STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
ENGINEERING SERVICE CENTER,
DIVISION OF MATERIALS ENGINEERING AND TESTING SERVICES

COMPLIANCE CRASH TESTING OF K-RAIL USED IN SEMI-PERMANENT INSTALLATIONS

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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 K-RAIL USED IN SEMI-PERMANENT INSTALLATIONS".

16. ABSTRACT

A semi-permanent K-rail barrier was tested in accordance with NCHRP Report 350. The barrier consisted of eight concrete segments 6045 mm in length. The segments were placed on AC pavement and connected with 61.8 x 660 - mm pins. Each segment was then secured to the ground using four 25 x 610-mm steel stakes. The barriers were constructed and tested at the Caltrans Dynamic Test Facility in West Sacramento, California.

A total of two crash tests were conducted under Report 350 test level 3, one with an 820 kg sedan, and one with a 2000-kg pickup truck. The results of both tests were within the limits of the Report 350 criteria.

It is recommended that the semi-permanent K-rail be approved for use on California State highways where semi-permanent TL–3 barriers are required.

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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
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	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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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

1.1. Problem

The Federal Highway Administration has established a number of deadlines by which roadside safety hardware will have to comply with the crash testing criteria embodied in the National Cooperative Highway Research Program (NCHRP) Report 350[1]. Two deadlines must be met regarding the use of temporary barrier (K-rail). The deadline for K-rail used in semi-permanent installations is October 1, 1998, while the deadline for temporary K-rail as used in work zones is October 1, 2002. Caltrans does not have an approved construction barrier that will meet NCHRP Report 350 Test Level 3 criteria for either the temporary or the semi-permanent applications. In the near term, this could result in the loss of federal funding on projects that use K-rail for semi-permanent installations.

1.2. Objective

This research project addresses compliance testing of semi-permanent installations of K-rail and is the first in a series of projects that will ultimately result in having temporary barrier which is approved for both work zone and semi-permanent applications. The objective of this project is two-fold. First is to determine whether or not the California K-rail, as configured for semi-permanent installation, will contain and redirect 820 to 2000-kg vehicles effectively in 100 km/h impacts at angles of 20° to 25° (see Table 1-1 below). Second is to modify the existing K-rail system, if necessary, so that it will meet the Report 350 criteria in work zone applications. Full-scale crash testing will be done in accordance with NCHRP Report 350 Test Level 3 for longitudinal barriers.

1.3. Background

California’s current standard for concrete temporary barrier is the K-rail.[2] This barrier, when properly installed, may also be used in semi-permanent applications. K-rail evolved from the Type 50 (“New Jersey”) median barrier, which has been used in California and other states since about 1970. By 1971, there was substantial interest in the U.S. in developing a movable barrier that could be used in work zones. In 1972, the California Department of Transportation ran a series of crash tests on what is now called K-rail. The results of the testing led to the approval of K-rail for use as a temporary barrier in California. The K-rail that has become the standard within California consists of 6.1-m long sections with pin-and-loop connections, each weighing approximately 3630 kg. Eventually, details were developed which also allowed K-rail to be used as a semi–permanent barrier.

Currently, there is a considerable amount of research being done on the various types of temporary barrier used in the United States.[3] The two principal barrier profiles used in this country are the New Jersey (used in the K-rail) and the F–shape. The lengths of the individual segments vary from 2.44 m to 9.14 m for both types of barriers.

Other states, including Iowa, Nebraska, Virginia, Washington, Indiana, Texas and New York are all doing research on temporary barrier. Only Iowa, Nebraska and New York are currently doing any research on New Jersey profile barriers, and no research at all is being conducted on 6.10-m long barrier sections with this profile (i.e., California K-rail).

1.4. Literature Search

A search for information about construction 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 the Caltrans Division of Materials Engineering and Testing Services. The third and final location was the Caltrans Library within Caltrans Headquarters.

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 two 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)
551	K-rail staked to asphalt concrete	2000	100	25
552	K-rail staked to asphalt concrete	820	100	20

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 m downstream from the barrier in test 551.

2.1.2. Test Barrier

2.1.2.1. Design

The primary design parameters 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.

Secondary design parameter for this project were two-fold:

1) If possible, use currently existing K-rail in the final design.

1) Use a currently established method of element restraint (see James B. Borden memo in appendix).

These design parameters lead to the following test profile.

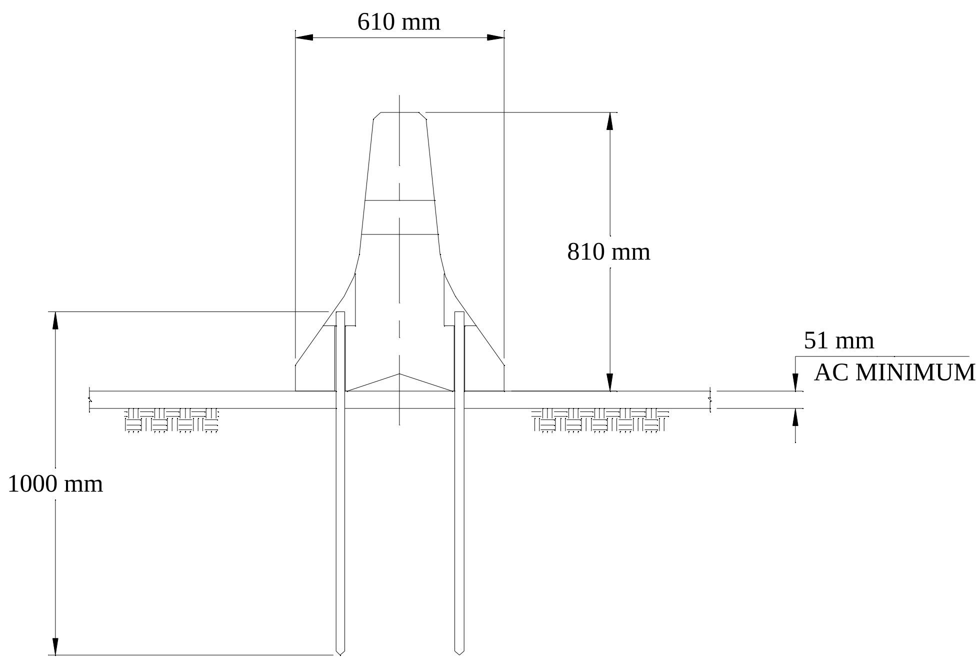


Figure 2-1 - Cross Section of Planned Test Barrier

The final test design consisted of placing eight segments of California K-rail (New Jersey profile) on asphalt concrete (AC) pavement 50-80 mm thick. Each 6.096-m long rail element connected to adjoining elements with 31.8 x 660-mm long pins. Each element was also secured to the AC pavement with four 25 x 1000-mm steel stakes. The head of each stake was driven below the face of the barrier to prevent snagging of the impacting vehicles.

2.1.3. Construction

Construction of the barrier consisted of obtaining the K-rail, clearing the holes for the stakes, placing and connecting the rail elements, and staking the individual elements to the AC pavement (see Figure 2-2). The final test barrier length was 48.77 m.

Because K-rail elements are vary common in California, it was decided to order eight used rail elements. The elements were in good condition, except for the stake holes. The quality control of the K-rail elements is clearly a problem. All but two holes had to be cleared of concrete using various methods. Some holes were pounded out with a hammer and chisel. Others were drilled out with a roto-hammer using a 32-mm bit. During some of the stake-hole clearing, the concrete spalled away from the rail element, revealing mislocated reinforcing steel or even the absence of such steel (see Figure 2-3). One hole split completely, eliminating the possibility of getting positive anchoring from the stake.

The barrier was assembled one segment at a time. The elements were placed using a 3600-kg capacity forklift. Pins were placed in the pin-and-loop connections by hand. Those segments that had spalled during the stake-hole clearing were placed at the ends of the test barrier. The barrier was not pulled tight to take up slack in the pin-and-loop connections (see Figure 2-4).

Where possible, four stakes were placed in each rail element. The stakes were pounded in with a tie-rod driver and either a 60 or 90-lb. jackhammer. The stakes went in smoothly, but occasionally bound up the tie-rod driver against the face of the rail. Where the stake-holes had spalled completely away a stake was still put in place to offer some lateral restraint. A stake was not placed at one of the stake-holes located at the upstream end of the barrier because it was located directly on top of a concrete footing that had been used for a previous test. Only two stakes were not placed in the stake-holes properly.

Note: Due to a misinterpretation of the original design, the stakes were cut to 610 mm instead of 1000 mm. The error in length was not discovered until the barrier was being constructed. It was decided that the shorter stakes would only make the test more conservative, so they were not replaced with the longer ones.

Figure 2-2 - View of Anchor Stake in Barrier

Figure 2-3 - Exposed Rebar

Figure 2-4 - Assembled Barrier

2.1.4. Test Vehicles

The test vehicles complied with NCHRP Report 350. For both 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 Figure 2-5 through Figure 2-9 and Figure 2-17 through Figure 2-20). 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)
551	1989 Chevrolet 2500	0	2016
552	1994 Geo Metro	0	844

The pickup was self-powered; a speed control device limited acceleration once the impact speed had been reached. The Geo was connected by a steel cable to another vehicle and towed to impact speed. Remote braking was possible at any time during the test for all vehicles through a tetherline. 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

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, one 35-mm still camera with an autowinder 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.

Two sets of orthogonal accelerometers were mounted at the centers of gravity for each of the test vehicles. An additional set of orthogonal accelerometers was mounted 600 mm behind the center of gravity in the small car test. Rate gyro transducers were also placed at the centers of gravity of the test vehicles to measure the 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 Test 552 to obtain 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 tests 551 and 552 has been compiled and is available for viewing.

2.2.1. Impact Description - Test 551

The vehicle impact speed and angle were 100.6 km/h and 25 degrees, respectively. Impact occurred at the joint between the forth and fifth segments (see Figure 2-6). As the vehicle hit the barrier, it yawed left until the entire right side of the vehicle was in contact with the face. At 0.2 seconds the vehicle started to ride upward. All four wheels lost contact with the ground as the front bumper reached the next segment (about 6 m downstream). The vehicle touched down 12 m further downstream. As the front left tire hit the ground, the roll and pitch were measured to be 12.8° and 25°, respectfully. The vehicle immediately started to right itself and was stable about 4 meters past the end of the barrier (about 16 m downstream of the point of impact). The exit speed and angle were 82 km/h and 6 degrees respectively. The 6-degree exit angle is well within the 60% limit of Report 350.

Figure 2-5 - Rear View of Vehicle with Barrier

Figure 2-6 - Vehicle 551 At Barrier

Figure 2-7 - Vehicle 551 At Point Of Impact

Figure 2-8 - Front View of Test Vehicle 551

Figure 2-9 - Side View of Vehicle 551

2.2.2. Vehicle Damage - Test 551

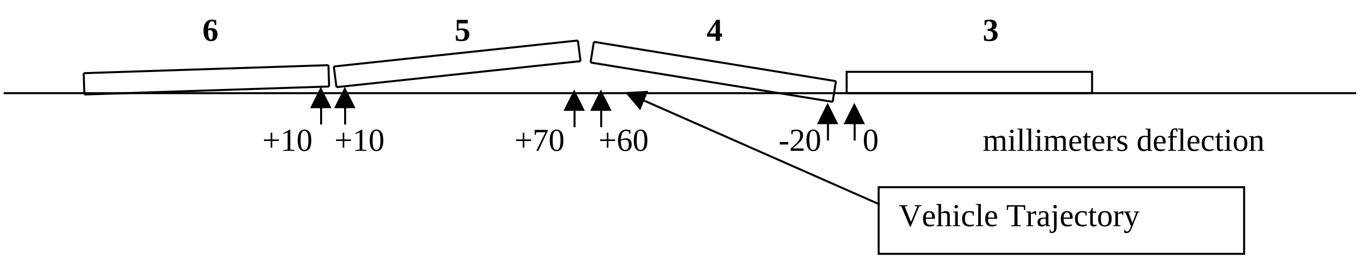
Most of the damage to the vehicle was confined to right front corner. The right front tire was separated from the wheel. The right front fender and bumper were crushed (Figure 2-10). The tie-rod was broken, but the left front wheel could still be controlled by the steering wheel. There were scuff marks and scratches along the entire right side of the vehicle. The left rear wheel sustained minor damage, but the tire was still inflated.

The occupant compartment sustained some minor crumpling on the right side floorboard. The maximum deformation was 40 mm. The right door was jammed closed. The windshield was not cracked. Figure 2-16 presents a summary of the test results.

Figure 2-10 - Front Impact Side of Vehicle

2.2.3. Barrier Damage - Test 551

The barrier underwent some permanent deflection:



Damage to the barrier was minimal (Figure 2-11 through Figure 2-15). The connecting pin-and-loop at joint 4-5 bent enough that it caused minor spalling and the pin had to be cut before the barrier could be moved. The maximum lateral displacement measured at the top of the barrier was 260 mm during impact. There was also some minor spalling of anchor stakes in segments 4 and 6.

Figure 2-11 - Post Impact View of Barrier

Figure 2-12 - Concrete Spalling At Anchor Stake

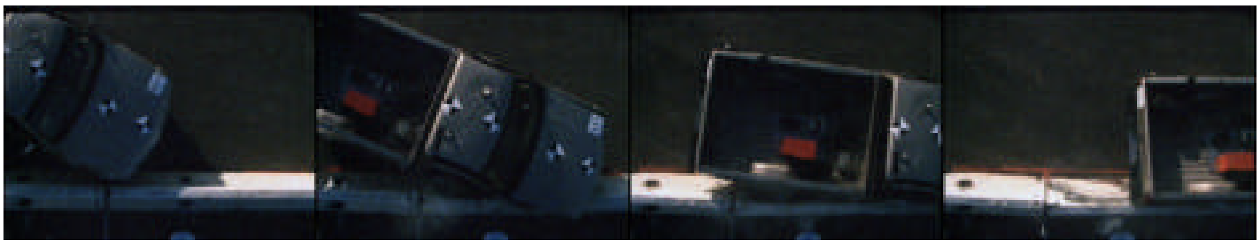
Figure 2-13 - Post Impact Scuff Marks Test 551

Figure 2-14 - Downstream View of Barrier Post Impact

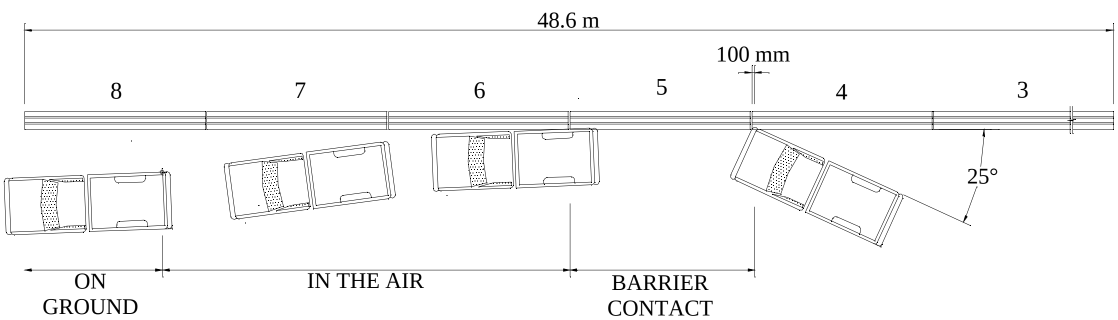
Figure 2-15 - Backside of Barrier Post Impact

Figure 2-16 - Test 551 Data Summary Sheet

t = 0.000 t = 0.200 t = 0.400 t = 0.600



t = 0.000 t = 0.080 t = 0.160 t = 0.240



General Information:	
Test Agency	California DOT
Test Number	551
Test Date	January 27, 1999
Test Article:	
Name	Pinned K-rail
Installation Length	48.77 m
Description	8 segments of K-rail, staked with 24-mm stakes & connected with 31.8-mm pins
Test Vehicle:	
Model	1989 Chevy 2500
Inertial Mass	2016 kg
Impact Conditions:	
Velocity	100.6 km/h
Angle	25°
Exit Conditions:	
Velocity	82 km/h
Angle	6 degrees

Test Dummy:	
Type	NA
Weight / Restraint	NA
Position	NA
Vehicle Exterior:	
VDS[4]	FR-4, RD-4
CDC[5]	02RFEW4
Vehicle Interior:	
O.C.D.I.	RF0000000
Barrier Damage:	Spalling at the pin-and-loop connection at point of impact, also at some of the anchor stakes. Superficial scuffing

Occupant Risk Values	*Longitudinal*	*Lateral*
Occupant Impact Velocity	5.17 m/s	6.62 m/s
Ridedown Acceleration	-5.48 g	-14.88 g
Max. 50 ms avg. Acceleration	-5.99 g	-11.33 g

2.2.4. Impact Description - Test 552

The vehicle impact speed and angle were 101.7 km/h and 20 degrees, respectively. Impact occurred at the joint between the forth and fifth segments (see Figure 2-17). Within the first 3 m of barrier contact, the vehicle rotated 20 degrees to the left, the rear hatch opened up and all four wheels left the ground. Contact with the barrier continued for about 8 m while the vehicle rose. The vehicle stayed level while rising to an ultimate height of 630 mm. The vehicle came back down 15 m downstream of the impact point (see Figure 2-21 through Figure 2-23).

The exit speed and angle were 97 km/h and 4 degrees respectively. This exit angle is well within the limit of 60% of the impact angle, as specified by Report 350. The vehicle stayed upright and tracked smoothly until coming to rest approximately 67 m downstream.

Figure 2-17 - Vehicle 552 At Impact Point

Figure 2-18 - Vehicle 552 With Barrier

Figure 2-19 - Side View of Test Vehicle 552

Figure 2-20 - Pre-Crash View of Impact Side of Vehicle

Figure 2-21 - Vehicle 552 Impacting Barrier

Figure 2-22 - Vehicle 552 Exiting Barrier

Figure 2-23 - Vehicle 552 Landing Upright and Stable

2.2.5. Vehicle Damage - Test 552

As in Test 551, most of the damage to the vehicle was confined to the right front corner. The right 300 mm of the bumper was slightly pushed into the fender panel and the fender had considerable sheet metal damage. The parking light was broken. The right wheel assembly was pushed back and to the left, with the bottom of the wheel canted outward (see Figure 2-24 and Figure 2-25).

Other damage to the vehicle was minor. The hood had some minor crumpling. The right front door was scraped and jammed closed, but could be worked open by hand. The rest of the right side received scraping and minor crumpling. The windshield was unbroken.

Figure 2-24 -Front View of Vehicle Impact Damage

Figure 2-25 - Side Impact Damage

2.2.6. Barrier Damage - Test 552

Damage occurred only on the front of the barrier. Vehicle contact was limited to segments 4 and 5, where the barrier received superficial scuffing (see Figure 2-27). The K-rail cracked around several of the stake holes, but they all retained their integrity. The barrier rotated back approximately 30 mm during impact, but righted itself as the vehicle lost contact with the barrier.

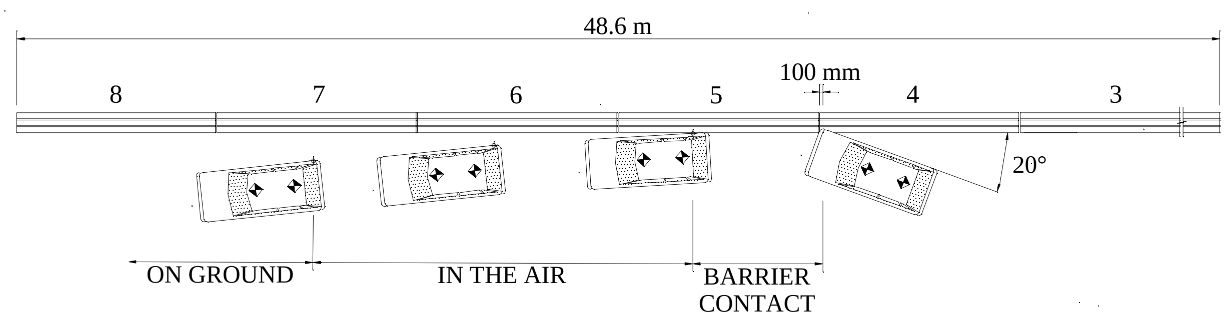
Segment 4 had a permanent deformation of 25 mm, with the front edge of the barrier raised about 10 mm. The loop connections did not incur any damage.

Figure 2-26 - Test 552 Barrier Scuffing

Figure 2-27 - Test 552 Data Summary Sheet

t = 0.000 t = 0.200 t = 0.400 t = 0.600

t = 0.800 t = 1.000 t = 1.200 t = 1.400



General Information:

Test Agency	California DOT
Test Number	552
Test Date	February 24, 1999

Test Article:

Name	Pinned K-rail
Installation Length	48.77 m
Description	8 segments of K-rail, staked with 24-mm stakes & connected with 31.8-mm pins

Test Vehicle:

Model	1994 Geo Metro
Inertial Mass	844 kg

Impact Conditions:

Velocity	101.7 km/h
Angle	20°

Exit Conditions:

Velocity	97 km/h
Angle	4 degrees

Test Dummy:

Type	Hybrid III
Weight / Restraint	74.8 kg / belted
Position	Front Right

Vehicle Exterior:

VDS[4]	FR-4, RD-4
CDC[5]	02RFEW3

Vehicle Interior:

OCDI	RF0000000

Barrier Damage: Superficial scuffing.

Occupant Risk Values	*Longitudinal*	*Lateral*
Occupant Impact Velocity	3.94 m/s	5.8 m/s
Ridedown Acceleration	-1.13 g	-17.62 g
Max. 50 ms avg. Acceleration	-7.29 g	-11.2 g

2.3. Discussion of Test Results - Crash Tests

2.3.1. General - Evaluation Methods (Tests 551 and 552)

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 adequacy, occupant risk and vehicle trajectories associated with both barriers were evaluated in comparison with Tables 3.1 and 5.1 of NCHRP Report 350.

2.3.2. Structural Adequacy

The structural adequacy of the K-rail is acceptable. The 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 2-3 through Table 2-4.

2.3.3. Occupant Risk

The occupant risk of the K-rail used in a semi-permanent installation is also acceptable. In each of the tests there were no signs of snagging or pocketing with the rail. 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 within the "preferred" range.

Please refer to Table 2-3 through Table 2-4 for a detailed assessment summary of occupant risk.

2.3.4. Vehicle Trajectory

The vehicle trajectory for the K-rail used in a semi-permanent installation is also acceptable. The detailed assessment summaries of the vehicle trajectories may be seen in Table 2-2 through 2-4.

Table 2-2 - Test 551 Assessment Summary

Test No. 551
Date January 27, 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 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. = 5.17 m/s Long. Occ. Ridedown = -5.48 *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 6 degrees, or 24% of impact angle	pass

Table 2-3 - Test 552 Assessment Summary

Test No. 552
Date February 24, 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 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.	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 -11.59, 6.46, and –25.74°, 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 velocities were within acceptable range.	
Occupant Impact Velocity Limits (m/s): Component: Longitudinal and lateral; Preferred: 9; Maximum: 12	Long. Occ. Impact Vel. = 3.94 m/s Lat. Occ. Impact Vel. = 5.80 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: Longitudinal and lateral; Preferred: 15; Maximum: 20	Longitudinal Acceleration = -1.13 *g* Lateral Acceleration = -17.62 *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 4 degrees, or 20% of impact angle	pass

Table 2-4 - 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]
551	25.0	15.0	6 deg.	100.6	82	18.4
552	20.0	12.0	4 deg.	101.7	97	4.7

3. CONCLUSION

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

1) The semi-permanent K-rail can smoothly and successfully contain and redirect an 820-kg sedan impacting at 20 degrees and 100 km/h.

2) The semi-permanent K-rail can successfully contain and redirect a 2000-kg pickup truck impacting at 25 degrees and 100 km/h.

3) Damage to the semi-permanent K-rail in accidents similar to the tests conducted for this project will result in small to moderate amounts of scraping and spalling of the rail.

4) The K-rail in semi-permanent installations meets the criteria set in the National Cooperative Highway Research Program's Report 350 "Recommended Procedures for the Safety Performance Evaluation of Highway Features" under test level 3 for longitudinal barriers.

4. RECOMMENDATION

The K-rail installed in a semi-permanent configuration using the 1.0-m X 24-mm steel stakes is recommended for use as a semi-permanent barrier on low and high-speed highways.

5. IMPLEMENTATION

The Traffic Operations Program will be responsible for the preparation of standard plans and specifications for the semi-permanent configuration of K-rail, with technical support from the Division of Materials Engineering and Testing Services and the Office of Structures Construction. In-service evaluation will be implemented by the Traffic Operations Program.

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 test 551, a 12-L safety gas tank was installed in the truck bed and connected to the fuel supply line. The stock fuel tanks had gaseous CO_2 added in order to purge the gas vapors and eliminate oxygen. For Test 552, 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 the electronic control box. A second 12-volt, deep cycle, gel cell battery powered the transient data recorder.

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.

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.

For Test 552, the vehicle speed 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 though using an ignition cutout on the tow vehicle that had been configured for the correct speed.

For Test 551, an accelerator switch was located on the rear fender. 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 of the remote braking system with a valve to adjust CO_2 flow rate.

For Test 551, 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.

For Test 551, 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 551 Vehicle Dimensions

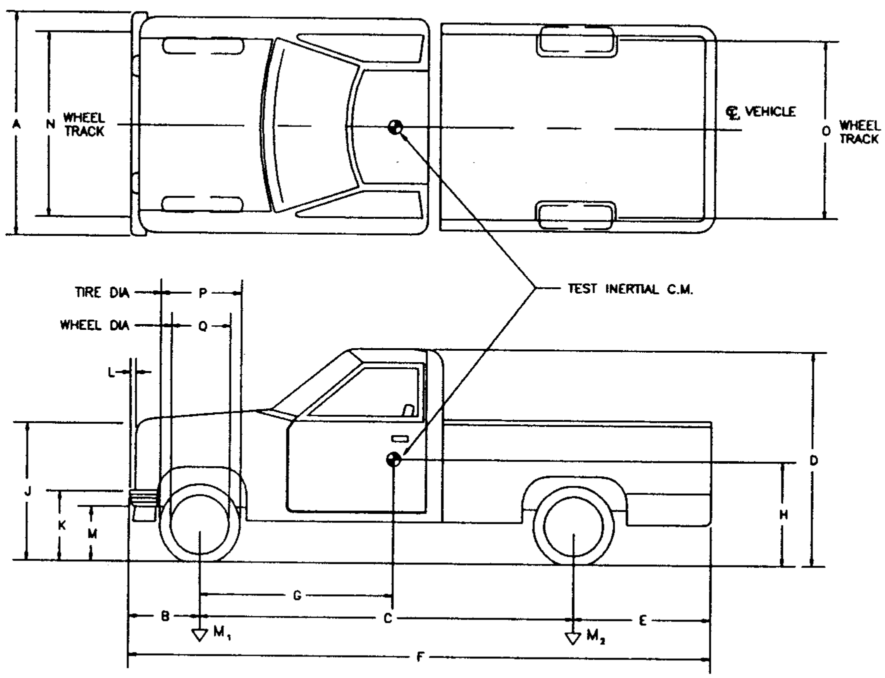
DATE: 1/27/99 **TEST NO:** 551 **VIN NO:** 1GTFC24K3KE551974 **MAKE:** GMC

MODEL: 2500 Pick-Up **YEAR:** 1989 **ODOMETER:** 154527 (MI) **TIRE SIZE:** LT245/75R16

TIRE INFLATION PRESSURE: 45 (PSI)

MASS DISTRIBUTION (kg) **LF** 574 **RF** 549 **LR** 383.5 **RR** 403

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST: NONE



ENGINE TYPE: V8

ENGINE CID: 350

TRANSMISSION TYPE :

X **AUTO**

____ **MANUAL**

OPTIONAL EQUIPMENT:

POWER WINDOWS/LOCKS

CASSETTE

SLIDING REAR WINDOW

DUMMY DATA:

TYPE: NA

MASS: NA

SEAT POSITION: NA

GEOMETRY (cm)

A	196	**D**	185	**G**	149.7	**K**	62.5	**N**	157.5	**Q**	44.3
B	91	**E**	128	**H**		**L**	9	**O**	162		
C	336	**F**	556	**J**	105	**M**	42	**P**	76.5		

MASS - (kg)	**CURB**	**TEST INERTIAL**	**GROSS STATIC**
M1	1123	1110	1106.5
M2	786.5	906	888.5
MT	1909.5	2016	1995

Table 6-2 - Test 552 Vehicle Dimensions

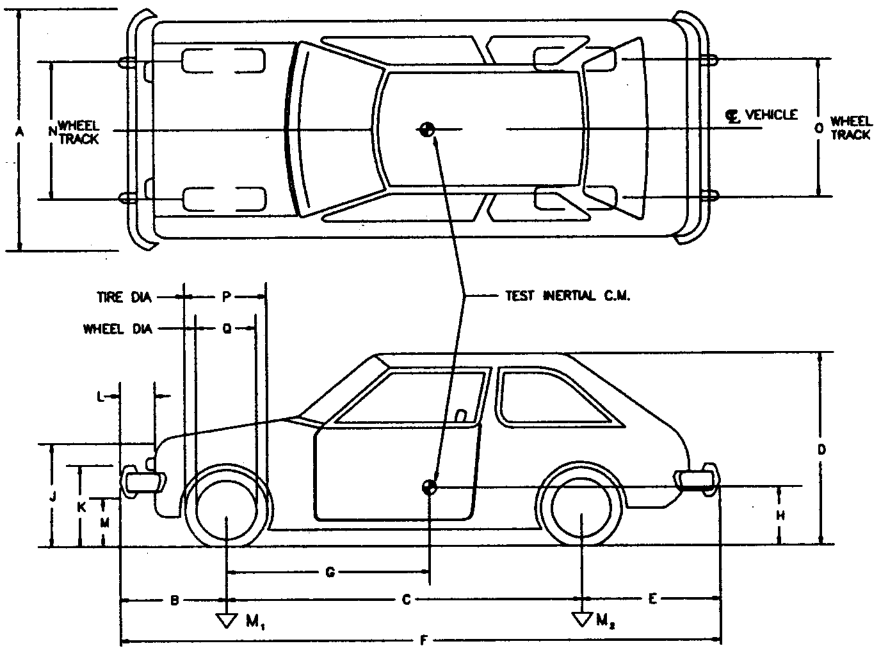
DATE: 2/24/99 **TEST NO:** 552 **VIN NO:** 2C1MR6461R6717324 **MAKE:** GEO

MODEL: METRO 4-DR **YEAR:** 1994 **ODOMETER:** 62865 (MI) **TIRE SIZE:** 155R12

TIRE INFLATION PRESSURE: 36 (PSI)

MASS DISTRIBUTION (kg) **LF** 246 **RF** 235 **LR** 195 **RR** 182

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST: Two minor creases in the left front corner of the hood. Two minor dents in the front roof panel just above the windshields.



ENGINE TYPE: IN-LINE 3 CYL.

ENGINE CID: 1.0 LITER

TRANSMISSION TYPE :

____ **AUTO**

X **MANUAL**

OPTIONAL EQUIPMENT:

Air conditioning

Cruise control

Cassette

DUMMY DATA:

TYPE: HYBRID III 50th %

MASS: 75 KG

SEAT POSITION: RIGHT FRONT

GEOMETRY (cm)

A 160	**D** 136	**G** 102.6	**K** 49	**N** 135	**Q** 33
B 81	**E** 72	**H**	**L** 9	**O** 133.5	
C 236.5	**F** 389.5	**J** 68..5	**M** 22.5	**P** 54	

MASS - (kg)	CURB	TEST INERTIAL	GROSS STATIC
M1	478	467	507
M2	314.5	377	412
MT	782.5	844	919

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 6-3.

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

A video camera and a 16-mm film camera were turned on by hand and used 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.

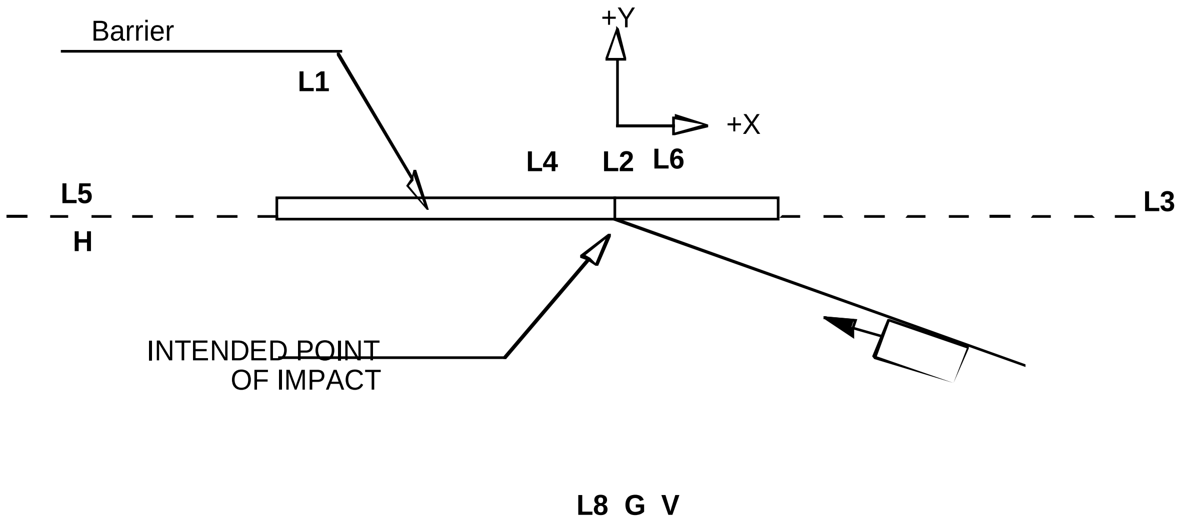


Figure 6-1 - Camera Locations

Typical Coordinates, m						
Camera Label	Film Size (mm)	Camera Type	Rate: (fr./sec.)	Test 551 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 6-3 - Camera Type and Locations for Test 551

Typical Coordinates, m						
Camera Label	Film Size (mm)	Camera Type	Rate: (fr./sec.)	Test 552		
				X*	Y*	Z*
L1	16	LOCAM 1	400	-40.3 m	+11.5 m	1.5 m
L2	16	LOCAM 2	400	0	0	12 m
L3	16	LOCAM 3	400	+41.7 m	+.3 m	1.5 m
L4	16	LOCAM 4	400	-.6 m	0	12 m
L5	16	LOCAM 5	400	-85.6 m	-1.1 m	1.5 m
L6	16	LOCAM 6	400	0	+.6 m	12 m
L8	16	LOCAM 8	400	0	-15.5 m	1.5 m
G	16	GISMO	64	-9.6 m	-18.6 m	6 m
V	1.27	SONY BETACAM	30	-1.8 m	-14.7 m	1.5 m
H	35	HULCHER	40	-85.4 m	-.2m	1.5 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 6-4 - Camera Type and Locations for Test 552

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 the application of the vehicle brakes. The impact flashbulbs begin to glow immediately upon activation, but have a delay of several milliseconds before lighting up to full intensity.

3) Five tape switches, placed at 4-m intervals, were attached to the ground near the barrier and were perpendicular to the path of the test vehicle. 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 independent 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.

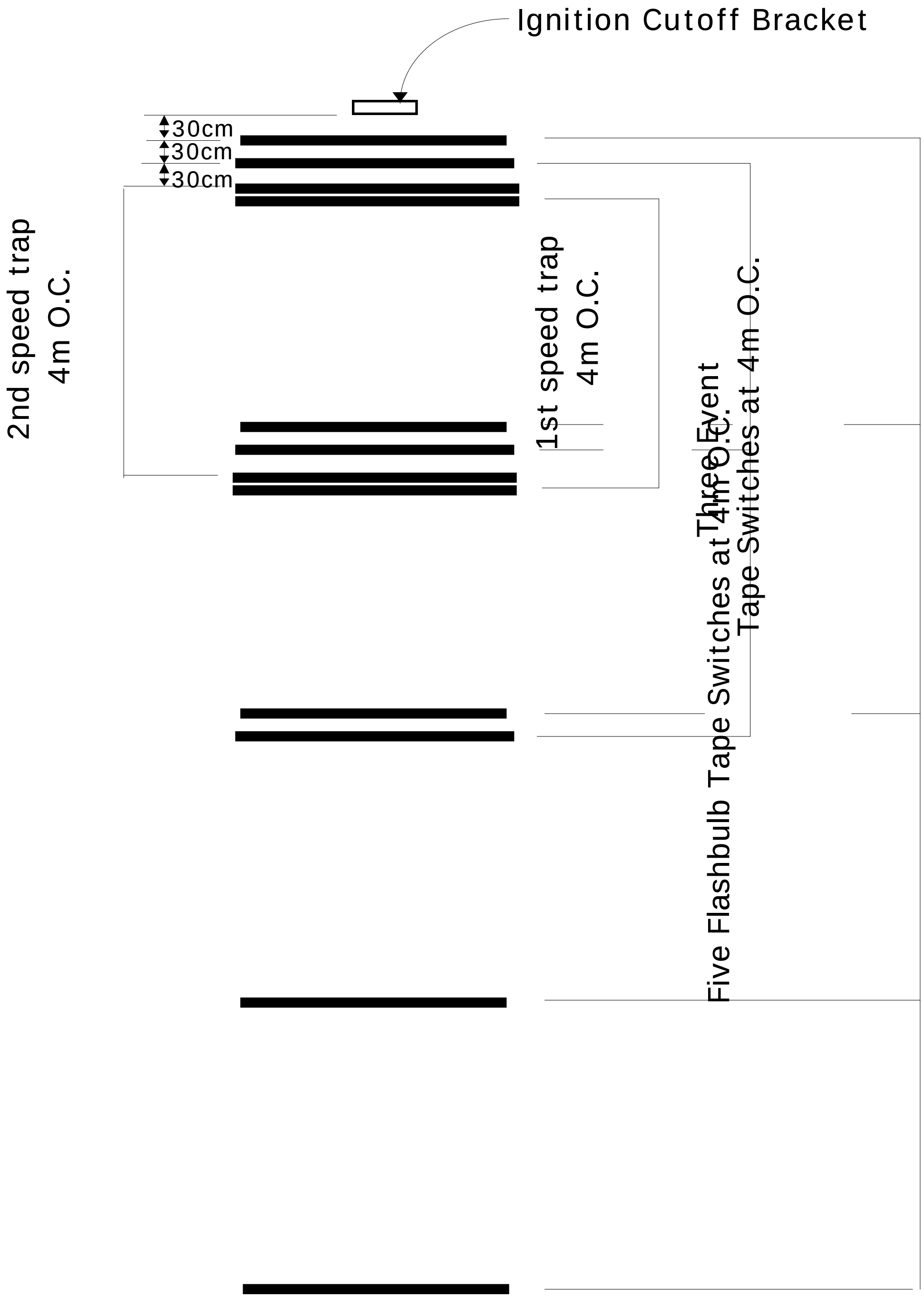


Figure 6-2 - Tape Switch Layout

State of California

Business, Transportation and Housing Agency

Memorandum

To: ALL DISTRICT DIVISION CHIEFS
Operations
Project Development

Date: November 28, 1994

File: 3.3.10

From: **DEPARTMENT OF TRANSPORTATION**
Division of Traffic Operations

Subject: Long-Term Installations of K-Rail

With the current interest within the districts to install low cost concrete median barriers, more districts have opted for long-time installations of K-Rail. Because of the extended life of these installations, it is necessary that they be installed according to higher standards than temporary ones. For long-term installations, where the barrier is expected to exist for more than 5 years, the traffic reviewers will concur with K-Rail use and the following design details shall be incorporated in the design:

1) The K-Rail elements or sections meet current California Department of Transportation's design with the latest pin connections;

2) All elements shall be pinned together to act as a single unit;

3) The elements are restrained against lateral movement by either:

   a) 1.0 meters (m) of minimum 24 millimeters (mm) diameter steel stakes, 4 per element driven so as to restrain the element but not to interfere with the smooth side of the element or

   b) a 38 mm x 1.2 m asphalt concrete (AC) pad against the base at each side;

4) The barrier will sit on a minimum 1.2 m x 50 mm thick AC pad or 1.2 m x 150 mm thick pad of compacted, Type 3 or better, base materials.

These criteria should be followed when using K-Rail in a long-term design to minimize maintenance efforts. As always, drainage and maintenance should be consulted during the median barrier planning and design. Should you have any questions about the barrier installation, please call Mr. JD Bamfield at (916) 654-5872 or CALNET 8-464-5872.

ORIGINAL SIGNED BY
JAMES B. BORDEN

JAMES B. BORDEN, Chief
Division of Traffic Operations

6.4. 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 two vehicles included two sets of accelerometers and one set of rate gyros at the center of gravity. For test 552 an additional set of accelerometers were mounted 600 mm behind the center of gravity. The TDR data were reduced using a desktop computer.

The rate gyro data for tests 551 and 552 recorded with multiple spikes due to loose wiring. The spikes are reflected in the plots. After test 551 was completed a failed attempt to correct the wiring was made, after test 552 the wiring was corrected.

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 vehicle. The tape switch layout for all tape switches is shown in Figure 6-2.

The data curves are shown in Figure 6-4 through Figure 6-11 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 6-5 - 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

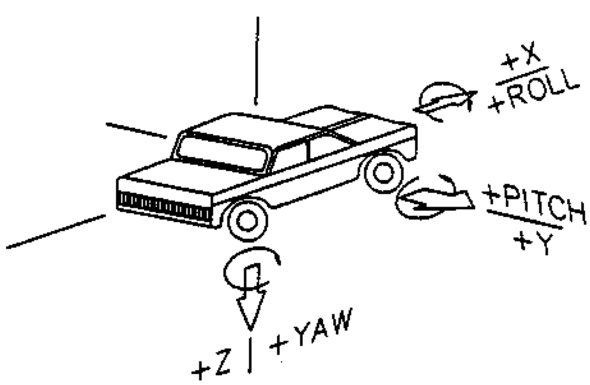


Figure 6-3 - Vehicle Accelerometer Sign Convention

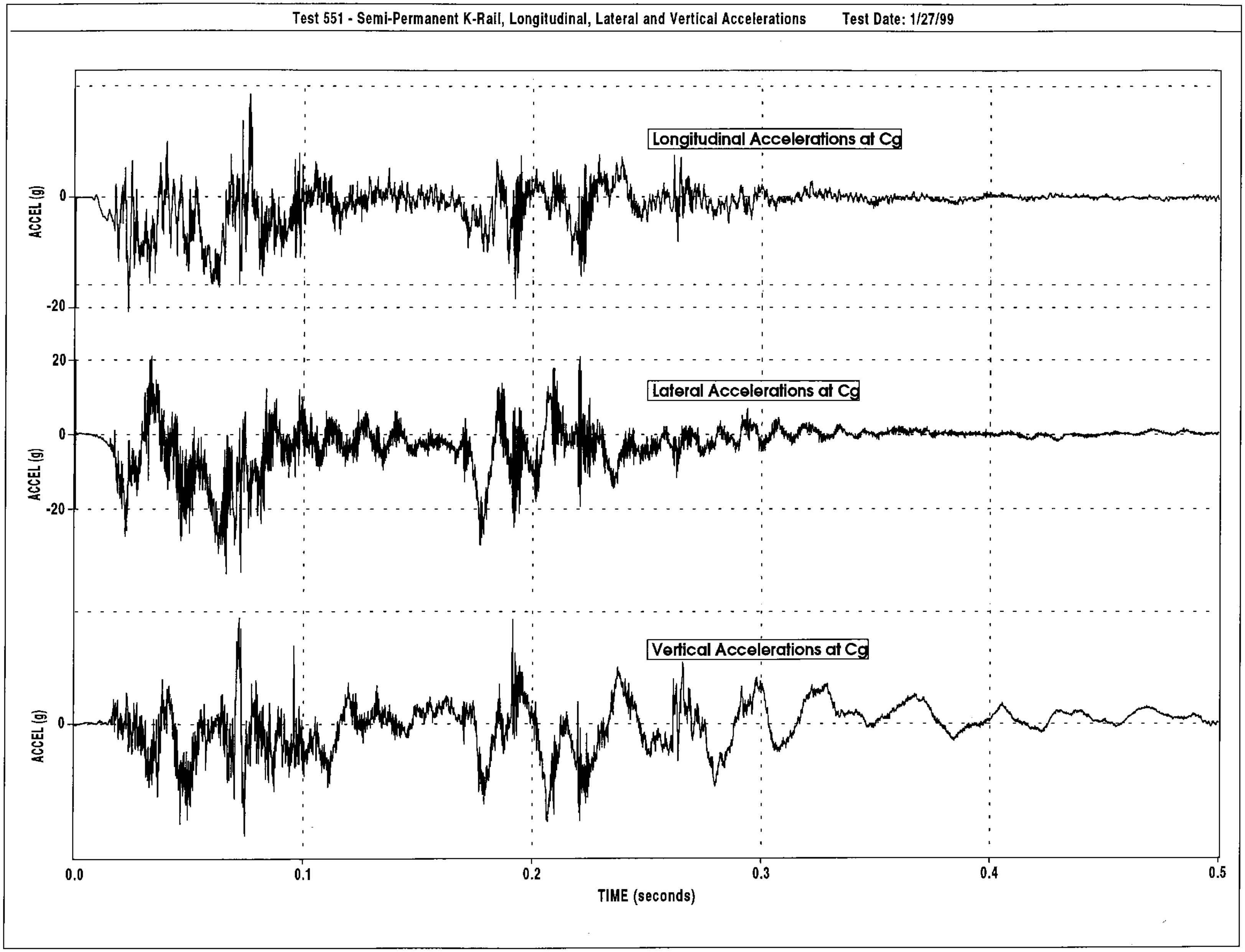


Figure 6-4 - Test 551 Vehicle Accelerations -Vs- Time

Figure 6-5 - Test 551 Vehicle Longitudinal Acceleration, Velocity and Distance -Vs- Time

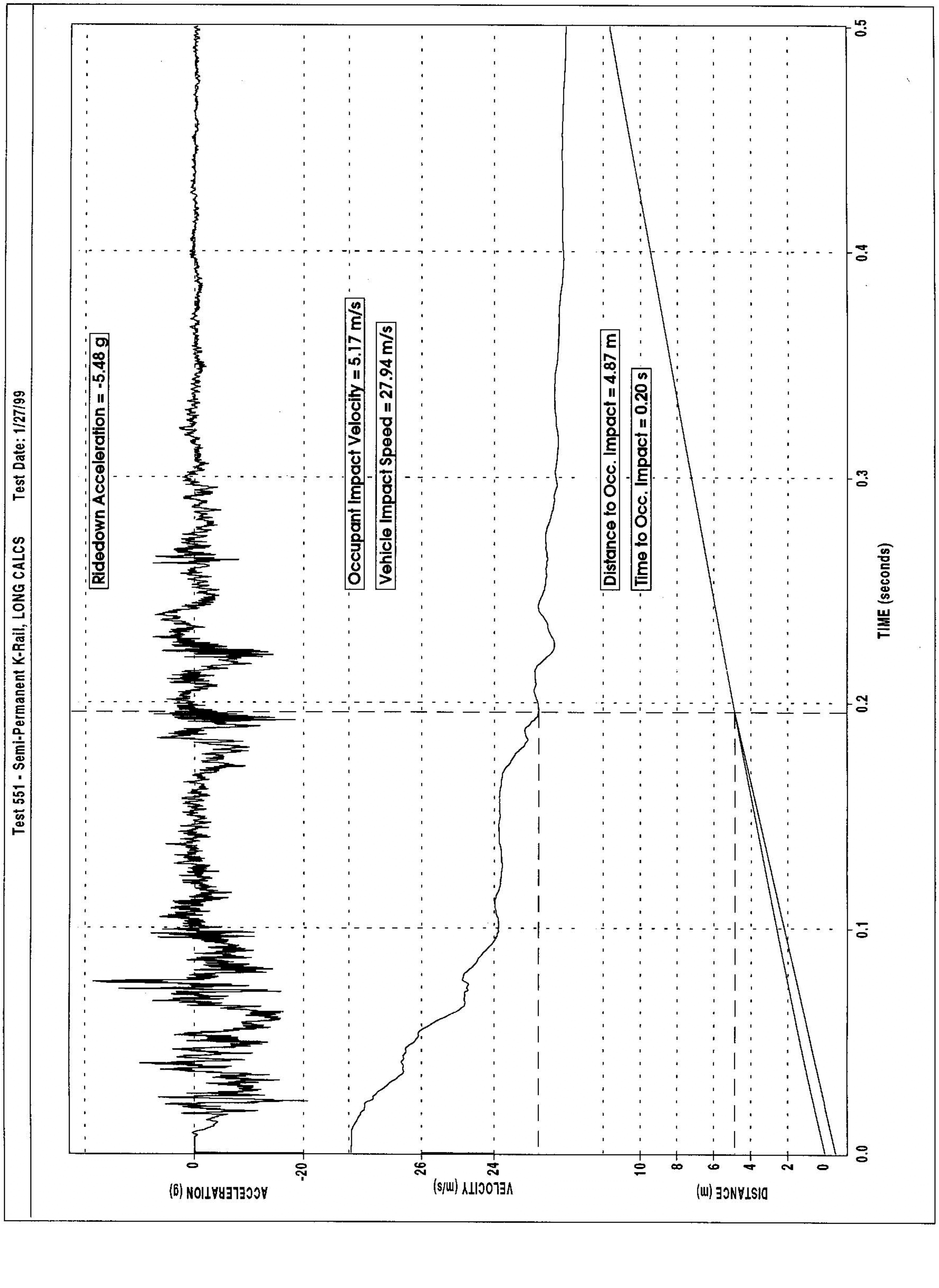
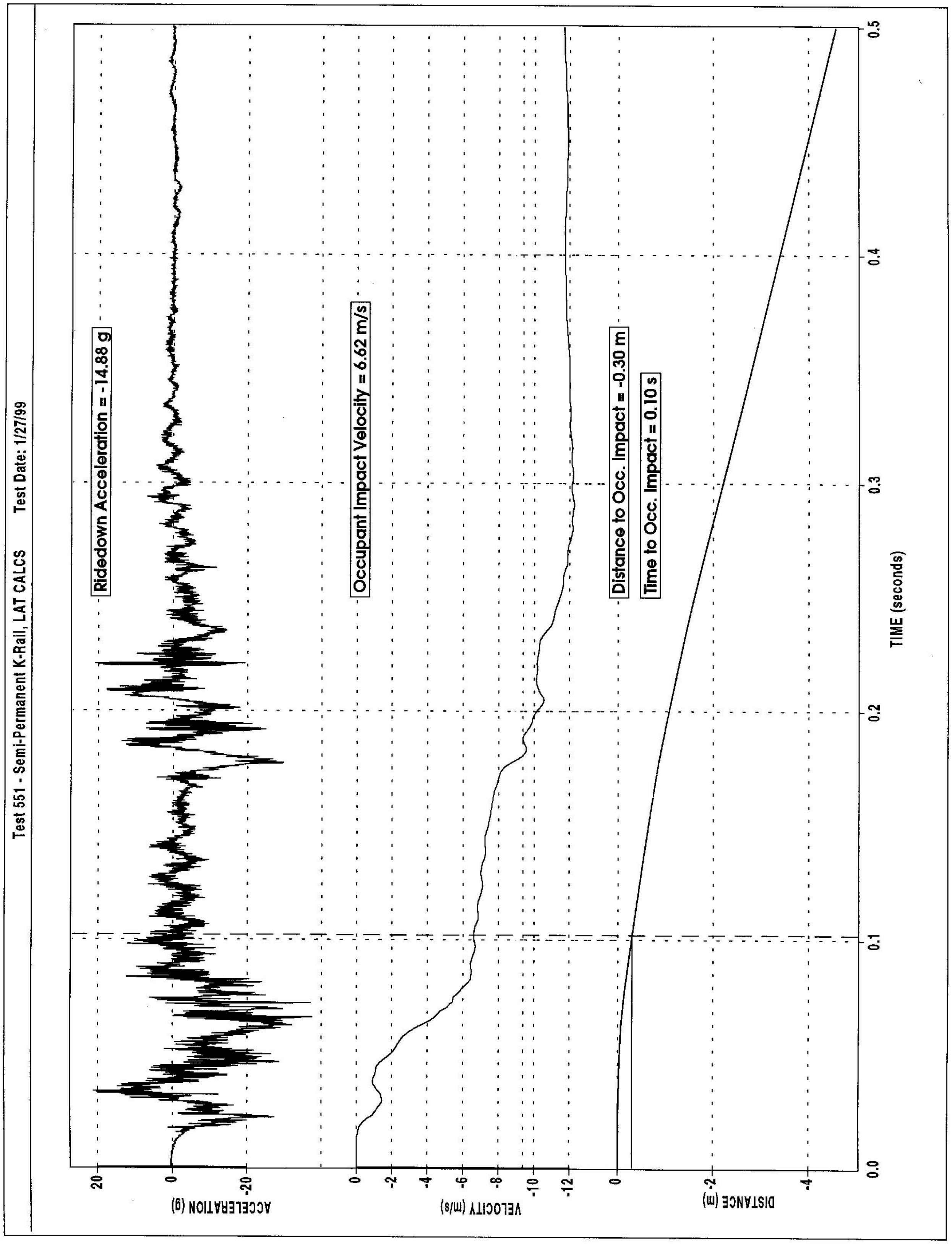


Figure 6-6 - Test 551 Vehicle Lateral Acceleration, Velocity and Distance -Vs- Time



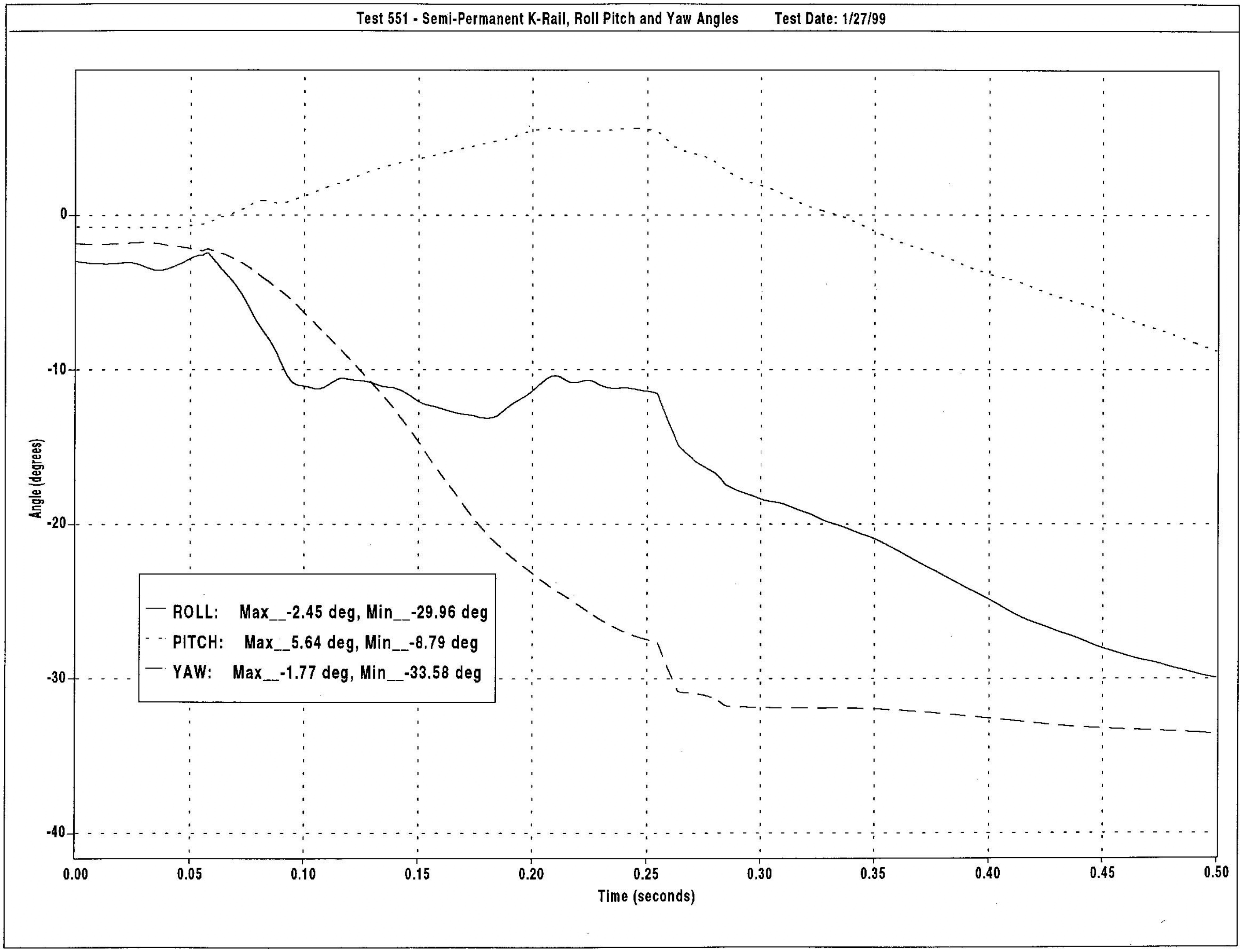
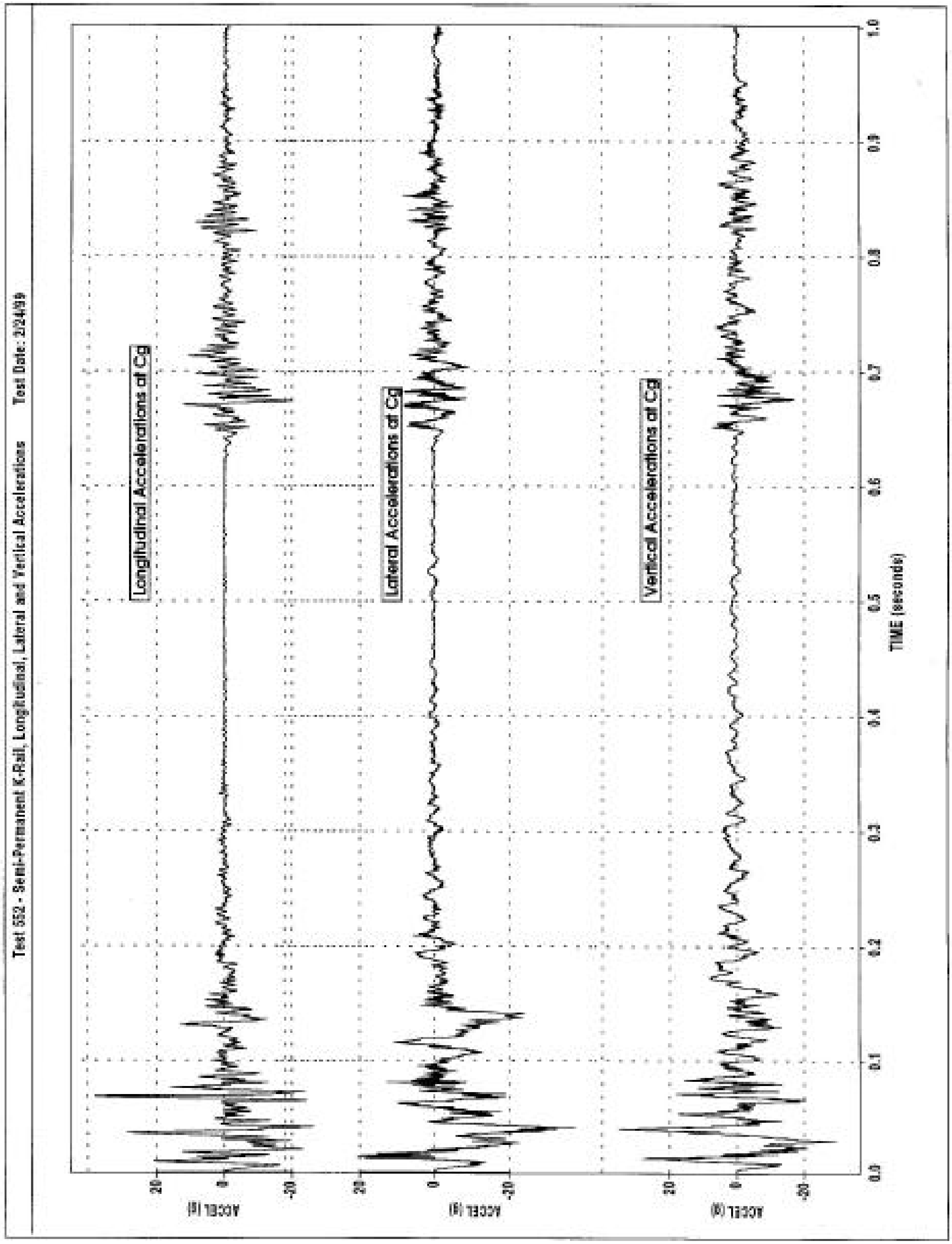


Figure 6-7 - Test 551 Vehicle Roll, Pitch and Yaw -Vs- Time

Figure 6-8 - Test 552 Vehicle Accelerations -Vs- Time



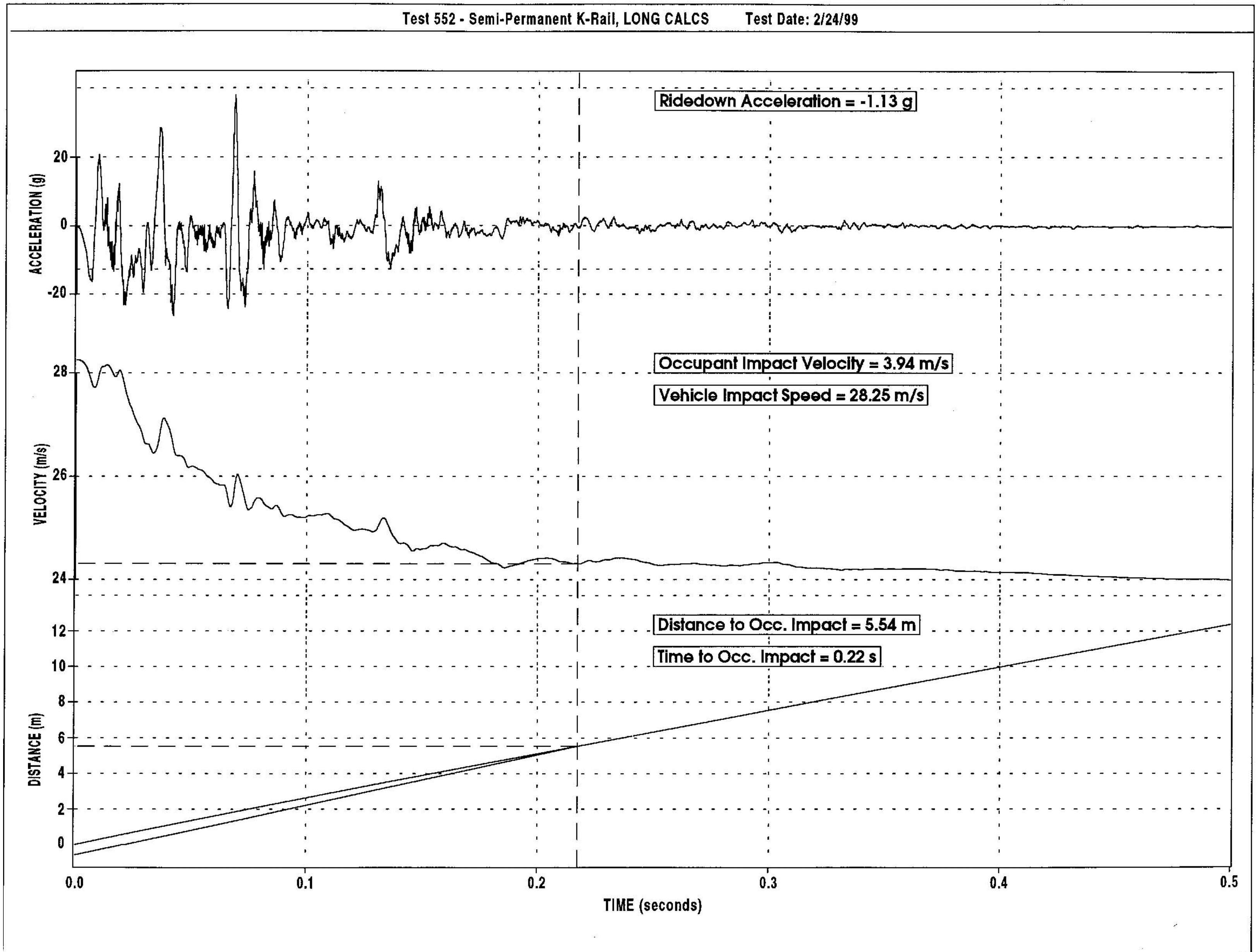


Figure 6-9 - Test 552 Vehicle Longitudinal Acceleration, Velocity and Distance -Vs- Time

Figure 6-10 - Test 552 Vehicle Lateral Acceleration, Velocity and Distance -Vs- Time

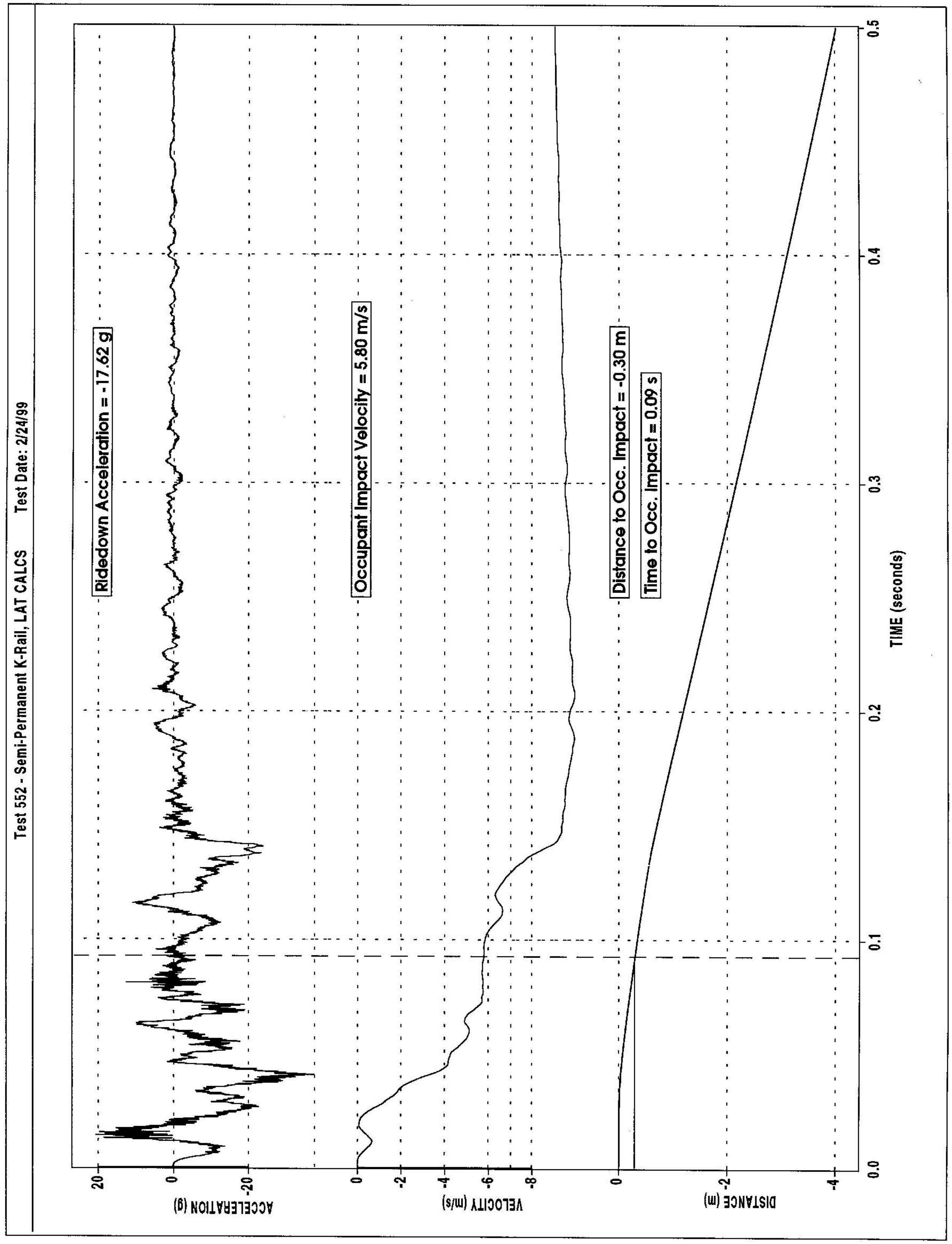
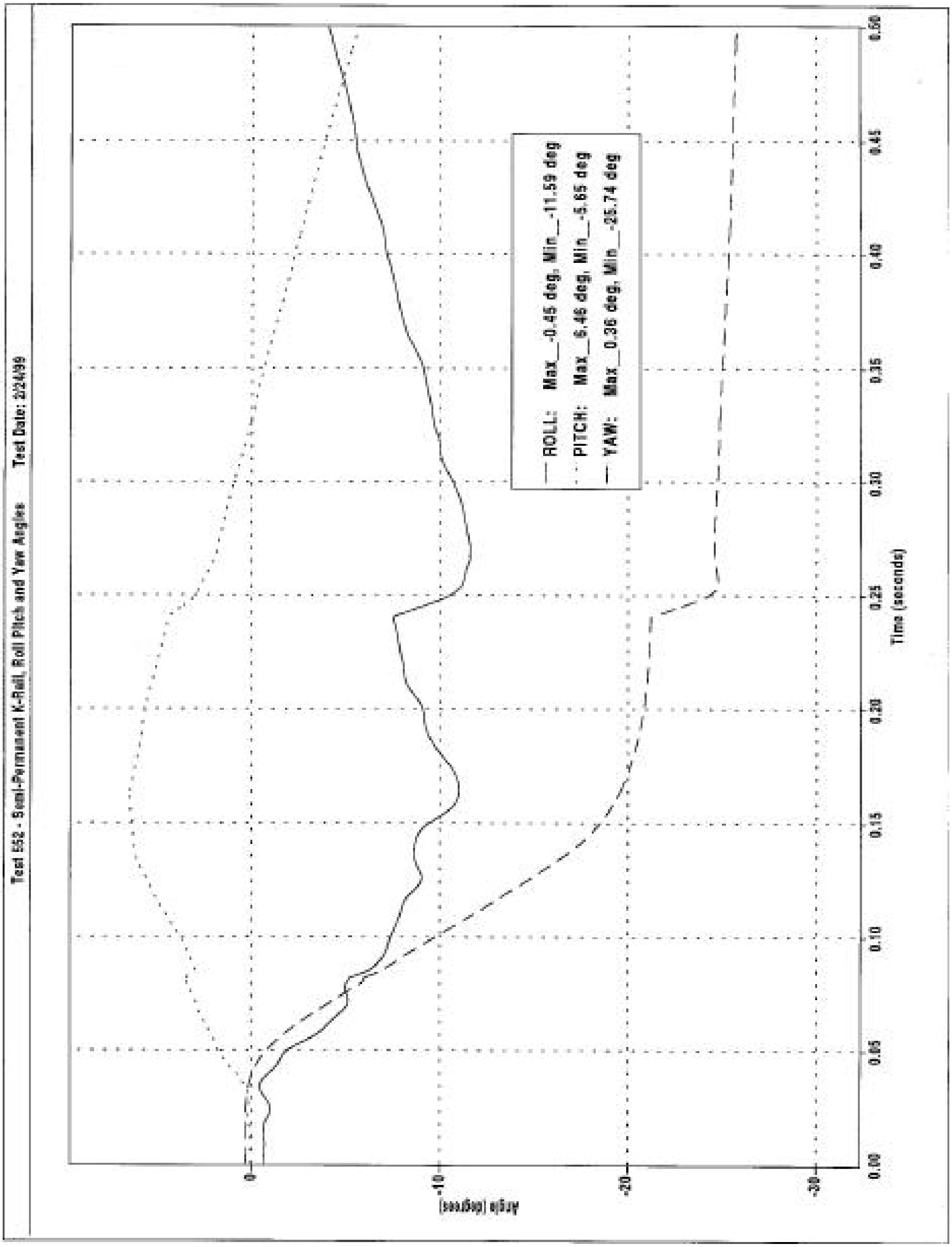
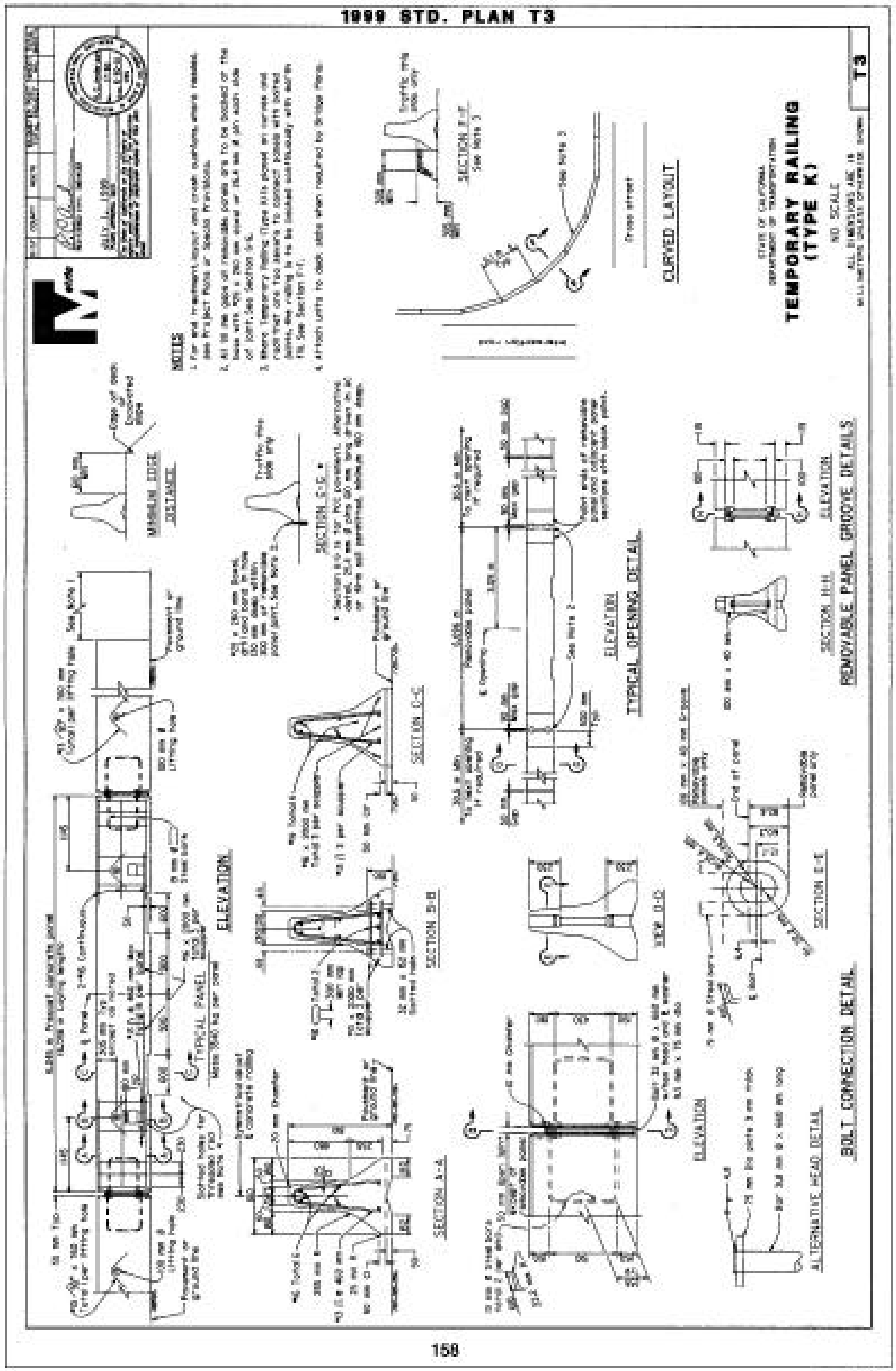


Figure 6-11 - Test 552 Vehicle Roll, Pitch and Yaw -Vs- Time



6.5. Detailed Drawing



7. REFERENCES

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