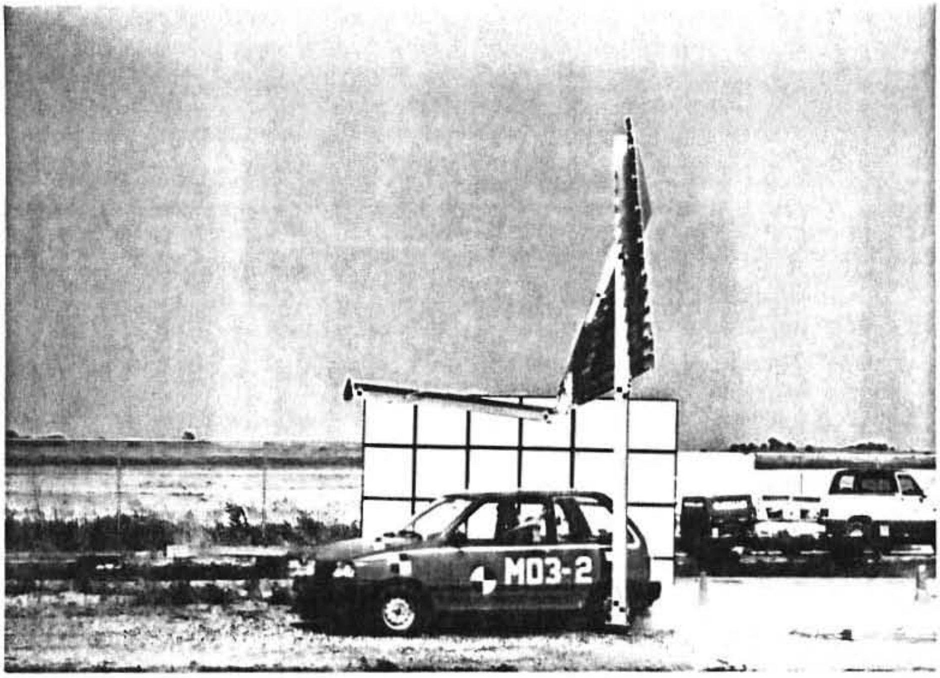
Design and Testing of a Dual Support Breakaway Sign



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9. Abstract

The Missouri Highway Transportation Department (MHTD) has been using a dual leg breakaway roadside sign supports with a perforated tension fuse plate. A very important feature of this system is the ability of its support to release upon impact and swing up and out of the way when impacted by an errant vehicle. Another critical feature of the sign system is its ability to withstand wind loads without causing structural damage to the system. A modified dual support breakaway sign system is proposed which improves both of these criteria.

Recently, MHTD added a multi-directional slip base to the breakaway sign design details. MHTD wished to evaluate the performance of the multi-directional slip base and the dual support breakaway system when impacted by a vehicle at some angle other than perpendicular to the face of the sign, to correspond to actual roadside data.

Two full-scale vehicle crash tests were conducted on the dual support breakaway sign and multi-directional slip base. The safety performance of the system was determined to be acceptable according to criteria set forth by National Cooperative Highway Research Program (NCHRP) Report No. 350, *Recommended Procedures for the Safety Performance Evaluation of Highway Features*.

Changing the material of the fuse plate from ASTM A36 steel to A572 Grade 50 steel created a stronger connection that significantly improved the wind load capacity of the sign system without hindering its safety performance.

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1 INTRODUCTION

1.1 Problem Statement

Dual support breakaway signs have been used across the country for over 25 years now, and have been credited with saving many lives. A very important feature of this system is the ability of its support to swing up and out of the way when impacted by an errant vehicle. Not only must the support break away easily at the base, it must swing away without becoming a projectile or impacting the vehicle a second time. Another critical feature of the sign system is its ability to withstand wind loads without causing any structural damage to the system.

Multi-directional slip bases for breakaway supports have existed for many years, as well. However, their safety performance when used in conjunction with dual support highway signs with ground mounted wide-flanged posts and attached fuse plates had not been previously evaluated. In addition, the Missouri Highway Transportation Department (MHTD) wished to evaluate the performance of the multi-directional slip-base and the dual support breakaway system when impacted by a vehicle at some angle other than perpendicular to the face of the sign, as this occurs frequently in actual accidents.

Further investigation into the fuse plate design was recommended in a 1993 report by the Midwest Roadside Safety Facility (MwRSF) (1). Concerns were expressed that the fuse plate currently employed in the breakaway systems used by MHTD would fail under design wind loads.

1.2 Objective

There were two major objectives of this research: to increase the wind load capacity of the dual support breakaway sign without reducing the quality of the hinge mechanism, and to determine the safety performance of a multi-directional slip base on the improved sign.

1.3 Scope

Prior to full scale crash testing, laboratory testing as well as structural analysis was performed in order to determine optimum design recommendations for specifying the material and design details of the fuse plate. This included an analysis of the wind loads on the sign, and component tests on various candidate fuse plates.

The performance of the highway sign was evaluated by impacting one post of the sign with a vehicle from a direction of 25 degrees perpendicular to the face of the highway sign with a 400-mm vehicle offset toward the passenger's side. Two full-scale vehicle crash tests were conducted with the designed fuse plate and multi-directional slip base using an 823-kg (1790-lb) mini-compact sedan at target speeds of 35 kph (21.7 mph) and 100 kph (62 mph). The safety performance was evaluated from criteria set forth by National Cooperative Highway Research Program (NCHRP) Report No. 350 (2).

2 BACKGROUND

In the early 1960s it became apparent that rigid sign supports were unsafe roadside appurtenance, as impacts with such signs by errant vehicles resulted in numerous fatalities. In order to resolve this problem, the Texas Transportation Institute (TTI) began to investigate the use of breakaway structures in roadside signs.(3)

A very important feature of the breakaway system is the ability of its support to swing up and out of the way when impacted by an errant vehicle. The support must not only break away easily at the base, but it must swing away without becoming a projectile or impacting the vehicle a second time. Today, the most common sign supports are made of steel W-shapes with a 4-bolt slip base and a plastic hinge located just under the sign.

During the first iteration of the hinge mechanism, the W-shape was cut entirely in half just below the sign. The front and back flanges were then reconnected with cast iron plates. When this system was impacted during a full scale vehicle crash test, both cast iron plates fractured, and the post support completely disengaged from the sign. As a result, the support fell on the test vehicle as it passed under the sign, breaking the windshield and deforming the roof of the vehicle. The need for a yielding hinge versus a fracturing hinge became evident during this test.

The yielding hinge was created by cutting through the front flange and web of the W-shape beam, and then reconnecting the front flange with a fuse plate. The concept is to design this fuse plate so that the post will be strong enough to withstand wind loads, but weak enough to fail when the support is impacted by a vehicle. Upon failure of the fuse plate, the support rotates about the back flange, and the support swings up and out of the way of the vehicle.

In the yielding hinge design, the first fuse plate was a cast-iron plate, shown in Figure 1. The fuse plate was bolted to the front face to provide support against wind loads, but would fracture when the post was impacted by a vehicle. Crash tests on this system were successful (3), however difficulties in casting, handling, bolting and maintaining cast-iron fuse plates led researchers to consider other alternatives.

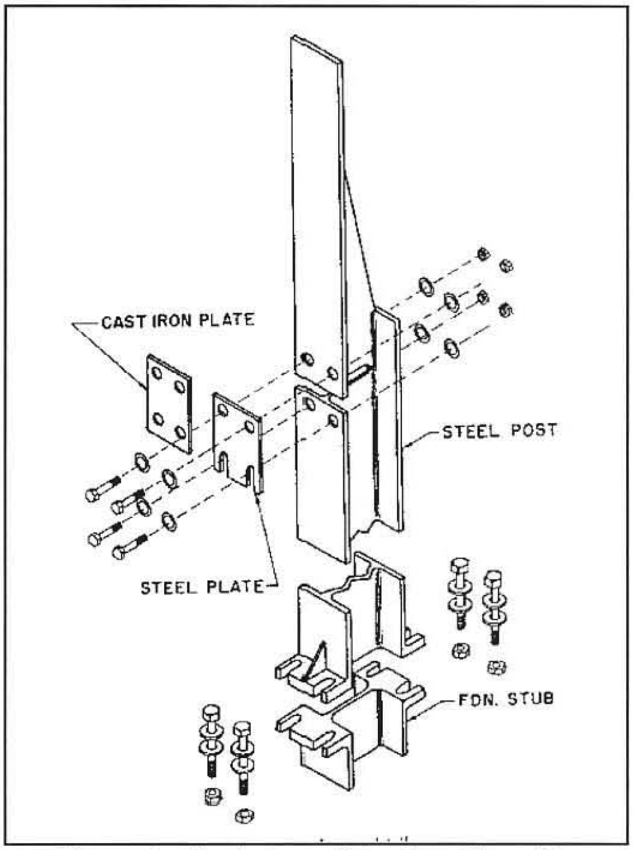


Figure 1. Evolution of the Fuse Plate (3).

A friction fuse plate was then developed to replace the cast-iron plate. A standard 9.5-mm ($\frac{3}{8}$-in.) thick ASTM 441 steel plate, also shown in Figure 1, was cut with the bottom two holes notched so that the plate would slip under impact. The operation of this fuse plate is based on the frictional resistance between the bolts, the plate, and the support. Several static tensile load tests were performed on the steel slip plate to verify that it would withstand design wind loads (4). This support performed well initially, but after a number of years the bolts became loose, and wind forces caused the hinge to fail, resulting in signs folding over during moderate wind storms. This problem was recognized and an alternate design to the steel slip plate was developed.

In 1984, TTI developed a breakaway sign that consisted of a steel, perforated tension fuse plate (5). The development of this system consisted of nine static tensile tests to determine the proper material and cross-sectional area of the plate. One full-scale vehicle crash test was conducted with an 828-kg (1800-lb) vehicle at 32.2 kph (20 mph) on the new design. The fuse plate did not activate during this test, but all of the safety criteria were met, so the system was approved for use.

The state of Missouri used this design on its highway systems from 1985 to 1989 and had numerous reports of the hinge failing to activate when the support was impacted by an errant vehicle. In 1990 this perforated tension fuse plate was modified by reducing the effective cross-sectional area, allowing it to fail when subjected to a smaller load. In 1993, by request of MHTD, MwRSF subjected this modified design to a series of full-scale vehicle crash tests to confirm its successful performance (1). Researchers verified the successful crash performance of this new design; the design easily passed all of the safety criteria. However, concerns were raised about the wind load capacity of the new fuse plate. Further analysis was recommended to create a design that would satisfy the wind load as well as meet the safety criteria.

Recently, MHTD began to use multi-directional slip bases on their dual support signs, as opposed to a rectangular slip base. The multi-directional slip base is triangular in shape and utilizes three slip bolts, as opposed to the four slip bolts used in the rectangular slip base. This system had not yet been tested according to NCHRP 350 specifications.

3 ANALYSIS AND DESIGN

3.1 Wind Load Analysis

Highway signs must be designed to withstand high wind loads. On breakaway signs which incorporate a fuse plate a contradiction occurs in the design of the fuse plate. It is desired that the fuse plate be strong to withstand the wind loads, but weak enough that it fails under impact of an errant vehicle. The following discussion will outline the minimum requirements the fuse plate must meet in order to support the wind loads.

3.1.1 Calculation of Wind Load

Figure 2 shows a schematic drawing of the sign system. The maximum force in the fuse plate, F_p, can not exceed the product of the material yield strength, S_y, and the cross-sectional area, A, of the fuse plate.

$$F_p \leq S_y A \tag{1}$$

Using statics, a summation of moments about the hinge point yields a relation for the force in the fuse plate. It was assumed in this calculation that the hinge point is fixed at 152 mm (6 in.).

$$F_p = F_s \frac{\frac{h}{2} + 0.1524}{s} \tag{2}$$

The effective static force on each support can be calculated from the pressure.

$$F_s = \frac{1}{2}(P \cdot h \cdot w) \tag{3}$$

The method used to determine the wind load on the sign is described in *Standard Specifications for Structural Supports for Highway Signs, Luminares, and Traffic Signals*, 1994 (6). According to this specification, the pressure exerted on a sign by the wind can be computed using the following formula:

$$P = 0.0474(1.3V)^2 C_d C_h \quad (4)$$

where:

P = Wind Pressure (Pa)

V = Wind Speed (kph), n-year mean recurrence interval (the factor 1.3 is a safety factor that accommodates for wind gusts of 30%)

C_h = Coefficient relating to the elevation of the sign

C_d = Drag Coefficient

According to AASHTO (6), the maximum wind speed in Missouri and across most of the United States is 112.6 kph (70 mph), so this value was used in the calculations. The coefficient of drag, C_d, and the elevation coefficient, C_h, depend on the geometry of the sign as shown in Tables 1 and 2, respectively.

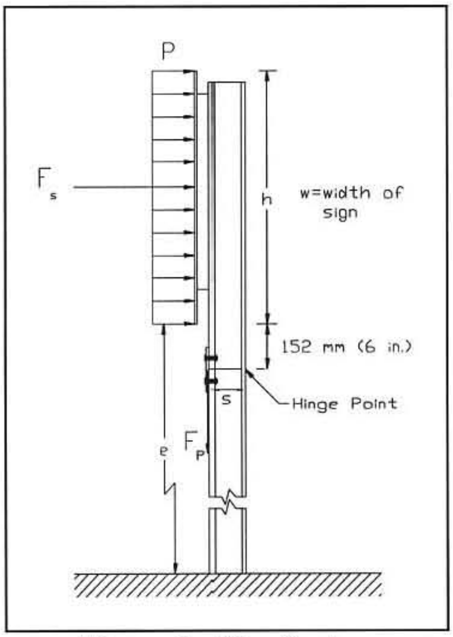


Figure 2. Sign System

e = Elevation of sign (in meters)

h = Height of Sign (in meters)

w = Width of Sign (in meters)

s = Hinge Length (in millimeters)

F_s = Effective Wind Force on the Sign

F_p = Force in the Fuse Plate

Table 1. Drag Coefficient

$\frac{w}{h}$	C_d
1.0	1.13
2.0	1.19
5.0	1.20
10.0	1.23
15.0	1.30

Table 2. Elevation Coefficient

$e+\frac{h}{2}$	C_h
0-4.6 m	0.8
4.6-9.1 m	1.0
9.1-15.2 m	1.10
15.2-30.5 m	1.25
30.5-91.4 m	1.50

The state of Missouri implements six different post sizes on breakaway systems. For each of these post sizes, the hinge length, *s*, and the cross-sectional area, *A*, varies for each post configuration. The details of each configuration are illustrated in Table 3.

Table 3. Post/Fuse Plate Configurations

Post Configuration	**Post Size**	**Fuse Plate Area mm² (in.²)**	**Web Thickness (*Hinge Length*) mm (in.)**
1	W6x9	121 (0.1875)	149 (5.875)
2	W6x15	161 (0.25)	152 (6.000)
3	W8x18	161 (0.25)	206 (8.125)
4	W10x22	252 (0.39)	257 (10.125)
5	W10x26	252 (0.39)	263 (10.375)
6	W12x26	252.0 (0.39)	211.2 (12.250)

3.1.2 Wind Load Charts

The Wind Load Charts show the maximum sign size each post configuration can withstand based on the fuse plate material and the elevation height (also known as clearance height). Equations 1-4 and Tables 1-3 can be used to construct wind load charts for any variety of fuse plate material and clearance height. One such example, for an A36 steel fuse plate with a sign elevation of 2.44 m (8 ft) is shown in Figure 3. The different lines on the figure represent the different post size configurations listed in Table 3. Note that the sign systems in this study are all dual post configurations.

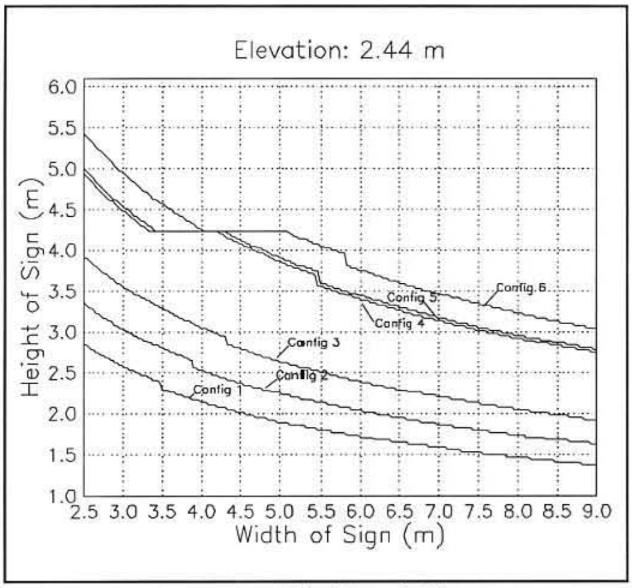


Figure 3. Wind Load Chart.

The Wind Load Charts are used by finding the point on the chart corresponding to the height and width of the sign which is of interest. The curve directly above this point represents a post configuration with an accompanying fuse plate that will support the wind loads incurred with a sign of such a size. For example, if you plan to install a sign that has a clear height of 2.44 m (8 ft) and is 4.88 m (16 ft)wide and 2.44 m (8 ft) high, then the Wind Load Chart specifies the use of 2-No. 3 posts.

3.1.3 Missouri Post Design Charts

The Missouri Post Design Charts (7) are currently used by MHTD to determine the proper post configuration for a certain sign size. There are several charts to use depending on the elevation, or *clear height* of the sign. Figure 4 shows one such chart for a clearance height of 2.44 m (8 ft). Once again, the chart shown depicts only dual leg sign systems. This chart is used in the same manner as the Wind Load Charts.

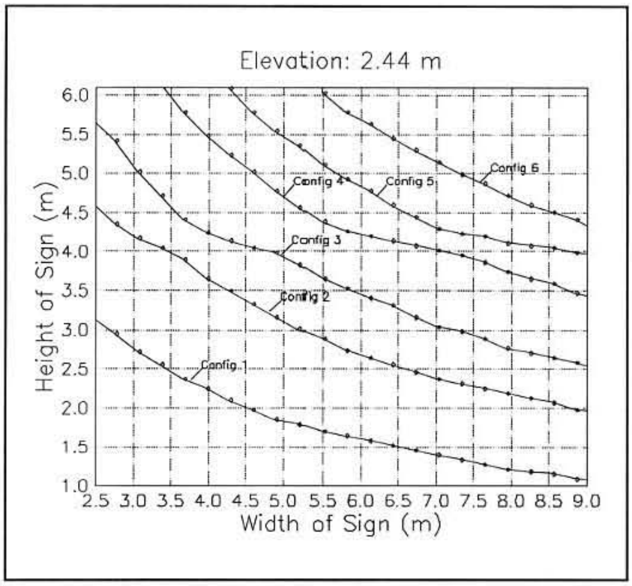


Figure 4. Missouri Post Design Charts.

3.1.4 Comparison of Post Design Charts

The Wind Load Charts and the Missouri Post Design Charts were each constructed in a different manner. Ideally, the post configuration specified by the Missouri Design Charts should be able to withstand the loads due to wind. Figure 5 shows that this is not the case. The demarcation lines for the Missouri Charts often lie well above the Wind Load lines. This indicates that, under the existing design criteria, the Missouri Design Charts do not always meet the wind load conditions. In order to alleviate this problem, alternative steels were examined as possible replacements for the A36 steel currently being used.

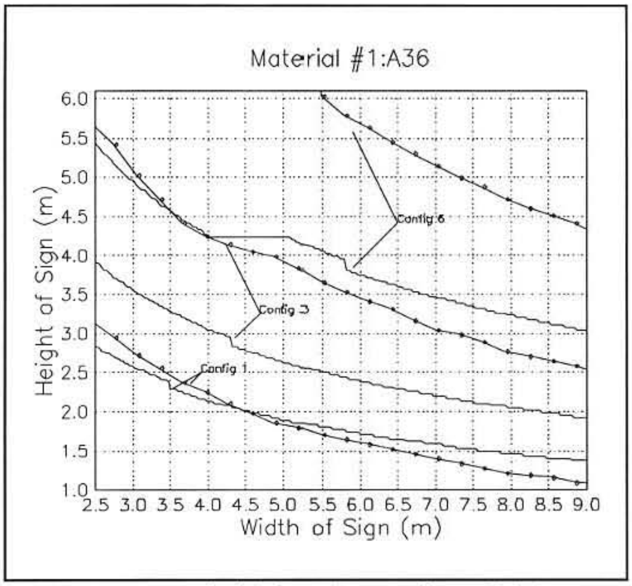


Figure 5. Wind Chart Comparison, 2.44 m.
Missouri chart lines have markers.

3.2 Fuse Plate Materials

Preliminary iterations, using equations 1-4, showed that if the fuse plate material had a yield strength of 410-450 MPa (60-65 ksi) it would support the wind loads adequately for smaller post configurations. Three different steel materials that met this criteria were examined, as well as the original material A36 steel. These materials and their manufacturer specified properties are listed in Table 4.

Table 4. Material Properties.

No.	Material ASTM Designation	Yield Strength MPa (ksi)	Ultimate Strength MPa (ksi)	% elongation
1	A36	284 (41.2)	410 (59.6)	25%
2	A572 Grade 50	462 (67.0)	537 (78.0)	27%
3	A516.86 Grade 70	424 (61.5)	562 (81.5)	18%
4	A514-87 Grade B	800 (116)	833 (121)	20%

After choosing these materials, wind load charts were constructed for each material, at an elevation of 2.44 and 6.10 m (8 and 20 ft), for post configurations 1, 3, and 6. These charts are shown in Appendix A, the Missouri Post Design Charts are superimposed on the charts for comparison purposes.

When calculating the wind load charts, the thickness of the plate for Material No. 4 was reduced from 4.76 mm (0.1875 in.) to 2.54 mm (0.1 in.) so that this material would have a yield force comparable to the materials with lower yield strength. This modification provides an effective Yield Strength of 426 MPa (61.9 ksi) in Material No. 4.

With the candidate materials, the Missouri Post Design Charts satisfied the wind load criteria to a greater degree than the current material (A36 steel). At an elevation of 6.10 m (20 ft), there are no wind load problems. However, at an elevation of 2.44 m (8 ft), the new materials do not always meet the wind load criteria for larger signs. The three candidate materials all satisfied the criteria to nearly the same degree. Material No. 2 (A572 steel) satisfies the criteria slightly better than the other materials.

3.3 Component Testing of Fuse Plate

After it was shown that the three candidate materials significantly improved the wind load capacity, component tests were performed. This was done to study how the candidate materials would behave under the dynamic loading that they would be subjected to on a sign impacted by an errant automobile.

3.3.1 <u>Test Setup</u>

To test the dynamic properties of the fuse plate, a W6x9 wide flange beam was cut and fit with a fuse plate according to Missouri design plans. Fuse plates were fabricated from each of the four test materials discussed in Table 4. The thickness of the plate for Material No. 4 was reduced from 4.76 mm (0.1875 in.) to 2.54 mm (0.1 in.) by scoring the plate across the face to reduce the cross-sectional area at the middle of the plate where the failure occurs. This was done so the physical test sample corresponded with the wind load analysis on the material, as discussed in Section 3.2.

To attain a high activation speed, a 15-ton crane outfitted with an 8:1 cable/pulley system was used to pull the end of the post leg. The test configuration is shown in Figure 6.

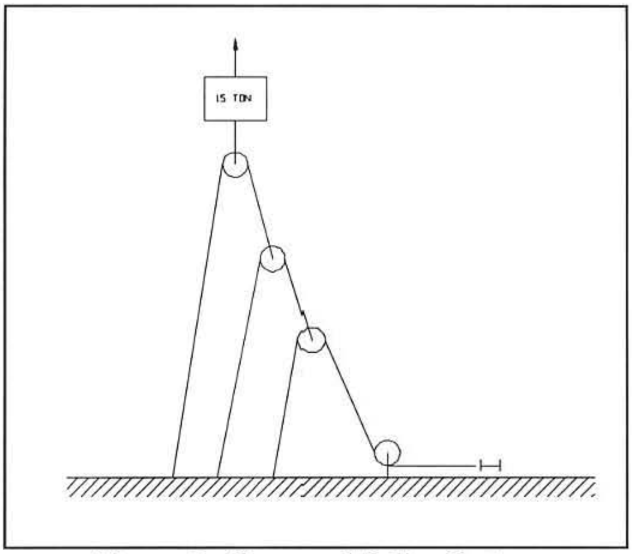


Figure 6. Crane and Pulley System

The cable was connected to the beam 711 mm (28 in.) from the hinge point (Figure 7). The crane alone had a travel speed of approximately 74 mm/sec (2.9 in./sec) and with the pulley system intact it would pull the end of the beam 589 mm/sec (23.3 in./sec). This would produce a speed equivalent to a 5.1 kph (3.2 mph) impact by an automobile 1753 mm (69 in.) below the hinge point. 1753 mm (69 in.) is the distance between the bumper of an average mini-compact car to the hinge point of a sign mounted 2.44 m (8 ft) off of the ground.

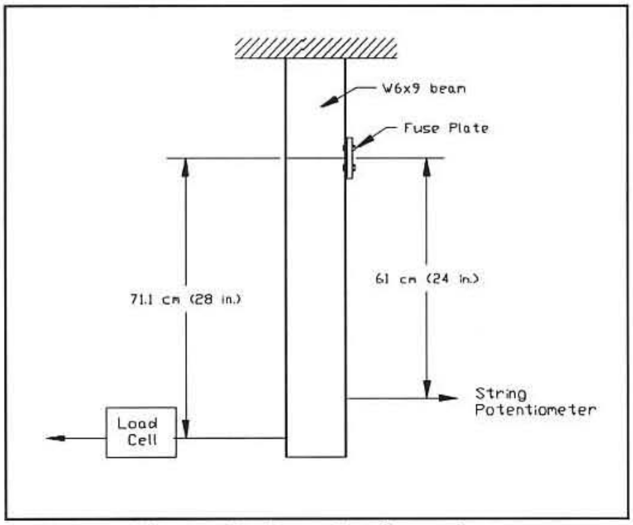


Figure 7. Test Configuration.

3.3.2 Data Acquisition System

To acquire the necessary force and deflection data, a string potentiometer and load cell were used. A 44.5 kN (10 kip) load cell was placed in series with the cable/pulley system. A 3810-mm (150-in.) string potentiometer was attached to the beam 610 mm (24 in) from the hinge point. The signals from each instrument were sampled at 1250 Hz.

3.3.3 Results and Discussion

Three tests, termed dynamic tests, were run on each material with the setup described above. Three additional tests, termed static tests, were run by removing the intermediate pulleys, which yielded a simple 2:1 cable/pulley system. The results from the tests are displayed in Appendix B. The peak force and energy absorption for each material is given in Table 5.

By analyzing the string potentiometer data, it was discovered that the actual activation speed of the end of the beam was 51 mm/s (2 in/s) which was much slower than expected. This speed correlates to an automobile impacting at 0.5 kph (0.33 mph). The static test yielded a speed of one-half of the dynamic test.

Recall that one of the purposes of the fuse plate is to fail when impacted by an errant vehicle. The exact force level the plate undergoes under impact is unknown, therefore, the best material is that which fails at the lowest force level during the physical tests.

From the charts in Appendix B, Material No. 4 fails at the lowest force level and lowest energy level of the three alternative materials. However, additional manufacturing concerns eliminated this material from consideration. A514-87 steel is a high strength steel that would have to be galvanized in a different process than the wide flange posts and other parts of the breakaway sign system. This factor, in addition to the relative unavailability of the material, would result in additional costs that did not appear to outweigh the benefits of the lower force level.

The elimination of Material No. 4 from consideration left two materials remaining. Because Material No. 2, A572 Grade 50, failed at a lower force and energy level than Material No. 3; and because it provides superior wind load capacity, it was the material of choice for full scale testing.

Table 5. Summary of Test Results

Material No.	ASTM Designation	Peak Force (kN)		Energy Absorption (kN-mm)	
		Static	Dynamic	Static	Dynamic
1	A36	10.36	10.85	297.8	347.4
2	A572 Grade 50	13.15	12.93	423.1	388.1
3	A516.86 Grade 70	14.24	14.00	476.5	480.6
4	A514-87 Grade B	10.69	11.35	284.6	276.9

4 FULL SCALE TEST CONDITIONS

Two vehicle crash tests were performed on the dual support breakaway sign system that incorporated the candidate fuse plate material (A572 Grade 50 steel). Additionally, the vehicle crash tests were performed at an impact angle of 25 degrees to test the safety performance of the multidirectional slip base.

4.1 Test Facility

4.1.1 Test Site

The testing facility is located at the Lincoln Air-Park on the NW end of the Lincoln Municipal Airport. The test facility is approximately 8.1 km (5 mi) NW of the University of Nebraska-Lincoln. The site is surrounded and protected by an 2.5-m (8-ft) high chain-link security fence.

4.1.2 Vehicle Tow System

A reverse cable tow with a 1:2 mechanical advantage was used to propel the test vehicle during the full scale vehicle crash tests. The distance traveled and the speed of the tow vehicle are one-half of that of the test vehicle. The test vehicle is released from the tow cable before impact with the sign support. The tow vehicle used in the test is equipped with a fifth-wheel speedometer apparatus. The 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.

4.1.3 Vehicle Guidance System

A vehicle guidance system developed by Hinch (8) was used to steer the test vehicle during the full-scale crash test. A guide flag attached to the right front wheel and the guide cable was sheared off before impact. The 0.95-cm (0.375-in.) diameter guide cable was tensioned to 13.4 kN (3,000 lbs), and supported laterally and vertically every 30.5 m (100 ft) by hinged stanchions. The hinged stanchions stood upright while holding up the guide cable, but as the vehicle was towed down the line, the guide-flag struck and knocked each stanchion to the ground. The vehicle guidance system was 215 m (700 ft) long for each test.

4.2 Missouri Dual Support Breakaway Sign Design Details

The installation of the Missouri Dual Support Breakaway Sign was constructed in accordance to 1994 Missouri Standard Plans for Highway Construction. Figure 8 shows a plan drawing of the system which consisted of four major components: (1) wide-flanged posts; (2) sign panel; (3) multi-directional slip base; and (4) fuse plate. The W6x9 wide flanged posts were 4.78 m (15 ft-8 in.) tall and extended from the anchored slip base to the top of the extruded aluminum sign panel. The 3.05-m (10-ft) wide by 2.44-m (8-ft) tall sign panel consists of 305-mm (12-in.) by 3.05-m (10-ft) long extruded sections. The sign panel is secured to each side of both posts every 305 mm (12 in.) with cast aluminum clips. The bottom of the sign was mounted 2.44 m (8 ft) above the ground surface. The hinge mechanism was located 76 mm (3 in.) below the sign. The hinge plate was constructed of 5 mm (0.1875 in.) thick A572 steel.

At the base of the sign post, a multidirectional, triangular slip base secured the sign to the ground. The slip base was secured to the anchor using three 16 mm (0.625 in.) diameter bolts torqued to 4030 kg-mm (345 in-lb). The slip bolts were held in place by a bolt retainer made from 30 gauge galvanized sheet metal. The height of the permanent slip base assembly was 102 mm (4 in.). The permanent slip base assemble was anchored in 1381 mm (15 in.) diameter by 0.91 m (3 ft) deep concrete footing.

4.3 Test Vehicle

The test vehicle used for Test MO3-1 and MO3-2 was a 1989 Ford Festiva. The test vehicle had a test inertial weight of 823 kg (1790 lbs). The vehicle dimensions are shown in Figure 9. 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. A surrogate occupant with a weight of 73.6 kg (160 lbs) was belted to the driver's seat for both of the tests. A remote controlled brake system was installed in the vehicle so it could be brought safely to a stop after the test.

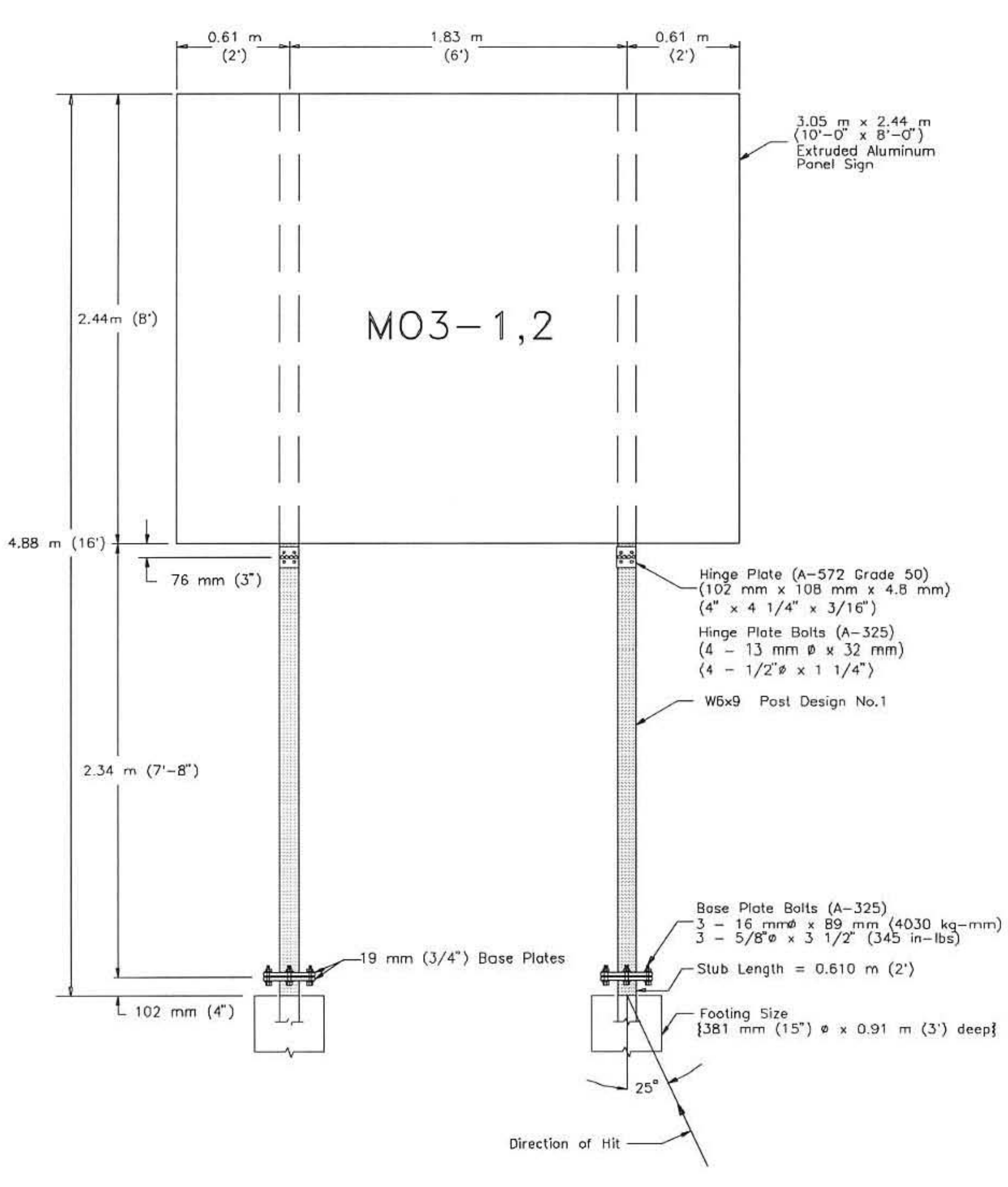
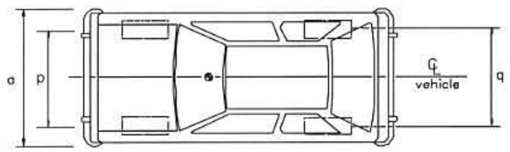
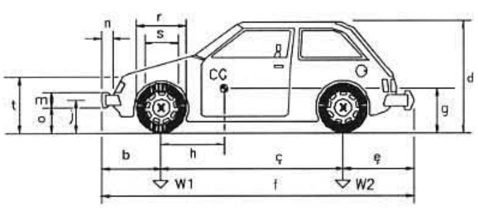


Figure 8. MO3-**1**,2 Test Installation.

Make:	Ford	Test No.:	M03-1,2
Model:	Festiva	Tire Size:	P145/80R12
Year:	1989	VIN:	KNJBT06K1K6143626
Date:	06/21/1995		





Vehicle Geometry
centimeters (in.)

a — 158.8 (62.5)	b — 62.2 (24.5)
c — 229.9 (90.5)	d — 142.2 (56.0)
e — 58.4 (23.0)	f — 350.5 (138.0)
g — 55.9 (22.0)	h — 83.8 (33.0)
j — 48.3 (19.0)	m — 15.2 (6.0)
n — 11.4 (4.5)	o — 40.6 (16.0)
p — 139.1 (54.75)	q — 139.1 (54.75)
r — 53.3 (21.0)	s — 33.0 (13.0)
t — 73.7 (29.0)	

Engine Size: 4 cyl.

Transmission: Manual

Mass kg (lbs)	Curb [1]	Test Inertial [2]	Gross Static [3]
W1	529 (1150)	522 (1135)	559 (1215)
W2	299 (650)	301 (655)	338 (735)
Wtotal	828 (1800)	823 (1790)	897 (1950)

Damage prior to test: NONE

[1] Curb – mass of test vehicle in its standard manufacture 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 9. Test Vehicle Dimensions.

4.4 Data Acquisition System

4.4.1 Accelerometers

A triaxial piezoresistive accelerometer system with a range of ±200 G's was used to measure the acceleration in the longitudinal, lateral, and vertical directions at a sample rate of 3,200 Hz. The environmental shock and vibration sensor/recorder system, Model EDR-3, was configured with 256 Kb of RAM memory and a 1,120 Hz filter. Computer software, "DynaMax 1 (DM-1)" and "DADiSP" were used to digitize, filter, analyze, and plot the accelerometer data. The data was filtered using a 180 Hz low pass filter and processed with a 10 ms moving average.

4.4.2 High Speed Photography

Four high-speed 16-mm cameras, with operating speeds of approximately 500 frames/sec, were used to film the crash test. A DC powered Locam, with a 76-mm lens, was placed approximately 75 m (250 ft) downstream of the impact point. A Locam, with a 12.5-mm lens was placed approximately 19 m (62 ft) perpendicular to the sign system. Two other Locams were placed to obtain closeup views of the critical components of the system. One Locam, with a 135-mm lens, was placed 20 m (65 ft) perpendicular to the system and focused on both slip base. A fourth camera was placed 10 m (33 ft) upstream from the sign system and focused on the fuse plate on the impacted post. The film was analyzed using a Vanguard Motion Analyzer.

4.4.3 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 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 could not be determined from the electronic data.

5 PERFORMANCE EVALUATION CRITERIA

The safety performance evaluation was conducted according to the guidelines presented in NCHRP Report 350 (2) and the 1994 AASHTO *Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals* (6). These guidelines, shown in Tables 6 and 7, require two compliance tests in order to evaluate the performance of a breakaway support. These two compliance tests are 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 impact angle for the full scale crash tests was changed to 25 degrees as this was determined to be the 80th percentile encroachment angle from accident data. In addition, the change in impact angle would also increase the severity of the impact and provide more insight in to the safety of the device.

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

Table 6. 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 7. AASHTO 1994 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 32 kph to 97 kph (20 mph to 60 mph) does not exceed 4.87 m/s (16 fps), but preferably does not exceed 3.05 m/s (10 fps)

6 FULL SCALE TEST RESULTS

6.1 Test MO3-1 (35.6 kph, 25 deg, offset 400 mm passenger side)

Test MO3-1 was conducted with a 1989 Ford Festiva under the impact conditions of 35.6 kph (22.1 mph) and 25 deg with respect to a line perpendicular to the face of the sign. The impact location, shown in Figure 10, was the offset 400 mm (15.75 in.) from the centerline of the vehicle toward the passenger's side of the vehicle. The vehicle impacted the sign system on the corner of the sign post. A summary of the test results and sequential photographs are shown in Figure 11.

The bumper of the car deformed for approximately 6 ms after impact at which point the slip base began to move. 14 ms after impact, the slip base was completely actuated, eliminating its effect on the vehicle. The slip base became completely clear from the stub at 34 ms. As the vehicle continued in a forward motion, the post remained straight as a large bend developed in the sign. At approximately 240 ms, the fuse plate failed and the sign post started to bend about the hinge. At 270 ms, the post lost contact with the vehicle and started to swing away. At 520 ms, the end of the post reached its highest peak and began to fall back down; however, the sign panel continued to rotate about the unimpacted post.

At 710 ms, the end of the post passed around the outside of the car on the driver's side. At 950 ms, the car was completely clear of the system. The sign panel continued to pivot around the unimpacted post until it became perpendicular to its original configuration at about 1.28 seconds. At 1.65 seconds the sign panel began to swing back towards its original position until it came to rest at 3.18 seconds.

Figure 12 shows the damage to the vehicle, which consisted of a maximum crush depth of 13 mm (0.5 in.) in the bumper. No other damage occurred to the vehicle and the bumper was replaced for test MO3-2. Damage to the sign is shown in Figure 13. The impacted support and corresponding fuse plate were destroyed when the hinge mechanism activated. The other support deformed during impact as the rest of the sign system rotated about it during impact. Both sign supports and fuse plates had to be replaced for the second test. The sign panel was replaced as well, even though it was undamaged.

The ridedown acceleration and occupant impact velocity were not applicable to this test since it was determined that the hypothetical occupant did not contact the dashboard within the time that sign was in contact with the vehicle. The results of the occupant risk, determined from accelerometer data, are summarized in Figure 11. The results are shown graphically in Appendix C. The appurtenance met the criteria set forth by NCHRP 350 Test Designation 3-60.

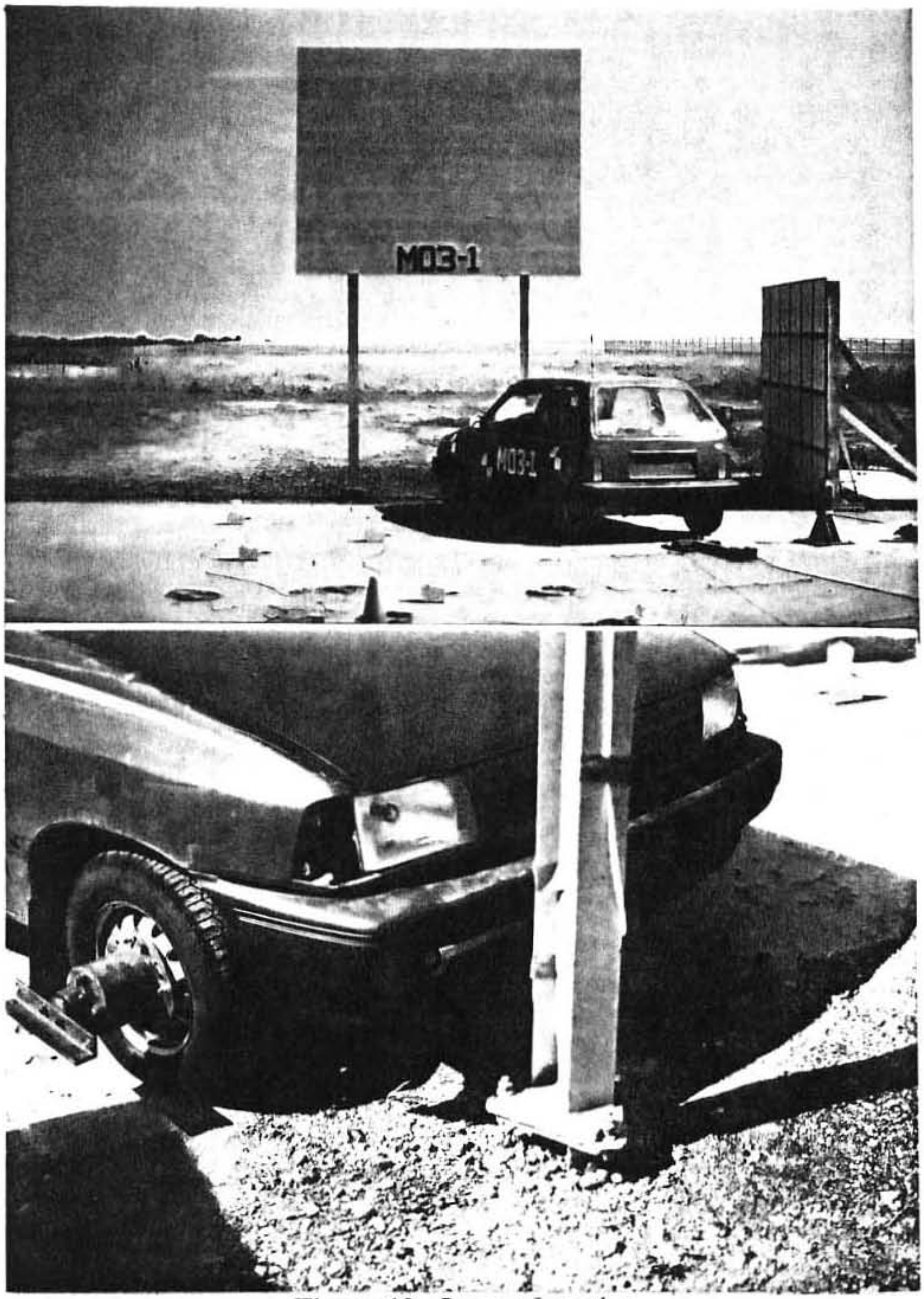


Figure 10. Impact Location

0 ms | 188 ms | 266 ms | 578 ms | 938 ms

Test Number	MO3-1
Test Date	6/21/1995
Appurtenance	Dual Steel Support Breakaway Sign
Sign Size	3.05 m x 2.44 m (10 ft x 8 ft)
Sign Mounting Height	2.44 m (8 ft)
Support Size	W6x9
Post Spacing	1.83 m (6 ft)
Perforated Tension Fuse Plate	
Location	76 mm (3 in.) below sign
Material	ASTM A572 Steel
Plate Thickness	4.8 mm (0.1875 in.)
Cross-Sectional Area	121 mm^2 (0.1875 in.^{2})
Triangular Slip Base Assembly	
Slip Bolt Size	15.9 mm (0.625 in.) dia.
Bolt Torque	39.0 N-m (345 in-lbs)
Stub Height	102 mm (4 in.)
Sign Panel	Extruded Aluminum
NCHRP 350 Vehicle Class	820C
Model	1989 Ford Festiva
Mass (Weight)	
Curb	828 kg (1800 lb)
Test Inertial	823 kg (1790 lb)
Gross Static	897 kg (1950 lb)

Vehicle Speed	
Impact	35.6 kph (22.1 mph)
Exit	32.6 kph (20.25 mph)
Vehicle Angle	
Impact	24.3 degrees
Exit	24.3 degrees
Vehicle Impact Location	400 mm (15.75 in.) right of center
Vehicle Snagging	None
Vehicle Stability	Satisfactory
Occupant Ridedown Deceleration	
Longitudinal	N/A (no occupant impact)
Occupant Impact Velocity	
Longitudinal	N/A (no occupant impact)
Vehicle Change in Speed	0.83 m/s (2.7 fps)
Vehicle Damage	
TAD (9)	1-FC-1
VDI (10)	01FRLN1
Vehicle Front-end Crush	13 mm (0.5 in.)
Sign Damage	Impacted Fuse Plate Destroyed Both Posts Bent

Figure 11. Summary of Test MO3-1.

Figure 12. Test Vehicle Damage, MO3-1.

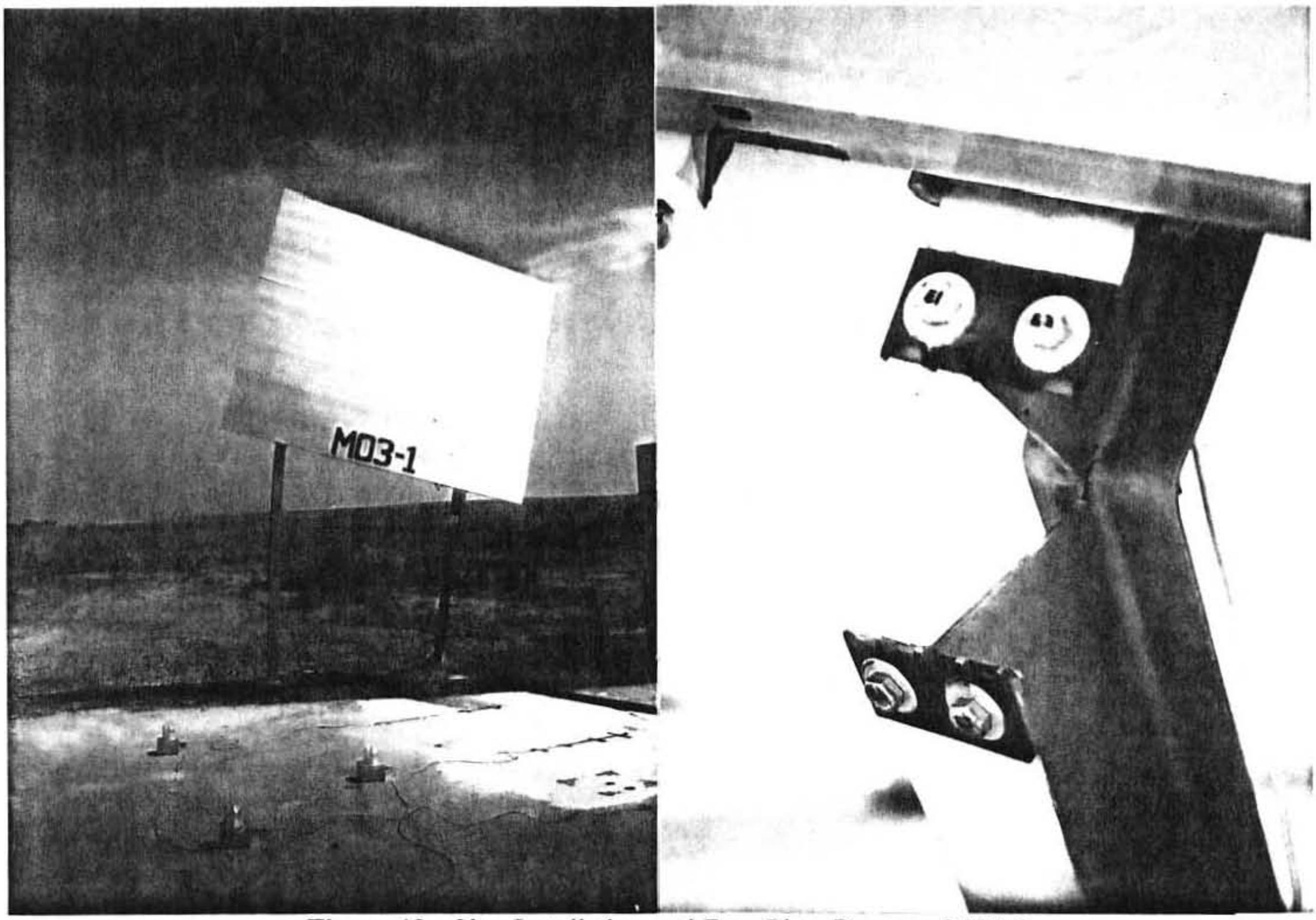


Figure 13. Sign Installation and Fuse Plate Damage: MO3-1.

6.2 Test MO3-2 (92.0 kph, 27.3 deg, offset 475 mm passenger side)

Test MO3-2 was conducted with a 1989 Ford Festiva under the impact conditions of 92.0 kph (57.2 mph) and 27.1 deg with respect to a line perpendicular to the face of the sign. The impact location was the offset 475 mm (18.75 in.) from the centerline of the vehicle toward the passenger side. The vehicle impacted the sign system at the corner of the sign post. The sign installation was constructed in the manner described in Section 4.2 A summary of the test results and sequential photographs are shown in Figure 15.

The car deformed for approximately 2 ms after impact at which point the slip base began to move. 6 ms after impact, the slip base slipped from all three bolts, eliminating its effect on the vehicle. The slip base became completely clear from the footing at 14 ms. Review of the fuse plate closeup film showed a gap developing in the web of the post at the fuse plate connection 4 ms after impact. The sign remained straight as the post began to bend and the fuse plate started to deform. At approximately 9.6 ms, the fuse plate failed.

At approximately 50 ms after impact, the post lost contact with the vehicle. At this point, the post had moved through an angle of 35 degrees. 82 ms after impact, the sign panel began to move, the sign developed a slight bend in it, and then started to rotate about the unimpacted post. At 219 ms, the car was completely clear of the system. The post continued to rotate about the hinge point at a high rate until it impacted the back side of the sign at 360 ms.

The sign panel rotated about the non-impacted post until it reached a point perpendicular to its original position at 700 ms. At 720 ms, the fuse plate on the non-impacted post failed due to the excess weight and swinging of the sign panel, at this point the sign began to fall to the ground. The sign system came to rest 1.9 seconds after initial impact.

Figure 14 shows damage to the vehicle consisting of a maximum crush depth of 76 mm (3.0 in.) in the bumper, and 38 mm (1.5 in) in the hood. No other damage occurred to the vehicle. The sign damage, shown in Figure 16, was extensive. Both fuse plates failed, and both sign supports were bent at the hinge point. The sign panel became damaged when it was impacted by the base of the post support.

The longitudinal occupant impact velocity and ridedown acceleration were not applicable to this test since it was determined that the hypothetical occupant did not contact the dashboard within the time that the sign was in contact with the vehicle. The results of the occupant risk, determined from accelerometer data, are summarized in Figure 15. The results are shown graphically in Appendix C. The appurtenance met the criteria set forth by NCHRP 350 Test Designation 3-61.

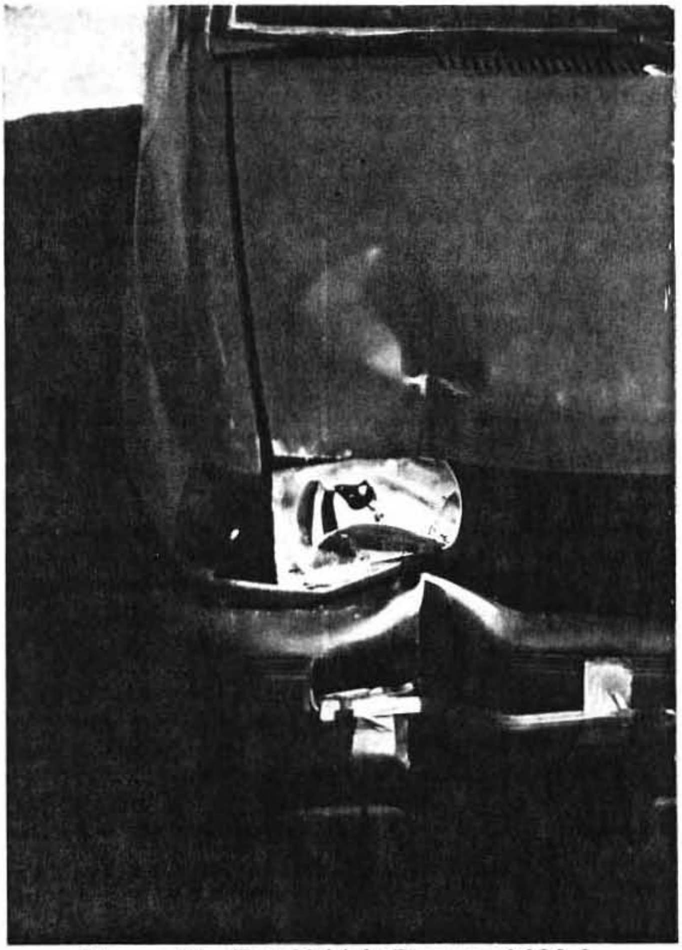
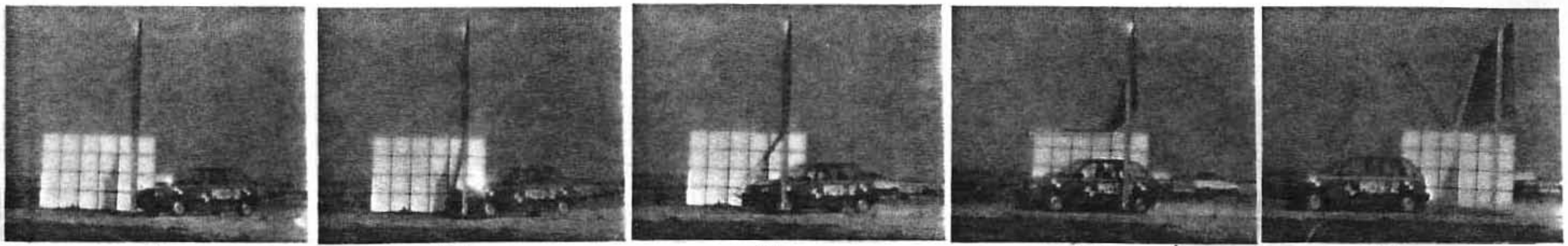


Figure 14. Test Vehicle Damage, MO3-2.



0 ms 24 ms 50 ms 127 ms 237 ms

Test Number	MO3-2
Test Date	6/21/1995
Appurtenance	Dual Steel Support Breakaway Sign
Sign Size	3.05 m x 2.44 m (10 ft x 8 ft)
Sign Mounting Height	2.44 m (8 ft)
Support Size	W6x9
Post Spacing	1.83 m (6 ft)
Perforated Tension Fuse Plate	
Location	76 mm (3 in.) below sign
Material	ASTM A572 Steel
Plate Thickness	4.8 mm (0.1875 in.)
Cross-Sectional Area	121 mm^2 (0.1875 $in.^2$)
Triangular Slip Base Assembly	
Slip Bolt Size	15.9 mm (0.625 in.) dia.
Bolt Torque	39.0 N-m (345 in-lbs)
Stub Height	102 mm (4 in.)
Sign Panel	Extruded Aluminum
NCHRP 350 Vehicle Class	820C
Model	1989 Ford Festiva
Mass (Weight)	
Curb	828 kg (1800 lb)
Test Inertial	823 kg (1790 lb)
Gross Static	897 kg (1950 lb)

Vehicle Speed	
Impact	92.0 kph (57.2 mph)
Exit	83.3 kph (52.1 mph)
Vehicle Angle	
Impact	27.3 degrees
Exit	27.3 degrees
Vehicle Impact Location	475 mm (18.75 in.) right of center
Vehicle Snagging	None
Vehicle Stability	Satisfactory
Occupant Ridedown Deceleration	
Longitudinal	N/A (no occupant impact)
Occupant Impact Velocity	
Longitudinal	N/A (no occupant impact)
Vehicle Change in Speed	2.35 m/s (7.7 fps)
Vehicle Damage	
TAD (9)	1-FC-1
VDI (10)	01FREN1
Vehicle Front-end Crush	76 mm (3.0 in.)
Sign Damage	Both Fuse Plates Destroyed
	Both Posts Bent
	Sign Panel Bent

Figure 15. Summary of Test MO3-2.

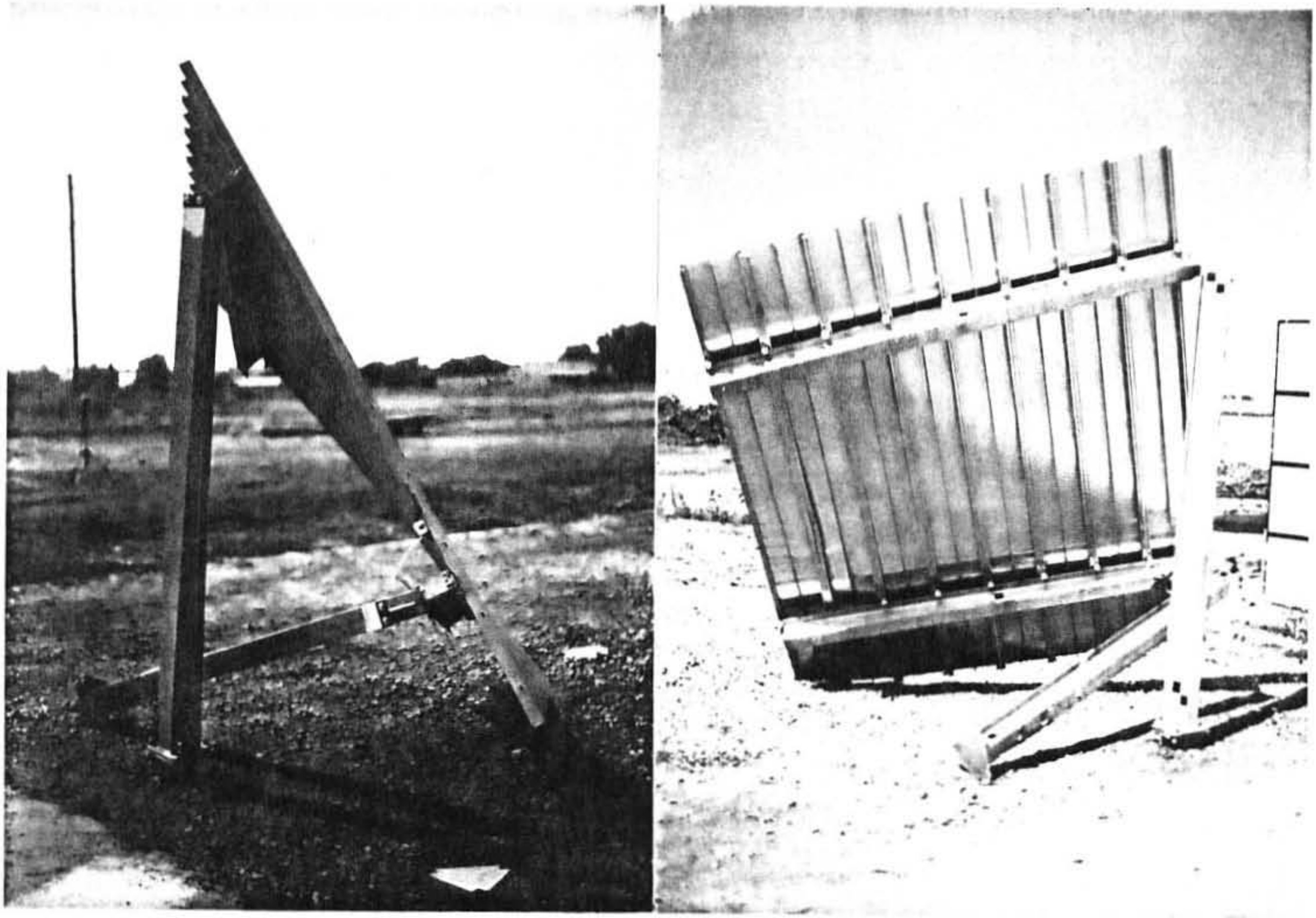


Figure 16. Sign Installation Damage: MO3-2.

7 CONCLUSIONS

The performance of the Missouri Dual Support Breakaway Sign was acceptable based on the requirements set forth by NCHRP Report 350 (2). The research study described herein clearly indicates that the system does not pose any significant hazard for vehicles impacting one of the supports at an angle. The multi-directional slip base performed as designed during the vehicle impact at 25 degrees.

Changing the material of the fuse plate creates a stronger connection that will satisfy the wind load criteria for smaller signs, and significantly improve performance for larger signs. The increased strength in the fuse plate did not hinder the safety performance of the fuse plate. During vehicle crash tests, MO3-1 and MO3-2, the fuse plate performed as designed under the impact conditions.

8 RECOMMENDATIONS

To further improve the wind load capacity of dual support signs additional research is required. Implementing higher strength materials, or increasing the cross-sectional area of the fuse plate, will create a more rigid connection, which may not activate upon impact of an errant vehicle. Therefore, alternative designs must be sought to improve the wind load capacity of larger signs. One such alternative is the balanced hinge point, shown in Figure 17 (11), where the hinge point is located in line with the effective wind load, eliminating all moment from this force.

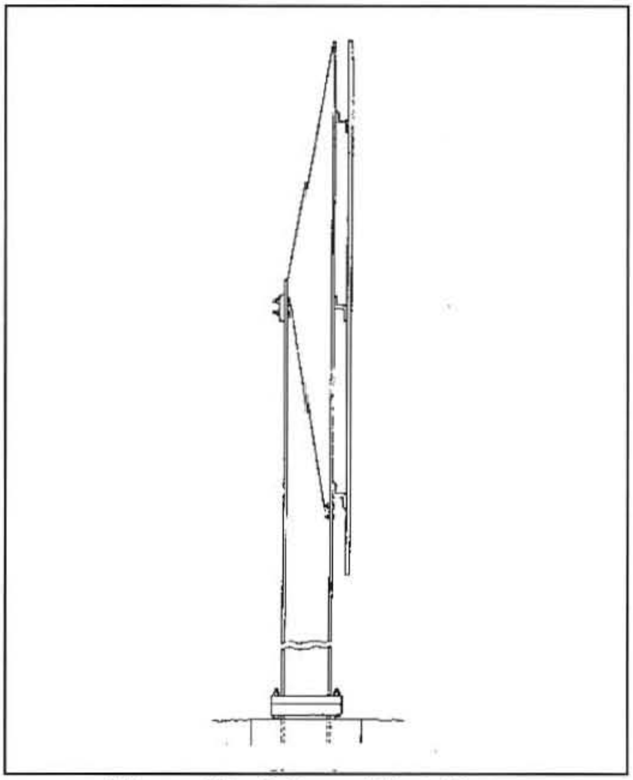


Figure 17. Balanced Post Hinge.

Vehicle crash tests were performed on a similar system by TTI in 1988 (12). However, in these crash tests a friction fuse plate was used, the cut in the post did not angle down below the sign (it remained horizontal), and the sign was not connected to the post below the hinge point. Crash tests were successful on this design; however, it will behave differently from the proposed design in Figure 17.

9 REFERENCES

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11. Bloom, J.A., and Hinch, J.A., *Laboratory Evaluation of Existing Breakaway Structures - Volume II - Technical Results*. ENSCO, Inc., June 1980.

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10 APPENDICIES

APPENDIX A. WIND LOAD CHARTS

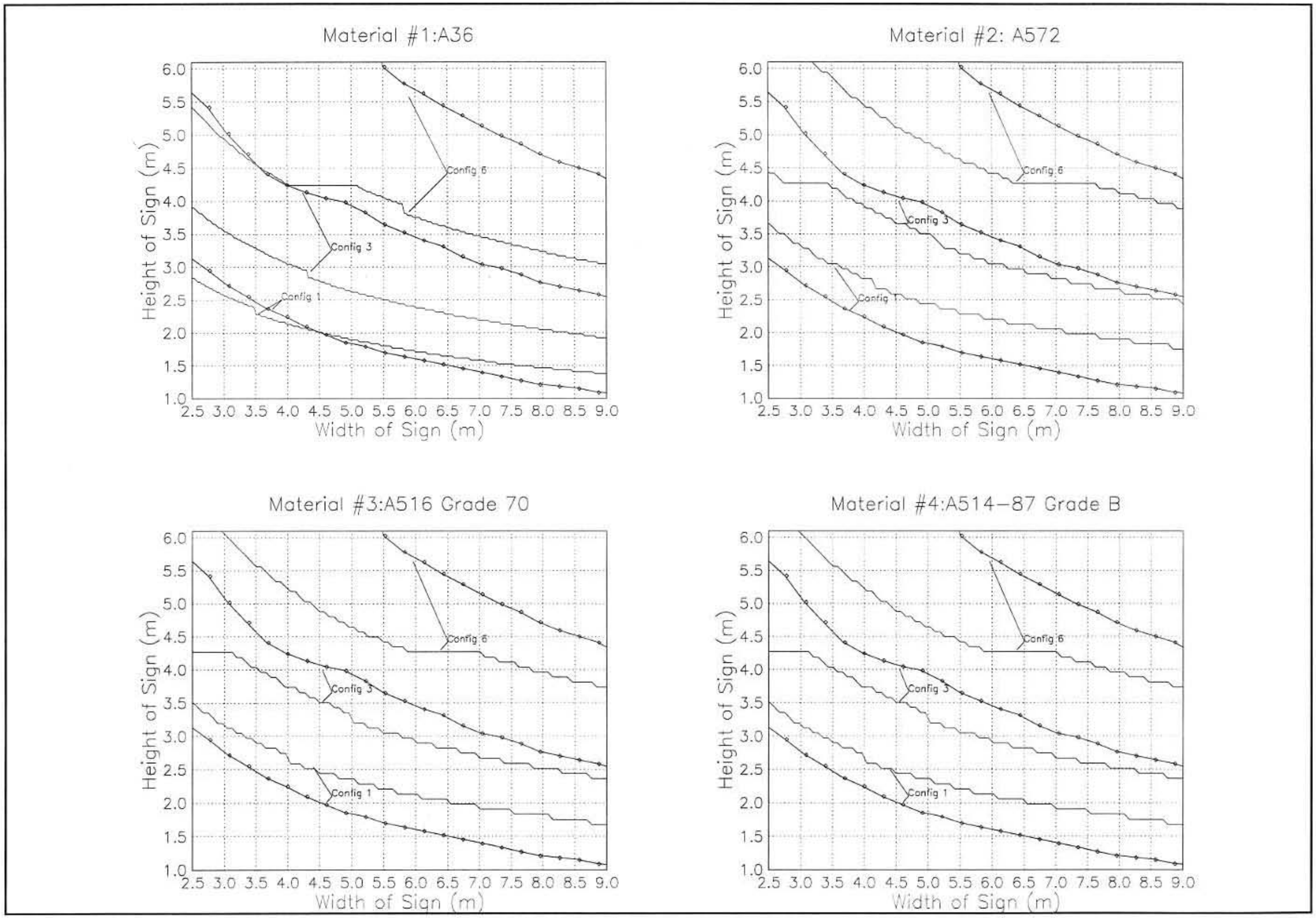

Figure A-1. Wind Load Charts, Elevation Height 2.44 m
Missouri chart lines have markers.

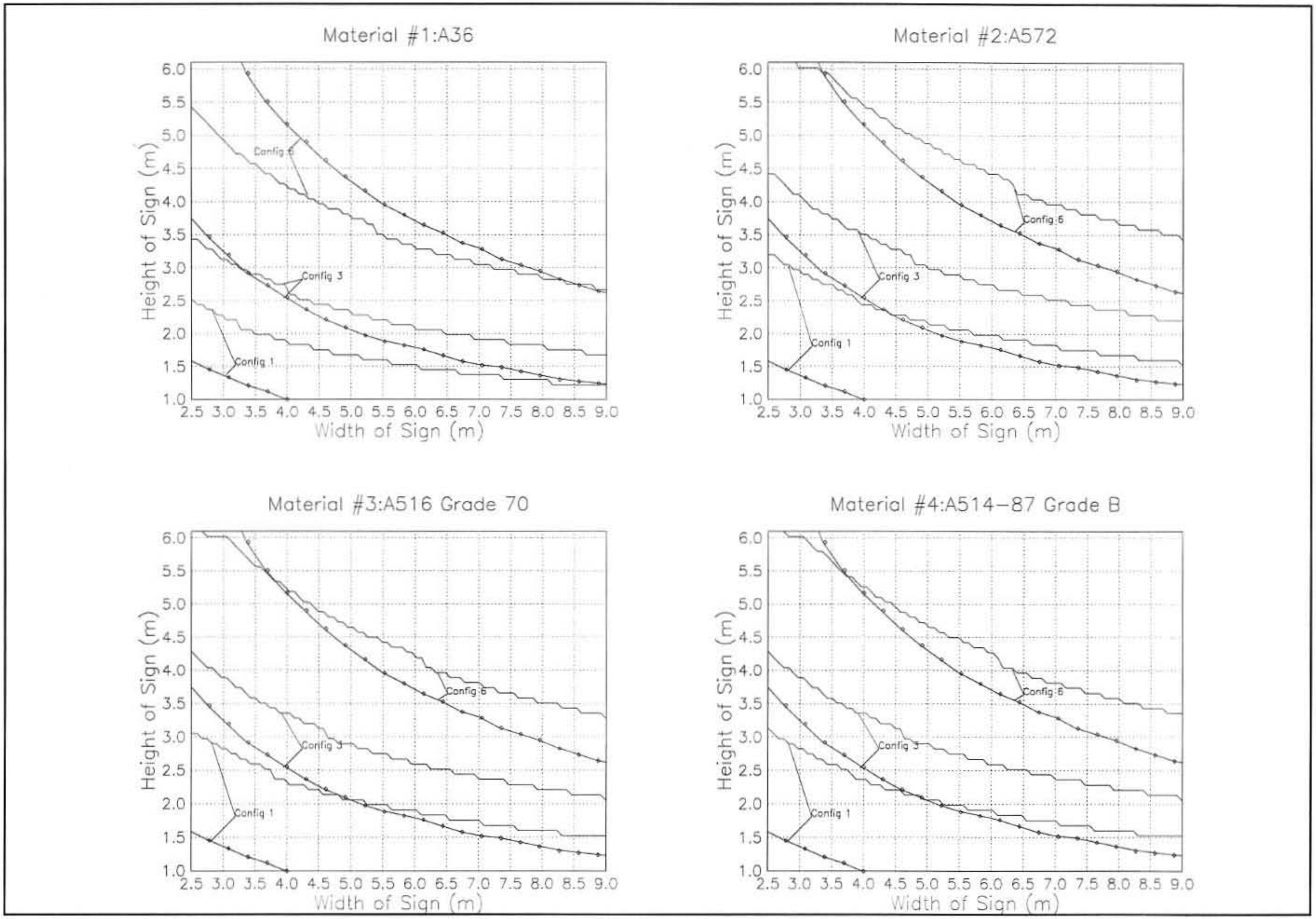

Figure A-2. Wind Load Charts, Elevation Height 6.10 m
Missouri chart lines have markers.

APPENDIX B. COMPONENT TEST RESULTS

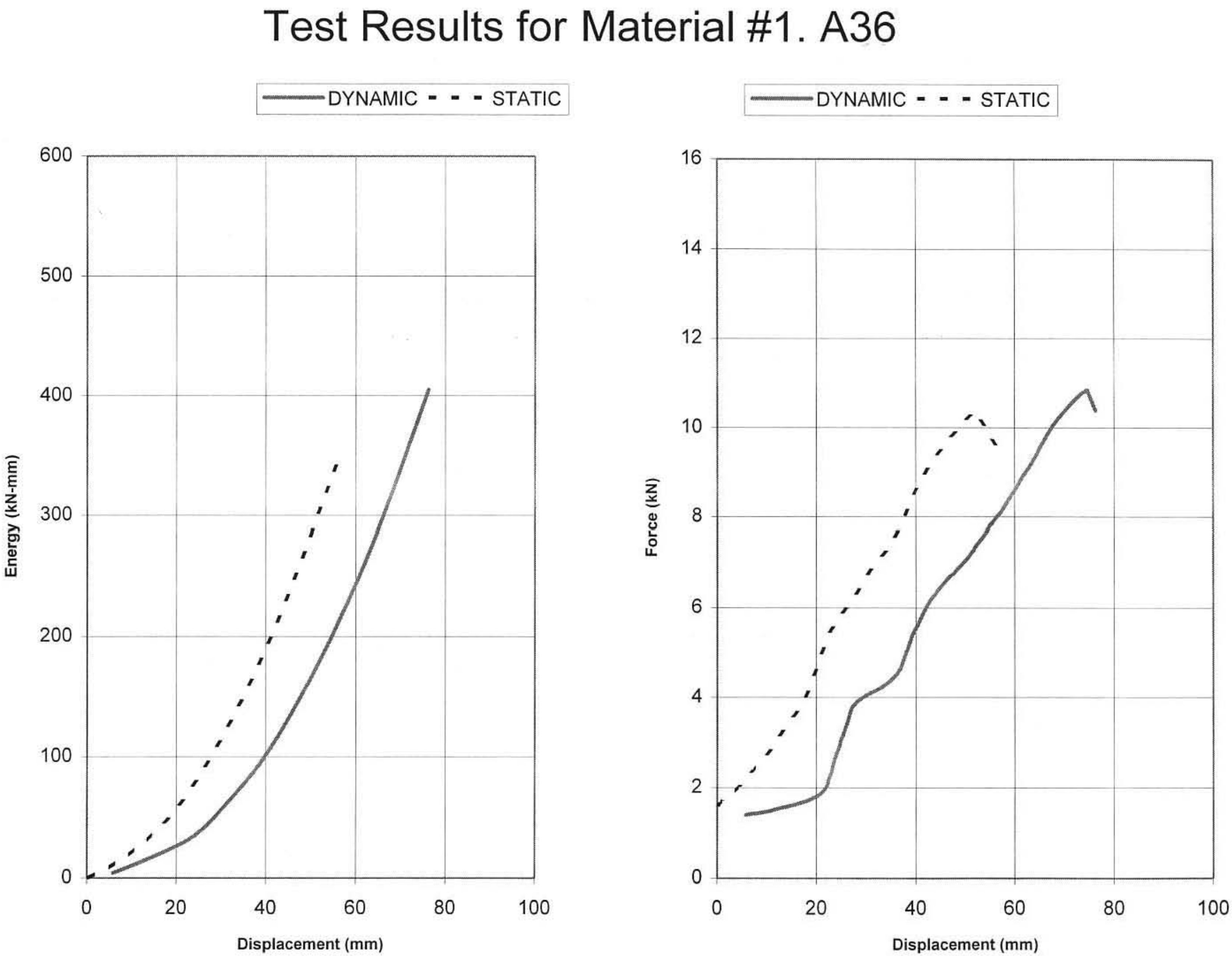

Figure B-1. Component Test Results for Material #1: A36

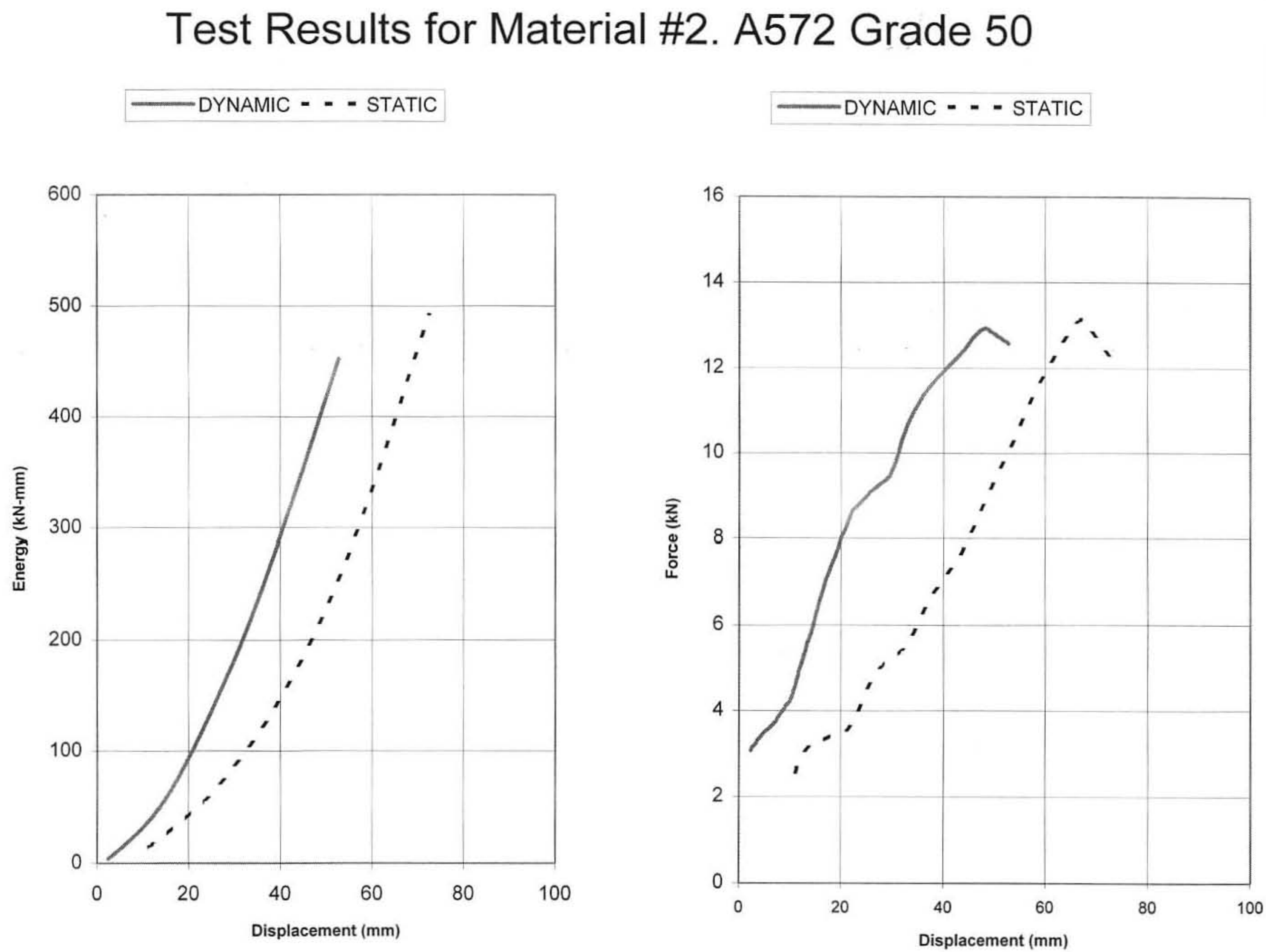

Figure B-2. Component Test Results for Material #2: A572

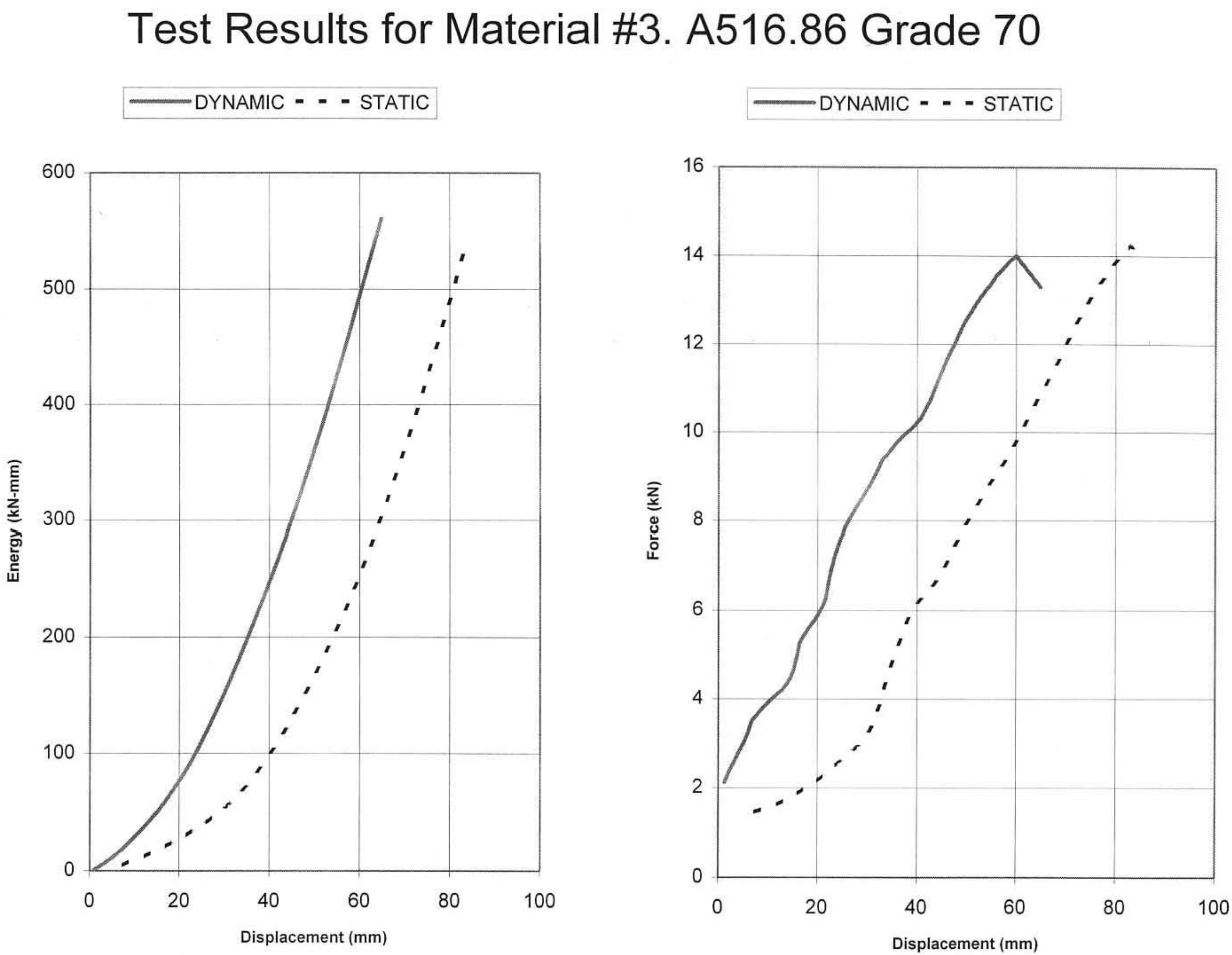

Figure B-3. Component Test Results for Material #3: A516.86 Grade 70

Test Results for Material #4. A514-87 Grade B

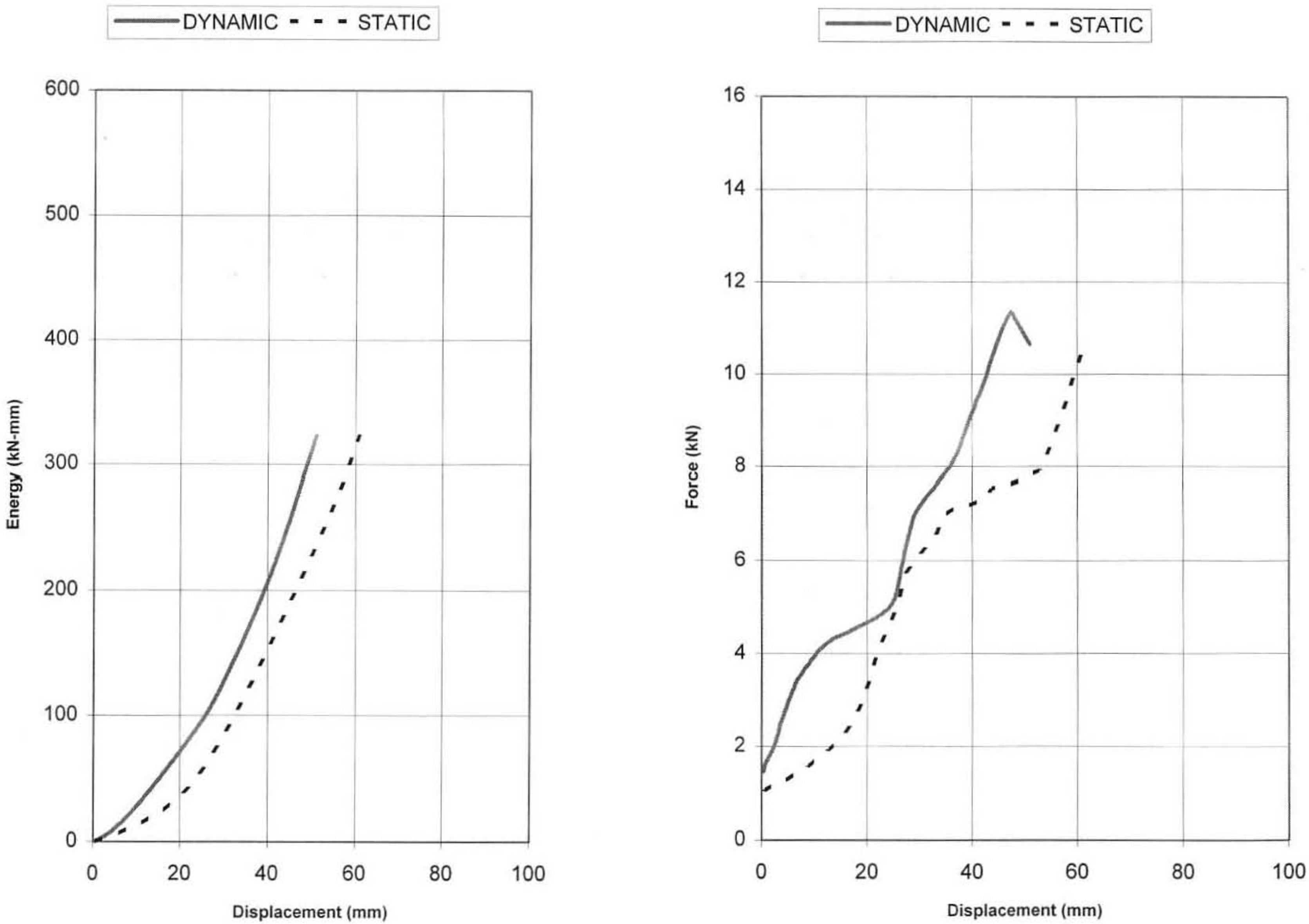

Figure B-4. Component Test Results for Material #4: A514-87 Grade B

APPENDIX C. ACCELEROMETER PLOTS

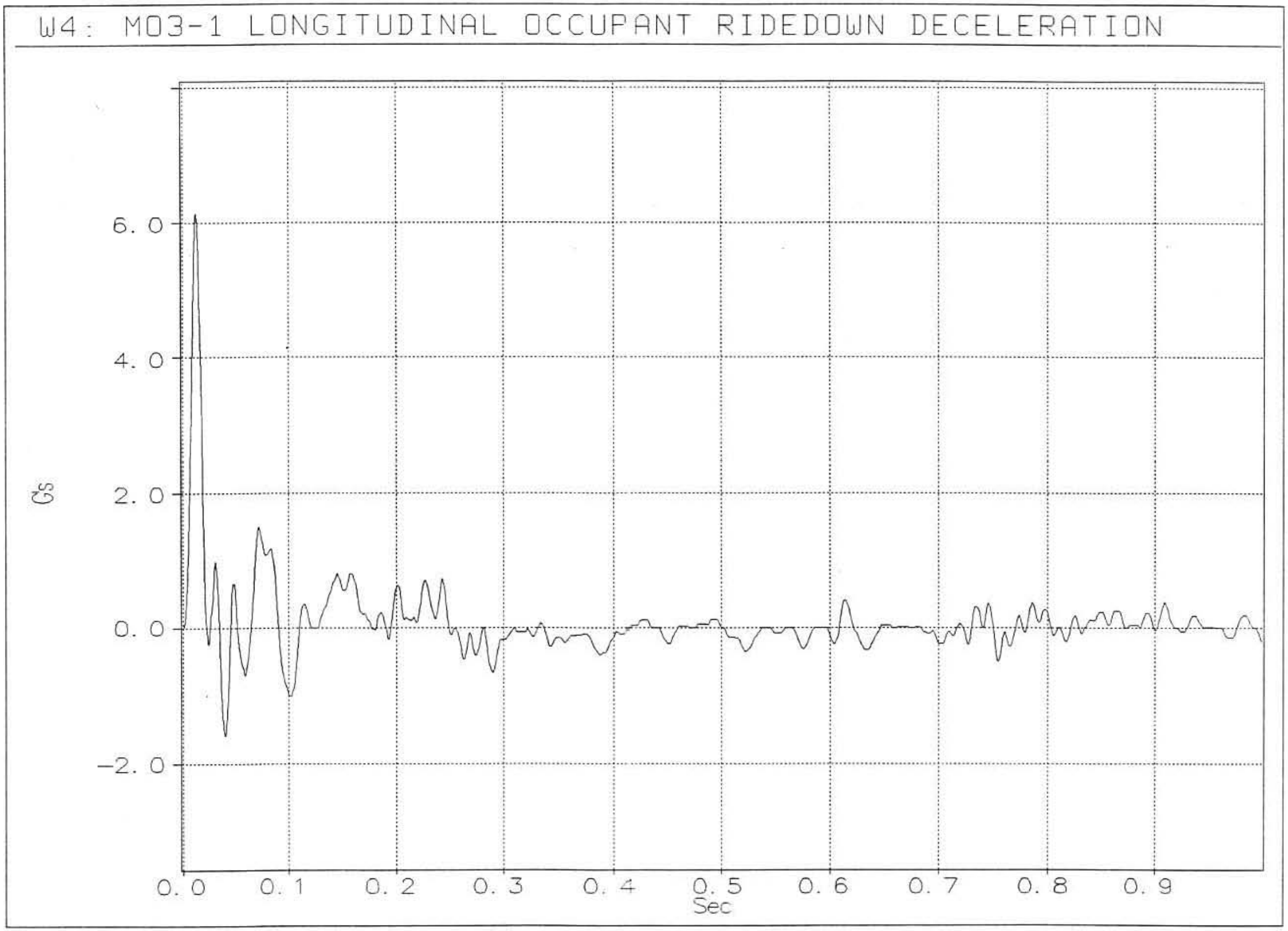

Figure C-1. Longitudinal Deceleration - Test MO3-1

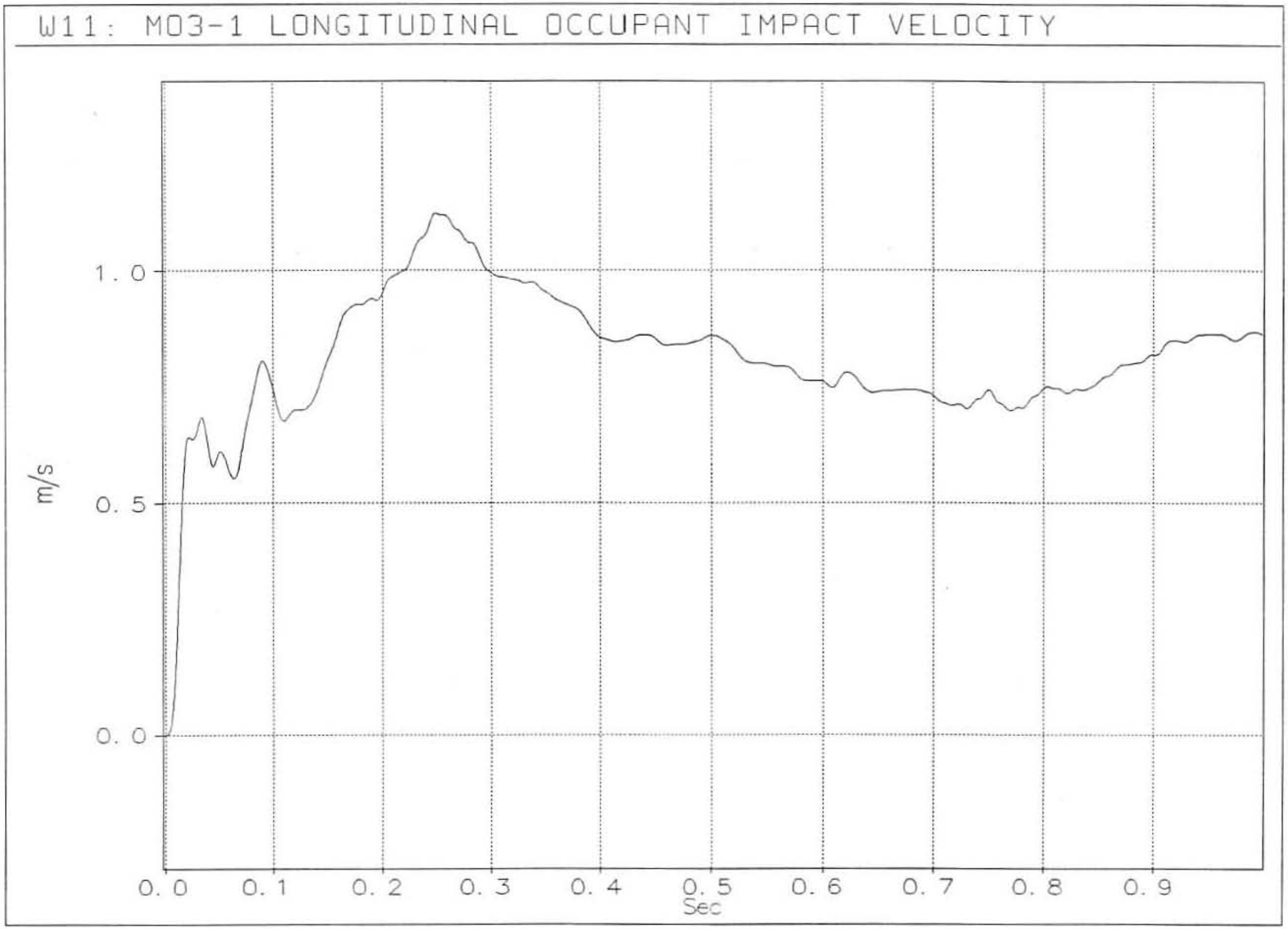

Figure C-2. Longitudinal Occupant Impact Velocity - Test MO3-1

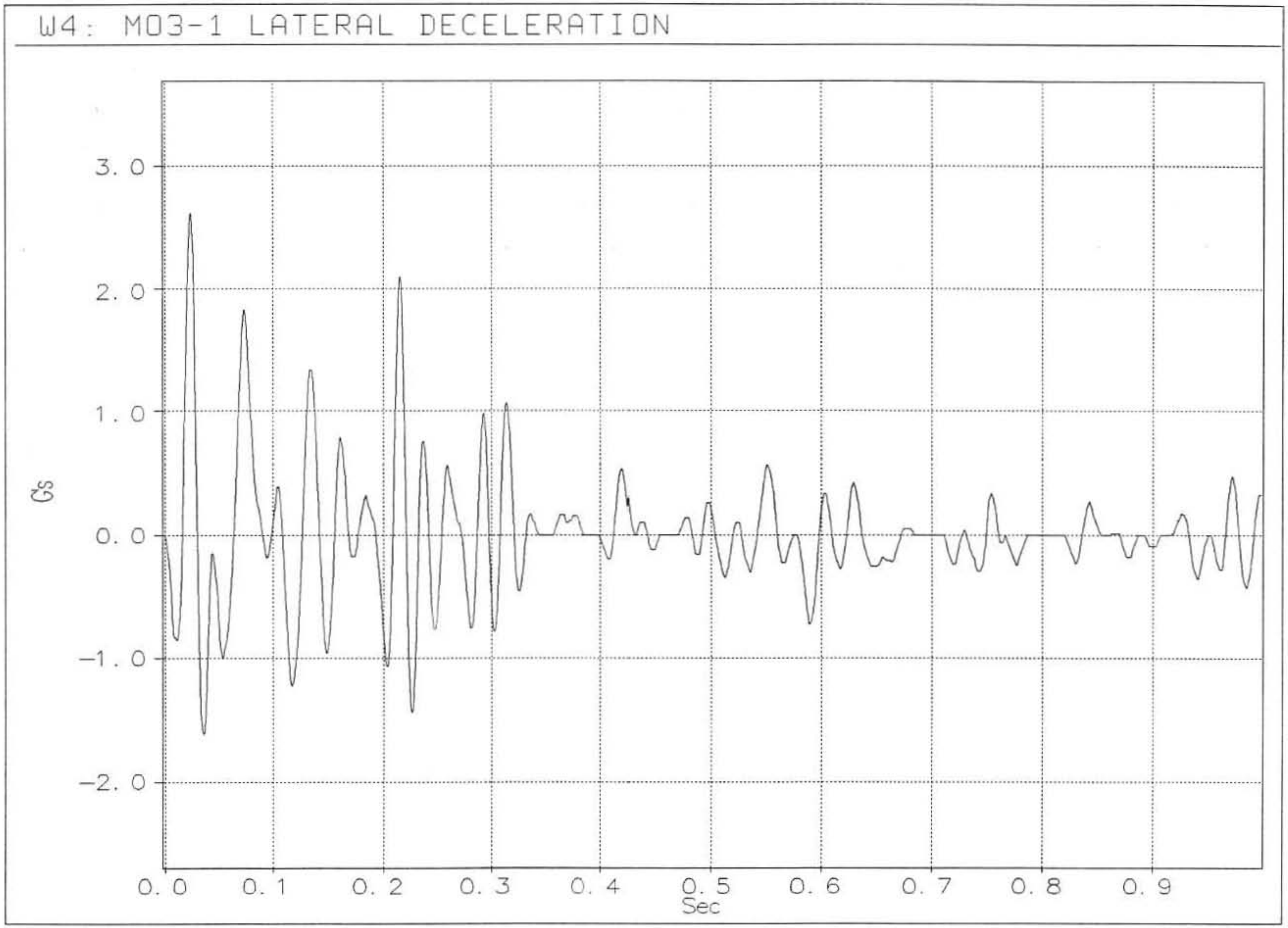

Figure C-3. Lateral Deceleration - Test MO3-1

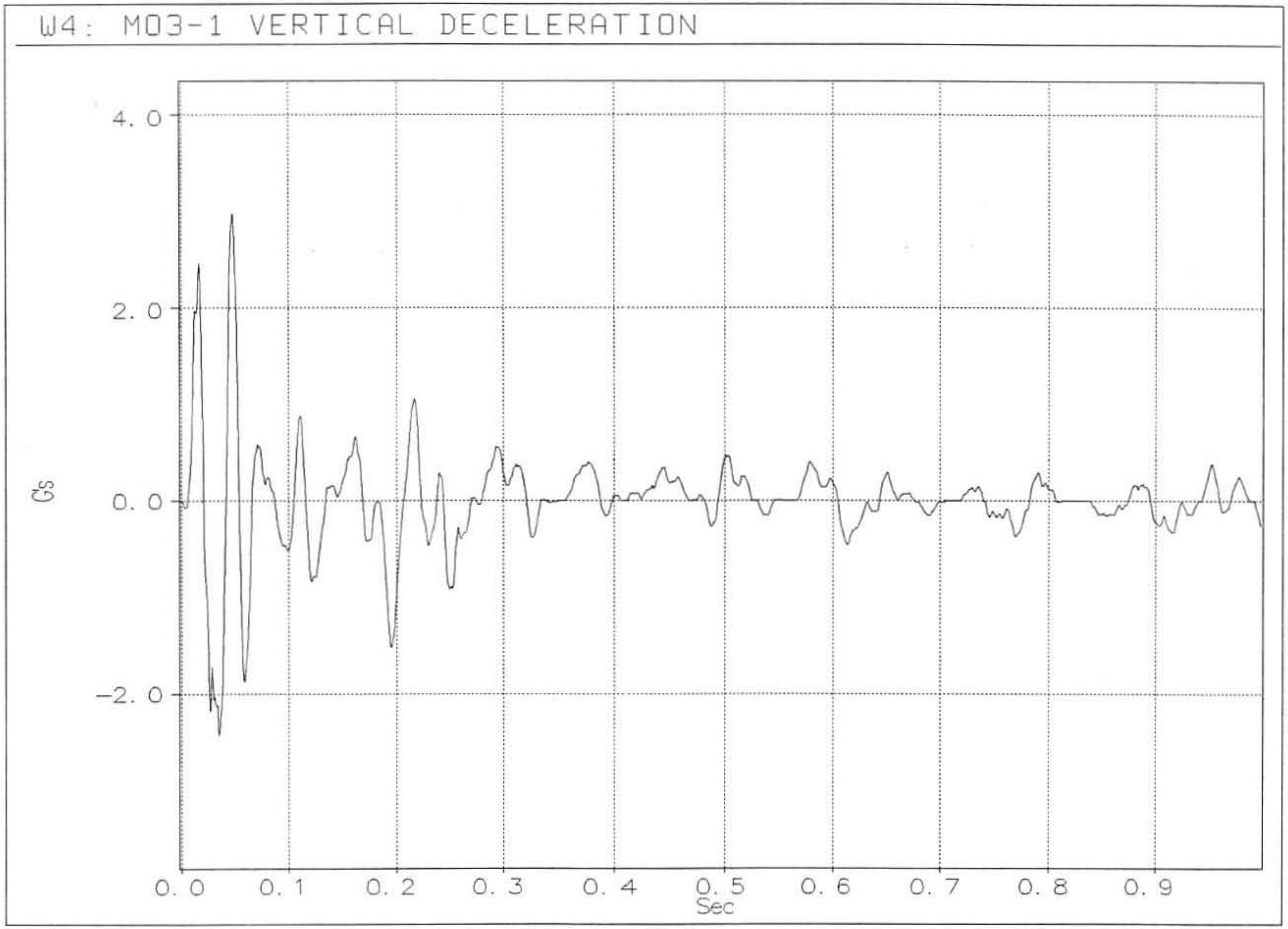

Figure C-4. Vertical Deceleration - Test MO3-1

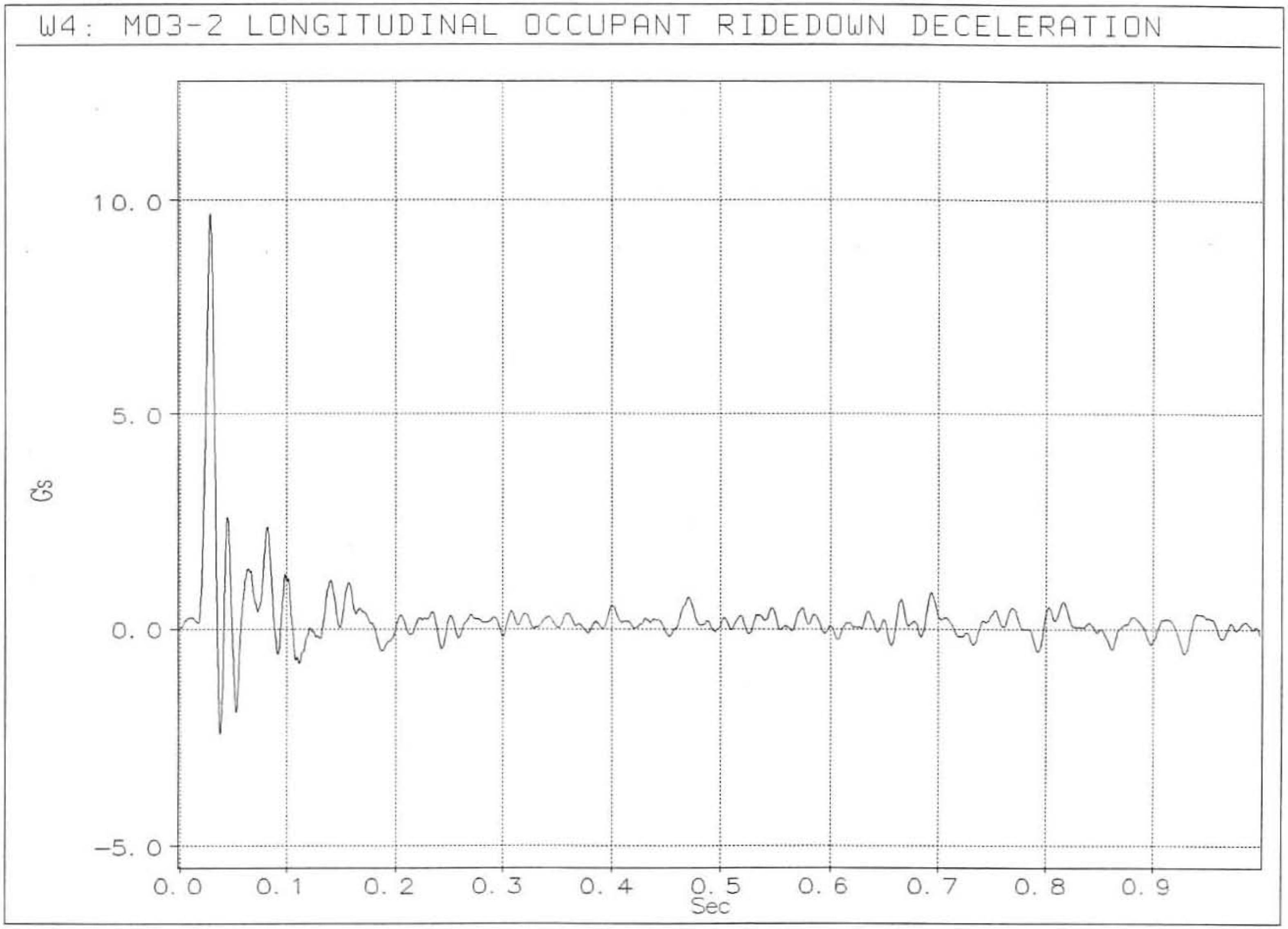

Figure C-5. Longitudinal Deceleration - Test MO3-2

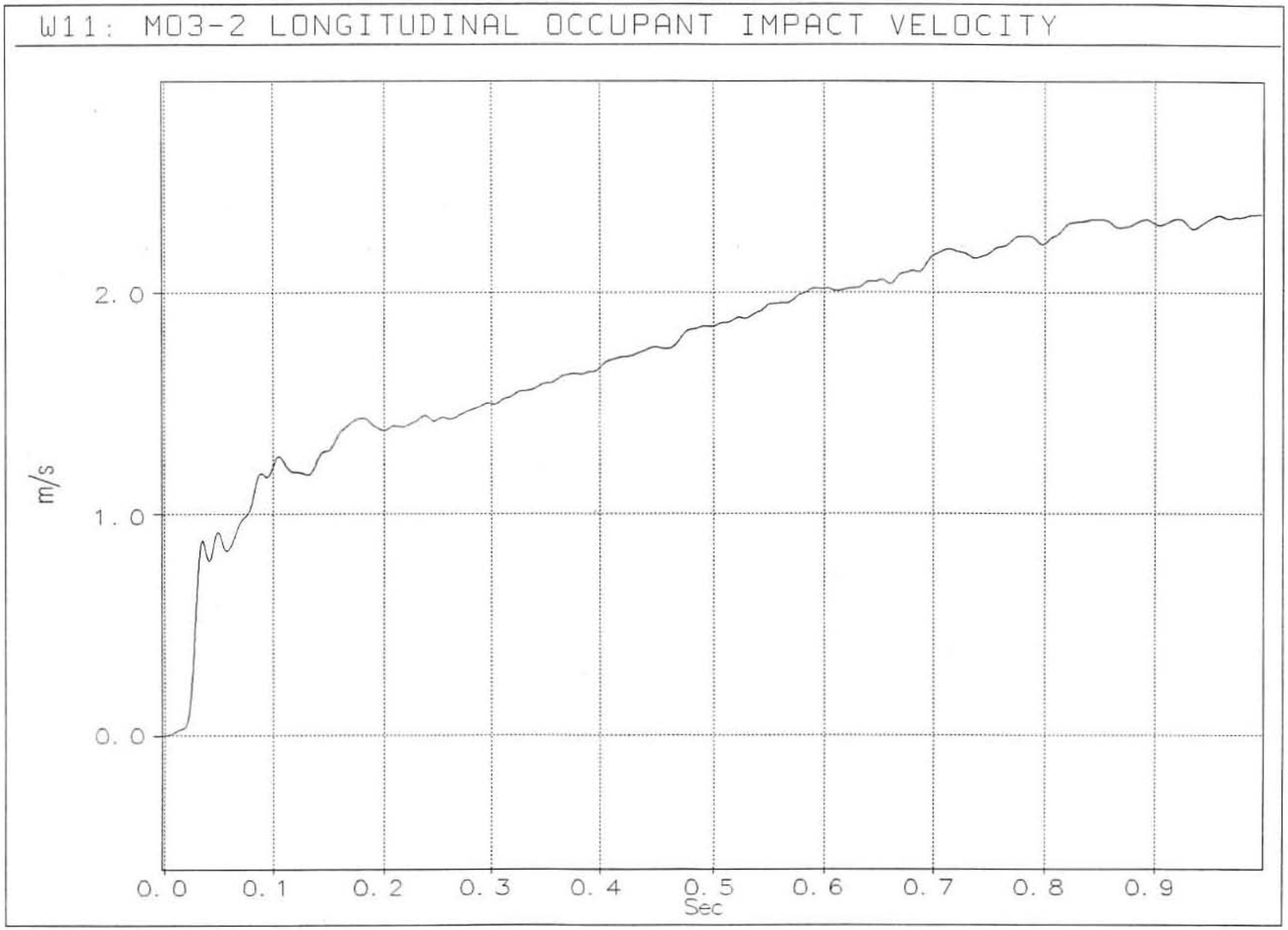

Figure C-6. Longitudinal Occupant Impact Velocity - Test MO3-2

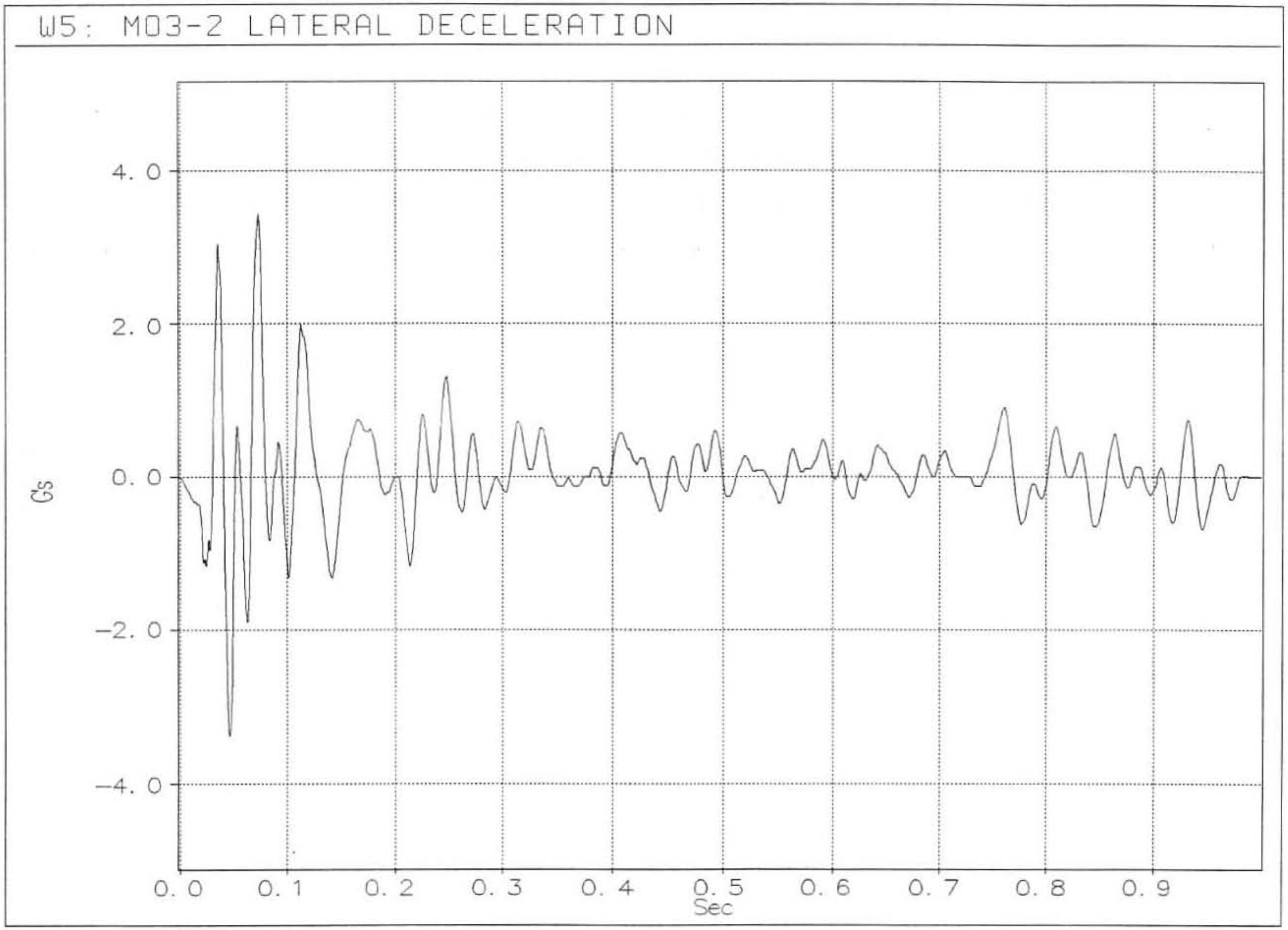

Figure C-7. Lateral Deceleration - Test MO3-2

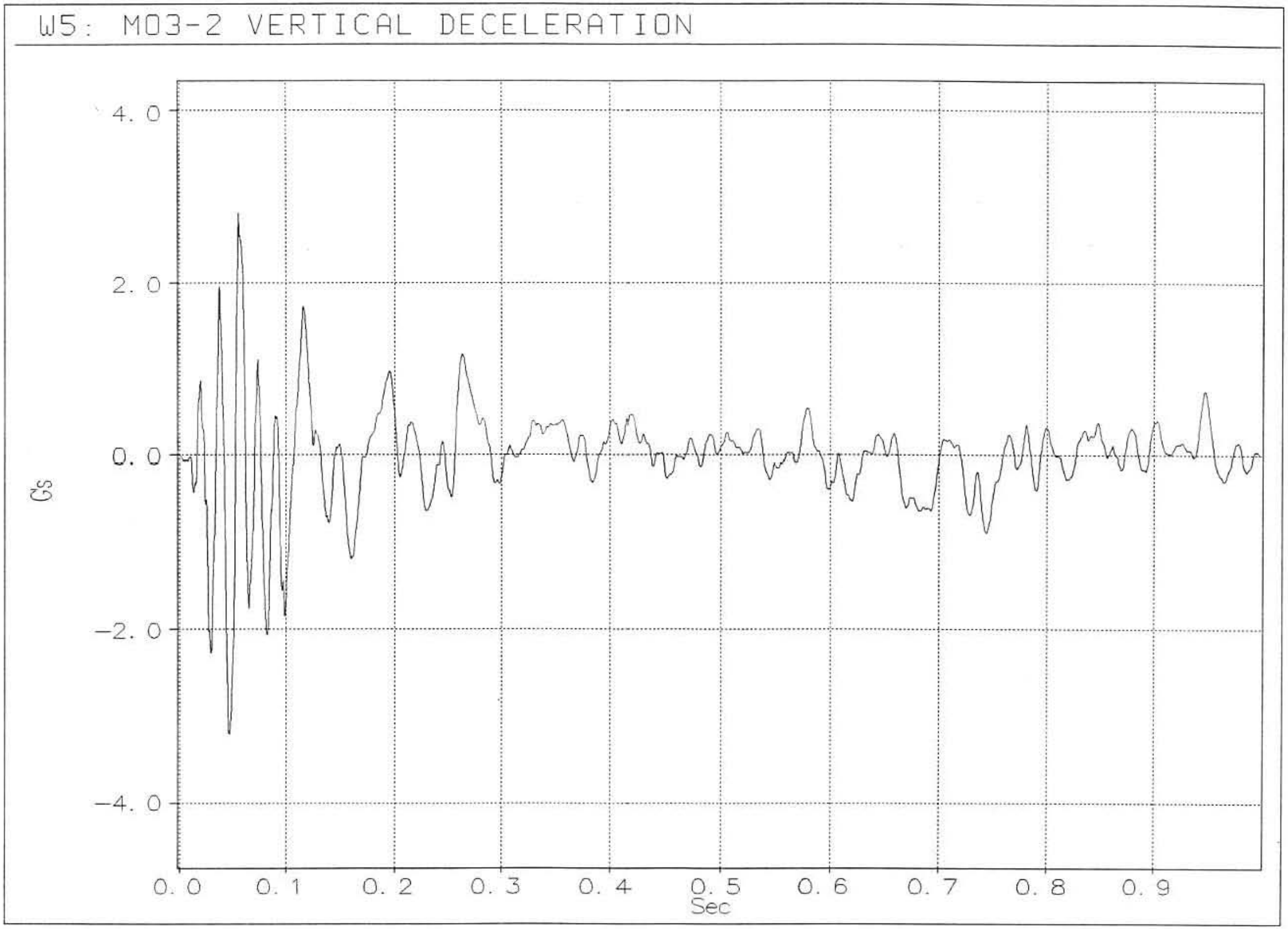

Figure C-8. Vertical Deceleration - Test MO3-2