

**COMPLIANCE CRASH TESTING OF A STEEL VERSION
OF THE TYPE 732 BRIDGE RAIL**



STATE OF CALIFORNIA

DEPARTMENT OF TRANSPORTATION
ENGINEERING SERVICE CENTER
MATERIALS ENGINEERING AND TESTING SERVICES

Supervised by Dan Speer, P.E.

Principal Investigator Rich Peter, P.E.

Report Prepared by Michael White, P.E. and John Jewell, P.E.

Research Performed by Roadside Safety Technology Unit

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<p>16. ABSTRACT</p> <p>A steel version of the Type 732 concrete bridge rail (Type 732S) was tested in accordance with NCHRP Report 350. The rail is composed of segments that are each 2.5 m in length and 813 mm high, constructed from 15-mm thick steel plate. It has a smooth face with a single slope of 9.1 degrees from vertical on the traffic side while the backside is vertical. The barrier tested was 25 m long and was constructed off-site and later installed at the Caltrans Dynamic Test Facility in West Sacramento, California. The steel version is approximately 595 kg lighter per linear meter than the concrete version. This weight saving was critical to the design of the East span of the new San Francisco/Oakland Bay Bridge.</p> <p>Two crash tests were conducted under Report 350 test Level 4, one with a 2000-kg pickup truck and one with an 8000-kg single unit van truck. The results of the two tests were within the limits of the Report 350 guidelines.</p> <p>The Type 732S bridge rail is recommended for approval on California highways requiring TL-4 bridge rails.</p>			
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NOTICE

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SI CONVERSION FACTORS

<u>To Convert From</u>	<u>To</u>	<u>Multiply By</u>
ACCELERATION		
m/s ²	ft/s ²	3.281
AREA		
m ²	ft ²	10.764
ENERGY		
Joule (J)	ft.lbf	0.7376
FORCE		
Newton (N)	lbf	0.2248
LENGTH		
m	ft	3.281
m	in	39.37
cm	in	0.3937
mm	in	0.03937
MASS		
kg	lb _m	2.205
PRESSURE OR STRESS		
kPa	psi	0.1450
VELOCITY		
km/h	mph	0.6214
m/s	ft/s	3.281
km/h	ft/s	0.9113

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T.Y. LIN International under the direction of Tom Ho designed the bridge rail. Christie Constructors Inc. of Richmond California fabricated the test article under the supervision of Alan Straub, Vice President.

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1. INTRODUCTION

1.1. Problem

The current design for the suspension section of the San Francisco-Oakland Bay Bridge (SFOBB) is nearly complete. The designers have determined that using a steel version of the concrete Type 732 bridge rail instead of a Type 25 barrier will reduce the overall cost of this span by approximately \$10.8 million by allowing the use of a lighter deck and cables. The Caltrans Division of Structures has requested a study of the viability of a steel version of the Type 732 for this reason. A steel version of the Type 732 bridge rail has not been tested for compliance with Test Level 4 of the National Cooperative Highway Research Program (NCHRP) Report 350⁽¹⁾.

1.2. Objective

To crash test a Type 732 bridge rail fabricated from steel plate rather than concrete (hereinafter referred to as the Type 732S) in accordance with NCHRP Report 350 Test Level 4 criteria for longitudinal barriers. These tests will involve impacts with a 2000-kg pickup truck at 100 km/h and an impact angle of 25° as well as with an 8000-kg single unit van at 80 km/h and an impact angle of 15°.

1.3. Background And Significance Of Work

A Type 25 concrete barrier was chosen for the eastern portion of the SFOBB during the initial design phase and all the way through the 45% submittal stage. Later in the design process it became apparent that there was eccentric loading on the tower which had to be alleviated by adding some counterweight to the westbound deck. This additional load on the cables and hangers was undesirable and had to be decreased. A logical choice was to change the concrete Type 25 barrier to some type of steel barrier, which would save approximately 595 kg per linear meter.

According to calculations done by the designer, the steel version of the Type 732 is expected to cost approximately \$1000 more per meter of length when compared to a concrete Type 732 barrier. The maintenance costs for the steel version are also expected to be higher than that of a standard concrete version. The savings to Caltrans come from the lower weight per unit length of the steel version over the concrete version. The lower overall weight will reduce the size, and therefore the costs, of the supporting sub-structure and super-structure of the bridge. This saving is projected to be approximately \$10.8 million.

The State of California tested the Type 70 barrier (which was later designated the Type 732) in 1997. The Type 70 is a steel reinforced concrete barrier 810 mm high with a single-slope face that is 9.1° from vertical with the top sloping away from traffic. The Type 70 rail was originally designed using the American Association of State Highway and Transportation

Officials (AASHTO) “Guide Specifications for Bridge Railing”⁽²⁾ requirements. The AASHTO Guide Specifications stipulate that bridge rails to be used for high-speed applications must conform to PL-2-level testing. According to the FHWA, the PL-2 test level has since been replaced by the similar NCHRP Report 350 test level 4. Therefore, the Type 70 rail was tested according to test level 4 criteria (TL-4). Table 1.1 summarizes the testing requirements for AASHTO levels PL-1, PL-2, and NCHRP Report 350 level TL-4. The TL-4 impact severity is higher than that of PL-2 due to the increased speed and angle, even though the mass is reduced. The report for the Type 70 concluded that it would successfully contain and redirect the 820C, the 2000P, and the 8000S vehicles under TL-4 conditions⁽³⁾.

The final design of a steel version of the Type 732 (the Type 732S) will become a non-proprietary design, which may be used on other bridge structures where weight savings are critical or economically sensible. The design may also be useful to other transportation entities.

Table 1-1 - Comparison of Different Test Levels

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

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 no reports that involved crash testing of steel versions of either the Type 732 or the Type 70.

1.5. Scope

A representative section of Type 732S bridge rail was fabricated by Christie Constructors Inc. and installed at the Caltrans Dynamic Test Facility in West Sacramento. Data were collected from two vehicular crash tests under the conditions shown in Table 1-2. These data were analyzed to determine if the Type 732S met the criteria set forth in NCHRP Report 350.

Table 1-2 – Intended Test Conditions

CALTRANS Test #	Barrier type	Mass (kg)	Speed (km/h)	Angle (deg)	NCHRP Report 350	
					Test Designation	Vehicle
571	Type 732S	2000	100	25	4-11	2000P
572	Type 732S	8000	80	15	4-12	8000S

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. The test article was mounted to an existing concrete anchor block, which was approximately 0.9 m deep by 1.1 m wide by 24.3 m long.

2.1.2. Test Barrier Design and Construction

The Type 732S barrier has the same traffic-side profile as the concrete Type 732 barrier. Both are 810 mm high as measured from the finished grade to the top of the barrier and both have a single-slope face, which is 9.1 degrees from vertical. The 732S was designed by T.Y. Lin International as part of their contract with the State of California for the design of the new San Francisco / Oakland Bay Bridge (SFOBB). See Appendix A for design drawings.

The Type 732S was fabricated from 15-mm thick steel plate formed into the appropriate shape for the barrier face. This face and the supporting gussets on the backside were welded together to form an individual segment 2.5 m long. Ten of these segments were then bolted to two separate deck assemblies that had a surface plate of 25-mm thick steel, (Figure 2-1 and Figure 2-2). A gap of approximately 20 mm was left between segments to allow for expansion of

the steel and for ease of removal in the event of damage. The barrier was fabricated by Christie Constructors Inc. at their Richmond, CA facility and then sent to ABC Paint in Vallejo, CA for the application of the primer and color coat. It was then transported as two 12.5-m long pieces to the Caltrans Dynamic Test Facility. The 12.5-m long deck assemblies, with attached 2.5-m long rail segments, were lifted from the flatbed semi trucks using a high capacity crane. They were positioned and slid over 25.4-mm diameter threaded rods, which had previously been horizontally bonded with epoxy resin into the back face of the existing concrete anchor block.



Figure 2-1 Type 732S barrier installation.

After each section was placed over the threaded rods, alignment was checked and nuts were tightened to draw the entire assembly tight against the concrete anchor block. The two deck assemblies were then welded together at their common seam along both the top and bottom side of this joint. After placing the steel deck assemblies into position, two rows of holes were cored vertically through existing deck holes into the concrete anchor block with a 241-mm center-to-center spacing (Figure 2-3). These rows were placed at 650 mm and 910 mm out from the traffic side of the barrier to attach the steel simulated bridge deck to the concrete anchor block. Threaded rods 25.4 mm in diameter were then bonded with epoxy resin into these holes. After a curing time of 24 hours, nuts were tightened onto these rods and the protruding threaded rod sections were cut off flush with the tops of the nuts (Figure 2-4). This area was later covered with a 50-mm thick asphalt-concrete overlay, which completely covered these nuts and vertical rod ends (Figure 2-5). This A/C overlay tapered down to less than 10 mm at approximately 6 m from the barrier to provide a smooth transition for the vehicle approach and run-out.

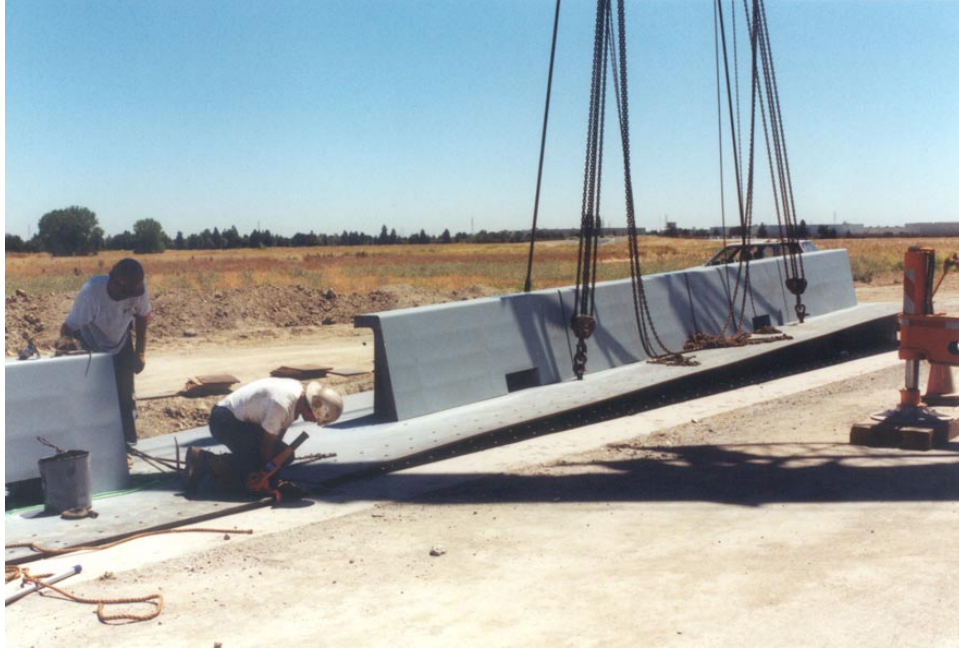


Figure 2-2. Second deck assembly of the Type 732S being installed.



Figure 2-3. Holes being drilled for installation of the vertical threaded rods.

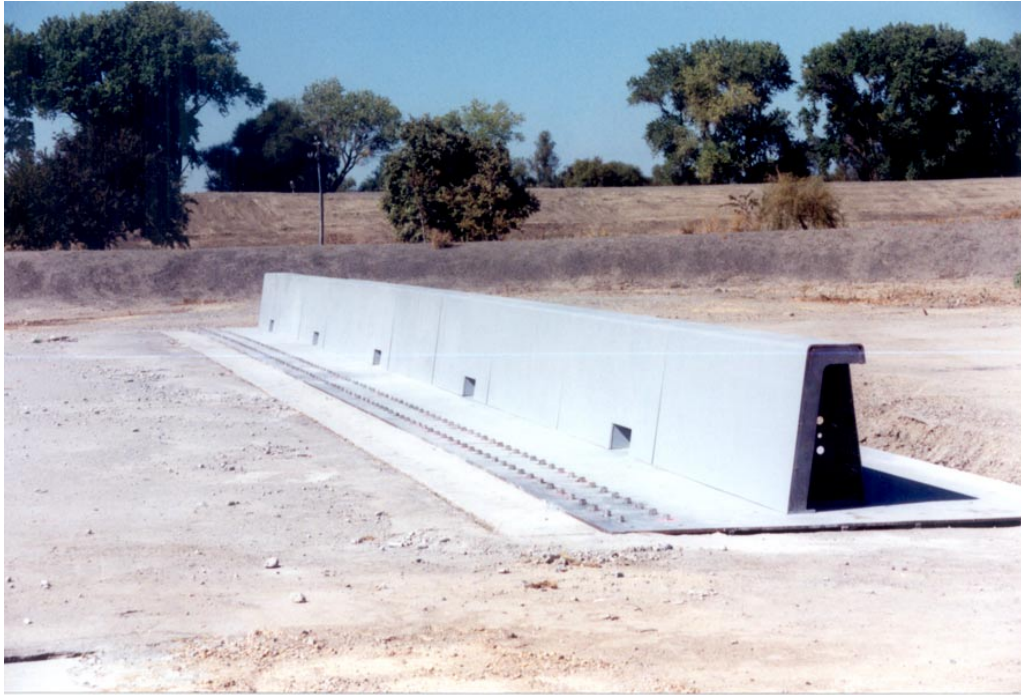


Figure 2-4. Type 732S barrier installed and ready for asphalt overlay.



Figure 2-5. Type 732S test article after installation of the asphalt concrete overlay.

2.1.3. Test Vehicles

The test vehicles complied with NCHRP Report 350⁽⁴⁾. 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 mass of the 8000S was within acceptable limits while the 2000P vehicle for Test 571 was slightly overweight due to its 454 cubic inch big-block engine (Table 2-1).

Table 2-1 - Test Vehicle Masses

Test No.	Vehicle	Ballast (kg)	Test Inertial (kg)
571	1992 Chevrolet 2500	0	2196
572	1992 GMC Top Kick	3049	8111

The Chevrolet 2500 pickup truck and the GMC TopKick single-unit van were self-powered and used a speed control device to limit acceleration once the impact speed had been reached. Remote braking was possible at any time during Test 571 via an electric cable tether, and during Test 572 via a radio-link remote controlled braking setup. A short distance before the point of impact each vehicle was released from the guidance rail and the ignition system was deactivated. A detailed description of the test vehicle equipment and guidance system is contained in Appendices 7.1 and 7.2.

2.1.4. Data Acquisition System

The impact event of each crash test was recorded with 7 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 auto-winder and one 35-mm sequence camera. The test vehicles and the barrier were photographed before and after impact with a normal-speed 16-mm movie camera, a Beta format video camera and a color 35-mm camera. A film report of this project was assembled using edited portions of the film coverage.

Three sets of orthogonal accelerometers were mounted in the 2000P vehicle, two at the center of gravity and one 600 mm behind the center of gravity. Rate gyro transducers were also placed at the center of gravity of the 2000P vehicle to measure the roll, pitch, and yaw. The data were used in calculating the occupant impact velocities, ridedown accelerations, and maximum vehicle rotation.

Anthropomorphic dummies were not used in any of the tests.

A digital transient data recorder (TDR) manufactured by Pacific Instruments (model 5600) was used to record electronic data during Test 571. Since accelerometers and rate gyros are not used on the 8000S vehicle, such data were not acquired during Test 572. 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 571 and 572 has been compiled and is available for viewing.

2.2.1. Impact Description - Test 571

The impact angle was set at 25° by placement of the guide rail and the vehicle did not deviate from this angle prior to impact. The impact speed of 98.2 km/h was obtained by an average of two different speed traps located just upstream from the impact point. The test vehicle impacted the barrier 779 mm upstream of the joint between segments 4 and 5 as intended. The top right corner of the vehicle hood rode over the top of the 810-mm high barrier to a maximum extension of approximately 450 mm as measured from the traffic side of the barrier face. The front tires lost contact with the pavement at approximately 0.125 seconds. The right front of the vehicle continued to deform moderately as the vehicle began to yaw slightly left (negative) until the back right side of the vehicle contacted the barrier 0.18 seconds after the initial impact. This secondary impact by the rear of the vehicle caused slight damage to the rear quarter section of the truck and also caused both rear tires to lose contact with the pavement. The vehicle-mounted brake flash erroneously triggered for unknown reasons 0.24 seconds after initial impact. At 0.30 seconds after initial impact the vehicle lost contact with the barrier at which time the speed was determined through film analysis to be 81.5 km/h and the exit angle was 5.8°. The secondary impact by the rear quarter of the vehicle slowed the negative yaw of the vehicle and initiated a moderate degree of negative pitch (nose down). The vehicle obtained a maximum height of 900 mm as measured from the ground to the undercarriage approximately 0.4 seconds after the initial impact. The vehicle came back into contact with the pavement in a nose-down orientation and reached a maximum pitch angle of -10° and a maximum roll angle of 41° before it righted itself and continued into the run-out area. The brakes were applied 1.8 seconds after the initial impact as indicated by the vehicle brake lights, which were visible from the upstream high-speed camera. The vehicle came to rest against an earthen berm approximately 23 m downstream from the end of the barrier. Figure 2-6 through Figure 2-11 show the pre-test and post-test condition of the test vehicle and test article. Sequence photographs of the impact for Test 571 are shown as Figure 2-12 on the data summary sheet on page 12.



Figure 2-6 Test vehicle for Test 571



Figure 2-7 Test article prior to Test 571



Figure 2-8 Test vehicle after Test 571



Figure 2-9 Right front corner of test vehicle after Test 571



Figure 2-10 Type 732S barrier face after Test 571



Figure 2-11 Type 732S barrier backside after Test 571

Data Summary Sheet

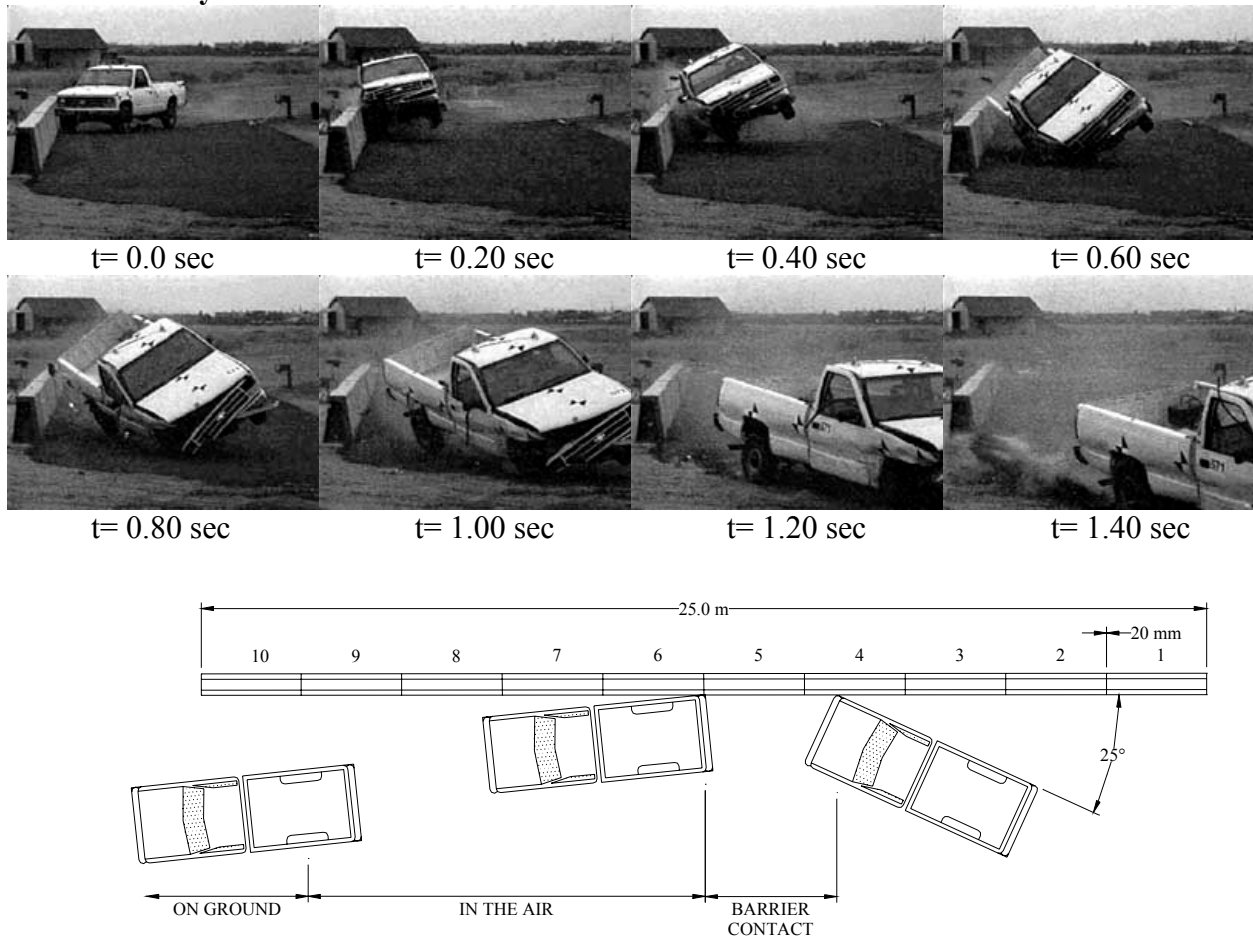


Figure 2-12 Impact sequence and diagram for Test 571

Test Barrier

Type: 810-mm high, Type 732S bridge rail, bolted to 25-mm steel plate
 Length: 25-m total length consisting of 10 segments of 2.5 m each.

Test Date: August 30, 2000

Test Vehicle:

Model: 1992 GMC 2500
 Inertial Mass: 2196 kg
 Impact / Exit Velocity: 98.2 km/h / 81.5 km/h
 Impact / Exit Angle: 25.0° / < 6°

Test Data:

Occ. Impact Velocity (Long / Lat): 4.64 m/s / 6.83 m/s
 Ridedown Acceleration (Long / Lat): -5.66 g / -10.18 g
 ASI: 10.03
 Exterior: VDS⁽⁴⁾/CDC⁽⁵⁾ FR-5, RFQ-5, RD-2/01RFEW3
 Interior: OCDI⁽¹⁾ RF0010001

Barrier Damage: Only superficial marring and less than 4 mm of permanent lateral deflection.

2.2.2. Vehicle Damage - Test 571

The right front corner of the vehicle was moderately damaged in the initial impact with the barrier. The right front fender, hood, bumper, headlamp area, grille, and suspension components were all affected. The passenger side doorframe was deformed outward but the door remained latched. The right front tire was also ruptured. Some minor damage along the right side of the vehicle and to the right rear quarter occurred as the vehicle continued to contact the barrier after the initial impact. The vehicle became briefly airborne, with the left rear corner reaching a maximum height of 900 mm. As the vehicle came back into contact with the ground it was in a nose-down pitch and right roll attitude which placed a majority of the landing force on the already damaged right front suspension components. This additional force caused the right front tire to push rearward and slightly into the passenger side footwell area. The maximum amount of passenger compartment deformation, 127 mm, occurred in the floorboard. This was within the accepted limit of 150 mm.¹

The longitudinal occupant impact velocity and longitudinal occupant ridedown acceleration were well below the allowed maximums of 12 m/s and 20 g, respectively. The longitudinal occupant impact velocity was 4.64 m/s and the longitudinal occupant ridedown acceleration was -5.66 g. Test results are summarized in Table 2.2 on page 22.

The vehicle used in Test 571 had a test inertial mass that was 151 kg above the upper limit given in NCHRP Report 350 for the 2000P test vehicle. This was due to the 7.4 liter (454 cid) engine in this particular vehicle. Because of the larger mass of this vehicle the impact speed was adjusted slightly downward to provide an impact severity comparable to a vehicle that was within the test inertial mass limits. The nominal impact severity value for Test Designation 4-11 as given in NCHRP Report 350 is 138.1 kJ with a suggested tolerance of -10.8 to +11.6. With a mass of 2196 kg and an impact speed of 98.2 km/h, the impact severity for this test was 145.9 kJ, which is below the upper limit of 149.7 kJ.

2.2.3. Barrier Damage - Test 571

There was essentially no permanent damage to the barrier during Test 571. The vehicle did scrape the paint off the barrier along the length of contact and the vehicle lug nuts created some minor gouges, which were no more than 5 mm deep. These gouges could be ground and filled on-site by maintenance crews without removing any barrier segments.

Three measurements were taken at each barrier segment joint before the test to determine the spatial relationship from one segment to the next. These measurements were later compared to ones taken after test 571 and it was determined there was no more than 4 mm of permanent deflection between any two segments at any of the joints.

¹ NCHRP Report 350 does not specify a maximum allowable limit for occupant compartment deformation. However, the Federal Highway Administration has established an informal limit of 150 mm that is generally accepted by the roadside safety community.

The 732S barrier was bolted to 25-mm thick steel plate for this test to simulate the actual bridge deck that may ultimately be used on the SFOBB. This was done so designers at T.Y. Lin International could use this test to determine if vehicular impacts on the bridge rail could cause permanent damage to the bridge deck. To help prevent this possibility from occurring, the designers used connecting bolts which would essentially act as "fuses" in the event of a severe impact. None of these bolts were severed or sheared during this test.

2.2.4. Impact Description - Test 572

The impact angle was set at 15° by placement of the guide rail and the vehicle did not deviate from this angle prior to impact. The impact speed of 82.6 km/h was obtained by an average of two different speed traps located just upstream from the impact point. The test vehicle impacted the barrier 250 mm upstream of the scupper of segment 4 as intended. The front right corner of the vehicle hood rode over the top of the 810-mm high barrier to a maximum extension of approximately 320 mm as measured from the traffic side of the barrier face. The left front tire lost contact with the pavement at approximately 0.10 seconds after impact. The right front of the vehicle continued to deform as the vehicle began to yaw slightly left (negative) until the vehicle became parallel with the barrier 0.30 seconds after the initial impact. At this point the vehicle had a right (positive) roll of about 13°. The roll angle reached a maximum of 47.2° approximately 1.15 seconds after initial impact. The vehicle remained in contact with the barrier until 1.2 seconds after impact at which point the end of the vehicle passed the end of the barrier. When this occurred the exit angle of the vehicle was less than 2° and the roll angle was still about 47°. The impact of the right front tire with the barrier caused failure of several suspension components, including the right-side U-bolts which secure the axle to the leaf springs. This allowed the front axle to begin to rotate about its connection point on the left side of the vehicle. The axle continued to rotate as the right front tire passed completely under the vehicle chassis. The lack of a right front tire and wheel assembly in its normal location helped contribute to the high roll angle of 47.2°. As the vehicle came to rest against an earthen berm the front axle had rotated a full 90° and in its final position was still attached to the left shock absorber and parallel to the longitudinal axis of the vehicle. The vehicle never fully lost contact with the ground and was able to right itself from its high roll angle as it continued into the run-out area. The vehicle-mounted brake flash never fired although the brakes were applied approximately 1.2 seconds after initial impact, at which time the vehicle was approximately 10 m past the end of the barrier. The brake application was implied from the rotation of the left front wheel being halted while that wheel was free from contact with any other surface. The berm at which the vehicle stopped was approximately 23 m downstream from the end of the barrier. Figure 2-13 through Figure 2-19 show the pre-test and post-test condition of the test vehicle and test article.

The 3049 kg of ballast was comprised of two separate pallets of sandbags and the associated mounting hardware all bolted and strapped down to the cargo floor. The pallets were constrained by 150-mm angle iron and the sandbags were held down by 100-mm nylon straps as shown in Figure 2-20. The sandbags shifted slightly, but it is unlikely that this affected the test. None of the sandbags broke loose during the test.

Sequence photographs of the impact for Test 572 are shown as Figure 2-21 on the data summary sheet on page 19.



Figure 2-13 Test vehicle for Test 572



Figure 2-14 Test vehicle for Test 572



Figure 2-15 Test article prior to Test 571



Figure 2-16 Right side of test vehicle after Test 571



Figure 2-17 Left side of test vehicle after Test 571



Figure 2-18 Type 732S barrier face after Test 572



Figure 2-19 Barrier face gouges from vehicle lug nuts after Test 572



Figure 2-20 Ballast strapped down in cargo bed of test vehicle after Test 572

Data Summary Sheet

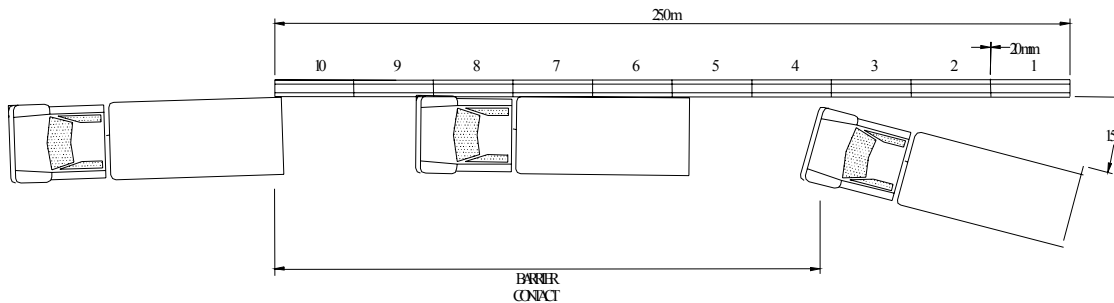
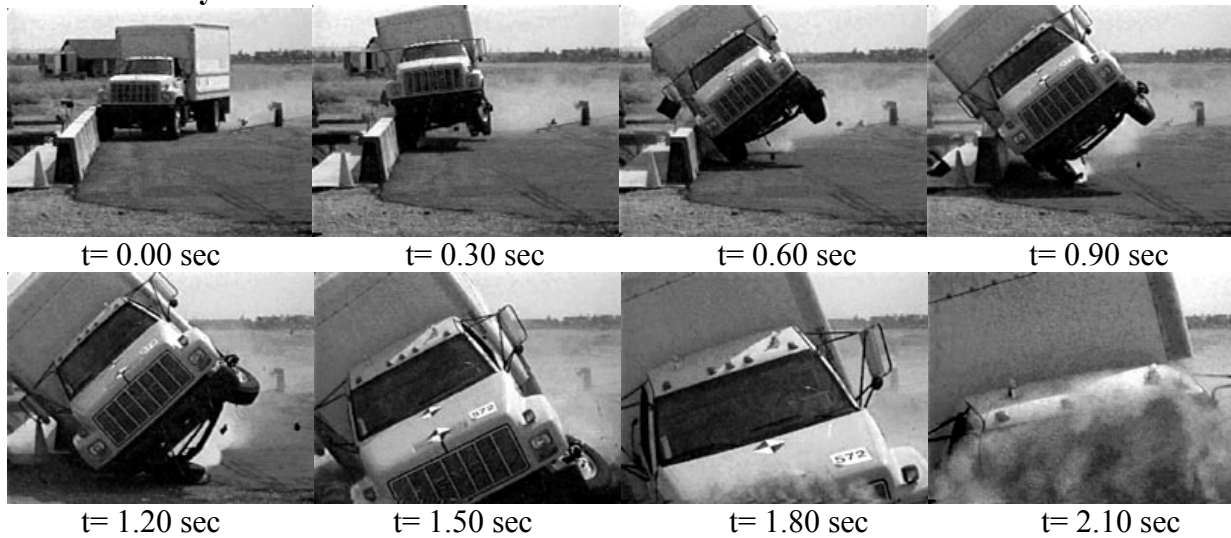


Figure 2-21 Impact sequence and diagram for Test 572

Test Barrier

Type: 810-mm high, Type 732S bridge rail, bolted to steel plate
 Length: 25-m total length consisting of 10 segments of 2.5 m each.
 Test Date: September 13, 2000

Test Vehicle:

Model: 1992 GMC Top Kick
 Inertial Mass: 8111 kg
 Impact / Exit Velocity: 82.6 km/h / 76 km/h
 Impact / Exit Angle: 15.0° / < 2°

Test Dummy:

Type: None used

Test Data:

Occ. Impact Velocity (Long / Lat):	not measured
Ridedown Acceleration (Long / Lat):	not measured
Max. 50 ms Avg. Accel (Long / Lat):	not measured
THIV/ASI	not measured
Exterior: VDS ⁽⁴⁾ /CDC ⁽⁵⁾	NA / NA
Interior: OCDF ⁽¹⁾	RF0000000

Barrier Damage:

Only superficial marring and less than 4 mm of permanent lateral deflection.

2.2.5. Vehicle Damage - Test 572

The right front corner of the vehicle and the fiberglass engine cowling were moderately damaged in the initial impact with the barrier. The right front bumper and right fender were pushed rearward. The right front tire and wheel assembly was broken loose from its attachment to the leaf springs, which allowed it to move rearward. The tire contacted the right-mounted diesel fuel tank, which damaged it and resulted in a minor leak. The tire also damaged the battery compartment and ruptured the battery, which was located directly under the passenger-side door. The passenger-side door remained latched even though film analysis showed a 25-50 mm gap opening and closing along the top of the door due to flexure of the cab and door. There was no passenger compartment or floorboard deformation.

2.2.6. Barrier Damage - Test 572

As in Test 571, there was essentially no permanent damage to the barrier during Test 572. The vehicle did scrape the paint off the barrier along the length of contact and the vehicle lug nuts created some minor gouges, which were no more than 7 mm deep. These gouges could be ground and filled on-site by maintenance crews without removing any barrier segments.

Three measurements were taken at each barrier segment joint before the test to determine the spatial relationship from one segment to the next. These measurements were later compared to ones taken after Test 572 and it was determined that there was no more than 4 mm of permanent deflection between any two segments at any of the joints.

The 732S barrier was bolted to 25-mm thick steel plate for this test to simulate the actual bridge deck that may ultimately be used on the SFOBB. This was done so designers at T.Y. Lin International could use this test to determine if vehicular impacts on the bridge rail could cause permanent damage to the bridge deck. To help prevent such damage, the designers used connecting bolts which would essentially act as "fuses" in the event of a severe impact. None of these bolts were severed or sheared during this test. Barrier segment number 4 did shift enough transversely to make removal of these bolts (for inspection) somewhat difficult.

2.3. Discussion of Test Results - Crash Tests

2.3.1. General - Evaluation Methods (Tests 571 and 572)

NCHRP Report 350⁽¹⁾ stipulates that crash test performance be assessed according to three evaluation factors: 1) Structural Adequacy, 2) Occupant Risk, and 3) Vehicle Trajectory. These evaluation factors are further defined by evaluation criteria and are shown for each test designation in Table 3.1 of NCHRP Report 350. Test 571 of this report has a NCHRP Report 350 test designation of 4-11 and for Test 572 it is 4-12. The evaluation criteria are detailed in Chapter 5 of NCHRP Report 350 and are summarized in Table 5.1 of that same report.

2.3.2. Structural Adequacy

The structural adequacy of the Type 732S 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 gouging. A detailed assessment summary of structural adequacy is shown in Table 2-2 and Table 2-3

2.3.3. Occupant Risk

The occupant risk for the Type 732S is also acceptable. In neither one of the tests did any material from the barrier 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 and Table 2-3 for a detailed assessment summary of occupant risk.

2.3.4. Vehicle Trajectory

The post-impact vehicle trajectory is also acceptable for the Type 732S. The detailed assessment summary of vehicle trajectories may be seen in Table 2-2 and Table 2-3. Vehicle trajectories and speeds are summarized in Table 2-4.

Table 2-2 - Test 571 Assessment Summary

Test No. 571
 Date August 30, 2000
 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, underride, 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>Only moderate amounts of scraping and gouging were created during impact. There was no significant debris from the vehicle.</p> <p>The amount of floorboard deformation was acceptable.</p> <p>There was moderate occupant compartment deformation.</p> <p>The observed levels of roll, pitch, and yaw were deemed acceptable.</p>	<p>pass</p> <p>pass</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>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.</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>Long. Occ. Impact Vel. = 4.64 m/s</p> <p>Long. Occ. Ridedown = -5.66 g</p> <p>Exit angle = 6°, 24% of the impact angle.</p>	<p>pass</p> <p>pass</p> <p>pass</p>

Table 2-3 - Test 572 Assessment Summary

Test No. 572
 Date September 13, 2000
 Test agency California Dept. of Transportation

Evaluation Criteria	Test Results	Assessment
Structural Adequacy A. Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the article is acceptable	The vehicle was contained and smoothly redirected	pass
Occupant Risk D. Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformation of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted. G. It is preferable, although not essential, that the vehicle remain upright during and after collision.	There was not any significant debris from the test article and negligible deformation of the occupant compartment. The vehicle remained upright	pass pass
Vehicle Trajectory K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes 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 Exit angle = 2°, 13% of the impact angle.	pass pass

Table 2-4 - Vehicle Trajectories and Speeds

Test Number	Impact Angle (deg)	60% of Impact Angle (deg)	Exit Angle (deg)	Impact Speed, V _i (km/h)	Exit Speed, V _e (km/h)	Speed Change V _i - V _e (km/h)
571	25.0	15	6	98.2	81.5	17
572	15.0	9	2	82.6	76	7

3. CONCLUSION

Based on the testing of the Type 732S discussed in this report, the following conclusions can be drawn:

1. The Type 732S 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. This deformation was judged to be insufficient to cause serious injury to vehicle occupants.
2. The Type 732S can successfully contain and redirect an 8000-kg, single unit, van-bodied truck impacting at 15° and 80 km/h.
3. Damage to the Type 732S in accidents similar to the tests conducted for this project will result in small to moderate amounts of scraping and gouging 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.”
4. The Type 732S 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 4 for longitudinal barriers.

In Test 571 (pickup truck) all of the barrier structural adequacy, occupant risk, and vehicle trajectory criteria, as outlined in NCHRP Report 350, were within acceptable limits. The exit angle was small enough that the vehicle would not impose undue risks to other motorists. No debris was scattered in such a way that it would create hazards to other motorists. The vehicle was safely contained and redirected by the barrier and it remained upright throughout the test.

In Test 572 (large truck) all of the barrier structural adequacy and vehicle trajectory criteria, as outlined in NCHRP Report 350, were within acceptable limits. None of the detached pieces of the vehicle penetrated or even showed the possibility of penetrating the passenger compartment of the test vehicle.

None of the damage done to the barrier during Tests 571 and 572 would pose safety concerns for other vehicles which may impact the same location before repairs could be accomplished by maintenance crews.

4. RECOMMENDATION

The Type 732S is recommended for use as new or retrofit bridge railing on high-speed highways as test level 4.

Vehicle behavior observed during these two tests demonstrated the ability of this barrier to provide pedestrian protection on the outside of the barrier 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”⁽⁶⁾ and Article G2.7 of the 1989 AASHTO “Guide Specification for Bridge Railings”⁽²⁾ clearly specify that a pedestrian sidewalk needs to be separated from traffic for high-speed applications (45 mi/h or greater). The Type 732S meets this requirement.

5. IMPLEMENTATION

The Office of Structures Design will be responsible for the preparation of standard plans and specifications for the Type 732S, with technical support from Materials Engineering and Testing Services and the Traffic Operations Program.

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. “Guide Specifications For Bridge Railings”, American Association of State Highway and Transportation Officials, 1989.
3. Jewell, John, et al., "Vehicle Crash Tests of Type 70 Bridge Rail", California Department of Transportation, Report No. FHWA/CA/ESC-98/06, January 1998.
4. “Vehicle Damage Scale for Traffic Accident Investigators”, Traffic Accident Data Project, National Safety Council, 1968.
5. “Collision Deformation Classification” - SAE J224 MAR80, SAE Recommended Practices, 1980.
6. “Development of a Comprehensive Bridge Specification and Commentary” – Section 13, National Cooperative Highway Research Program Project 12-33, 1993.

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 CO₂ added in order to purge fuel vapors.
- One pair of 12-volt wet cell motorcycle storage batteries was mounted in the vehicle. The batteries operated the solenoid-valve braking/accelerator system, rate gyros, and the electronic control box. A second 12-volt deep cycle gel cell battery powered the transient data recorder.
- A 4800-kPa CO₂ system, actuated by a solenoid valve, controlled remote braking after impact and emergency braking if necessary. Part of this system was a pneumatic ram that 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 via a radio link transmitter at a console trailer. When the brakes were applied by remote control from the console trailer, the ignition was automatically rendered inoperable by removing power to the coil.
- For tests 571 and 572, an accelerator switch was located on the rear of the vehicle. The switch opened an electric solenoid which, in turn, released compressed CO₂ from a reservoir into a pneumatic ram that had been attached to the accelerator pedal. The CO₂ pressure for the accelerator ram was regulated to the same pressure of the remote braking system with a valve to adjust CO₂ flow rate.
- For tests 571 and 572, 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.
- For tests 571 and 572, 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.

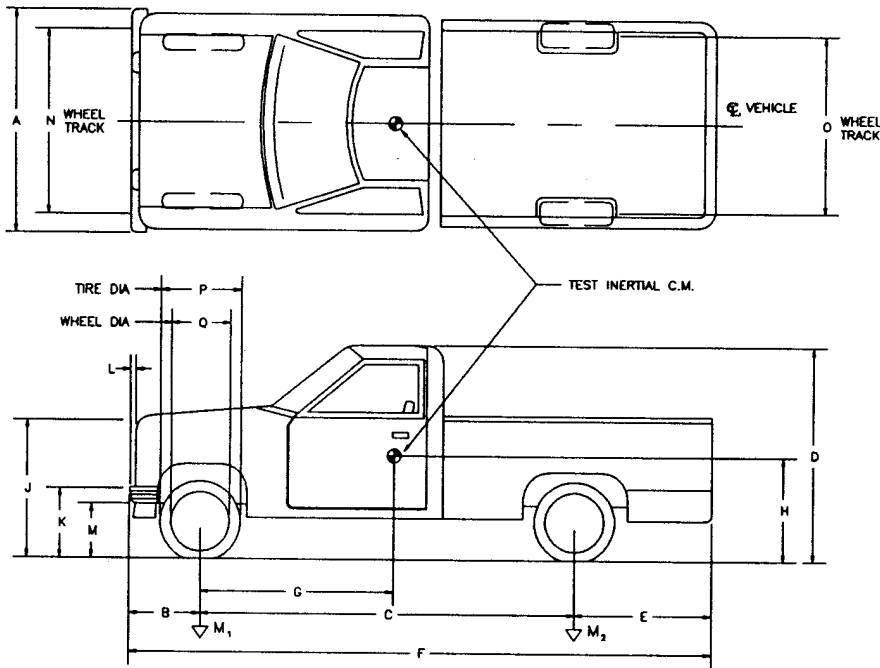
Table 7-1 and Table 7-2 give specific information regarding vehicle dimensions and weights for Test 571 and Test 572 respectively.

Table 7-1 - Test 571 Vehicle Dimensions

DATE: 2/8/00 TEST NO: 571 VIN NO: 1GCGC24N0NE121757 MAKE: CHEVROLET
 MODEL: 2500 YEAR: 1992 ODOMETER: 163929 (MI) TIRE SIZE: L 245 175R16
 TIRE INFLATION PRESSURE: 60 (PSI)

MASS DISTRIBUTION (kg) LF 609.5 RF 646.5 LR 476.5 RR 457.0

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST: Rear Bumper has small dents on face on both sides. Tailgate has small ding on top center.



ENGINE TYPE: Gas V8

ENGINE CID: 454

TRANSMISSION TYPE :

AUTO

MANUAL

OPTIONAL EQUIPMENT:

Air Conditioning

DUMMY DATA:

TYPE: NA

MASS: NA

SEAT POSITION: NA

GEOMETRY (cm)

A	<u>188.0</u>	D	<u>183.0</u>	G	<u>143.5</u>	K	<u>65.5</u>	N	<u>160.0</u>	Q	<u>44.5</u>
B	<u>91.0</u>	E	<u>136.0</u>	H	<u> </u>	L	<u>7.3</u>	O	<u>166.5</u>		
C	<u>335.5</u>	F	<u>544.0</u>	J	<u>107.0</u>	M	<u>43.8</u>	P	<u>75.0</u>		

MASS - (kg)	<u>CURB</u>	<u>TEST INERTIAL</u>	<u>GROSS STATIC</u>
M1	<u>1256.0</u>	<u>1257.0</u>	<u>1257.0</u>
M2	<u>933.5</u>	<u>939.0</u>	<u>939.0</u>
MT	<u>2189.5</u>	<u>2196.0</u>	<u>2196.0</u>

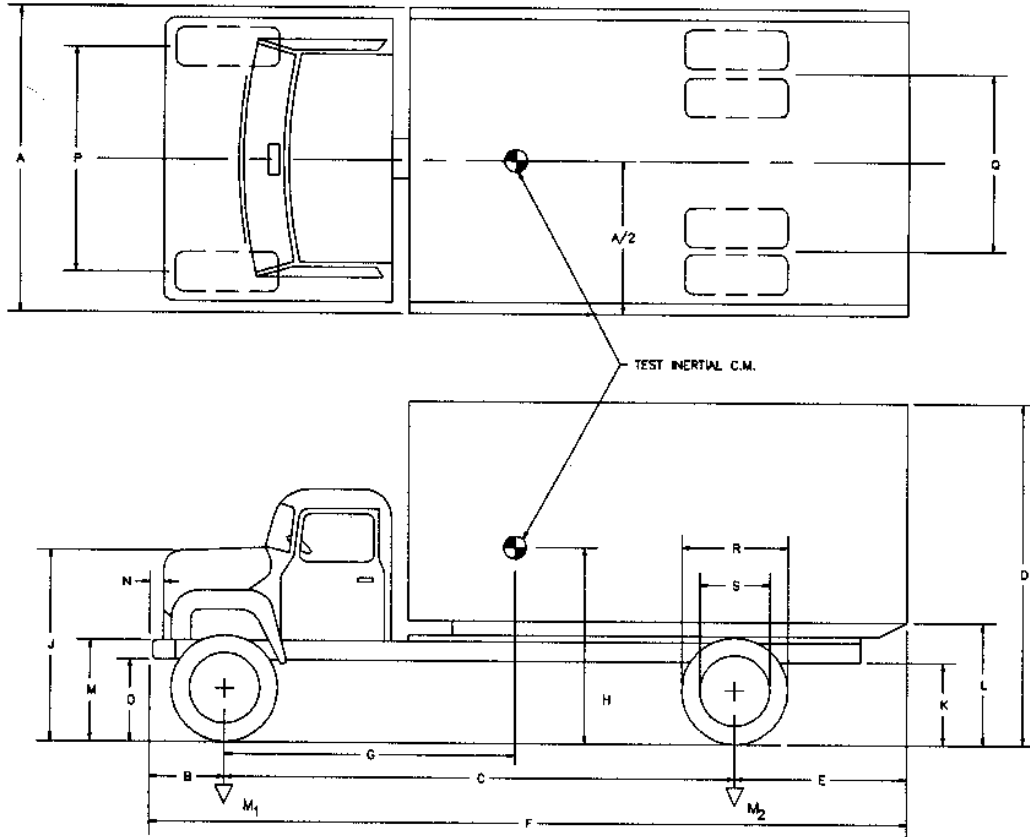
Table 7-2 - Test 572 Vehicle Dimensions

DATE: 9/7/00 TEST NO: 572 VIN NO: 1GDJ7H1P0NJ516558 MAKE: GMC

MODEL: TOP KICK YEAR: 1992 ODOMETER: 88861 (MI) TIRE SIZE: 11R22.5

MASS DISTRIBUTION (kg) LF _____ RF _____ LR _____ RR _____

DESCRIBE ANY DAMAGE TO VEHICLE PRIOR TO TEST: None



GEOMETRY (cm)

A	243.5	D	334.0	G	_____	K	47.5	N	_____	Q	182.5
B	84.0	E	230.0	H	_____	L	107.5	O	58.0	R	103.5
C	533.5	F	837.5	J	177.0	M	95.0	P	201.5	S	59.3

MASS - (kg)	<u>CURB</u>	<u>TEST INERTIAL</u>	<u>GROSS STATIC</u>
M1	2168	2749	2749
M2	2894	5362	5362
MT	5062	8111	8111

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 in Table 7-3 and Figure 7-1.

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

A video camera and a 16-mm film camera were turned on by hand and used for panning during the test. Switches on a console trailer near the impact area remotely triggered all other cameras. 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.

Table 7-3 - Typical Camera Type and Locations

Typical Coordinates, m						
Camera Label	Film Size (mm)	Camera Type	Rate: (fr./sec.)	Test 571		
				X*	Y*	Z*
L1	16	LOCAM 1	400	-24.8	9.0	1.2
L2	16	LOCAM 2	400	0.0	0.0	9.1
L3	16	LOCAM 3	400	31.6	0.0	1.2
L4	16	LOCAM 4	400	-0.457	0.0	9.1
L5	16	LOCAM 5	400	-46.1	-0.838	2.4
L6	16	LOCAM 6	400	0.457	0.0	9.1
L8	16	LOCAM 8	400	-1.2	-24.2	1.7
V	1.27	SONY BETACAM	30	-2.3	-27.0	1.7
H	35	HULCHER	40	-46.3	-0.254	2.4

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.

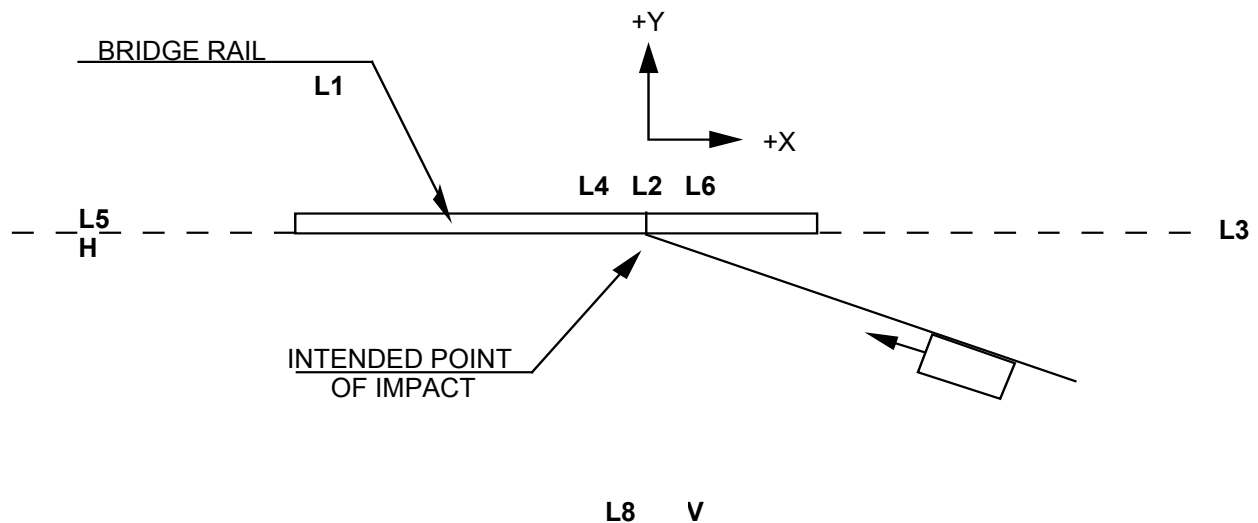


Figure 7-1 - Camera Locations

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 meter.

2) Flashbulbs, mounted on the test vehicle, were electronically triggered to establish 1) initial vehicle-to-barrier contact, and 2) the time of the application of the vehicle brakes. The impact flashbulbs begin to glow immediately upon activation, but have a delay of several milliseconds before lighting up to full intensity.

3) Five tape switches, placed at 4 m intervals, were attached to the ground near the barrier and were perpendicular to the path of the test vehicle. Flash bulbs were activated sequentially when the tires of the test vehicle rolled over the tape switches. The flashbulb stand was placed in view of most of the cameras. The flashing bulbs were used to correlate the cameras with the impact events and to calculate the impact speed independent of the electronic speed trap. The tape switch layout is shown in Figure 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.

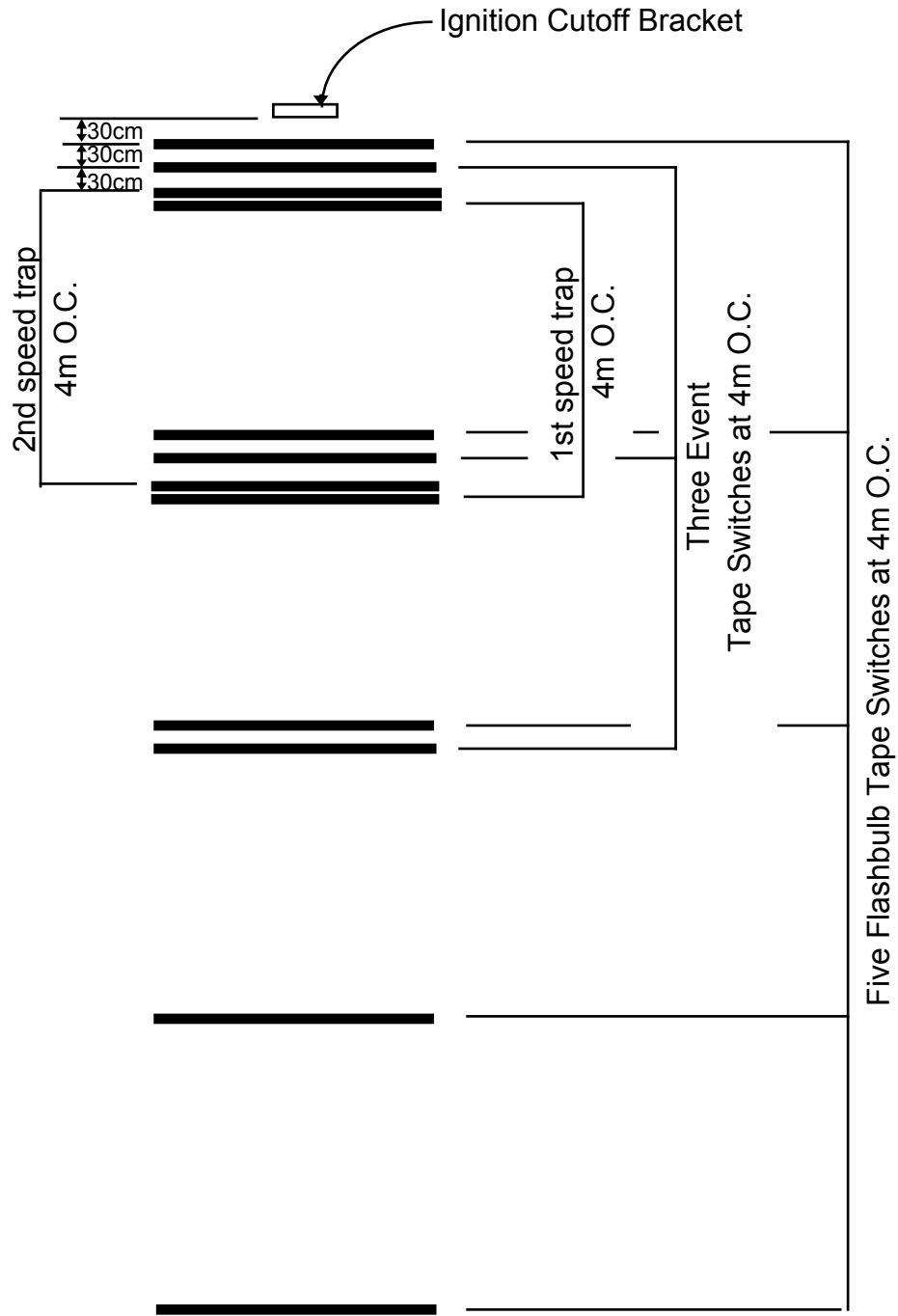


Figure 7-2 - Tape Switch Layout

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 for Test 571. 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.

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

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 7-7 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 572 because NCHRP Report 350 does not require accelerometer data for the 8000S test series.

Table 7-4 - 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

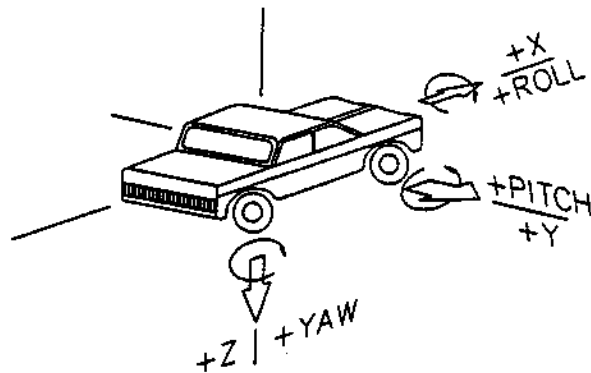


Figure 7-3 - Vehicle Accelerometer Sign Convention

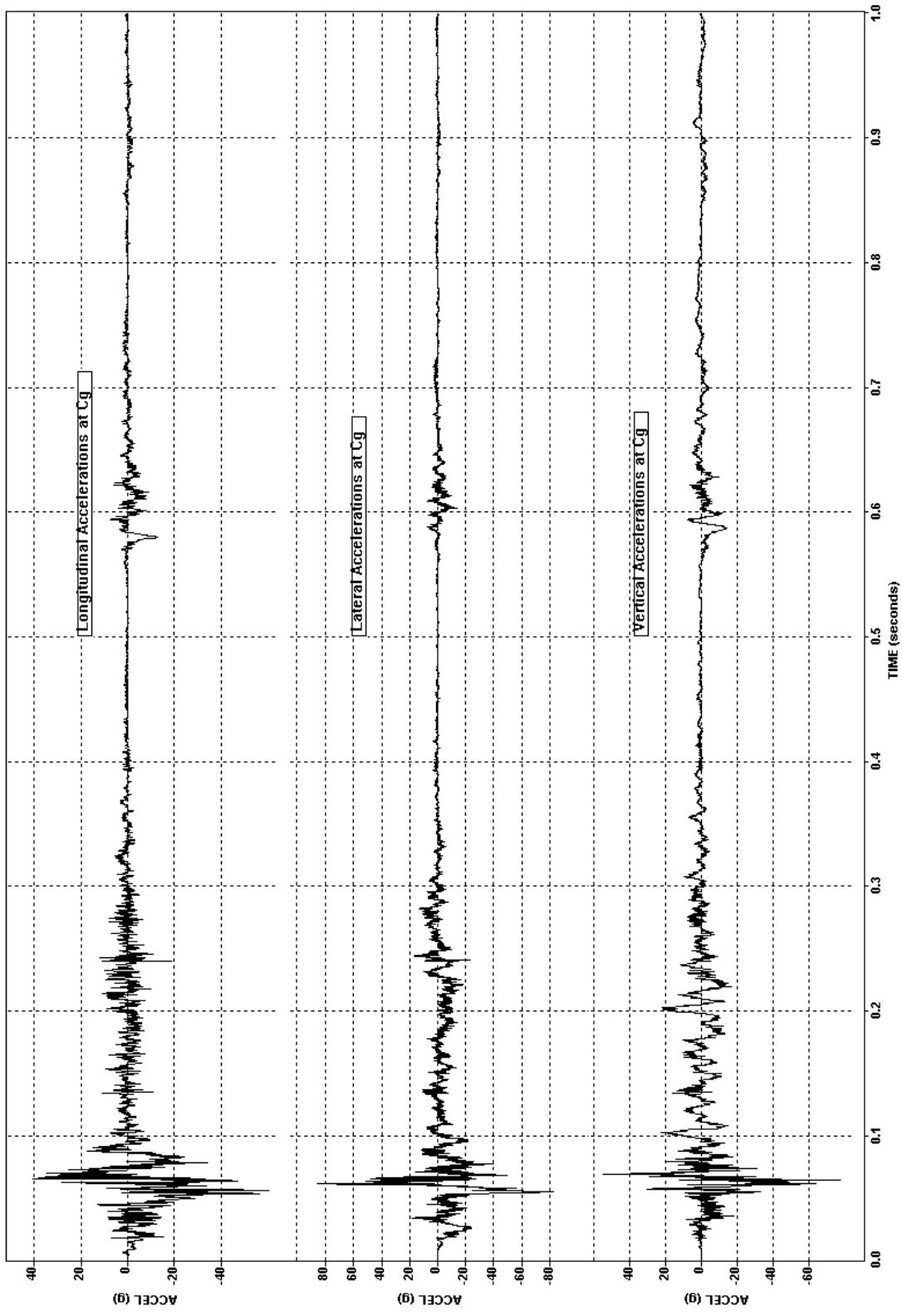


Figure 7-4 - Test 571 Vehicle Accelerations Vs Time

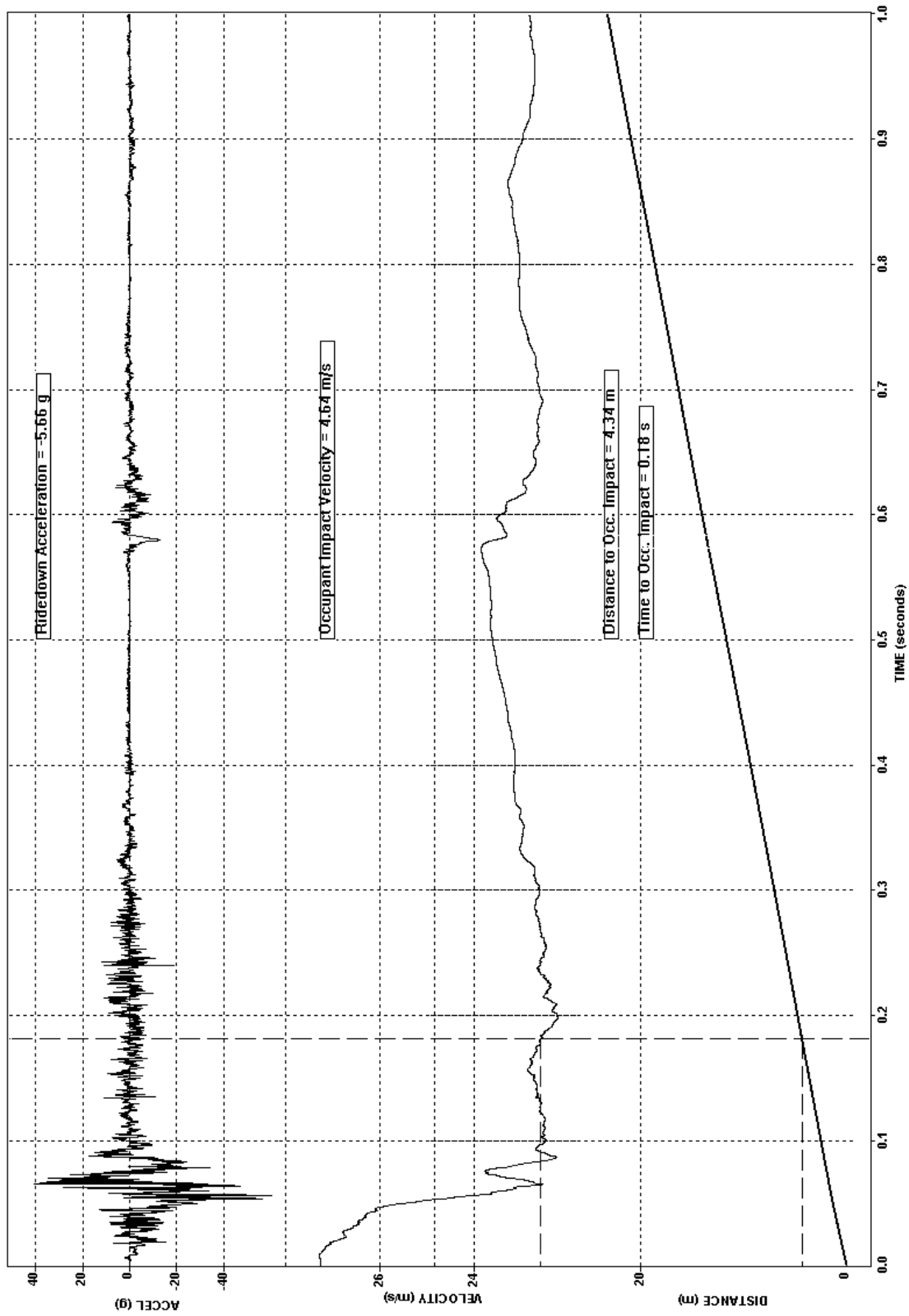


Figure 7-5 - Test 571 Vehicle Longitudinal Acceleration, Velocity, and Distance Vs Time

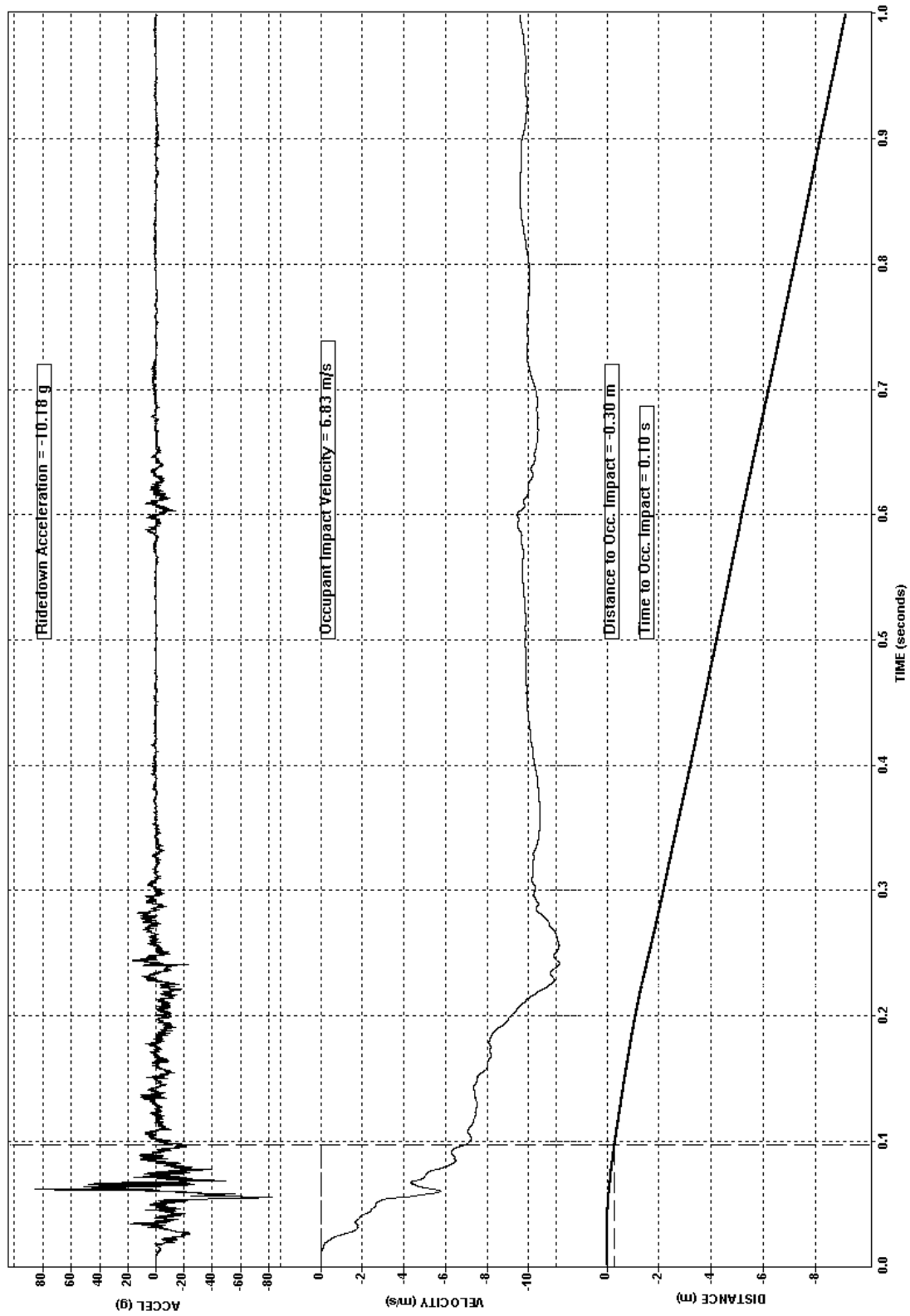


Figure 7-6 - Test 571 Vehicle Lateral Acceleration, Velocity, and Distance Vs Time

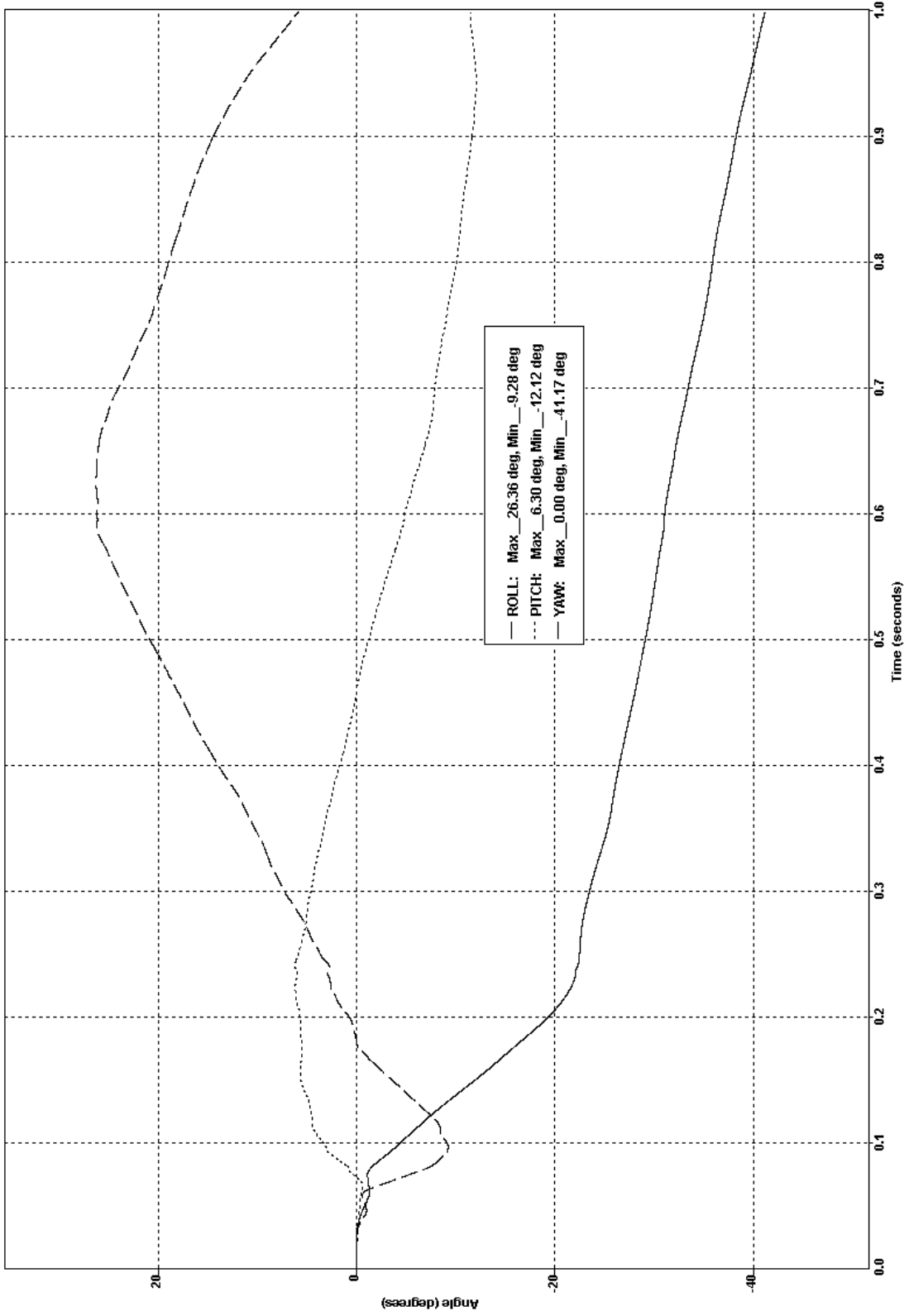


Figure 7-7 - Test 571 Vehicle Roll, Pitch, and Yaw Vs Time

7.5. Detailed Drawings

The following two pages are “as built” construction drawings of the Type 732S and were produced by the designers at T. Y. Lin International. Please contact Caltrans, Structures Design for the most current and complete plans.

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Telephone: 916-227-8805

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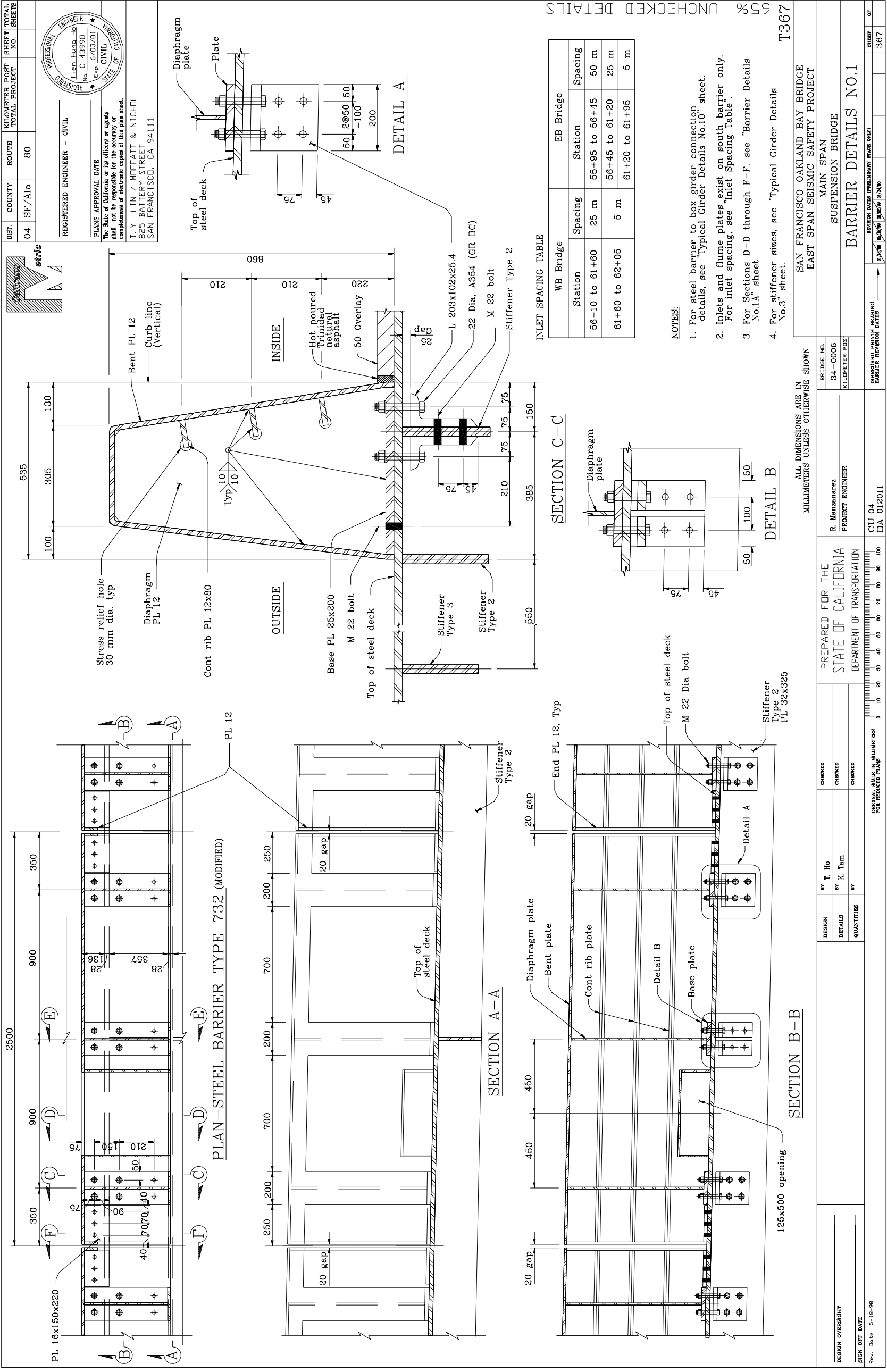
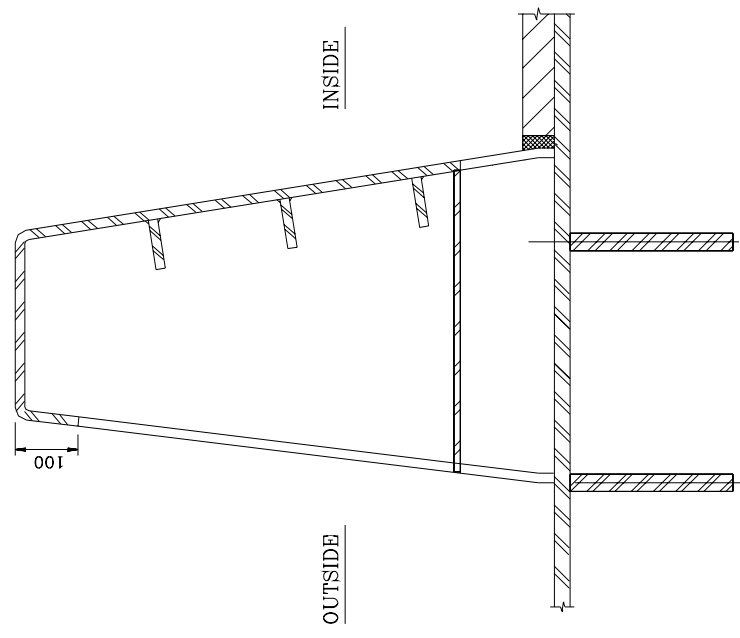
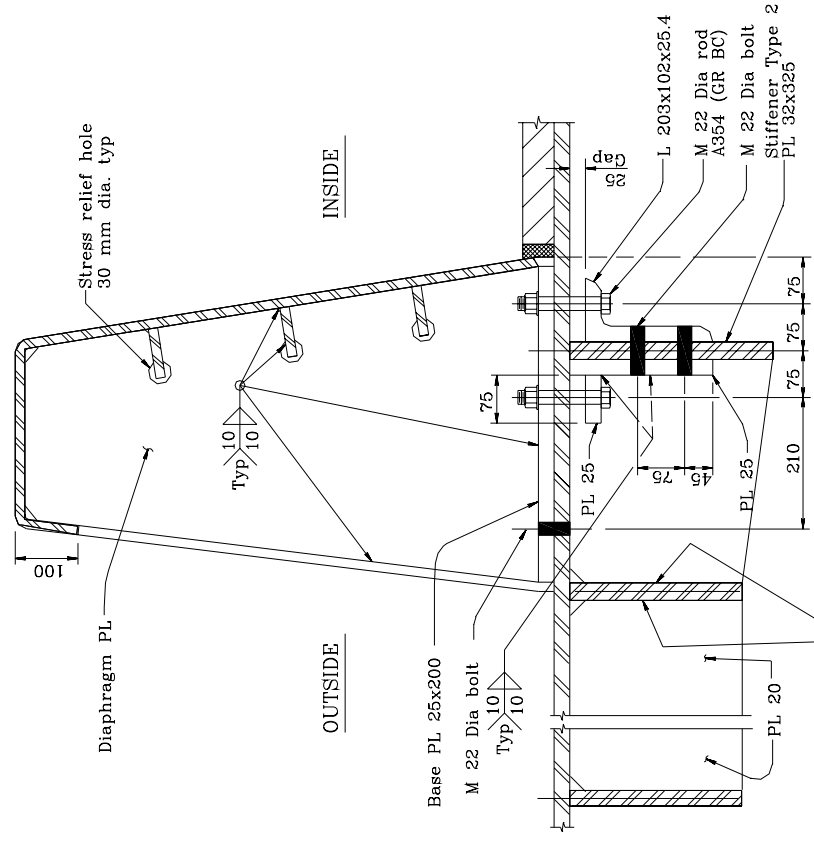


Figure 7-8 - As built drawing for the Type 732S

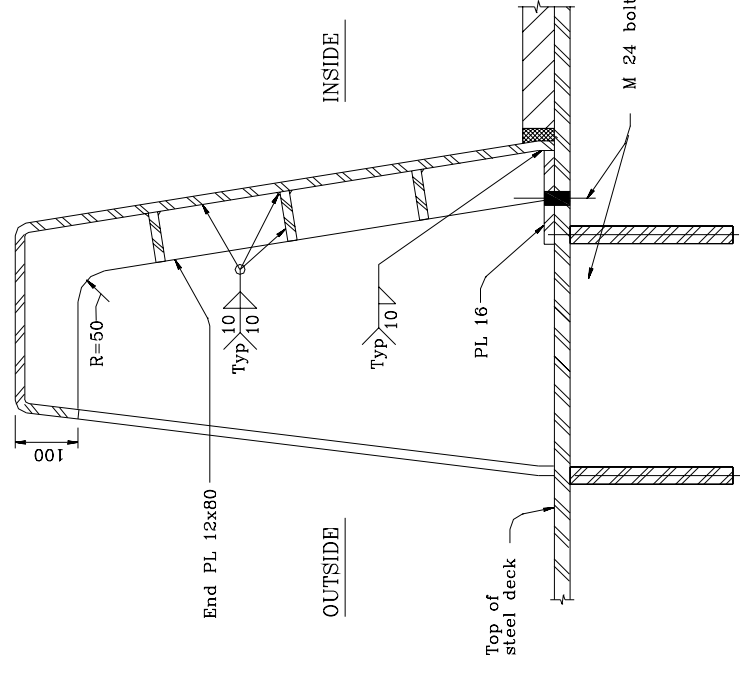
DIST. 04	COUNTY SF/Ala	ROUTE 80	KILOMETER POST TOTAL PROJECT	SHEET NO.	TOTAL SHEETS
REGISTERED ENGINEER - CIVIL T.Y. LIN / MOFFATT & NICHOL 825 BATTERY STREET SAN FRANCISCO, CA 94111					
PLANS APPROVAL DATE The State of California certifies that the undersigned is duly licensed and qualified in the practice of civil engineering and that the completion of electronic copies of this plan sheet.					
T.Y. LIN / MOFFATT & NICHOL 825 BATTERY STREET SAN FRANCISCO, CA 94111					



SECTION D-D



SECTION E-E



SECTION F-F

NOTES:

1. For steel barrier to box girder connection details, see "Typical Girder Details No.9" sheet.
2. Inlets and flume plates exist on south barrier only. For inlet spacing, see "Inlet Spacing Table" No.1" sheet.
3. For typical Barrier dimensions, see "Barrier Details No.3" sheet.
4. For stiffener sizes, see "Typical Girder Details No.3" sheet.

T367A

UNCHECKED DETAILS

DESIGN OVERSIGHT		PREPARED FOR THE STATE OF CALIFORNIA DEPARTMENT OF TRANSPORTATION		BRIDGE NO. 34-0006		KILMETER POST		SAN FRANCISCO OAKLAND BAY BRIDGE EAST SPAN SEISMIC SAFETY PROJECT	
DESIGN BY T. Ho	CHECKED	PROJECT ENGINEER R. Manzanarez	MAIN SPAN		KILMETER POST		BARRIER DETAILS NO.1A		
DETAILS BY K. Tam	CHECKED	PROJECT ENGINEER		KILMETER POST		REVISION DATE (PRECEDENCE FROM LEFT)			
QUANTITIES BY	CHECKED	PROJECT ENGINEER		KILMETER POST		REVISION DATE			
SIGN OFF DATE	Rev. Date 5-18-98	CU 04		EA 012011		REVISION DATE			
ORIGINAL SCALE IN MILLIMETERS FOR REDUCED PLANS		0 10 20 30 40 50 60 70 80 90 100		DISREGARD PRINTS BEARING EARLIER REVISION DATES		367A			

Figure 7-9 – As built cross section and attachment detail for the Type 732S