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 Velocity Limits (m/s) Component / Preferred / Maximum Longitudinal and lateral / 9 / 12	Occupant impact velocities were within acceptable range. 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 / Preferred / Maximum Longitudinal and lateral / 15 / 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

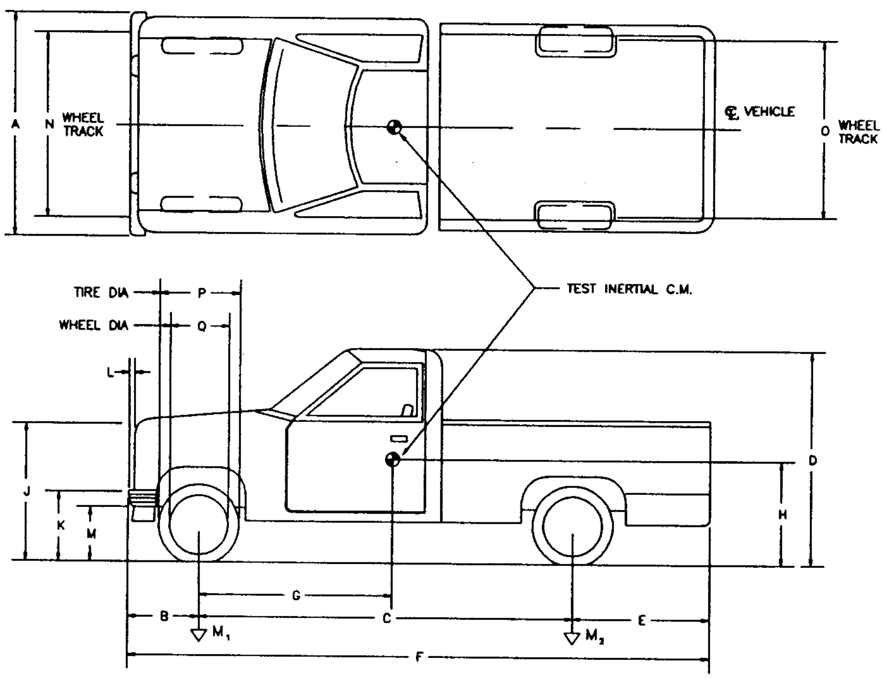
DATE: 1/27/99 **TEST NO:** 551 **VIN NO:** 1GTFC24K3KE551974 **MAKE:** GMC

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

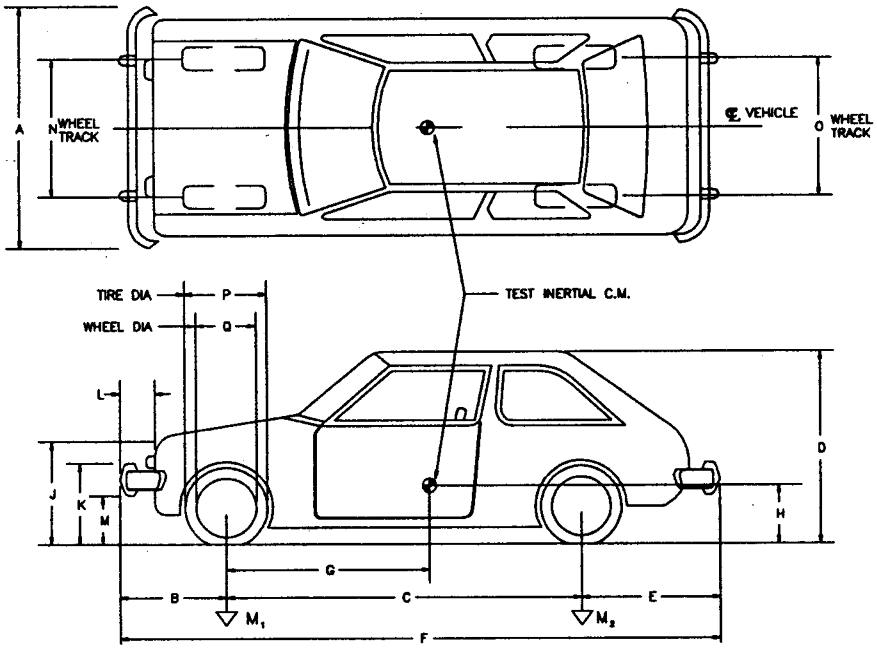
DATE: 2/24/99 **TEST NO:** 552 **VIN NO:** 2C1MR6461R6717324 **MAKE:** GEO

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.

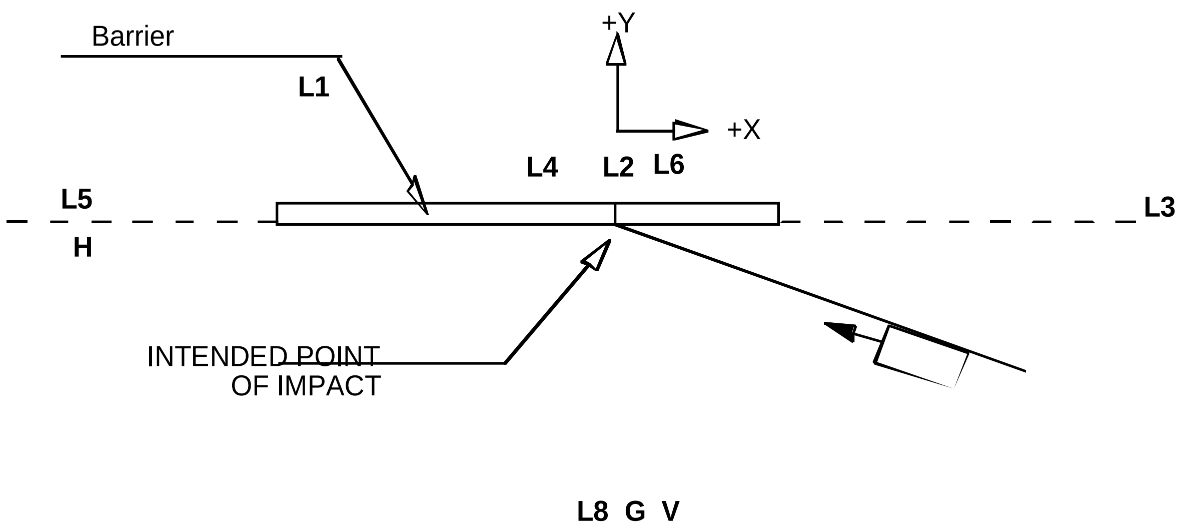


Figure 6-1 - Camera Locations

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.

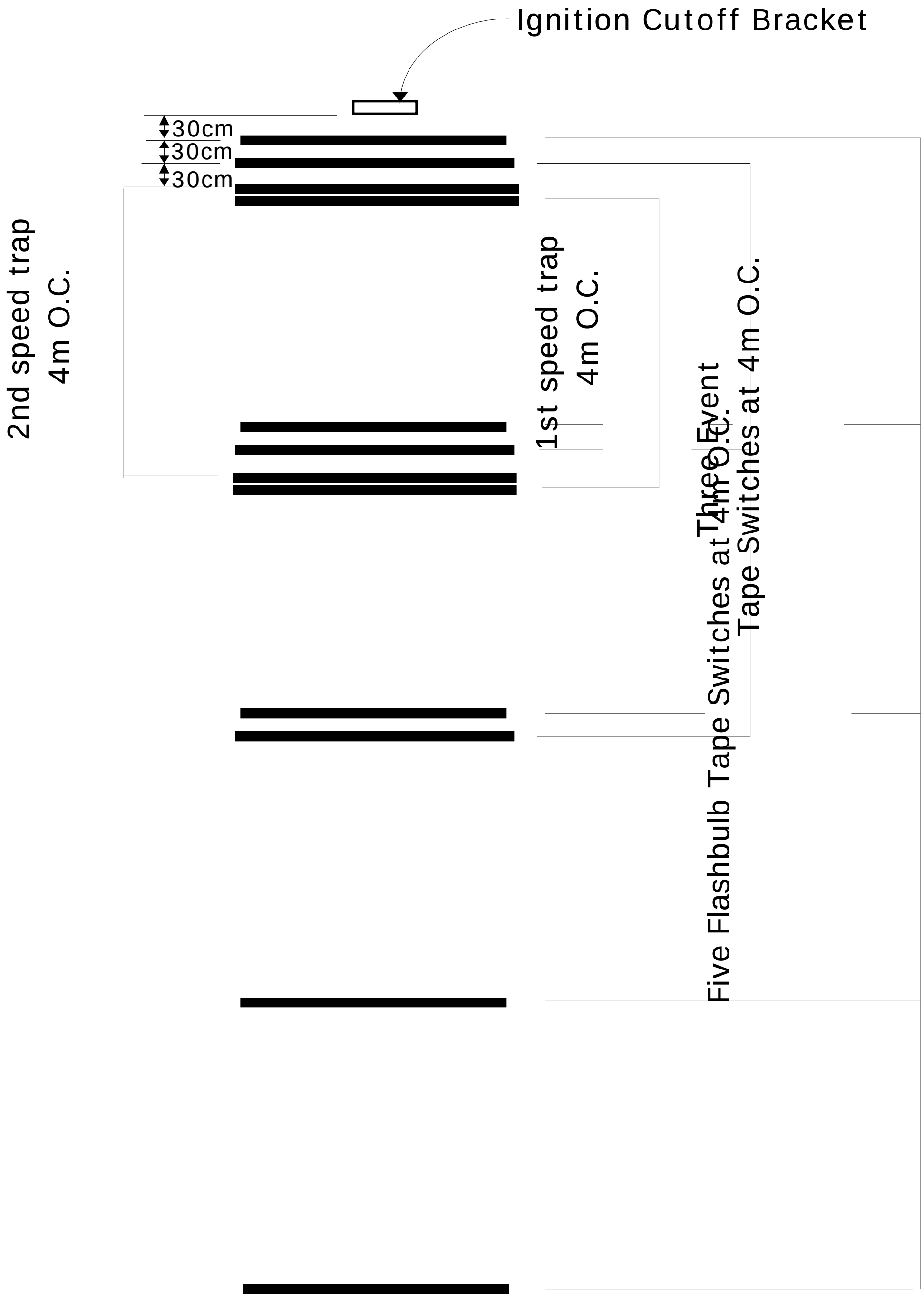


Figure 6-2 - Tape Switch Layout

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

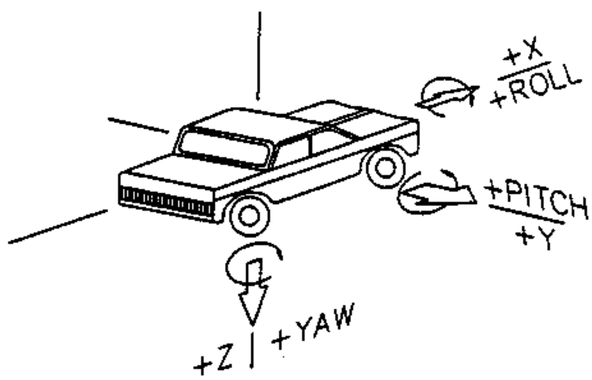


Figure 6-3 - Vehicle Accelerometer Sign Convention

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

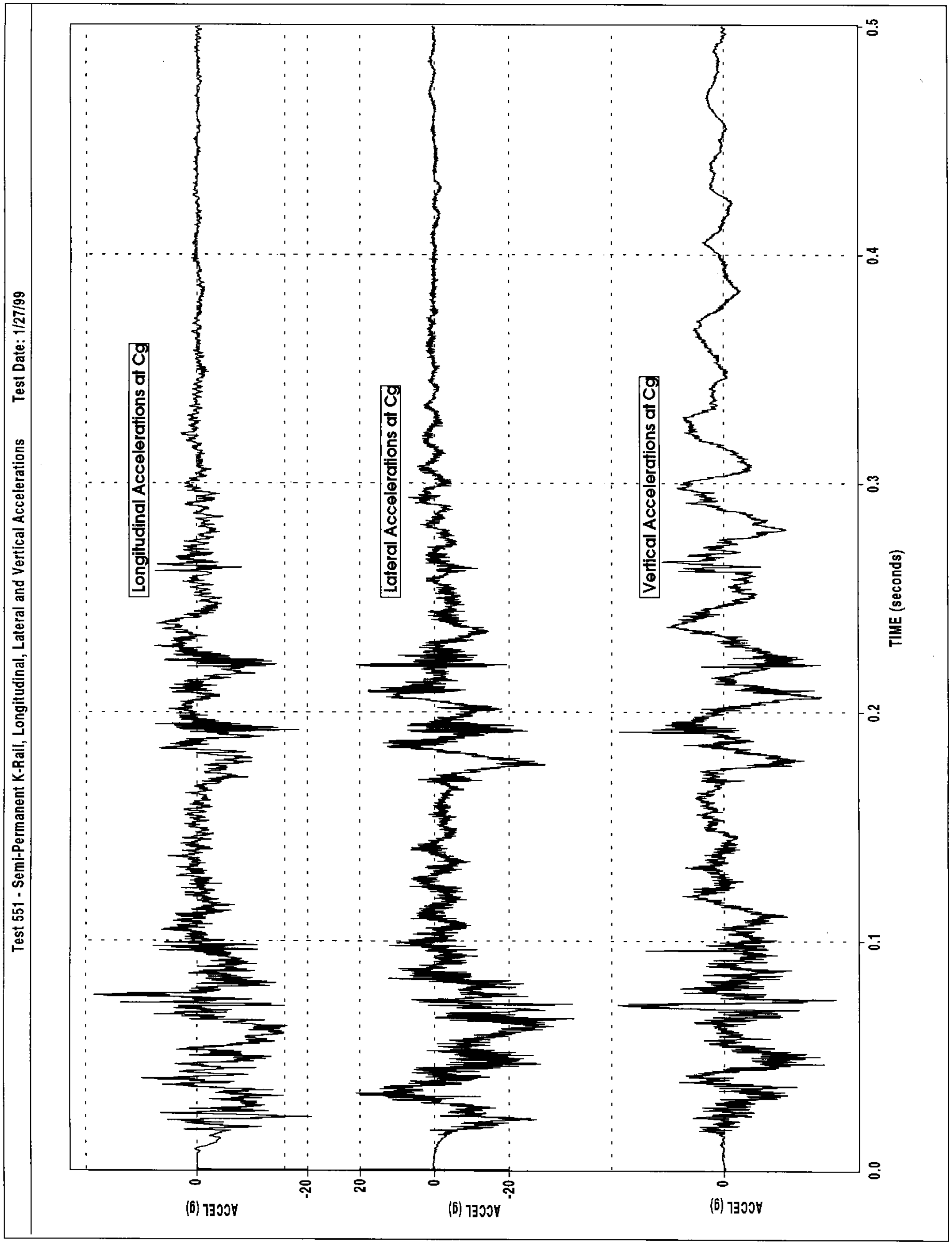


Figure 6-5 - Test 551 Vehicle Longitudinal Acceleration, Velocity and Distance -Vs- Time

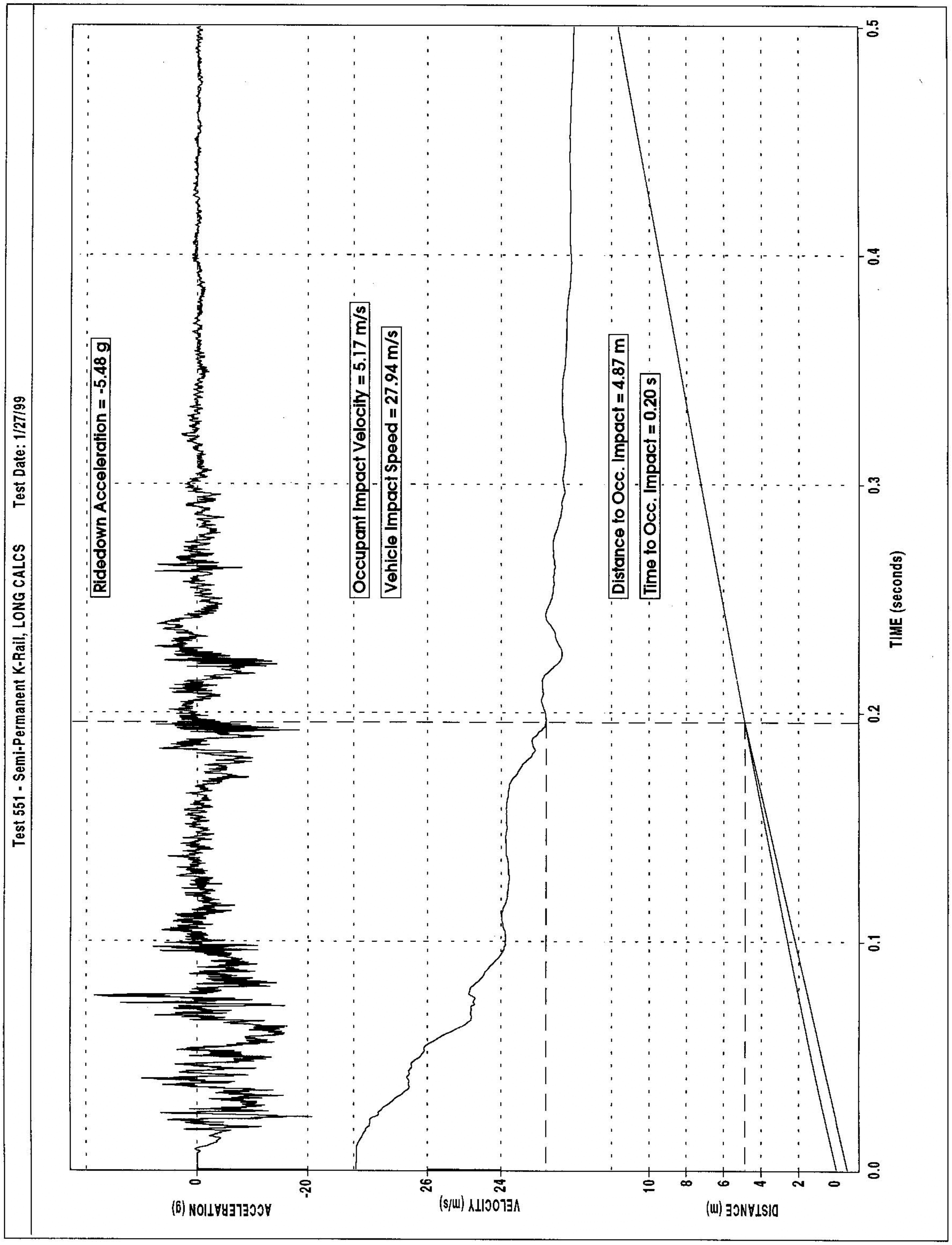


Figure 6-6 - Test 551 Vehicle Lateral Acceleration, Velocity and Distance -Vs- Time

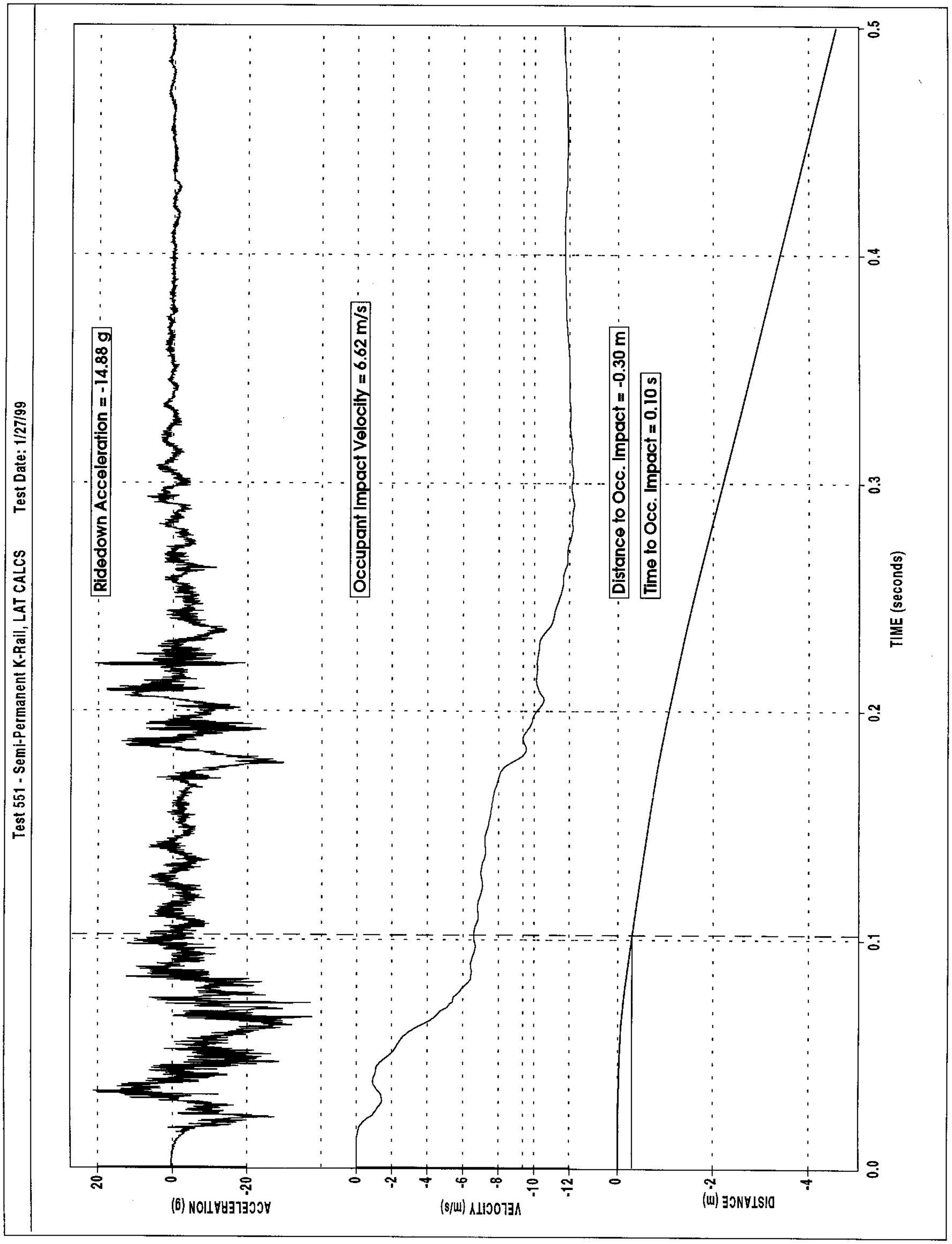


Figure 6-7 - Test 551 Vehicle Roll, Pitch and Yaw -Vs- Time

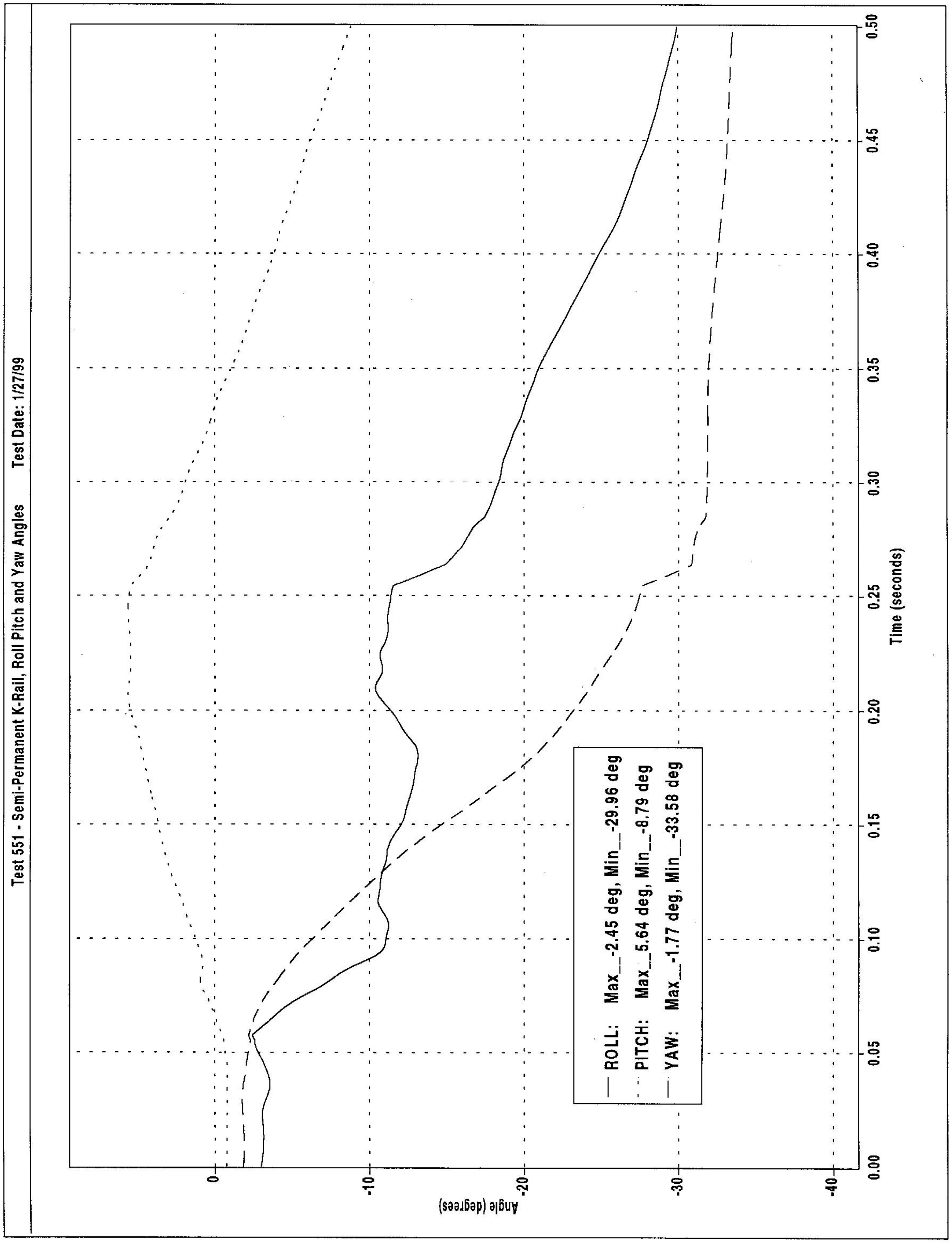


Figure 6-8 - Test 552 Vehicle Accelerations -Vs- Time

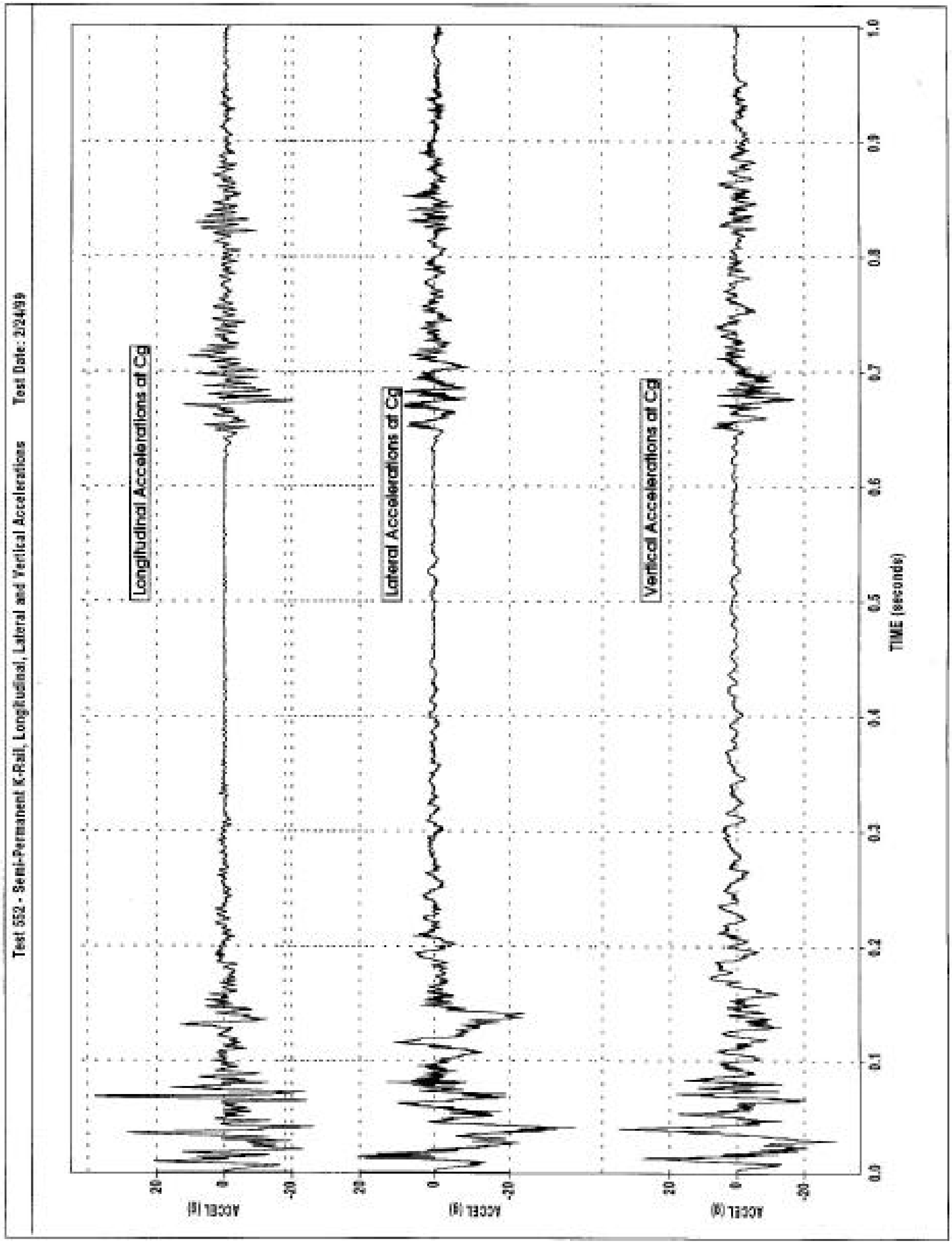


Figure 6-9 - Test 552 Vehicle Longitudinal Acceleration, Velocity and Distance -Vs- Time

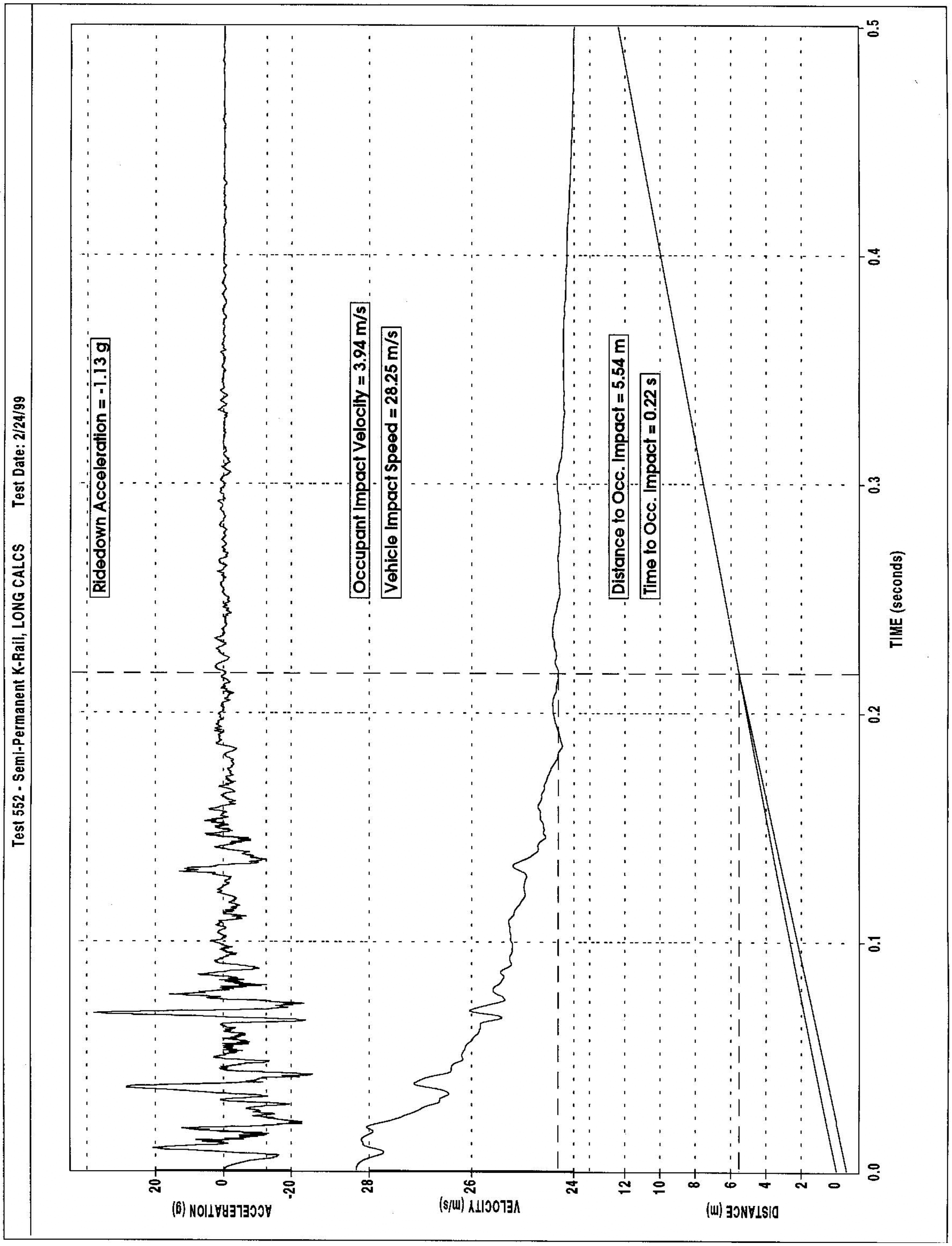


Figure 6-10 - Test 552 Vehicle Lateral Acceleration, Velocity and Distance -Vs- Time

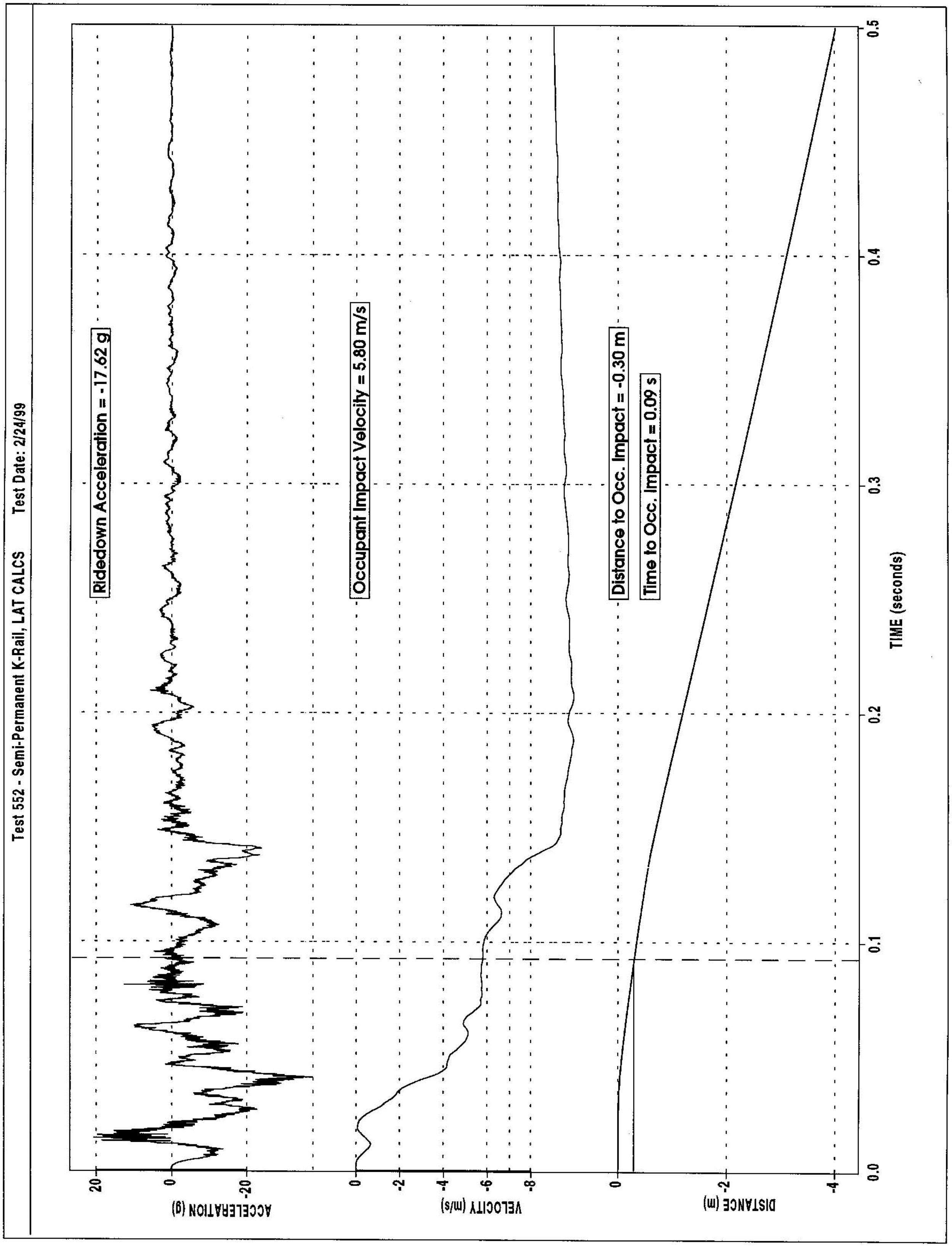
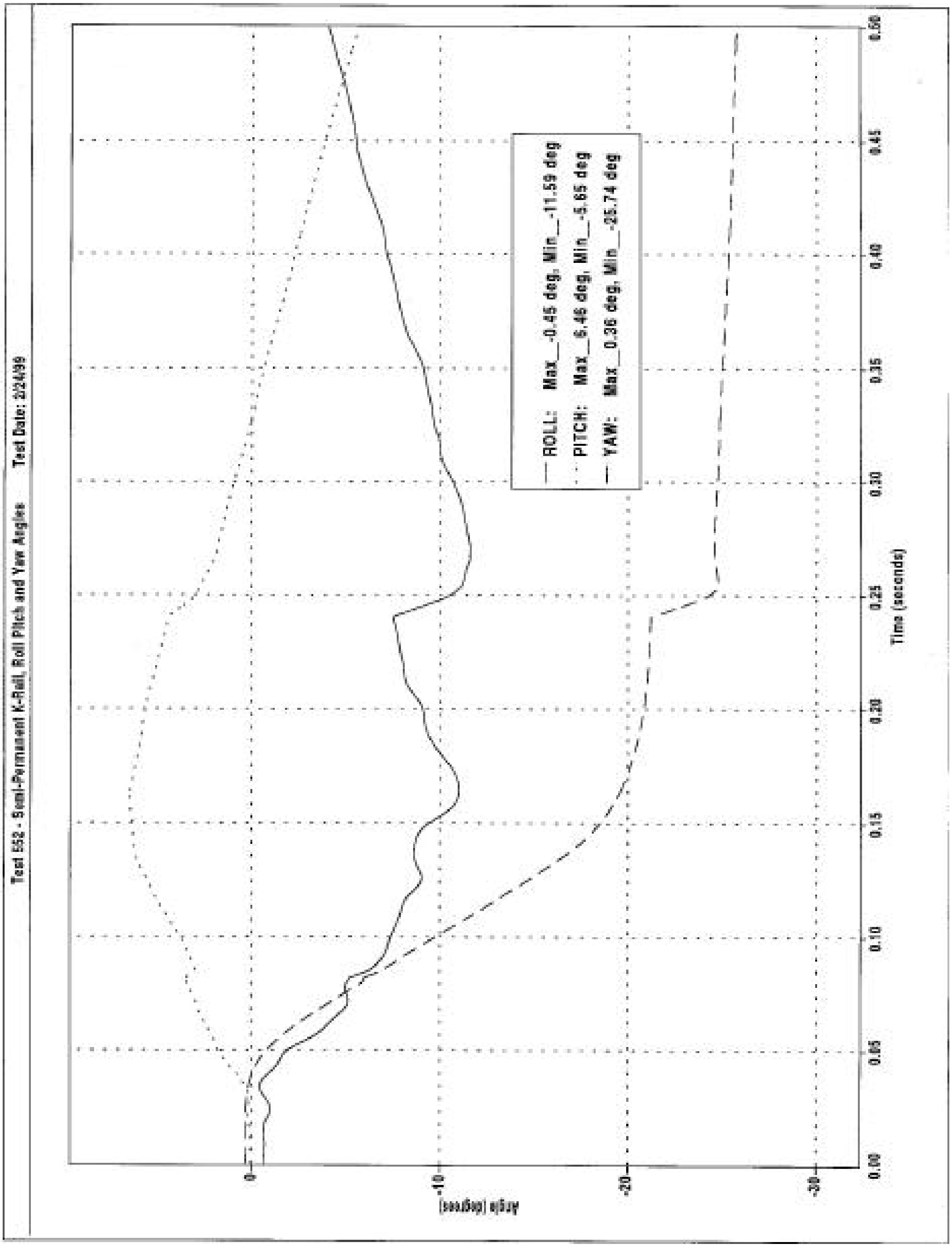
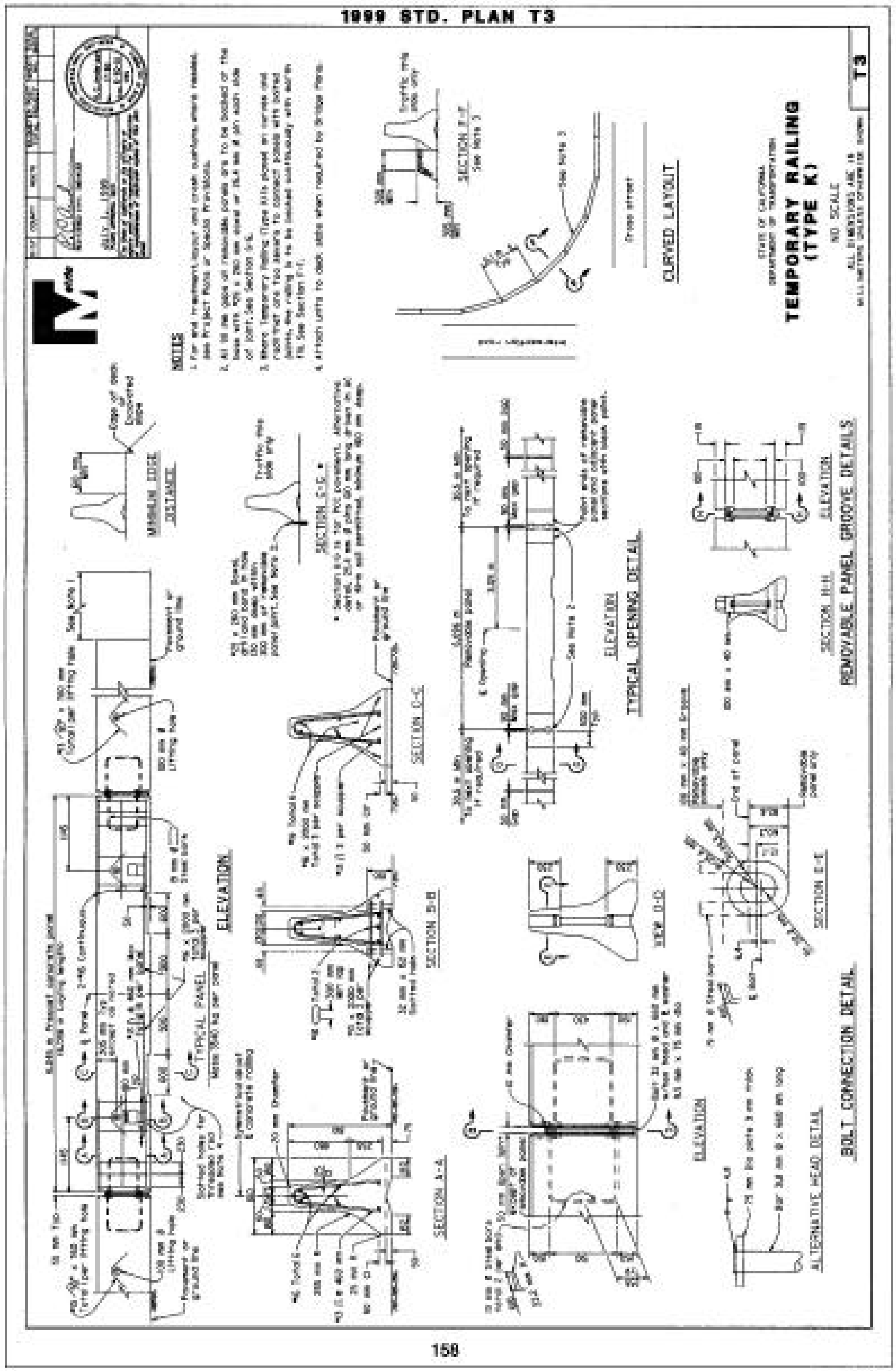


Figure 6-11 - Test 552 Vehicle Roll, Pitch and Yaw -Vs- Time



6.5. Detailed Drawing



7. REFERENCES

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