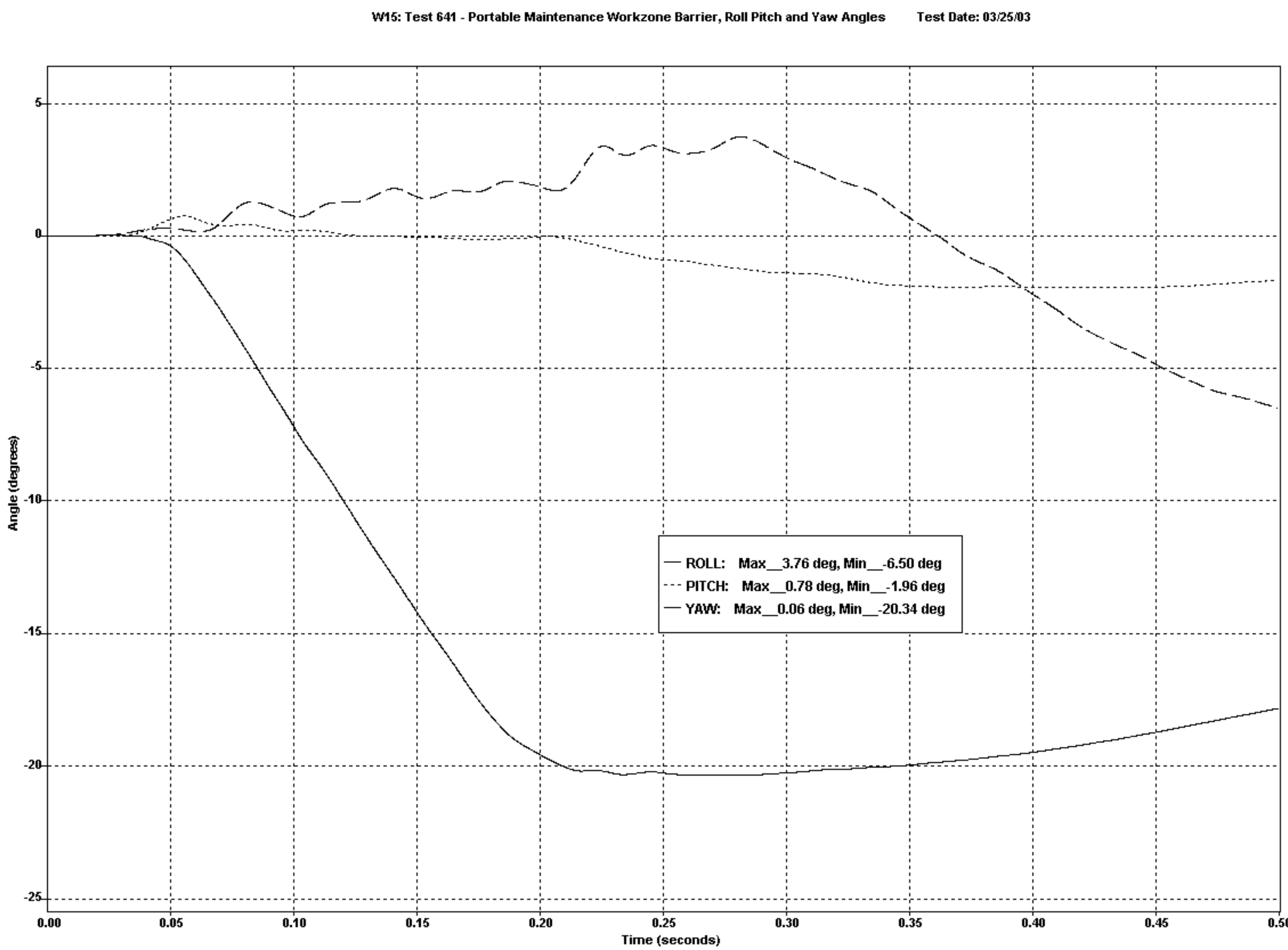


Figure 7-7 Test 641 Vehicle Roll, Pitch, and Yaw -Vs- Time

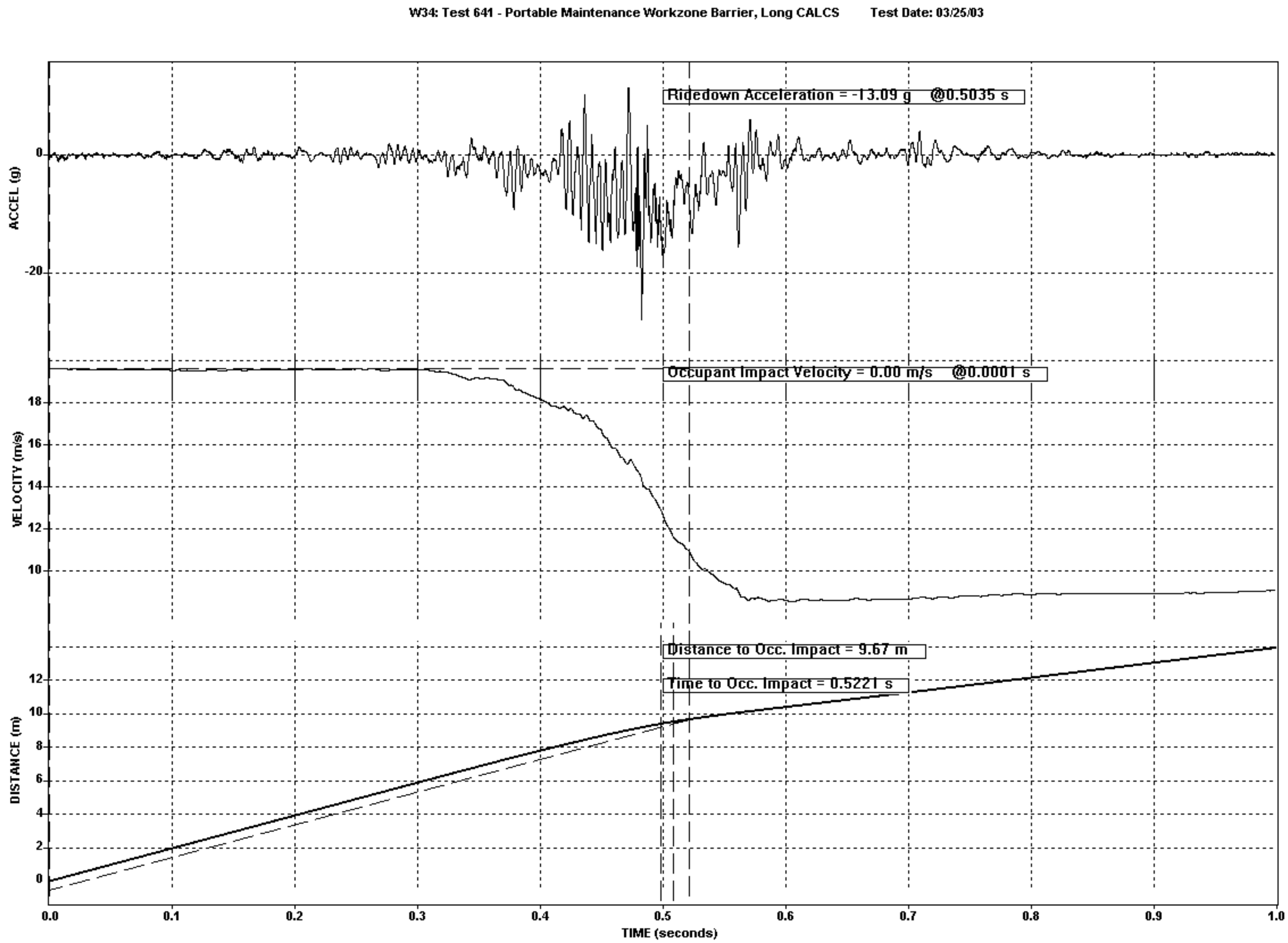


Figure 7-8 Test 641 Second Impact Vehicle Longitudinal Acceleration, Velocity, and Distance -Vs- Time

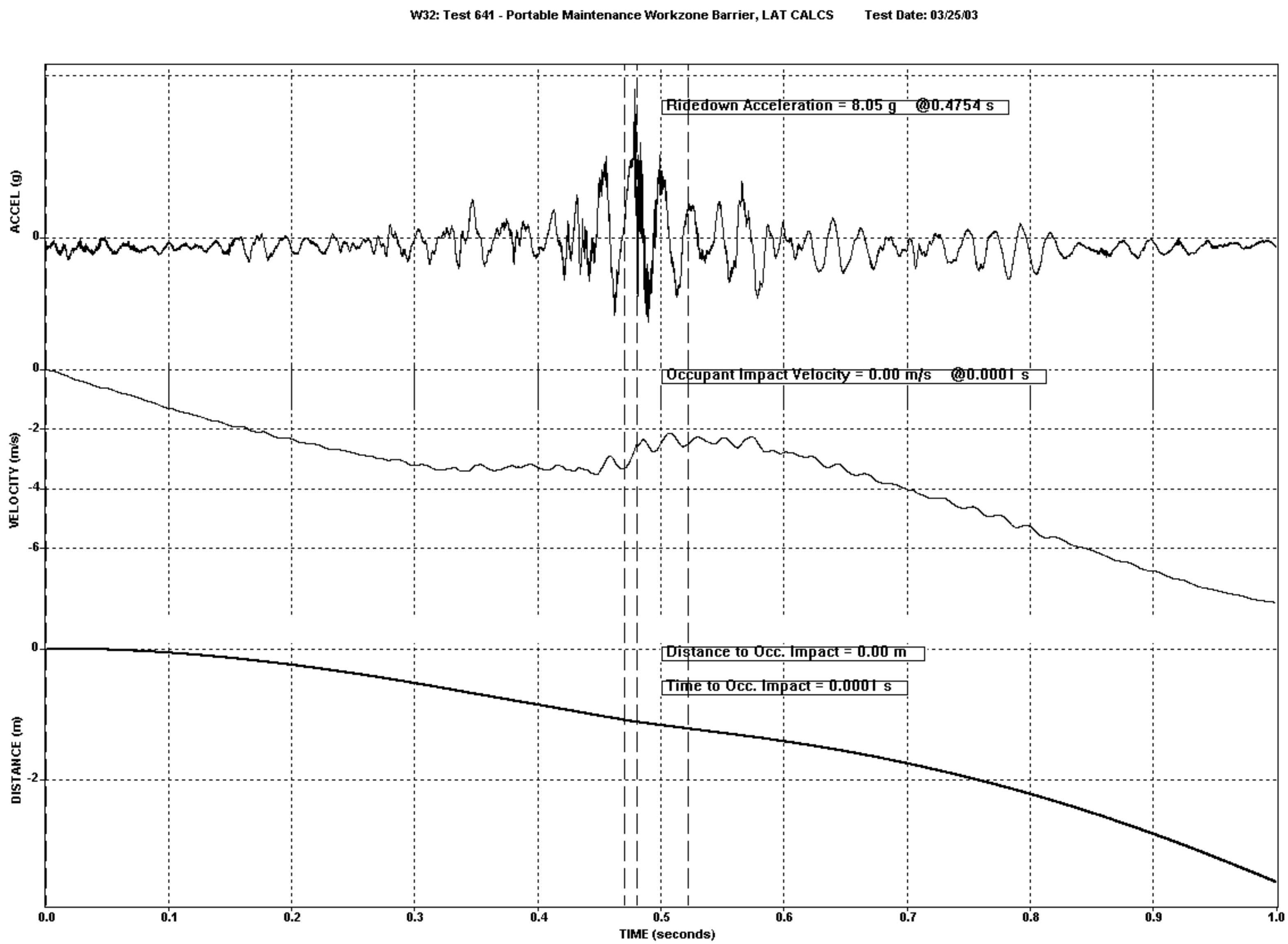


Figure 7-9 Test 641 Second Impact Vehicle Lateral Acceleration, Velocity, and Distance -Vs- Time

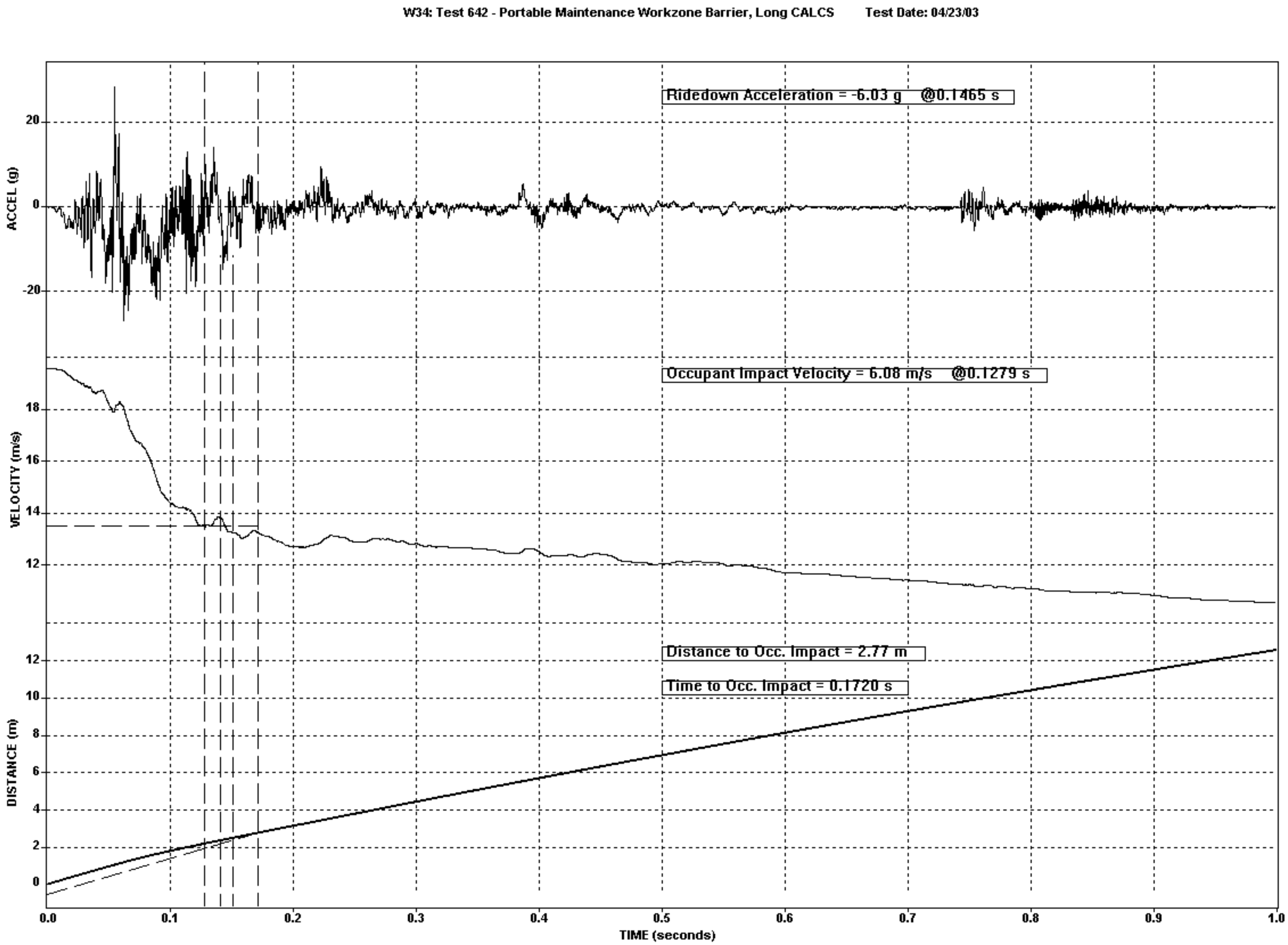


Figure 7-10 Test 642 Vehicle Longitudinal Acceleration, Velocity, and Distance -Vs- Time

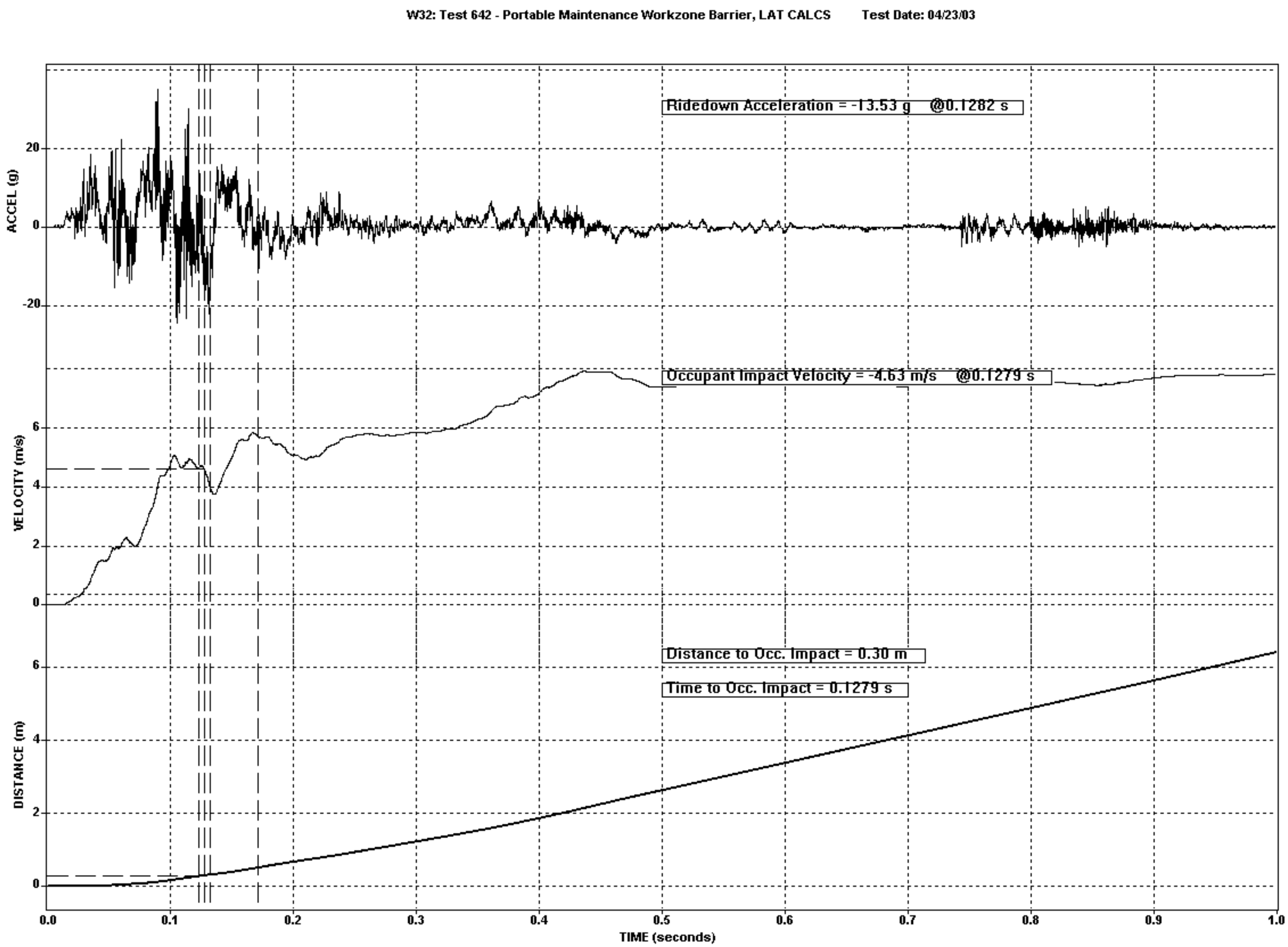


Figure 7-11 Test 642 Vehicle Lateral Acceleration, Velocity, and Distance -Vs- Time

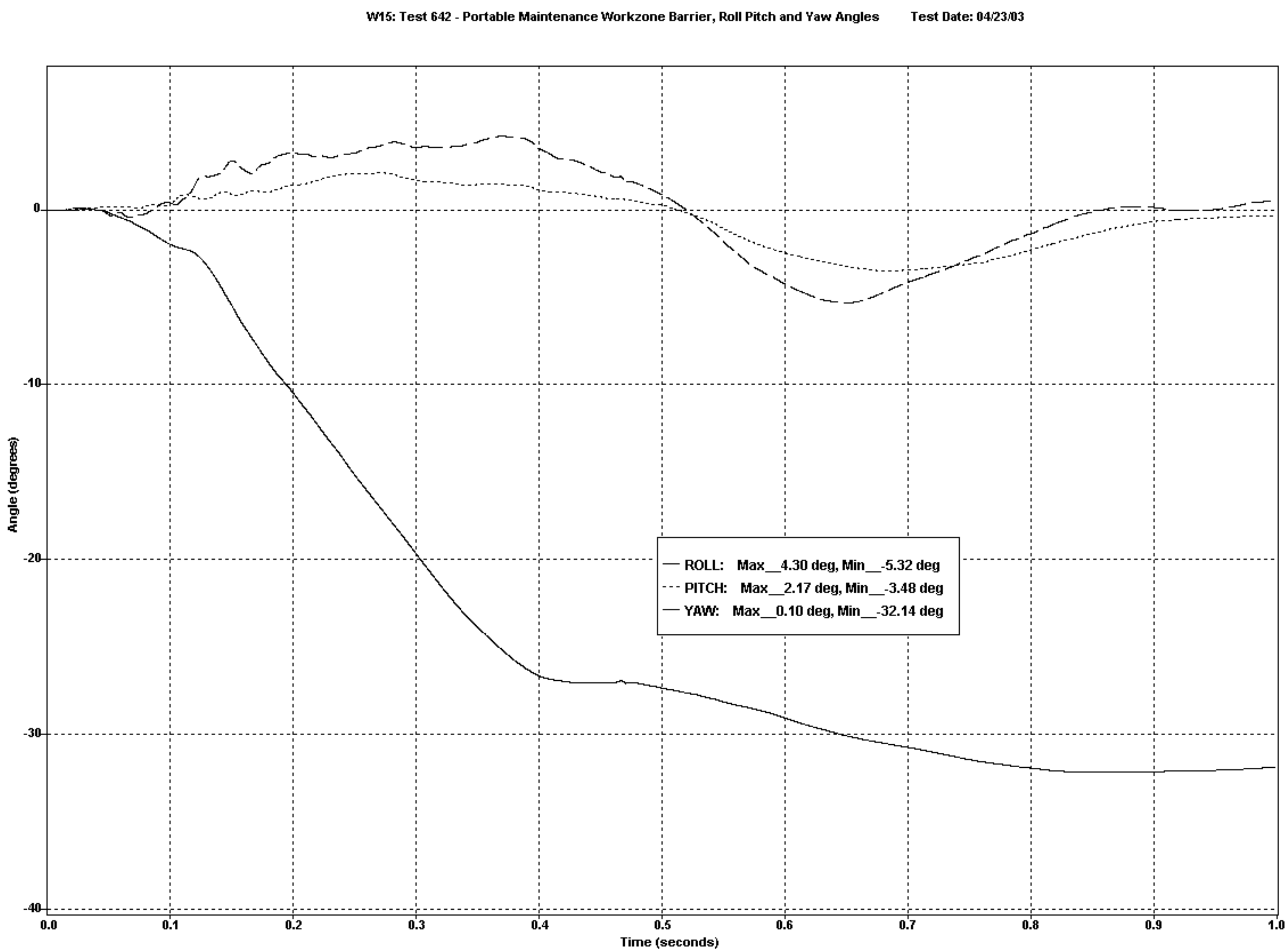


Figure 7-12 Test 642 Vehicle Roll, Pitch, and Yaw -Vs- Time

7.6 Computer Modeling Summary and Results

7.6.1 Introduction

The purpose of this analysis was to help assess the crashworthiness of the portable maintenance work-zone barrier during the design process of the prototype. This analysis was based on the preliminary design details from the Caltrans Division of Equipment concept proposal drawings dated 10/2001. The analysis focuses on the structural adequacy of the beam elements comprising the barrier, and on its ability to redirect an impacting pickup truck. This analysis was accomplished by using LS_DYNA finite element models in a simulation of NCHRP Report 350 crash test 2-11. The simulated crash test involves a 2000-kg pickup truck impacting a longitudinal barrier at 70-km/h and 25 degrees. Three different simulations were run, all following test 2-11 conditions, but at different impact points along the barrier. Table 7-5 shows the test matrix where the impact locations are approximately where the right front bumper of the truck contacted the barrier.

Table 7-5 Computer Modeling Test Matrix

Simulation Designation	Impact Point
WZTrlr_211_US03	Impact at the upstream support
WZTrlr_211_MidX	Impact at mid-span (center of the beam overlap section)
WZTrlr_211_DSX	Impact just downstream from the beam overlap section

7.6.2 Simulation Results

7.6.2.1 Simulation WZTrlr_211_US03

The crash test simulation at the upstream support ran with no apparent numerical analysis problems. Figure 7-13 shows initial orientation of the crash test simulation. Global energy totals seem realistic, with hourglass energy (HE) less than 10% of the internal energy (IE). Some individual parts registered very high HE with respect to IE, but these are small parts in the truck, and insignificant. The pickup truck was contained and redirected without penetration, overriding or underriding the barrier, see Figure 7-14. The maximum dynamic lateral deflection of the barrier was just less than 70 mm. The vehicle showed no precarious instability after impact. The simulation was only run for 400 ms due to the long CPU run time, but initial redirection angle of the vehicle appeared to be satisfactory. The longitudinal occupant impact velocity (OIV) was 4-m/s and the lateral OIV was less than 1 m/s, both well below the limit of 12-m/s. The longitudinal ridedown acceleration was 9.1 g's and the lateral was 16.2 g's, both below the limit of 20 g's.

From the results of this computer analysis, it appears that a physical crash test conducted under the same parameters and conditions would pass. There is no guarantee, however, that these results would be replicated in a real test. This model has not been validated against experiential data since there are no known crash tests conducted with a similar test article. Given available data, this analysis is one of the best ways to determine crashworthiness of the design prior to physical testing.

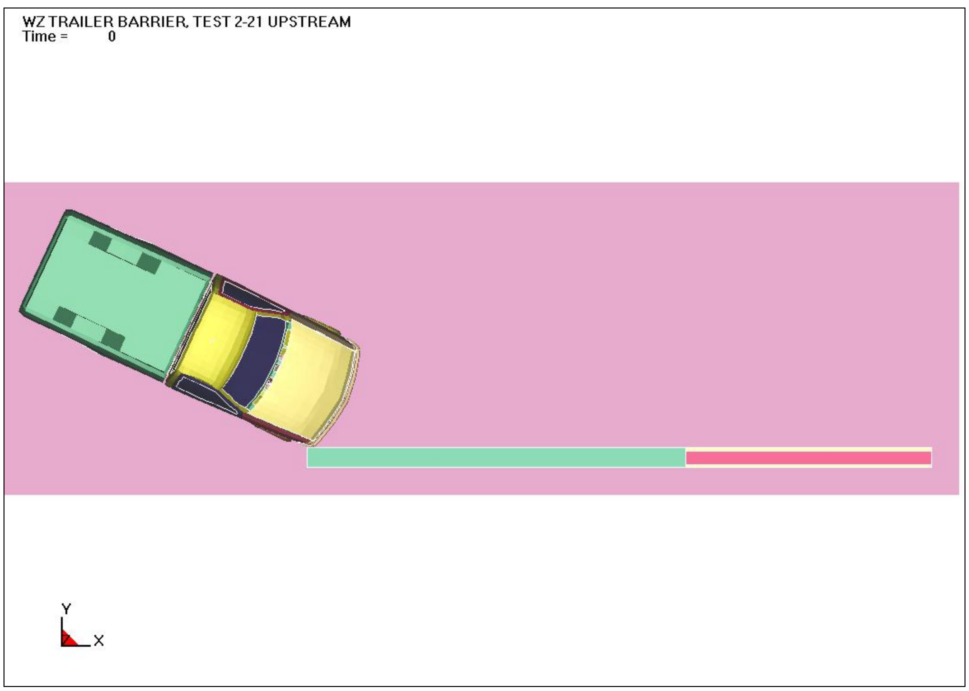


Figure 7-13 Initial Orientation in Plan View for the Upstream Impact Simulation

Figure 7-14 Upstream Impact Simulation Impact Sequence

7.6.2.2 Simulation WZTrlr_211_MidX

This crash test simulation at mid-span ran with no apparent numerical analysis problems. Figure 7-15 shows initial orientation of the crash test simulation. Global energy totals seem realistic, with HGE less than 10% of IE. Some individual parts registered very high HGE with respect to IE, but these are small parts in the truck, and insignificant. The pickup truck was contained and redirected without penetration, overriding or underriding the barrier, see Figure 7-16. The maximum dynamic lateral deflection of the barrier was about 190 mm. The vehicle showed no precarious instability after impact. The simulation was only run for 400 ms due to the long CPU run time, but initial redirection angle of the vehicle appeared to be satisfactory. The longitudinal OIV was 4.3 m/s and the lateral OIV was 1.06 m/s, both well below the limit of 12-m/s. The longitudinal ridedown acceleration was 4.5 g's and the lateral was 10.2 g's, both below the limit of 20-g's.

From the results of this computer analysis, it appears that a physical crash test conducted under the same parameters and conditions would pass. There is no guarantee, however, that these results would be replicated in a real test.

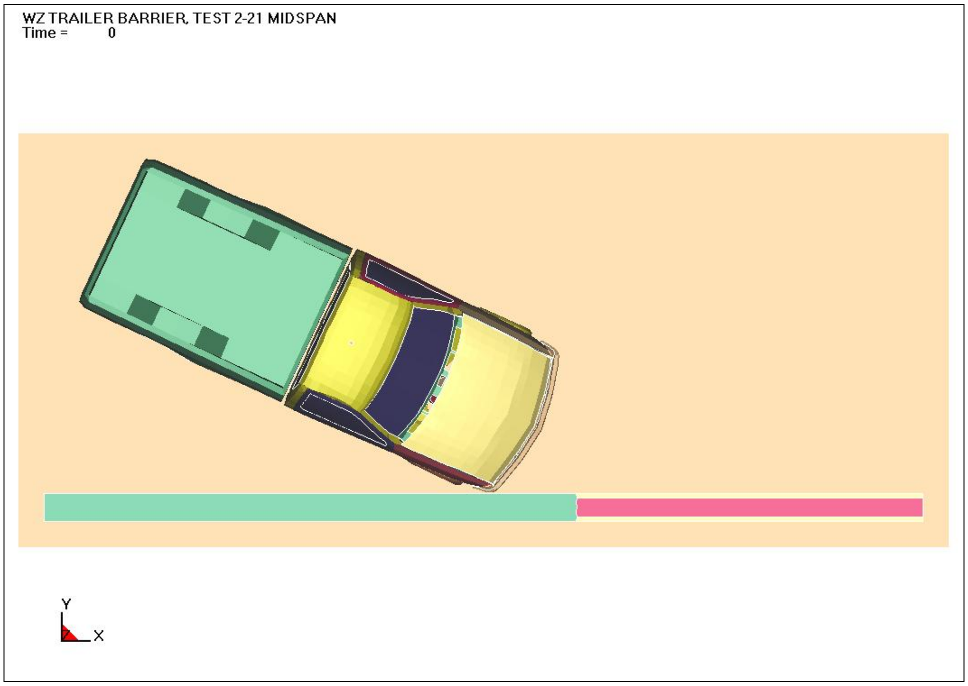


Figure 7-15 Initial Orientation in Plan View for the Mid-Span Impact Simulation

Figure 7-16 Mid-Span Impact Simulation Impact Sequence

7.6.2.3 Simulation WZTlrl_211_DSX

This crash test simulation with impact just downstream from the overlap section ran with no apparent numerical analysis problems. Figure 7-17 shows initial orientation of the crash test simulation. Global energy totals seem realistic, with HGE less than 10% of IE. Some individual parts registered very high HGE with respect to IE, but these are small parts in the truck, and insignificant. The pickup truck was contained and redirected without penetration, overriding or underriding the barrier, see Figure 7-18. The maximum dynamic lateral deflection of the barrier was about 185 mm. The vehicle showed no precarious instability after impact. The simulation was only run for 400 ms due to the long CPU run time, but initial redirection angle of the vehicle appeared to be satisfactory. The longitudinal OIV was 4.1 m/s and the lateral OIV was 0.868-

m/s, both well below the limit of 12-m/s. The longitudinal ridedown acceleration was 5.1 g's and the lateral was 13.3 g's, both below the limit of 20-g's.

From the results of this computer analysis, it appears that a physical crash test conducted under the same parameters and conditions would pass. There is no guarantee, however, that these results would be replicated in a real test.

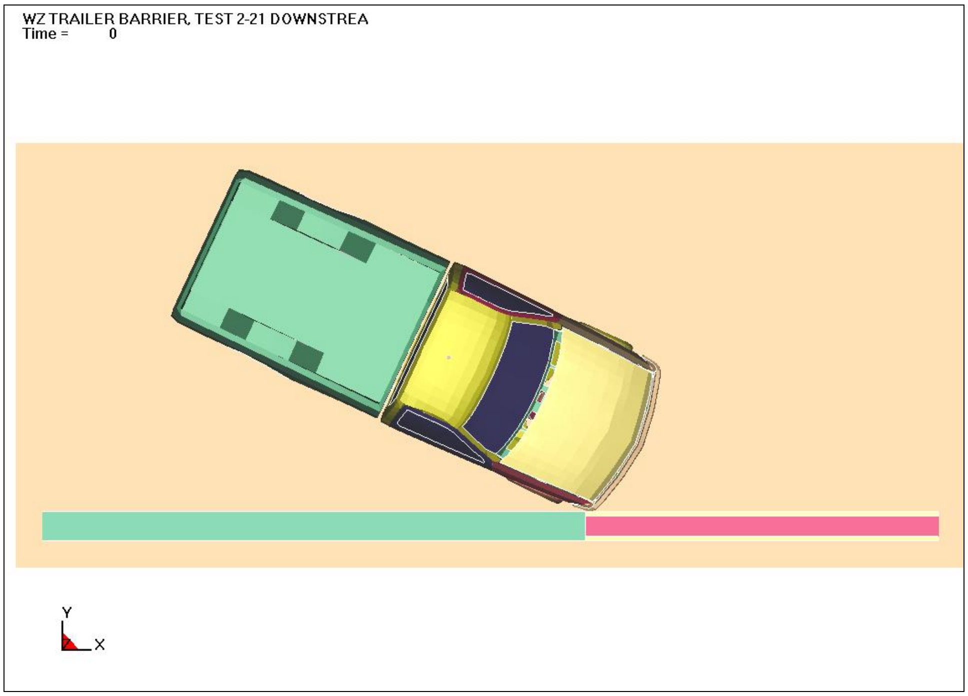


Figure 7-17 Initial Orientation in Plan View for the Downstream Impact Simulation

Figure 7-18 Downstream Impact Simulation Impact Sequence

7.6.3 Conclusion

All three simulations of crash tests indicate that the steel beams comprising the barrier in this work zone protection concept will adequately redirect the vehicle without failure in a test NCHRP Report 350 test level 2 collision. It should be noted that the modeled test article only represented the steel beam barrier of the trailer, and was fixed at the barrier ends for all three impacts. As a component of the trailer sitting on pavement, the barrier would actually have much higher total deflections but see less stress and strain. The impacting vehicle would likely cause the whole trailer to shift and skid on the pavement, thus transferring impact energy beyond the barrier beams. Hence this analysis for structural adequacy is a more conservative case for strength, but does not address the issue of overall deflections into the work zone. Further analyses will be required to completely assess the crashworthiness of the design before testing.

7.7 Detail Drawings

Detailed Drawings for the Portable Maintenance Work-Zone Barrier are available through the California Department of Transportation's Division of Equipment.