Performance Evaluation of a Dual Support Sign with Ground Mounted Pipe Posts and Multi-Directional Slip Bases

Prepared by:
Midwest Roadside Safety Facility (MwRSF)
Center for Infrastructure Research
Civil Engineering Department
University of Nebraska-Lincoln
1901 Y Street, Building C
Lincoln, Nebraska 68588-0601
(402) 472-6864

September 1995

TECHNICAL REPORT STANDARD TITLE PAGE

1. Performing Organization Report No.	2. Report Date	3. Type of Report and Period Covered
TRP-03-50-95	September 20, 1995	Final Report: December 1994 to September 1995

4. Title and Subtitle
Performance Evaluation of a Dual Support Sign with Ground Mounted Pipe Posts and Multi-Directional Slip Bases

5. Author(s)
Holloway, J.C., Reid, J.D.

6. Performing Organization Name and Address
Midwest Roadside Safety Facility (MwRSF)
Civil Engineering Department
University of Nebraska - Lincoln
1901 Y St., Bldg C
Lincoln, Nebraska 68588-0601
(402) 472-6864

7. Sponsoring Agency Name and Address
Missouri Highway and Transportation Department
Design Division
P.O. Box 270
Jefferson City, MO 65102

8. Contract or Grand No.
SPR-3(017), FY-94 Midwest States Regional Pooled Fund Program

9. Abstract
Two full-scale vehicle crash tests were performed on a dual support sign with ground mounted pipe posts and multi-directional slip bases. Test MO2-1 was conducted with a 1987 Yugo GV weighing 845 kg (1862 lbs) at an impact speed of 36.4 km/h (22.6 mph) and an angle of 0 degrees. Test MO2-2 was conducted with the same vehicle at an impact speed of 96.7 km/h (60.1 mph) and an angle of 0 degrees. The vehicle impacted both posts simultaneously, according to the recommended criteria.

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), 1994 *Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals*. The safety performance evaluation of the highway sign was determined to be acceptable according to these criterion for support structures.

10. Keywords	11. Distribution Statement
Highway Signs, Breakaway Supports, Multi-Directional Slip Base, Highway Safety, Crash Tests	No restrictions. This document is available to the public from the sponsoring agency.

12. Security Classification (of this report)	13. Security Classification (of this page)	14. No. of Pages
Unclassified	Unclassified	41

DISCLAIMER STATEMENT

The contents of this report reflect the views of the authors who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Missouri Highway and Transportation Department or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

ACKNOWLEDGEMENTS

The authors wish to acknowledge several sources that made this project possible: (1) the Midwest States Regional Pooled Fund Program funded by the Missouri Highway and Transportation Department, Iowa Department of Transportation, Kansas Department of Transportation, Nebraska Department of Roads, and Minnesota Department of Transportation for sponsoring this project; and (2) the Center for Infrastructure Research Center for matching support.

A special thanks is also given to the following individuals who made a contribution to the completion of this research project.

Midwest Roadside Safety Facility
Dean L. Sicking, Ph.D., P.E., Director, Assistant Professor
Barry T. Rosson, Ph.D., P.E., Assistant Professor
Ronald K. Faller, P.E., Research Associate Engineer
Brian G. Pfeifer, P.E., Research Associate Engineer
Kenneth L. Krenk, Field Operations Manager
Don L. Dye, Undergraduate Research Assistant

Missouri Highway and Transportation Department
Pat McDaniel, P.E., Special Assignments Engineer
Vince Imhoff, P.E., Specifications and Standards Engineer

Iowa Department of Transportation
David Little, P.E., Design Methods Engineer

Kansas Department of Transportation
Ron Seitz, P.E., Road Design Squad Leader

Nebraska Department of Roads
Leona Kolbet, Research Coordinator

Minnesota Department of Transportation
Khani Sahebjam, P.E., State Aid Bridge Engineer

Federal Highway Administration
Milo Cress, P.E., Nebraska Division Office

TABLE OF CONTENTS   Page

LIST OF FIGURES

Page

LIST OF TABLES

Page

1 INTRODUCTION

1.1 Problem Statement

Multi-directional slip bases for breakaway supports have existed for many years. However, its safety performance when used in conjunction with dual support highway signs with ground mounted pipe posts has not been evaluated. There is concern whether multi-directional slip bases will provide acceptable safety performance when used in this configuration. The Missouri Highway and Transportation Department (MHTD) has requested that this two-post system be crash tested and evaluated concerning its performance.

1.2 Objective

The objective of this research study was to evaluate the safety performance of the highway sign according to Test Level 3 evaluation criteria set forth in the National Cooperative Highway Research Program (NCHRP) 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, 1994* (2).

1.3 Scope

Compliance testing was conducted using an 820 kg (1,808 lb) vehicle impacting at speeds of 35 km/h (21.7 mph) and 100 km/h (62.1 mph) and an angle of 0 degrees (NCHRP Report No. 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 for the second test. The tests were conducted with the vehicle striking both posts simultaneously because it was determined that this would result in the most severe impact condition. This was reasonable, since the vehicle would be required to activate both breakaway mechanisms. Subsequently, there were two posts and attached hardware that could potentially interfere with the vehicle's occupant compartment and post-impact trajectory. Finally, the test results were analyzed, evaluated, documented, and conclusions were formed regarding the safety and use of the dual support sign with ground mounted pipe posts and multi-directional slip bases.

2 TEST CONDITIONS

2.1 Test Installation Design Details

The test installation was constructed in accordance with the 1994 Missouri Standard Plans for Highway Construction. The test installation consisted of four major components: (1) sign panel; (2) posts; (3) stub posts; and (4) the multi-directional slipbase assemblies. A schematic of the system, containing component details, is shown in Figure 1.

The 1.8-m (6-ft) wide by 1.5-m (5-ft) tall flat sheet sign panel was fabricated from 3.2-mm (0.125-in.) thick aluminum material. The sign was supported by two, standard weight steel pipe posts with a nominal diameter of 76 mm (3 in.). Each post was 3.8-m (12-ft 4¾-in.) long, including a 25-mm (1-in.) thick triangular slip base located at the bottom of the sign post. The center to center post spacing was 1,118 mm (3 ft - 8 in.). The mounting height (measured from the ground to the bottom of the sign panel) was 2.4 m (7 ft - 9 in.).

The sign was connected to the pipe posts by three clamps per post, spaced at 813 mm (2 ft - 3 in.). The clamp type sign supports were made of aluminum alloy extrusions with a minimum width of 32 mm (1¼ in.). The fasteners used to connect the clamps were 8 mm (5/16-in.) x 51 mm (2 in.) hex head stainless steel all thread bolts.

The stub posts, containing 25-mm (1-in.) thick triangular slip bases, were 1,295-mm (4-ft 3-in.) long, and were set in concrete footings measuring 305 mm (12 in.) in diameter by 1372-mm (4-ft 6-in.) deep. The concrete was a L-4000 mix with a 28-day compressive strength of 34.5 MPa (5000 psi). The top of the stub posts were placed 102 mm (4 in.) above the top of the footing as shown in Figure 1.

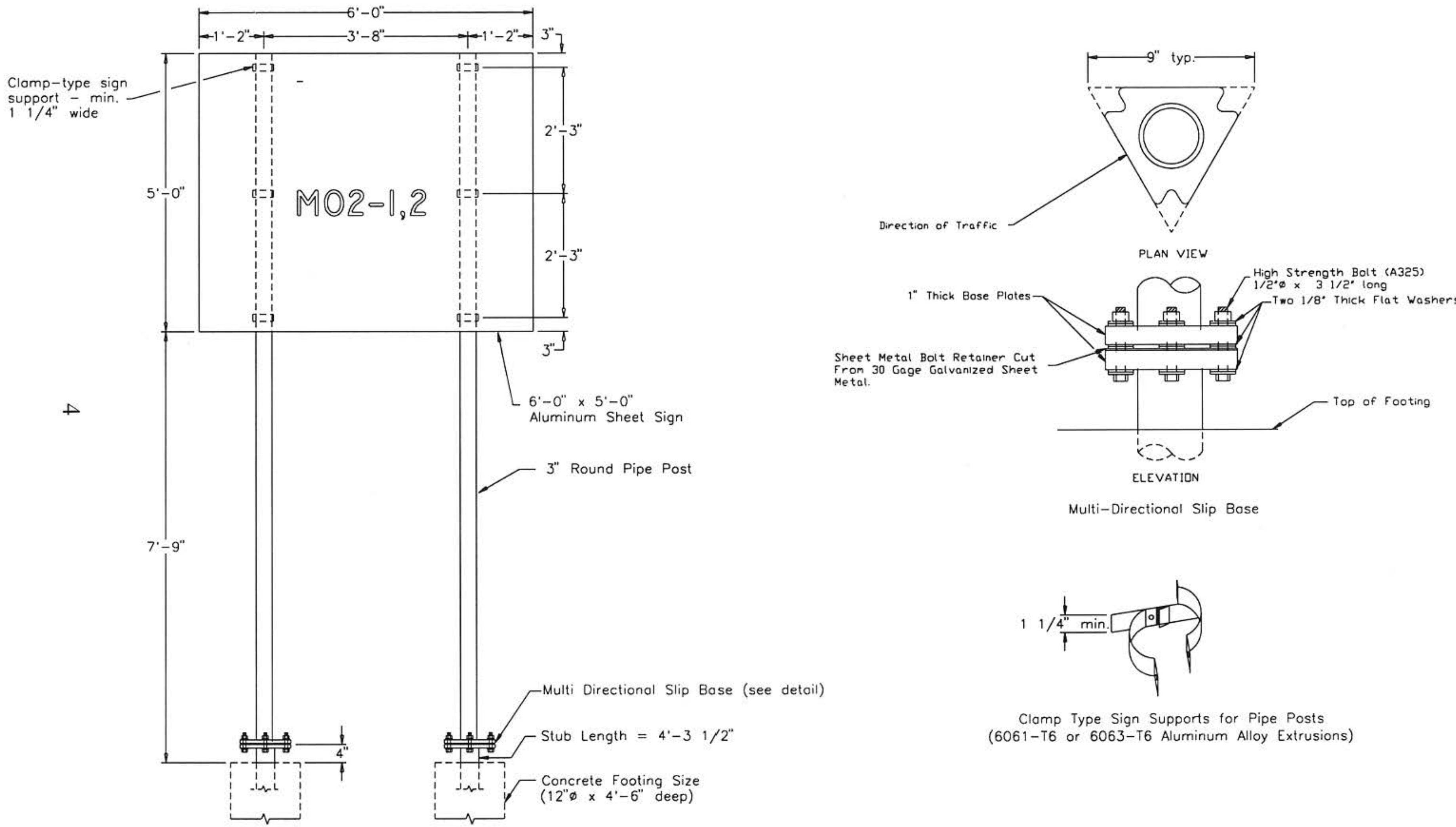


Figure 1. Schematic and Design Details of Highway Sign System

The posts were secured to the ground by mounting them to the stub posts using three 13-mm (1/2-in.) diameter by 89-mm (3½-in.) long, high strength (A325) bolts torqued to 15.8 N·m (140 in-lbs.). The three bolts were held in place by a bolt retainer, cut from 30 gage sheet metal, located between the base plates. The slip bolt assembly contained six 3-mm (1/8-in.) thick round washers per bolt. Two were placed on top of the post slip base, two in between the post and stub post slip bases, and two on the bottom of the stub post slip base. This configuration is shown in Figure 1.

2.2 Test Vehicle

A 845-kg (1862-lb) 1987 Yugo GV, shown in Figure 2, was used as a test vehicle in both tests MO2-1 and MO2-2. Dimensions and axle weights of the test vehicle are shown in Figure 3. Black and white-checkered targets were strategically placed on the vehicle for high-speed film analysis. 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.

Figure 2. Photographs of Test Vehicle and Impact Location, MO2-1,2

Make: Yugo

Model: GV

Year: 1987

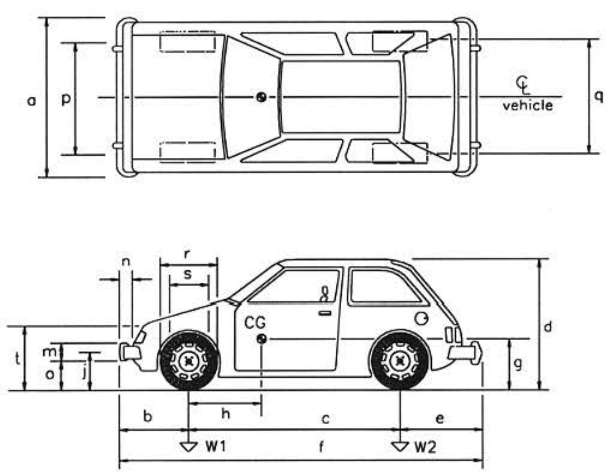
Test No.: MO2-1,2

Tire Size: 155 80 R13

VIN: VX1BA1213HK372032

Vehicle Geometry
centimeters (in.)

a —	149.9 (59.0)	b —	68.6 (27.0)
c —	214.0 (84.25)	d —	137.8 (54.25)
e —	66.7 (26.25)	f —	349.3 (137.5)
g —	55.9 (22.0)	h —	79.4 (31.25)
j —	55.9 (22.0)	m —	13.3 (5.25)
n —	7.6 (3.0)	o —	37.5 (14.75)
p —	129.5 (51.0)	q —	129.5 (51.0)
r —	54.6 (21.5)	s —	36.2 (14.25)
t —	79.4 (31.25)		



Engine Size: 4 cyl.

Transmission: Manual

Weight: kg (lbs)	Curb	Test Inertial	Gross Static
W1	535 (1180)	538 (1185)	565 (1245)
W2	286 (630)	307 (677)	343 (757)
Wtotal	821 (1810)	845 (1862)	908 (2002)

Figure 3. Test Vehicle Dimensions and Weights, MO2-1,2

2.3 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.

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

Additionally, an Environmental Data Recorder (EDR-3), developed by Instrumented Sensor Technology (IST) of Okemos, Michigan, was 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, "Dyna Max 1 (DM-1)" was then used to download the EDR-3 unit and filter the data with an 180 Hz low-pass filter.

2.4 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 sign supports.

A vehicle guidance system developed by Hinch (3) 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-m (300-ft) and 244-m (800-ft) long for the low and high-speed tests, respectively.

3 PERFORMANCE EVALUATION CRITERIA

The safety performance evaluation was conducted according to the guidelines presented in NCHRP Report No. 350 (1) and AASHTO (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 Test Level 3 compliance tests are (Test Nos. 60 and 61), and descriptions 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 center 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.

According to NCHRP Report No. 350 (1) recommendations, a surrogate occupant with a weight of 73.6 kg (160 lbs) was belted to the driver's seat for both tests, and the vehicle's approach path was aligned so that the maximum number of supports were contacted, as shown in Figure 2. The vehicle damage was assessed by the traffic accident scale (TAD) (4) and the vehicle damage index (VDI) (5).

TABLE 1. NCHRP Report No. 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 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 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

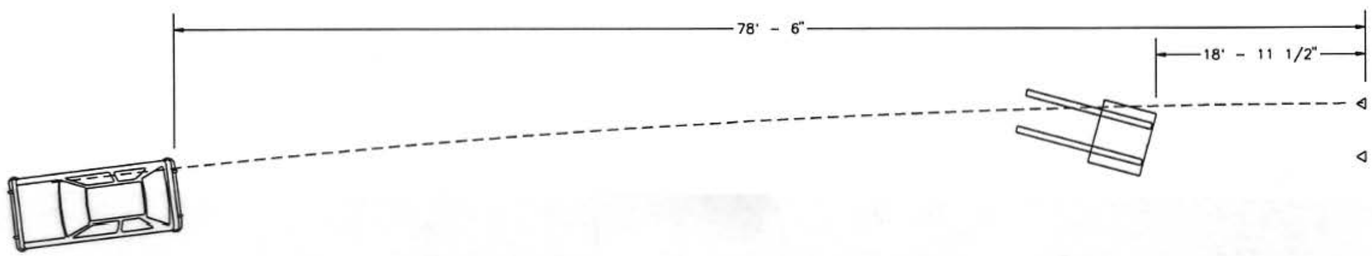
4.1 Test MO2-1

The test vehicle impacted the sign head-on at an angle of 0 degrees and 36.4 km/h (22.6 mph). The actual impact points on the vehicle were approximately 559 mm (22 in.) outward from the center of the bumper on both the left and right sides. A summary of the test, including test results, sequential photos, and post-test trajectory is shown in Figure 4. Additional high-speed film sequential photographs of the full-scale crash test are shown in Figure 5.

After the initial impact with the sign post, the front bumper crushed inward for approximately 0.019 sec before the slipbase began to activate. The post lost contact with the car at approximately 0.078 sec. Approximately 0.409 sec after impact, the sign made contact with the top of the vehicle, causing a slight crease in the roof.

Test vehicle damage consisted of frontal crush to the bumper and hood, as shown in Figure 6. A maximum crush depth of 64 mm (2.5 in.) was measured on the front bumper. Other damage included scrapes and minor dents on the right-side door handle and roof from sign and post contact. The vehicle safely passed over the post stub, resulting in no suspension or undercarriage damage, although two of the left-front wheel screw-type lugs pulled out during the test. The pipe posts and sign were undamaged and remained connected together by the clamp type sign supports, as shown in Figure 6. The final resting position of the sign was approximately 5.8 m (19 ft) downstream of the stub posts. The vehicle came to rest approximately 24 m (79 ft) downstream of the stub posts, as shown in Figure 4.

IMPACT | 0.027 sec | 0.078 sec | 0.389 sec | 0.681 sec



Test Number	MO2-1
Date	3/9/95
Appurtenance	Dual Support Highway Sign with Ground Mounted Pipe Posts and Multi-Directional Slip Bases
Sign Size	1829 mm x 1524 mm (6 ft x 5 ft)
Sign Panel	Aluminum Flat Sheet
Sign Panel Thickness	3 mm (0.125 in.)
Sign Mounting Height From Ground Level	2362 mm (7 ft - 9 in.)
Support Size	76 mm (3 in.) Nominal Diam. Pipe
Post Spacing	1118 mm (3 ft - 8 in.)
Concrete Footing Size	305 mm (12 in.) x 1372 mm (4½ ft) deep
Multi-directional Slip Base	
Slip Bolt Size	12.7 mm (½ in.) x 89 mm (3½ in.)
Bolt Torque	15.8 N-m (140 in-lbs)
Stub Height	101.6 mm (4 in.)
NCHRP 350 Vehicle Class	820C
Model	1987 Yugo GV
Mass	
Curb	821 kg (1810 lb)
Test Inertial	845 kg (1862 lb)
Gross Static	908 kg (2002 lb)

Vehicle Speed	
Impact	36.4 km/h (22.6 mph)
Exit	32.0 km/h (19.9 mph)
Vehicle Angle	
Impact	0.0 deg
Exit	0.0 deg
Vehicle Impact Location	Center of both posts
Vehicle Snagging	None
Vehicle Stability	Satisfactory
Occupant Impact Velocities	
Longitudinal	NA (no occupant impact)
Lateral	NA (no occupant impact)
Occupant Ridedown Decelerations	
Longitudinal	NA (no occupant impact)
Lateral	NA (no occupant impact)
Vehicle Damage	
TAD (4)	12-FL-1, 12-FR-1
VDI (5)	12FLEN1, 12FREN1
Front End Crush	64 mm (2.5 in.)
Vehicle Change in Speed	1.2 m/s (4.0 fps)
Sign Damage	None

Figure 4. Summary and Sequential Photographs, MO2-1

IMPACT

0.019 sec

0.047 sec

0.078 sec

0.280 sec

0.389 sec

0.409 sec

0.681 sec

Figure 5. Additional Sequential Photographs, MO2-1

Figure 6. Vehicle and Installation Damage, MO2-1

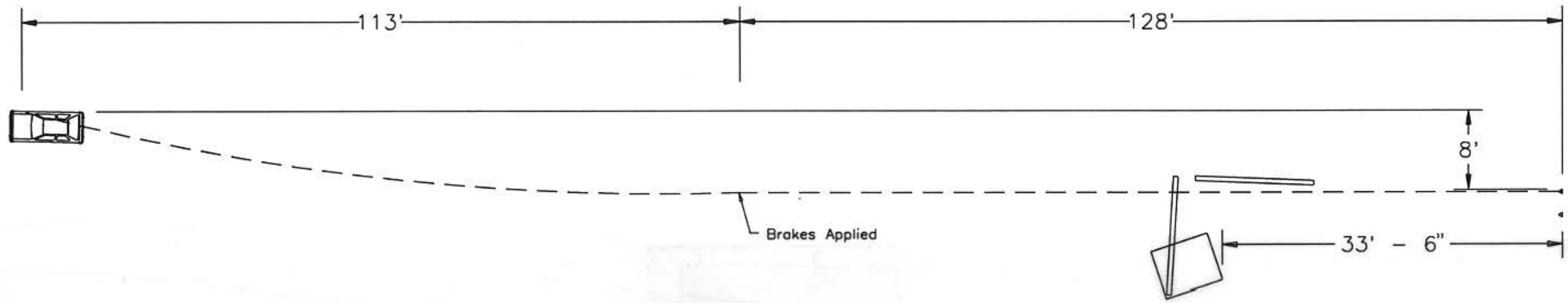
Based upon the analysis of the accelerometer data, the longitudinal occupant impact velocity (OIV) and ridedown accelerations were not applicable to this test. It was determined that the hypothetical occupant did not contact the dashboard within the time that the vehicle was in contact with the sign following the activation of the breakaway assembly. The vehicle change in speed (ΔV), determined at loss of contact, was 1.2 m/s (4.0 fps). Angular rotations measured during the test were less than 3 degrees in all three directions (roll, pitch, and yaw). The positive sign convention used for the plots are shown in Figure 4.6 of reference (1). Plots of the accelerometer analysis and angular displacements can be found in Appendix A.

4.2 Test MO2-2

The test vehicle impacted the sign head-on at an angle of 0 degrees and 96.7 km/h (60.1 mph). The actual impact points on the vehicle were approximately 559 mm (22 in.) outward from the center of the bumper on both the left and right sides. A summary of the test, including test results, sequential photos, and post-test trajectory is shown in Figure 7. Additional high-speed film sequential photographs of the full-scale crash test are shown in Figure 8.

After the initial impact with the sign post, the front bumper crushed inward for approximately 0.006 sec before the slipbase began to activate. The post lost contact with the car at approximately 0.069 sec after impact. At 0.099 sec, the rear tires of the test vehicle hit the stub post causing the vehicle's rear end to leave the ground. The rear wheels returned to the ground at 0.187 sec. The sign hit the ground at approximately 0.266 sec and became detached from the passenger side post at 0.720 sec. The vehicle came to rest approximately 73.5 m (241 ft) downstream of the stub posts, as shown in Figure 7.

IMPACT | 0.016 sec | 0.099 sec | 0.148 sec | 0.187 sec



Test Number	MO2-2
Date	3/21/95
Appurtenance	Dual Support Highway Sign with Ground Mounted Pipe Posts and Multi-Directional Slip Bases
Sign Size	1829 mm x 1524 mm (6 ft x 5 ft)
Sign Panel	Aluminum Flat Sheet
Sign Panel Thickness	3 mm (0.125 in.)
Sign Mounting Height From Ground Level	2362 mm (7 ft - 9 in.)
Support Size	76 mm (3 in.) Nominal Diam. Pipe
Post Spacing	1118 mm (3 ft - 8 in.)
Concrete Footing Size	305 mm (12 in.) x 1372 mm (4½ ft) deep
Multi-directional Slip Base	
Slip Bolt Size	12.7 mm (½ in.) x 89 mm (3 ½ in)
Bolt Torque	15.8 N-m (140 in-lbs)
Stub Height	101.6 mm (4 in.)
NCHRP 350 Vehicle Class	820C
Model	1987 Yugo GV
Mass	
Curb	821 kg (1810 lb)
Test Inertial	845 kg (1862 lb)
Gross Static	908 kg (2002 lb)

Vehicle Speed	
Impact	96.7 km/h (60.1 mph)
Exit	90.4 km/h (56.2 mph)
Vehicle Angle	
Impact	0.0 deg
Exit	0.0 deg
Vehicle Impact Location	Center of both posts
Vehicle Snagging	None
Vehicle Stability	Satisfactory
Occupant Impact Velocities	
Longitudinal	NA (no occupant impact)
Lateral	NA (no occupant impact)
Occupant Ridedown Decelerations	
Longitudinal	NA (no occupant impact)
Lateral	NA (no occupant impact)
Vehicle Damage	
TAD (4)	12-FL-1, 12-FR-1
VDI (5)	12FLEN1, 12FREN1
Vehicle Front End Crush	203 mm (8 in.)
Vehicle Change in Speed	1.8 m/s (5.8 fps)
Sign Damage	Minor

Figure 7. Summary and Sequential Photographs, MO2-2

IMPACT

0.049 sec

0.099 sec

0.148 sec

0.198 sec

0.297 sec

0.396 sec

0.495 sec

Figure 8. Additional Sequential Photographs, MO2-2

Vehicle damage consisted of frontal crush to the bumper and hood at the impact location. A maximum crush depth of approximately 203 mm (8 in.) was measured on the hood at the driver's side impact location. Both fenders were curved inward around the headlights. Other damage included the disengagement of the left front bumper connection, buckling of the hood, and minor scrapes and dents on the right rear corner of the roof and the right-rear quarter panel. There was no significant damage to the suspension or the undercarriage and no broken glass or occupant compartment damage occurred. The damage to the test vehicle is shown in Figure 9.

Five of the six clamps that connect the sign to the posts were broken off after the sign contacted the ground. Other damage included buckling of the sign, and tire marks on the stub post. There was no damage to the posts. The components of the sign were scattered, as shown in Figure 7.

Based upon the analysis of the accelerometer data, the longitudinal occupant impact velocity (OIV) and ridedown accelerations were not applicable to this test. It was determined that the hypothetical occupant did not contact the dashboard within the time that the vehicle was in contact with the sign following the activation of the breakaway assembly. The vehicle change in speed (ΔV), determined at loss of contact, was 1.8 m/s (5.8 fps). Angular rotations measured during the test were less than 3 degrees in all three directions (roll, pitch, and yaw). Plots of the accelerometer analysis and angular displacements can be found in Appendix A.

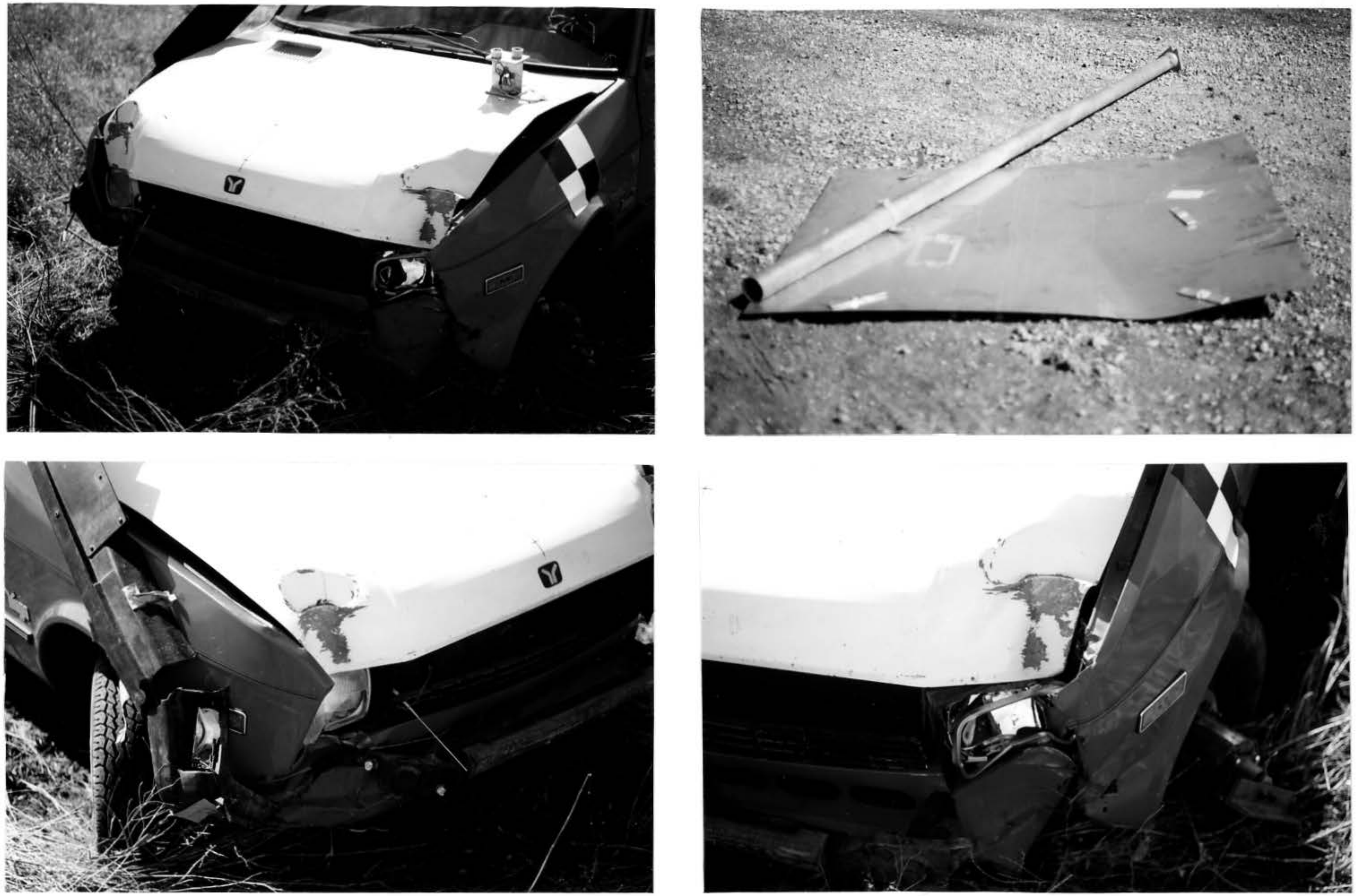


Figure 9. Vehicle and Installation Damage, MO2-2

5. CONCLUSIONS

The safety performance of the dual support sign system was determined to be acceptable according to the evaluation criteria presented in NCHRP Report No. 350 (1) and AASHTO 1994 (2). Table 3 presents the summary of performance evaluation results.

Exit signs placed in the gore area on divided highways are often installed on pipe posts and are frequently impacted by errant drivers. Therefore, because of the excellent performance exhibited during this investigation, the dual support sign with ground mounted pipe posts and multi-directional slip bases can be safely used for this application, as well as for other highway and interstate sign installations.

Table 3. Summary of Safety Performance Evaluation

Evaluation Factors	Evaluation Criteria		Test MO2-1		Test MO2-2	
			NCHRP (1)	AASHTO (2)	NCHRP (1)	AASHTO (2)
Structural Adequacy (NCHRP)	B.	The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.	S	NA	S	NA
Occupant Risk (NCHRP)	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)	NA[1]	NA	NA[1]	NA
	I.	Occupant ridedown accelerations should satisfy the following longitudinal and lateral limits: Preferred: 15 G's Maximum: 20 G's	NA[1]	NA	NA[1]	NA
Occupant Risk (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 (NCHRP)	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)

[1] No hypothetical occupant impact occurred during post and vehicle contact

6. REFERENCES

1. Ross, H.E., Sicking, D.L., Zimmer, R.A., Michie, J.D., *Recommended Procedures for the Safety Performance Evaluation of Highway Features*, National Cooperative Research Program Report No. 350, Transportation Research Board, Washington, D.C., 1993.

2. *Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals*, American Association of State Highway and Transportation Officials, 1994.

3. Hinch, J., Yang, T-L, and Owings, R., *Guidance Systems for Vehicle Testing*, ENSCO, Inc., Springfield, VA 1986.

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

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

7. APPENDIX

Appendix A - Accelerometer and Rate Gyro Analysis Plots

<u>MO2-1</u>:

<u>MO2-2</u>:

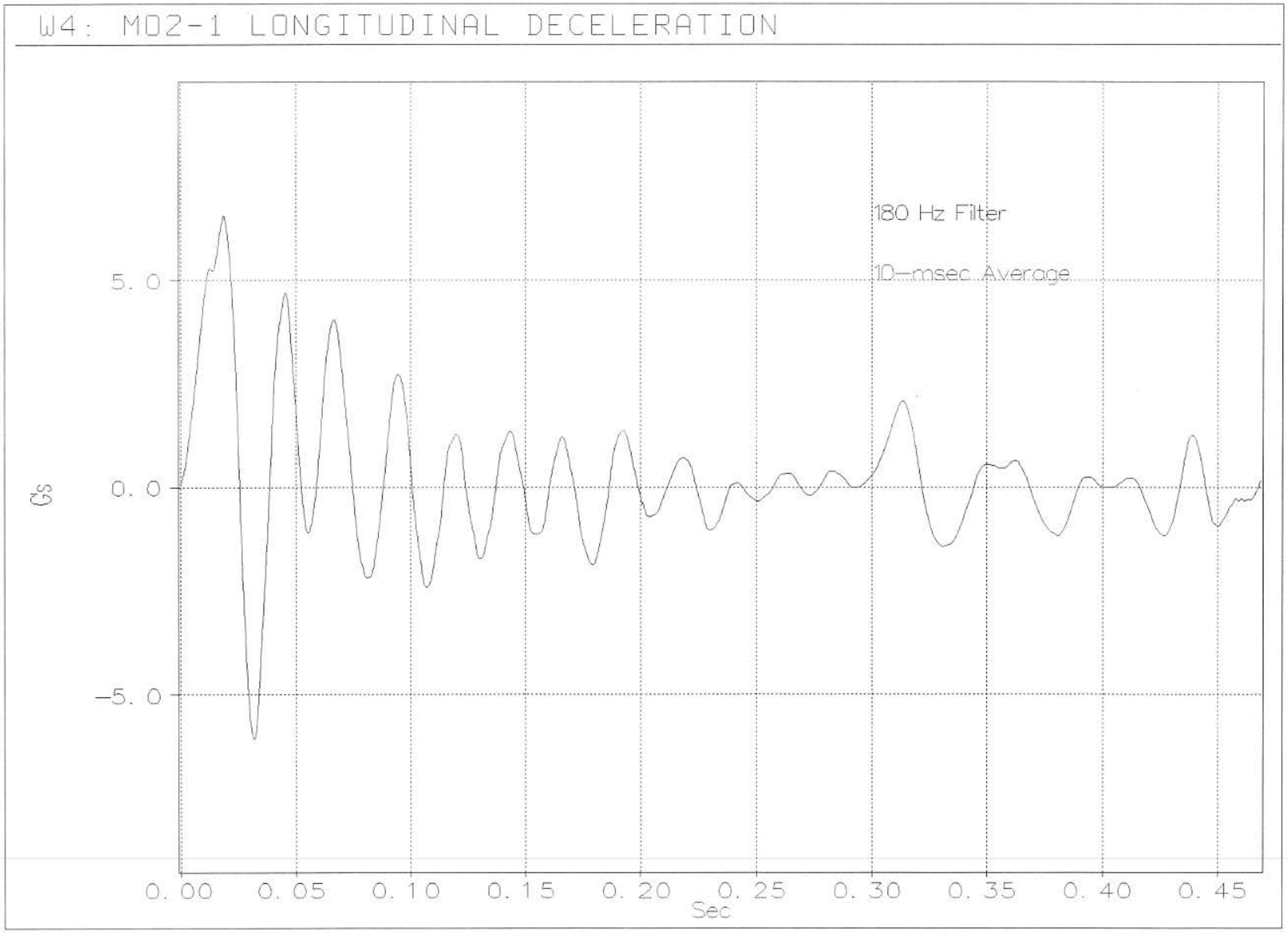


Figure A-1. Graph of Longitudinal Deceleration, MO2-1

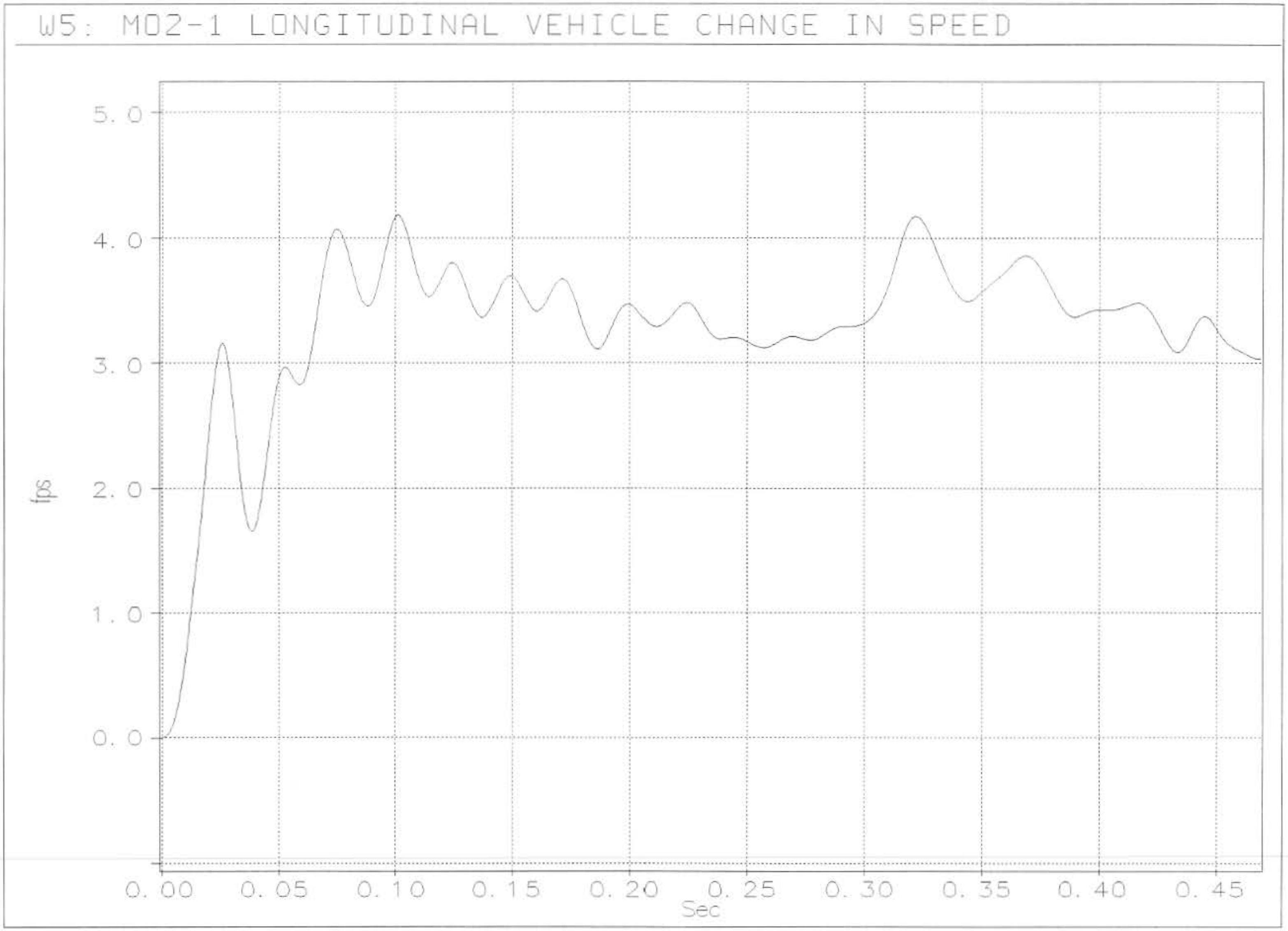


Figure A-2. Graph of Longitudinal Vehicle Change in Speed, MO2-1

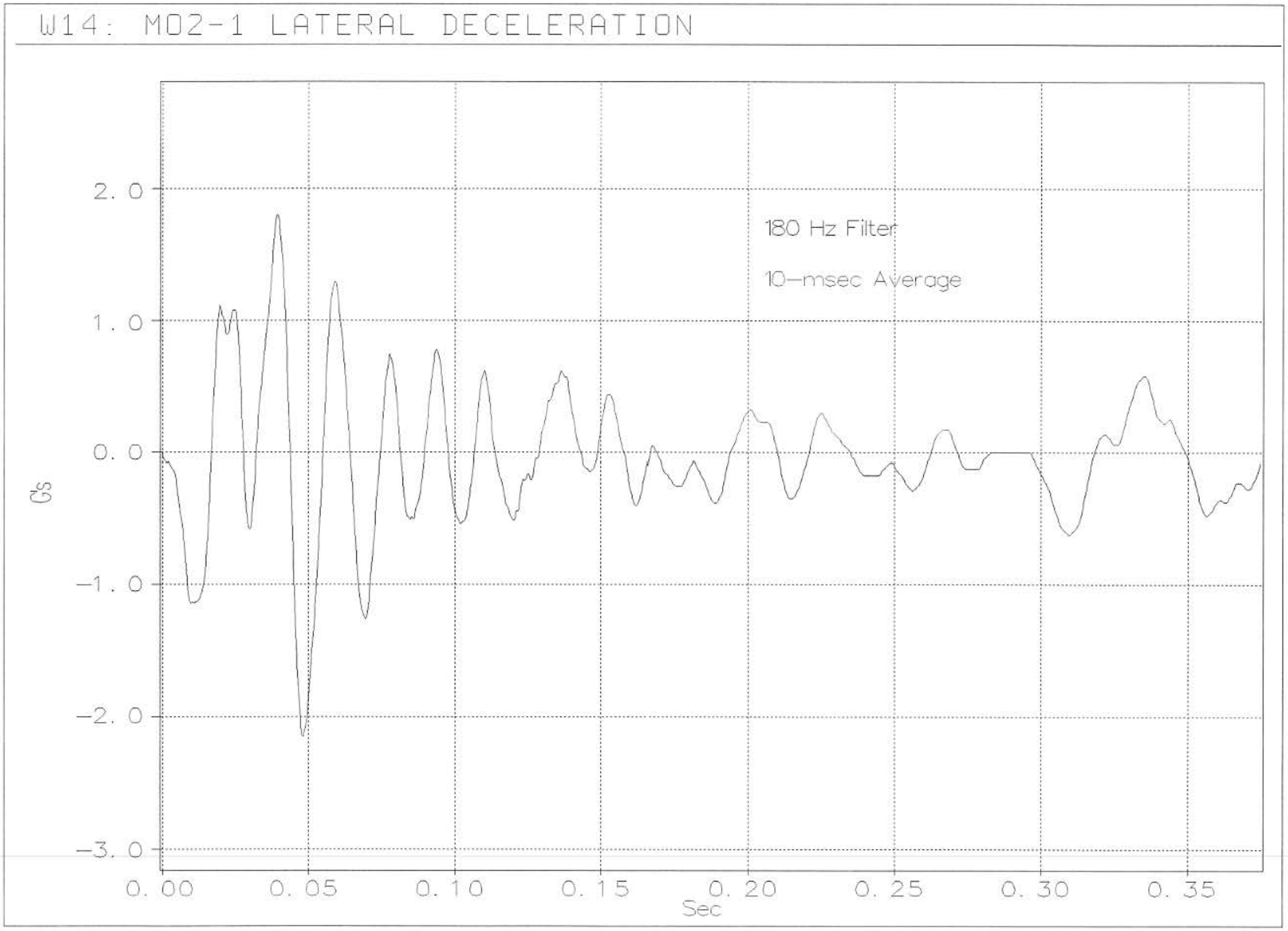


Figure A-3. Graph of Lateral Deceleration, MO2-1

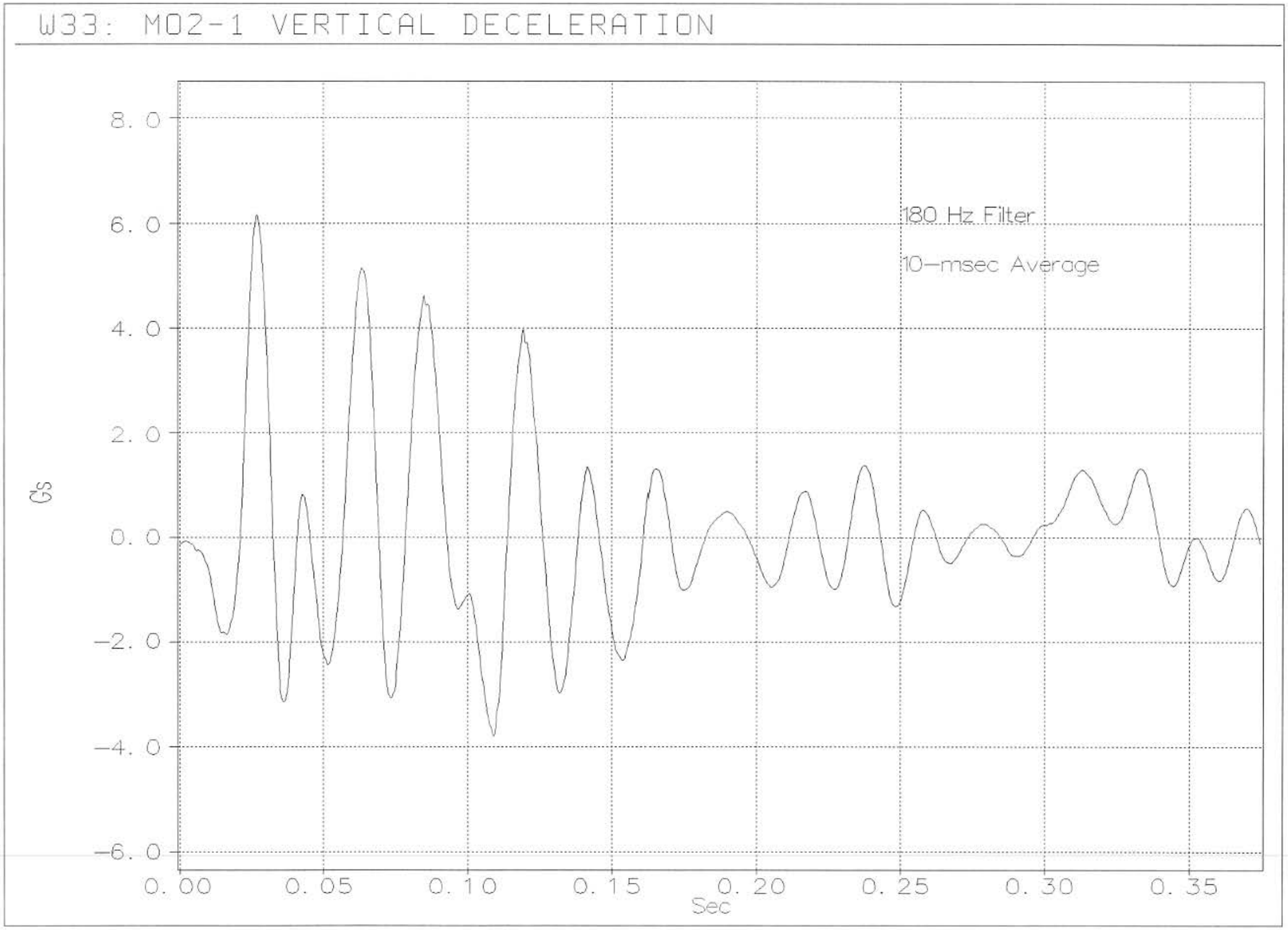


Figure A-4. Graph of Vertical Deceleration, MO2-1

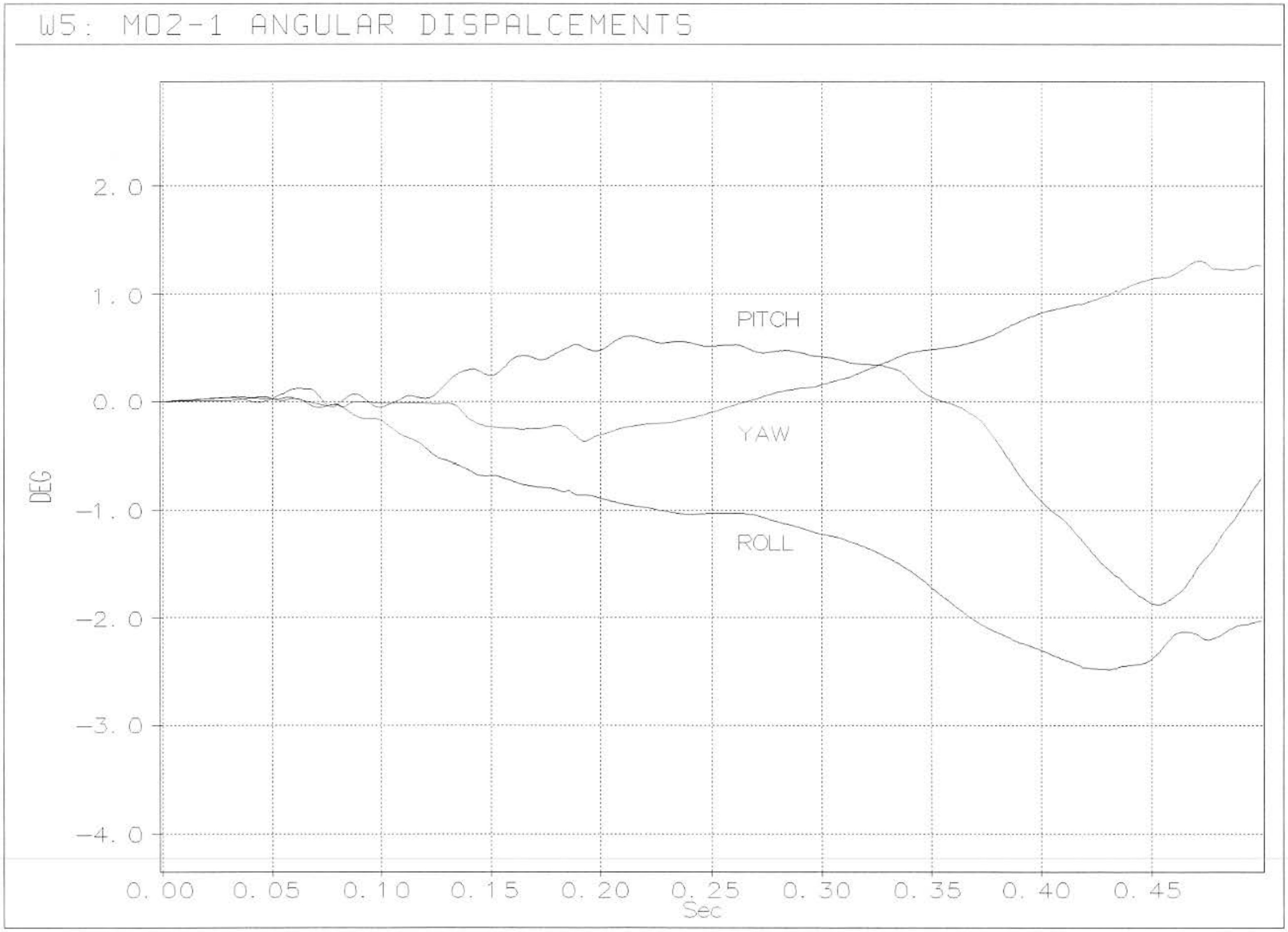


Figure A-5. Graph of Angular Displacements, MO2-1

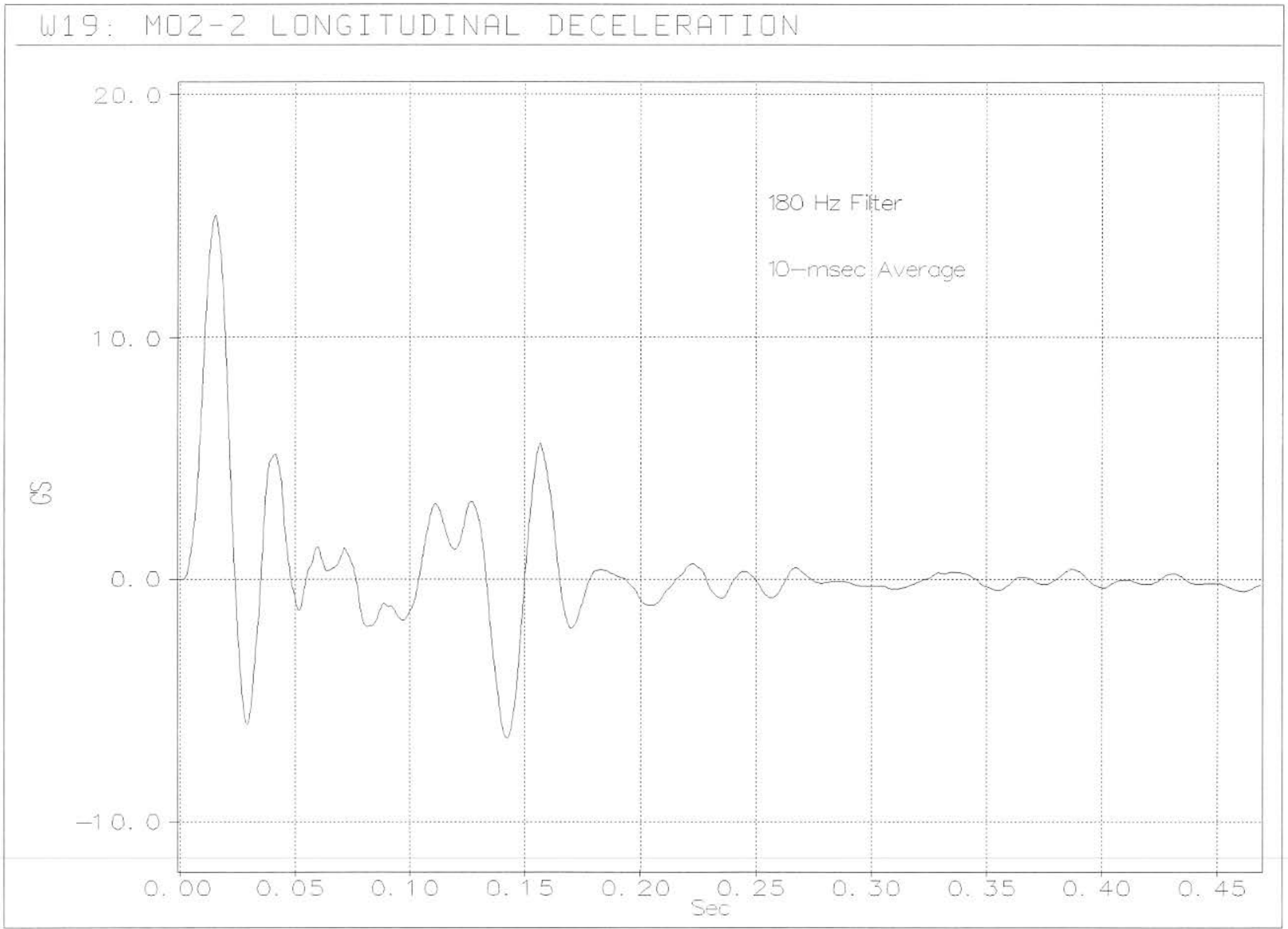


Figure A-6. Graph of Longitudinal Deceleration, MO2-2

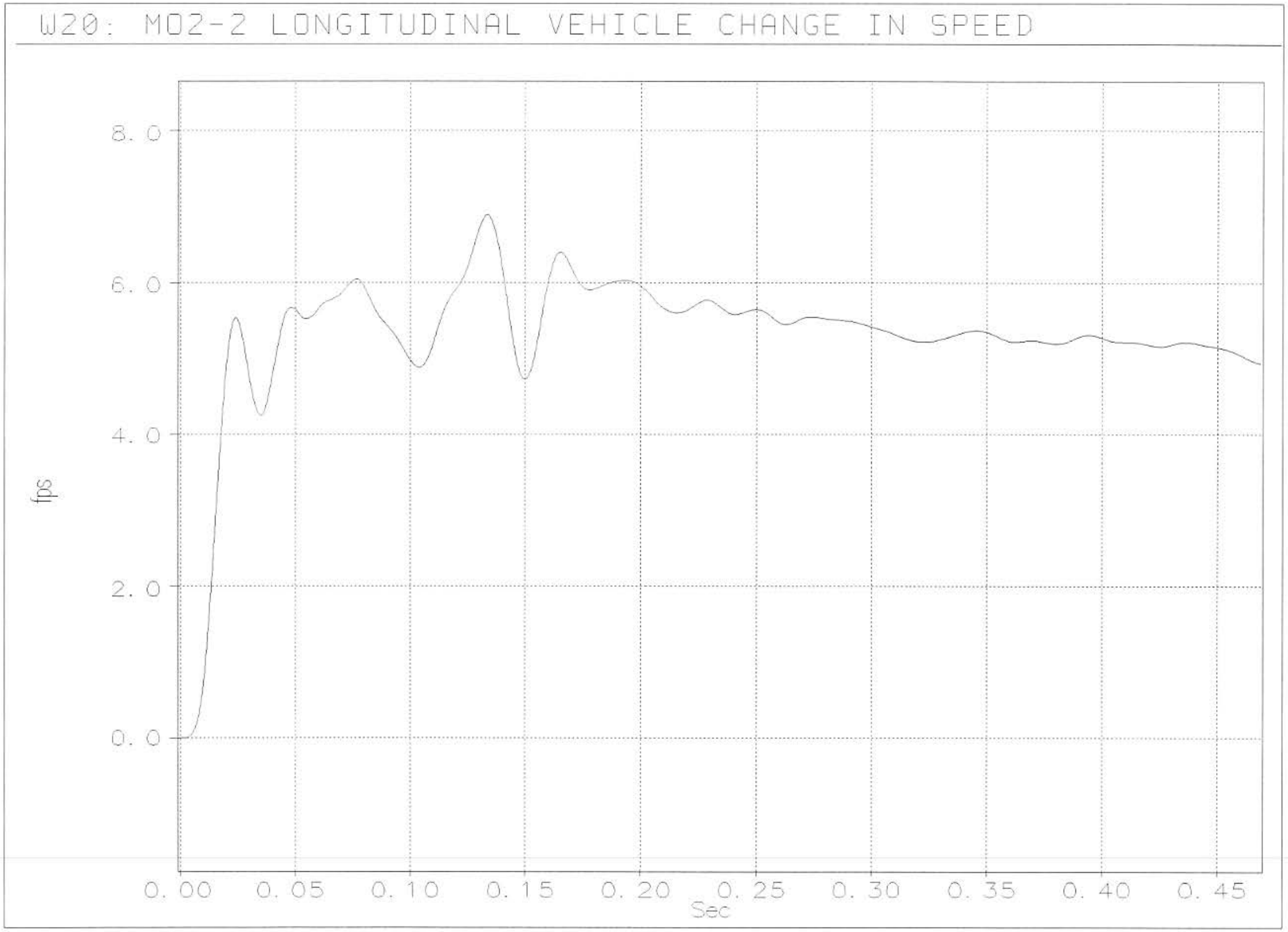


Figure A-7. Graph of Longitudinal Vehicle Change in Speed, MO2-2

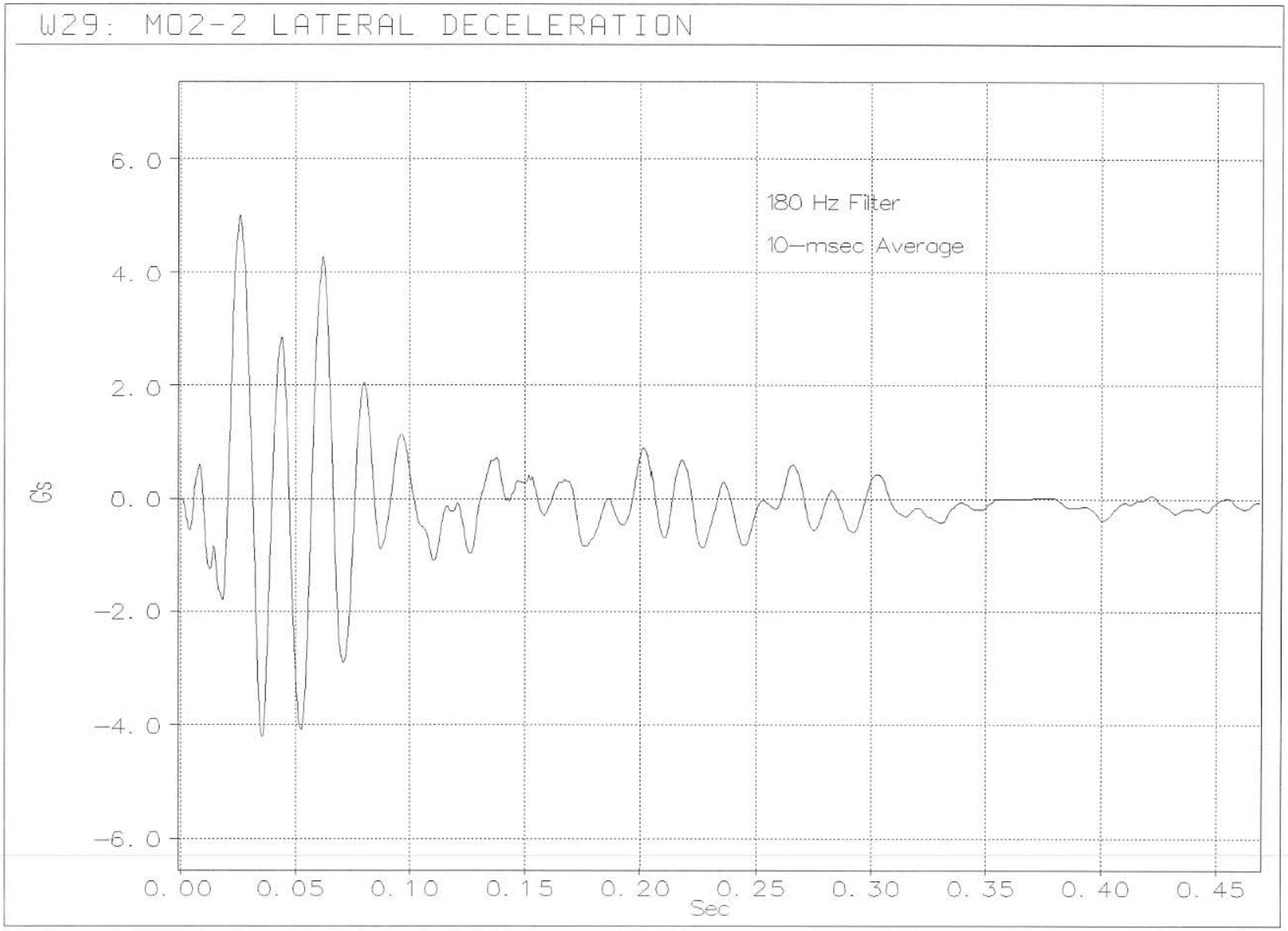


Figure A-8. Graph of Lateral Deceleration, MO2-2

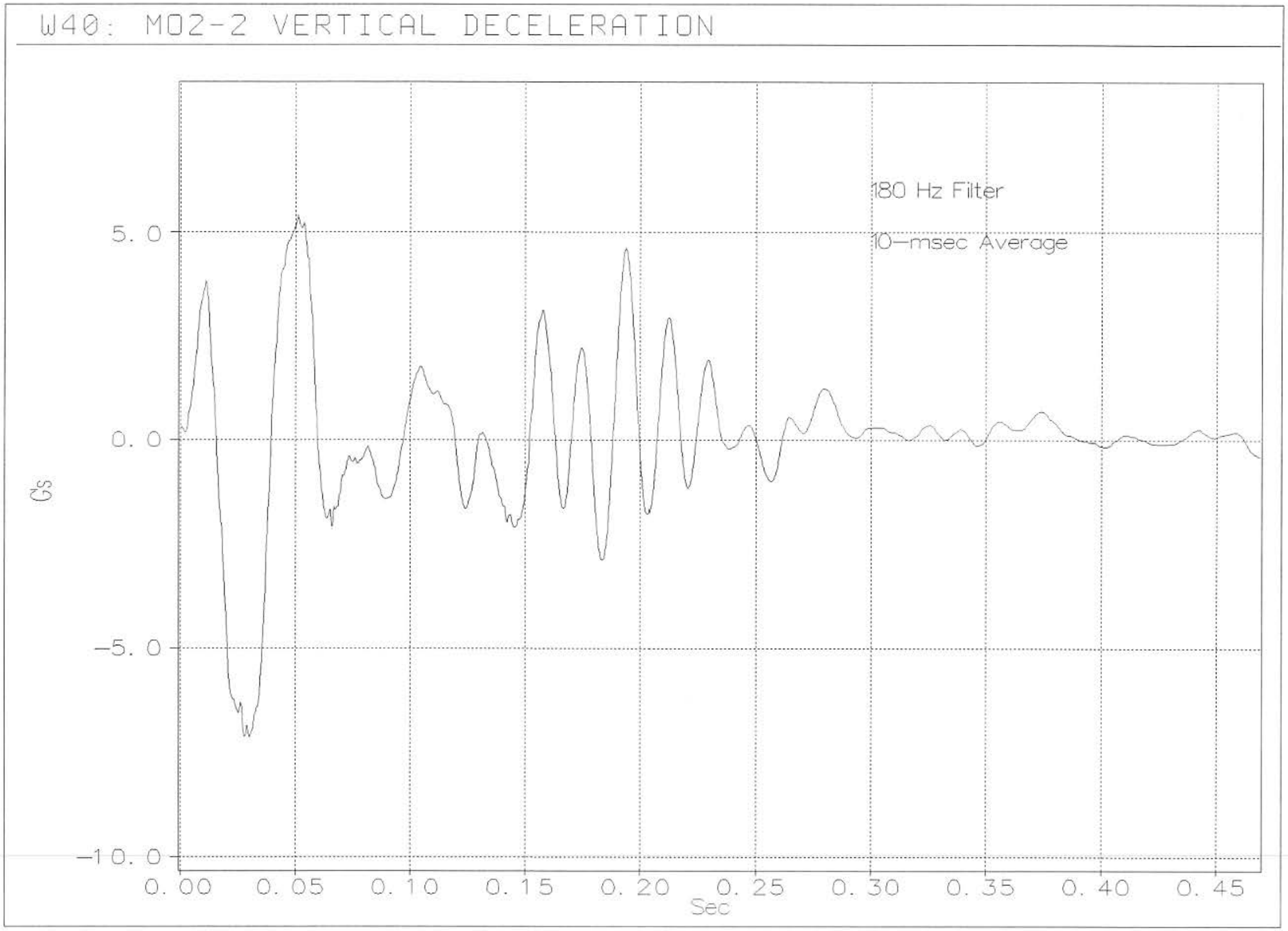


Figure A-9. Graph of Vertical Deceleration, MO2-2

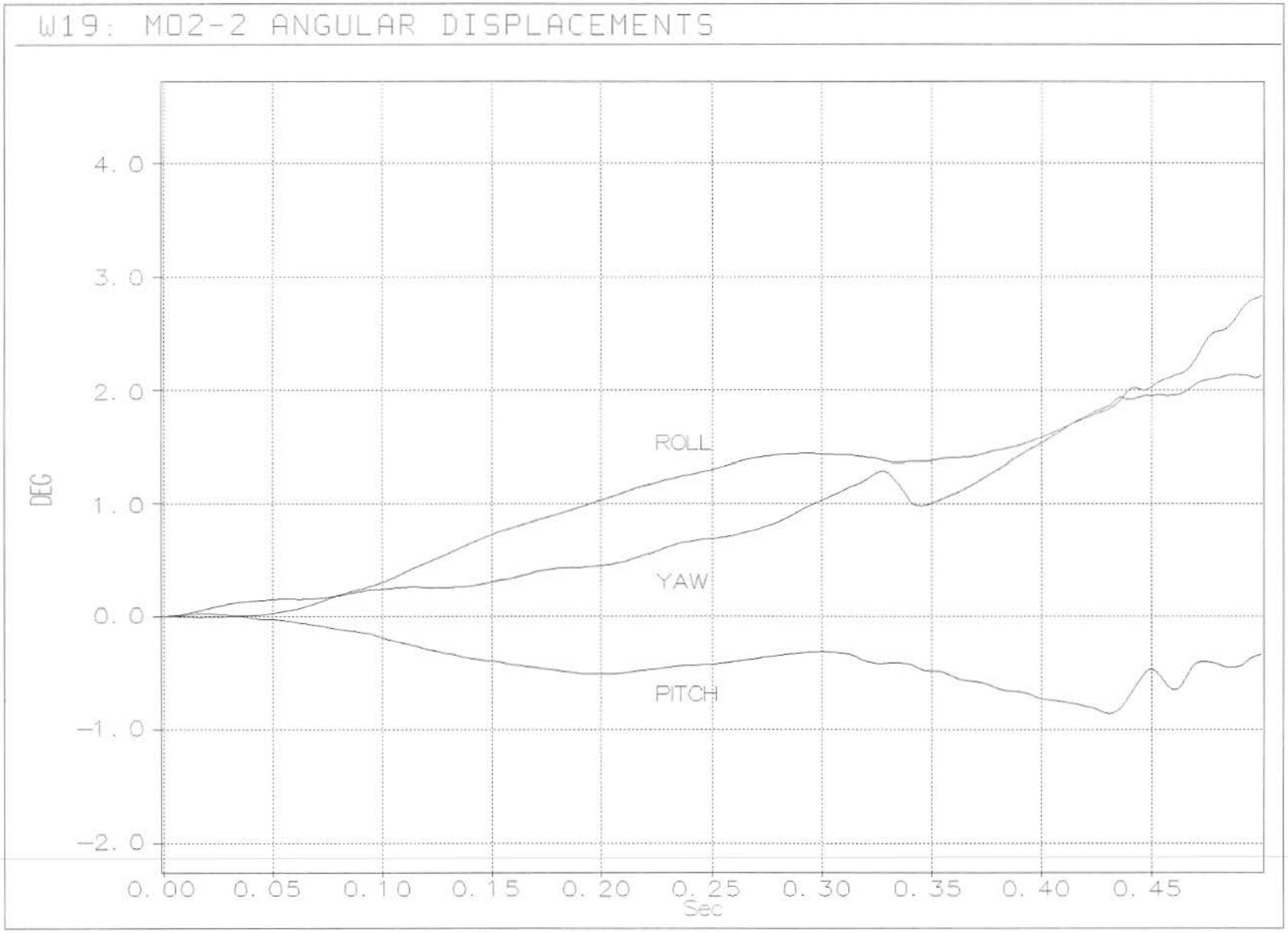


Figure A-10. Graph of Angular Displacements, MO2-2