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**16. ABSTRACT**

An aesthetic, see-through concrete bridge rail with sidewalk, Type 80SW, was built and tested in accordance with NCHRP Report 350. The Type 80SW is an 810 mm-tall, reinforced concrete barrier on a 200 mm-high sidewalk. The rail has 280 mm-high by 1620 mm-long gaps, 230 mm above the sidewalk surface. The rail is fitted with a single metal tube spanning the gap and a 250 mm-high handrail attached to the top of the concrete barrier. The barrier tested was 22.8 m-long and was constructed at the Caltrans Dynamic Test Facility in West Sacramento, California.

A total of four crash tests were conducted under Report 350 test Level 4, two with 820 kg cars, one with a 2000 kg pickup truck and one with an 8000 kg single unit van truck. The first test of the 820 kg car showed a potential snagging problem on one of the vertical members. The potential problem with the first car led to a reduction in the vertical gap from 310 mm to 280 mm and a retest with a different car. The second test did not show snagging problems, with all results within the guidelines. The hood of the 2000 kg pickup snagged on a vertical handrail support tube during impact causing minor occupant compartment deformation.

Since this bridge rail is intended for pedestrian use and alone does not provide for pedestrian protection, it should only be used in low speed applications of 70 km/h or less. In addition, the handrail has been found to be a snagging hazard at the higher speed. For these two reasons, the Type 80SW is recommended for approval on California highways requiring TL-2 bridge rails.

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**VEHICLE CRASH TESTS OF THE  
AESTHETIC, SEE-THROUGH CONCRETE  
BRIDGE RAIL WITH SIDEWALK, TYPE 80SW**



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

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Research Performed by .....Roadside Safety Technology Unit

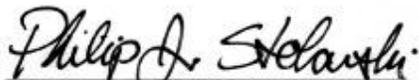
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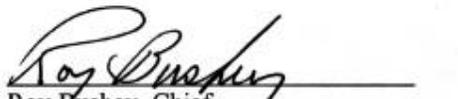
**DEPARTMENT OF TRANSPORTATION**  
ENGINEERING SERVICE CENTER,  
OFFICE OF MATERIALS ENGINEERING AND TESTING SERVICES

**VEHICLE CRASH TESTS OF THE AESTHETIC,  
SEE-THROUGH CONCRETE BRIDGE RAIL  
WITH SIDEWALK, TYPE 80SW**

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## SI CONVERSION FACTORS

<u>To Convert From</u>	<u>To</u>	<u>Multiply By</u>
<b>ACCELERATION</b>		
m/s <sup>2</sup>	ft/s <sup>2</sup>	3.281
<b>AREA</b>		
m <sup>2</sup>	ft <sup>2</sup>	10.76
<b>ENERGY</b>		
Joule (J)	ft.lbf	0.7376
<b>FORCE</b>		
Newton (N)	lbf	0.2248
<b>LENGTH</b>		
m	ft	3.281
m	in	39.37
cm	in	0.3937
mm	in	0.03937
<b>MASS</b>		
kg	lb <sub>m</sub>	2.205
<b>PRESSURE OR STRESS</b>		
kPa	psi	0.1450
<b>VELOCITY</b>		
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*

Most new or retrofit bridge rails on California highways since the 1970's have been the standard Caltrans solid concrete parapet, 810 mm high, with a New Jersey safety-shape profile. When districts requested a self-cleaning "see-through" bridge rail about 14 years ago, Caltrans developed a steel post and beam design, the Type 18. This design has been used infrequently because it is relatively expensive. It requires a minimum 300 mm thick deck overhang. Though it is attached to the side of the deck, it occupies 600 mm of deck width. It is also more likely to need repairs after an impact and to exhibit corrosion problems than a reinforced concrete bridge rail. Another design which was developed was the Type 115 bridge rail. This system had problems with the wheels of impacting vehicles snagging on the posts. Additionally, neither the Type 115 nor the Type 18 met the AASHTO PL-2 requirement that the rail be able to contain an 8000 kg, medium-duty cargo truck.

It was clear an alternative bridge rail was desired by Caltrans' district offices. This alternative would need to be more attractive and have better see-through characteristics than existing approved designs and meet the design criteria discussed in Section 2.1.2.1 Design.

### 1.2. *Objective*

To crash test an 810 mm-tall, reinforced concrete bridge railing with sidewalk, lower metal rail and hand rail (designated throughout this report as the Type 80SW) to test level 4 in NCHRP Report 350<sup>(1)</sup>. These crash testing procedures include impacts of an 820 kg sedan at 100 km/h, a 2000 kg pickup at 100 km/h and an 8000 kg truck at 80 km/h.

### 1.3. *Background*

Several bridge barrier railings have been tested by Caltrans and other agencies in recent years. None of these designs nor the ten railings in the AASHTO "Roadside Design Guide"<sup>(2)</sup> meet Caltrans' current requirements for an aesthetic, see-through railing. Of the ten railings listed in the AASHTO Guide, four are concrete barriers which are not see-through. Three out of the ten are mounted on reinforced concrete posts, or on concrete curbs and parapets. None of the designs have been tested to retain the 8000 kg truck. One of these (the Oklahoma TR-1 bridge rail) is a see-through, self-cleaning design, but the aesthetics of the rail are arguable. The size of the posts and rail are too large to provide good see-through qualities. The other three designs are based on three beam and w-section guardrail which do not provide the see-through, low maintenance or aesthetic properties that Caltrans wants in a bridge rail.

A few years ago California crash tested the Type 115 bridge rail<sup>(3)</sup>. It consists of two structural steel rails on structural steel posts which are mounted on the side of the bridge deck. Even though the design could structurally withstand impacts from pickup trucks at 100 km/h, there were some problems with front wheel snagging on the posts during the tests. The railing was consequently downgraded to a PL-1 level as defined in the AASHTO "Guide Specifications for Bridge Railings"<sup>(4)</sup> and is only recommended for use on narrow, low-volume, low-speed roads.

## 1. INTRODUCTION (Continued)

The Type 80SW was designed using the AASHTO “Guide Specifications for Bridge Railings”<sup>(4)</sup> requirements. The AASHTO Guide Specifications stipulate that a bridge rail to be used for high-speed applications must conform to PL-2 level testing. However, according to the FHWA, the PL-2 test level has since been replaced by the similar NCHRP Report 350<sup>(1)</sup> test level 4, so the railing was tested according to test level 4 criteria. Table 1.1 summarizes the testing requirements for PL-1, PL-2 and Test Level 4, including test vehicle masses and vehicle impact angles. Notice that the pickup truck weight is different in AASHTO than in NCHRP Report 350. Nevertheless, the higher impact angle required in Report 350 provides a higher impact severity because the kinetic energy due to the lateral component of the impact velocity is 33% higher. Test level 4 requires testing with an 8,000 kg, two-axle, single-unit truck in addition to the 820 kg sedan and the 2000 kg pickup.

Levels	Small Automobile	Pick-up truck	Single-Unit Truck
PL-1 (AASHTO)	816 kg (1800 lb <sub>m</sub> ) 80 km/h (50 mph) @ 20°	2449 kg (5400 lb <sub>m</sub> ) 72 km/h (45 mph) @ 20°	
PL-2 (AASHTO)	816 kg (1800 lb <sub>m</sub> ) 97 km/h (60 mph) @ 20°	2449 kg (5400 lb <sub>m</sub> ) 97 km/h (60 mph) @ 20°	8165 kg (18,000 lb <sub>m</sub> ) 80 km/h (50 mph) @ 15°
Test Level 4 (NCHRP 350)	820 kg 100 km/h @ 20°	2000 kg 100 km/h @ 25°	8000 kg 80 km/h @ 15°

Table 1.1 - Comparison of Different Test Levels

### 1.4 Literature

### Search

A literature search using the TRIS, NTIS, and the Compendex Plus databases was conducted at the beginning of the project to find research reports or publications related to the objectives of this project. There were two references found and both were for the Texas Type T411<sup>(2), (6)</sup>. The Texas T411 is a concrete beam and post bridge rail 813 mm high by 305 mm thick and contains openings 203 mm wide by 457 mm high. This rail had not been tested to Report 350<sup>(1)</sup> or to the PL-2 requirements discussed above. The post arrangement also made it difficult to see through the rail except at near perpendicular angles. In addition, the post configuration seemed to provide an excessively high effective coefficient of friction<sup>(6)</sup>. The Texas T411 did not meet Caltrans' requirements.

### 1.5 Scope

A total of four tests were performed and evaluated in accordance with NCHRP Report 350<sup>(1)</sup>. The testing matrix established for this project is shown in Table 1.2. Although test 541 was properly conducted, concerns with the test findings led to the conclusion that a reduction in the

## 1. INTRODUCTION (Continued)

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concrete bridge rail gap was preferred (see Section 2.2.1.5 for more detail). The concerns prompted a retest designated as Test 548.

<b>Test #</b>	<b>Barrier type</b>	<b>Mass (kg)</b>	<b>Speed (km/h)</b>	<b>Angle (deg)</b>
541	Type 80SW	820	100	20
542	Type 80SW	2000	100	25
543	Type 80SW	8000	80	15
548*	Type 80SW	820	100	20
*This is a retest of Test 541				

Table 1.2 - Target Impact Conditions

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## 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 bridge rail. A temporary bridge deck was constructed for the purpose of this project.

#### 2.1.2. Test Barriers

##### 2.1.2.1. Design

The Type 80SW was designed to meet specific design criteria. The bridge rail had to be crash-worthy according to the latest federal guidelines as well as functional, aesthetically pleasing and allow a partial view otherwise obscured by a “solid” concrete rail design.

The general shape of the barrier was determined for three main reasons. The first reason was to provide a partial view through the rail. A viewing space 310 mm high by 1620 mm long was chosen to meet structural and safety requirements. The space height was later reduced to 280 mm due to evidence of potential wheel snagging from the first 820 kg test. The second reason for the general shape was based on the satisfactory results of previous testing concerning wheel snagging potential on posts<sup>(2)</sup> and involved setting the posts back 100 mm from the barrier beam face. The final main reason was to provide an aesthetically pleasing rail. These criteria were kept in mind during the design process and a conscious effort was made to provide a clean and simple-appearing rail while meeting the other design criteria. The general shape of the bridge rail is the same with or without the sidewalk. However, to provide the necessary pedestrian safety, a metal handrail and lower rail were added to the “with sidewalk” design. A “without sidewalk” design is also being constructed for testing but will be discussed in a future report. The functionality of a concrete rail was another desired feature.

The low maintenance of concrete is advantageous in regard to long-term costs and roadside worker exposure. In general, concrete barriers see less damage and require fewer repairs. There is also a decreased corrosion problem in marine environments and fewer specially-fabricated, galvanized parts in a concrete barrier compared with a steel barrier. However the “with sidewalk” version of this rail does include some galvanized, non-structural parts for pedestrian safety. After the purpose of the barrier was resolved, the design criteria were applied.

The design criteria were based on highway safety design standards and material specifications. Section 13 from NCHRP Project 12-33 “Development of a Comprehensive Bridge Specification and Commentary”<sup>(2)</sup> and the 1989 AASHTO “Guide Specifications for Bridge Railings”<sup>(4)</sup> were used as guidelines for the design standard. These guidelines were followed for Performance Level Two (PL-2) crash test requirements. Material specifications for the steel reinforcement and concrete were provided by the July, 1995 Caltrans “Standard

## 2. TECHNICAL DISCUSSION (Continued)

Specifications<sup>(8)</sup>. Once the design criteria were evaluated and the necessary changes were incorporated, a specific configuration was determined.

The design configuration for the Type 80SW includes viewing spaces 310 mm high by 1620 mm long, chosen to meet structural and safety requirements. A structural cross-section is shown in Figure 2-1. The space height was later reduced to 280 mm due to evidence of potential wheel snagging from Test 541. The reinforcing steel is covered with a minimum of 25 mm of concrete and all longitudinal reinforcing is terminated in 90 degree hooks. The 810 mm-high design was used in the tests as the shortest configuration to be placed in service. This provided a more conservative test configuration for the evaluation. Additional as-built drawings for the Type 80SW can be found in Appendix 7.5. Caltrans, Office of Structures Design should be contacted to obtain the most current and complete plans for future construction projects.

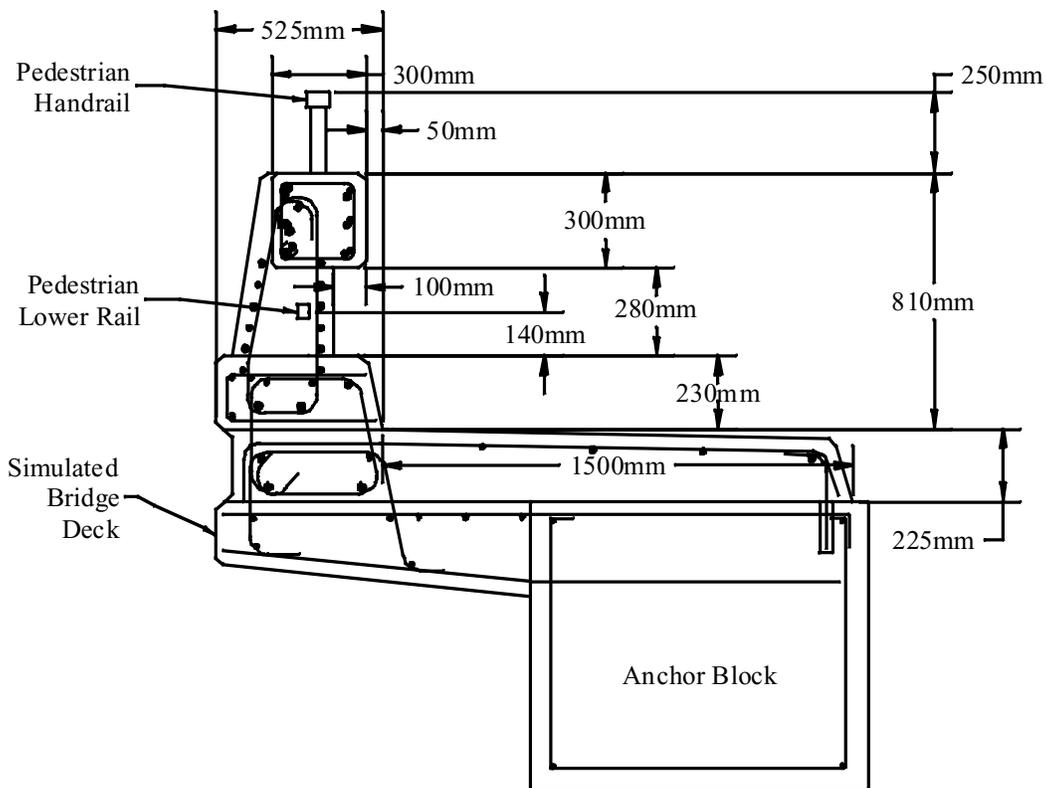


Figure 2-1 - Type 80SW

### 2.1.3. Construction

The Type 80SW was constructed at the north end of the Caltrans Dynamic Test Facility in West Sacramento, California. The north end of the facility was chosen in order to accommodate the trajectory and acceleration distance needed for the 8000 kg test vehicle. Over 600 m of test track was made available for test, with 550 m used to get the self-powered vehicle up to speed. A simulated bridge deck was attached to an existing anchor block for the bridge rail installation.

## **2. TECHNICAL DISCUSSION (Continued)**

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The bridge rail was constructed in several stages. An existing anchor block with a simulated bridge deck was utilized for the new bridge rail. The existing simulated bridge deck was demolished with the reinforcing steel retained for use in the new deck (Figure 2-2). Additional reinforcing steel was added to the steel retained including bars which looped up out of the deck approximately 200 mm above the deck surface. The forms for the new simulated deck were completed and concrete was poured level to the deck surface (Figure 2-3). To construct the sidewalk, reinforcing steel was placed over part of the anchor block and deck. Short curved bars were doweled into the anchor block at the front edge of the sidewalk to provide a positive connection. At the same time reinforcing steel for the barrier base and posts were tied into place as shown in Figure 2-4. The forms were completed and concrete poured to include the sidewalk and the base of the barrier, 200 mm above the back edge of the sidewalk (Figure 2-5).

Next, the reinforcing steel was installed for the beam section of the barrier (Figure 2-6 through Figure 2-9). The orientation of reinforcement loops and end loops for some of the bars were changed from the original plans to aid installation due to the high concentration of reinforcement. After all of the post and beam reinforcing was tied in place and the forms set, the last concrete pour was completed. The final items installed were the galvanized lower pedestrian rail and the pedestrian handrail. The handrail was attached to the top of the beam with threaded rods on a 25 mm-high grout pad. Wood forms were used throughout and all concrete was vibrated. Figure 2-10 through Figure 2-13 show the completed barrier.

## 2. TECHNICAL DISCUSSION (Continued)

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Figure 2-2 -  
Concrete Anchor  
Block with  
Simulated Bridge  
Deck Reinforcing  
Steel



Figure 2-3 -  
Simulated Bridge  
Deck Construction

Figure 2-4 - Reinforcing Steel for  
the Sidewalk and Lower Portion  
of the Bridge Rail



## 2. TECHNICAL DISCUSSION (Continued)

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Figure 2-5 -  
Concrete Pour  
for Sidewalk  
and Curb  
Section of  
Bridge Rail

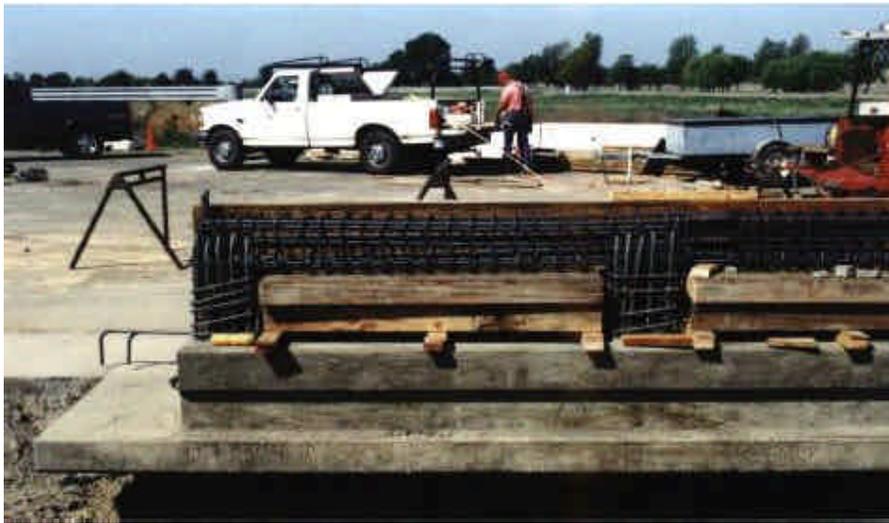


Figure 2-6 -  
Reinforcing Steel  
for Posts and  
Beam Section of  
Bridge Rail

Figure 2-7 -  
Close up of Post  
and Beam  
Reinforcing Steel,  
Couplers and  
Wood Forms



**2. TECHNICAL DISCUSSION (Continued)**

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Figure 2-8 -  
Expansion Joint  
Post and Beam  
Configuration



Figure 2-9 -  
Reinforcing  
Steel Placement  
for the Post and  
Beam Sections

Figure 2-10 -  
Pedestrians  
Walking on  
Completed  
Sidewalk



## 2. TECHNICAL DISCUSSION (Continued)

---

Figure 2-11 -  
View of  
Completed  
Barrier and  
Sidewalk



Figure 2-12 -  
Completed  
Expansion Joint

Figure 2-13 -  
Backside of  
Completed Bridge  
Rail



## 2. TECHNICAL DISCUSSION (Continued)

### 2.1.4. Test Vehicles

The test vehicles complied with NCHRP Report 350<sup>(4)</sup>. For all tests, the vehicles were in good condition, free of major body damage and were not missing any structural parts. All of the vehicles had standard equipment and front-mounted engines. The vehicle inertial masses were within acceptable limits (Table 2.1).

Table 2.1 - Test Vehicle Masses

Test No.	Vehicle	Ballast (kg)	Test Inertial (kg)
541	1992 Geo Metro	0	823
542	1993 Chevrolet 2500	5	1954
543	1992 GMC Top Kick	2918	8020
548*	1994 Geo Metro	0	824

\*Test 548 is a retest of Test 541 which had a potential snagging problem with the passenger side front wheel.

The Chevrolet truck and the GMC TopKick were self-powered; a speed control device limited acceleration once the impact speed had been reached. The two Geos were 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. For Test 542 an elastic cord was attached to the vehicle's steering wheel to prevent oscillation in the steering system. A short distance before the point of impact, each vehicle was released from the guidance rail and the ignition was turned off (for the Geos, the tow cable was released). A detailed description of the test vehicle equipment and guidance system is contained in Appendix 7.1 and 7.2.

### 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. Due to technical difficulties not all of the cameras functioned properly for each test, as will be discussed later. 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.

Three sets of orthogonal accelerometers were mounted in all vehicles (except the 8000 kg truck), two at the center of gravity and one at 600 mm behind the center of gravity. Rate gyro transducers were also placed at the center of gravity of each vehicle (except the 8000 kg truck) to measure the roll, pitch and yaw. The data were used in calculating the occupant impact velocities and ridedown accelerations, and maximum vehicle rotation.

## **2. TECHNICAL DISCUSSION (Continued)**

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An anthropomorphic dummy was used in Test 541 and Test 548 to obtain motion data. The dummy, a Hybrid III built to conform to Federal Motor Vehicle Safety Standards by the Sierra Engineering Company, 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 with custom DADiSP workbooks using a Fieldworks Model FW 7666P portable computer.

### **2.2 Test Results - Crash Tests**

A film report with edited footage from tests 541, 542, 543, and 548 has been compiled and is available for viewing.

#### **2.2.1.1. Impact Description - Test 541**

The measured speed of the 823 kg vehicle on impact with sidewalk curb was 102.0 km/h with an angle of 20°. Impact with the sidewalk curb and bridge rail occurred 0.38 m and 4.9 m, respectively, from the upstream end of the 23-m long bridge rail. Contact with the bridge rail continued for approximately 4.3 m, as determined by scuff marks on the rail. At the point of last contact with the bridge rail, all four vehicle wheels were on or above the sidewalk. As the vehicle continued its exit trajectory, the driver's front then rear wheel went off the sidewalk approximately 5 m and 10 m, respectively, after the point of last contact with the bridge rail face. The exit angle and speed of the car were 10° and 75 km/h, respectively. The brakes were applied approximately 25 m after impact with the bridge rail. The stopping point for the vehicle was about 40 m from the point of last contact with the barrier as shown in Figure 2-22. The vehicle remained upright throughout and after the collision.

Due to a global camera error none of the seven 16 mm, high speed cameras or the one 35 mm sequence camera functioned during the test. The test was documented with the manually operated 16 mm normal speed film camera, 35 mm film still camera with an autowinder and betacam video camera. From the on-board data acquisition system, available photo and film documentation and physical evidence, enough information was available to be confident in the results presented for this test.

The first point of contact for the constructed test article was the sidewalk. The right front passenger wheel was damaged and the tire deflated as a result of the impact with the sidewalk curb. During the examination of the impact area after the test there was evidence that the front passenger wheel had contacted and rotated around the post 6 m from the upstream end of the barrier (Figure 2-25 and Figure 2-26). The tire also contacted the pedestrian steel tube within the gap. The next post at 8 m had black tire marks along its face, but the wheel did not enter into the gap (Figure 2-23). It was the contact and rotation around post 6 and the contact with the steel tube that led to the decision to reduce the gap and re-run the 820 kg test. The retest was performed as Test 548 and is discussed starting in Section 2.2.1.11.

**2. TECHNICAL DISCUSSION (Continued)**

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Figure 2-14 - Downstream View of the Bridge Rail with Vehicle 541



Figure 2-15 - Side View Of Vehicle 541

**2. TECHNICAL DISCUSSION (Continued)**

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Figure 2-16 - Front View Of The Bridge Rail at the Impact Location



Figure 2-17 - Side View Of Vehicle 541 at the Impact Location

**2. TECHNICAL DISCUSSION (Continued)**

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Figure 2-18 - Vehicle 541 Impact Sequence Photos

**2. TECHNICAL DISCUSSION (Continued)**

---

Figure 2-19 -  
Post Impact  
Passenger  
Floorboard  
Damage,  
Vehicle 541



Figure 2-20 -  
Post Impact  
Side View of  
Vehicle 541

Figure 2-21 -  
Close up of  
Passenger Side  
Front Damage,  
Vehicle 541



**2. TECHNICAL DISCUSSION (Continued)**

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Figure 2-22 -  
Post Impact  
Front View,  
Vehicle 541



Figure 2-23 -  
Post Impact  
Bridge Rail  
Scuff Marks Test  
541

Figure 2-24 -  
Post Impact  
Bridge Rail  
Scuff Marks Test  
541



## 2. TECHNICAL DISCUSSION (Continued)

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Figure 2-25 -  
Close up of Post  
Impact Bridge  
Rail Scuff Marks



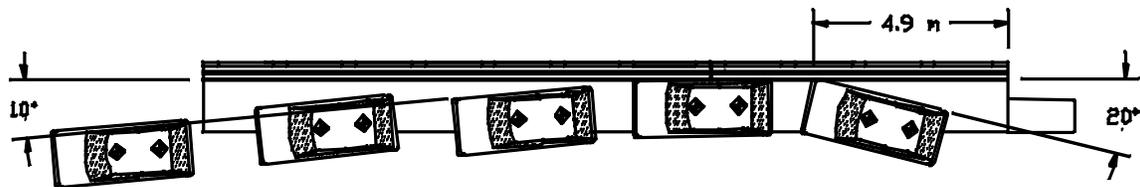
Figure 2-26 -  
Wheel Rotation  
Marks Around  
Bridge Rail Post



## 2. TECHNICAL DISCUSSION (Continued)

Figure 2-27 - Test 541 Data Summary Sheet

Frontal impact photo series unavailable,  
refer to Figure 2-18 for alternate photo series.



### Test Barrier

Type: Type 80SW  
Length: 22.8 m

Test Date: December 10, 1997

### Test Vehicle:

Model: 1992 Geo Metro  
Inertial Mass: 823 kg  
Impact / Exit Velocity: 102 km/h / 75 km/h  
Impact / Exit Angle: 20° / 10°

### Test Dummy:

Type: Hybrid III  
Weight / Restraint: 74.8 kg / Lap and shoulder  
Position: Front Right

### Test Data:

Occ. Impact Velocity (Long / Lat): 5.98 m/s / 6.34 m/s  
Ride-down Acceleration (Long / Lat): -5.5 g / -9.9 g  
Max. 50 ms Avg. Accel. (Long / Lat): -8.58 g / -10.15 g  
Exterior: VDS<sup>(9)</sup>/CDC<sup>(10)</sup> FR-5, RD-4 / 02RFEW3  
Interior: OCID<sup>(11)</sup> RF0000000

### Barrier Damage:

Superficial scuffing

## **2. TECHNICAL DISCUSSION (Continued)**

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### ***2.2.1.2 Vehicle Damage - Test 541***

The right front section of the vehicle sustained crushing of the bumper and minor unibody frame deformation, damage to the suspension and a flat tire. Initial right front wheel damage occurred on impact with the sidewalk 0.38 m from the beginning of the bridge rail installation. The sidewalk contact caused deformation of the wheel and tire deflation. Other tires experienced minor deformation on impact with the sidewalk but remained inflated. After contacting the bridge rail the right front wheel was pushed back, forcing the wheel well area to deform (Figure 2-21).

As the vehicle turned parallel to the bridge rail, the sheet metal on both the right doors came into contact with the bridge rail face and caused minor scraping. The right rear tire rubbed along the bridge rail, but was not damaged beyond moderate scuffing. The vehicle continued along the sidewalk with the left wheels dropping off the curb 19 m from the beginning of the bridge rail. The shock absorber and right drive shaft of the right front wheel were bent but remained attached. The interior of the vehicle experienced minor deformation, less than 130 mm in the front passenger right foot floorboard area with negligible deformation elsewhere. The right front passenger door was jammed but the other three doors and hatchback functioned properly. The windshield was cracked on the passenger side. The hood and headlights were not damaged.

Occupant impact velocities and occupant ride-down accelerations were below the preferred maximums summarized in Table 2.2 - Test 541 Assessment Summary, page 45. The lateral and longitudinal occupant impact velocities were 6.34 m/s and 5.98 m/s, respectively. The lateral and longitudinal occupant ride-down accelerations were -9.90 g and -5.50 g, respectively.

### ***2.2.1.3 Barrier Damage - Test 541***

Barrier damage was cosmetic only, consisting of scrapes and tire marks. Both of the right side tires left marks on the sidewalk curb then on the curb and beam section of the bridge rail. Small amounts of concrete spalled from the face of the barrier where the vehicle's sheet metal and wheels made contact.

### ***2.2.1.4 Dummy Response - 541***

The dummy was lap and shoulder belted into the passenger's seat. Due to the lack of film coverage, the dummy response at impact is unavailable. However, an examination of the dummy revealed no apparent contact between the dummy and the barrier face. The dummy remained upright and secure during the remainder of the test. The final resting position of dummy was upright in the passenger's seat.

### ***2.2.1.5 Impact Description - Test 542***

The measured speed of the 1954 kg vehicle on impact with sidewalk curb was 110.2 km/h with an angle of 25.0°. The impact speed was substantially above the intended 100 km/h and was due to an onboard speed control device malfunction. Impact with the sidewalk curb then bridge rail occurred 2.5 m and 5.9 m, respectively, from the upstream end of the 23 m-long bridge rail. The right front tire was damaged by the curb section of the bridge rail and deflated quickly. Following the impact with the sidewalk curb the vehicle started to roll left and pitch up slightly. The maximum roll of -7.1° occurred just before impact with the rail, then shifted to a maximum positive roll of 5.6° after impact with the rail.

## **2. TECHNICAL DISCUSSION (Continued)**

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The vehicle bumper first contacted the beam section of the bridge rail 0.11 s after the right front tire contacted the sidewalk. At this point the right rear wheel was in contact with the sidewalk curb and moving upward, causing the vehicle to pitch down. The vehicle was redirected parallel with the rail at about 0.23 s after contact with the beam section. It continued to pitch down after the vehicle left contact with the rail due in part to the deflated front tires and the left front wheel dropping off the sidewalk. A maximum pitch of 15.5° occurred after the vehicle passed the downstream end of the bridge rail.

During the impact with the rail, the vehicle hood overlapped the top of the beam section of the rail and caught on the vertical handrail support tubes. The right front corner of the hood was held back as the vehicle continued along the rail. As a result the hood was pulled toward the barrier and backward, impacting the passenger side “A” pillar and windshield, causing minor occupant compartment deformation.

The vehicle stayed in contact with the rail for approximately 6.5 m. The exit angle and speed were 7° and 77 km/h respectively. The vehicle remained upright throughout and after the collision. Brakes were applied 0.75 s after initial contact with the rail and the stopping point for the vehicle was approximately 34 m from the point of last contact with the barrier. Figure 2-34 shows the vehicle in its final resting position.

**2. TECHNICAL DISCUSSION (Continued)**

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Figure 2-28 -  
Vehicle and  
Bridge Rail  
before  
Test 542



Figure 2-29  
- Vehicle  
and Bridge  
Rail before  
Test 542

Figure 2-30 -  
Impact Side  
of Vehicle  
before  
Test 542



## 2. TECHNICAL DISCUSSION (Continued)

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Figure 2-31 -  
Bridge Rail  
before Test  
542-View  
from Upstream



Figure 2-32 -  
Bridge Rail  
before Test 542-  
Close-up View

Figure 2-33 -  
Bridge Rail  
before  
Test 542-  
Close-up  
View



**2. TECHNICAL DISCUSSION (Continued)**

---

Figure 2-34 -  
Final Position  
Of Test  
Vehicle 542



Figure 2-35 -  
Impacting  
Corner Of  
Tested  
Vehicle 542

Figure 2-36 -  
Close-up of  
Impacting  
Corner Of  
Tested  
Vehicle 542



**2. TECHNICAL DISCUSSION (Continued)**

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Figure 2-37 - Interior View of Test Vehicle 542



Figure 2-38 - Floor board of Vehicle 542

**2. TECHNICAL DISCUSSION (Continued)**

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Figure 2-39 -  
Bridge Rail  
after Test  
542-View  
from  
Upstream



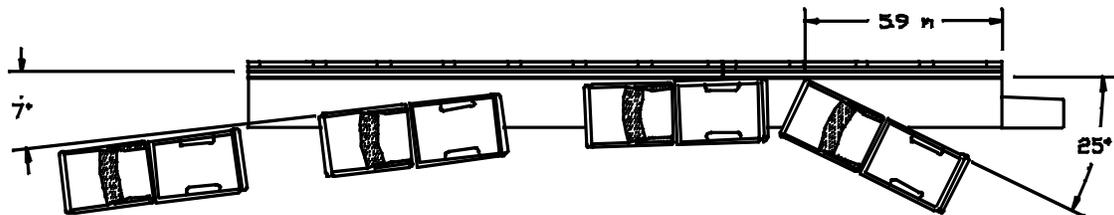
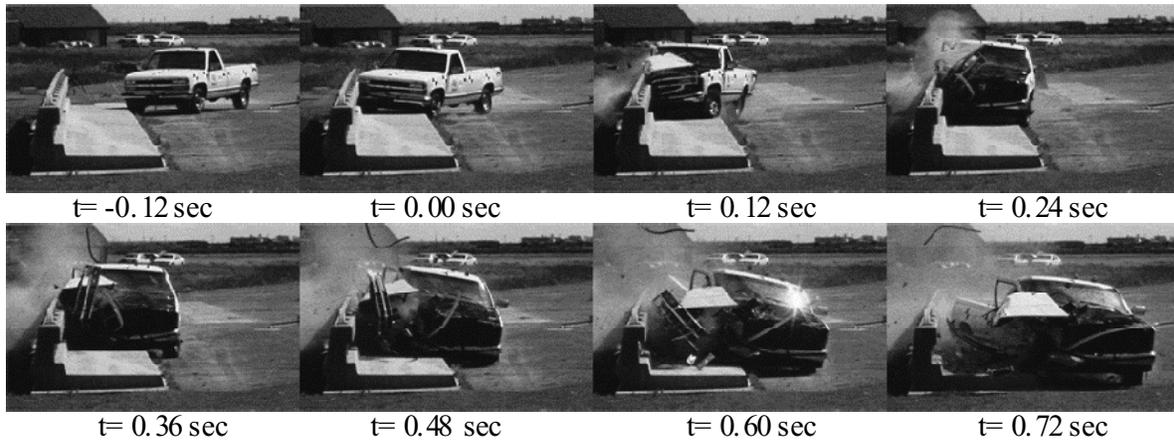
Figure 2-40 -  
View  
Perpendicu  
r to Point of  
Impact

Figure 2-41 -  
Impact Area  
and Expansion  
Joint



## 2. TECHNICAL DISCUSSION (Continued)

Figure 2-42 - Test 542 Data Summary Sheet



### Test Barrier

Type: Type 80SW  
Length: 22.8 m

### Test Date:

April 1, 1998

### Test Vehicle:

Model: 1993 Chevrolet 2500  
Inertial Mass: 1954 kg  
Impact / Exit Velocity: 110.2 km/h / 77 km/h  
Impact / Exit Angle: 25.0° / 7°

### Test Dummy:

Type: NA  
Weight / Restraint: NA  
Position: NA

### Test Data:

Occ. Impact Velocity (Long / Lat): 9.37 m/s / 8.16 m/s  
Ride-down Acceleration (Long / Lat): -7.45 g / -12.75 g  
Max. 50 ms Avg. Accel. (Long / Lat): -9.26 g / -14.41 g  
Exterior: VDS<sup>(9)</sup>/CDC<sup>(10)</sup> FR-5, RD-6 / 02RFEW9  
Interior: OCD<sup>(1)</sup> RF2012110

### Barrier Damage:

The barrier sustained minor spalls from the point of impact to roughly 4 m downstream. Other barrier damage was cosmetic only, consisting of scrapes and tire marks.

## **2. TECHNICAL DISCUSSION (Continued)**

---

### **2.2.1.6 Vehicle Damage - Test 542**

The sidewalk curb and the bridge rail face were the two initial impact locations causing vehicle damage. The sidewalk curb damaged the wheels and quickly deflated all the tires on impact except the left rear. The first point of contact with the bridge rail occurred on the beam section, causing the majority of damage to the right front quarter panel area. Additional damage occurred when the hood caught on the handrail, breaking the left hinge.

The extra speed of the vehicle, 10.2 km/h over target, undoubtedly contributed to higher deformation of the impacting right corner of the vehicle than would have otherwise occurred. Figure 2-36 shows the right front wheel pushed back into the wheel well, caused by impact with the rail curb and beam face. All of the wheels stayed connected to the vehicle throughout the test. The front right shock absorber, stabilizer bar and upper and lower control arms were bent but still attached. The rear and left front suspension components were intact and appeared undamaged. There was minor deformation of the right front frame.

As contact continued along the rail, the vehicle hood slid along the top of the beam section, extending approximately 0.38 m past the beam face toward the backside of the barrier. As the hood slid along the top of the beam, it caught on the handrail support tubes. The left hinge mechanism attached to the hood failed and the hood buckled over the right hinge. As mentioned in section "Impact Description - Test 542" above, the hood was then pushed into the passenger side "A" pillar and windshield. The "A" pillar was pushed back about 170 mm and the windshield was torn vertically 150 mm, 100 mm from the "A" pillar.

Additional damage included other notable items specifically attributed to the right front wheel being forced to the rear of the wheel well. The dashboard was pushed upward just left of the centerline of the cab with the right side displaced down from the center (Figure 2-37). A crease in the passenger floor board extending from the front center to the right rear of the cab was 130 mm at its highest point (Figure 2-37). There was also minor sheet metal deformation in the roof near the rear of the door sill. The vehicle battery was demolished but the engine components were intact. The rear glass was undamaged and the driver's door and the tail gate still functioned properly.

The occupant compartment deformation was judged not to be serious because of the nature and location of the deformation. Creasing in the floor of the compartment would not have affected the driver significantly. The passenger seat would have tilted backward and perhaps to the right, but neither headroom nor overall passenger compartment volume appeared to be seriously reduced. Moreover, as mentioned previously, the deformation would have been less if the vehicle had impacted the bridge rail at the target speed. At 110.2 km/h, the test vehicle had 21% greater kinetic energy than if it had impacted the rail at the intended 100 km/h.

The longitudinal occupant impact velocity and longitudinal occupant ridedown acceleration were below the allowed maximums of 12 m/s and 20 g, respectively. The longitudinal occupant impact velocity was 9.37 m/s and the longitudinal occupant ridedown acceleration was -7.45 g.

## **2. TECHNICAL DISCUSSION (Continued)**

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### ***2.2.1.7. Barrier Damage - Test 542***

The barrier sustained minor spalls from the point of impact to roughly 4 m downstream. Other barrier damage was cosmetic only, consisting of scrapes and tire marks. Both of the right side tires left marks along the face of the barrier for the 6.5 m of contact. Small amounts of concrete spalled from the face of the barrier where the vehicle's sheet metal and wheel made contact with the beam face and beam lower edge. The pedestrian handrail remained intact. The barrier remained fully functional after the impact with only minor, mainly cosmetic, repairs needed for complete restoration.

### ***2.2.1.8. Impact Description - Test 543***

The measured speed of the 8020 kg single-unit, van-bodied truck on impact with the sidewalk curb was 80.8 km/h with an angle of 15.0°. Impact with the sidewalk curb and bridge rail occurred 1.1 m and 7.38 m, respectively, from the upstream end of the 23 m-long bridge rail. Following the impact with the sidewalk, the right front tire stayed in contact with the upper surface of the sidewalk. The vehicle was not instrumented with accelerometers or rate gyros. The vehicle impacted the bridge rail 0.04 s after contact with the sidewalk curb, 1.0 m in front of the expansion joint.

It appeared that the right front lug nuts scraped along the beam face, causing most of the concrete spalling seen in Figure 2-55. The right wheel well hit the handrail 0.028 s after initial contact with the bridge rail. Beginning 0.177 s after contact with the bridge rail, both the left front and left rear tires rose approximately 1 m off the ground and remained off the ground for 0.480 s and 0.757 s, respectively. The vehicle continued to make contact with the barrier for approximately 4.5 m. A peak roll of the vehicle box section to the right and then left was 17.5° at 0.521 s and 14.5° at 1.099 s, respectively, from the impact with the rail. These peaks were taken before the vehicle exited the end of the test article installation. Higher values may have occurred later after the brakes were applied. The vehicle continued to a point of rest on an earth berm about 43 m from the point of impact. The vehicle remained upright throughout and after the collision.

The 2918 kg of ballast, comprised of two separate pallets of sand bags strapped down to the cargo floor. The pallets were constrained by 150 mm angle iron and the sand bags were held down by 100 mm trucking straps as shown in Figure 2-47. The sand was allowed to shift slightly but is unlikely to have affected the test. None of the sand bags broke loose during the test (Figure 2-49).

## 2. TECHNICAL DISCUSSION (Continued)

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Figure 2-43 -  
543 Test  
Vehicle



Figure 2-44 -  
Vehicle 543  
Relative To  
Bridge Rail

Figure 2-45 -  
Rear View of  
543 Test  
Vehicle



## 2. TECHNICAL DISCUSSION (Continued)

---

Figure 2-46 -  
Impact Side of  
543 Test  
Vehicle



Figure 2-47 -  
150 mm Angle  
Irons Used To  
Constrain Two  
Pallets of Sand

Figure 2-48 -  
Before Test View  
of Bridge Rail  
from Upstream



**2. TECHNICAL DISCUSSION (Continued)**

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Figure 2-49 -  
Impact Side  
View of Vehicle  
543 after Impact



Figure 2-50 -  
Vehicle 543  
after Impact

Figure 2-51 -  
Close-up of  
Impact side of  
Vehicle 543



**2. TECHNICAL DISCUSSION (Continued)**

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Figure 2-52 -  
Left Side Of  
Cab After Test  
543



Figure 2-53 -  
Bridge Rail and  
Vehicle After  
Test 543

Figure 2-54 -  
Impact Area for  
Test 543



**2. TECHNICAL DISCUSSION (Continued)**

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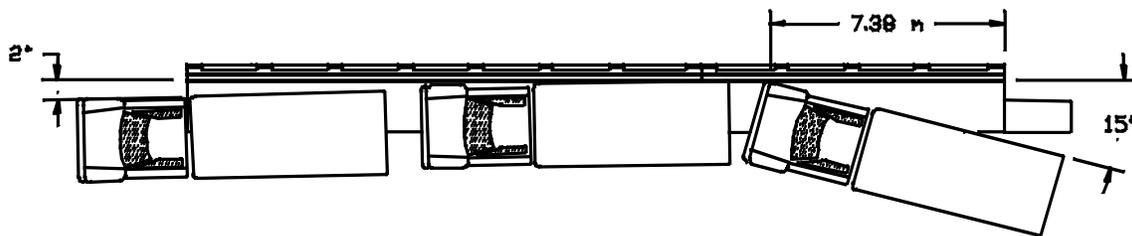
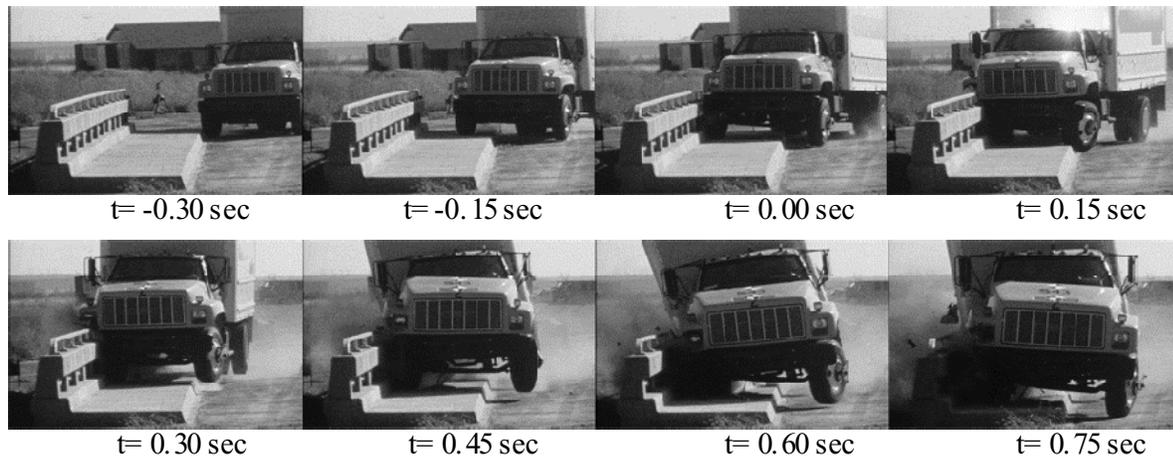
Figure 2-55 -  
Close-up of  
Impact Area for  
Test 543



Figure 2-56 -  
Backside of  
Expansion Joint  
Area after  
Test 543

## 2. TECHNICAL DISCUSSION (Continued)

Figure 2-57 - Test 543 Data Summary Sheet



### Test Barrier

Type: Type 80SW  
Length: 22.8 m

### Test Date:

October 28, 1997

### Test Vehicle:

Model: 1992 GMC TopKick  
Inertial Mass / Ballast: 8020 kg / 2918 kg  
Impact / Exit Velocity: 80.8 km/h / 72 km/h  
Impact / Exit Angle: 15.0 / 2°

### Test Dummy:

Type: NA  
Weight / Restraint: NA  
Position: NA

### Test Data:

Occ. Impact Velocity (Long / Lat): not measured  
Ride-down Acceleration (Long / Lat): not measured  
Max. 50 ms Avg. Accel (Long / Lat): not measured  
Interior: OCDA RF0000000

### Barrier Damage:

The barrier was scraped along the face and edges over a 3 m length. There was also spalling on the underside of the beam and at the expansion joint with no structural damage.

## **2. TECHNICAL DISCUSSION (Continued)**

---

### ***2.2.1.9. Vehicle Damage - Test 543***

The sidewalk curb and the bridge rail face were the two initial impact locations. The impact with the sidewalk curb did not damage the tires or wheels of the 8000 kg truck. On contact with the bridge rail the impacting tire was pushed back and to the left. This severed the U-bolts connecting the shock absorbers and leaf springs to the front axle and sheared the pitman arm to the power steering. The right front wheel lug nuts were worn due to scraping along the rail. None of the tires deflated during the test.

Also damaged were the battery box, fuel tank and right front quarter panel. The battery box sustained substantial crushing. The fuel tank was deflected about 0.5m and dented in about 0.15 m, but was not penetrated. Damage to the right front quarter panel occurred on contact with rail face and handrail. There was no visible damage to the cargo box or frame beyond minor scuffing. Both doors, the hood and rear rolling door functioned properly with no visible occupant compartment deformation.

### ***2.2.1.10. Barrier Damage - Test 543***

The barrier was scraped along the face and edges over a 3 m length. There was also spalling on the underside of the beam caused by the downward force of the rotating right front wheel lug nuts. The tire marks along the barrier were only a little longer than the scraping along the face. A concrete spall at the expansion joint was 80 mm to 100 mm deep and extended to the back face of the rail, shown in Figure 2-55 and Figure 2-56. The spall exposed the end of a piece of rebar but no structural damage was evident. The bridge rail withstood the impact from vehicle 543 well with only spall repairs necessary before subsequent tests.

### ***2.2.1.11. Impact Description - Test 548***

The measured speed of the vehicle on impact with sidewalk curb was 80.5 km/h with an angle of 19.5°. The impact speed was substantially below the intended 100 km/h and was a result of an improper speed obtained by the tow vehicle. Impact with the sidewalk curb and bridge rail occurred 0.4 m and 5.3 m, respectively, from the upstream end of the 23 m long bridge rail. Following the impact with the sidewalk curb, the vehicle started to roll left and pitch up.

As the vehicle continued toward the bridge rail, first the right front then right rear tires left contact with the top of the sidewalk. Figure 2-69 provides a frontal view of the vehicle during impact. The right front of the vehicle continued to rise until it contacted the bridge rail. On contact with the bridge rail both right wheels were off the ground, the left front wheel was on the sidewalk and the left rear wheel was on the pavement. After contact with the bridge rail the vehicle was redirected parallel to the barrier. The vehicle was in contact with the barrier face 0.27 seconds and for a distance of approximately 4 m.

The exit speed and angle were approximately 62 km/h and 4°, respectively. The maximum roll of -14.3° occurred during the initial contact with the bridge rail and a maximum pitch of 5° was obtained as the vehicle's side came into contact with the beam section. The vehicle remained upright throughout and after the collision. Brakes were not applied and the stopping point for the vehicle was approximately 37 m from the point of last contact with the barrier. Figure 2-64 and Figure 2-67 show the vehicle in its resting position.

## **2. TECHNICAL DISCUSSION (Continued)**

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Test 548 was a supplement to Test 541 due to the potential snagging of the right front wheel as mentioned previously. The only change to the bridge rail from Test 541 to 548 was that the gap was reduced 30 mm. The gap was reduced by raising the bridge rail curb height. The guidance rail used had not been moved from Test 541 to provide the same angle and impact location for Test 548. Attention was directed to the wheel and its snag potential on post 6 during Test 548.

The right front wheel of test vehicle 548 did not show the snagging potential that was seen in Test 541. Tire marks are seen on post 6, Figure 2-68, but they do not enter the gap area to the extent they did on Test 541. It is unknown how much the lower than anticipated impact velocity affected the wheel penetration for Test 548. However, both impacts were similar, other than the speeds, and the initial concerns of wheel snagging were largely eliminated based on the results of the second test. Moreover, by reducing the bridge rail gap by 30 mm, the gap was smaller than the vehicle wheel diameter, so there should be much less chance for significant wheel snagging. There were no problems encountered for either test other than tire marks in the gap area in Test 541. For both tests the vehicle was smoothly redirected at an acceptable angle, meeting all of the criteria listed for test level 4 in NCHRP Report 350<sup>(1)</sup>.

**2. TECHNICAL DISCUSSION (Continued)**

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Figure 2-58 -  
Right Side of  
Vehicle 548



Figure 2-59 -  
Left Side of  
Vehicle 548

Figure 2-60 -  
Rear and  
Impact side of  
Vehicle 548



## 2. TECHNICAL DISCUSSION (Continued)

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Figure 2-61 -  
Downstream  
View of The  
Bridge Rail



Figure 2-62 -  
Perpendicular  
View of the  
Bridge Rail

Figure 2-63 -  
Upstream  
View of the  
Bridge Rail



**2. TECHNICAL DISCUSSION (Continued)**

---

Figure 2-64 -  
Final Resting  
Position of  
Vehicle 548



Figure 2-65 -  
Right Side of  
Vehicle 548  
after Impact

Figure 2-66 -  
The Front Right  
Tire of Vehicle  
548 after  
Impact



## 2. TECHNICAL DISCUSSION (Continued)

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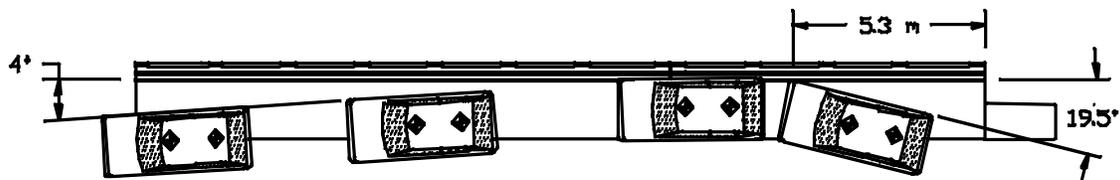
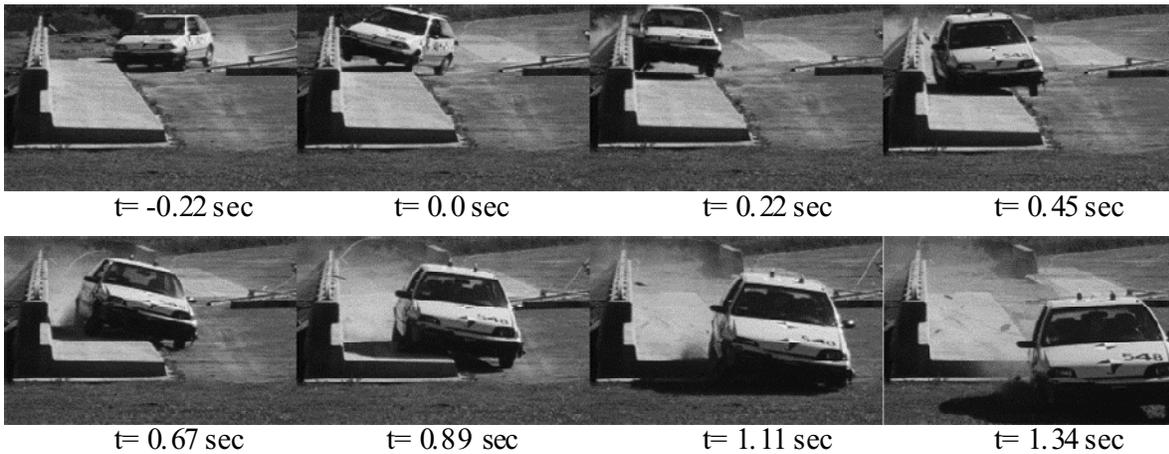
Figure 2-67 - Downstream View of Bridge Rail and Vehicle after Test 548



Figure 2-68 - Close-up View of Bridge Rail at Impact Point for Test 548

## 2. TECHNICAL DISCUSSION (Continued)

Figure 2-69 - Test 548 Data Summary Sheet



### Test Barrier

Type: Type 80SW  
Length: 22.8 m

**Test Date:** March 4, 1998

### Test Vehicle:

Model: 1994 Geo Metro  
Inertial Mass: 824  
Impact / Exit Velocity: 80.5 km/h / 62 km/h  
Impact / Exit Angle: 19.5° / 4°

### Test Dummy:

Type: NA  
Weight / Restraint: NA  
Position: NA

### Test Data:

Occ. Impact Velocity (Long / Lat): 4.54 m/s / 4.22 m/s  
Ride down Acceleration (Long / Lat): -3.22g / -8.15g  
Max. 50 ms Avg. Accel. (Long / Lat): -5.50g / -7.28g  
Exterior: VDS<sup>(2)</sup>/CDC<sup>(10)</sup> FR-3, RD-4 / 02RFEW3  
Interior: OCDI<sup>(1)</sup> RF0001000

### Barrier Damage:

Damage consisted of only moderate scraping and tire scuffing over a length of four meters

## **2. TECHNICAL DISCUSSION (Continued)**

---

### **2.2.1.12. Vehicle Damage - Test 548**

The right front section of the vehicle sustained crushing of the bumper and right front quarter panel, damage to the suspension and a flat tire. Initial right front wheel damage occurred on impact with the sidewalk 0.4 m from the beginning of the bridge rail. The sidewalk contact caused deformation of the wheel and tire deflation. Wheel damage is shown in Figure 2-66. Other wheels were slightly deformed upon impact with the sidewalk, but the tires remained inflated. The vehicle first contacted the bridge rail on the curb section below the beam approximately 5.1 m from the beginning of the rail. After contacting the bridge rail, the right front wheel was pushed back, forcing the wheel well area to deform (Figure 2-65). The strut and axle for the right front wheel were bent, but remained attached.

As the vehicle turned parallel to the bridge rail, the sheet metal on the right rear quarter panel came into contact with the bridge rail face and caused minor scraping. The passenger door was not scraped during the test. The right rear tire rubbed along the bridge rail, but was not damaged beyond moderate scuffing. All four wheels were on or above the sidewalk as the vehicle left contact with the beam face. The vehicle continued along the sidewalk with the left wheels dropping off the sidewalk curb about 17 m from the beginning of the bridge rail. The interior of the vehicle experienced negligible deformation in the front passenger floorboard and elsewhere in the occupant compartment. Both vehicle doors and hatchback functioned properly and there was no windshield or other glass damage to the vehicle. Headlights and hood remained undamaged.

Occupant impact velocities and occupant ridedown accelerations were below the preferred maximums summarized in Table 2.5 - Test 548 Assessment Summary, page 48. The lateral and longitudinal occupant impact velocities were 4.22 and 4.54 m/s, respectively. The lateral and longitudinal occupant ridedown accelerations were -8.15 and -3.22 g, respectively.

### **2.2.1.13. Barrier Damage - Test 548**

Since this was a repeat of Test 541, the impact location for Test 548 was set at the same location as Test 541. In order to see clearly the impact marks on the test article, previously damaged or marked areas of the rail had been painted. The impact damage due to Test 548 consisted of only minor scraping and tire scuffing. The total length of impact with the bridge rail was only slightly more than 4 m.

## **2.3. Discussion of Test Results - Crash Tests**

### **2.3.1. General - Evaluation Methods (Tests 541-543,548)**

NCHRP Report 350<sup>(1)</sup> 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. TECHNICAL DISCUSSION (Continued)**

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### **2.3.2. Structural Adequacy**

The structural adequacy of the Type 80SW bridge rail is acceptable. There was negligible movement of the rail during any of the tests. During the time of contact between the test vehicles and the barriers there were minor amounts of scraping and spalling.

A detailed assessment summary of structural adequacy is shown in Table 2.2 through Table 2.5.

### **2.3.3. Occupant Risk**

The occupant risk for the Type 80SW is also acceptable. In none of the tests did spalling concrete exhibit any tendency to penetrate the occupant compartment of the vehicles. All of the calculated occupant ridedown accelerations and occupant impact velocities were within the “preferred” range. Please refer to Table 2.2 through Table 2.5 for a detailed assessment summary of occupant risk.

### **2.3.4. Vehicle Trajectory**

The post-impact vehicle trajectory is also acceptable for the Type 80SW. The detailed assessment summary of vehicle trajectories may be seen in Table 2.6.

## 2. TECHNICAL DISCUSSION (Continued)

Table 2.2 - Test 541 Assessment Summary

Test No. 541  
 Date May 6, 1997  
 Test agency California Dept. of Transportation

Evaluation Criteria	Test Results	Assessment									
<p>Structural Adequacy</p> <p>A. Test article should contain and redirect the vehicle; the vehicle should not penetrate, underide, or override the installation although controlled lateral deflection of the article is acceptable</p>	<p>The vehicle was contained and smoothly redirected</p>	<p>pass</p>									
<p>Occupant Risk</p> <p>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.</p> <p>F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable</p> <p>H. Occupant impact velocities (see Appendix A, Section A5.3 for calculation procedure) should satisfy the following:</p> <table border="1" data-bbox="256 1108 841 1276"> <thead> <tr> <th colspan="3">Occupant Impact Velocity Limits (m/s)</th> </tr> <tr> <th>Component</th> <th>Preferred</th> <th>Maximum</th> </tr> </thead> <tbody> <tr> <td>Longitudinal and lateral</td> <td>9</td> <td>12</td> </tr> </tbody> </table>	Occupant Impact Velocity Limits (m/s)			Component	Preferred	Maximum	Longitudinal and lateral	9	12	<p>The impact resulted only in a small amount of barrier spalling. Debris generated was insignificant. There was no significant deformation of the occupant compartment.</p> <p>The maximum roll, pitch and yaw were -12.3°, -5.2°, and -32.0°, respectively. These are all acceptable.</p> <p>Long. Occ. Impact Vel. = 5.98 m/s                      Lat. Occ. Impact Vel. = 6.34 m/s</p>	<p>pass</p>
Occupant Impact Velocity Limits (m/s)											
Component	Preferred	Maximum									
Longitudinal and lateral	9	12									
<p>I. Occupant Ridedown Accelerations (see Appendix A, Section A5.3 for calculation procedure) should satisfy the following:</p> <table border="1" data-bbox="256 1377 841 1545"> <thead> <tr> <th colspan="3">Occupant Ridedown Acceleration Limits (g)</th> </tr> <tr> <th>Component</th> <th>Preferred</th> <th>Maximum</th> </tr> </thead> <tbody> <tr> <td>Longitudinal and lateral</td> <td>15</td> <td>20</td> </tr> </tbody> </table>	Occupant Ridedown Acceleration Limits (g)			Component	Preferred	Maximum	Longitudinal and lateral	15	20	<p>Longitudinal Acceleration = -5.50 g                      Lateral Acceleration = -9.90 g</p>	<p>pass</p>
Occupant Ridedown Acceleration Limits (g)											
Component	Preferred	Maximum									
Longitudinal and lateral	15	20									
<p>Vehicle Trajectory</p> <p>K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes</p> <p>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."</p>	<p>The vehicle maintained a relatively straight course after exiting the barrier</p> <p>The exit angle was 10°, or 50% of the impact angle.</p>	<p>pass</p>									

## 2. TECHNICAL DISCUSSION (Continued)

Table 2.3 - Test 542 Assessment Summary

Evaluation Criteria	Test Results	Assessment
Test No. <u>542</u> Date <u>June 11, 1997</u> Test agency <u>California Dept. of Transportation</u>		
<b>Structural Adequacy</b> A. Test article should contain and redirect the vehicle; the vehicle should not penetrate, underide, or override the installation although controlled lateral deflection of the article is acceptable.	The vehicle was contained and smoothly redirected	pass
<b>Occupant Risk</b> 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. F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	Only moderate amounts of spalling were created during impact. There was no significant debris from the vehicle. The vehicle hood snagged on the handrail, damaging but not penetrating the windshield. There was moderate occupant compartment deformation. The maximum roll, pitch and yaw were -7.08, -15.47, and -25.75°, respectively. These are all acceptable.	pass marginal pass pass
<b>Vehicle Trajectory</b> K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes. 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. 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 vehicle maintained a relatively straight course after exiting the barrier. Long. Occ. Impact Vel. = 9.37 m/s Long. Occ. Ridedown = -7.45 g Exit angle = 7°, 28% of the impact angle.	pass pass pass

## 2. TECHNICAL DISCUSSION (Continued)

Table 2.4 - Test 543 Assessment Summary

Test No. 543  
 Date September 3, 1997  
 Test agency California Dept. of Transportation

Evaluation Criteria	Test Results	Assessment
<p>Structural Adequacy</p> <p>A. Test article should contain and redirect the vehicle; the vehicle should not penetrate, underide, or override the installation although controlled lateral deflection of the article is acceptable</p>	<p>The vehicle was contained and smoothly redirected</p>	<p>pass</p>
<p>Occupant Risk</p> <p>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.</p> <p>G. It is preferable, although not essential, that the vehicle remain upright during and after collision.</p>	<p>There was not any significant debris from the test article and negligible deformation of the occupant compartment.</p> <p>The vehicle remained upright</p>	<p>pass</p> <p>pass</p>
<p>Vehicle Trajectory</p> <p>K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes</p> <p>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."</p>	<p>The vehicle maintained a relatively straight course after exiting the barrier</p> <p>Exit angle =4°, 27% of the impact angle.</p>	<p>pass</p> <p>pass</p>

**2. TECHNICAL DISCUSSION (Continued)**

Table 2.5 - Test 548 Assessment Summary

Test No. 548  
 Date March 4, 1998  
 Test agency California Dept. of Transportation

Evaluation Criteria	Test Results	Assessment									
<p>Structural Adequacy</p> <p>A. Test article should contain and redirect the vehicle; the vehicle should not penetrate, underide, or override the installation although controlled lateral deflection of the article is acceptable</p>	<p>The vehicle was contained and smoothly redirected</p>	<p>pass</p>									
<p>Occupant Risk</p> <p>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.</p> <p>F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable</p> <p>H. Occupant impact velocities (see Appendix A, Section A5.3 for calculation procedure) should satisfy the following:</p> <table border="1" data-bbox="256 1108 841 1276"> <thead> <tr> <th colspan="3">Occupant Impact Velocity Limits (m/s)</th> </tr> <tr> <th>Component</th> <th>Preferred</th> <th>Maximum</th> </tr> </thead> <tbody> <tr> <td>Longitudinal and lateral</td> <td>9</td> <td>12</td> </tr> </tbody> </table>	Occupant Impact Velocity Limits (m/s)			Component	Preferred	Maximum	Longitudinal and lateral	9	12	<p>There was no significant debris from the test article nor substantial deformation of the occupant compartment.</p> <p>The maximum roll, pitch and yaw were -14.27, 4.97, and -22.5°, respectively. All are acceptable.</p> <p>Long. Occ. Impact Vel. = 4.54 m/s Lat. Occ. Impact Vel. = 4.22 m/s</p>	<p>pass</p>
Occupant Impact Velocity Limits (m/s)											
Component	Preferred	Maximum									
Longitudinal and lateral	9	12									
<p>I. Occupant Ridedown Accelerations (see Appendix A, Section A5.3 for calculation procedure) should satisfy the following:</p> <table border="1" data-bbox="256 1377 841 1545"> <thead> <tr> <th colspan="3">Occupant Ridedown Acceleration Limits (g)</th> </tr> <tr> <th>Component</th> <th>Preferred</th> <th>Maximum</th> </tr> </thead> <tbody> <tr> <td>Longitudinal and lateral</td> <td>15</td> <td>20</td> </tr> </tbody> </table>	Occupant Ridedown Acceleration Limits (g)			Component	Preferred	Maximum	Longitudinal and lateral	15	20	<p>Longitudinal Acceleration. = -3.22 g                      Lateral Acceleration. = -8.15 g</p>	<p>pass</p>
Occupant Ridedown Acceleration Limits (g)											
Component	Preferred	Maximum									
Longitudinal and lateral	15	20									
<p>Vehicle Trajectory</p> <p>K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes</p> <p>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."</p>	<p>The vehicle maintained a relatively straight course after exiting the barrier</p> <p>Exit angle = 4°, 20% of the impact angle.</p>	<p>pass</p>									

## 2. TECHNICAL DISCUSSION (Continued)

Table 2.6 - 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)
541	20	12	10	102.0	75	27
542	25.0	15	7	110.2	77	33
543	15.0	9	2	80.8	72	7
548*	19.5	12	4	80.5	62	18

\*Test 548 is a retest of Test 541.

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### 3. CONCLUSION

Based on the testing of the Type 80SW discussed in this report, the following conclusions can be drawn:

1. The Type 80SW can smoothly and successfully contain an 820 kg sedan impacting at 20° and 100 km/h.
2. The Type 80SW can successfully contain and redirect a 2000 kg pickup truck impacting at 25° and 100 km/h. There was moderate occupant compartment deformation, mainly in the cab floorboard area. In addition, the vehicle hood snagged on the vertical handrail support tube, causing moderate occupant compartment deformation. However, this deformation was judged to be insufficient to cause serious injury to vehicle occupants.
3. The Type 80SW can successfully contain and redirect an 8000 kg, single unit, van-bodied truck impacting at 15° and 80 km/h.
4. Damage to the Type 80SW in accidents similar to the tests conducted for this project will result in small to moderate amounts of scraping and spalling of the rail. Therefore, the majority of impacts into the rail will not require urgent repairs. By structurally performing well at NCHRP Report 350 Test Level 4, the bridge rail meets the Performance Level 2 requirements of the 1989 AASHTO "Guide Specifications for Bridge Railings."
5. The Type 80SW 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.

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#### 4. RECOMMENDATION

The Type 80SW is recommended for use as new or retrofit bridge railing on low-speed (70 km/h or less) highways as Test Level 2.

Vehicle behavior observed during the test series demonstrated the inability of the sidewalk to provide any pedestrian protection at the tested speeds and angles. This vehicle behavior evidence and requirements given in Section 13.4 from NCHRP Project 12-33 “Bridge Design Specification”<sup>(2)</sup> and Article G2.7 of the 1989 AASHTO “Guide Specification for Bridge Railings”<sup>(4)</sup> clearly specify that a pedestrian sidewalk needs to be separated from traffic for high-speed applications (45 mi/h or greater).

In addition, the 2000 kg truck hood overlapped the top of the barrier and snagged on a vertical handrail support tube. The snagging caused minor occupant compartment deformation. The need for pedestrian sidewalk protection and the problem of the hood snagging make it appropriate to recommend the Type 80SW for low-speed (70 km/h or less) highways. At the lower speeds of Test Level 2, there would be substantially reduced front fender crush resulting in significantly reduced potential for hood snagging.

---

## **5. IMPLEMENTATION**

The Office of Structures Design will be responsible for the preparation of standard plans and specifications for the Type 80SW, with technical support from the Office of Materials Engineering and Testing Services and the Traffic Operations Program. Similarly, the Office of Structures Design, with assistance from the Office of Materials Engineering and Testing Services and the Traffic Operations Program, will be responsible for the in-service evaluation.

---

## 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. "Roadside Design Guide", American Association of State Highway and Transportation Officials, 1988.
3. Jewell, John, et al., "Vehicle Crash Tests of Type 115 Barrier Rail Systems for Use on Secondary Highways", Transportation Research Record 1419, Transportation Research Board, Oct. 1993.
4. "Guide Specifications For Bridge Railings", American Association of State Highway and Transportation Officials, 1989.
5. Hirsch, T.J. et. al., "Aesthetically Pleasing Concrete Beam and Posts Bridge Rail - Texas Type T411", Texas Transportation Institute, Report No. TTI-2-5-88/89-1185-1, March 1989.
6. Hirsch, T.J. et. al., "Aesthetically Pleasing Concrete Beam-and-Post Bridge Rail", Transportation Research Record 1258, Transportation Research Board, 1990.
7. "Development of a Comprehensive Bridge Specification and Commentary" - Section 13, National Cooperative Highway Research Program Project 12-33, 1993.
8. "Standard Specifications", California Department of Transportation, Sacramento, CA., 1995.
9. "Vehicle Damage Scale for Traffic Accident Investigators", Traffic Accident Data Project, National Safety Council, 1968.
10. "Collision Deformation Classification" - SAE J224 Mar80, SAE Recommended Practices, 1980.

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## 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 12 L safety gas tank was installed in the truck bed or non-impact cab step and connected to the fuel supply line. The stock fuel tanks had dry ice or gaseous CO<sub>2</sub> added in order to purge the gas vapors.

(For Test 541 and 548, 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 were 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<sub>2</sub> 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 trailer. From there, the remote brake signal was carried on one channel of a multi-channel tether line which was connected to the test vehicle. Any loss of continuity in these cables would have activated the brakes and cut off the ignition automatically. Also, when the brakes were applied by remote control from the console trailer, the ignition for self-powered vehicle was automatically cut by removing power to the coil.
- For Test 541 and 548, 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 through a calibrated speedometer in the tow vehicle.
- For tests 542 and 543, an accelerator switch was located on the rear fender of the vehicle. The switch opened an electric solenoid which, in turn, released compressed CO<sub>2</sub> from a reservoir into a pneumatic ram that had been attached to the accelerator pedal. The CO<sub>2</sub> pressure for the accelerator ram was regulated to the same pressure of the remote braking system with a valve to adjust CO<sub>2</sub> flow rate.
- For tests 542 and 543, a speed control device, connected in-line with the primary winding of the coil, was used to regulate the speed of the test vehicle based on the signal from a speed sensor output from the vehicle transmission. This device was calibrated prior to 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.

## **7. APPENDICES (continued)**

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- For tests 542 and 543, a microswitch was mounted below the front bumper and connected to the ignition system. A trip plate on the ground near the impact point triggered the switch when the car passed over it. The switch would open the ignition circuit and shut off the vehicle's engine prior to impact.

**7. APPENDICES (continued)**

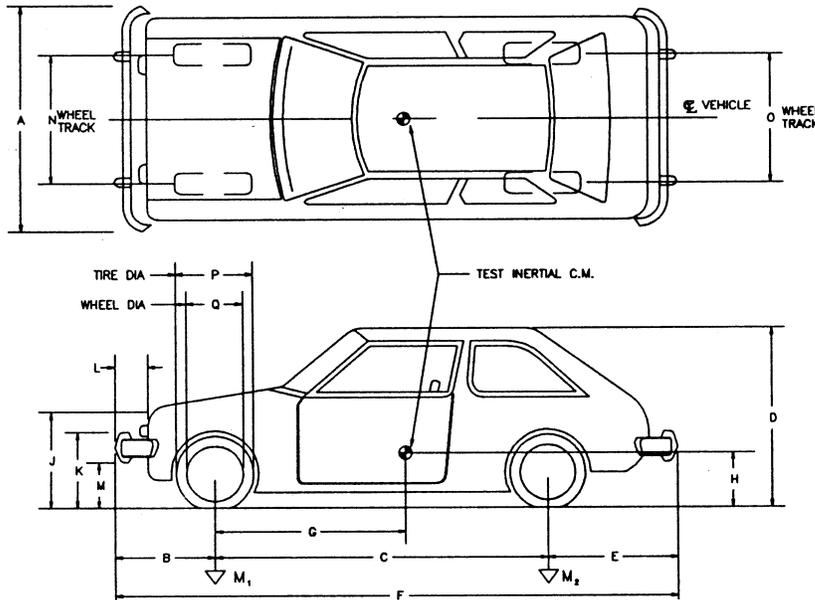
**Table 7.1 - Test 541 Vehicle Dimensions**

DATE: 12/3/97 TEST NO: 541 VIN NO: 2CIMR646XN6721298 MAKE: GEO  
 MODEL: METRO YEAR: 1992 ODOMETER: 66386 (MI) TIRE SIZE: 155R1276T  
 TIRE INFLATION PRESSURE: 36 (PSI)

MASS DISTRIBUTION (kg) LF 258.5 RF 237.2 LR 168.7 RR 158.3

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST: SCRATCH ON HOOD, APPROXIMATELY 30 MMLONG ON RIGHT FRONT SIDE OF

HOOD



ENGINE TYPE: IN-LINE 3 CYL.

ENGINE CID: 1.0 LITER

TRANSMISSION TYPE:

AUTO

MANUAL

OPTIONAL EQUIPMENT:

AIR CONDITIONING

DUMMY DATA:

TYPE: HYBRID II 50ch%

MASS: 75 KG

SEAT POSITION: RIGHT FRONT

**GEOMETRY (cm)**

A 157 D 140 G 112 K 47 N 136 Q 34  
 B 79 E 70 H 25 L 9 O 135  
 C 237 F 390 J 70 M 20 P 56

**MASS - (kg)**

	<u>CURB</u>	<u>TEST INERTIAL</u>	<u>GROSS STATIC</u>
M1	<u>                    </u>	<u>496</u>	<u>534</u>
M2	<u>                    </u>	<u>327</u>	<u>372</u>
MT	<u>                    </u>	<u>823</u>	<u>898</u>

7. APPENDICES (continued)

Table 7.2 - Test 542 Vehicle Dimensions

DATE: 3/16/98 TEST NO: 542 VIN NO: 1GCFC24K5PE177505 MAKE: CHEVROLET  
 MODEL: 2500 YEAR: 1993 ODOMETER: 118457 (MI) TIRE SIZE: LT 245 175R16  
 TIRE INFLATION PRESSURE: 44 (PSI)

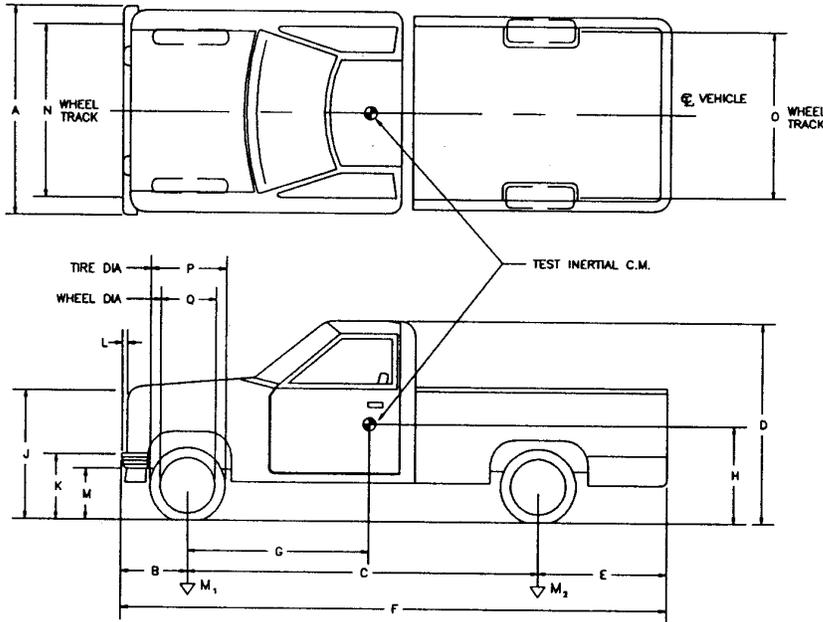
MASS DISTRIBUTION (kg) LF 542.2 RF 555.4 LR 430.8 RR 425.8

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST: NONE

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ENGINE TYPE: V8

ENGINE CID: 5.8L

TRANSMISSION TYPE:

AUTO

MANUAL

OPTIONAL EQUIPMENT:

DUMMY DATA:

TYPE: NA

MASS: NA

SEAT POSITION: NA

GEOMETRY (cm)

A 192.3 D 169.3 G 150.5 K 74.0 N 166.0 Q 43.2  
 B 76.8 E 131.2 H 55.9 L 6.3 O 166.0  
 C 340.5 F 544.7 J 120.0 M 50.8 P 79.8

MASS - (kg)	<u>CURB</u>	<u>TEST INERTIAL</u>	<u>GROSS STATIC</u>
M1	<u>1079</u>	<u>1097.6</u>	<u>1097.6</u>
M2	<u>800</u>	<u>856.6</u>	<u>856.6</u>
MT	<u>1879</u>	<u>1954.2</u>	<u>1954.2</u>

**7. APPENDICES (continued)**

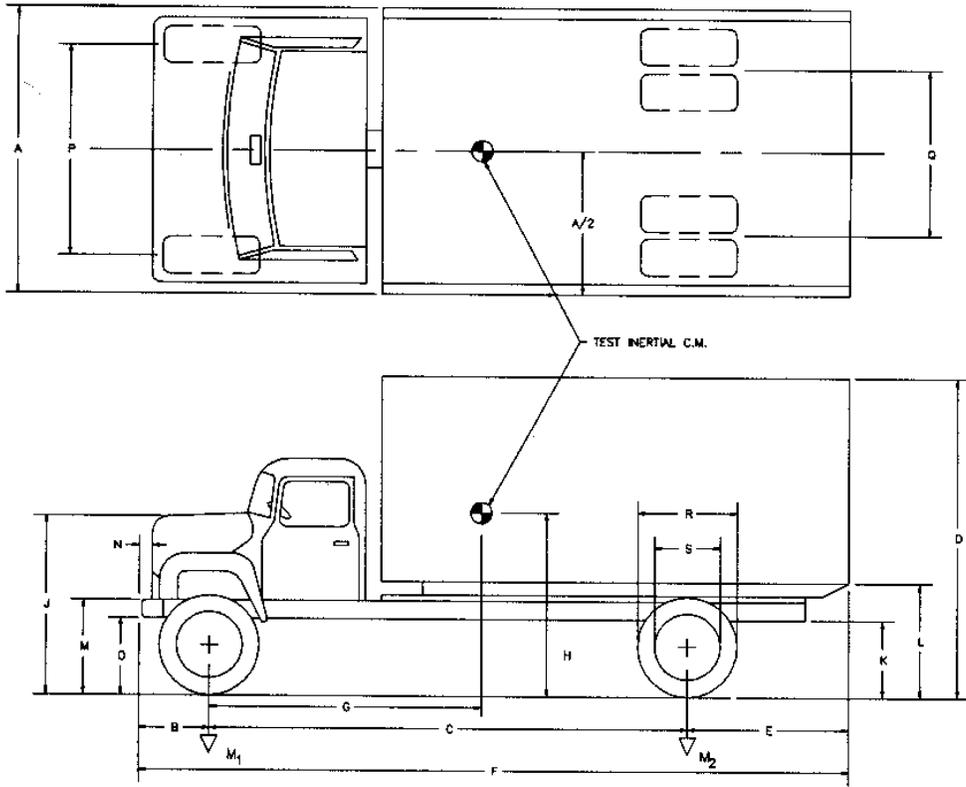
**Table 7.3 - Test 543 Vehicle Dimensions**

DATE: 9/30/97 TEST NO: 543 VIN NO: 1GDJ7H1P4NJ516563 MAKE: GMC

MODEL: TOP KICK YEAR: 1992 ODOMETER: 109902 (MI) TIRE SIZE: 11R22.5

MASS DISTRIBUTION (kg) LF \_\_\_\_\_ RF \_\_\_\_\_ LR \_\_\_\_\_ RR \_\_\_\_\_

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST: Right rear backup light missing



**GEOMETRY (cm)**

A	<u>243</u>	D	<u>345</u>	G	<u>363</u>	K	<u>73.5</u>	N	<u>10</u>	Q	<u>183</u>
B	<u>85</u>	E	<u>242</u>	H	_____	L	<u>111</u>	O	<u>57</u>	R	<u>103</u>
C	<u>530</u>	F	<u>858</u>	J	<u>174</u>	M	<u>96</u>	P	<u>202</u>	S	<u>59</u>

**MASS - (kg)**

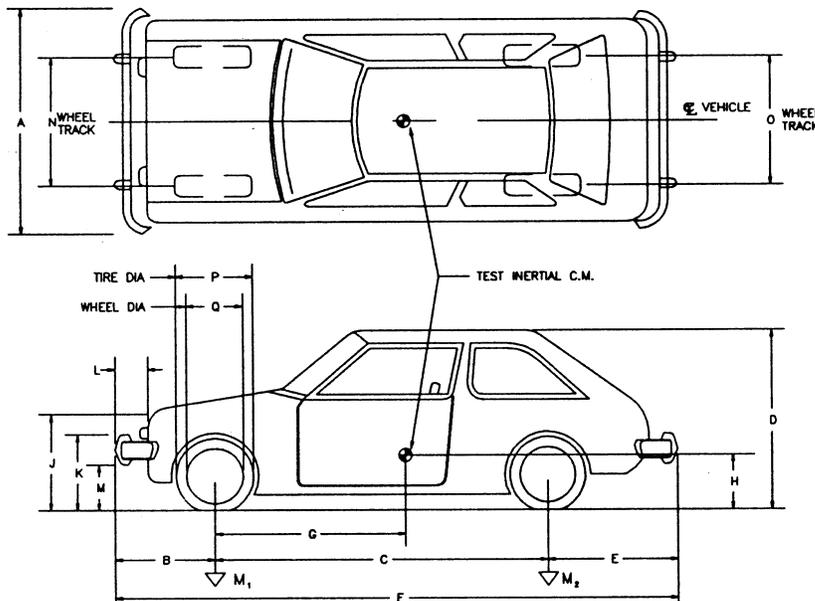
	<u>CURB</u>	<u>TEST INERTIAL</u>	<u>GROSS STATIC</u>
MI	<u>2136</u>	<u>2558</u>	<u>2558</u>
M2	<u>2966</u>	<u>5461</u>	<u>5461</u>
MT	<u>5102</u>	<u>8020</u>	<u>8020</u>

7. APPENDICES (continued)

Table 7.4 - Test 548 Vehicle Dimensions

DATE: 2/26/98 TEST NO: 541 VIN NO: 2C1MR2465R6757107 MAKE: GEO  
 MODEL: METRO YEAR: 1994 ODOMETER: 60992 (MI) TIRE SIZE: 155 S R12  
 TIRE INFLATION PRESSURE: 32 (PSI)  
 MASS DISTRIBUTION (kg) LF 255 RF 238 LR 166 RR 165

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST: NONE



ENGINE TYPE: IN-LINE 3 CYL.  
 ENGINE CID: 1.0 LITER  
 TRANSMISSION TYPE:  
X AUTO  
 \_\_\_\_\_ MANUAL  
 OPTIONAL EQUIPMENT:  
\_\_\_\_\_ AIR CONDITIONING \_\_\_\_\_  
 DUMMY DATA:  
 TYPE: HYBRID II 50th%  
 MASS: 75 KG  
 SEAT POSITION: RIGHT FRONT

GEOMETRY (cm)

A 140 D 124 G 91 K 47 N 138 Q 34  
 B 76 E 68 H \_\_\_\_\_ L 8 O 134  
 C 226 F 365 J 69 M 20 P 55

MASS - (kg)	<u>CURB</u>	<u>TEST INERTIAL</u>	<u>GROSS STATIC</u>
M1	<u>487</u>	<u>493</u>	<u>531</u>
M2	<u>263</u>	<u>331</u>	<u>368</u>
MT	<u>750</u>	<u>824</u>	<u>899</u>

## **7. APPENDICES (continued)**

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### **7.2 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 vehicles. A rope was used to trigger the release mechanism on the guidance arm, thereby releasing the vehicle from the guidance system before impact.

### **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 Figure 7-1 and Table 7.5.

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. All other cameras were remotely triggered by switches on a console trailer near the impact area. The test vehicle and test 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.

7. APPENDICES (continued)

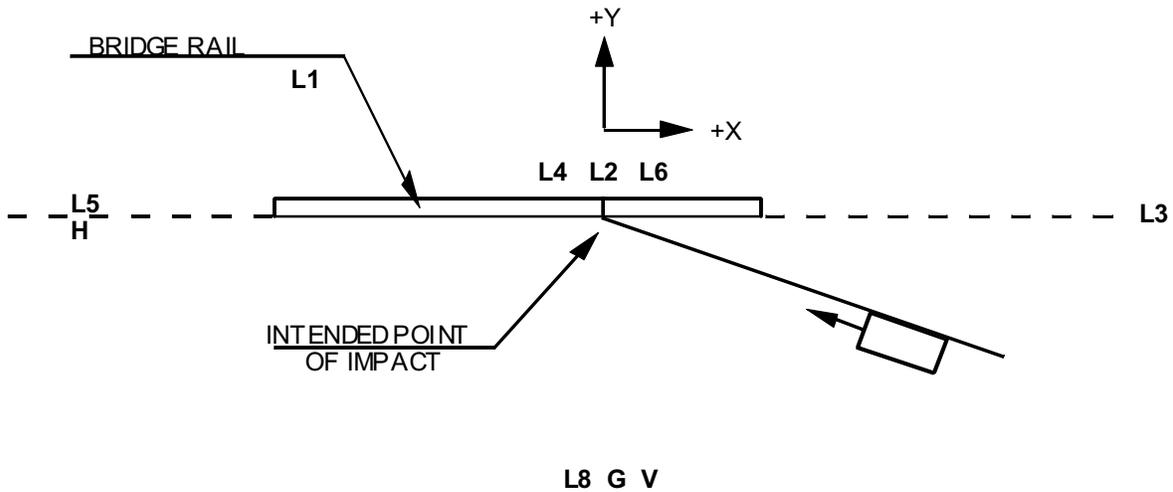


Figure 7-1 - Camera Locations

Typical Coordinates, m						
Camera Label	Film Size (mm)	Camera Type	Rate: (fr./sec.)	Test 541		
				X*	Y*	Z*
L1	16	LOCAM 1	400	-33.8	10.1	1.5
L2	16	LOCAM 2	400	0.0	0.0	12.0
L3	16	LOCAM 3	400	30.4	1.1	1.5
L4	16	LOCAM 4	400	-0.6	0.0	12.0
L5	16	LOCAM 5	400	-49.6	-2.7	3.5
L6	16	LOCAM 6	400	+0.6	0.0	12.0
L8	16	LOCAM 8	400	-4.5	-19.3	1.5
G	16	GISMO	64	-3.2	-24.3	1.5
V	1.27	SONY BETACAM	30	-6	-19.1	1.5
H	35	HULCHER	40	-49.7	-1.8	3.5

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

Table 7.5 - Typical Camera Type and Locations

The following are the pretest procedures that were required to enable film data reduction to be performed using a film motion analyzer:

1) Butterfly targets were attached to the top and sides of each test vehicle. The targets were located on the vehicle at intervals of 0.305, 0.610 and 1.219 meters (1, 2 and 4 feet.). The targets established scale factors and horizontal and vertical alignment. The test barrier was targeted with stenciled numbers every 1 or 2 meters..

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

## **7. APPENDICES (continued)**

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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 7-2.

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.

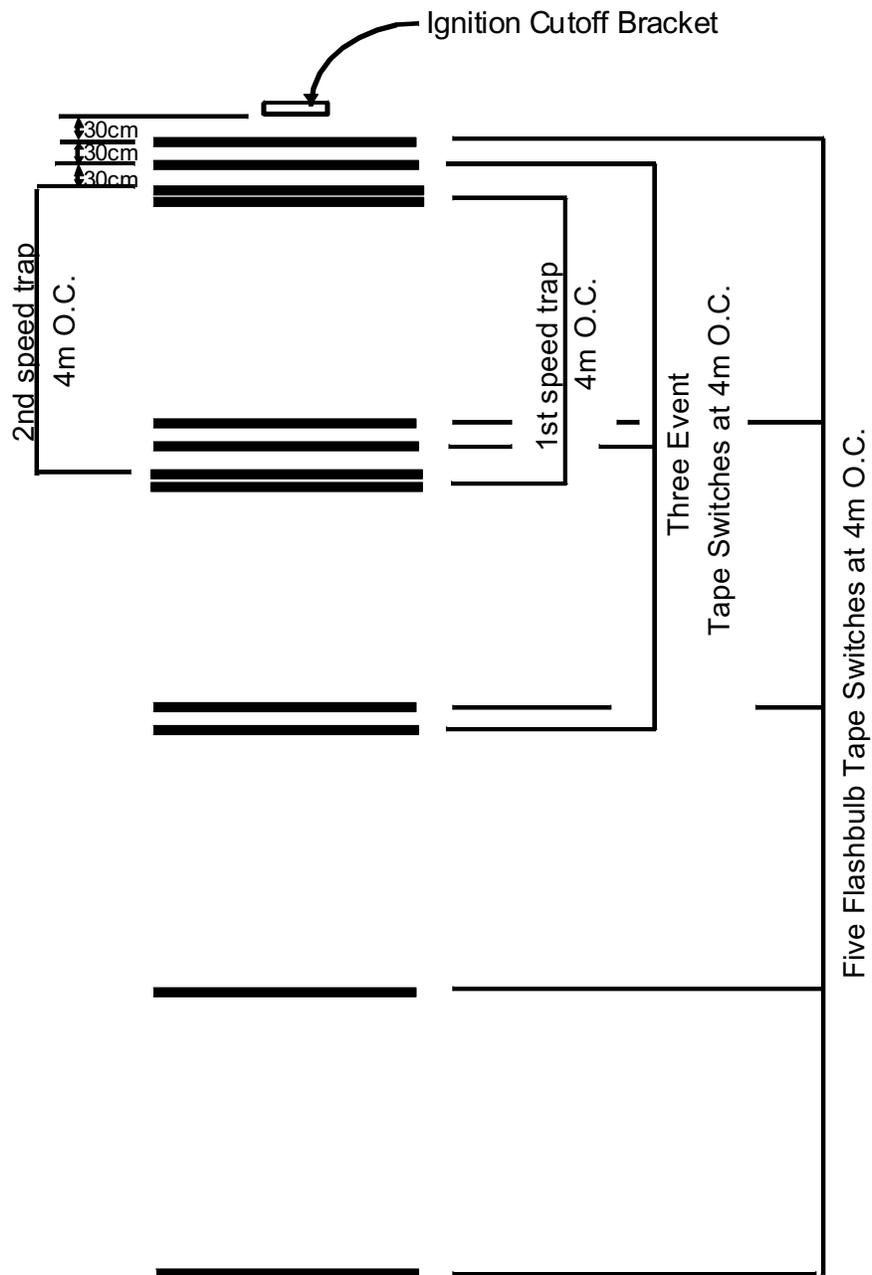


Figure 7-2 - Tape Switch Layout

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#### 7.4 *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 vehicle include two sets of accelerometers at the center of gravity, one set of accelerometers 600 mm behind the center of gravity, and one set of rate gyros at the center of gravity. The TDR data were reduced using a laptop computer.

Three pressure-activated tape switches were placed on the ground in front of the test barrier (see Figure 7-2). 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. A time cycle was recorded continuously on the TDR with a frequency of 500 cycles per second. 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 7-2.

The data curves are shown in Figure 7-4 through Figure 7-8 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.

NOTE: There are no data plots for Test 543 because NCHRP Report 350 did not require accelerometer data.

7. APPENDICES (continued)

Table 7.6 - Accelerometer Specifications

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

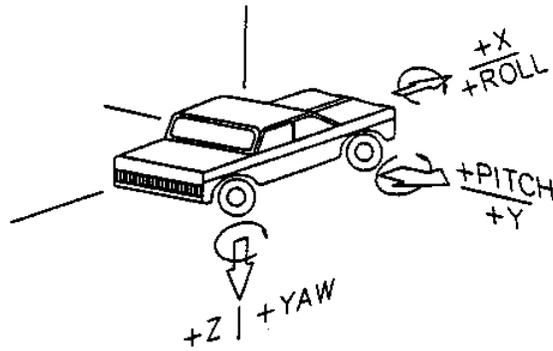
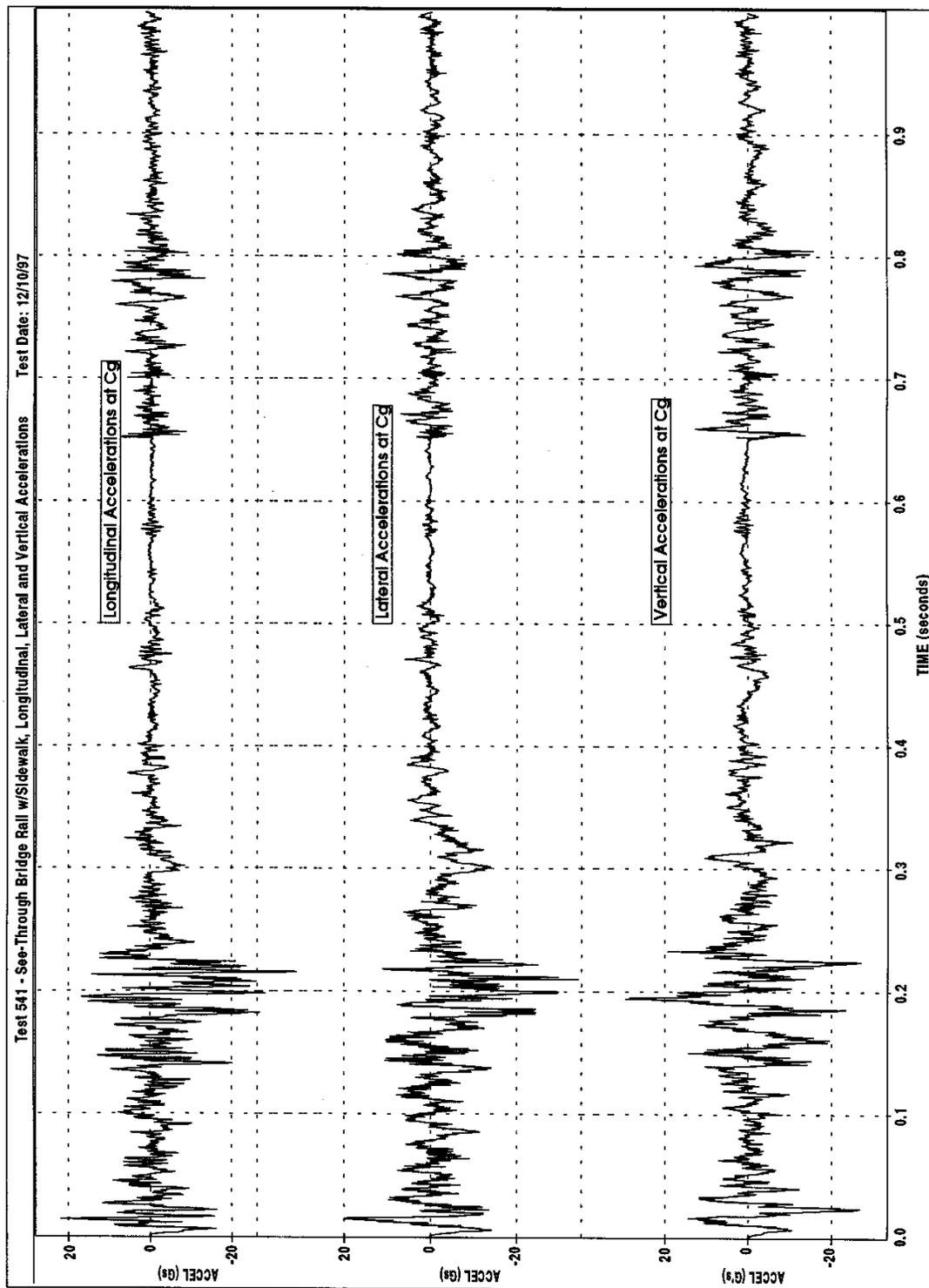


Figure 7-3 - Vehicle Accelerometer Sign Convention

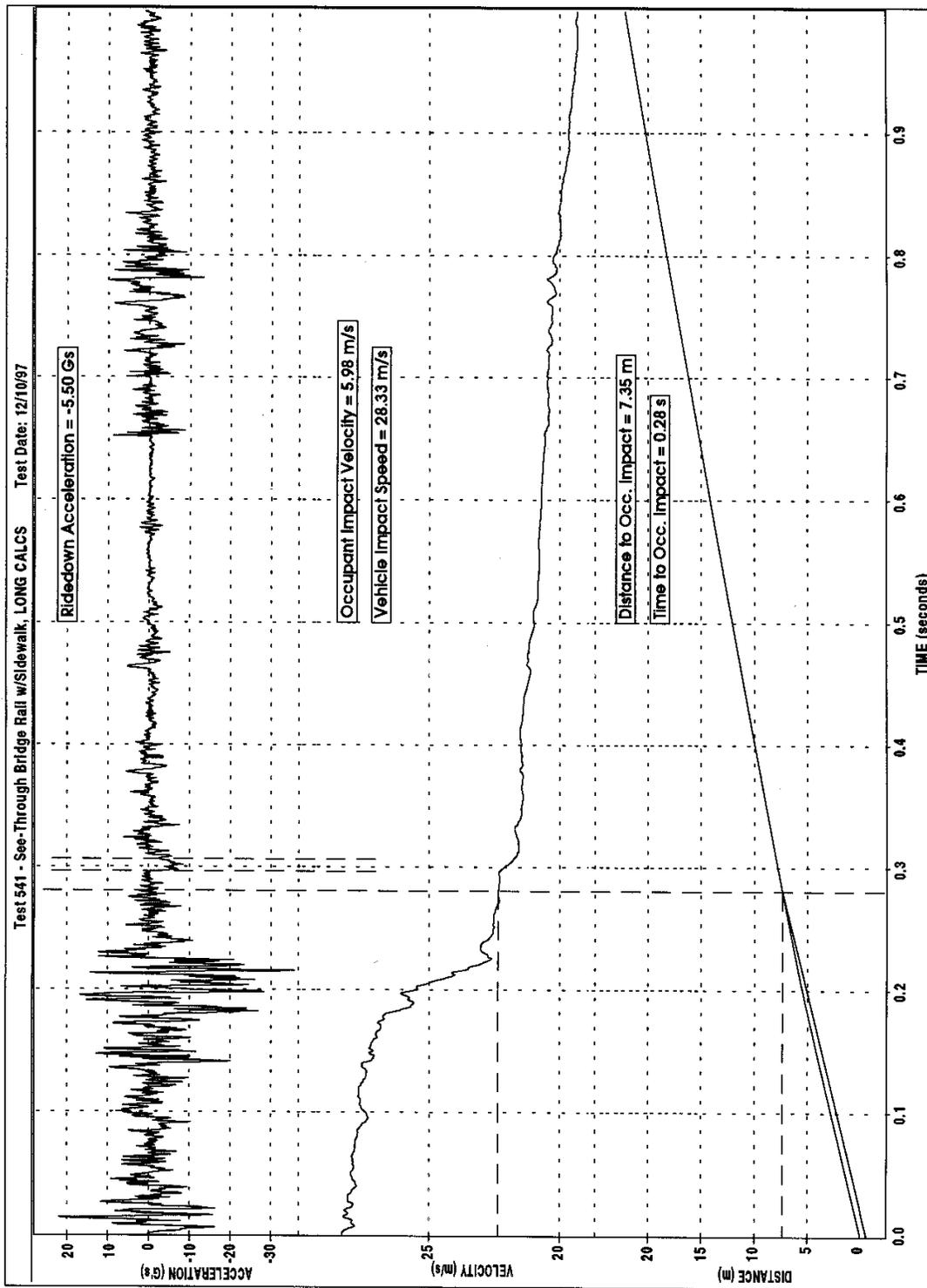
7. APPENDICES (continued)

Figure 7-4 - Test 541 Vehicle Accelerations -vs- Time



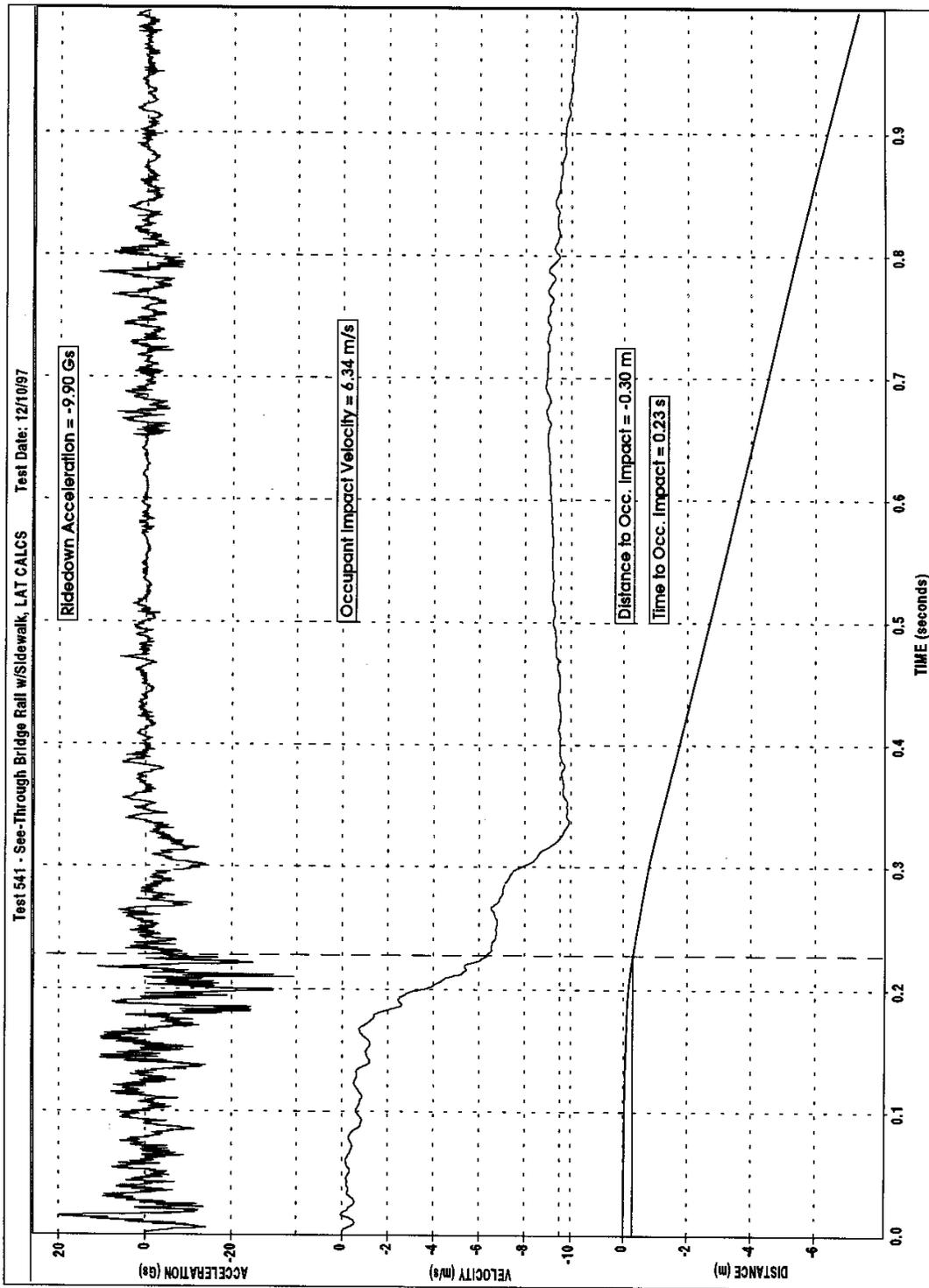
## 7. APPENDICES (continued)

Figure 7-5 - Test 541 Vehicle Longitudinal Acceleration, Velocity and Distance -vs- Time



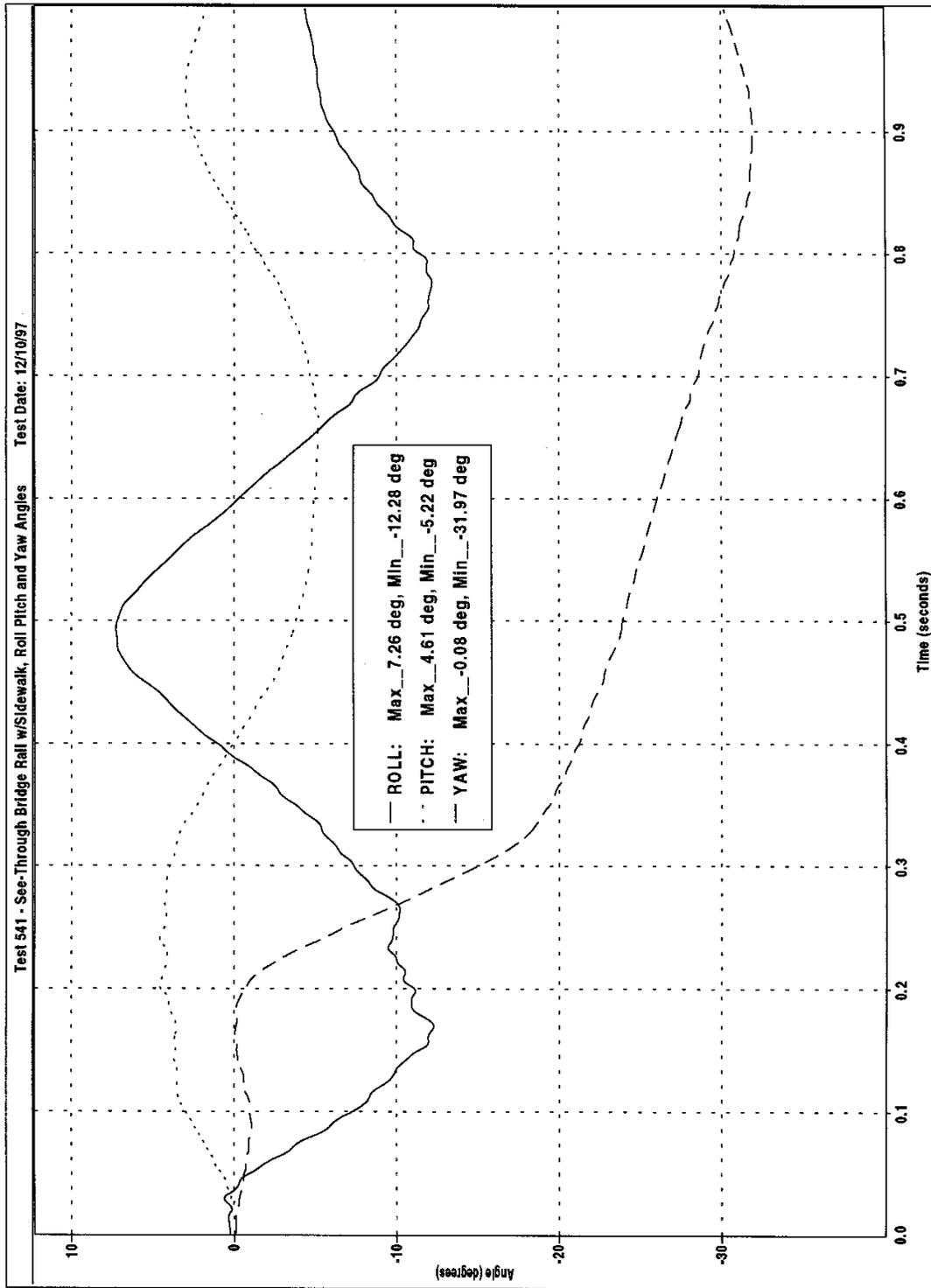
7. APPENDICES (continued)

Figure 7-6 - Test 541 Vehicle Lateral Acceleration, Velocity and Distance -vs- Time



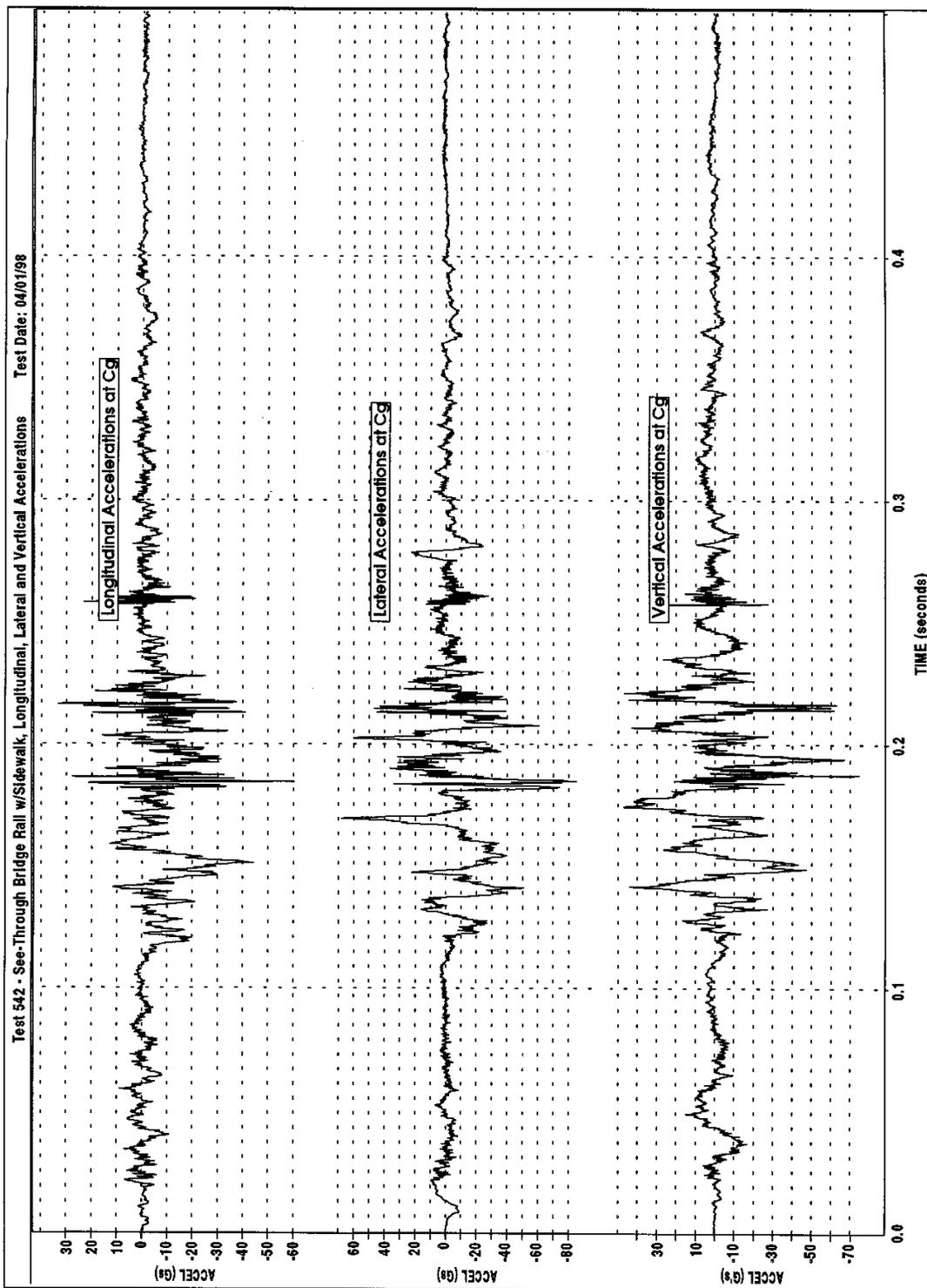
7. APPENDICES (continued)

Figure 7-7 - Test 541 Vehicle Roll, Pitch and Yaw -vs- Time



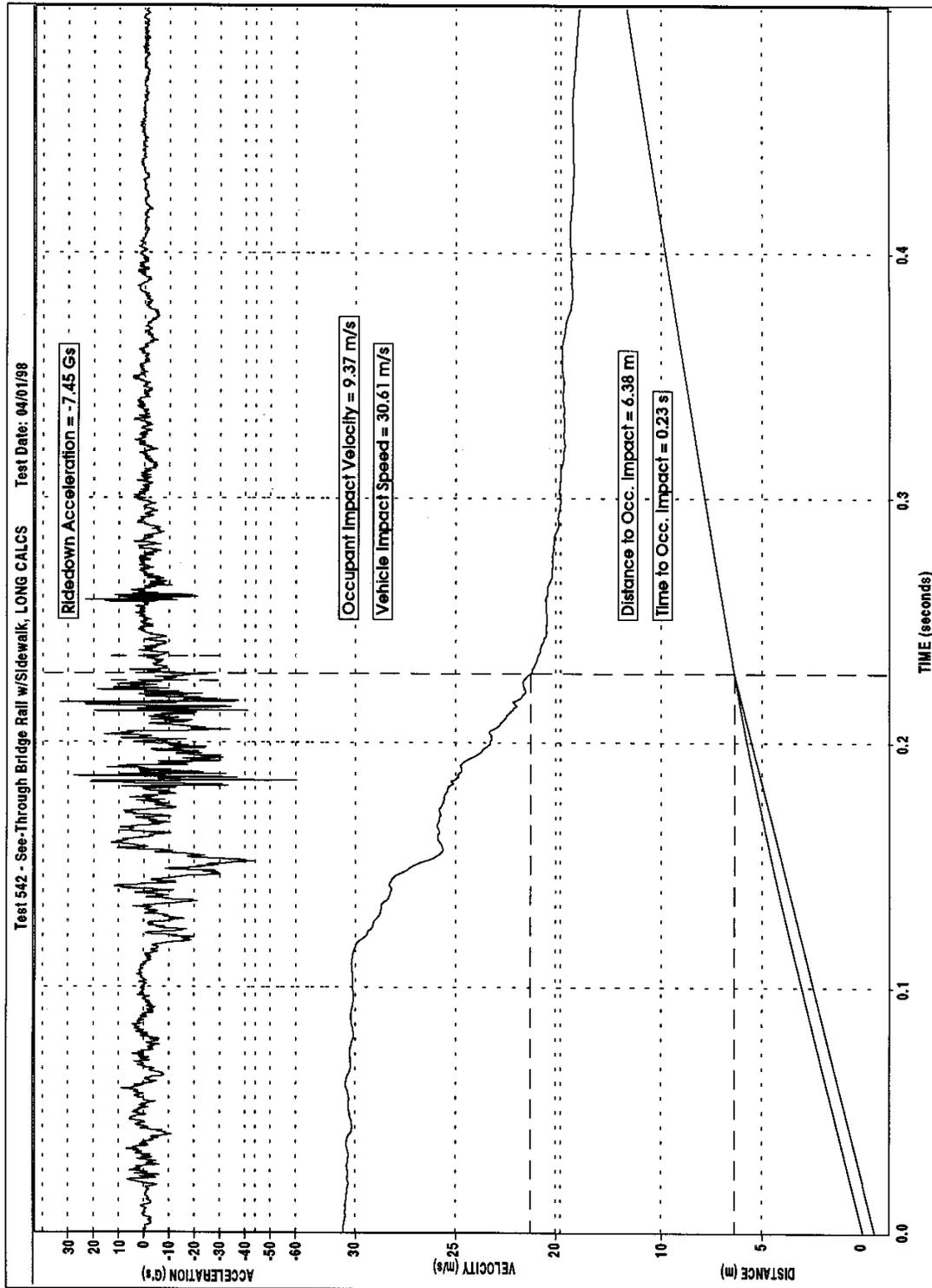
7. APPENDICES (continued)

Figure 7-8 - Test 542 Vehicle Accelerations -vs- Time



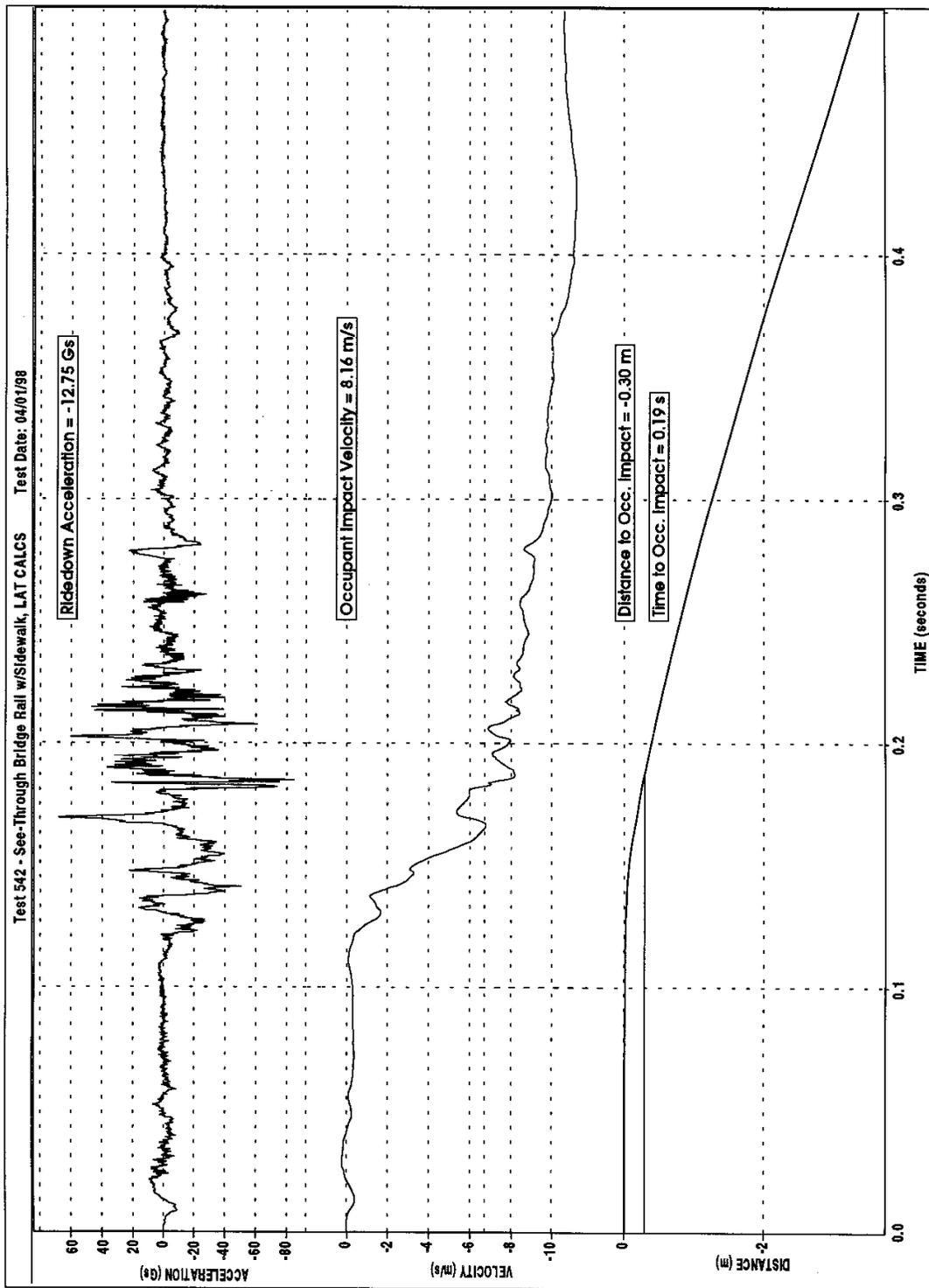
7. APPENDICES (continued)

Figure 7-9 - Test 542 Vehicle Longitudinal Acceleration, Velocity and Distance -vs- Time



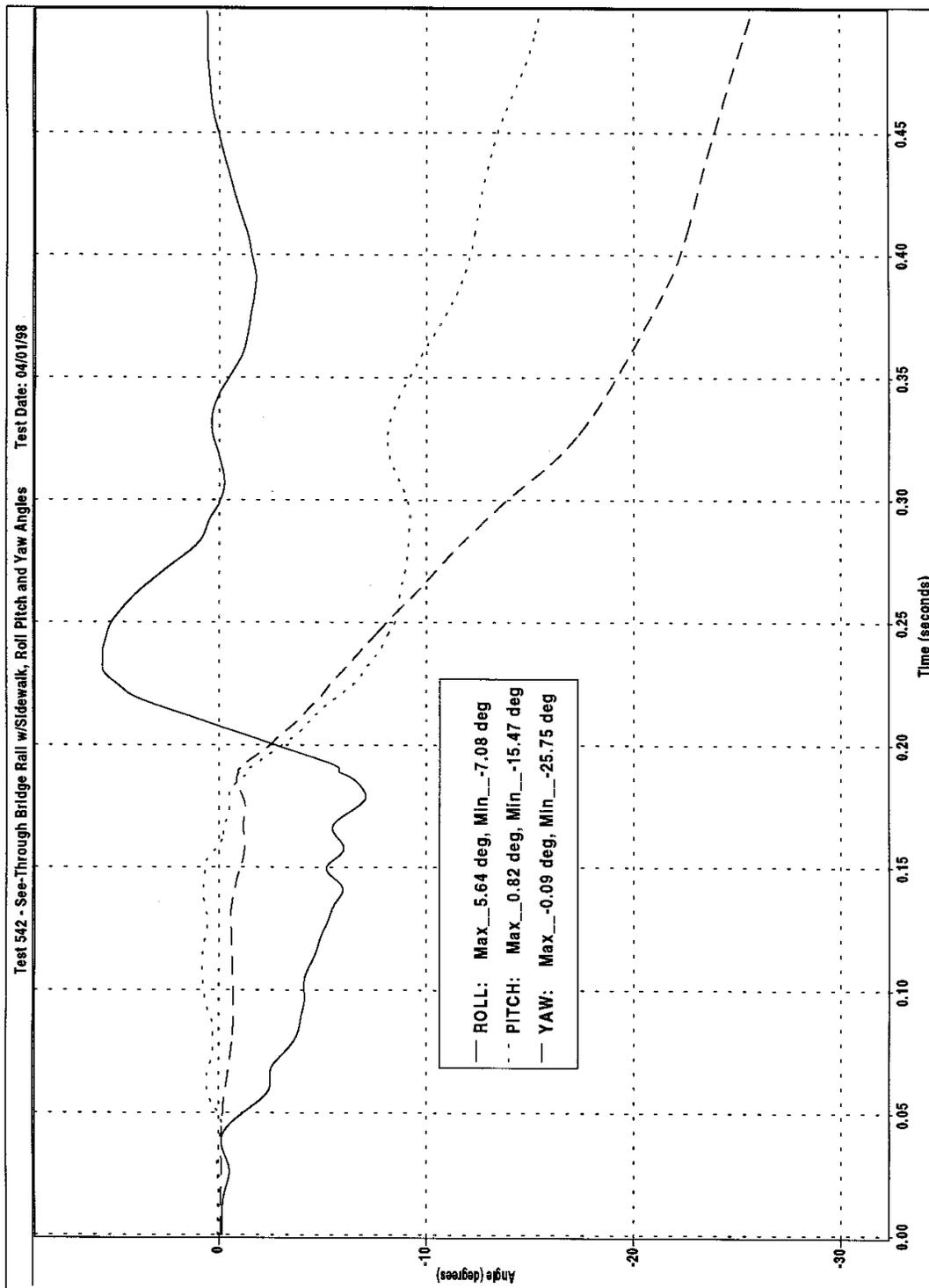
7. APPENDICES (continued)

Figure 7-10 - Test 542 Vehicle Lateral Acceleration, Velocity and Distance -vs- Time



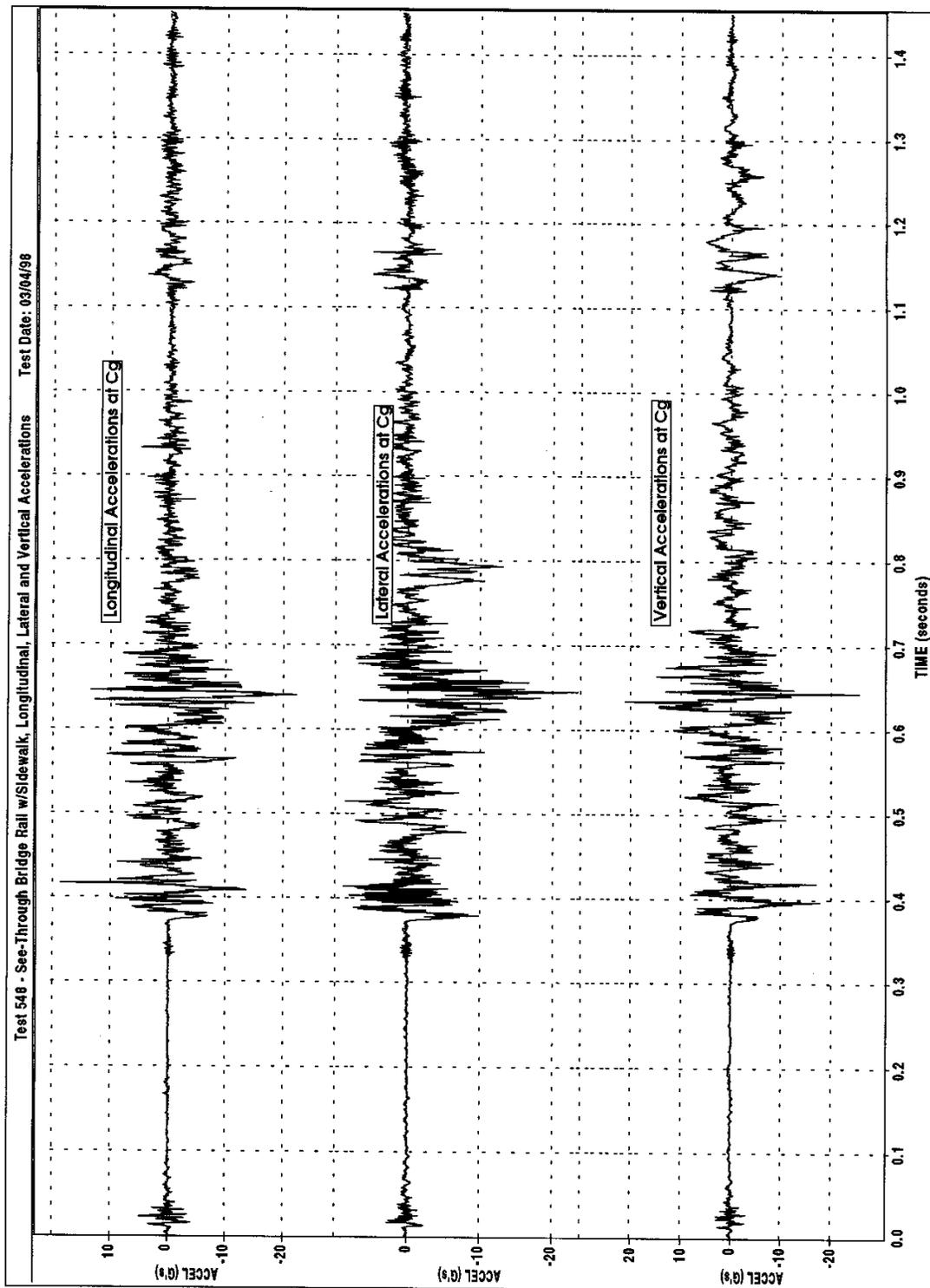
7. APPENDICES (continued)

Figure 7-11 - Test 542 Vehicle Roll, Pitch and Yaw -vs- Time



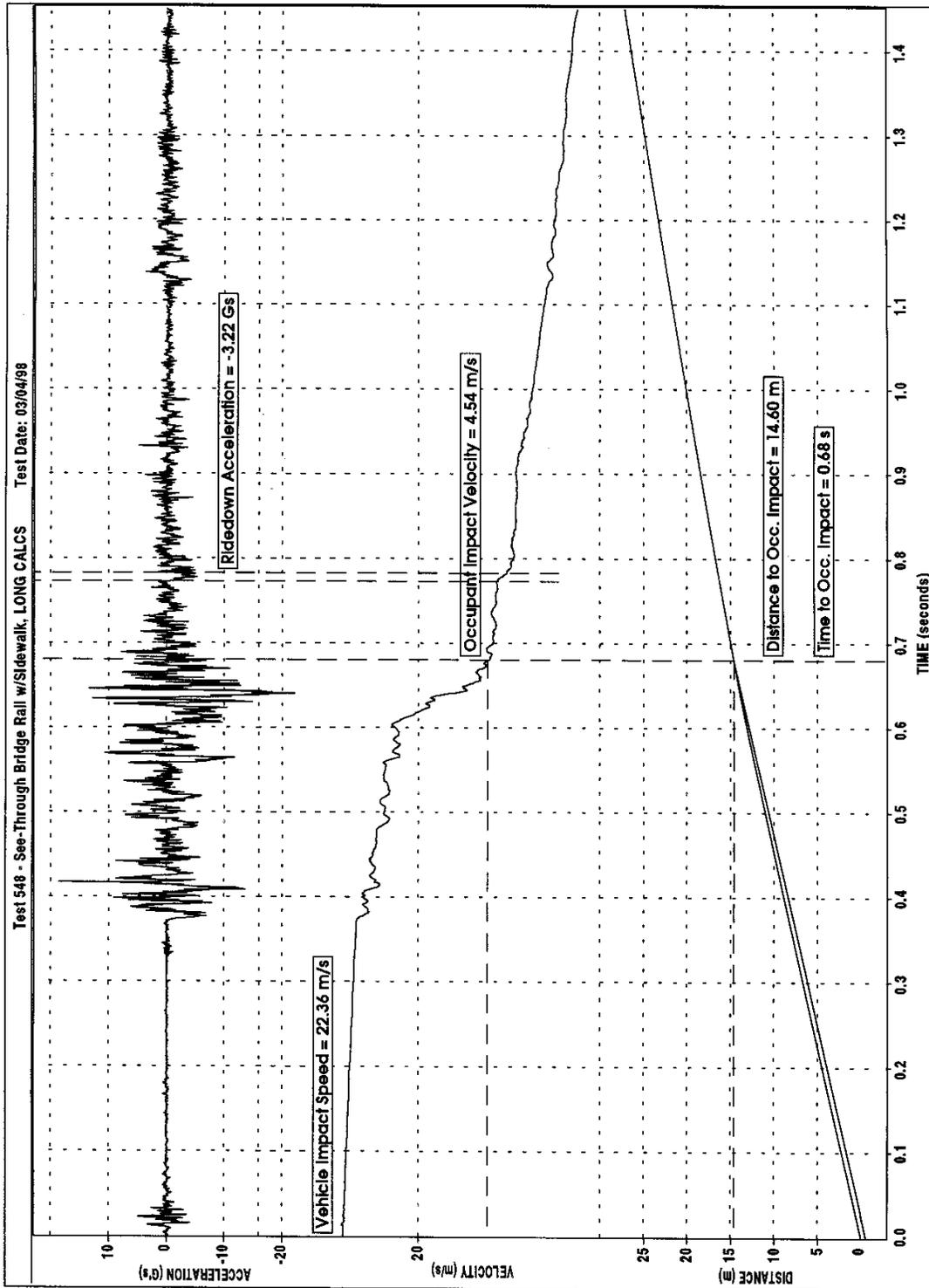
7. APPENDICES (continued)

Figure 7-12 - Test 548 Vehicle Accelerations -vs- Time



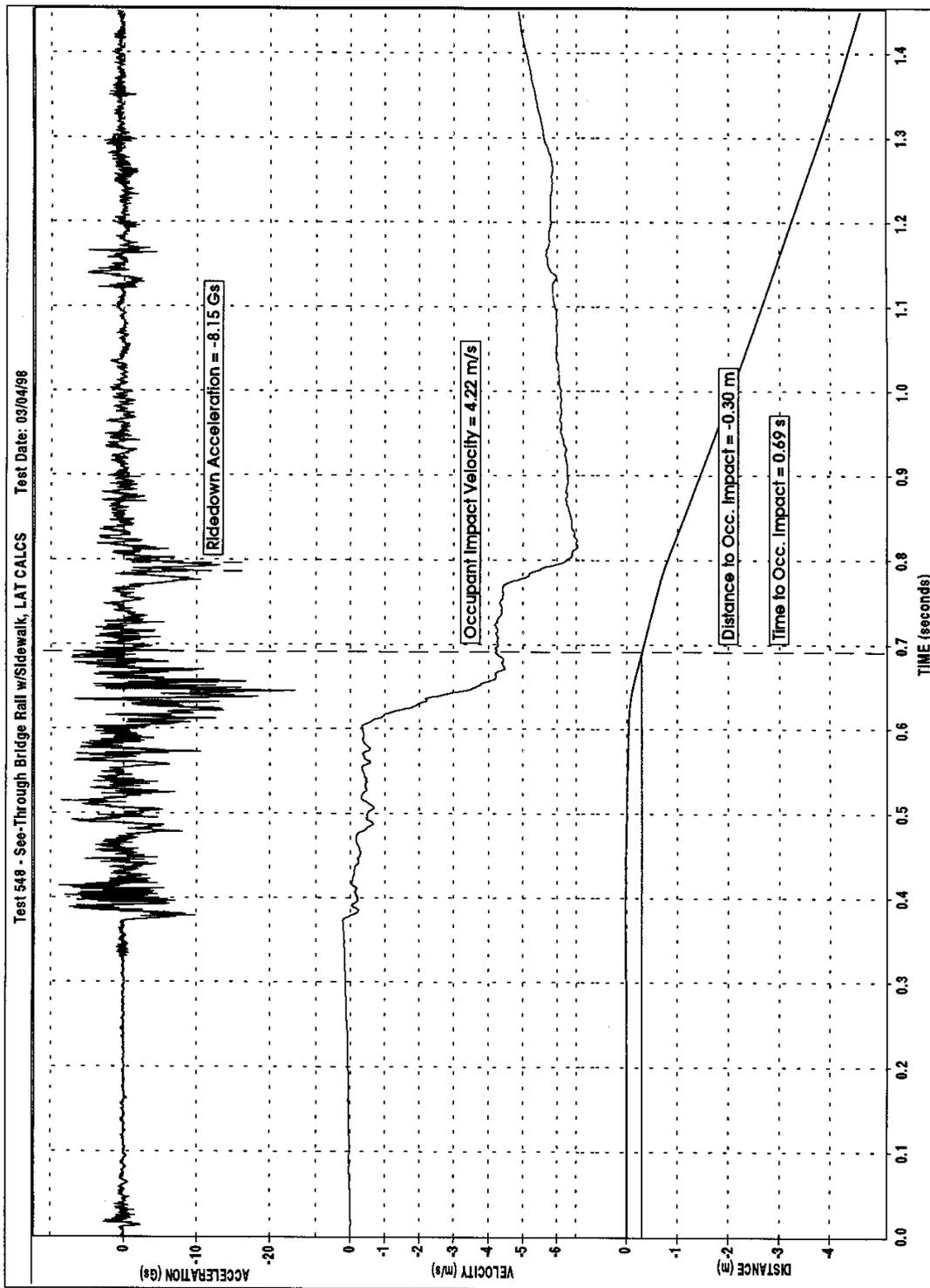
7. APPENDICES (continued)

Figure 7-13 - Test 548 Vehicle Longitudinal Acceleration, Velocity and Distance -vs- Time



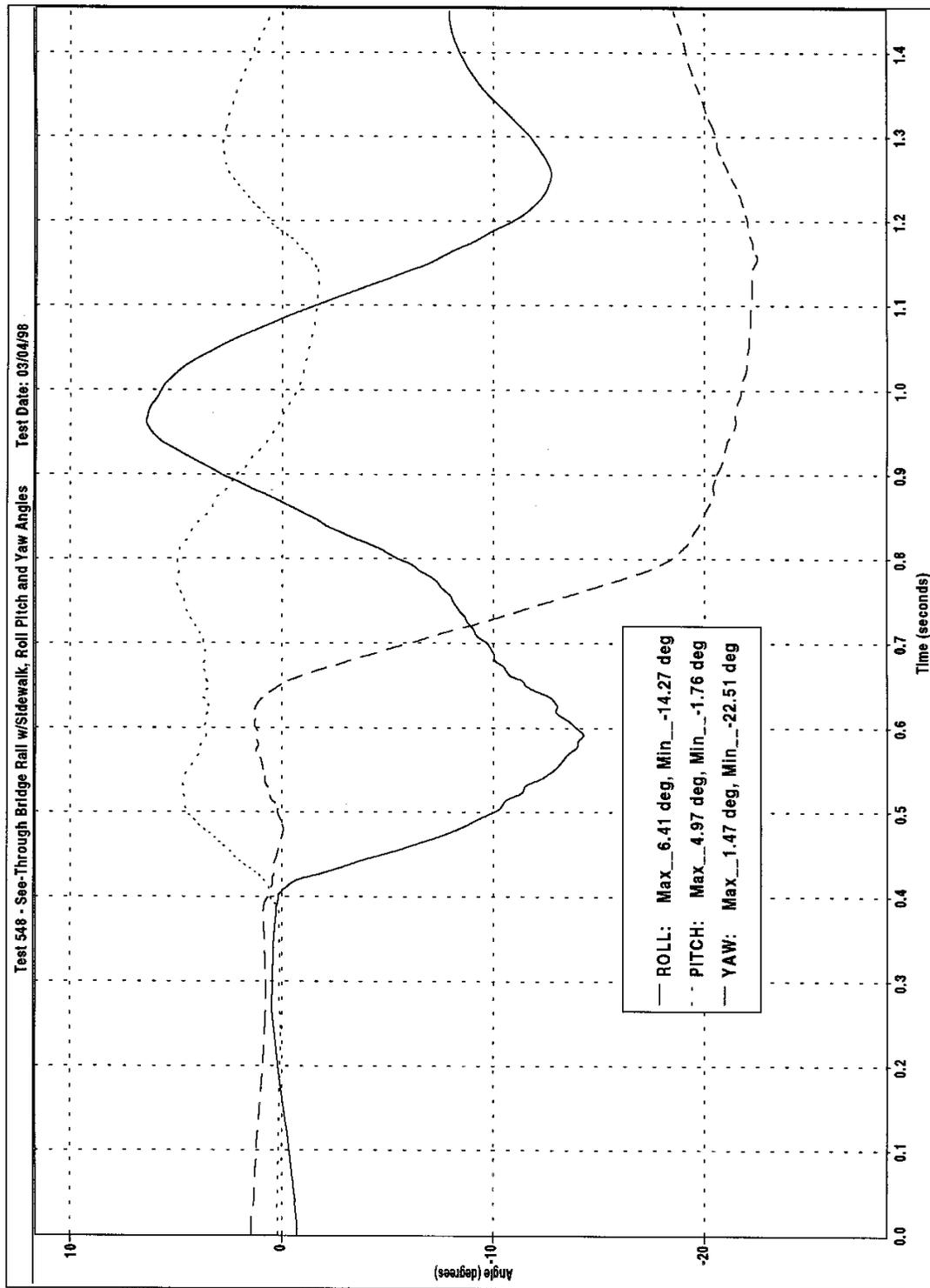
7. APPENDICES (continued)

Figure 7-14 - Test 548 Vehicle Lateral Acceleration, Velocity and Distance -vs- Time



7. APPENDICES (continued)

Figure 7-15 - Test 548 Vehicle Roll, Pitch and Yaw -vs- Time



## **7. APPENDICES (continued)**

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### **7.5. *Detailed Drawing***

The following three pages are “as-built” construction drawings. They do not contain some rebar modifications changed to aid constructability. Please contact Caltrans, Structures Design for the most current and complete plans.

California Department of Transportation  
Engineering Service Center  
Structures Design  
1801 30<sup>th</sup> Street  
Sacramento, CA 95816

Telephone: 916-227-8115

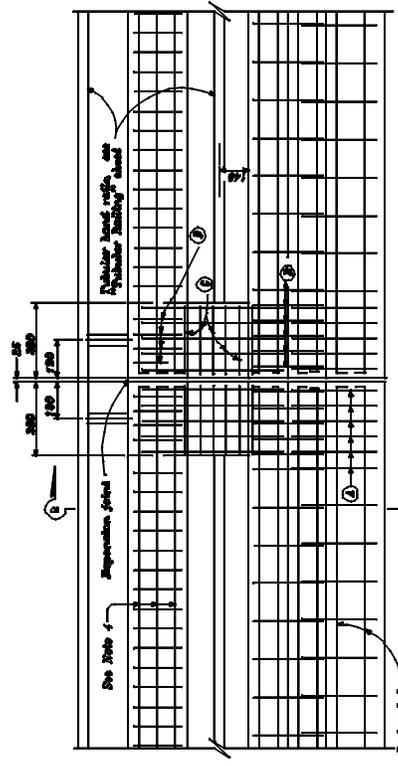


SAC COUNTY SUPERVISOR  
 REGISTERED ENGINEER - CIVIL  
 LICENSE NO. 12345  
 EXPIRES 12/31/2024

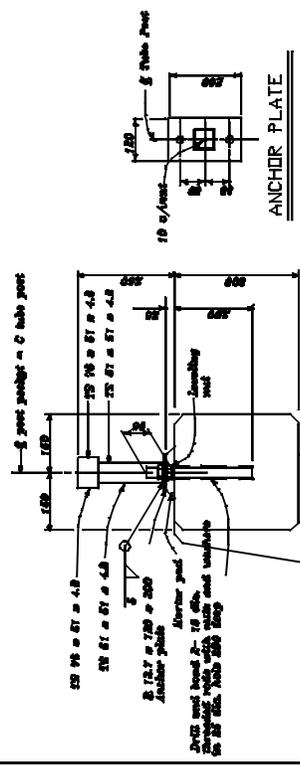


The State of California, by its officers or agents, shall not be responsible for the safety or the performance of any structure designed by any person herein.

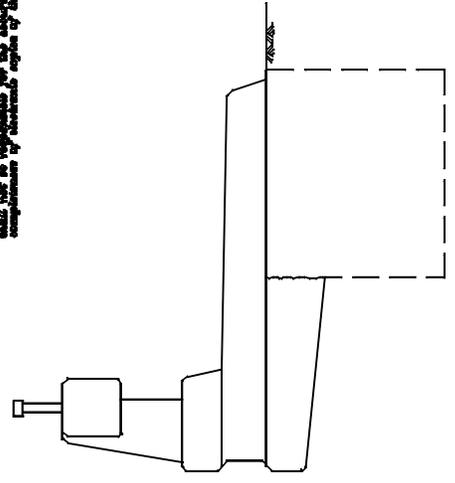
- 1. Reinforcing (Subsequent) 400 mesh 1/2" x 6" x 7/8" each side of expansion joint
- 2. #10 @ 12" on center each side of expansion joint
- 3. #10 @ 12" on center
- 4. #10 @ 12" on center



EXPANSION JOINT DETAIL  
1 of 2



HAND RAIL ANCHORAGE DETAIL  
1 of 2



SECTION B-B  
1 of 2

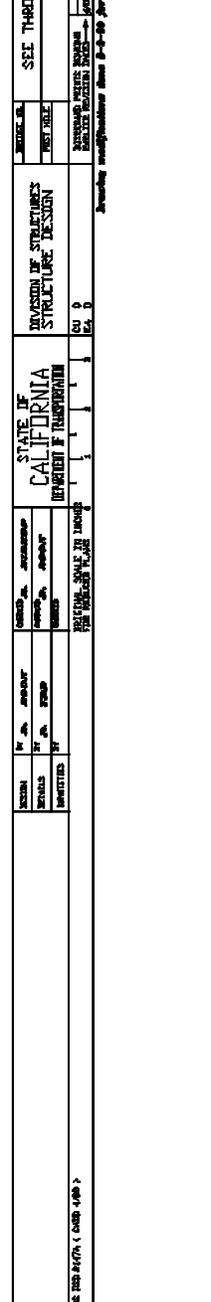
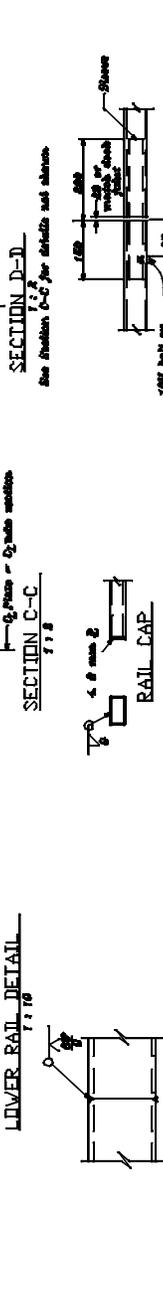
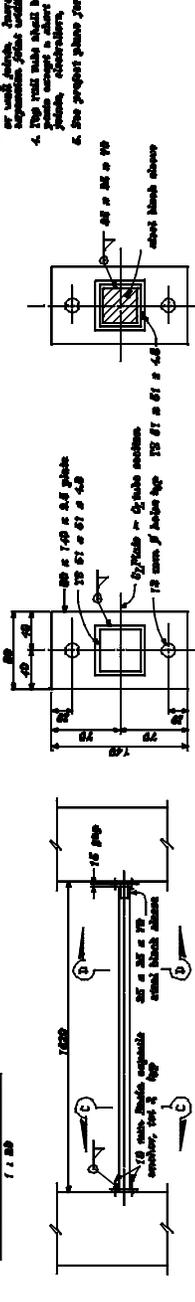
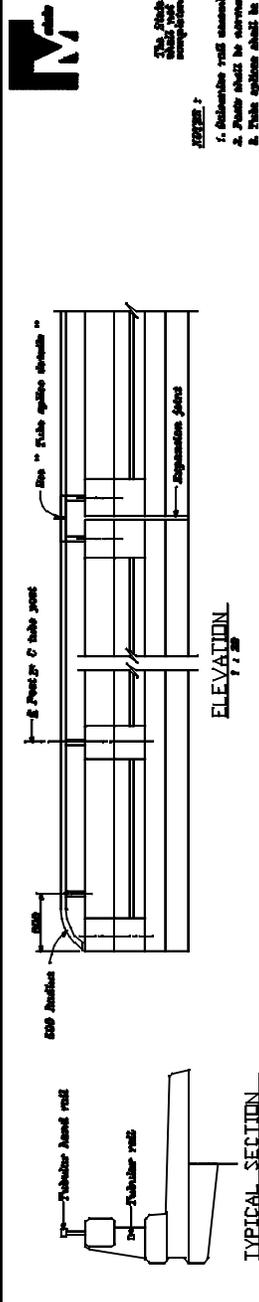
Show Bar Details and notes not shown on other sheets.

ALL DIMENSIONS ARE IN INCHES UNLESS OTHERWISE SHOWN SEE THROUGH CONCRETE BARRIER TEST SEE THROUGH CONCRETE BARRIER WITH SIDEWALK-DETAILS #2	
DIVISION OF HIGHWAYS STRUCTURE DESIGN	PROJECT NO. SHEET NO.
STATE OF CALIFORNIA DEPARTMENT OF TRANSPORTATION	COUNTY CITY
DESIGNER CHECKED APPROVED	DATE SCALE

DRAWING NO. 12345  
 SHEET NO. 1 OF 2  
 DATE: 12/31/2024  
 SCALE: AS SHOWN

NO. 1	CURT	NO. 2	NO. 3	NO. 4	NO. 5	NO. 6	NO. 7	NO. 8	NO. 9	NO. 10
										
DIVISION OF HIGHWAYS - CIVIL										

**NOTE 1:**  
 1. Disassemble rail assembly after fabrication.  
 2. Joints shall be covered in weather.  
 3. This system shall be tested in the shop (assembly shop) before installation. The test shall be conducted in accordance with the test procedure specified in the contract documents. The test shall be conducted in the presence of the Engineer and the contractor. The test shall be conducted in the presence of the Engineer and the contractor. The test shall be conducted in the presence of the Engineer and the contractor.



NO. 1	NO. 2	NO. 3	NO. 4	NO. 5	NO. 6	NO. 7	NO. 8	NO. 9	NO. 10	
STATE OF CALIFORNIA DEPARTMENT OF TRANSPORTATION										
SEE THROUGH CONCRETE BARRIER TEST TUBULAR RAILING										



U.S. Department  
of Transportation  
**Federal Highway  
Administration**

400 Seventh St., S.W.  
Washington, D.C. 20590

May 18, 1999

Refer to: HMHS

Mr. Richard Peter, Chief  
Roadside Safety Technology Section  
Office of Materials Engineering and  
Testing Services - MS #5  
5900 Folsom Boulevard  
Sacramento, California 95819-0128

Dear Mr. Peter:

In your April 6 letter to Mr. Henry Rentz, you requested formal Federal Highway Administration acceptance of the California Type 80 Bridge Rail at NCHW Report 350 test level 4 (TL-4). To support your request, you also sent a copy of your March 1999 report entitled "Vehicle Crash Tests of the Type 80 Bridge Rail" and a video tape of the three tests you conducted. Copies of these materials were also sent to Mr. Charles McDevitt for his concurrent review and comments.

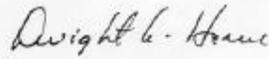
The Type 80 Bridge Rail is an aesthetic concrete post and beam design incorporating a 230-mm high curb, a 280-mm clear opening, and a 300-mm deep top beam. The posts are offset 100 mm from the face of the upper beam. Enclosure 1 is a schematic drawing of the final design. Staff members have reviewed the results of the tests you conducted on the Type 80 Bridge Rail and concur with your assessment that appropriate NCHW Report 350 evaluation criteria were met. The summary results of each test are shown in Enclosure 2. This design may be considered acceptable for use on the National Highway System as a TL-4 bridge railing.

As you recall, you previously sent information to Mr. Rentz on a similar design called the Type 80SW Bridge Railing. This design was identical to the Type 80, but it was tested behind a 200-mm high curb and a 1500-mm wide sidewalk. Additionally, it had a horizontal TS 51 x 51 x 4.8 steel tube at the midpoint of the clear opening, and a TS 76 x 51 x 4.8 steel tube mounted on the top beam to raise the total height to 1060 mm. This design is shown in Enclosure 3. The Type 80SW Bridge Railing was actually tested at TL-4, but there was significant passenger compartment intrusion when this design was impacted by the 2000-kg pickup truck at 100 k/hr

and at an angle of 25 degrees. Summary results for 0 three tests are shown in Enclosure 4. My December 2, 1998 letter to you indicated that we would accept the Type SOSW Bridge Rail as a TL-2 design without additional testing, thus permitting its use on the NHS at locations where impact speeds are not expected to exceed 70 k/hr.

There is a significant interest in acceptable, aesthetic bridge railing designs nationwide. I am assuming that any agency interested in using the Type 80 or the Type 80SW designs will be able to obtain copies of detailed plans and specifications directly from your Department.

Sincerely yours,

A handwritten signature in cursive script that reads "Dwight A. Home". The signature is written in dark ink on a light-colored background.

Dwight A. Home  
Director, Office of Highway Safety  
Infrastructure

4 Enclosures