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SD Department of Transportation
Office of Research

Crash Testing of Standard South Dakota Road Closure Gates

Study SD94-10
Final Report

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16. Abstract

Two full-scale vehicle crash tests were performed on South Dakota's Standard Road Closure Gate. Test SDG-1 was conducted with a 1986 Chevrolet Sprint weighing 794 kg (1751 lbs) at an impact speed of 37.1 km/h (23.1 mph) and an angle of 0 degrees. The center line of the vehicle impacted the upstream end and center line of the gate. Test SDG-2 was conducted with the same vehicle at an impact speed of 95.5 km/h (59.4 mph) and an angle of 0 degrees. The quarter point of the vehicle impacted the upstream end and center line of the gate.

The tests were conducted and reported in accordance with the requirements specified in the *Recommended Procedures for the Safety Performance Evaluation of Highway Features*, National Cooperative Research Program (NCHRP) Report No. 350 and the American Association of State Highway and Transportation Officials (AASHTO), 1985 *Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals*. The safety performance evaluation of the road closure gate was determined to be acceptable according to these criteria for support structures.

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1 INTRODUCTION

1.1 Problem Statement

The South Dakota Department of Transportation (SDDOT) currently uses road closure gates for access control at several interchanges. These road closure gates have been installed for the purpose of preventing motorists from accessing and traveling on the state trunk highway system during severe weather conditions and hazardous roadway situations. When not in use, the road closure gates are oriented in a stowed or open position parallel to and along the side of the roadway. When in use, the road closure gates are placed in a closed position with the gate projecting across the roadway, perpendicular to the direction of travel.

Recently, there have been safety concerns regarding the use of these access control devices. The Federal Highway Administration (South Dakota Division Office) has requested that these access control devices be evaluated in order to determine if they are crash worthy when impacted by an errant vehicle.

1.2 Objective

The objective of this research study was to evaluate the safety performance of the SDDOT road closure gates according to the evaluation criteria set forth in the National Cooperative Highway Research Program Report No. 350, *Recommended Procedures for the Safety Performance Evaluation of Highway Features* (1) and the American Association of State Highway and Transportation Officials (AASHTO), *Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals,*(2).

1.3 Scope

The research objective was achieved by performing a literature search on the crash testing of existing road closure gates and a design review of the current road closure gate assembly. Compliance testing was then conducted using an 820 kg (1,808 lb) mini-compact impacting at speeds of 35 km/h (21.7 mph) and 100 km/h (62.1 mph) and an angle of 0 degrees (NCHRP 350 Test Nos. 3-60 and 3-61). The low-speed test rather than the high-speed test was performed first in order to minimize vehicle damage and repair costs. Finally, the test results were analyzed, evaluated, documented, and conclusions were formed regarding the safety and use of the SDDOT standard road closure gates.

The full-scale vehicle crash tests were conducted on the road closure gates in the stowed position rather than the closed position because it was determined that it would result in the most severe impact condition. This was reasonable, since the vehicle would be required to break both the gate support post and the hold back post. In addition, the entire mass of the gate assembly would be impacted and concentrated on the front of the vehicle. SDDOT reasoned that vehicle impacts into road closure gates in the closed position rather than the stowed position would not be as likely to occur due to the significant increase in delineation and subsequent lower driving speeds.

1.4 Background

A preliminary investigation has revealed that very little research has been performed on the testing and evaluation of road closure gates. One research project, conducted by the Texas Transportation Institute (TTI) (3), evaluated a single-arm road closure gate using a luminaire pole as the support post. The luminaire pole was attached to the ground using a 4-bolt slipbase breakaway device. Originally, the road closure gate did not meet the safety performance criteria found in NCHRP Report No. 350. Following a redesign, the road closure gate successfully met the NCHRP Report No. 350 evaluation criteria.

Another related research project, conducted at the Federal Outdoor Impact Laboratory (FOIL) (4), consisted of full-scale bogie crash tests on 16.2-m (53-ft) high, breakaway aluminum luminaire supports weighing 237 kg (523 lbs). The breakaway mechanism consisted of PrecisionForm breakaway couplers (Type PFI 200-1). Both low and high speed tests were conducted, and the results showed that the tests were acceptable according to the evaluation criteria. The criteria included vehicle change in velocity (ΔV), theoretical occupant impact velocity, and the stub height requirements of less than 10.2 cm (4 in.). These breakaway couplers were approved for use on Federal-Aid highway projects when the luminaire combinations weigh less than 363 kg (800 lbs).

2 TEST CONDITIONS

2.1 Test Facility

The Midwest Roadside Safety Facility's outdoor test site is located at the Lincoln Air-Park on the NW end of the Lincoln Municipal Airport. The test facility is approximately 8 km (5 mi) NW of the University of Nebraska-Lincoln. The site is surrounded and protected by an 2.4-m (8-ft) high chain-link security fence.

2.2 Vehicle Tow and Guidance System

A reverse cable tow system with a 1:2 mechanical advantage was used to propel the test vehicle. The distance traveled and the speed of the tow vehicle are one-half that of the test vehicle. The test vehicle was released from the tow cable before impact with the bridge rail. A fifth wheel, built by the Nucleus Corporation, was used in conjunction with a digital speedometer to increase the accuracy of the test vehicle impact speed.

A vehicle guidance system developed by Hinch (6) was used to steer the test vehicle. The guide-flag, attached to the front-left wheel and the guide cable, was sheared off before impact. The 0.95-cm (3/8-in.) diameter guide cable was tensioned to approximately 13.3 kN (3,000 lbs), and supported laterally and vertically every 30.5 m (100 ft) by hinged stanchions. The vehicle guidance cable was approximately 91.4-m (300-ft) and 243.8-m (800-ft) long for the low and high-speed tests, respectively.

2.3 Test Installation Design Details

The test installation was a mainline road closure gate. This gate is most often located on a major State Highway or Interstate as opposed to the ramp closure gate which is located at the on ramps. Ramp road closure gates have a shorter overall length. Typical locations of these gates are shown in Figure 1. The test installation consisted of several components such as the gate, gate post, breakaway support, hold back hardware, and gate attachments. Each of these components are described in the following sub-sections.

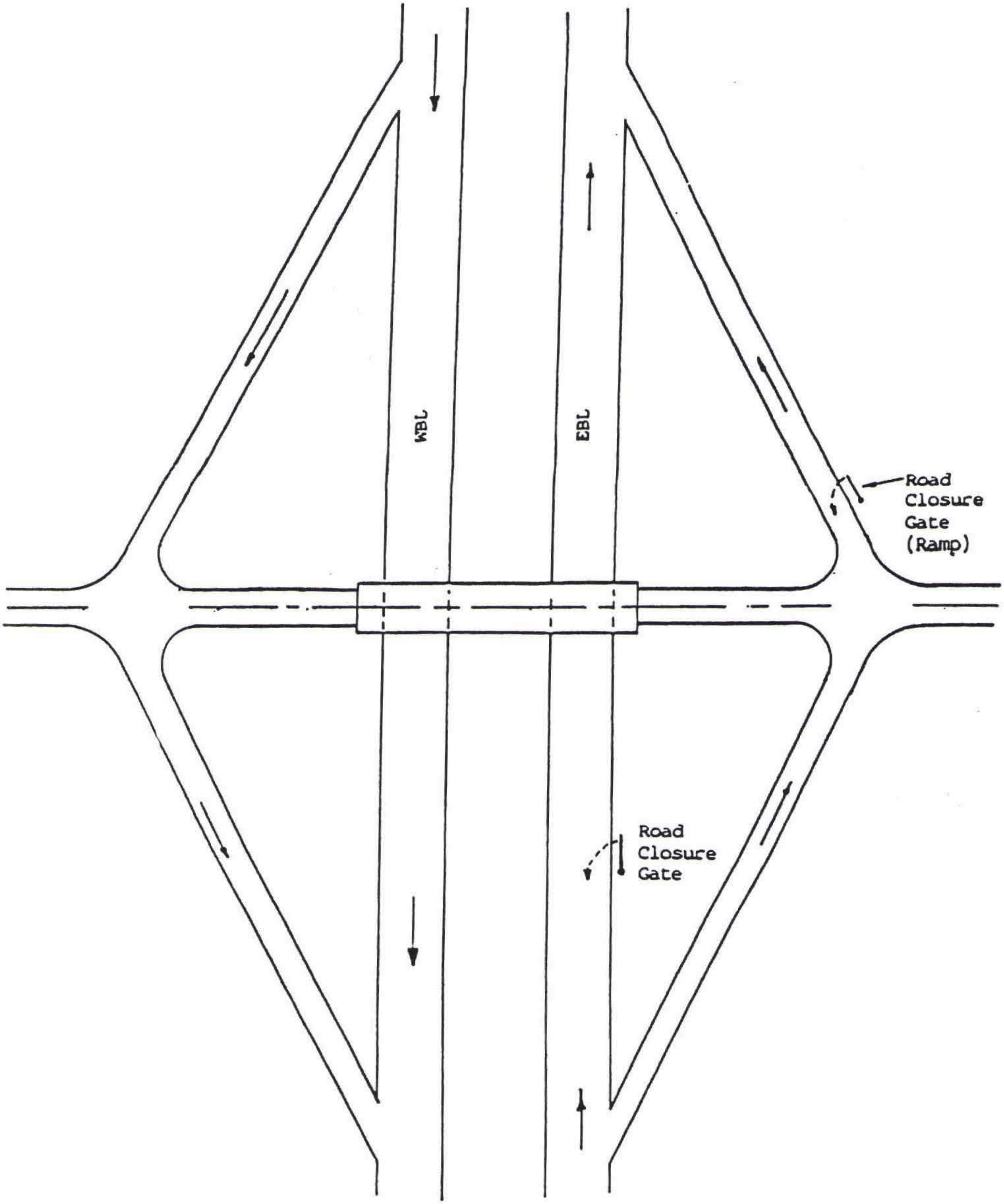


Figure 1. Typical Road Closure Gate Locations

2.3.1 Gate

The gate detail is shown in Figure 2. Photographs of the installation are shown in Figure 3. A layout of the gate in the stowed or open position is shown in Figure 4. The gate was 8.5-m (28-ft) long and 76.2-cm (30-in.) tall and was constructed of 5.1-cm (2-in.) square aluminum tubing with a minimum wall thickness of 3.2 mm (0.125 in.), welded at all the joints. The tubing layout consisted of three longitudinal members and seven vertical members. The total weight of the gate was 68 kg (150 lbs) including attachments (i.e., signs, object markers, warning lights, stands, and cables).

2.3.2 Gate Post

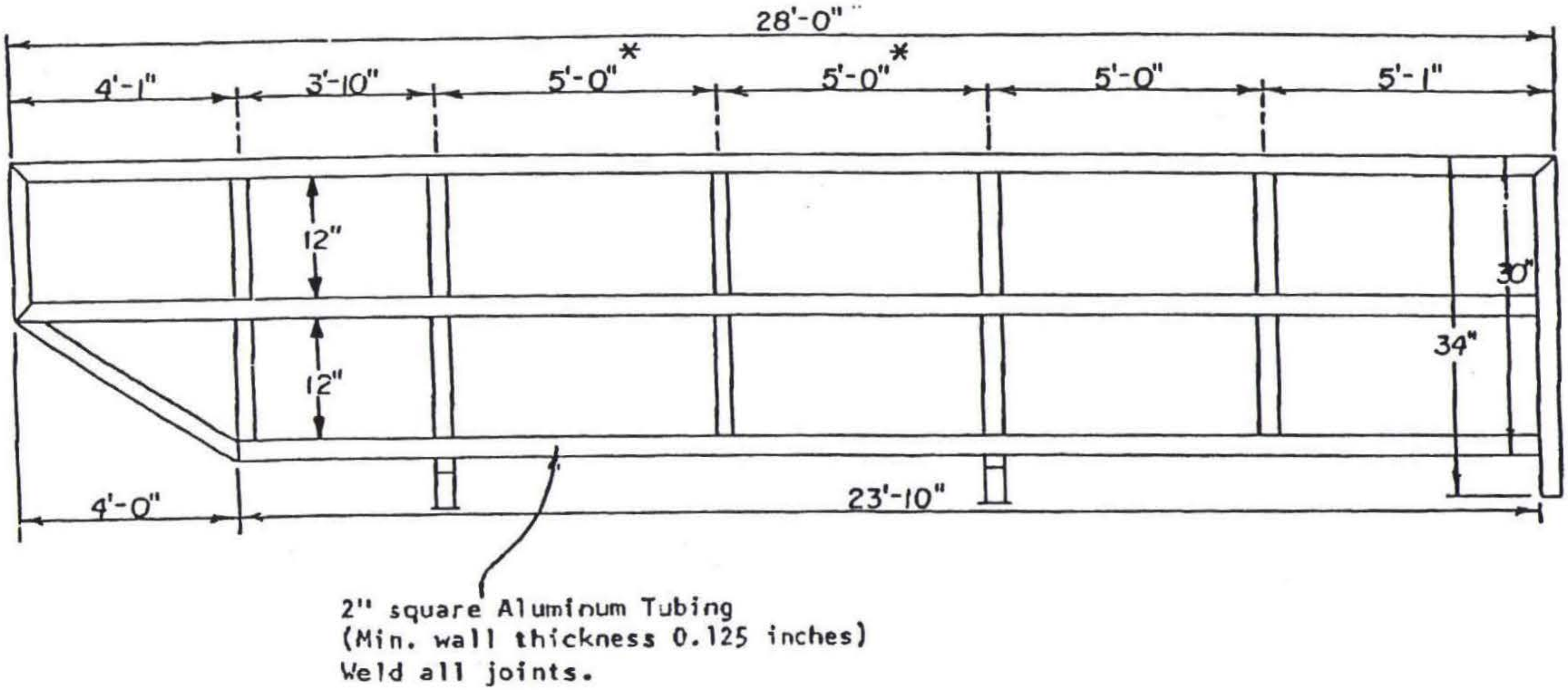
The gate was supported by the gate post, around which the gate was allowed to pivot or rotate. Details on the gate post are shown in Figure 5. The post consisted of a standard weight, 12.7-cm (5-in.) diameter ASTM A36 steel pipe. The gate post, including the base plate weighed approximately 34 kg (75 lbs). The post was 1.2-m (4-ft) long with no taper and was capped on the top end. Photographs of the gate post and base plate are shown in Figure 6. An ASTM A36 steel base plate, measuring 30.5-cm (12-in.) square x 1.9-cm (3/4-in.) thick, was welded to the base of the steel post, as shown in Figure 7.

The gate was attached to the gate post with three 1.9-cm (3/4-in.) diameter bent threaded rods as shown on the hinge detail in Figure 5. The hinge was formed by inserting each bent threaded rod into a 1.9-cm (3/4-in.) diameter pipe section which was welded to the gate post. This connection allowed the gate to be opened and closed freely and was also used for leveling the gate by tightening/loosening each of the threaded bars. In addition, the gate was supported and leveled on the level grade with two stands. The details for the stands are shown in Figure 8. The stands were located at the third and fifth vertical gate tubes downstream of the gate post, as shown in Figure 2.

2.3.3 Breakaway Support

The gate post was attached to the concrete using breakaway support couplings. commonly referred to as frangible couplers, as shown in Figure 7. The frangible couplers were Pole-Safe breakaway support couplings (Model No. 201), manufactured by Transpo Industries, Inc. The frangible couplers conformed

GATE DETAIL



* Delete 10' section for Ramp Gate

Figure 2. Road Closure Gate Detail

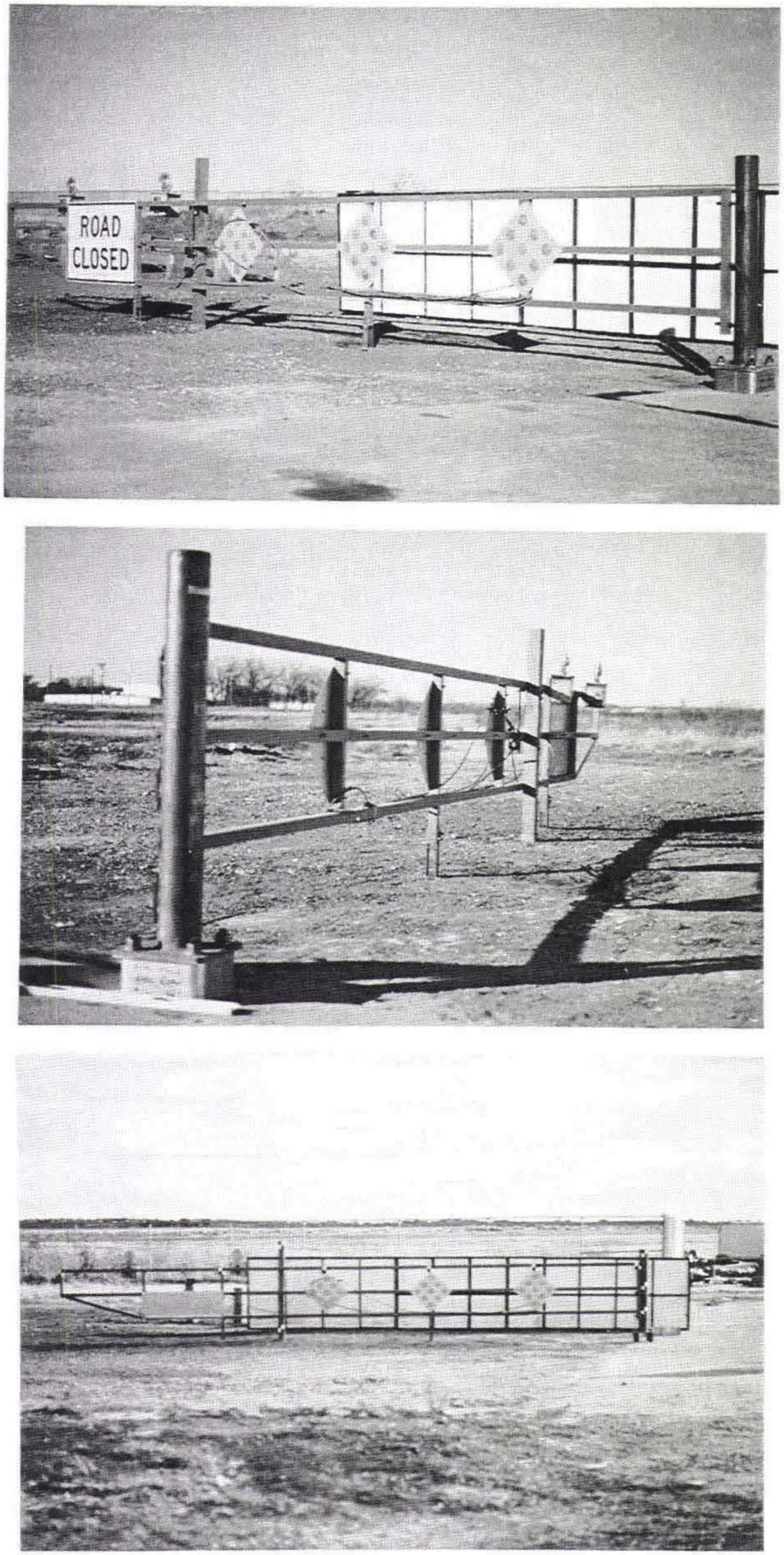


Figure 3. Road Closure Gate

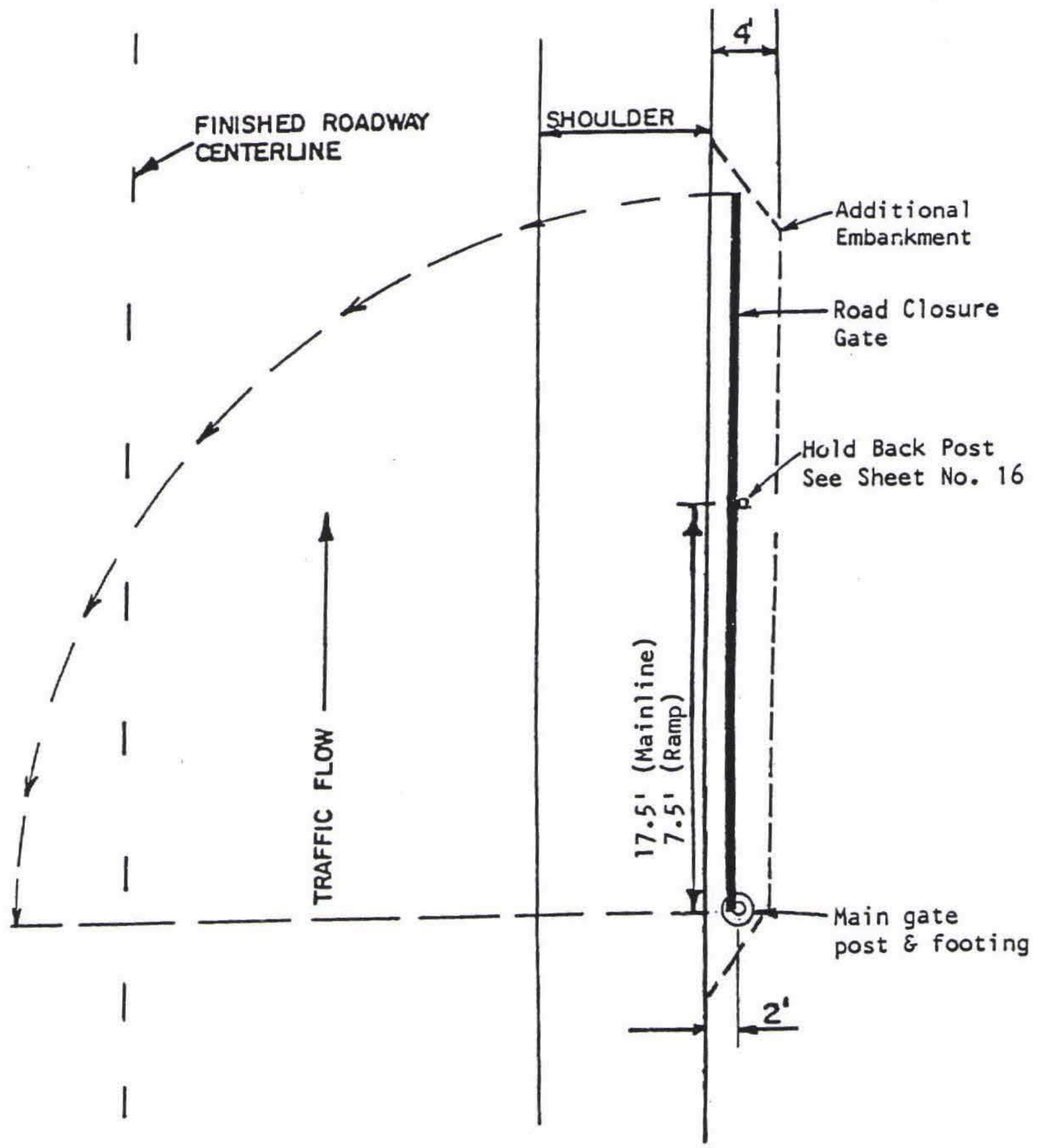


Figure 4. Plan View of Gate

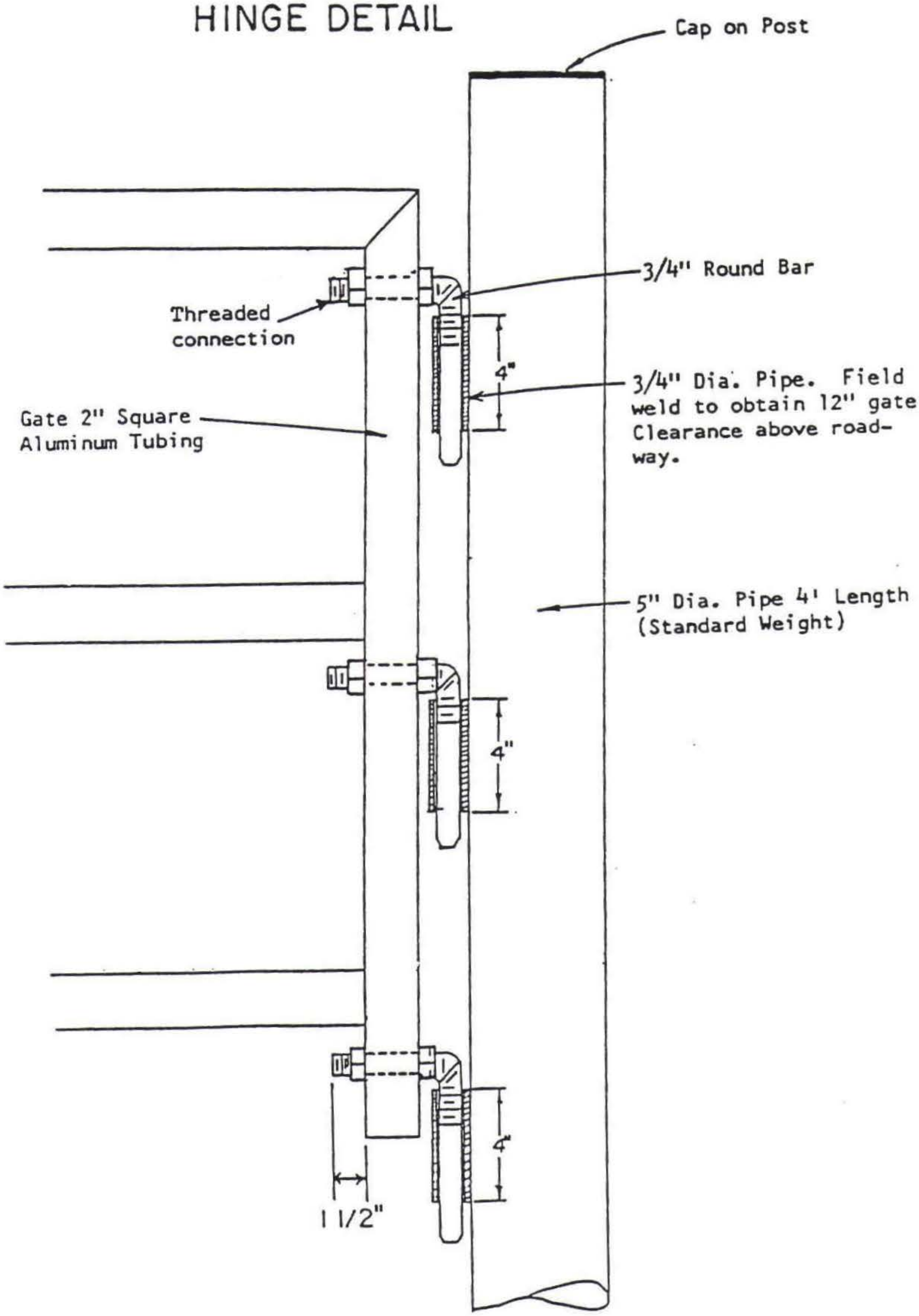


Figure 5. Hinge Detail

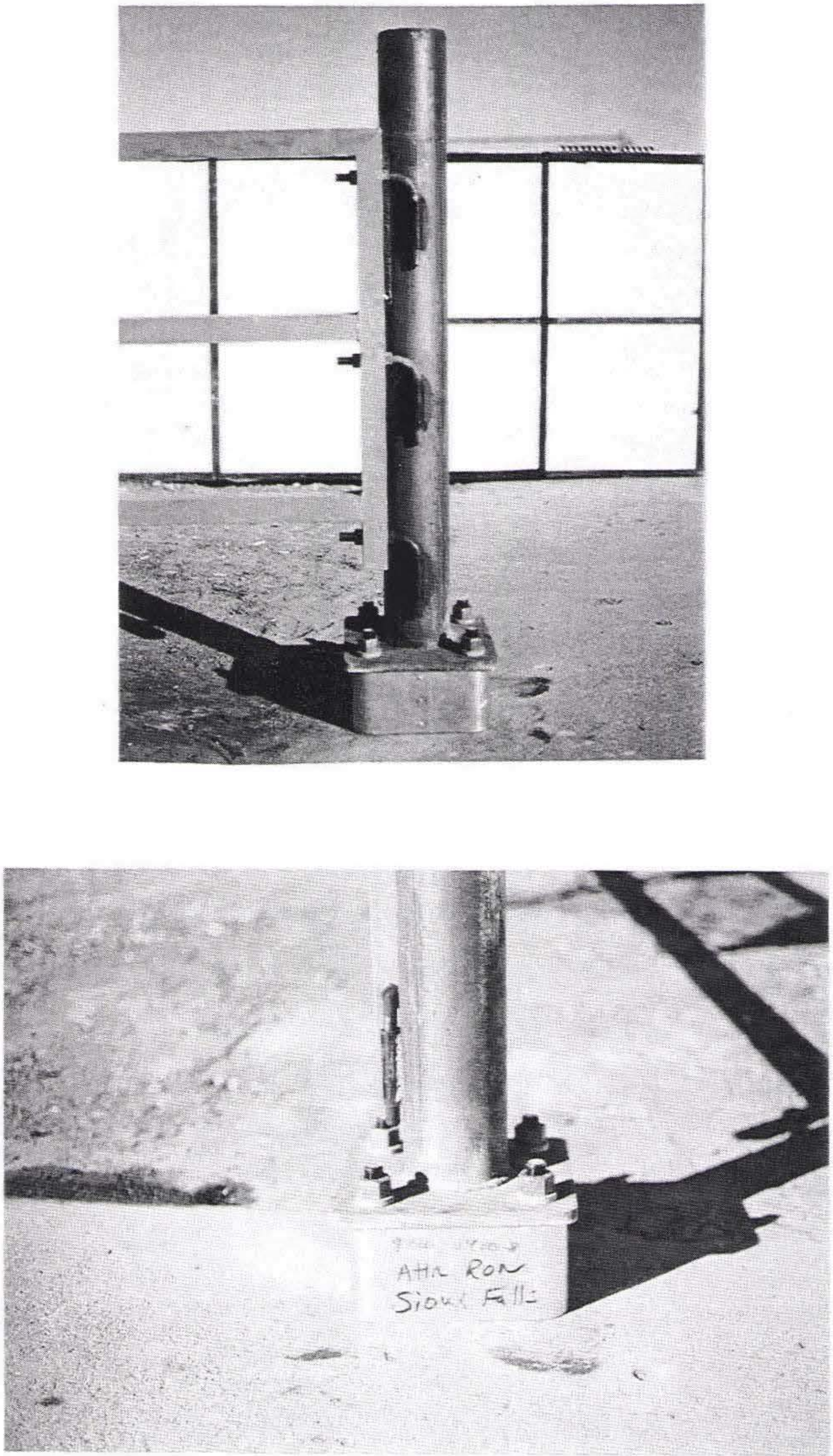


Figure 6. Gate Post and Base Plate

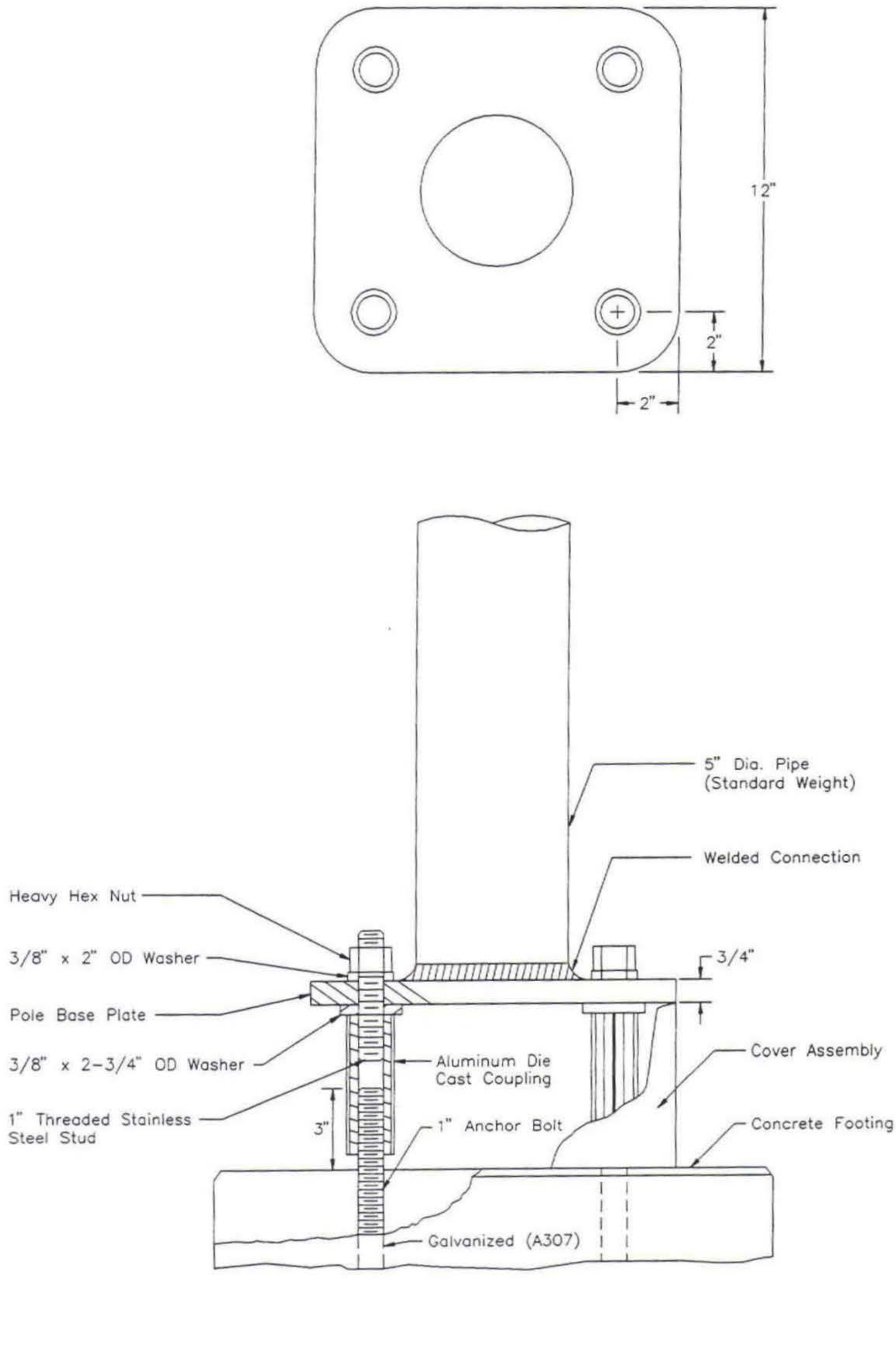


Figure 7. Breakaway Support Detail

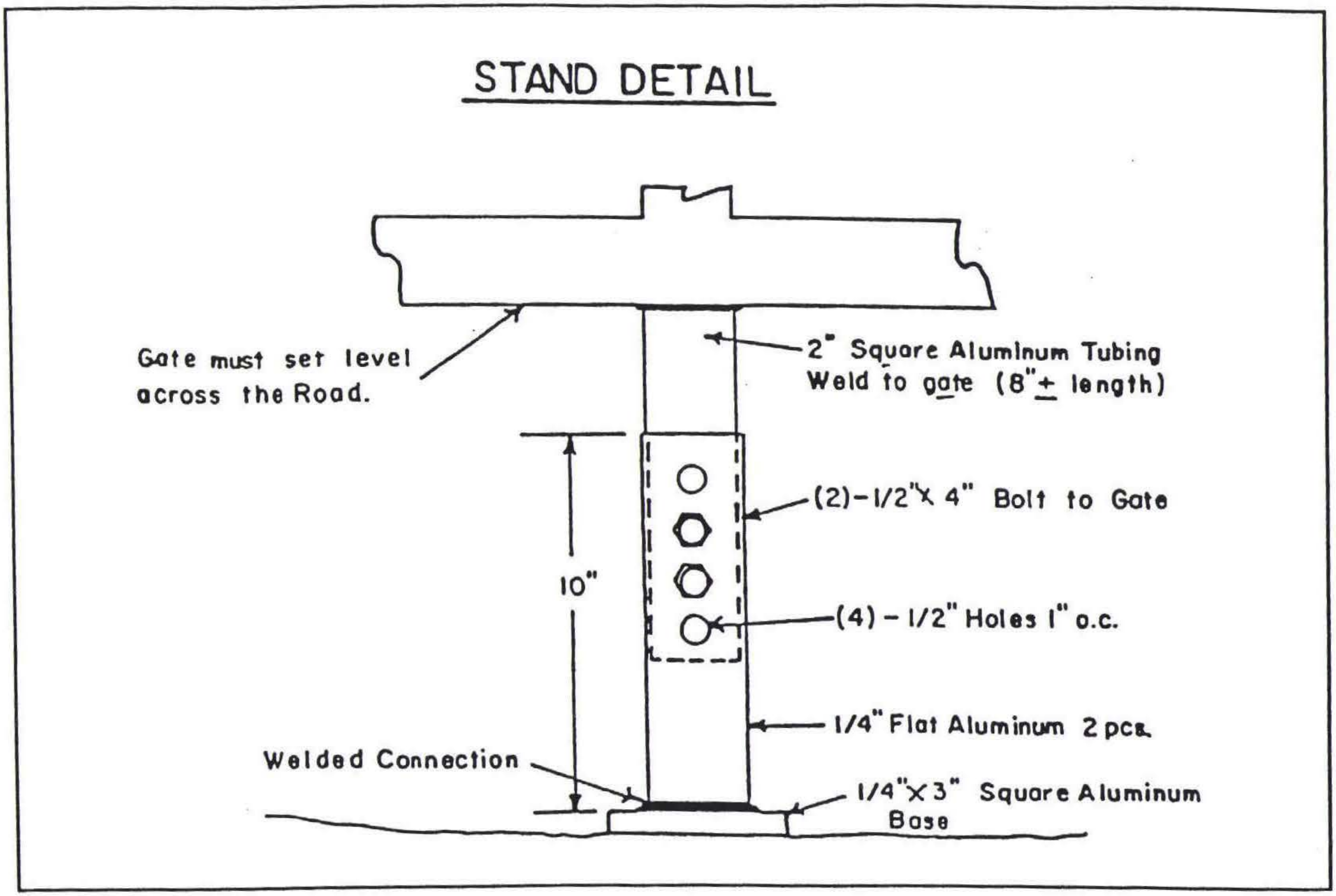


Figure 8. Stand Detail

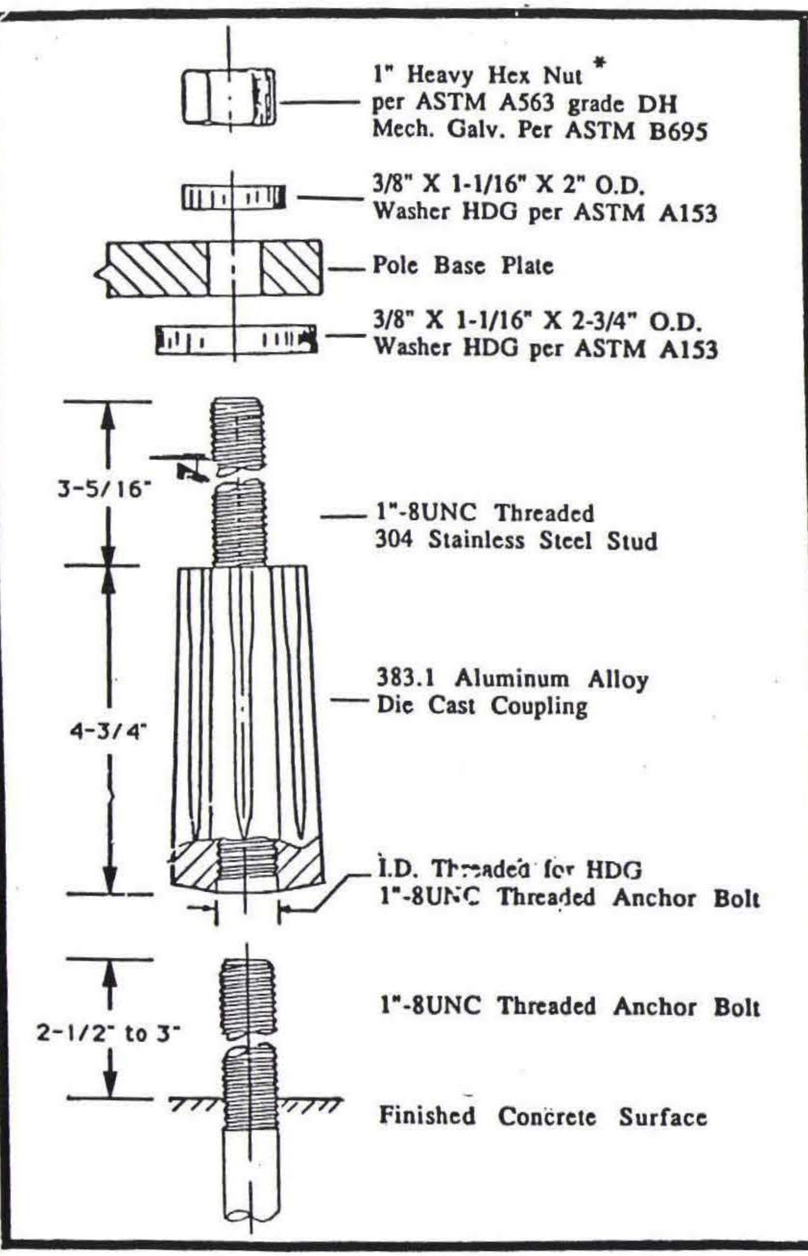
to the AASHTO 1985 standards for breakaway luminaire poles and were approved by the Federal Highway Administration (FHWA) for use on Federal-Aid projects. Specifications for the frangible couplers are shown in Figure 9.

The frangible couplers were attached to 2.54-cm (1-in.) diameter x 38.1-cm (15-in.) long ASTM A307 galvanized threaded rods embedded 30.5 cm (12 in.) into the existing 61-cm (24-in.) thick concrete apron. Each rod was set with a structural epoxy adhesive that conformed to ASTM C-881 and AASHTO M-235 specifications (Sikudar 32, Hi-Mod) (5). The total length of the rods were 38.1 cm (15 in.), providing a 7.6-cm (3-in.) stub height above the concrete surface. The thread depth of each frangible couplers was 7.0 cm (2 3/4 in.). This provided a 6.4-cm (1/4-in.) gap between the concrete and the bottom of the frangible coupler, which was used for leveling the post base plate. The overall length of the coupler was approximately 20.3 cm (8 in.).

Four 2.54-cm (1-in.) diameter 8UNC threaded 304 stainless steel studs, extending from the top of the frangible couplers, were used to attach the gate post base plate to the tops of the four frangible couplers. After placing the gate post onto the frangible couplers, the washers were installed and the heavy hex nuts were hand tightened. The post was then plumbed and squared, and the installation of the gate post was completed by tightening the heavy hex nut to the specified torque of 117.5 Nm (175 ft-lbs). Photographs of the installed frangible couplers are shown in Figure 10. The frangible couplers were covered with a sheet metal cover assembly, attached with 1.27-cm (1/2-in.) diameter sheet metal screws.

2.3.4 Hold Back Hardware

The gate was held back in the stowed position using a hold back post, as shown in Figure 11. The 10.2-cm (4-in.) square x 1.8-m (6-ft) long, wooden hold back post measured 8.9-cm (3½-in.) square actual size. The hold back post was placed in a 10.2-cm (4-in.) square x 1.5-m (5-ft) long x 0.48-cm (3/16-in.) thick galvanized, steel tube. The top of the tube extended 5.1 cm (2 in.) above the ground line, as shown in Figure 11. The post was held in the foundation tube with two 1.27-cm (1/2-in.) diameter x 5.1-cm (2-in.) long lag bolts. The gate was fastened to the hold back post with a steel strap and padlock assembly.



SPECIFICATION

Breakaway Support Couplings (longitudinally grooved) conforms to AASHTO 1985 standards for breakaway supports for light poles and are approved by FHWA for use on Federal Aid projects.

Tensile strength	24.0 kips min.
Restrained shear	3.6 kips min., 6.5 kips max.
Nut torque	175 ± 25 ft. lbs.

*Torque control nut should not be used in highly corrosive environment.

Coupling coating	*External surface:* Phosphate per Mil. Std. TTC-490 method 3 type 2, prime using cathodic epoxy electrocoat and fusion bond black nylon #11, 7-15 mil *Internal Threads:* Dry Film Lubricant per Mil-L-23398
Anchor Bolt	1"-8 UNC HDG per ASTM 153, 2-1/2" - 3" above foundation. (Supplied by others.)
Installation note:	Coupling is installed 1/8" min. to 3/8" max. off the anchor foundationand and provides for leveling. (See installation instructions).

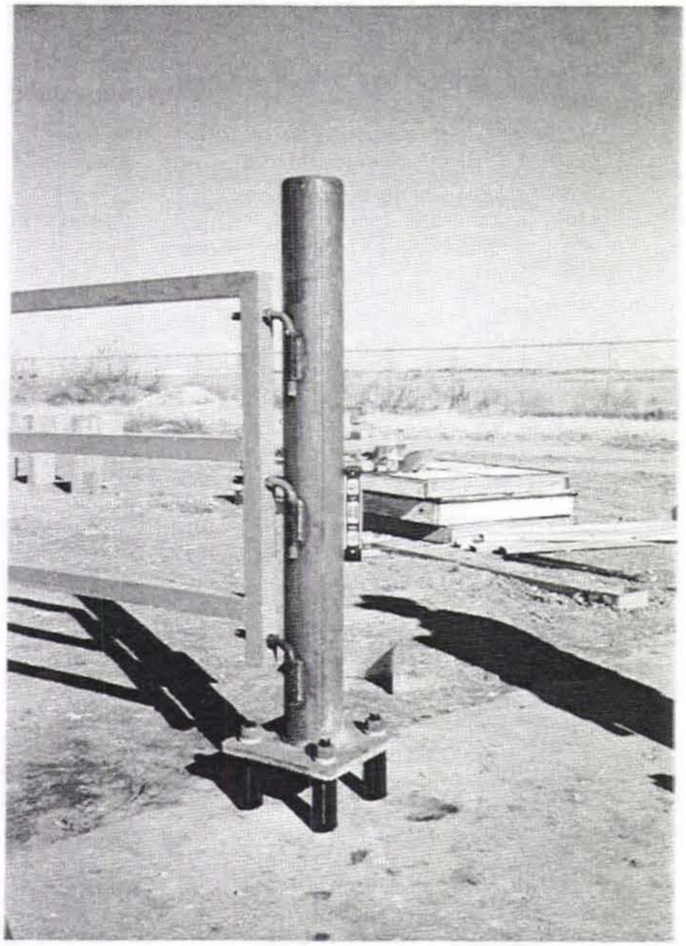
INTENDED USE

The breakaway support coupling is used with base plate equipped poles installed in locations exposed to vehicular collisions, on 1" diameter HDG anchor bolts.

BREAKAWAY SUPPORT COUPLINGS FOR LIGHT POLES
FOR USE WITH 1" DIAMETER HDG ANCHOR BOLT
Model No. 201

pole-safe® BY TRANSPO® INDUSTRIES, INC.

Figure 9. Breakaway Support Couplings Specifications



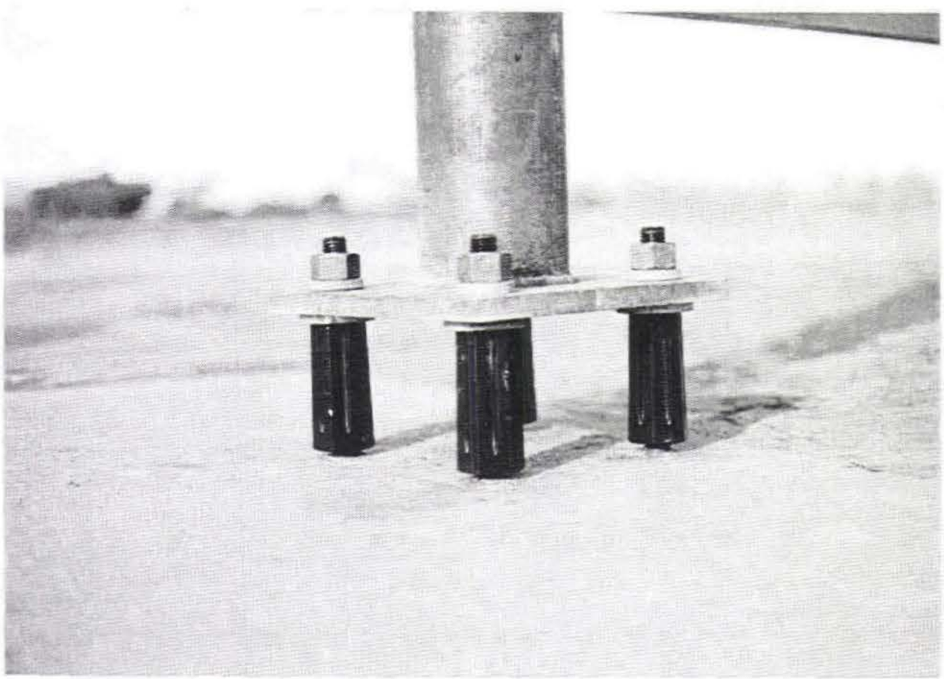


Figure 10. Installed Breakaway Couplings

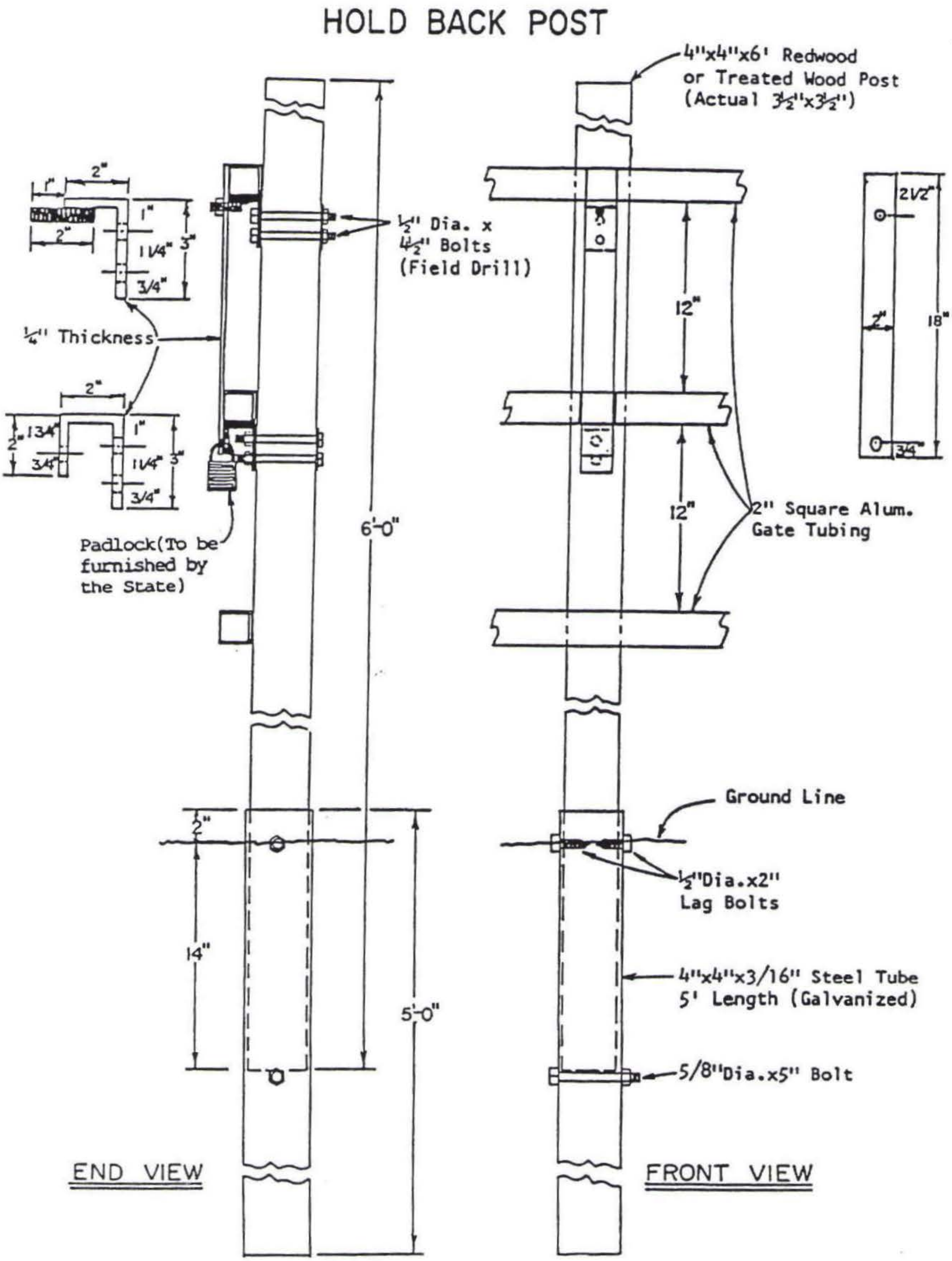


Figure 11. Hold Back Post Detail

2.3.5 Gate Attachments

Details of the sign and Type 1 object markers used during testing are shown in Figure 12. Three object markers were attached to the second through fourth vertical supports on the gate while the sign was attached to the last two vertical supports. Although not typically used in the stowed position, two Type "B" flashing warning lights with battery packs were attached to the top horizontal aluminum tube on each side of the sign.

In addition to the object markers, sign, and warning lights, two cables were attached to the gate. The 0.95-cm (3/8-in.) diameter galvanized aircraft cables were stored on the gate while in the stowed position. During testing, the cables were wrapped around the second vertical support and each end was hooked at the bottom of the fifth vertical support. The cable hooks and pinned connections are shown on the cable detail in Figure 13(a). The orientation of the cables in the closed gate position are shown in Figure 13(b).

2.4 Test Vehicle

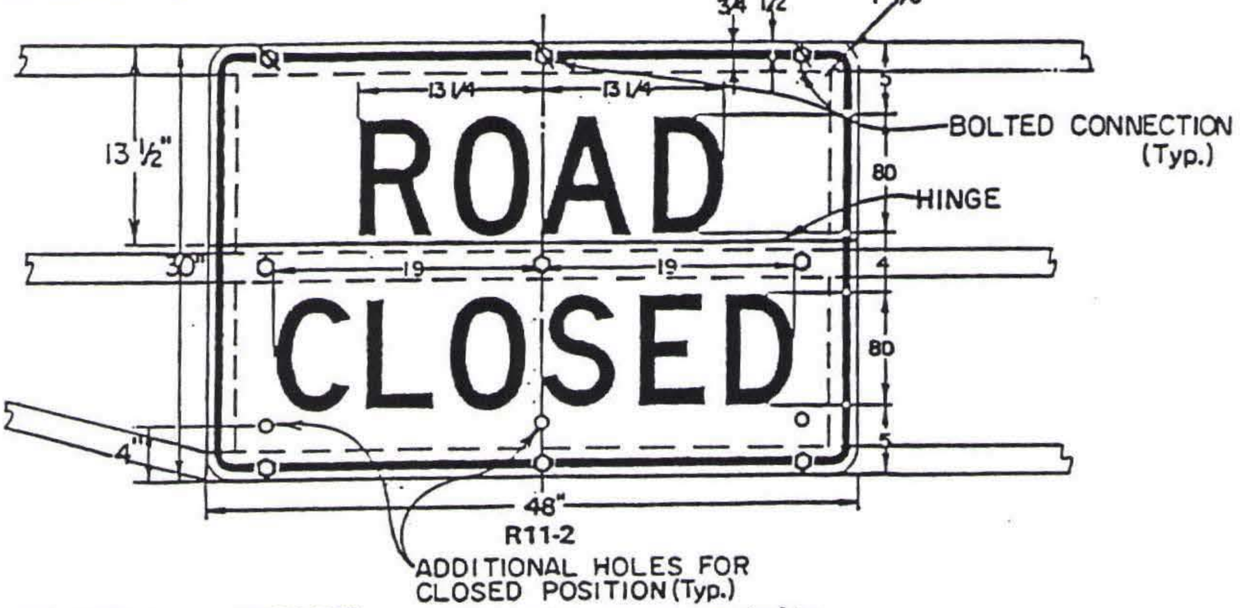
A 794-kg (1751-lb) 1986 Chevrolet Sprint, shown in Figure 14, was used as a test vehicle in both tests SDG-1 and SDG-2. Dimensions and axle weights of the test vehicle are shown in Figure 15. Black and white-checkered targets were placed on the vehicle for high-speed film analysis, as shown in Figure 16. Two targets were located on the center of gravity, one on the driver's side and one on the passenger side of the test vehicle. Additional targets were located for reference so that they could be viewed from all cameras. The front wheels of the test vehicle were aligned for camber, caster, and toe-in values of zero so that the vehicle would track properly along the guide cable. Two 5B flash bulbs, fired by a pressure tape switch on the front bumper, were mounted on the roof of the vehicle to establish the time of impact on the high-speed film.

2.5 Data Acquisition Systems

Vehicle reactions during the full-scale testing program were monitored with SVHS video, high-speed photography, accelerometers, rate gyro, and tape pressure switches. Each of these data acquisition

Use nut on back side of sign and wing nut on front side along the top of ROAD CLOSED sign.

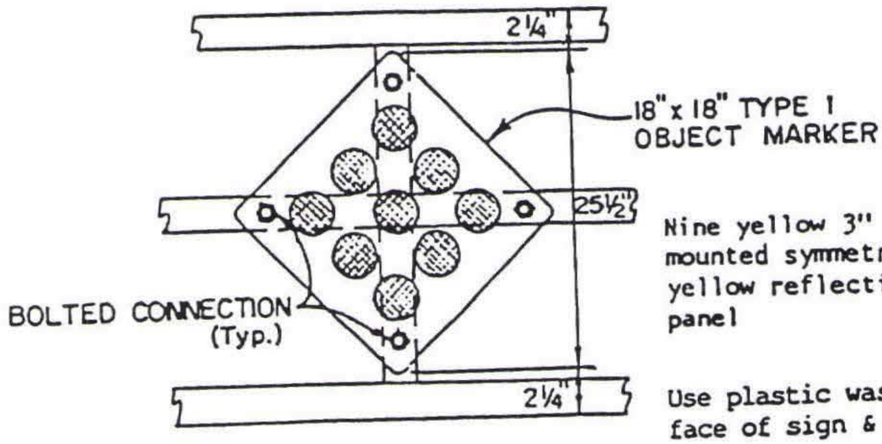
SIGN DETAILS



THE SIGN SHALL MEET THE REQUIREMENTS OF AN R11-2 SIGN. (MUTCD). IT MUST BE REFLECTORIZED.

Furnish necessary bolts.

TYPICAL TYPE 1 OBJECT MARKERS



Nine yellow 3" reflectors, mounted symmetrically on a yellow reflective diamond panel

Use plastic washers on face of sign & object marker.

Figure 12. Sign and Object Marker Detail

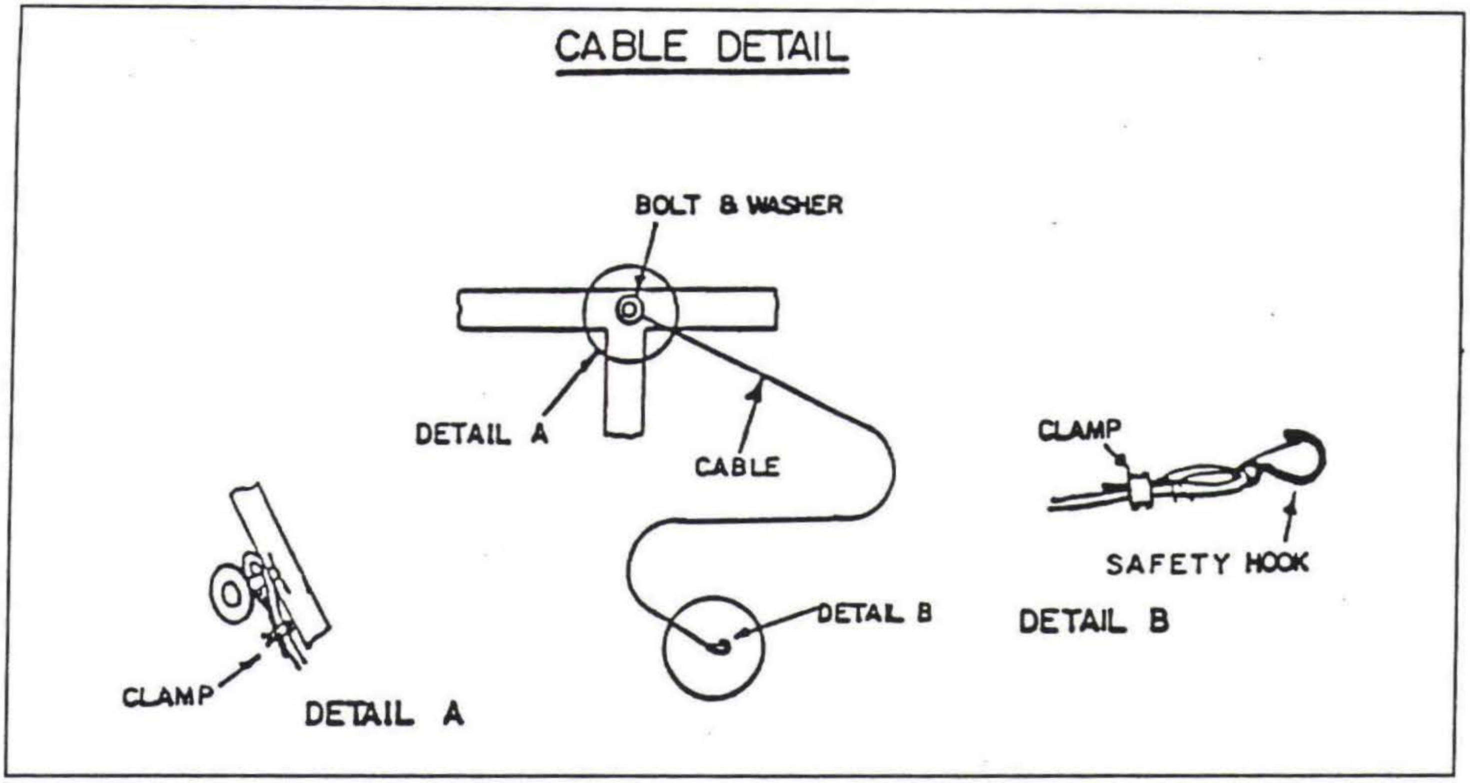


Figure 13(a). Cable Details

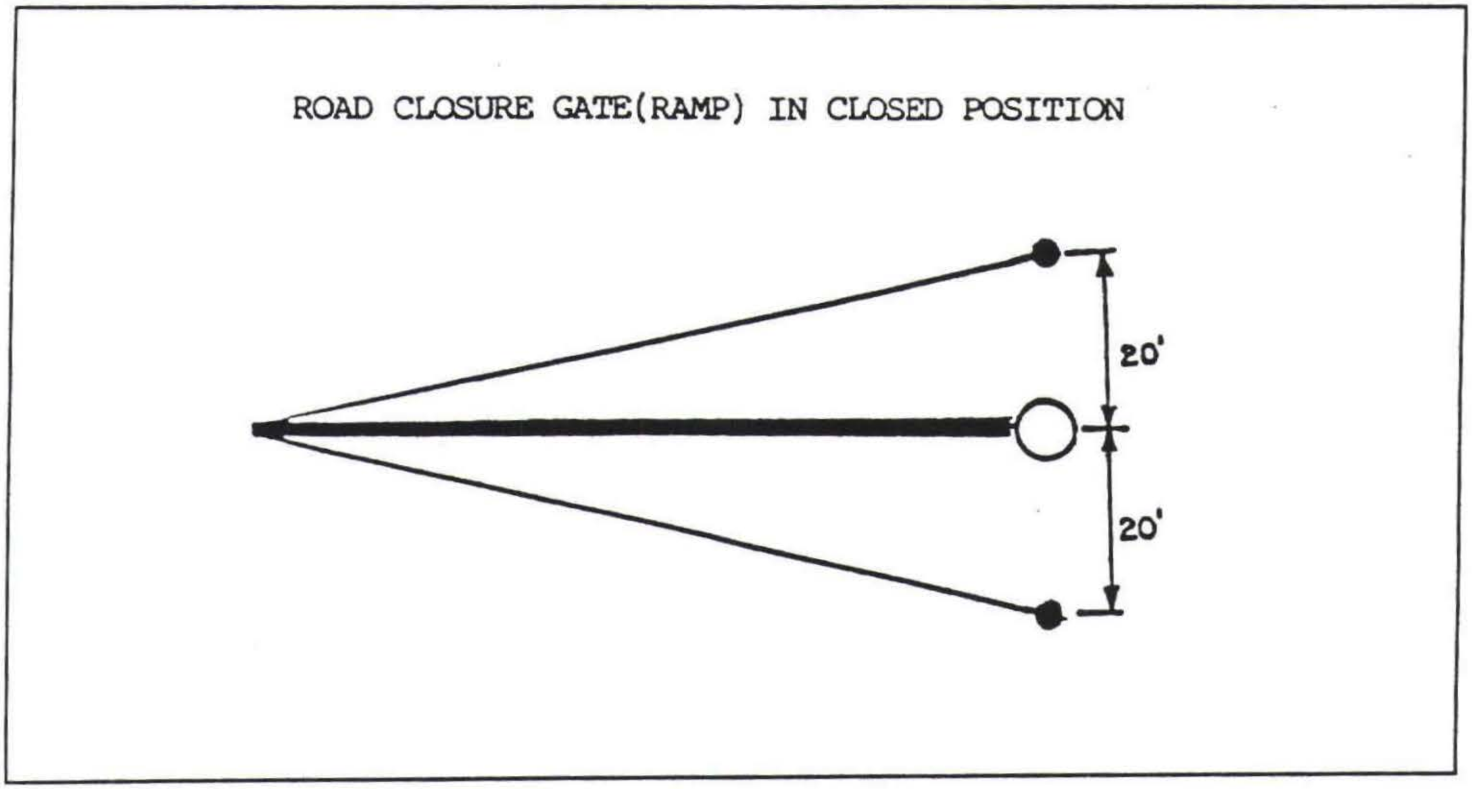


Figure13(b) Cable Orientation in Closed Position

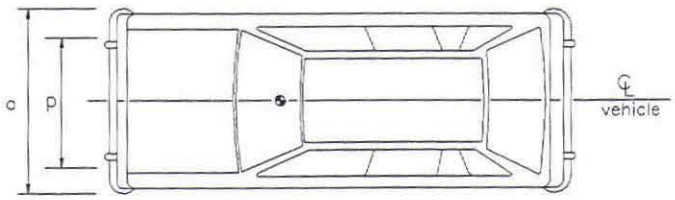
Figure 14. Test Vehicle, SDG-1,2

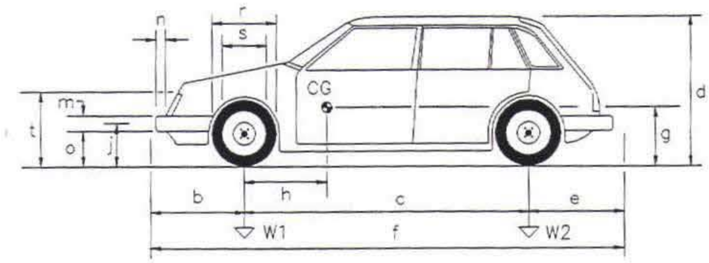
Make: Chevrolet　　Test No.: SDG-1,2

Model: Sprint　　Tire Size: 145/R12

Year: 1986　　VIN: JG1MR6857GK814924

Damage prior to test: None





Vehicle Geometry
cm (in.)

a	141/(55.5)	b	95.6/(27)
c	234/(92.5)	d	132/(52)
e	63.5/(25)	f	367/(144.5)
g	55.9/(22)	h	88.9/(35)
j	40.6/(16)	m	45.7/(18)
n	8.3/(3.25)	o	34.9/(13.75)
p	134.6/(53)	r	54.6/(21.5)
s	33/(13)	t	68.6/(27)

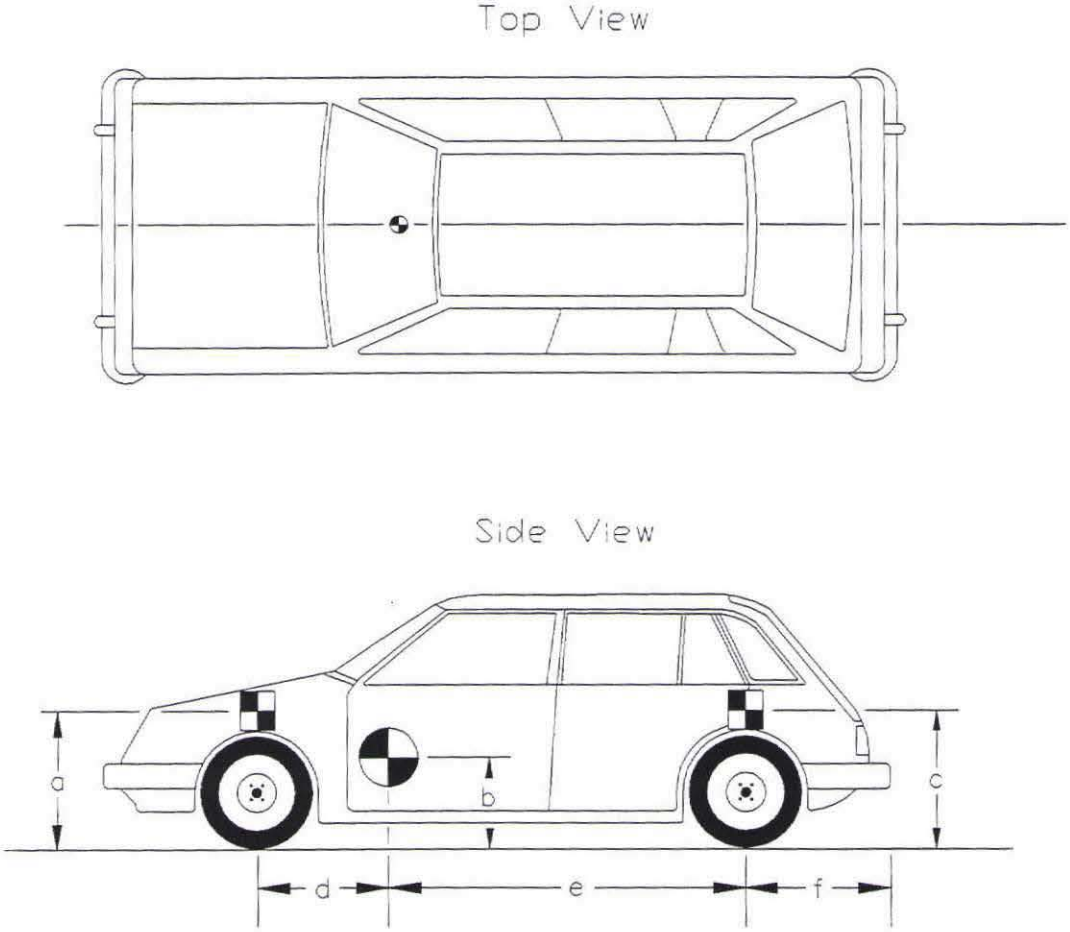
Engine Size: 3cyl. 1.0L

Transmission: man. 5-speed

Mass (kg/lbs)	Curb[1]	Test[2] Inertial	Gross[3] Static
W1	367/(810)	469/(1033)	469/(1033)
W2	277/(610)	326/(718)	326/(718)
Wtotal	644/(1420)	794/(1751)	794/(1751)

[1] Curb – mass of test vehicle in its standard manufactured condition.
[2] Test Inertial – mass of test vehicle and all items including ballast and test equipment.
[3] Gross Static – total of test inertial and dummy masses.

Figure 15. Test Vehicle Dimensions and Weights, SDG-1,2



TARGET GEOMETRY
cm (in.)

a 71.1 (28.0)	c 68.6 (27.0)	e 147.3 (58.0)
b 55.9 (22.0)	d 88.9 (35.0)	f 63.5 (25.0)

Figure 16. Test Vehicle Target Dimensions, SDG-1,2

systems are described in the following subsections.

2.5.1 High-Speed Photography

Three high-speed 16-mm cameras, with operating speeds of approximately 500 frames/sec, were used to film the crash tests. The camera locations are shown in Figure 17. Two Red Lake Model 51 LoCam high-speed cameras were used to provide perpendicular views of the tests. One with a wide-angle 12.5-mm lens and the other with a 12- to 75-mm zoom lens. The third high-speed camera was a Red Lake Model 50 Locam with a 76-mm lens located parallel to the installation and downstream of the gate. In addition to the high-speed cameras, three other cameras were used for documentary footage. These three cameras were a 16-mm Bolex (64 fr/sec), a SVHS video camera, and 35-mm camera with a high-speed shutter

A 1.2-m (4-ft) high by 7.3-m (24-ft) long backboard with a 0.6-m (2-ft) grid was located 2.4 m (94 in.) behind the road closure gate. The grid was used to provide a visible reference system which could be used in the analysis of the perpendicular high-speed film. Targets, measuring 10.2-cm (4-in.) square, were also strategically placed on the gate and the steel post in order to monitor hardware displacements using the high-speed film. The film was analyzed using a Vanguard Motion Analyzer. Actual camera speed and camera divergence factors were considered in the analysis of the high-speed film.

2.5.2. Accelerometers and Rate Gyro

Two triaxial piezoresistive accelerometer systems with a range of ±200 G's (Endevco Model 7264) were used to measure vehicle accelerations. A Humphrey 3-axis rate transducer with a range of 250 deg/sec in each of the three directions (roll, pitch, and yaw) was used to measure the rotational rates. Since vehicle rotations become coupled in the presence of high rotation rates, an uncoupling procedure of the measured angular velocities was conducted. The accelerometers and rate gyro were rigidly attached to a metal block mounted near the vehicle's center of gravity.

Signals were transmitted and received via telemetry and stored to a Honeywell 101 Analog Tape Recorder. The signals were then conditioned by an onboard Series 300 Multiplexed FM Data System built

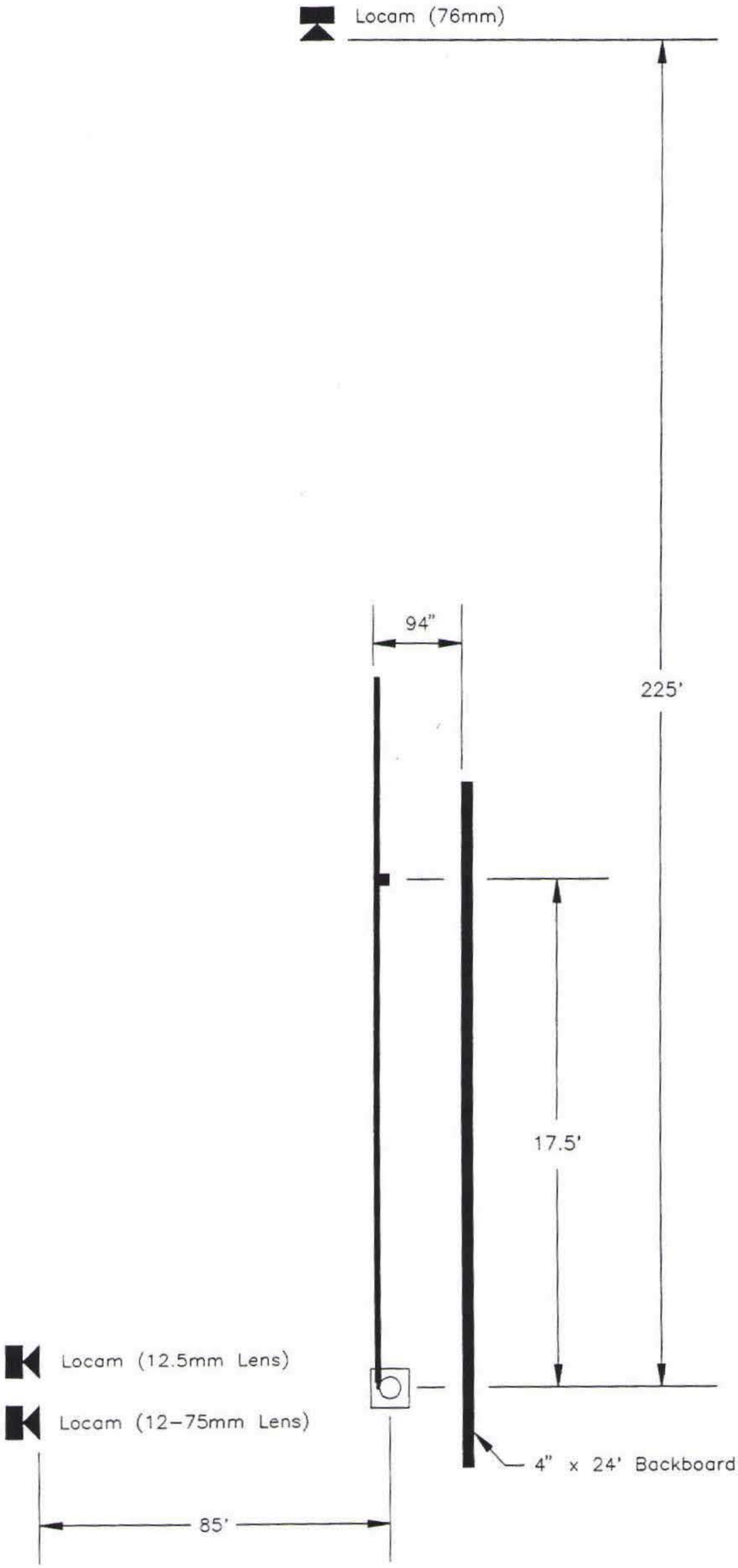


Figure 17. Layout of High-Speed Cameras, SDG-1,2

by Metraplex Corporation. "Enhanced Graphics Acquisition and Analysis" (EGAA) (7) software was used to digitize the data and store the data for analysis with "Data Analysis and Display Software" (DaDiSP) (8).

An Environmental Data Recorder (EDR-3), developed by Instrumented Sensor Technology (IST) of Okemos, Michigan was also used to record the accelerations during the full-scale tests at a sample rate of 3200 Hz. This self-contained unit consists of a triaxial accelerometer system, triggering upon impact and storing the data on board. The EDR-3 was configured with 256 Kb of RAM memory and a 1,120 Hz filter. Computer software, "DynaMax 1 (DM-1)" software was then used to download the EDR-3 unit and filter the data with an 180 Hz low-pass filter.

2.5.3 Pressure Tape Switches

Five pressure tape switches, spaced at 1.52-m (5-ft) intervals, were used to determine the speed of the vehicle before and after impact. Each tape switch fired a strobe light and sent an electronic timing mark to the data acquisition system as the left front tire of the test vehicle passed over it. Test vehicle speeds were determined from recorded electronic timing mark data. Strobe lights and high speed film analysis were used only as a backup in the event that vehicle speeds were not able to be determined from the electronic data.

3 PERFORMANCE EVALUATION CRITERIA

The safety performance evaluation was conducted according to the guidelines presented in NCHRP 350 (1) and the 1985 AASHTO *Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals* (2). These guidelines, shown in Tables 1 and 2, require two compliance tests in order to evaluate the performance of a breakaway support. These two compliance tests are test level 3 tests (Tests 60 and 61). Descriptions of these tests are as follows:

1) Test 3-60: An 820-kg (1808-lb) vehicle impacting the support structure head-on at a nominal impact speed of 35 km/h (21.7 mph) with the center of the front bumper aligned with the center of the installation. The objective of this test is to investigate the breakaway or fracture mechanism of the support.

2) Test 3-61: An 820-kg (1808-lb) vehicle impacting the support structure head-on at a nominal impact speed of 100 km/h (62.1 mph) with the quarter point of the front bumper aligned with the center of the installation. The objective of this test is to investigate the trajectories of both the test installation and the test vehicle.

The vehicle damage was assessed by the traffic accident scale (TAD) (9) and the vehicle damage index (VDI) (10).

TABLE 1. NCHRP Report 350 Safety Evaluation Guidelines.

Evaluation Factors	Evaluation Criteria	
Structural Adequacy	B.	The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.
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. Deformations 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.
	H.	Longitudinal occupant impact velocity should satisfy the following limits: Preferred: 3 m/s (9.8 fps) Maximum: 5 m/s (16.4 fps)
	I.	Occupant ridedown accelerations should satisfy the following longitudinal and lateral limits: Preferred: 15 G's Maximum: 20 G's
Vehicle Trajectory	K.	After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.
	N.	Vehicle trajectory behind the test article is acceptable.

TABLE 2. AASHTO 1985 Safety Evaluation Guidelines.

Evaluation Factors	Evaluation Criteria
Vehicle Change in Speed (ΔV)	Satisfactory dynamic performance is indicated when the maximum change in velocity of the vehicle, striking a breakaway support at speeds from 20 mph to 60 mph (32 km/h to 97 km/h does not exceed 15 fps (4.57 m/s), but preferably does not exceed 10 fps (3.05 m/s)

4 TEST RESULTS

4.1 Test SDG-1 (794 kg (1751 lbs), 37.1 km/h (23.1 mph), 0 deg)

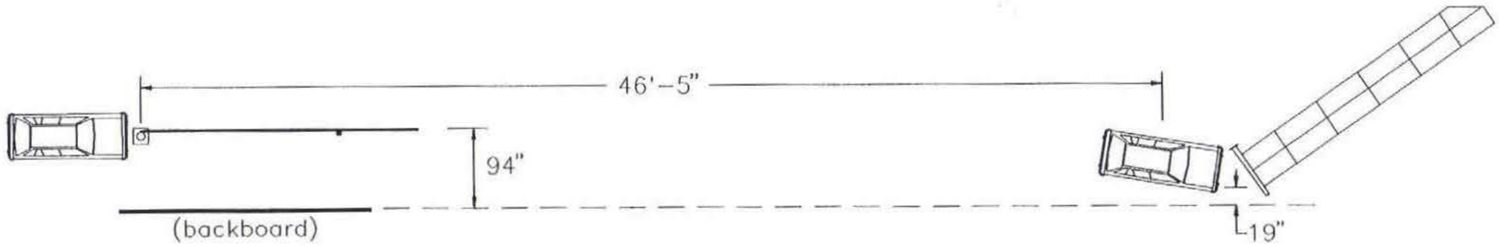
In Test SDG-1, the 1986 Chevrolet Sprint impacted the road closure gate head-on in the stowed position at an angle of 0 degrees and 37.1 km/h (23.1 mph). The impact point on the vehicle was approximately at the center of the front bumper and was aligned with the center of the hinged connection between the gate post and the gate. A summary of the test including test results, sequential photos, and post-test trajectory is shown in Figure 18.

High-speed film sequential photographs of the full-scale crash test are shown in Figures 19 and 20, and photographs of the full-scale test are shown in Figure 21. After the initial impact with the gate post, the front bumper crushed inward for approximately 0.024 sec before the gate post was disengaged from the breakaway support. Subsequently, the vehicle continued its forward movement while pushing the interlocked gate post in front of the vehicle. The gate post and gate were cleanly disengaged from the breakaway support without producing any significant vehicle angular rotations.

The warning lights disengaged at 0.079 sec, and the hold back post fractured at 0.128 sec, causing small positive and negative yaw rotations to the vehicle and gate, respectively. The vehicle reference system is shown in Figure 22. At 0.523 sec, the rear axle of the vehicle smoothly passed over the fractured frangible couplers. At 0.707 sec, the downstream end of the gate contacted the ground and began to dig into the soil. The vehicle continued to push the entire installation forward until the gate post slipped off the front end of the vehicle at approximately 2.46 sec. The vehicle came to rest approximately 14.0-m (46-ft) downstream of the breakaway support at 3.71 sec after impact, as shown in Figure 19.

Test vehicle damage consisted of only frontal crush to the bumper, hood, and grill. A maximum crush depth of 20.3 cm (8 in.) was measured on the front bumper of the test vehicle and approximately 27.9 cm (11 in.) of crush was measured on the hood of the test vehicle. There was no damage to the suspension or undercarriage of the test vehicle. The minimal damage to the test vehicle is shown in Figure 23.

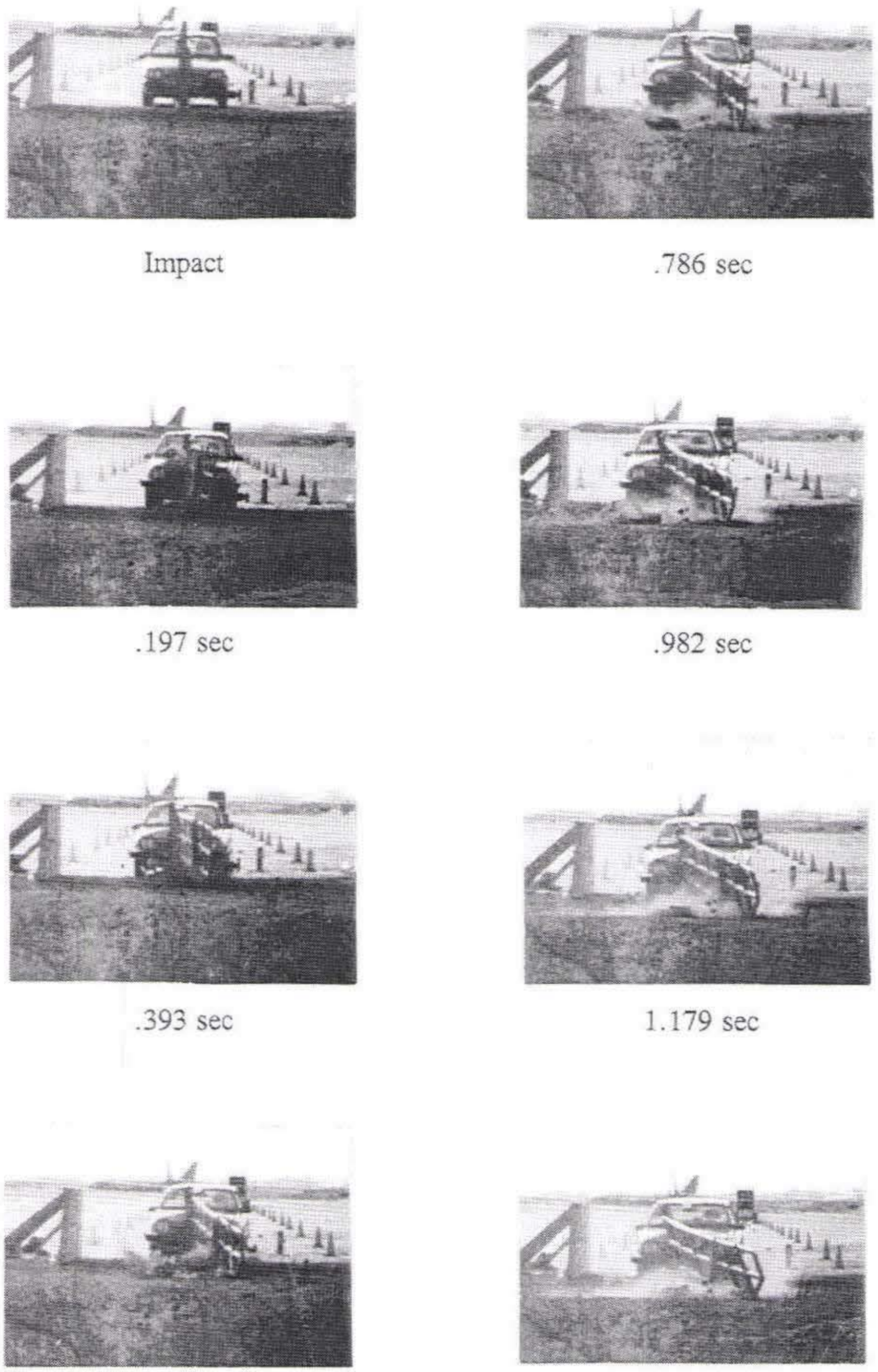
Impact .393 sec .786 sec 1.179 sec 1.572 sec



• Test Number	SDG-1
• Date	11/16/94
• Project Sponsor	South Dakota DOT
• Appurtenance	Standard Road Closure Gate Mainline Type
Total Mass (Weight)	68 kg (150 lbs)
• Gate	
Length	8.5 m (28 ft)
Height	86.4 cm (34 in.)
Material	Aluminum
• Gate Post	
Size	12.7 cm (5 in.)
Length	1.2 m (4 ft)
Material	ASTM A36 Steel
• Breakaway Assembly	Frangible Couplers (4 each)
• NCHRP 350 Vehicle Class	820C
Model	1986 Chevy Sprint
Mass (Weight)	
Curb	644 kg (1420 lbs)
Test Inertial	794 kg (1751 lbs)
Gross Static	794 kg (1751 lbs)

• Vehicle Speed	
Impact	37.1 km/h (23.1 mph)
Exit	Not Applicable
• Vehicle Angle	
Impact	0 degrees
Exit	Not Applicable
• Vehicle Impact Location	Center of Hinges
• Vehicle Snagging	None
• Vehicle Stability	Satisfactory
• Occupant Ridedown Deceleration	
Longitudinal	0.95 G's
• Occupant Impact Velocity	
Longitudinal	3.1m/s (10.3 fps)
• Vehicle Change in Speed	3.6 m/s (11.8 fps)
• Vehicle Damage	Minimal
TAD(9)	12-FC-2
VDI (10)	12FCEN1
• Vehicle Stopping Distance	14.2 m (46.5 ft) from impact
• Road Closure Gate Damage	Minor
• Vehicle Front-End Crush	20.3 cm (8 in)

Figure 18. Summary of Test, SDG-1



Impact

.786 sec

.197 sec

.982 sec

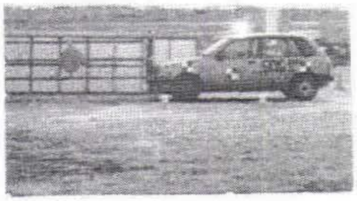
.393 sec

1.179 sec

.589 sec

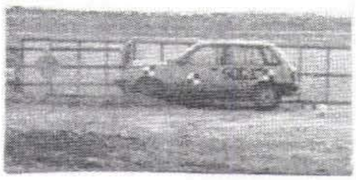
1.375 sec

Figure 19. High-Speed Downstream Sequentials, SDG-1



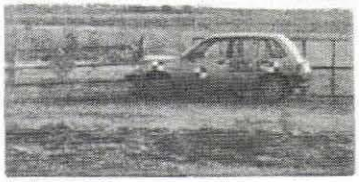
Impact

.286 sec



.513 sec

.769 sec



1.026 sec

1.282 sec

1.538 sec

1.795 sec

Figure 20. Perpendicular Sequentials, SDG-1

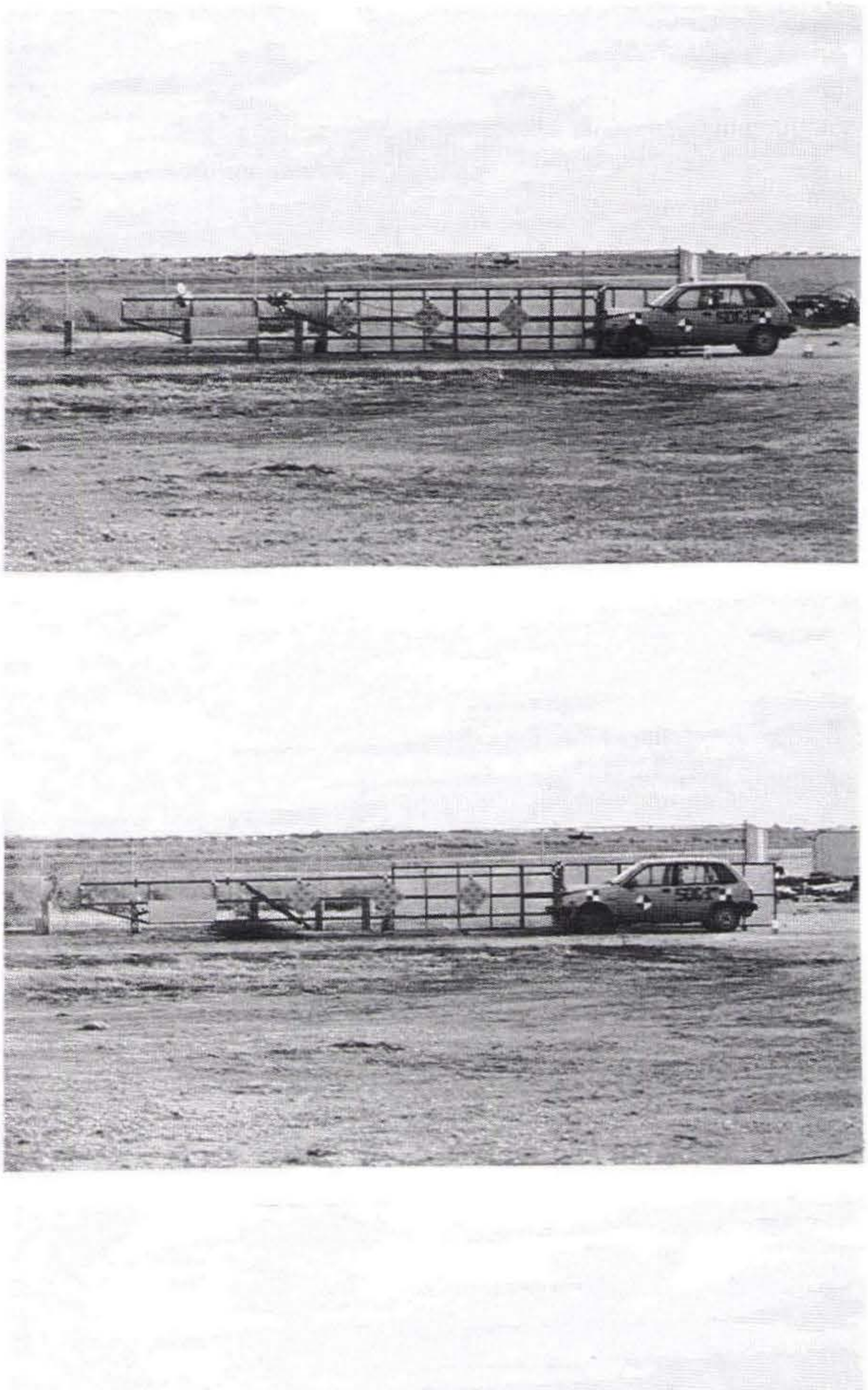


Figure 21. Full-Scale Test, SDG-1

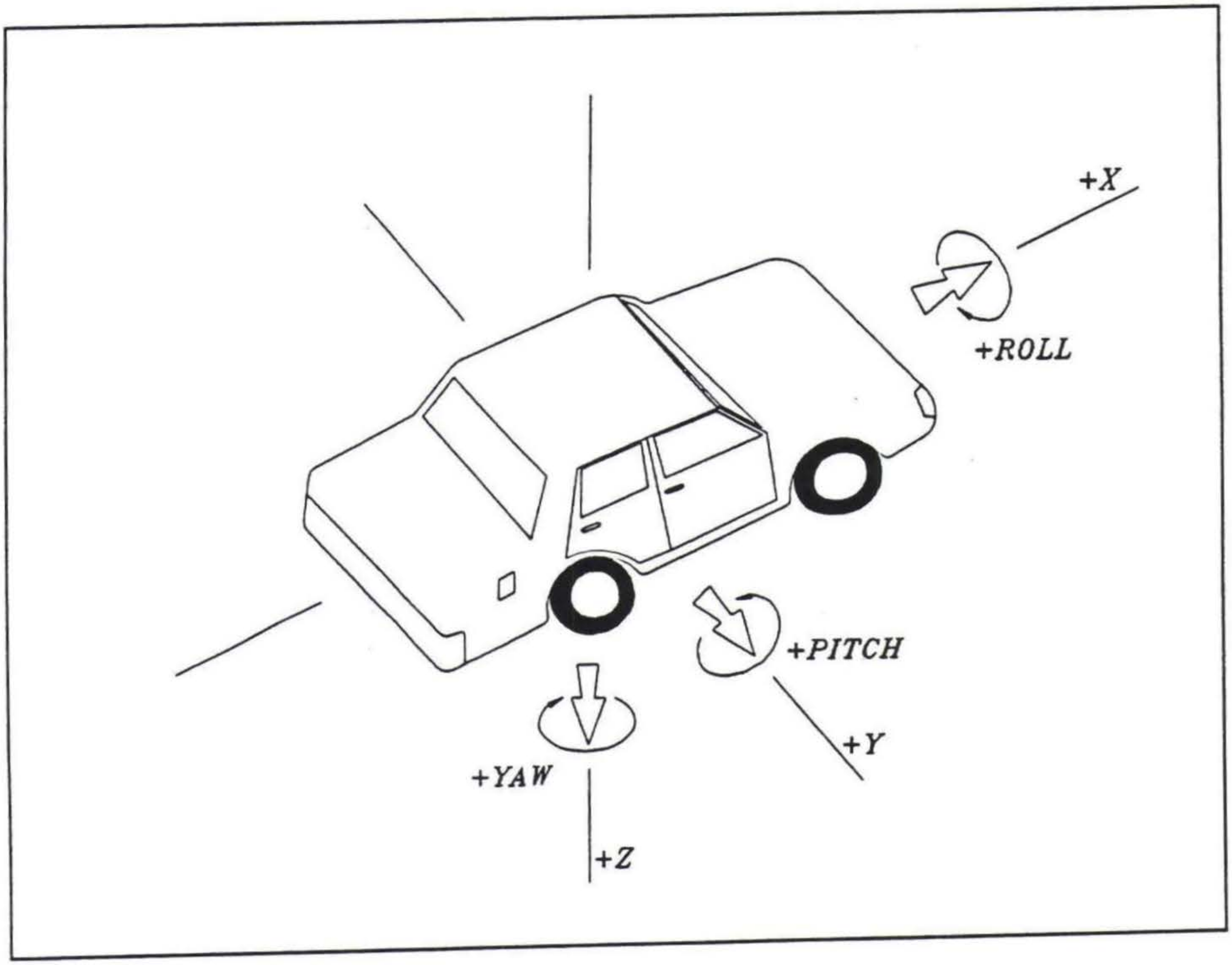


Figure 22. Vehicle Coordinate Reference System

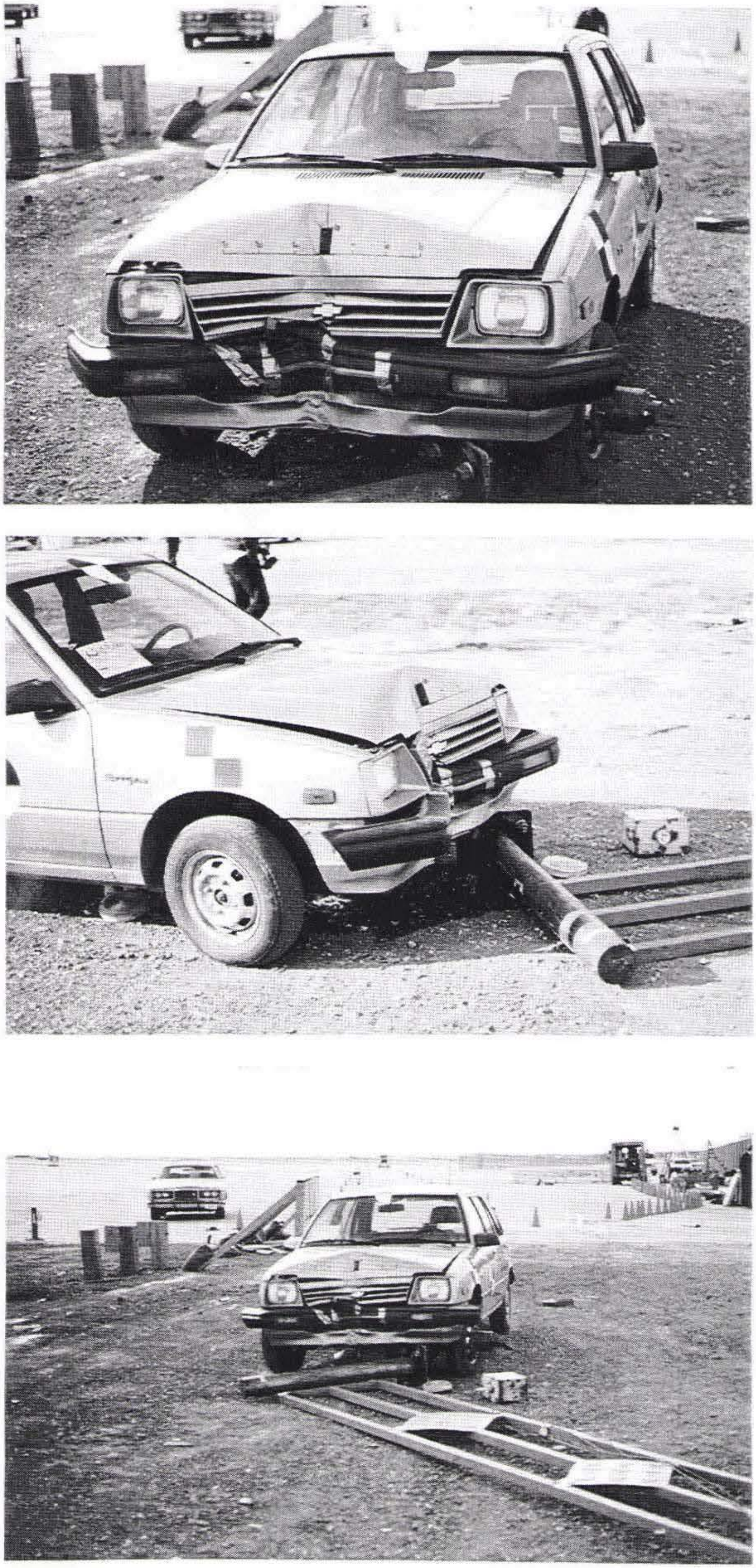


Figure 23. Vehicle Damage, SDG-1

Damage to the road closure gate consisted only of fracture of the frangible couplers, hold back post, and gate stands, as shown in Figure 24. The frangible couplers were broken off flush with the top of the anchor rods, leaving a 7.6-cm (3-in.) stub height above the concrete surface. Two of the anchor bolts were bent forward. Damage to these components is shown in Figure 24. The gate post and gate were undamaged and remained connected. The final resting position of the gate was approximately 15.2-m (50-ft) downstream of impact, as shown in Figure 18.

Based upon the analysis of the accelerometer data, the longitudinal occupant impact velocity (OIV) was 3.13 m/s (10.3 fps), and the vehicle change in speed (ΔV) was determined to be 3.6 m/s (11.8 fps). Since the gate post remained in contact with the front of the vehicle after it broke away, the vehicle's (ΔV) was determined at the point when the vehicle's rear axle passed over the remaining breakaway support. The maximum 10-msec average longitudinal ridedown deceleration was 0.95 G's. Plots of the accelerometer data and the angular displacements can be found in Appendix A.

4.2 Test SDG-2 (794 kg (1751 lbs), 95.5 km/h (59.4 mph), 0 deg)

In Test SDG-2, the 1986 Chevrolet Sprint impacted the road closure gate head-on in the stowed position at an angle of 0 degrees and 95.5 km/h (59.4 mph). The impact point on the vehicle was approximately at the quarter point of the front bumper (offset towards the passenger side of the vehicle), and was aligned with the center of the hinged connection between the gate post and gate. A summary of the test including test results, sequential photos, and post-test trajectory is shown in Figure 25.

High-speed film sequential photographs of the full-scale crash test are shown in Figures 26 and 27, and photographs of the full-scale test are shown in Figure 28. After the initial impact with the gate post, the front bumper crushed inward for approximately 0.010 sec before the gate post was disengaged from the breakaway support. As the front axle of the vehicle passed over the breakaway support at approximately 0.028 sec, the vehicle began to yaw in a positive direction (refer to Figure 22 for sign convention). The holdback post and the upstream stand fractured at 0.056 sec. Subsequently, the vehicle continued its forward movement while pushing the interlocked gate post in front of the vehicle causing

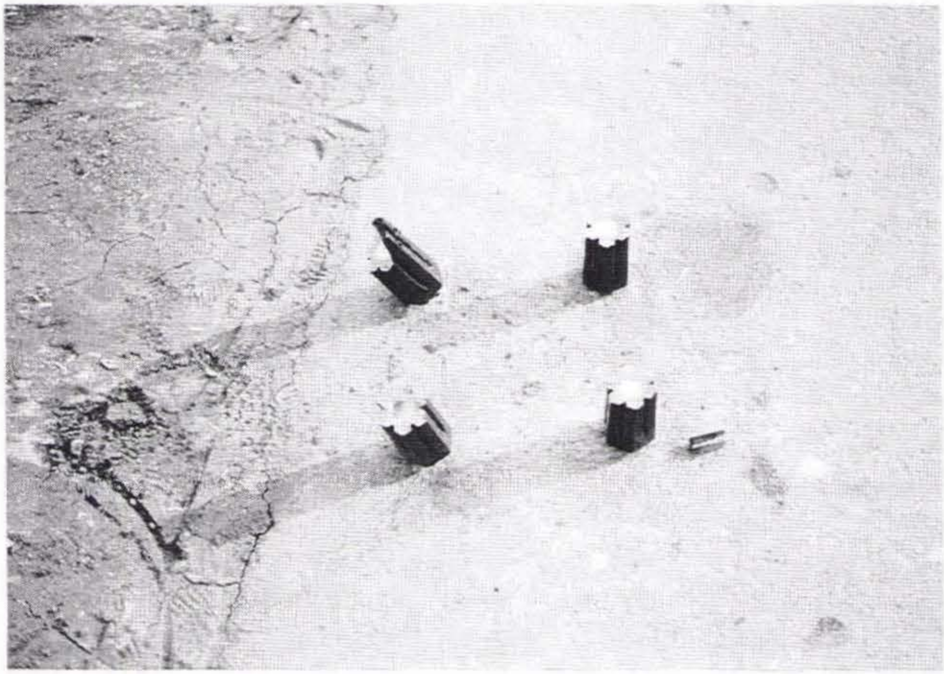
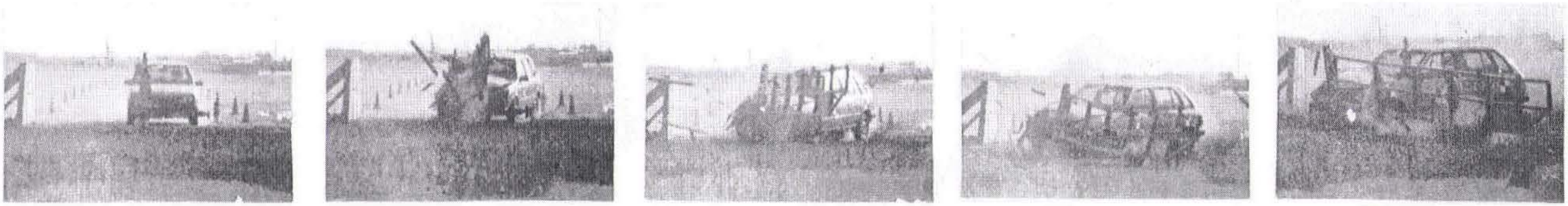
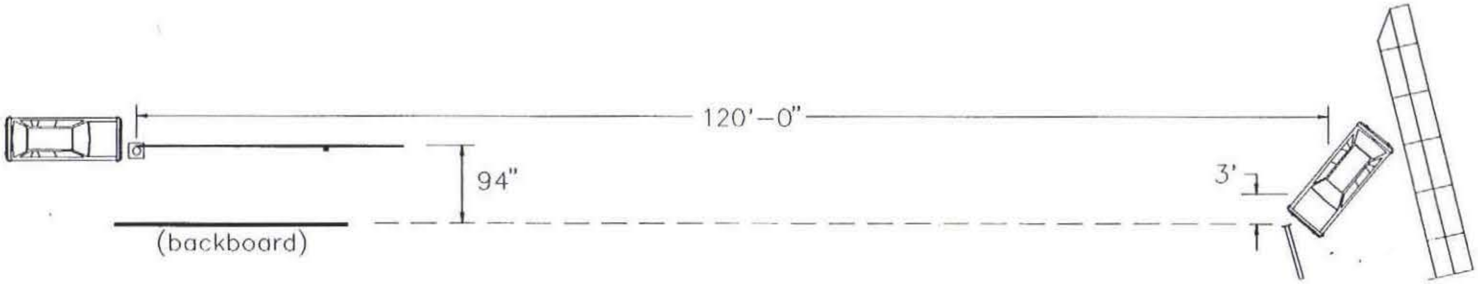


Figure 24. Component Damage, SDG-1

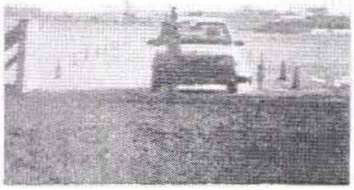


Impact | .197 sec | .395 sec | .592 sec | .789 sec



- Test Number SDG-2
- Date 11/16/94
- Project Sponsor .... South Dakota DOT
- Appurtenance .... Standard Road Closure Gate Mainline Type
  - Total Mass (Weight) .... 68 kg (150 lbs)
- Gate
  - Length .... 8.5 m (28 ft)
  - Height .... 86.4 cm (34 in.)
  - Material .... Aluminum
- Gate Post
  - Size .... 12.7 cm (5 in.)
  - Length .... 1.2 m (4 ft)
  - Material .... ASTM A36 Steel
- Breakaway Assembly .... Frangible Couplers (4 each)
- NCHRP 350 Vehicle Class 820C
  - Model .... 1986 Chevy Sprint
  - Mass (Weight)
    - Curb .... 644 kg (1420 lbs)
    - Test Inertial .... 794 kg (1751 lbs)
    - Gross Static .... 794 kg (1751 lbs)
- Vehicle Speed
  - Impact .... 95.5 km/h (59.4 mph)
  - Exit .... Not Applicable
- Vehicle Angle
  - Impact .... 0 degrees
  - Exit .... Not Applicable
- Vehicle Impact Location .... Center of Hinges
- Vehicle Snagging .... None
- Vehicle Stability .... Satisfactory
- Occupant Ridedown Deceleration
  - Longitudinal .... 2.8 G's
- Occupant Impact Velocity
  - Longitudinal .... 4.2 m/s (13.9 fps)
- Vehicle Change in Speed .... 3.7 m/s (12.2 fps)
- Vehicle Damage .... Minimal
  - TAD(9) 12-FR-3
  - VDI(10) 12FREN2
- Vehicle Stopping Distance ...... 36.6 m (120 ft) from impact
- Road Closure Gate Damage .... Minor
- Vehicle Front-End Crush .... 30.5 cm (12 in)

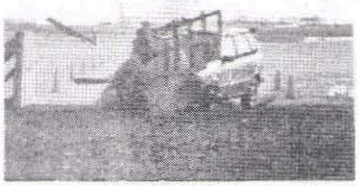
Figure 25. Summary of Test, SDG-2



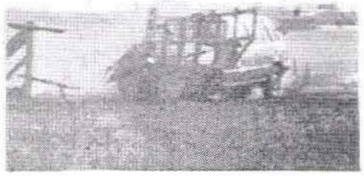
Impact

.098 sec

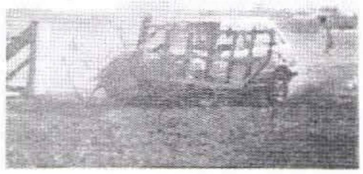
.197 sec



.296 sec



.395 sec

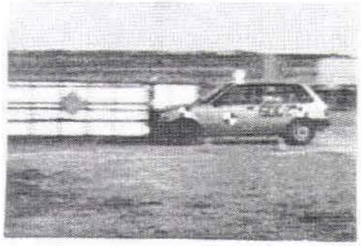


.494 sec

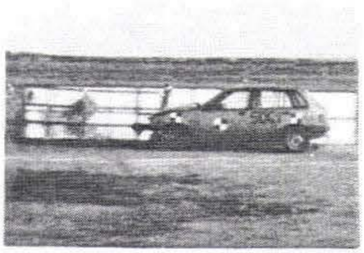
.592 sec

.691 sec

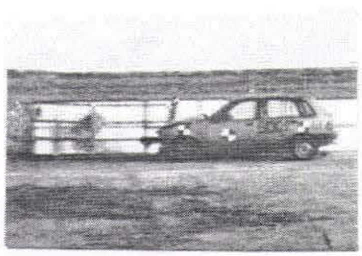
Figure 26. High-Speed Downstream Sequentials, SDG-2



Impact

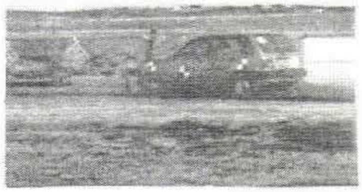


.114 sec

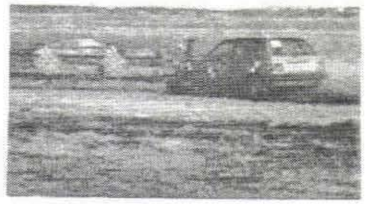


.227 sec

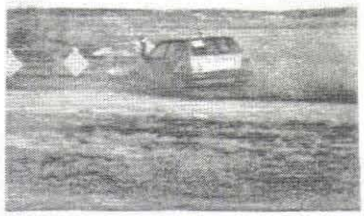
.341 sec



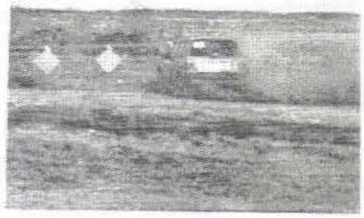
.455 sec



.568 sec



.682 sec



.796 sec

Figure 27. Perpendicular Sequentials, SDG-2

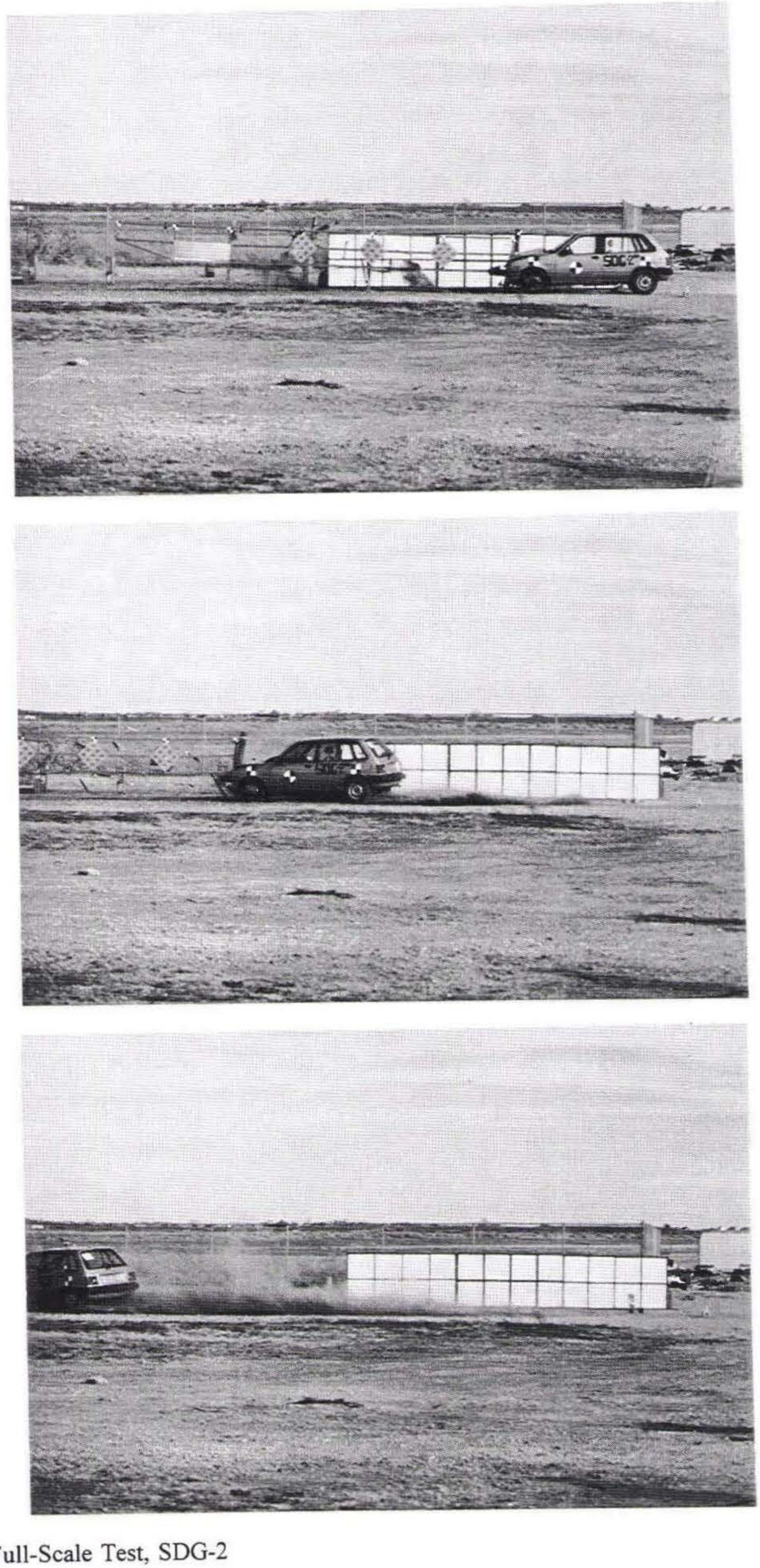


Figure 28. Full-Scale Test, SDG-2

positive and negative yaw rotations to the vehicle and gate, respectively.

At 0.130 sec, the rear axle of the vehicle smoothly passed over the fractured frangible couplers. The downstream end of the gate continued to rise until approximately 0.336 sec when the gate began to drop towards the ground. At this time, the vehicle was yawing in a positive direction and moving forward, pushing the gate assembly. At 0.632 sec, the downstream end of the gate contacted the ground and began to dig into the soil. The vehicle continued to push the entire installation forward until the gate post slipped off the front-end of the vehicle at approximately 0.987 sec, resulting in the gate post becoming disengaged from the gate. At 1.17 sec, the gate was laying flat on the ground and being pushed forward by the vehicle. The vehicle came to rest approximately 36.6-m (120-ft) downstream of the breakaway support at 2.47 sec after impact, as shown in Figure 25.

Test vehicle damage consisted of frontal crush to the bumper, hood, and grill at the quarter point location. A maximum crush depth of approximately 30.5 cm (12 in.) was measured on the front bumper and hood. The right-front fender, wheel well, and hood were slightly buckled. There was no significant damage to the suspension or the undercarriage, since the vehicle did not run over any parts of the gate. There were no broken glass, flat tires, or occupant compartment damage. The damage to the test vehicle is shown in Figure 29.

Damage to the road closure gate consisted of fracture of the couplers, hold back post, and gate stands, as shown in Figure 30. The frangible couplers were partially broken off with the top of the anchor rods on the upstream end of the couplers. The anchor rods were not bent, as shown in Figure 30. The gate post was undamaged, and the gate suffered minimal damage including the tear-out of the 1.9-cm (3/4-in.) bolts that connected the gate and gate post. The vertical aluminum tube on the upstream end of the gate was bent slightly. The final resting position of the gate was approximately 39.6 m (130 ft) downstream of impact, as shown in Figure 25.

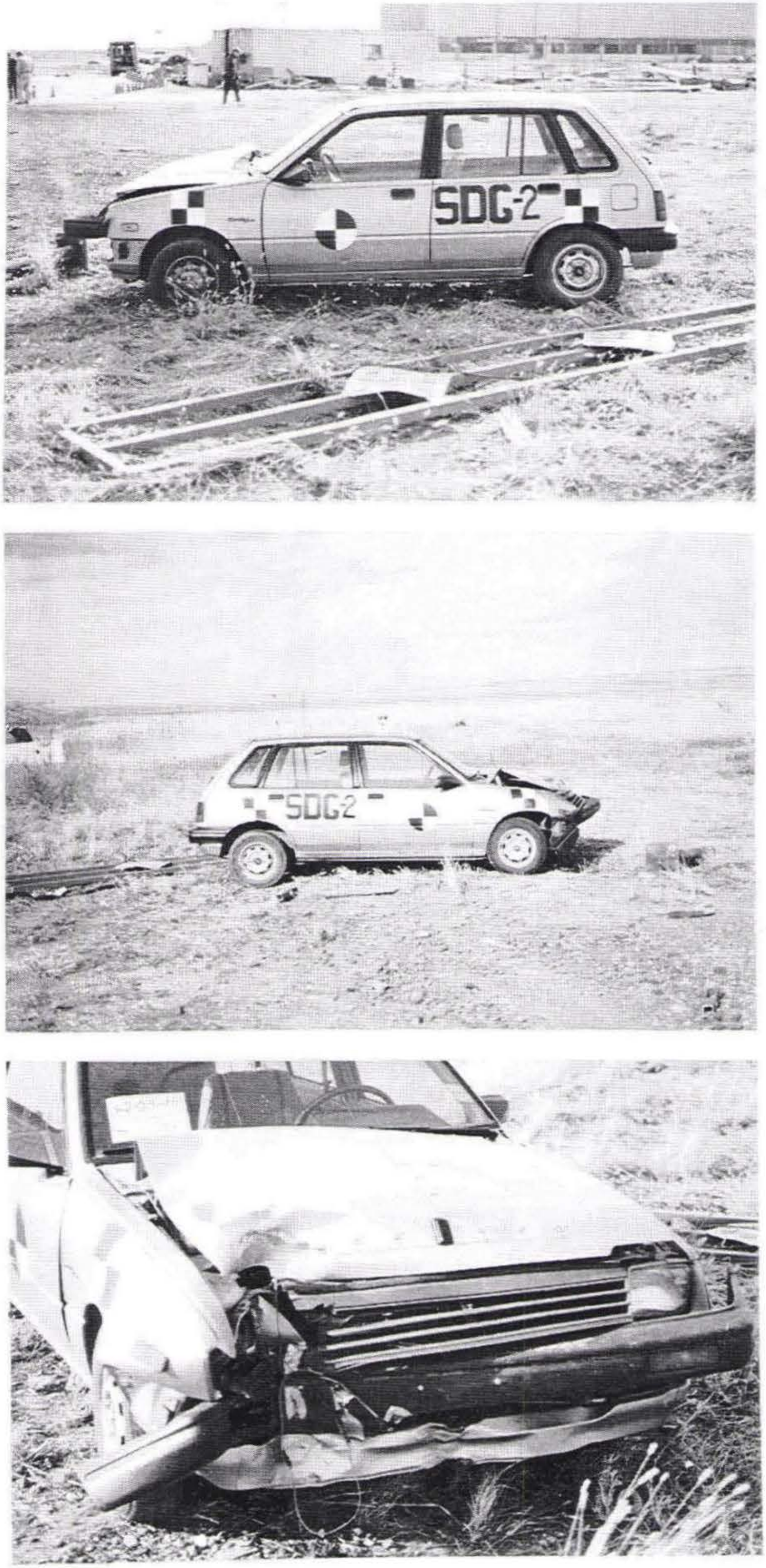


Figure 29. Vehicle Damage, SDG-2

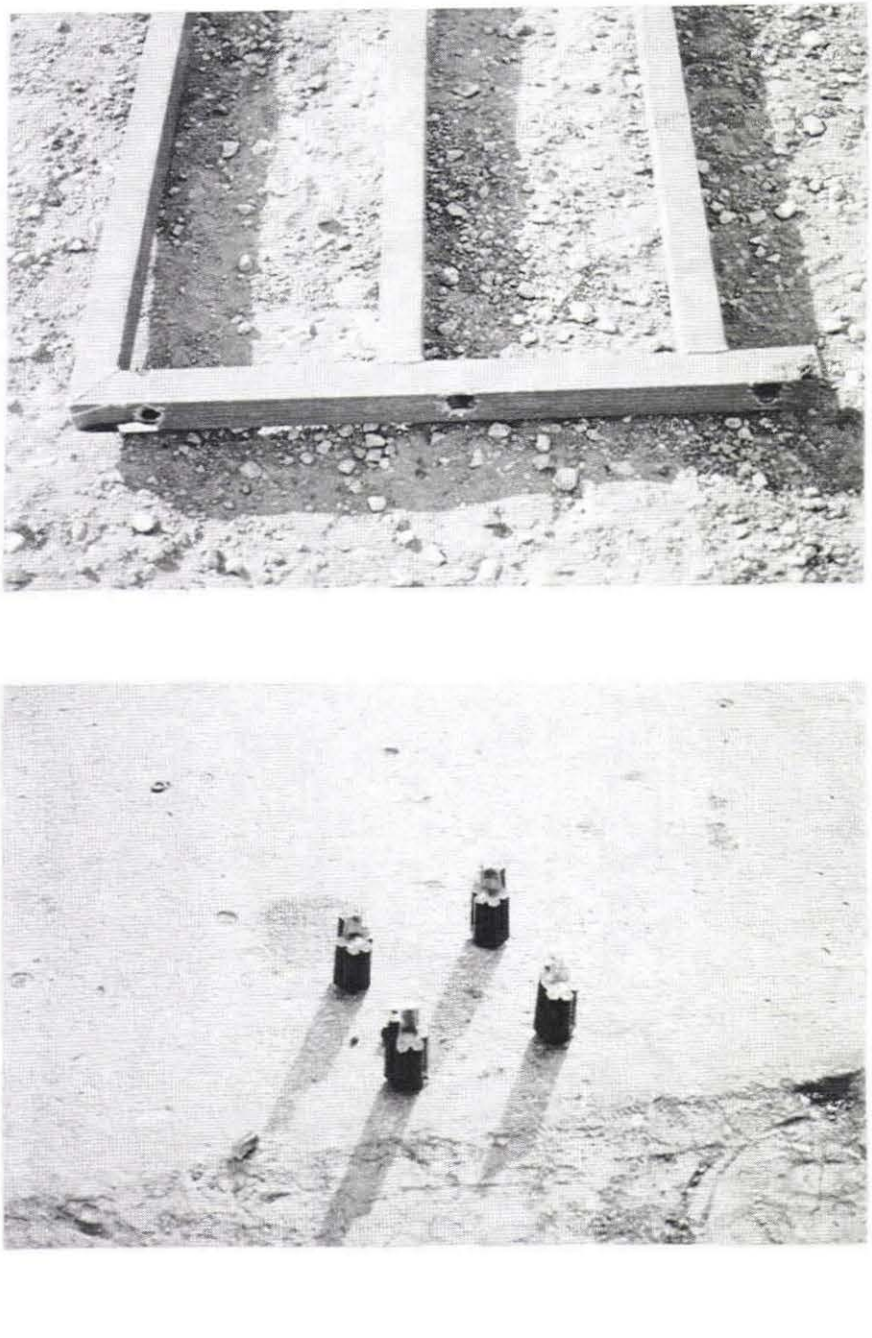


Figure 30. Component Damage, SDG-2

Based upon the analysis of the accelerometer data the longitudinal occupant impact velocity (OIV) was 4.2 m/s (13.9 fps) and the vehicle change in speed (ΔV) was determined to be 3.7 m/s (12.2 fps). Since the gate post remained in contact with the front of the vehicle after it broke away, the vehicle's (ΔV) was determined at the point when the vehicle's rear axle passed over the remaining breakaway support. The maximum 10-msec average longitudinal ridedown deceleration was 2.8 G's. Plots of the accelerometer data and the angular displacements can be found in Appendix A. A summary of the safety performance results for both tests is given in Table 3.

Table 3. Summary of Performance Evaluation Results

Evaluation Factors	Evaluation Criteria	Test SDG-1		Test SDG-2	
Structural Adequacy	B. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.	NCHRP (1)	AASHTO[1] (2)	NCHRP (1)	AASHTO[1] (2)
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. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.	S	NA	S	NA
	F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	S	NA	S	NA
	H. Longitudinal occupant impact velocity should satisfy the following limits: Preferred: 3 m/s (9.8 fps) Maximum: 5 m/s (16.4 fps)	S	NA	S	NA
	I. Occupant ridedown accelerations should satisfy the following longitudinal and lateral limits: Preferred: 15 G's Maximum: 20 G's	S	NA	S	NA
Occupant Risk[1] (AASHTO)	A. Vehicle change in speed (ΔV): Preferred: 3 m/s (10 fps) Maximum: 4.6 m/s (15 fps)	NA	S	NA	S
Vehicle Trajectory	K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	S	NA	S	NA
	N. Vehicle trajectory behind the test article is acceptable.	S	NA	S	NA

S (Satisfactory) U (Unsatisfactory) NA (Not Applicable)

5. CONCLUSIONS

The research study described herein clearly indicates that the Standard South Dakota Road Closure Gate does not pose any significant hazard for vehicles impacting the gate in a stowed position. The crash tests were conducted on the road closure gate oriented in a stowed position as opposed to a closed position, since it was believed that it would result in the most severe impact. In addition, SDDOT reasoned that vehicle impacts into road closure gates in the closed position rather than the stowed position would not be as likely to occur due to the significant increase in delineation and subsequent lower driving speeds. Head-on tests were conducted since the vehicle would be required to break both the gate support post and the hold back post. The impact location, consisting of the centerline of the hinged connection, was selected because the post and gate weights were approximately equal.

The safety performance of the road closure gate was determined to be acceptable according to the evaluation criteria presented in NCHRP Report 350 and AASHTO 1985. It has successfully passed all of the safety criteria, and in nearly all cases, the limits of acceptability were near the "preferred range" as opposed to the "maximum range". The success of this research study should result in significant benefits for the SDDOT, one being that they will not be required to remove the road closure gates and replace them with alternative access control devices.

6. REFERENCES

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4. Federal Highway Administration (FHWA) Correspondence with PrecisonForm Inc., HNG-14, January, 1990.

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9. *Vehicle Damage Scale for Traffic Investigators*, Traffic Accident Data Project Technical Bulletin No.1, National Safety Council, Chicago, IL, 1971.

10. *Collision Deformation Classification*, Recommended Practice J224 March 1980, SAE Handbook Vol. 4, Society of Automotive Engineers, Warrendale, Penn., 1985.

7.1 Appendix A - Accelerometer and Rate Gyro Analysis Plots

SDG-1:

SDG-2:

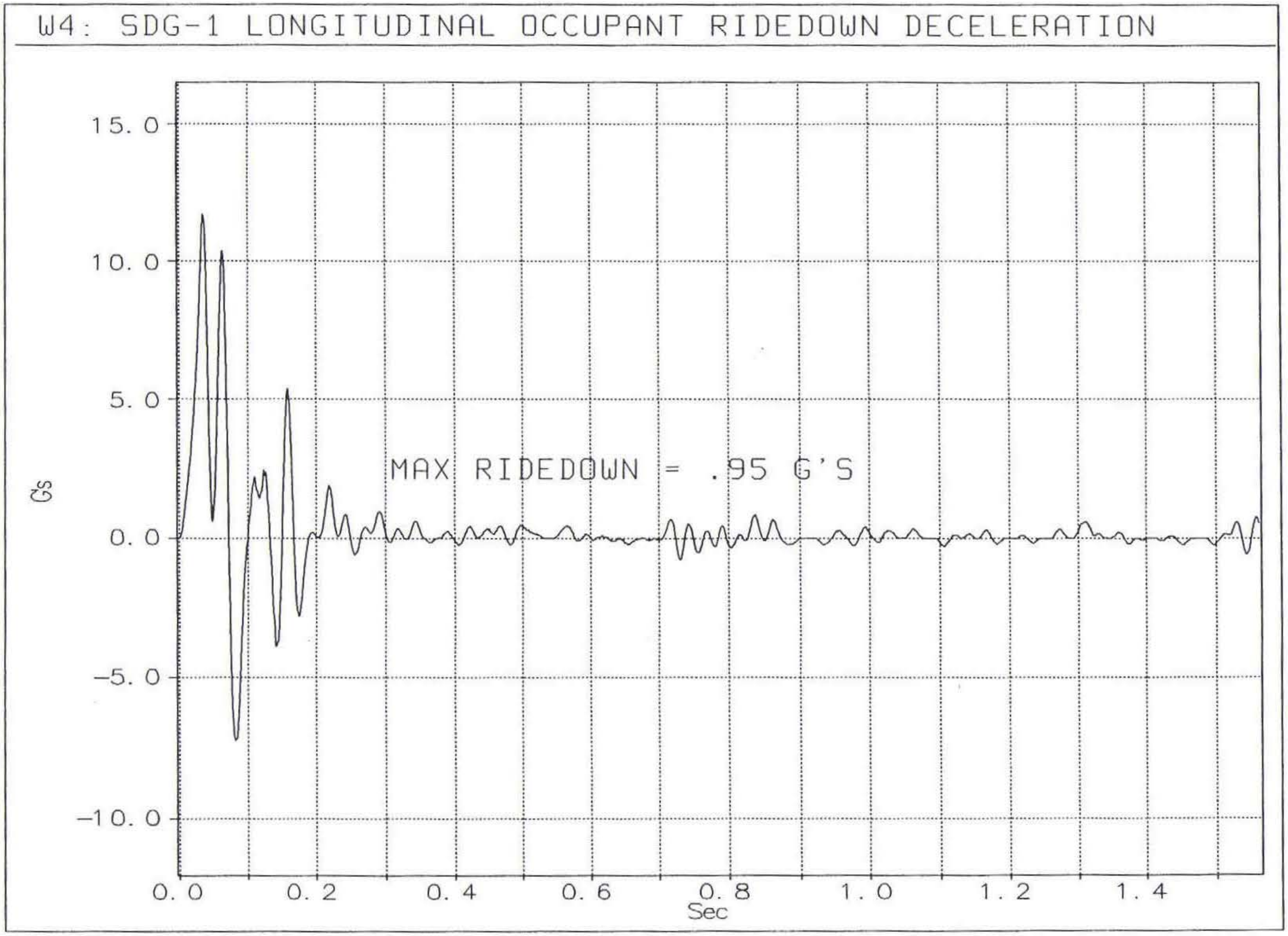

Figure A-1. Graph of Longitudinal Occupant Ridedown Deceleration, SDG-1

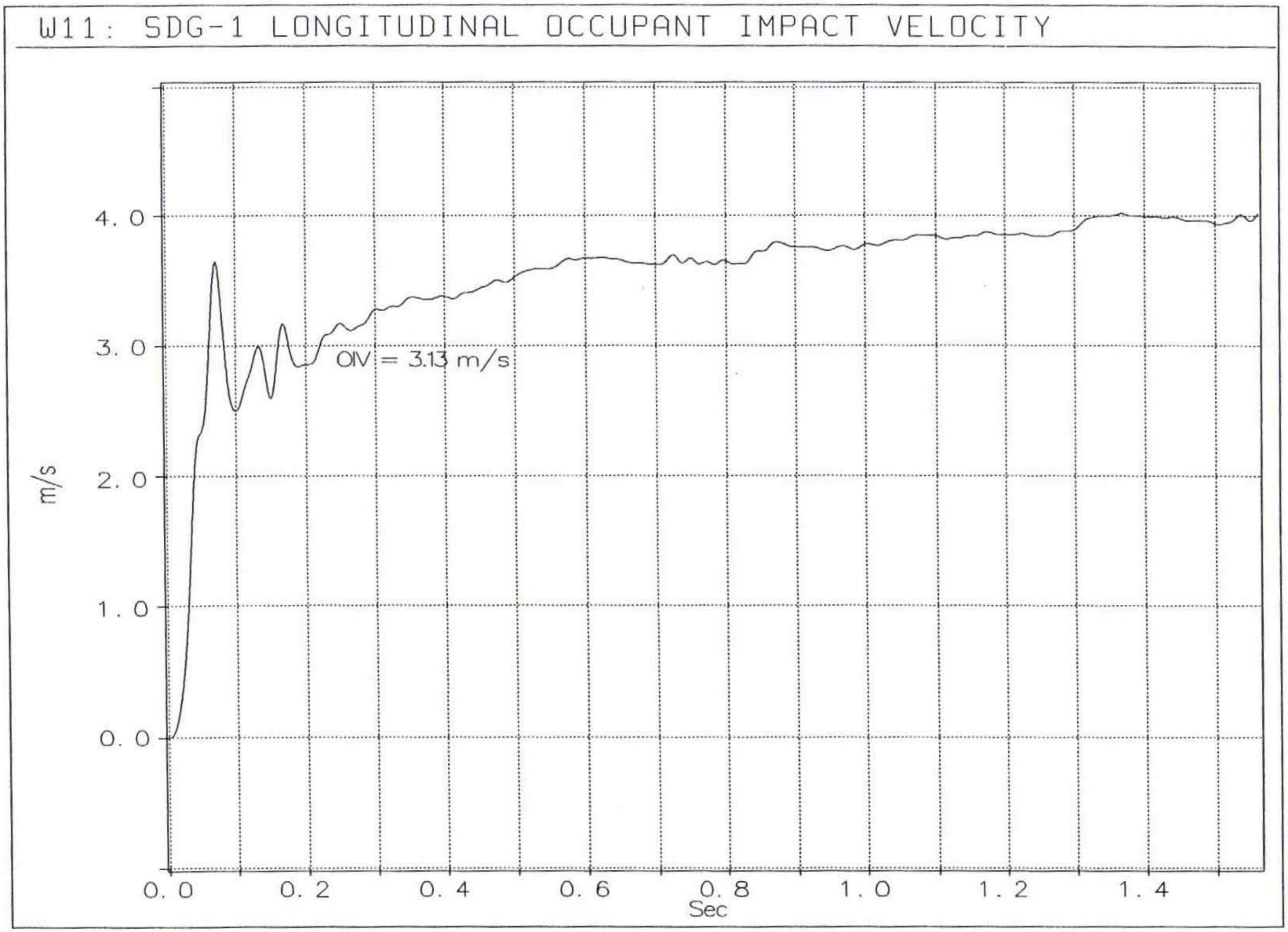

Figure A-2. Graph of Longitudinal Occupant Impact Velocity, SDG-1

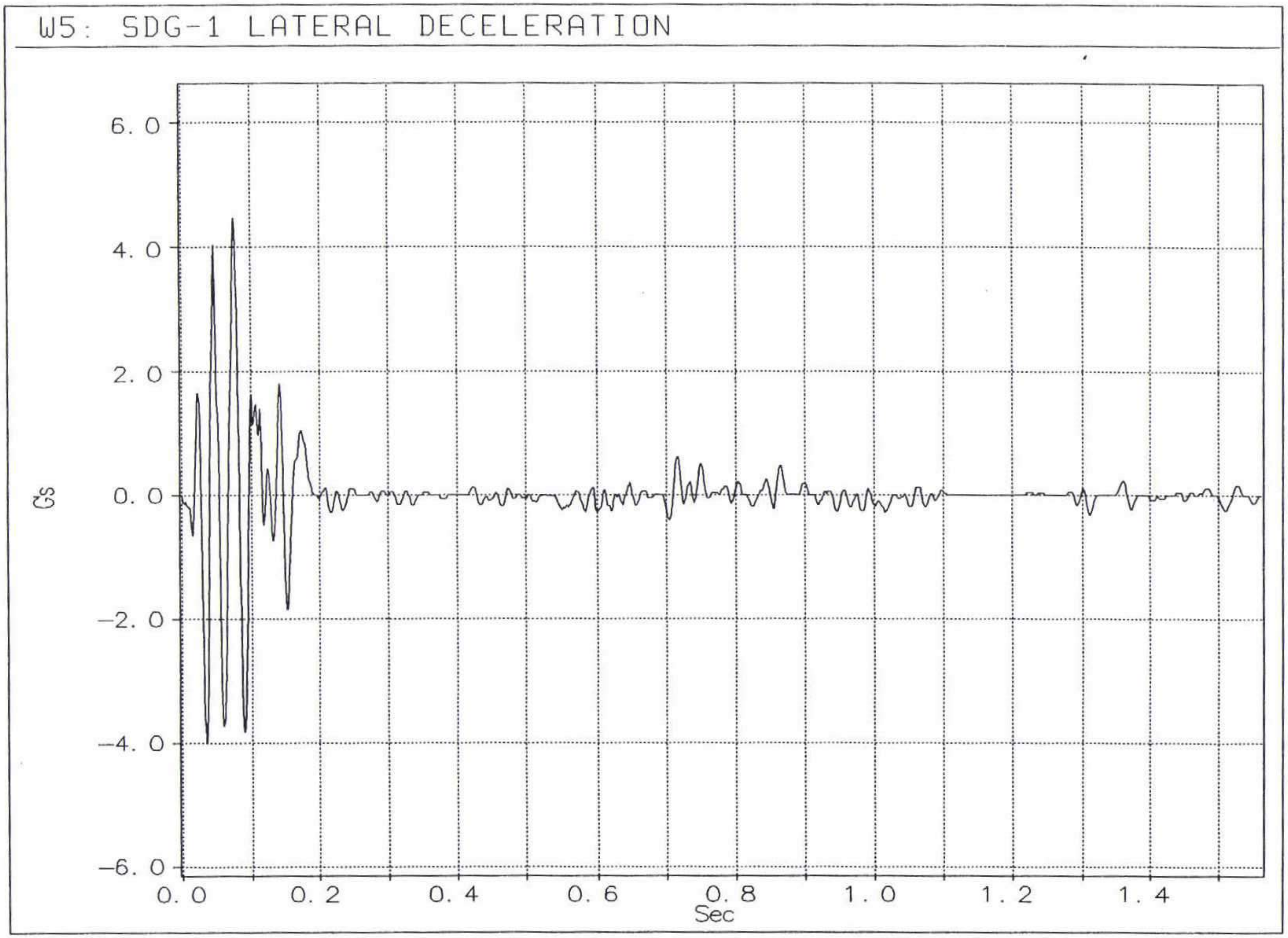

Figure A-3. Graph of Lateral Deceleration, SDG-1

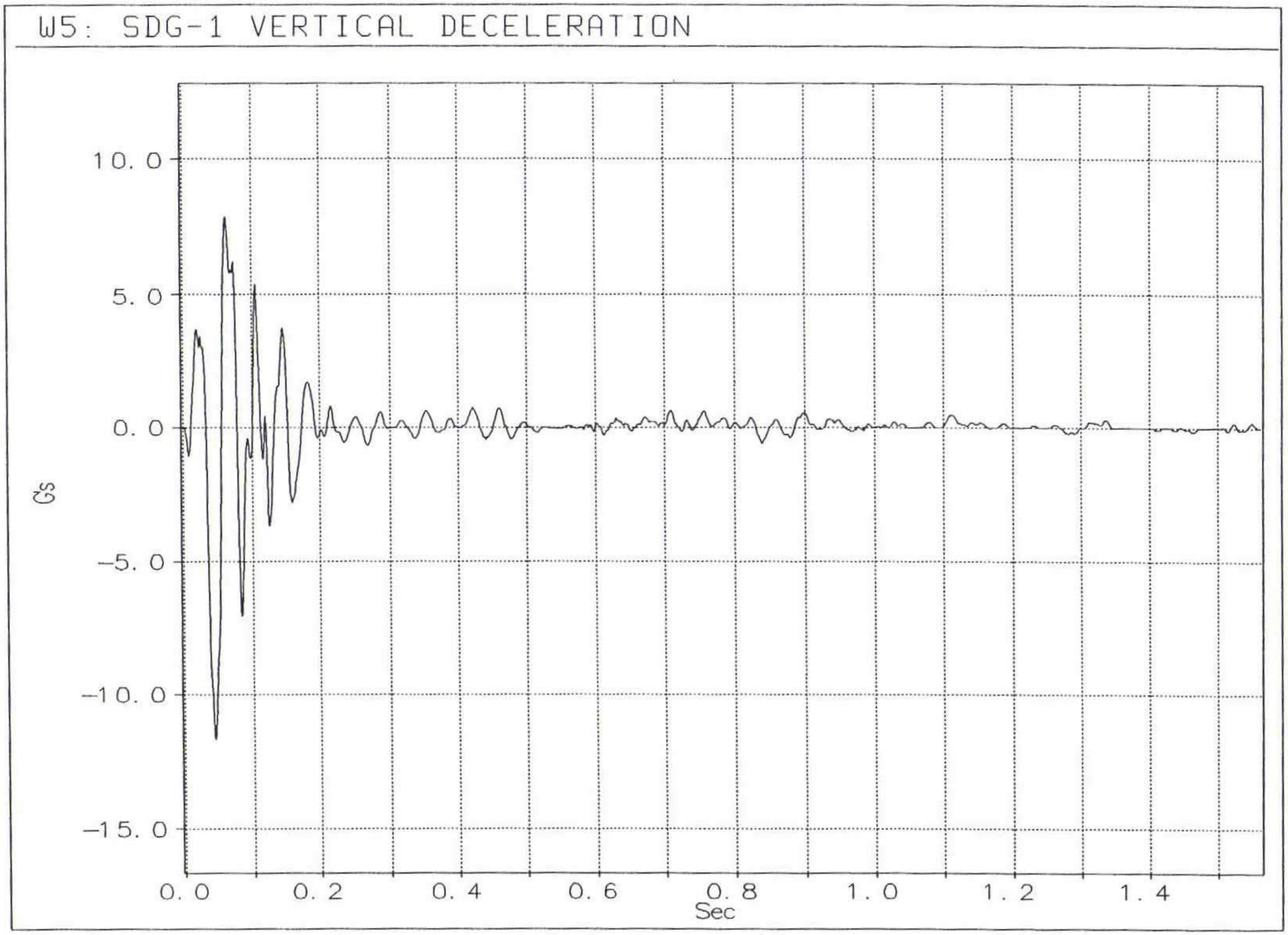

Figure A-4. Graph of Vertical Deceleration, SDG-1

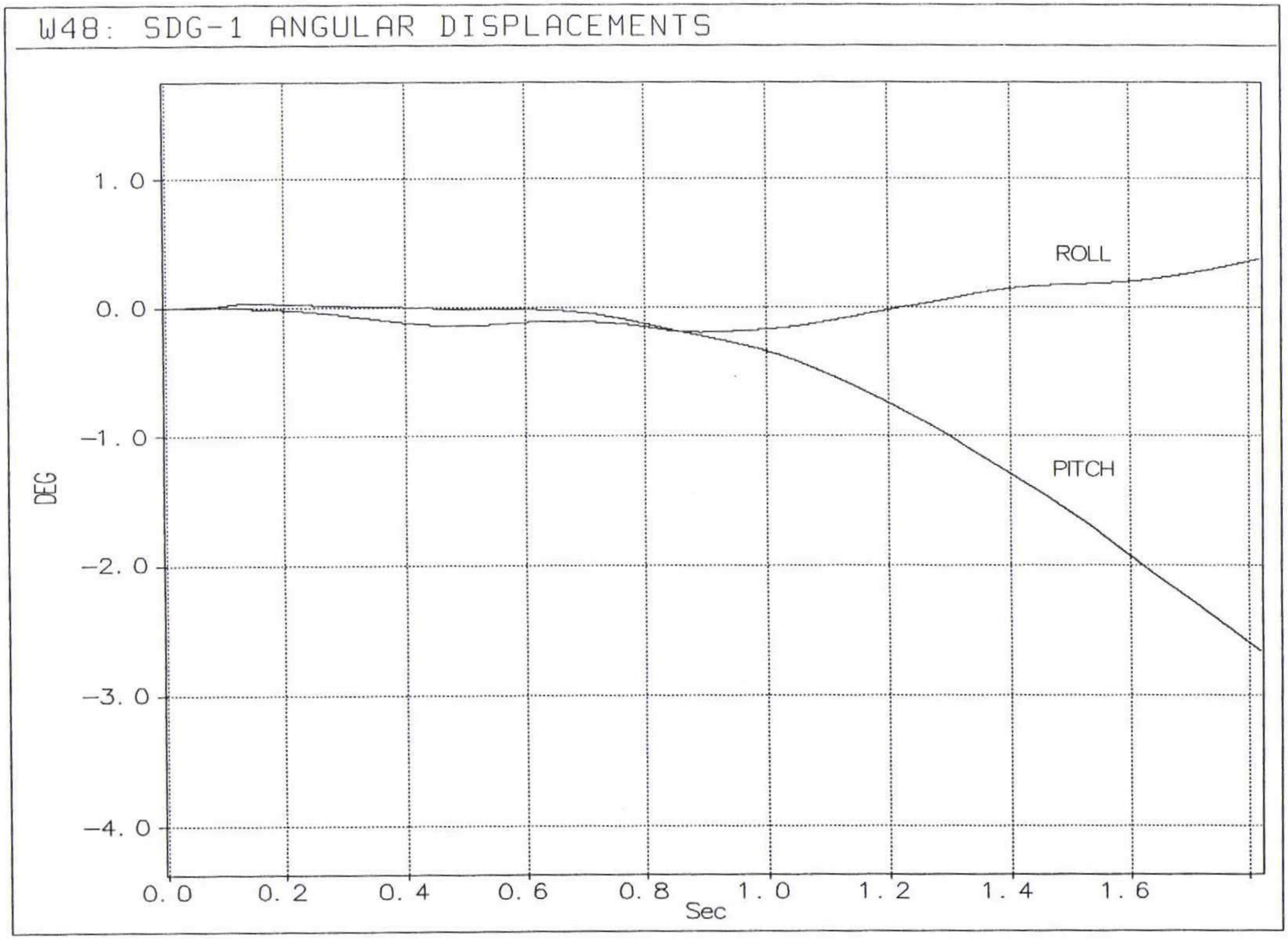

Figure A-5. Graph of Roll and Pitch Angular Displacements, SDG-1

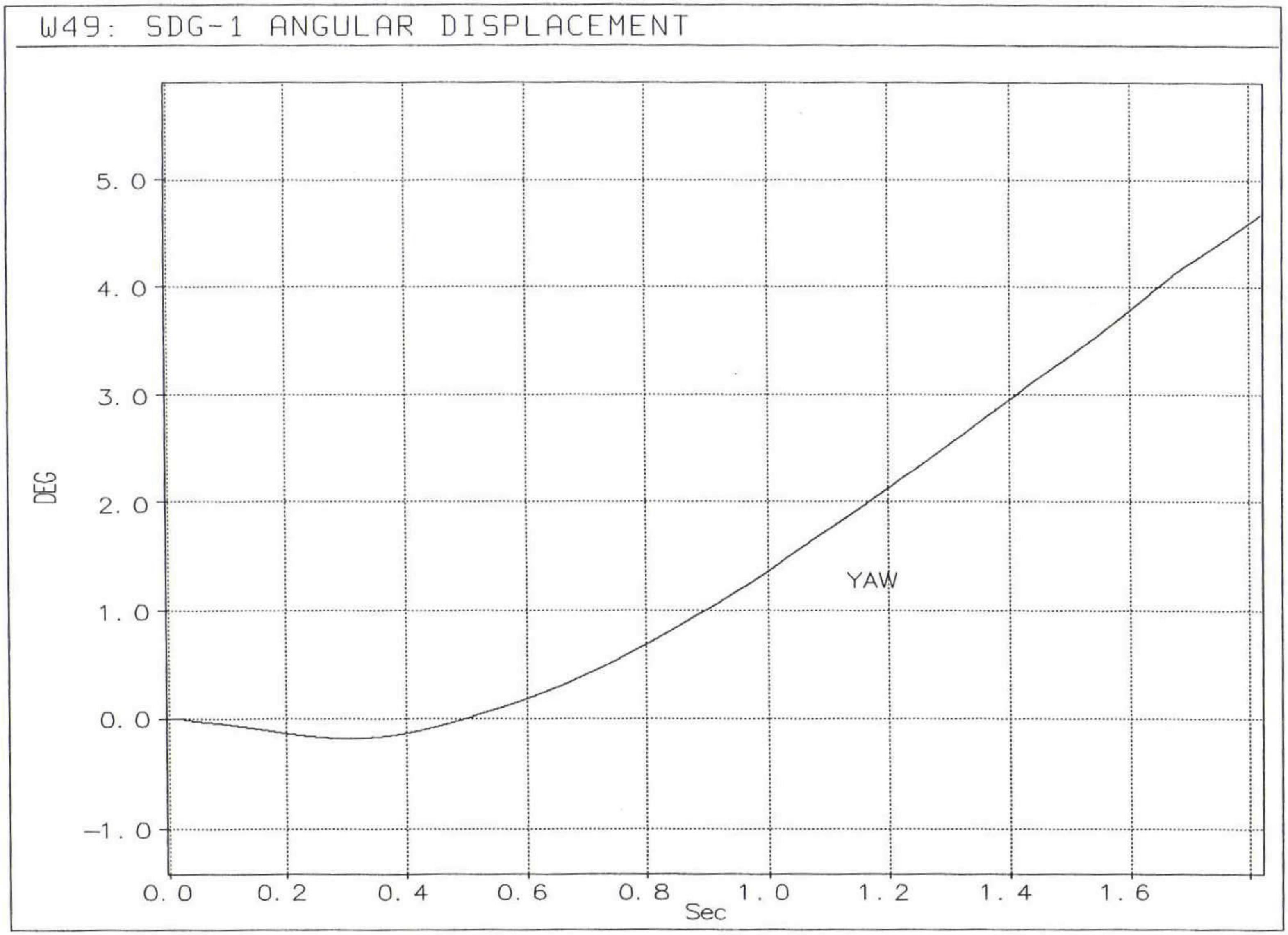

Figure A-6. Graph of Yaw Angular Displacement, SDG-1

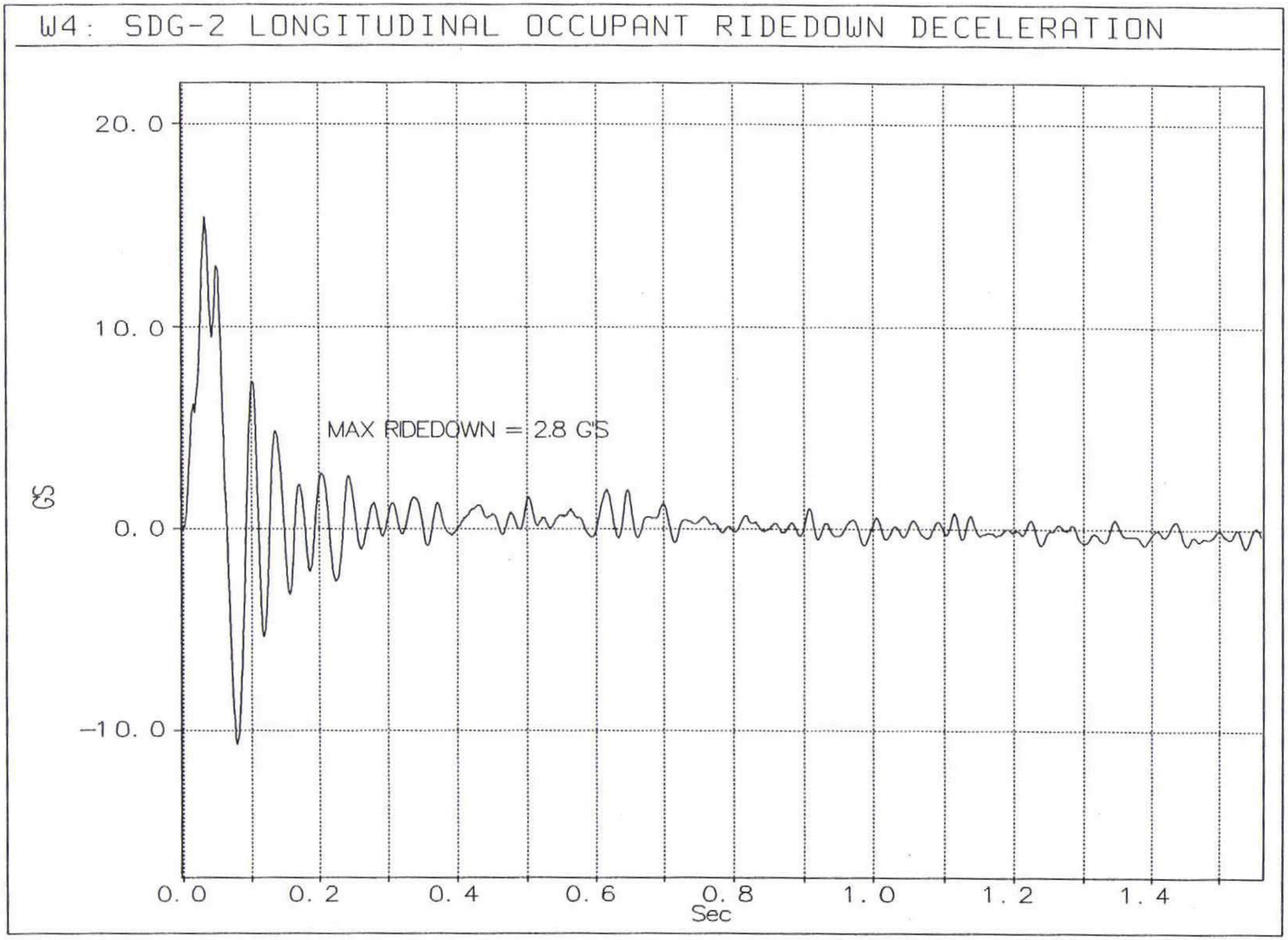

Figure A-7. Graph of Longitudinal Occupant Ridedown Deceleration, SDG-2

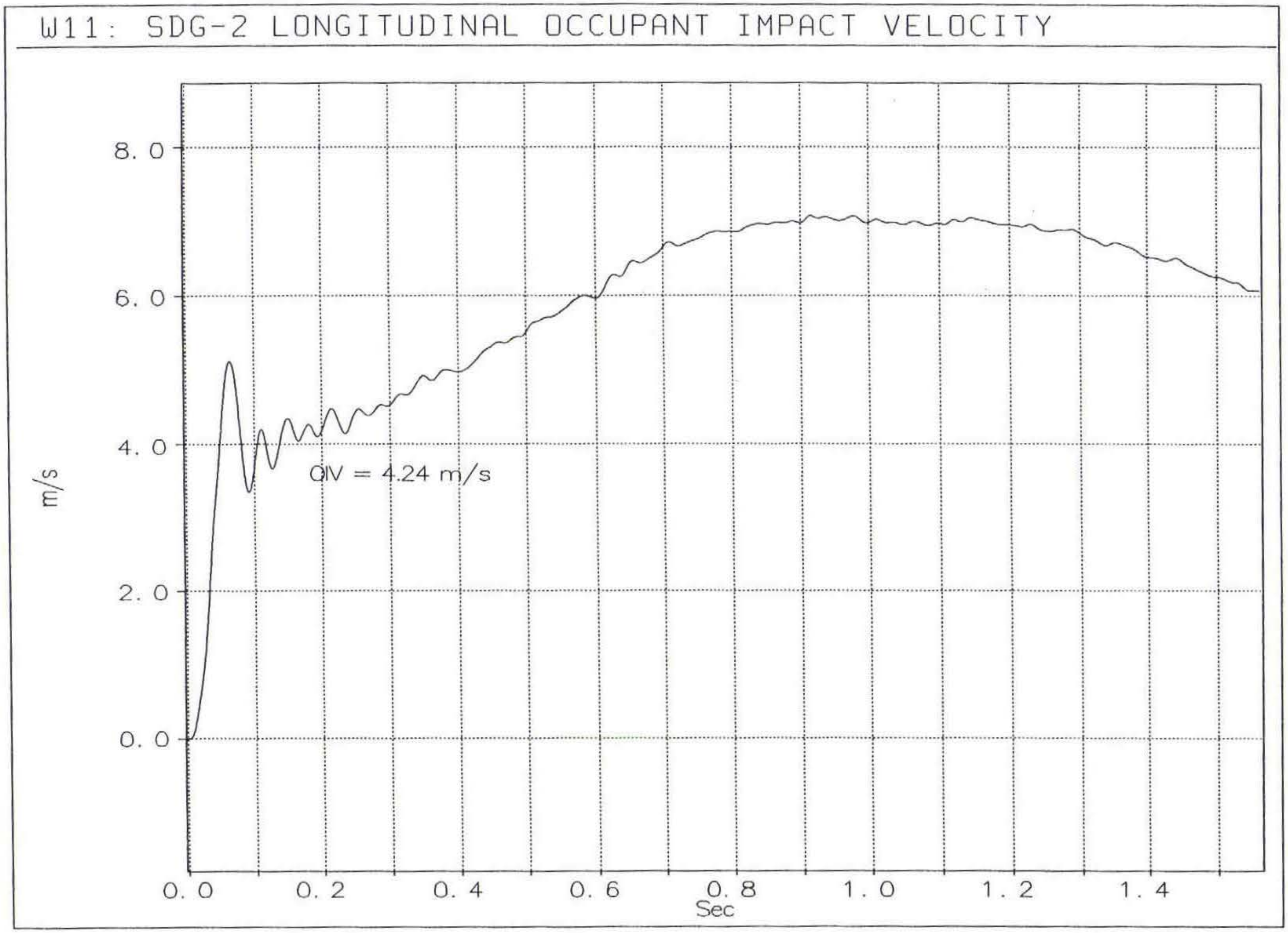

Figure A-8. Graph of Longitudinal Occupant Impact Velocity, SDG-2

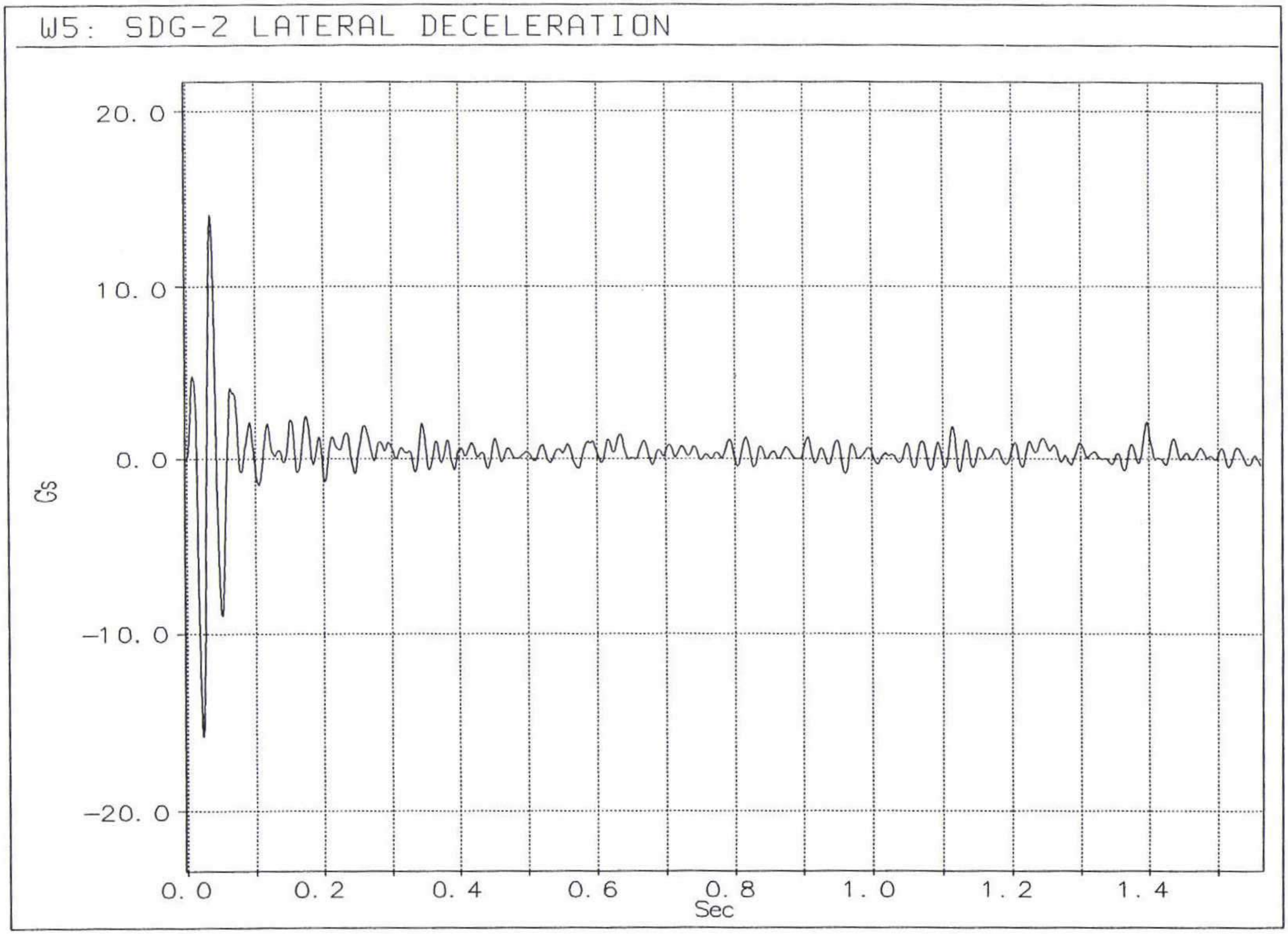

Figure A-9. Graph of Lateral Deceleration, SDG-2

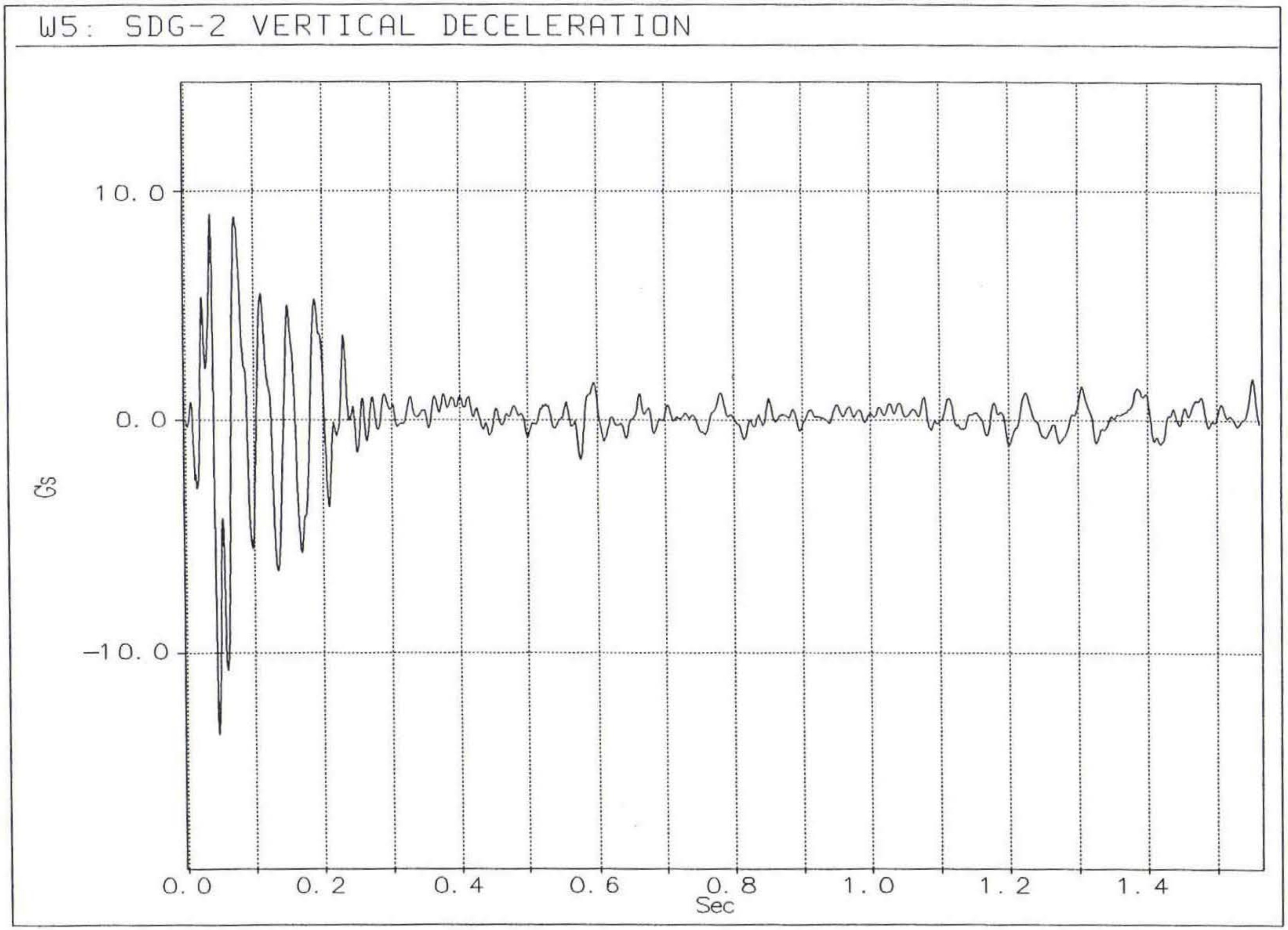

Figure A-10. Graph of Vertical Deceleration, SDG-2

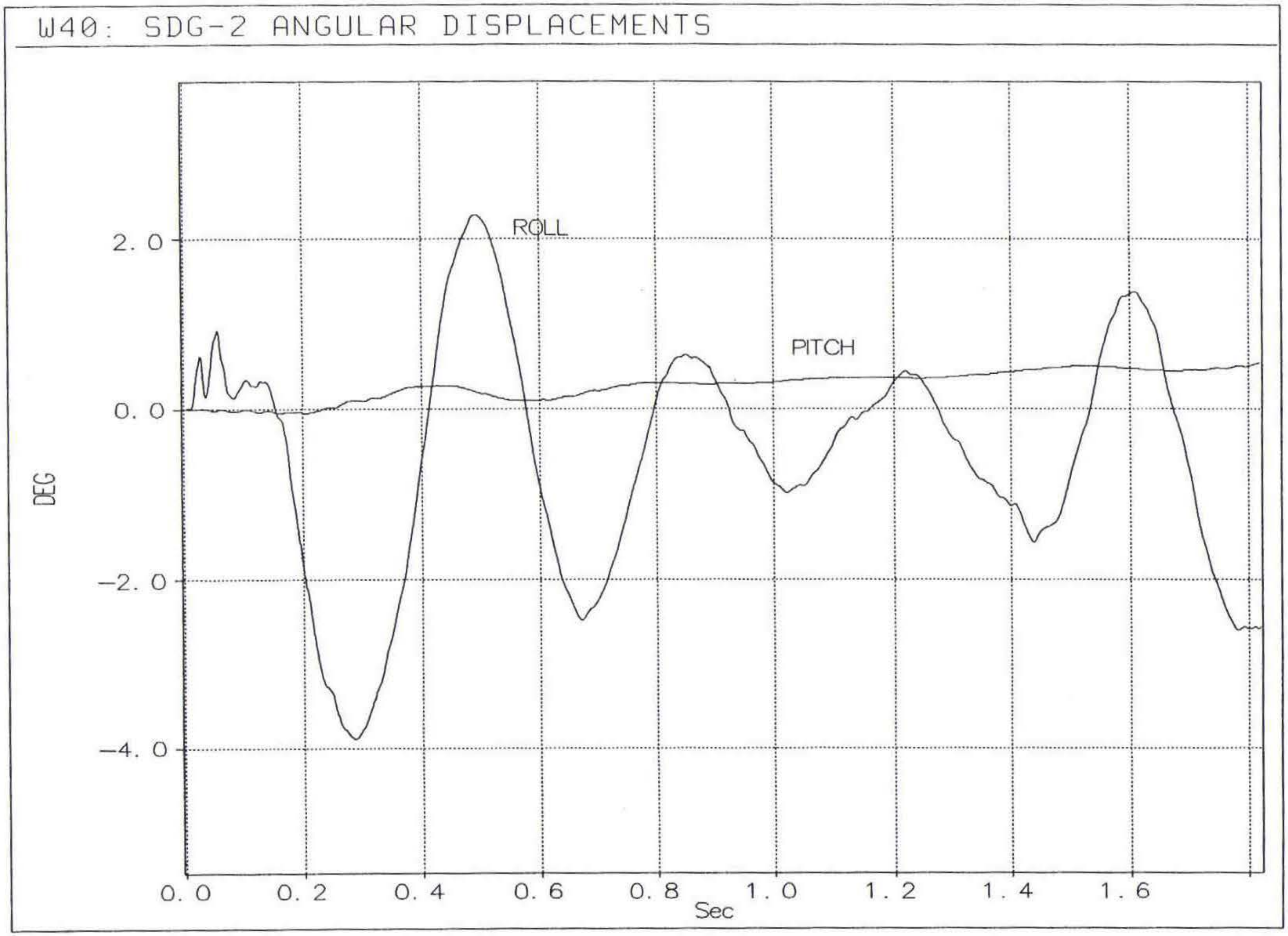

Figure A-11. Graph of Roll and Pitch Angular Displacements, SDG-2

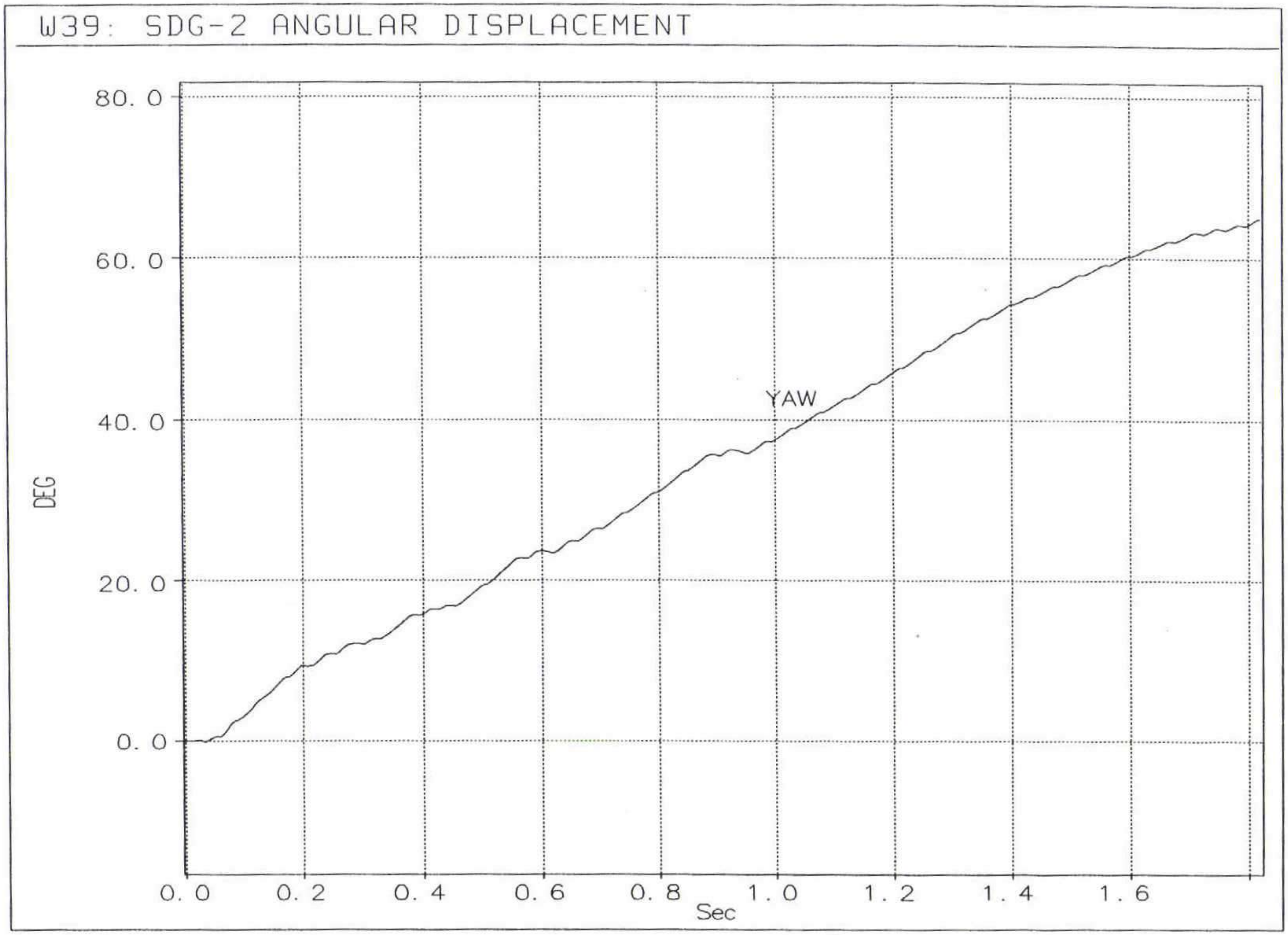

Figure A-12. Graph of Yaw Angular Displacement, SDG-2