Midwest State's Regional Pooled Fund Research Program - Fiscal Year 1993
NDOR Research Project Number RES1(0099) P473

DYNAMIC EVALUATION OF MISSOURI'S MODIFIED BRIDGE ANCHOR SECTION

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MwRSF Research Report No. TRP-03-38-93

February 1994

DISCLAIMER STATEMENT

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ACKNOWLEDGEMENTS

The authors wish to express their appreciation and thanks to the members of the Midwest States Regional Pooled Fund Program for funding the research described herein and the Center for Infrastructure Research for providing matching support. A special thanks is also given to the following individuals who made a contribution to the completion of this research project.

Nebraska Department of Roads

Leona Kolbet, Research Coordinator
Dalyce Ronnau, Assistant Maintenance Engineer (former Chairman - Pooled Fund Program)
Larry Brown, Chairman - Pooled Fund Program

Missouri Department of Transportation

Dan Davidson, Design Division
Pat McDaniel, Design Division
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Kansas Department of Transportation

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Center for Infrastructure Research

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Federal Highway Administration

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Brent Prauner, A.E. Student
Keith Robertson, Engineering Student
Matt Rief, C.E. Student
Matt Branting, E.E. Student
Brian Oetken, M.E. Student

ABSTRACT

One full-scale vehicle crash test was performed on Missouri's Modified Bridge Anchor Section. Test MBAS-1 was conducted with a 1985 Mercury Grand Marquis weighing 4,501-lbs (test inertial) at an impact speed of 59.0 mph and impact angle of 26.7 degrees. The impact location was 8 ft upstream from the end of the concrete barrier curb section.

The test was conducted and reported in accordance with the requirements specified in the *Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances*, National Cooperative Highway Research Program (NCHRP) Report No. 230. The safety performance of Missouri's Modified Bridge Anchor Section was determined to be unacceptable according to the NCHRP 230 criteria.

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1 INTRODUCTION

1.1 Problem Statement

The Missouri Highway and Transportation Department (MHTD) currently constructs a bridge anchor section at the upstream end of a New Jersey Safety-Shape bridge railing. The bridge anchor section or approach guardrail transition attaches the bridge rail to standard guardrail. The bridge anchor section consists of two 12-ft 6-in. sections of nested thrie beam rail (12-gauge) supported by W6 x 9 steel posts (1). The MHTD realized a potential for economy by using a single thrie beam rail (10-gauge) instead of two nested thrie beam sections. The modified bridge anchor section would provide economy due to lower material costs, simplicity in construction, and a potential reduction in maintenance costs following a vehicle impact. The research effort described herein was therefore undertaken to evaluate the safety performance of the modified bridge anchor section.

1.2 Objective

The objective of the research project was to conduct a safety performance evaluation on Missouri's modified bridge anchor section according to the National Cooperative Highway Research Program Report No. 230 *Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances* (2). One full-scale vehicle crash test (Test MBAS-1) was conducted with a 4,500-lb sedan impacting the barrier at a speed of 60 mph and an angle of 25 degrees (NCHRP 230 Test Designation No. 30).

1.3 Background

In 1989, Southwest Research Institute (SwRI) conducted a safety performance evaluation on Missouri's bridge anchor section or thrie beam transition to a concrete safety-shape bridge end. The bridge anchor section consisted of two 12-ft 6-in. sections of nested thrie beam rail

(12-gauge) supported by W6 x 9 steel posts (3). The spacing from the concrete end to the first post was 2 ft - 6¼ in. while subsequent post spacings in the transition were 3 ft - 1½ in.

One full-scale vehicle crash test was performed with a 1978 Dodge Sedan weighing 4,610 lbs. The test vehicle impacted the transition approximately 10-ft 1 3/4-in. upstream of the concrete end at a speed of 62.1 mph and an impact angle of 27.1 degrees. The safety performance of the thrie beam transition was judged to be acceptable according NCHRP 230 criteria (2). However, the researchers recommended that closer post spacing could probably improve the system's safety performance. Following the SwRI evaluation, the Federal Highway Administration (FHWA) recommended that Missouri construct the bridge anchor section with an additional post placed 11½ in. upstream from the concrete end (Appendix A).

2 TEST CONDITIONS

2.1 Missouri's Modified Bridge Anchor Section Design Details

The installation consisted of four major structural components: (1) New Jersey Safety-Shape bridge rail, barrier curb end section and footing; (2) bridge anchor section (thrie beam rail); (3) W-beam to thrie beam transition section; and (4) standard W-beam guardrail attached to a breakaway cable terminal (BCT). A detailed drawing of Missouri's modified bridge anchor section is shown in Figure 1. Design details of the safety barrier curb at end bents are shown in Figure 2. A schematic of the New Jersey Safety-Shape bridge rail, barrier curb, and footing are shown in Figure 3. Photographs of the actual installation are shown in Figures 4 through 6.

The total installation length was 68 ft - 4 3/4 in., consisting of 10 ft of New Jersey Safety-Shape bridge rail, 2 ft - 9 in. of barrier curb end section, 18 ft - 1 3/4 in. of bridge anchor section and W-beam to thrie beam transition section, and 37 ft - 6 in. of standard W-beam guardrail including a breakaway cable terminal (BCT) (Figure 7). A concrete anchor block or footing was placed in the soil to support the New Jersey Safety-Shape bridge rail and barrier curb end sections (Figure 3). The footing measured 2-ft 3-in. wide x 2-ft deep x 12-ft 9-in. long. The size of the footing was determined through a simplified analytical procedure provided by Ray (4). Ten feet of standard New Jersey Safety-Shape bridge rail and 2-ft 9-in. of barrier curb were rigidly anchored to the top surface of the concrete footing with steel reinforcement (Figure 3). The bridge rail and barrier curb sections had a top mounting height of 2 ft - 8¼ in. Grade 60 reinforcement was used in the footing, bridge rail section, and barrier curb end section. The concrete used for all of the above components was a L4000 mix with a minimum 4,000 psi compressive strength. The 35-day concrete compressive strength of the footing was approximately 6,070 psi, while the 29-day concrete compressive strength of the bridge rail and

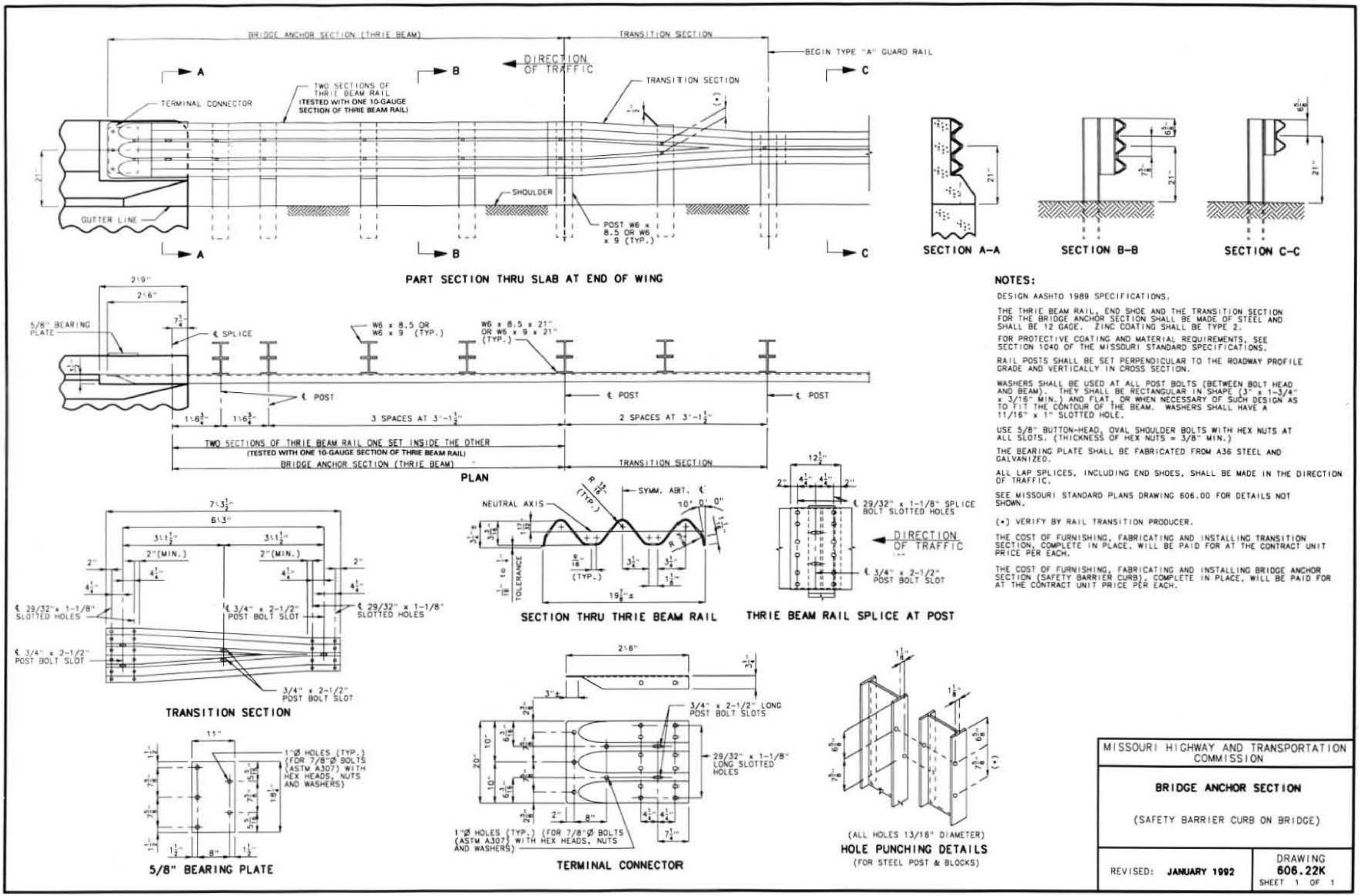


Figure 1. Modified Bridge Anchor Section Design Details

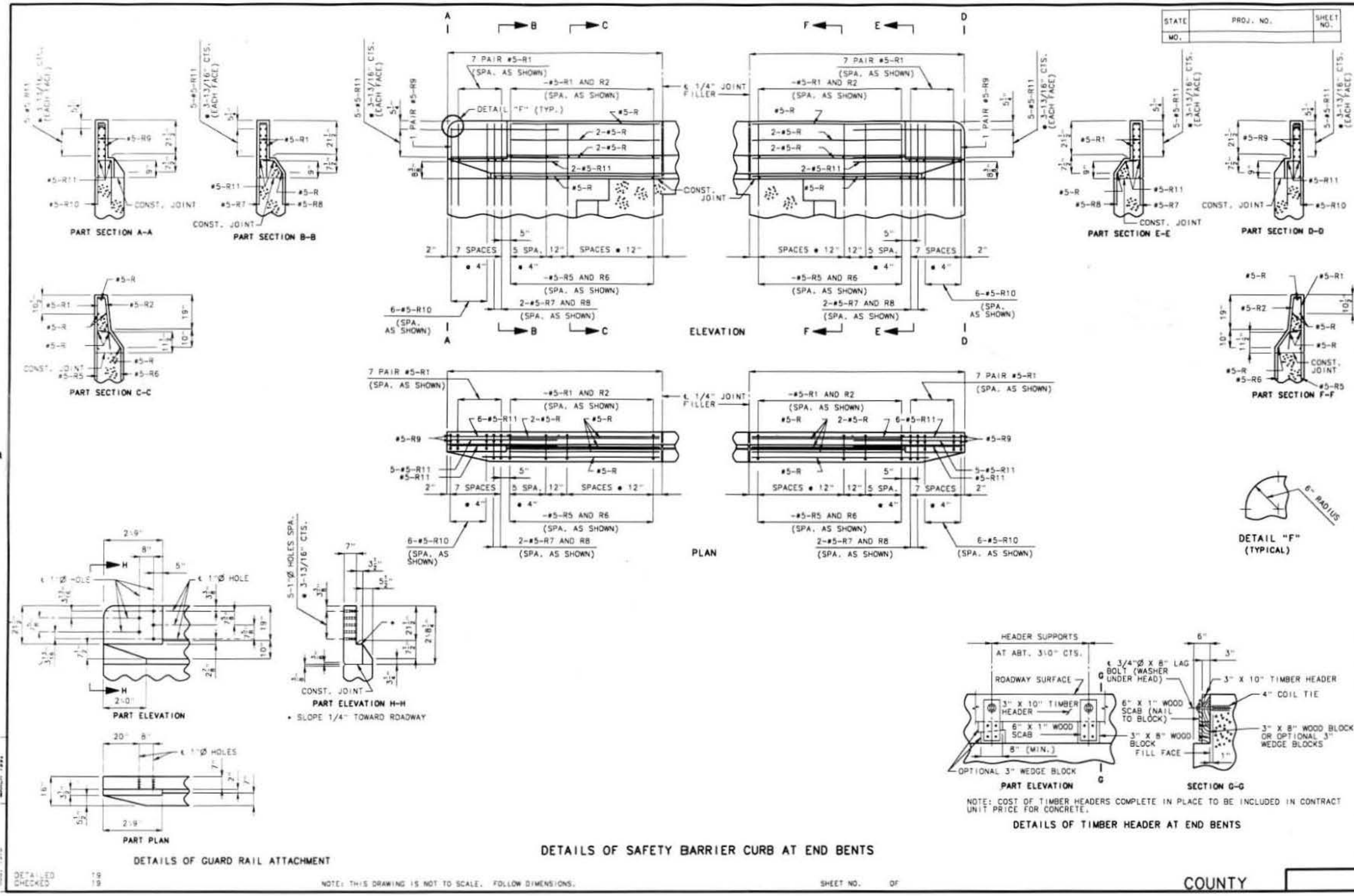


Figure 2. Design Details of Safety Barrier Curb at End Bents

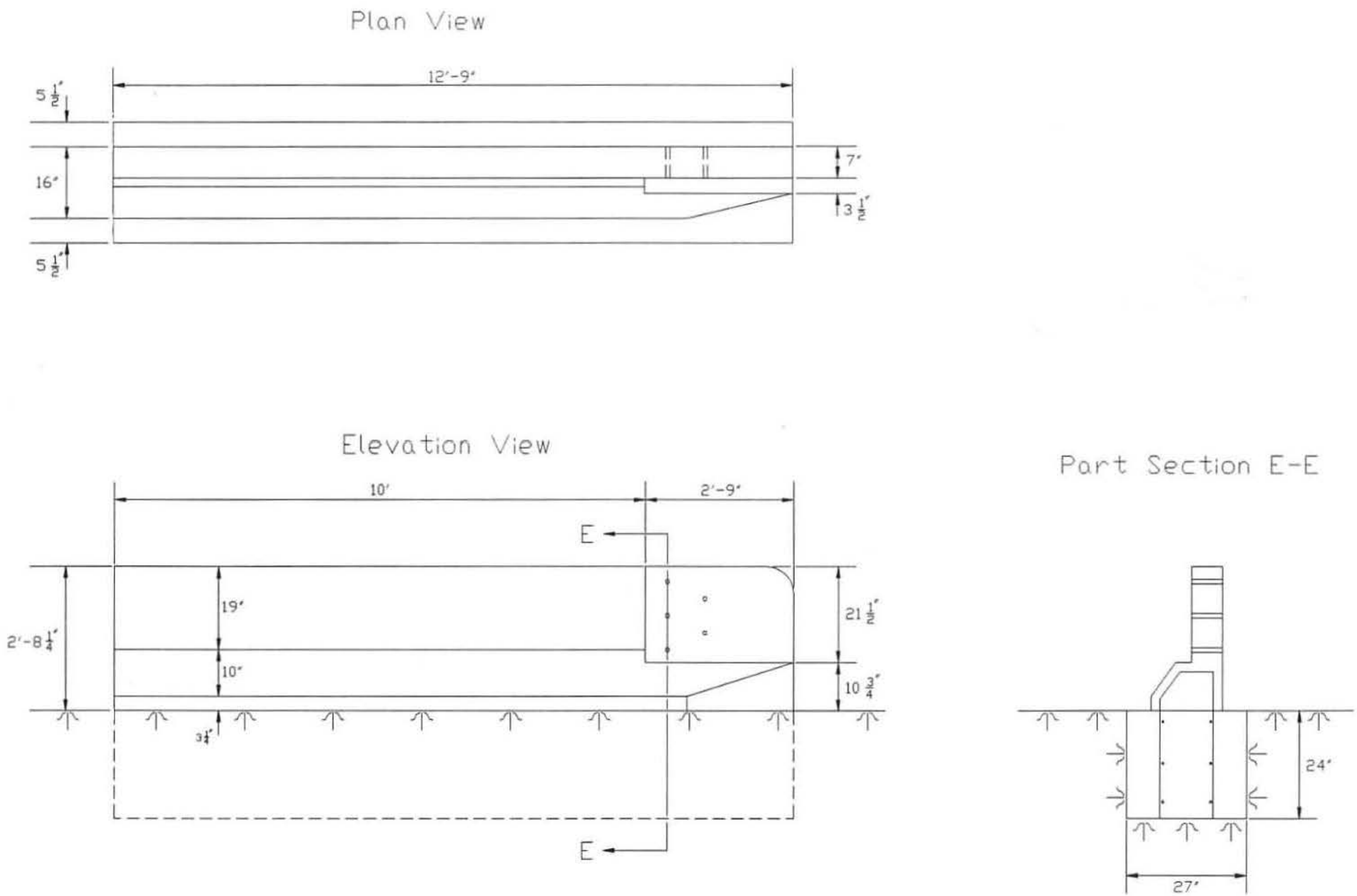


Figure 3. Schematic of Concrete End Section

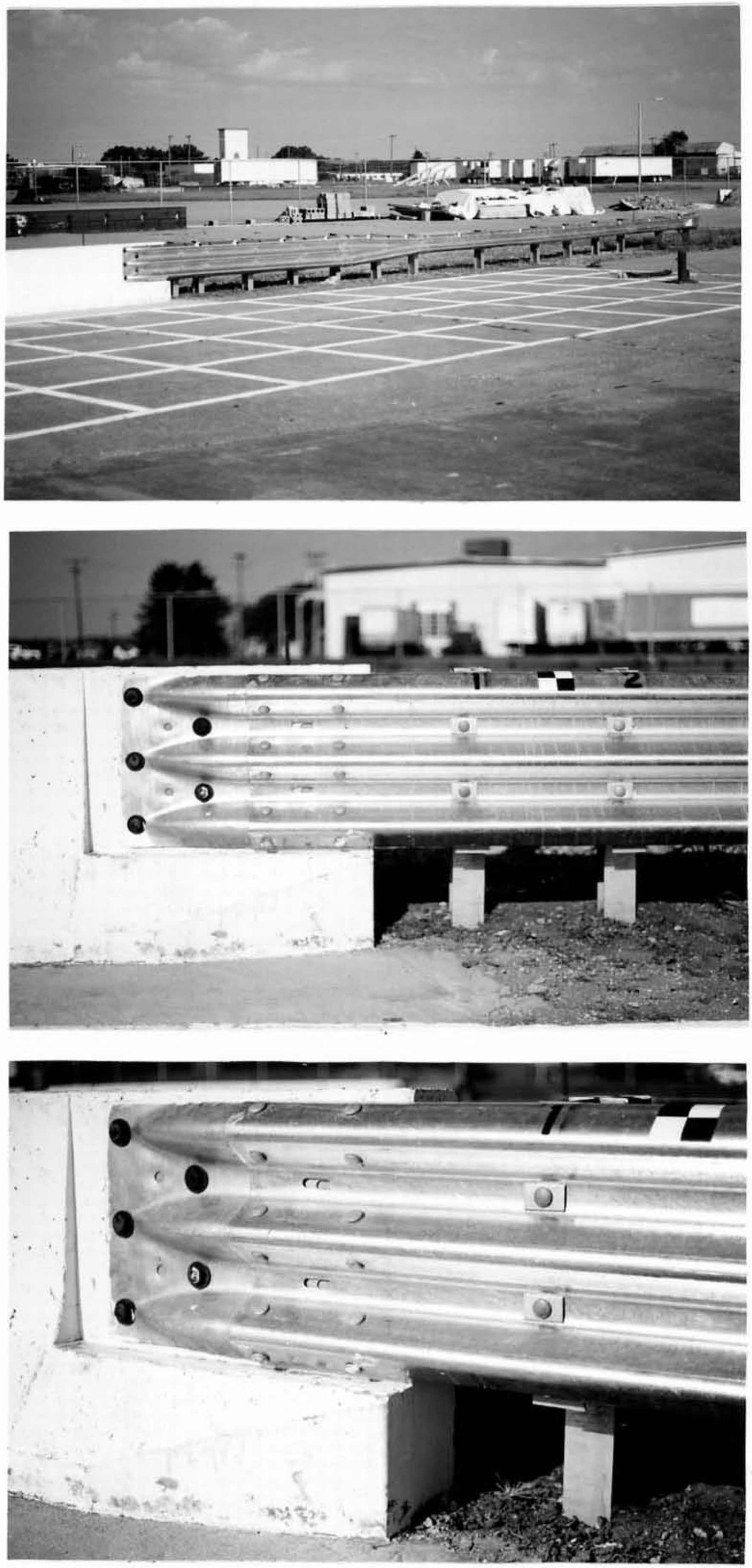


Figure 4. Modified Bridge Anchor Section

Figure 5. Modified Bridge Anchor Section

Figure 6. Modified Bridge Anchor Section

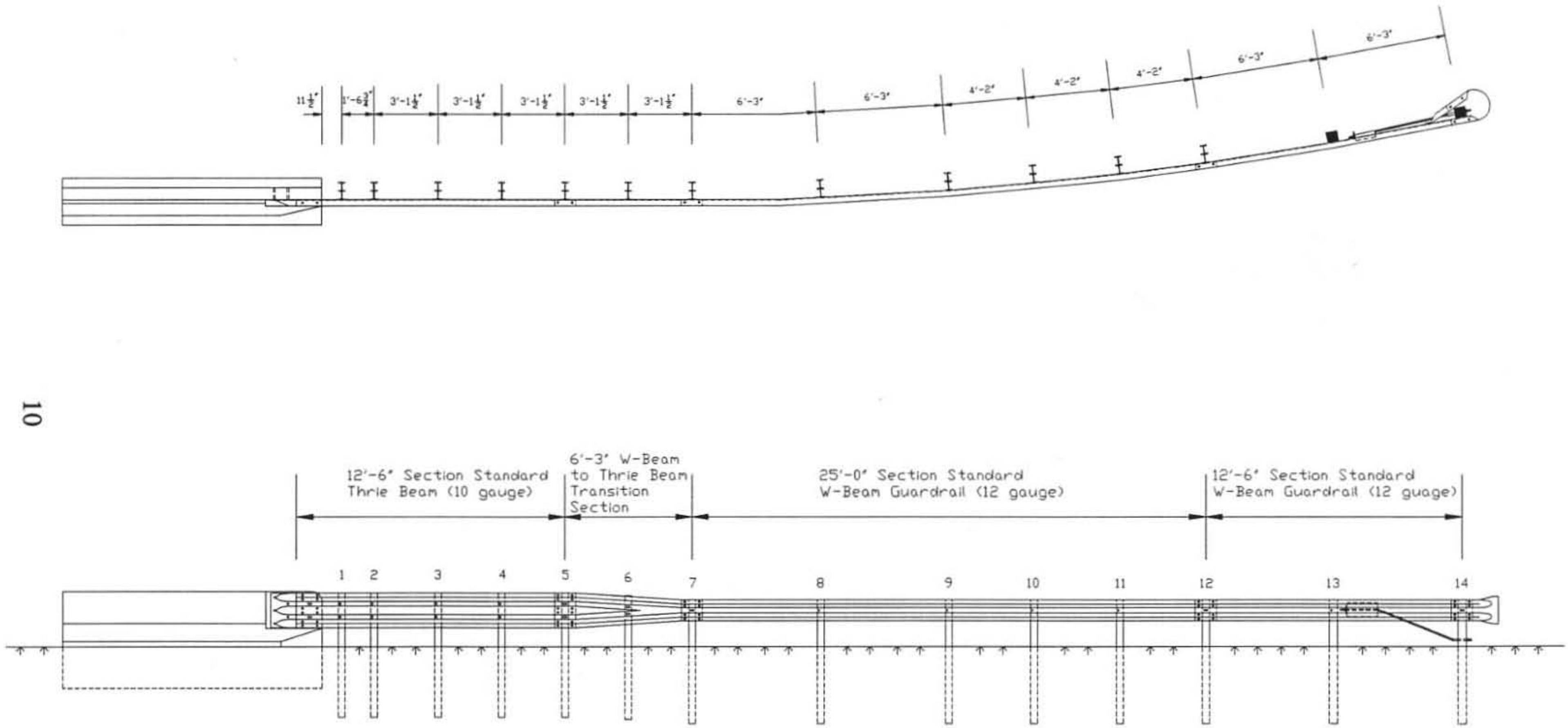


Figure 7. Installation Layout

barrier curb sections was approximately 5,920 psi.

The bridge anchor section consisted of one 12-ft 6-in. section of thrie beam rail (10-gauge) with a top mounting height of 2 ft - 7 in. (Figures 1 and 7). A thrie beam terminal connector attached the thrie beam rail to the concrete barrier curb end section. A 6-ft 3-in. W-beam to thrie beam transition section attached the upstream end of the bridge anchor section to the standard W-beam guardrail. The 37-ft 6-in. section of W-beam guardrail (12-gauge) had a top mounting height of 2 ft - 3 in. The W-beam guardrail was anchored with a standard breakaway cable terminal (BCT). Steel backup plates were placed between the steel guardrail and steel posts at all non-splice locations, except at the midspan of the W-beam to thrie beam transition section.

The total installation was constructed with fourteen posts (Figure 7). Post Nos. 1 through 12 consisted of W6 x 9 by 6-ft long steel posts with W6 x 9 steel spacer blocks, while Post Nos. 13 and 14, placed in the BCT end treatment, consisted of 5½-in. x 7½-in. x 3-ft 6½-in. timber breakaway posts. The breakaway posts were drilled with a 2 3/8-in. diameter hole at a location 25-in. below the top of the post and perpendicular to the 7½-in. face, and were placed in steel foundation tubes. The steel posts were driven into a compacted silty-clay topsoil material in order to evaluate the system's performance in soil conditions typically encountered along Missouri highways. Note that these soil conditions are not in conformance with either the strong soil (S-1) or the weak soil (S-2) defined in NCHRP 230 (2). Prior to full-scale crash testing, the soil conditions, from a visual inspection, were found to be dry and crumbly at a depth of 1 ft.

The spacing from the concrete end to Post No. 1 was 11½ in. while the spacing between Post Nos. 1 and 2 was 1 ft - 6 3/4 in. on centers. Post Nos. 2 through 7, 7 through 9, 9 through 12, and 12 through 14 were spaced on 3-ft 1½-in., 6-ft 3-in., 4-ft 2-in., and 6-ft 3-in. centers, respectively.

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 (5) was used to steer the test vehicle. A guide-flag, attached to the front-left wheel and the guide cable, was sheared off before impact. The 3/8-in. diameter guide cable was tensioned to approximately 3,000 lbs, and supported laterally and vertically every 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 approximately 1,500-ft long.

2.3 Test Vehicle

A 1985 Mercury Grand Marquis sedan was used as the test vehicle. The test vehicle had a test inertial weight and gross static weight of 4,501 lbs. The test vehicle is shown in Figure 8, and vehicle dimensions are shown in Figure 9.

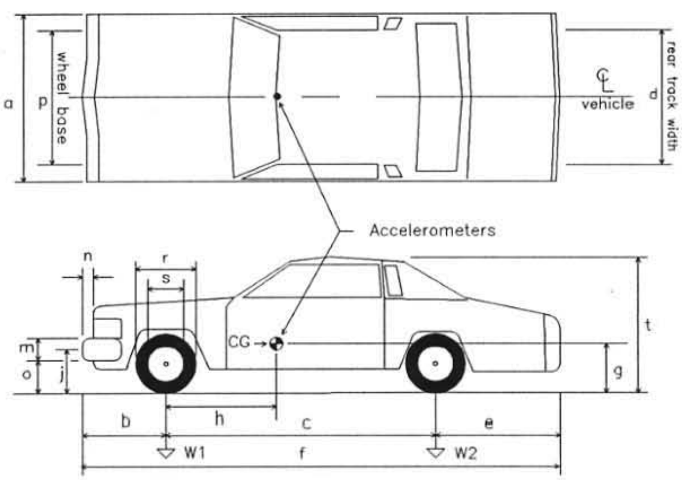
The Elevated Axle Method (6) was used to determine the vertical component of the center of gravity. This method converts measured wheel weights at different elevations to the location of the vertical component of the center of gravity. The longitudinal component of the center of gravity was determined using the measured axle weights. The location of the final center of gravity is shown in Figure 9. Vehicle ballast consisted of steel plates rigidly attached to the floor

Figure 8. Test Vehicle, Test MBAS-1

Date: 7/30/93 Test No.: MBAS-1 Tire Size: P215/75R15

Make: Mercury Model: Grand Marquis Year: 1985

Vehicle I.D.#: 2MEBP95F1FX635162



Vehicle Geometry
Inches

a	77	b	44.25
c	114	d	55.75
e	56.75	f	215
g	22.5	h	50.2
j	17	m	8
n	7	o	13
p	62.5	q	62
r	27	s	15.25
t	34.5		

Engine Size: 302 cu. in.

Transmission Type: automatic

Weight – pounds	Curb	Test Inertial	Gross Static
W1	2220	2519	2519
W2	1450	1982	1982
Wtotal	3670	4501	4501

Moment of Inertia (lb–sec²–in) – Gross Static

Roll (Ix)	N/A
Pitch (Iy)	N/A
Yaw (Iz)	N/A

Damage prior to test: None

Figure 9. Vehicle Dimensions, Test MBAS-1

gravity is shown in Figure 9. Vehicle ballast consisted of steel plates rigidly attached to the floor of the test vehicle.

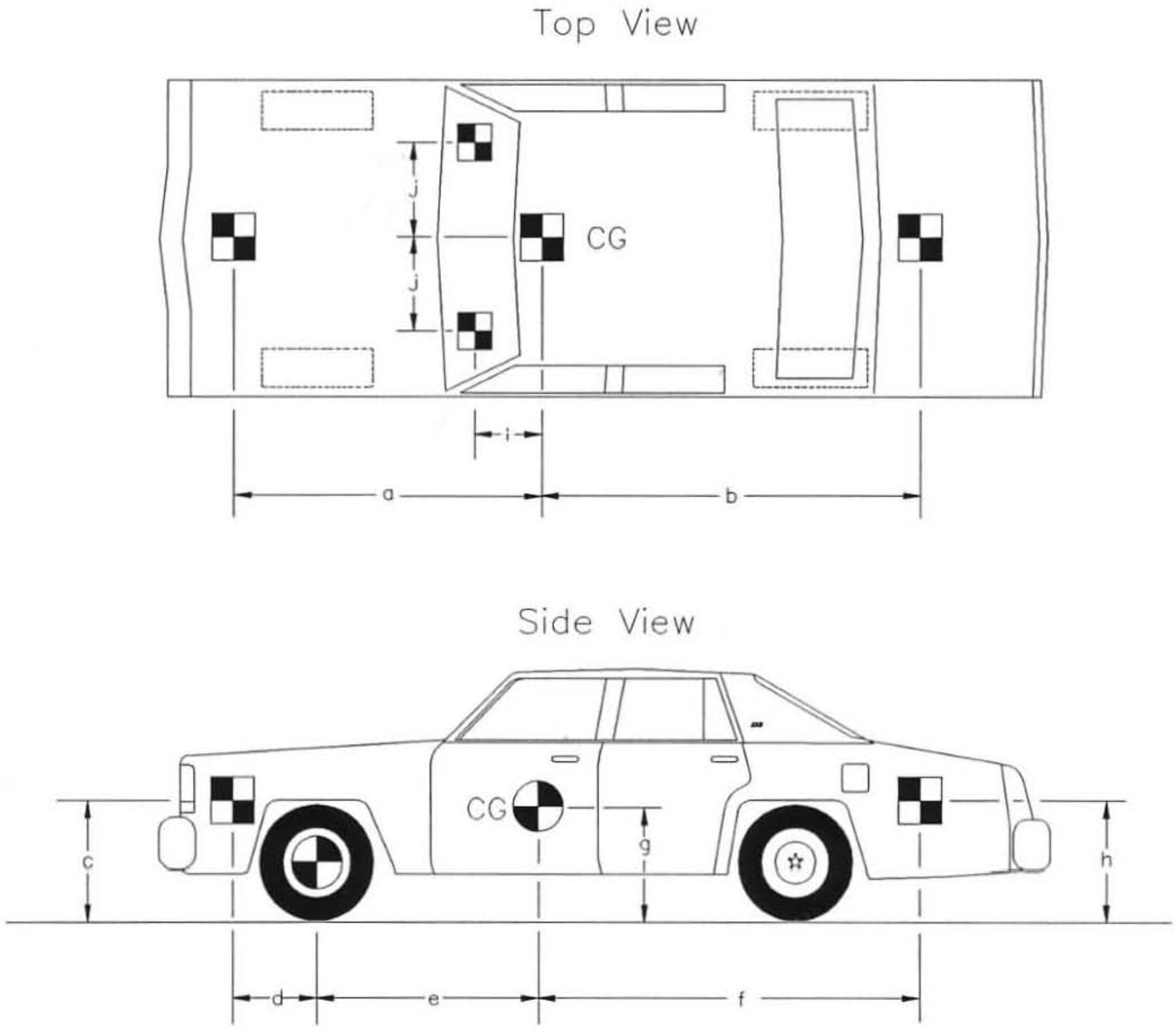
Eight square, black and white-checkered targets were placed on the vehicle to aid in the analysis of the high-speed film (Figure 10). Two targets were placed on the center of gravity, one on the top and one on the driver's side of the vehicle. The remaining targets were located for reference so that they could be viewed from all four high-speed 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 were mounted on the hood of the vehicle to pinpoint the time of impact with the bridge anchor section on the high-speed film. The flash bulbs were fired by a pressure tape switch mounted on the front face of the bumper.

2.4 Data Acquisition Systems

2.4.1 Accelerometers

Two triaxial piezoresistive accelerometer systems with a range of $\pm$200 g's (Endevco Model 7264) were used to measure the acceleration in the longitudinal, lateral, and vertical directions. Two accelerometers were mounted in each of the three directions and were rigidly attached to a metal block mounted at the center of gravity. Accelerometer signals were received and conditioned by an onboard Series 300 Multiplexed FM Data System built by Metraplex Corporation. The multiplexed signal was then transmitted to the Honeywell 101 Analog Tape Recorder. Computer software, "EGAA" and "DSP" were used to digitize, analyze, and plot the accelerometer data.



TEST# MBAS-1

TARGET GEOMETRY
INCHES

a 50.5	c 31.75	e 50.2	g 22.5	i 16
b 95.5	d 0	f 96.5	h 32	j 18

Figure 10. Vehicle Target Locations, Test MBAS-1

2.4.2 Rate Transducer

A Humphrey 3-axis rate transducer with a range of 250 deg/sec in each of the three directions (pitch, roll, and yaw) was used to measure the rates of motion of the test vehicle. The rate transducer was rigidly attached to the vehicle near the center of gravity of the test vehicle. Rate transducer signals were received and conditioned by an onboard Series 300 Multiplexed FM Data System built by Metraplex Corporation. The multiplexed signal was then transmitted by radio telemetry to a Honeywell 101 Analog Tape Recorder. Computer software, "EGAA" and "DSP" were used to digitize, analyze, and plot the accelerometer data.

2.4.3 High-Speed Photography

Four high-speed 16-mm cameras, with operating speeds of approximately 500 frames/sec, were used to film the crash tests. A Red Lake Locam with a wide-angle 12.5-mm lens was placed above the test installation to provide a field of view perpendicular to the ground. A Photec IV with an 80-mm lens and a Red Lake Locam with a 76-mm lens were placed downstream from the impact point and had a field of view parallel to the bridge rail. A Red Lake Locam, with a 25-mm lens, was placed on the traffic side of the bridge rail and had a field of view perpendicular to the bridge rail. A schematic of all four camera locations is shown in Figure 11. In addition, a Bolex camera, with an operating speed of approximately 64 frames/sec, was used as a documentary camera. A 20-ft wide by 55-ft long, white-colored grid was painted on the surface on the traffic side of the bridge rail. This grid was incremented in 5-ft divisions in both directions to provide a visible reference system for use in the analysis of the overhead high-speed film. The film was analyzed using the Vanguard Motion Analyzer. Actual camera speed and camera divergence factors were considered in the analysis of the high-speed film.

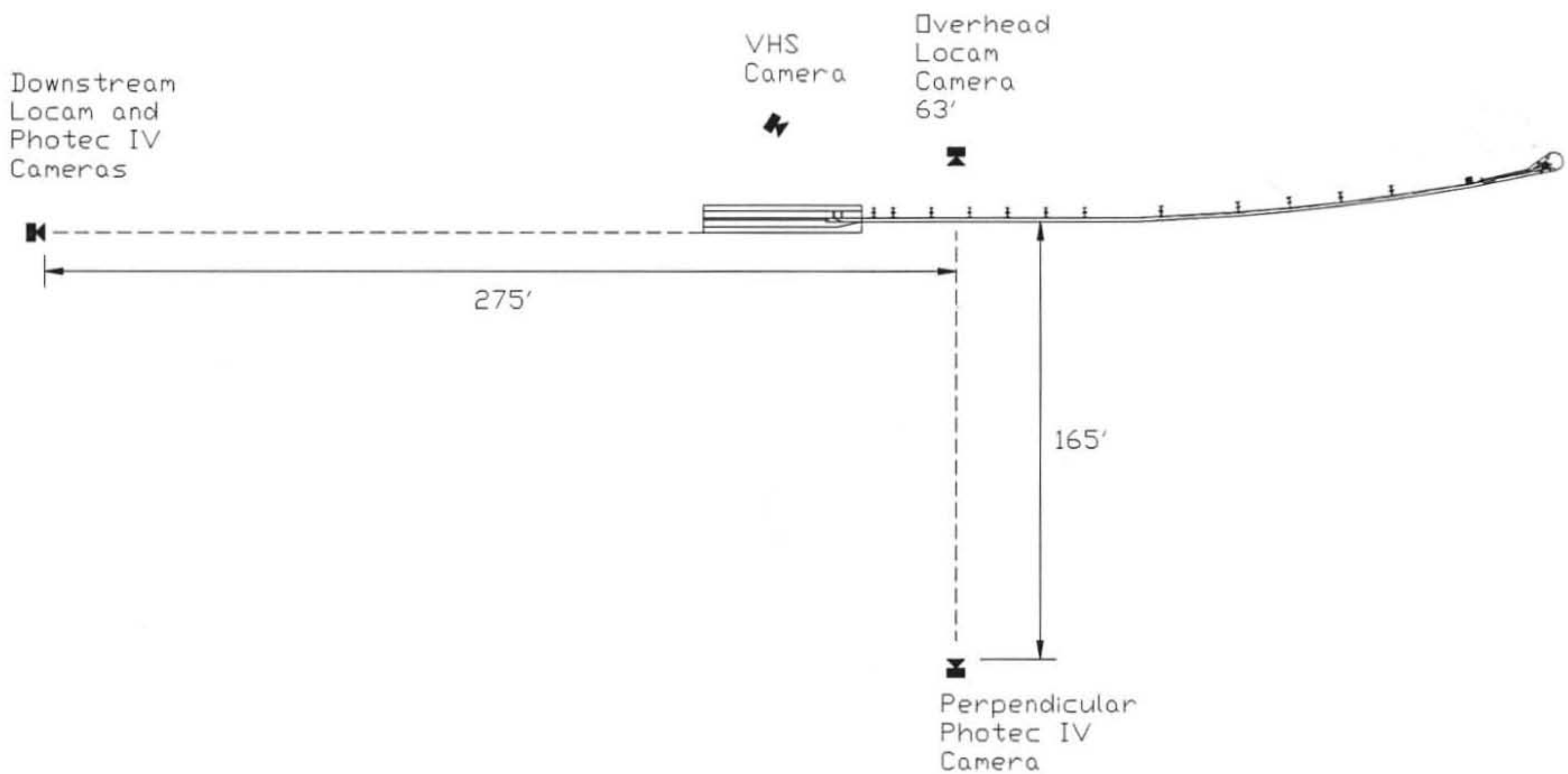


Figure 11. Location of High-Speed Cameras, Test MBAS-1

2.4.4 Speed Trap Switches

Seven pressure-activated tape switches, spaced at 5-ft intervals, were used to determine the speed of the vehicle before impact. Each tape switch fired a strobe light which sent an electronic timing signal to the data acquisition system as the left front tire of the test vehicle passed over it. Test vehicle speeds were determined from electronic timing mark data recorded on "EGAA" software. Strobe lights and high-speed film analysis are used only as a backup in the event that vehicle speeds cannot be determined from the electronic data.

3 PERFORMANCE EVALUATION CRITERIA

Roadside safety hardware, including approach guardrail transitions, must satisfy the requirements provided in NCHRP Report No. 230 (2) in order to be accepted for use on new construction projects or as a replacement for existing transition designs. NCHRP Report 230 requires that approach transitions safely redirect a 4,500-lb automobile impacting at a speed of 60 mph and an angle of 25 degrees. The safety performance of Missouri's modified bridge anchor section was evaluated according to three major factors: (1) structural adequacy; (2) occupant risk; and (3) vehicle trajectory after collision. These three evaluation criteria are defined in Table 1. The full-scale crash test was conducted and reported in accordance with the procedures provided in NCHRP 230.

Table 1. NCHRP Report 230 Evaluation Criteria

Structural Adequacy	A.	Test article shall smoothly redirect the vehicle; the vehicle shall not penetrate or go over the installation although controlled lateral deflection of the test article is acceptable.
	D.	Detached elements, fragments or other debris from the test article shall not penetrate or show potential for penetrating the passenger compartment or present undue hazard to other traffic.
Occupant Risk	E.	The vehicle shall remain upright during and after collision although moderate roll, pitching and yawing are acceptable. Integrity of the passenger compartment must be maintained with essentially no deformation or intrusion.
Vehicle Trajectory	H.	After collision, vehicle trajectory and final stopping position shall intrude a minimum distance, if at all, into adjacent traffic lanes.
	I.	In test where the vehicle is judged to be redirected into or stopped while in adjacent traffic lanes, vehicle speed change during test article collision should be less than 15 mph and the exit angle from the test article should be less than 60 percent of the test impact angle, both measured at time of vehicle loss of contact with test device.

4 COMPUTER SIMULATION

4.1 Background

Computer simulation modeling with BARRIER VII was performed to analyze and predict the dynamic performance of the modified bridge anchor section prior to full-scale vehicle crash testing (7). In addition, computer simulation was used to determine the critical impact point (CIP) of the bridge anchor section. The CIP location, as determined by BARRIER VII, was then used to check the simplified procedures for determining CIP locations found in NCHRP Report No. 350, *Recommended Procedures for the Safety Performance Evaluation of Highway Features* (8).

During the computer simulation modeling phase, it was anticipated that the full-scale vehicle crash test would be conducted according to NCHRP 350 (8). The NCHRP 350 strength test required that a 2000-kg (4,409-lb) pickup truck be conducted at an impact speed of 100 km/h (62.14 mph) and an impact angle of 25 degrees. Computer simulation was conducted modeling a 4,400-lb pickup truck impact at 62.14 mph and 25 degrees. The BARRIER VII model of the bridge anchor section is shown in Appendix B. The computer simulation input file is shown in Appendix C.

4.2 BARRIER VII Results

Six computer simulation runs were performed at different locations to determine the dynamic response and critical impact point (Table 2). The critical impact point was based upon the impact condition which produced the greatest potential for wheel-hub snagging on the lower blunt-end face of the upstream end of the concrete barrier curb. This blunt-end face extended ¼ in., as measured toward the roadway, away from the traffic-side face of the undeformed thrie beam rail. Therefore, the potential for wheel-hub snagging would exist with any significant rail

Table 2. Computer Simulation Test Matrix and Results

Test No.	Impact Node	Impact Distance[1]	Maximum Dynamic Rail Deflection (in.)	Lateral Wheel-Hub Snag Distance[2] (in.)
1	19	11 ft - 10 3/4 in.	12.98	0.8
2	23	8 ft - 9 1/4 in.	10.11	4.3
3	27	5 ft - 7 3/4 in.	6.10	3.0
4	25	7 ft - 2 1/2 in.	7.89	3.5
5	24	7 ft - 11 7/8 in.	10.33	4.7[3]
6	22	9 ft - 6 5/8 in.	11.73	4.5

[1] - Longitudinal distance measured from impact location to upstream end of concrete barrier curb.

[2] - Lateral distance of wheel-hub measured behind original location of traffic-side face of rail. This lateral distance is measured when the steel rim of the wheel hub contacts the blunt-end of barrier curb.

[3] - Assumed critical impact point (CIP).

deflections and/or rail flattening near the blunt-end face.

The results of the computer simulation indicated a potential for wheel-hub snagging on the blunt-end face of the concrete barrier curb. This was evident with wheel-hub snag distances ranging from approximately 3 to 4.7 in. (Table 2). Computer simulation with BARRIER VII revealed that a vehicle impacting approximately 8 ft upstream from the blunt-end of the barrier curb produced the greatest snag potential with a lateral wheel-hub snag distance of 4.7 in. The critical impact point (CIP), as determined by the simplified procedures for Test No. 21 found in NCHRP 350 (8), was determined to be approximately 1.63 m (5.3 ft) and less than 1.5 m (4.9 ft) for post spacings equal to 3 ft - 1 1/2 in. and 1 ft - 6 3/4 in., respectively. The CIP values from computer simulation (8 ft) and NCHRP 350 (4.9 to 5.3 ft) were not found to be in agreement. It appears that there may be a problem with the CIP graphs developed for Test No. 21 (Figure 3.14 of NCHRP 350).

Following the CIP comparison, it was determined that a CIP equal to 8 ft, as determined from BARRIER VII, would be used for the full-scale vehicle crash test. The crash test was to be conducted according to the new NCHRP 350 guidelines with a 4,409-lb pickup truck impacting at a speed of 62.14 mph and an angle of 25 degrees. However, after discussions with the MHTD, it was decided to perform the crash test according to the existing NCHRP 230 guidelines with a 4,500-lb sedan impacting at a speed of 60 mph and an angle of 25 degrees. This change in testing criteria was made in order to compare the results with the previous SwRI crash test on the original bridge anchor section (3).

5 TEST RESULTS

5.1 Test MBAS-1 (4,501 lbs, 59.0 mph, 26.7 deg)

Test MBAS-1 impacted the bridge anchor section at approximately 8 ft upstream from the end of the concrete barrier curb section (Figure 12). A summary of the test results and the sequential photographs is presented in Figure 13. Additional sequential photographs are shown in Figure 14. Documentary photographs of the crash test are shown in Figures 14 through 17.

5.2 Test Description

After the initial impact with the bridge anchor section, the right-front corner of the bumper and quarter panel crushed inward. At 0.022 sec, the right-front corner of the vehicle was near Post No. 3. The front of the engine hood buckled at 0.038 sec after impact. At 0.048 sec, the front-end of the vehicle was bent toward the left away from the longitudinal centerline of the vehicle. The right-front corner of the vehicle was near Post No. 2 at 0.064 sec after impact. Buckling of the left-front quarter panel occurred at 0.070 sec. The right-front corner of the vehicle was near Post No. 1 and at the upstream end of the concrete barrier curb section at 0.080 sec and 0.096 sec, respectively. The roof of the occupant compartment buckled at 0.121 sec. At 0.131 sec, the maximum dynamic lateral deflections were measured at midspan rail and post locations. The vehicle became parallel to the bridge anchor section at 0.193 sec with a velocity of 40.7 mph. At 0.237 sec, the right-rear corner of the vehicle reached a position near Post No. 3. The vehicle exited the bridge anchor section at approximately 0.287 sec at a speed of 37.5 mph and an angle of 3.0 degrees. The vehicle's trajectory is shown in Figure 13. The vehicle came to rest approximately 90 ft downstream from impact.

5.3 Vehicle Damage

Exterior vehicle damage was extensive (Figures 18 through 20), and interior vehicle

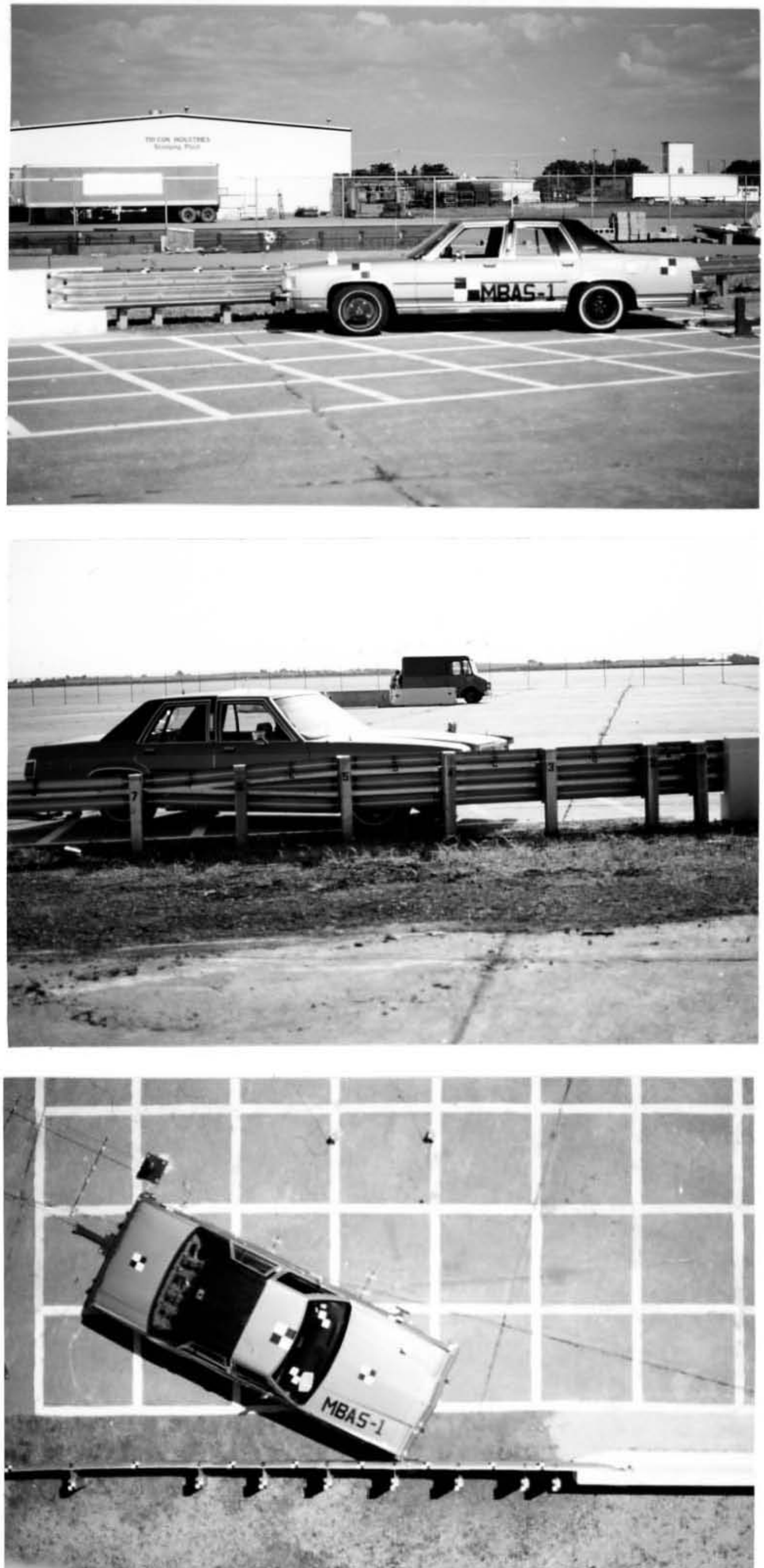
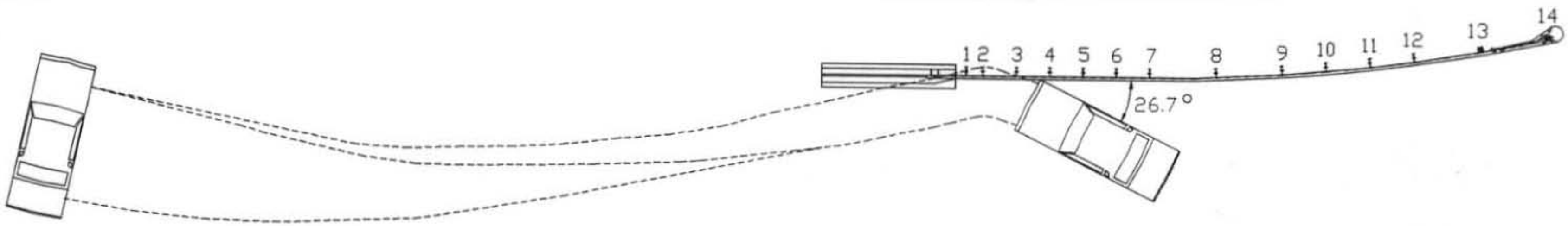


Figure 12. Impact Location, Test MBAS-1

0.000-sec | 0.080-sec | 0.121-sec | 0.193-sec | 0.287-sec



- Test Number MBAS-1
- Date 7/30/93
- Appurtenance . . . . Missouri's Modified Bridge Anchor Section
- Total Length . . . . 68 ft - 4 3/4 in.
- Steel Thrie Beam
  - Top Mounting Height . . . . 31 in.
  - Material Size . . . . 10 Gauge
- Steel Posts
  - Post Nos. 1 - 5 . . . . W6 x 9 by 6-ft long
  - Embedment . . . . 41 in.
- Steel Spacer Blocks
  - Post Nos. 1 - 5 . . . . W6 x 9 by 1-ft 9-in. long
- Soil Type . . . . Silty-Clay (SL) (Dry)
- Vehicle
  - Model . . . . 1985 Mercury Grand Marguis
  - Weight
    - Curb 3,670-lb
    - Test Inertial 4,501-lb
    - Gross Static 4,501-lb
- Vehicle Speed
  - Impact . . . . 59.0 mph
  - Exit . . . . 37.5 mph
- Vehicle Angle
  - Impact . . . . 26.7 deg
  - Exit . . . . 3.0 deg
- Vehicle Snagging . . . . Wheel-hub snagging on concrete barrier curb end section
- Vehicle Stability . . . . Satisfactory
- Occupant Ridedown Deceleration
  - Longitudinal . . . . 12.3 g's < 15
  - Lateral . . . . 19.4 g's > 15
- Occupant Impact Velocity (Normalized)
  - Longitudinal . . . . 25.6 fps < 30
  - Lateral . . . . 24.6 fps > 20
- Vehicle Damage . . . . Extensive
  - TAD 1-RFQ-5
  - VDI 01RYAW4
- Vehicle Stopping Distance . . . . 90-ft from impact
- Barrier Damage . . . . Moderate
- Maximum Deflections
  - Permanent Set
    - Midspan Rail . . . . 12.0 in.
    - Post . . . . 11.2 in.
  - Dynamic
    - Midspan Rail . . . . 13.5 in.
    - Post . . . . 13.0 in.

Figure 13. Summary of Test Results and Sequential Photographs, Test MBAS-1

Figure 14. Full-Scale Crash Test, Test MBAS-1

Figure 15. Full-Scale Crash Test, Test MBAS-1

Figure 16. Full-Scale Crash Test, Test MBAS-1

Figure 17. Full-Scale Crash Test, Test MBAS-1

Figure 18. Vehicle Damage, Test MBAS-1

Figure 19. Vehicle Damage, Test MBAS-1

Figure 20. Occupant Compartment Deformation - Dash and Roof, Test MBAS-1

damage was also significant (Figures 20 and 21). Vehicle damage occurred to several body locations, such as door and quarter panels, front bumper and grill, right-side wheels and rims, engine housing and hood, roof, windshield and windows, and occupant compartment floorboard and dashboard. Both right-side tires were deflated in conjunction with deformed steel rims (Figures 18 and 19). The right-side body panels were deformed due to vehicle-railing interlock and contact with concrete barrier curb (Figure 18). The right-side frame and undercarriage rested on the concrete surface. The right-front bumper and quarter panel were crushed inward (Figures 18 and 19). The engine housing was bent toward the left, away from the longitudinal centerline of the vehicle (Figure 18). In addition, the engine housing, radiator, and grill were displaced approximately 1 ft behind the rear-side of the front bumper (Figures 18 and 19). The rear-side of the engine hood was also deformed. Buckling occurred to the occupant compartment roof, steel supports, and window frames (Figures 18 and 20). The front windshield was fractured (Figures 18 through 20). The front and rear floorboards on the vehicle's right-side received extensive deformation. Deformation to the right-front floorboard, shown in Figure 21, was judged to be sufficient to cause injury to vehicle occupants. The front dashboard, shown in Figure 20, was also severely deformed and buckled transversely.

5.4 Barrier Damage

Barrier damage was moderate as shown in Figures 22 through 24. The thrie beam and terminal connector were deformed (Figures 22 and 23). In addition, the thrie beam and terminal connector received 11 ft of black marks and scrapes beginning at 2 ft upstream from impact. Post Nos. 1 and 2 were found to be pushed back and twisted. In addition, at Post Nos. 1 and 2, the steel backup plates were flattened and the steel spacer blocks were deformed. The rectangular washers at Post Nos. 1 and 2 were scuffed and bent; however, the washers showed

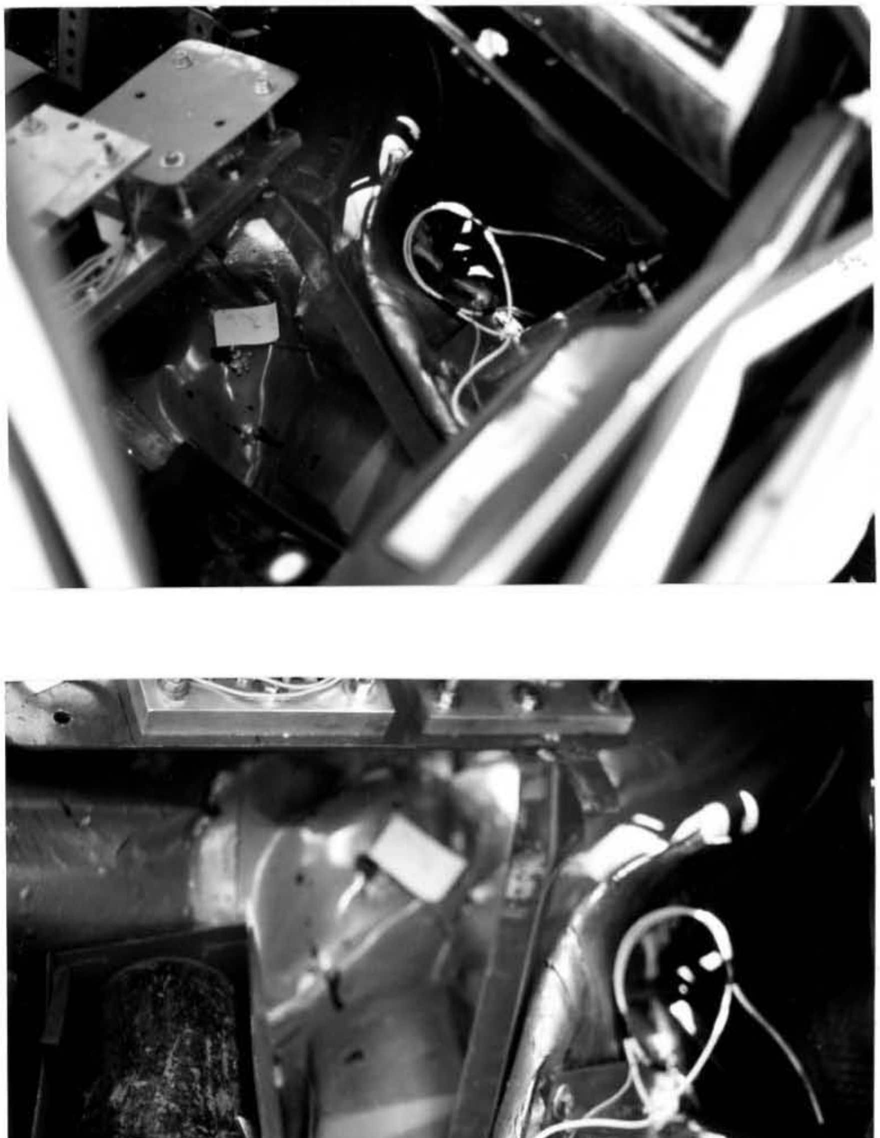


Figure 21. Occupant Compartment Deformation - Floorboard, Test MBAS-1

Figure 22. Bridge Anchor Section Damage, Test MBAS-1

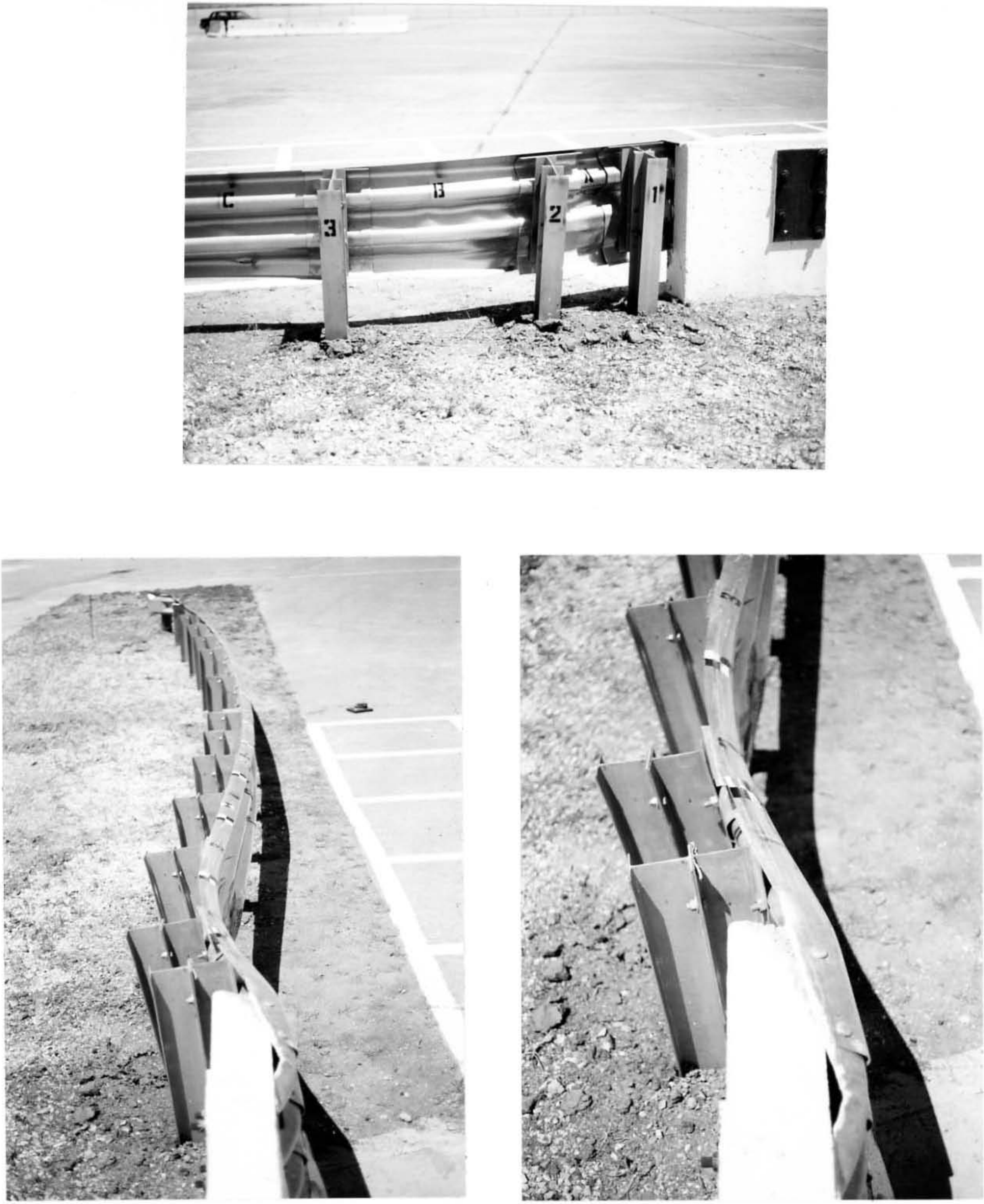


Figure 23. Bridge Anchor Section Damage, Test MBAS-1

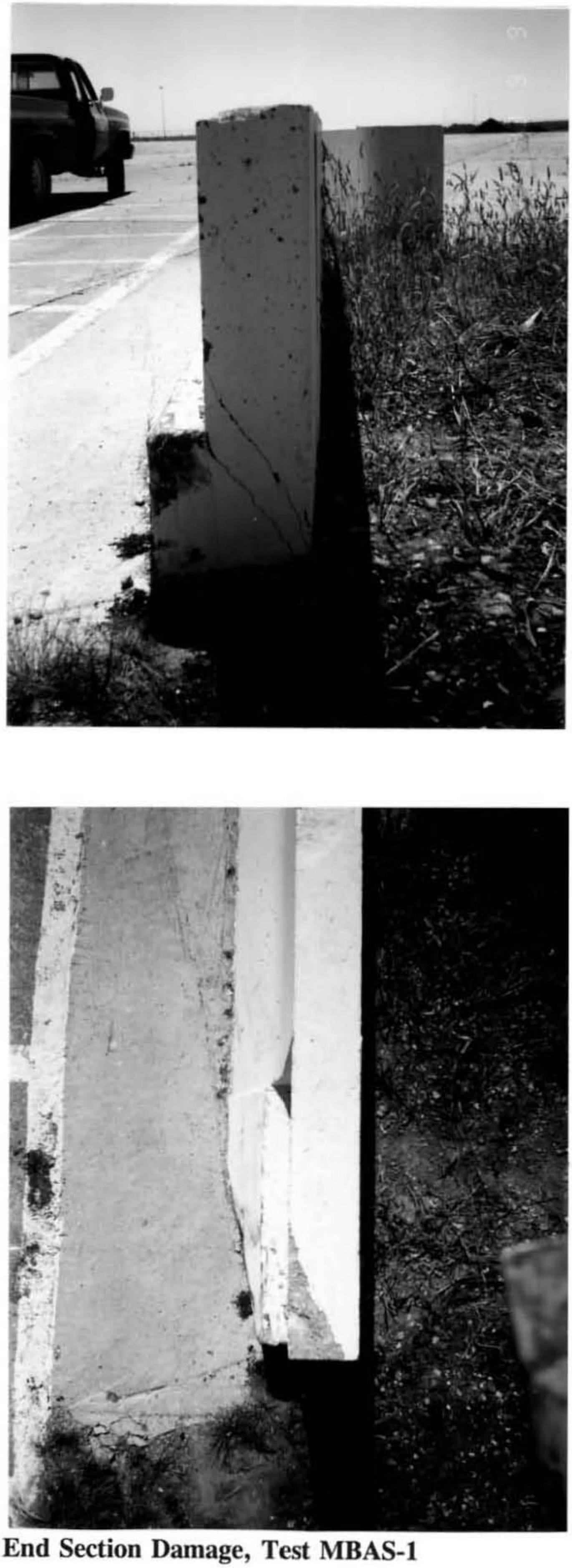


Figure 24. Concrete End Section Damage, Test MBAS-1

no evidence of pulling through the thrie beam rail (Figure 22). The concrete barrier curb section received black marks, scrapes, spalling, and cracks (Figures 22 through 24). The upstream end of the concrete barrier curb showed evidence of concrete cracking along an approximate 45 degree plane with a vertical line (Figures 22 and 24). Concrete spalling occurred at the top and the lower front-face on the upstream end of the concrete barrier curb (Figures 22 through 24). The maximum lateral permanent set deflections for midspan rail and post locations, as determined from high-speed film analysis, were approximately 12.0 in. (11.8 in. field-measured) and 11.2 in. (10.5 in. field-measured), respectively. The maximum dynamic lateral deflections for midspan rail and post locations, as determined from high-speed film analysis, were 13.5 in. and 13.0 in., respectively. Midspan rail and post deflections are shown graphically in Figure 25.

5.5 Occupant Risk Values

The longitudinal and lateral occupant impact velocities (normalized) were determined to be 25.6 fps and 24.6 fps, respectively. The highest 0.010-sec average occupant ridedown decelerations in the longitudinal and lateral directions were 12.3 g's and 19.4 g's, respectively. The results of the occupant risk, determined from accelerometer data, are summarized in Figure 13. The results are shown graphically in Appendix D.

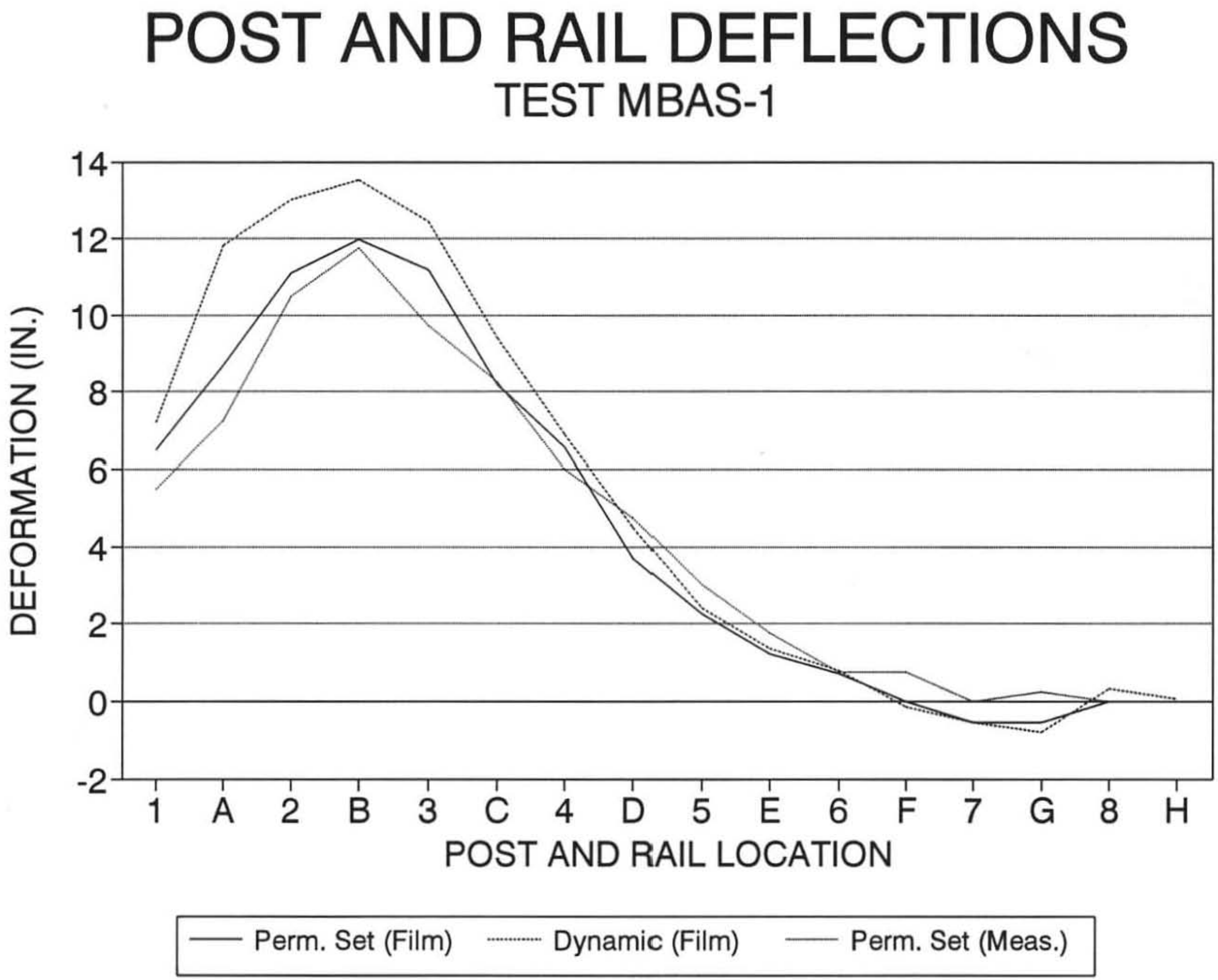


Figure 25. Post and Rail Deflections

6 CONCLUSIONS

The safety performance of Missouri's modified bridge anchor section proved to be unacceptable according to NCHRP Report 230 criteria (2). The safety performance summary is presented in Table 3. The analysis of the test results revealed that the test article successfully redirected the test vehicle and the barrier did not penetrate into the occupant compartment. The vehicle also remained upright both during and after impact. However, the integrity of the occupant compartment was not maintained. Excessive interior deformations due to vehicle wheel-hub snagging and contact with the end of the concrete barrier curb were deemed to be sufficient to cause occupant injury. Vehicle trajectory and final stopping distance were also within recommended limits. In summary, the safety performance of Missouri's modified bridge anchor section was determined to be unacceptable according to the NCHRP 230 criteria presented in Table 3.

Table 3. Summary of Safety Performance Results

Structural Adequacy	A.	Test article shall smoothly redirect the vehicle; the vehicle shall not penetrate or go over the installation although controlled lateral deflection of the test article is acceptable.	S
	D.	Detached elements, fragments or other debris from the test article shall not penetrate or show potential for penetrating the passenger compartment or present undue hazard to other traffic.	S
Occupant Risk	E.	The vehicle shall remain upright during and after collision although moderate roll, pitching and yawing are acceptable. Integrity of the passenger compartment must be maintained with essentially no deformation or intrusion.	U
Vehicle Trajectory	H.	After collision, vehicle trajectory and final stopping position shall intrude a minimum distance, if at all, into adjacent traffic lanes.	S
	I.	In test where the vehicle is judged to be redirected into or stopped while in adjacent traffic lanes, vehicle speed change during test article collision should be less than 15 mph and the exit angle from the test article should be less than 60 percent of the test impact angle, both measured at time of vehicle loss of contact with test device.	S

S - Satisfactory
U - Unsatisfactory

7 RECOMMENDATIONS

First, it is recommended that the lower blunt-end face at the upstream end of the concrete barrier curb be modified to prevent wheel-hub snagging. This modification may consist of reducing the width of the blunt-end face located below the thrie beam rail by approximately 3½ in. The blunt-end face of the current design extends ¼ in. and 3½ in., as measured toward the roadway, away from the front and rear faces of the undeformed thrie beam rail, respectively. Figure 26 shows a barrier curb configuration that may allow the modified bridge anchor section to meet NCHRP Report 230 safety standards. Further, increased reinforcement and/or increased concrete wall thickness may be necessary to prevent cracking in the concrete barrier curb section.

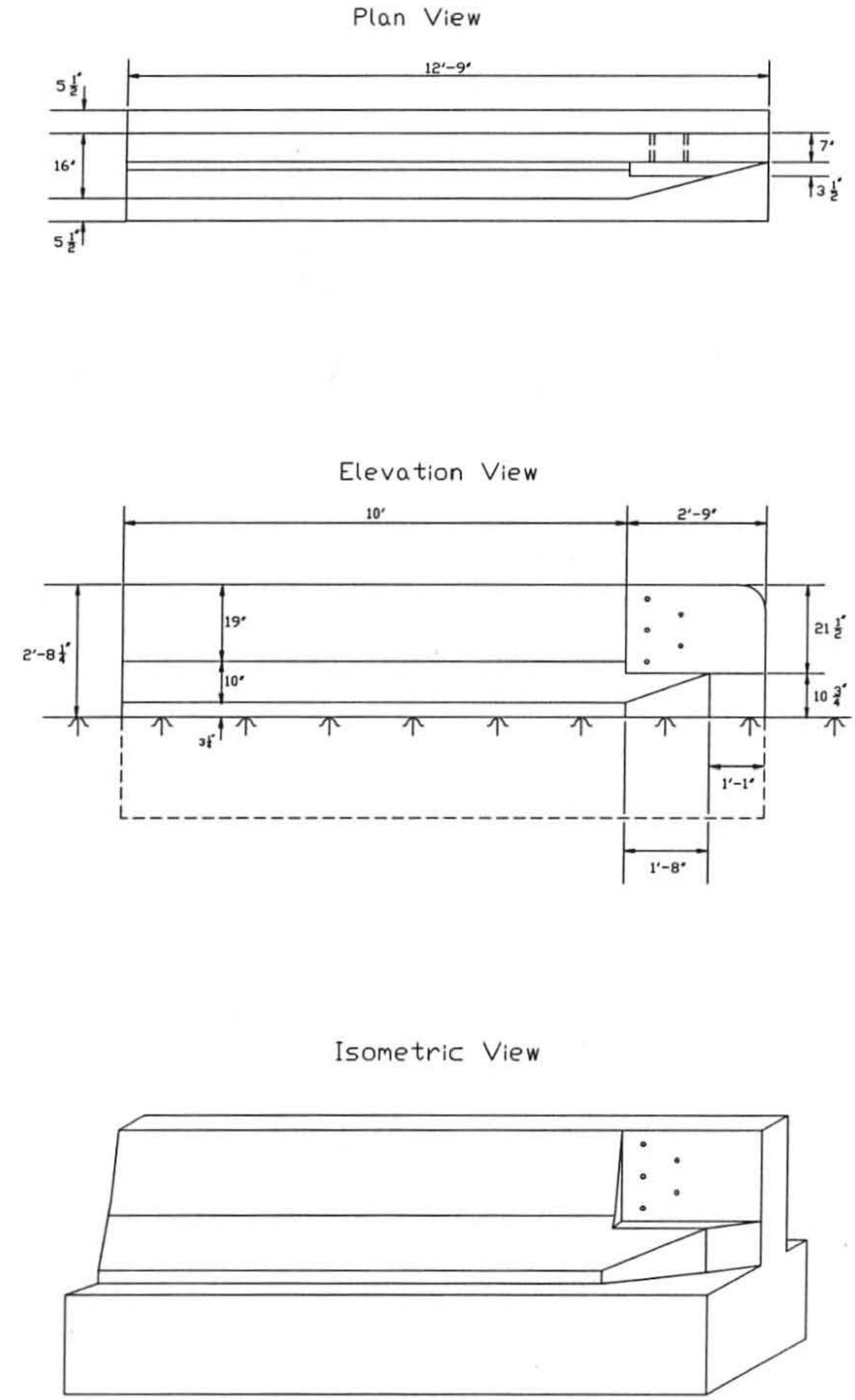


Figure 26. Proposed Front-Face for Modified Barrier Curb End Section

8 REFERENCES

1. *Missouri Standard Plans For Highway Construction*, Missouri Highway and Transportation Commission, Drawing No. 606.22K, January 1992.

2. Michie, J.D., *Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances*, National Cooperative Highway Research Program Report No. 230, Transportation Research Board, Washington, D.C., March 1981.

3. *Warrants for Bridge Barriers on Low-Volume Roads - Test No. MT-1*, Test Report Prepared for the Federal Highway Administration, Performing Agency: Southwest Research Institute, SwRI Project No. 06-8299-001, September 1989.

4. Ray, M.H., *The Design of Independent Anchor Blocks for Vehicular-Impact Loadings,* Transportation Research Record No. 1133 - Roadside Safety Features, Transportation Research Board, National Research Council, Washington, D.C., 1987.

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

6. Taborck, J.J., "*Mechanics of Vehicles - 7*", Machine Design Journal, May 30, 1957.

7. Powell, G.H., *BARRIER VII: A Computer Program For Evaluation Of Automobile Barrier Systems*, Prepared for: Federal Highway Administration, Report No. FHWA RD-73-51, April 1973.

8. Ross, H.E., Jr., Sicking, D.L., Zimmer, R.A., and 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.

9 APPENDICES

APPENDIX A.

RELEVANT CORRESPONDENCE

October 20, 1989

BRIDGES/PLANNING
Crash Test Report
Missouri Guardrail Transition Section

Mr. Wayne Muri, Chief Engineer
Missouri Highway and Transportation Department
Jefferson City, Missouri

Dear Mr. Muri:

Enclosed are two copies of the subject crash test report and a copy of the crash test film prepared by the Southwest Research Institute. Although the test was considered successful, we have the following comments for your consideration:

> We recommend adding an additional post near the bridge end, which would improve the performance of the transition section.
>
> Additional reinforcement should be considered for the concrete end post to avoid maintenance problems with concrete barrier damage. A sketch of the actual reinforcing that Southwest Research Institute used in the bridge end post is also enclosed.

If there are any questions, please let us know.

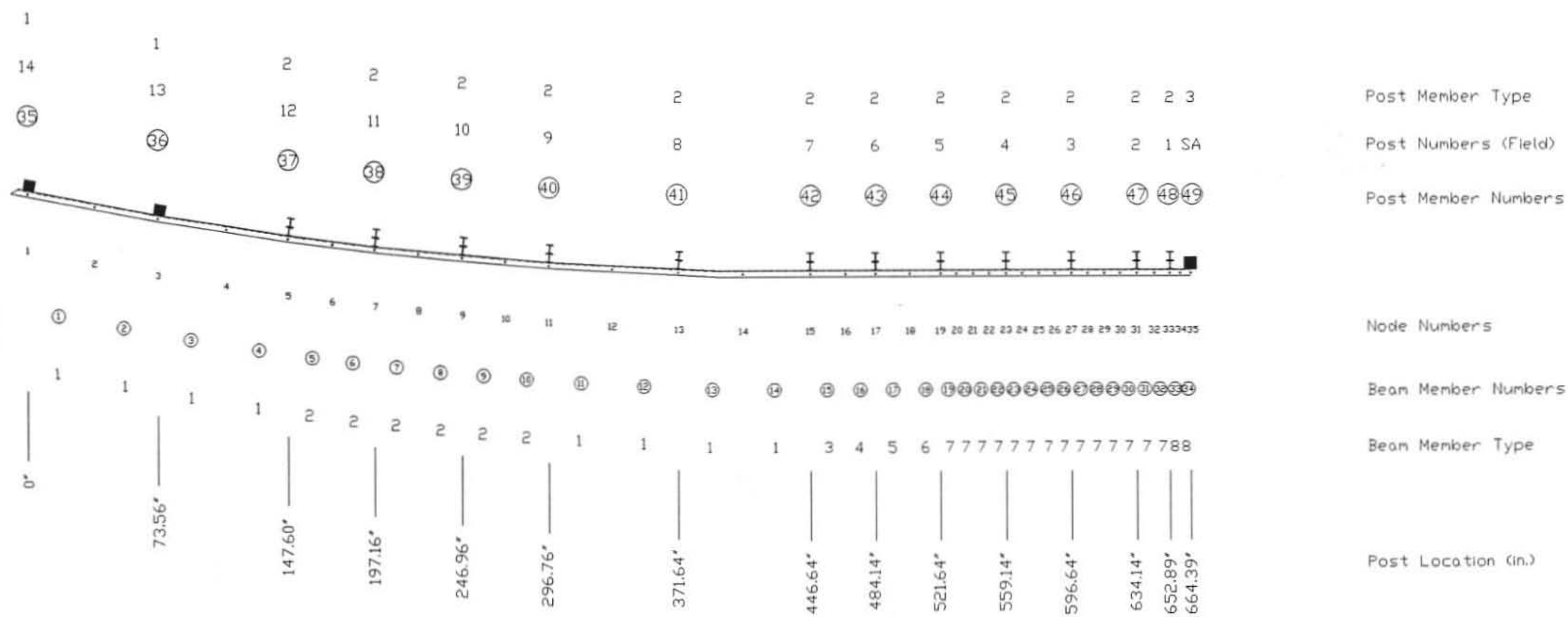
Sincerely yours,

Gerald J. Reihsen, P.E.
Division Administrator

Enclosures

APPENDIX B.

BARRIER VII COMPUTER MODEL


Post Member Type
Post Numbers (Field)
Post Member Numbers
Node Numbers
Beam Member Numbers
Beam Member Type
Post Location (in.)
0"
73.56"
147.60"
197.16"
246.96"
296.76"
371.64"
446.64"
484.14"
521.64"
559.14"
596.64"
634.14"
652.89"
664.39"
SA

APPENDIX C.

BARRIER VII INPUT FILE

```
MISSOURI BRIDGE ANCHOR SECTION 4400-LB PICKUP TRUCK, 62.14 MPH, 25 DEG, NODE 19
   35   12   11    1   49   14    2    0
   0.0010    0.0010      0.75  200    0       1.0    1
    1    5    5    5    5    5    1
    1      0.0       48.0
    3    73.56      33.48
    5   147.60      21.48
    7   197.16       15.0
    9   246.96        9.6
   11   296.76        5.4
   13   371.64       1.32
   15   446.64        0.0
   19   521.64        0.0
   31   634.14        0.0
   33   652.89        0.0
   35   664.39        0.0
    1    3    1    1        0.0
    3    5    1    1        0.0
    5    7    1    1        0.0
    7    9    1    1        0.0
    9   11    1    1        0.0
   11   13    1    1        0.0
   13   15    1    1        0.0
   15   19    3    1        0.0
   19   31   11    1        0.0
   31   33    1    1        0.0
   33   35    1    1        0.0
    1   35      0.35
   35   34   33   32   31   30   29   28   27   26
   25   24   23   22   21   20   19   18   17   16
   15   14   13   12   11   10    9    8    7    6
    5    4    3    2    1
  100    8
    1      2.30       1.99      37.50   30000.0      6.92      99.5       68.5 0.10
    2      2.30       1.99      25.00   30000.0      6.92      99.5       68.5 0.10
    3     2.475      2.125      18.75   30000.0     7.405    106.25      73.75 0.10
    4      2.84       2.40      18.75   30000.0     8.375     120.0       84.0 0.10
    5     3.205       2.68      18.75   30000.0      9.35     134.0       94.0 0.10
    6     3.575       2.96      18.75   30000.0    10.325     148.0     104.25 0.10
    7      4.82       4.00      9.375   30000.0     13.95     200.0      140.0 0.10
    8      4.82       4.00       5.75   30000.0     13.95     200.0      140.0 0.10
  300    3
    1      21.0        0.0     1000.0    1000.0     250.0    1000.0     1000.0 0.10
    200.0     200.0        1.0       1.0
    2      21.0        0.0       4.44     12.17      54.0      92.8     254.35 0.10
     4.44     12.17       16.0      16.0
    3      21.0        0.0     2000.0    2000.0     500.0    2500.0     2500.0 0.10
    400.0     400.0        1.0       1.0
    1    1    2    4    1  101       0.0       0.0       0.0
    5    5    6   10    1  102       0.0       0.0       0.0
   11   11   12   14    1  101       0.0       0.0       0.0
   15   15   16         1  103       0.0       0.0       0.0
   16   16   17         1  104       0.0       0.0       0.0
   17   17   18         1  105       0.0       0.0       0.0
   18   18   19         1  106       0.0       0.0       0.0
   19   19   20   32    1  107       0.0       0.0       0.0
   33   33   34   34    1  108       0.0       0.0       0.0
   35    1        36    2  301       0.0       0.0       0.0       0.0       0.0
   37    5        44    2  302       0.0       0.0       0.0       0.0       0.0
   45   23        47    4  302       0.0       0.0       0.0       0.0       0.0
```

```
48   33              302      0.0      0.0      0.0      0.0      0.0
49   35              303      0.0      0.0      0.0      0.0      0.0
 4400.0   40000.0   20   6   4   0   1
  1    0.055     0.12     6.00    17.0
  2    0.057     0.15     7.00    18.0
  3    0.062     0.18    10.00    12.0
  4    0.110     0.35    12.00     6.0
  5     0.35     0.45     6.00     5.0
  6     1.45     1.50    15.00     1.0
  1   100.75   15.875   1     12.0   1   0   0   0
  2   100.75   27.875   1     12.0   1   0   0   0
  3   100.75   39.875   2     12.0   1   0   0   0
  4    88.75   39.875   2     12.0   1   0   0   0
  5    76.75   39.875   2     12.0   1   0   0   0
  6    64.75   39.875   2     12.0   1   0   0   0
  7    52.75   39.875   2     12.0   1   0   0   0
  8    40.75   39.875   2     12.0   1   0   0   0
  9    28.75   39.875   2     12.0   1   0   0   0
 10    16.75   39.875   2     12.0   1   0   0   0
 11   -13.25   39.875   3     12.0   1   0   0   0
 12   -33.25   39.875   3     12.0   1   0   0   0
 13   -53.25   39.875   3     12.0   1   0   0   0
 14   -73.25   39.875   3     12.0   1   0   0   0
 15   -93.25   39.875   3     12.0   1   0   0   0
 16  -113.25   39.875   4     12.0   1   0   0   0
 17  -113.25  -39.875   4     12.0   0   0   0   0
 18   100.75  -39.875   1     12.0   0   0   0   0
 19    69.25    37.75   5      1.0   1   0   0   0
 20   -62.75    37.75   6      1.0   1   0   0   0
  1    69.25    37.75      0.0    608.
  2    69.25   -37.75      0.0    608.
  3   -62.75    37.75      0.0    492.
  4   -62.75   -37.75      0.0    492.
  1      0.0      0.0
  3   521.64      0.0     25.0   62.14      0.0      0.0      1.0
```

APPENDIX D.

ACCELEROMETER DATA ANALYSIS, MBAS-1

Figure D-1 Graph of Longitudinal Deceleration, Acc. #1

Figure D-2 Graph of Longitudinal Occupant Impact Velocity, Acc. #1

Figure D-3 Graph of Longitudinal Occupant Displacement, Acc. #1

Figure D-4 Graph of Lateral Deceleration, Acc. #2

Figure D-5 Graph of Lateral Occupant Impact Velocity, Acc. #2

Figure D-6 Graph of Lateral Occupant Displacement, Acc. #2

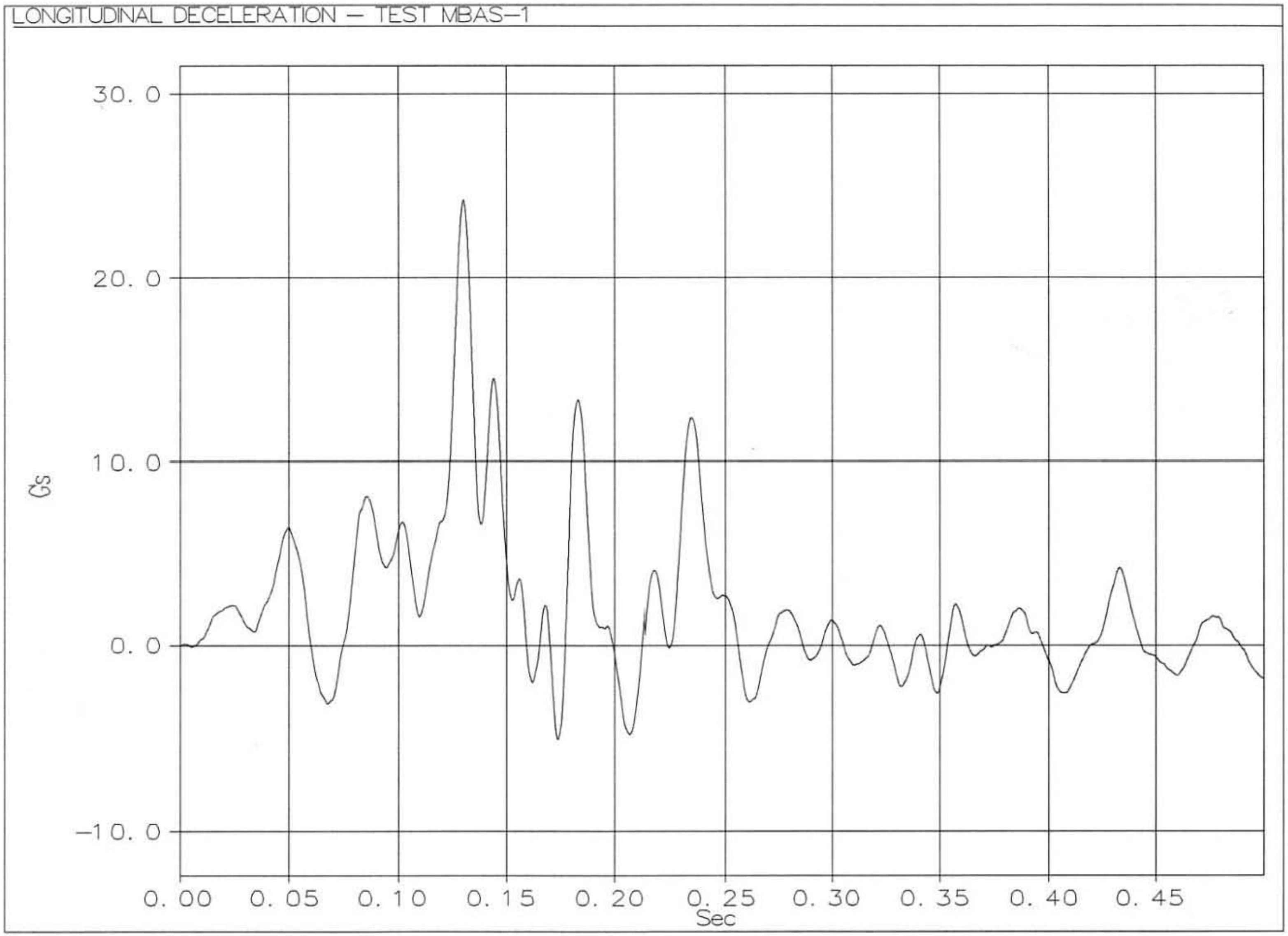


Figure D-1 Graph of Longitudinal Deceleration, Acc. #1

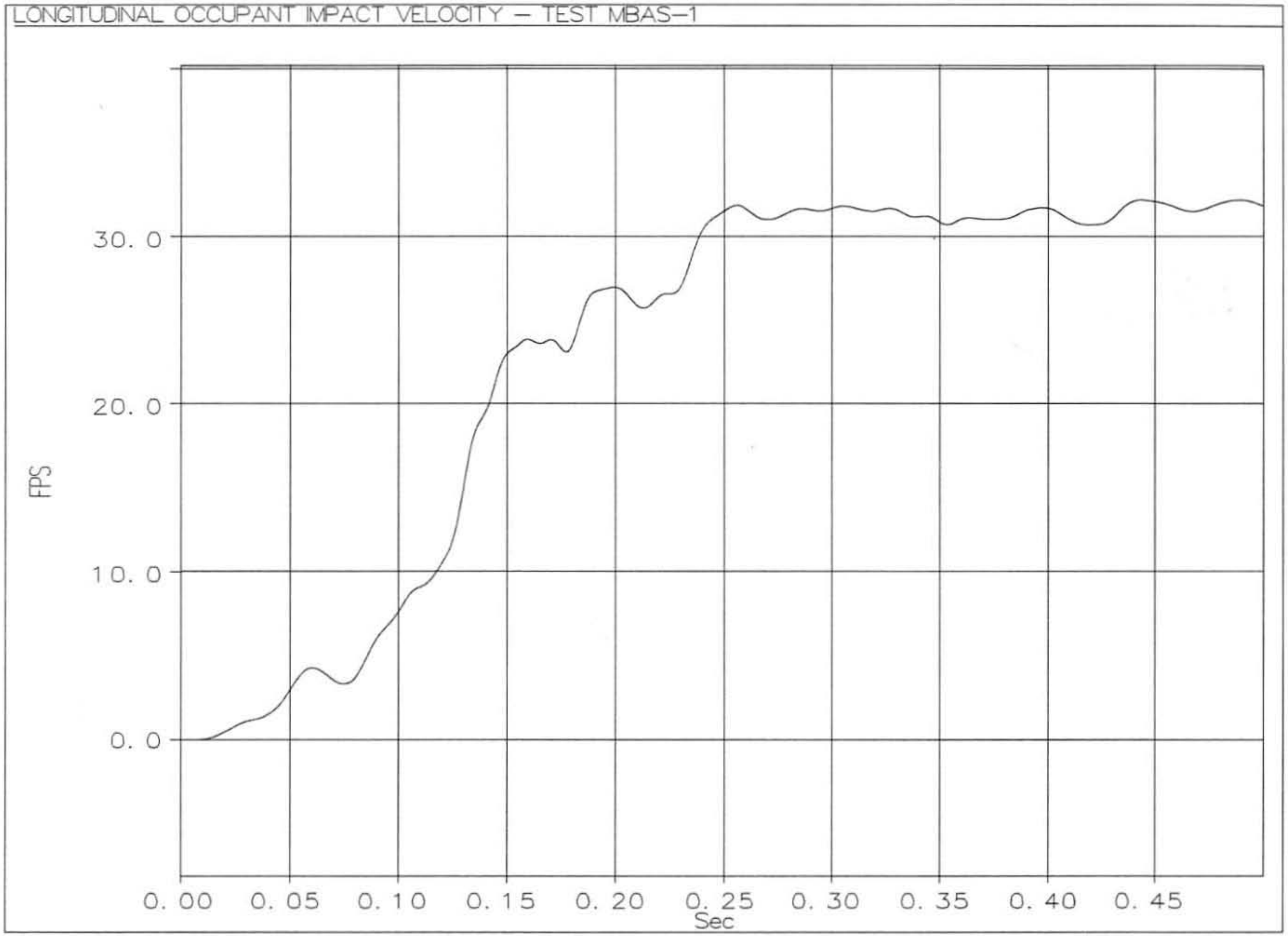


Figure D-2 Graph of Longitudinal Occupant Impact Velocity, Acc. #1

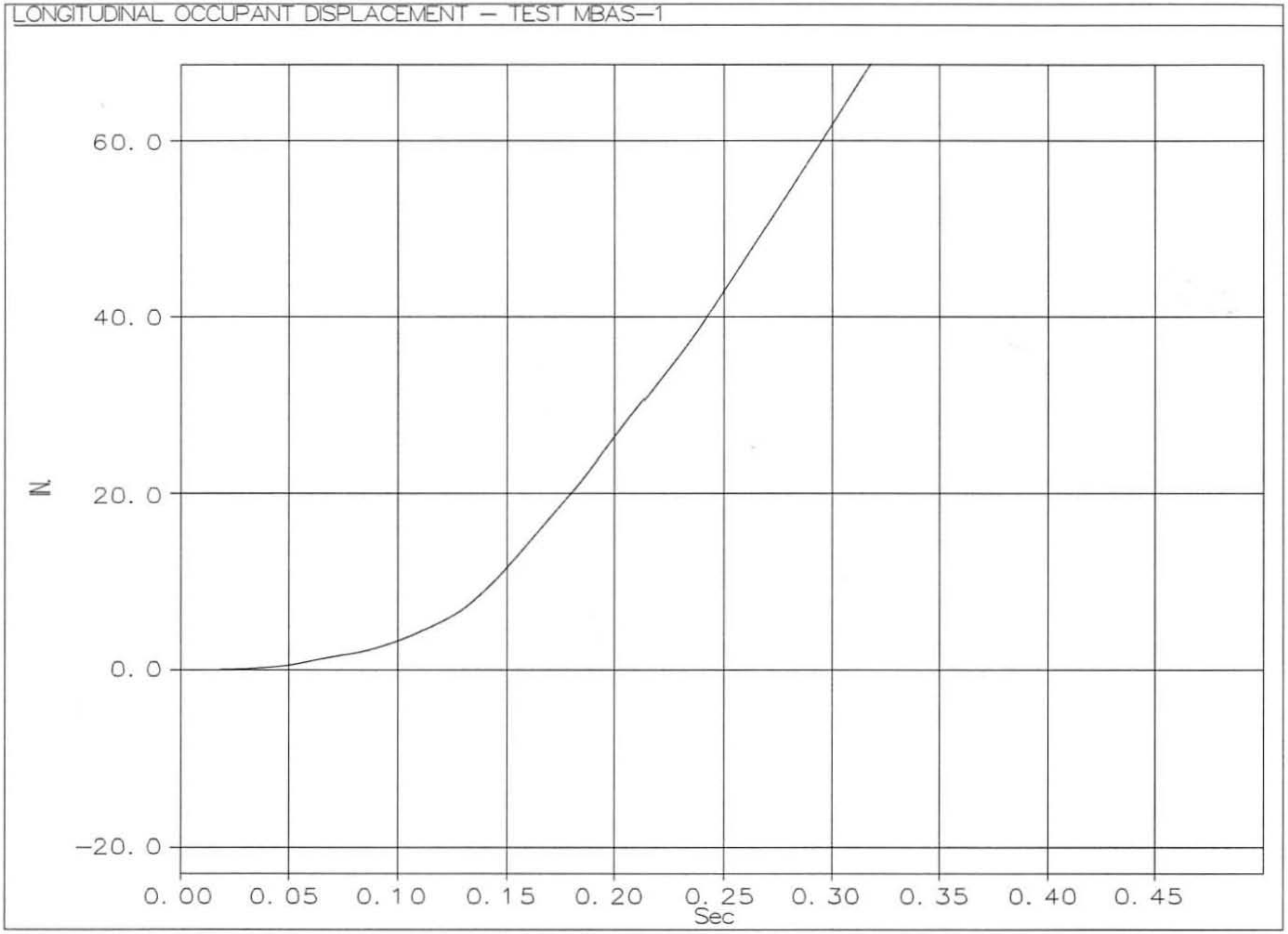


Figure D-3 Graph of Longitudinal Occupant Displacement, Acc. #1

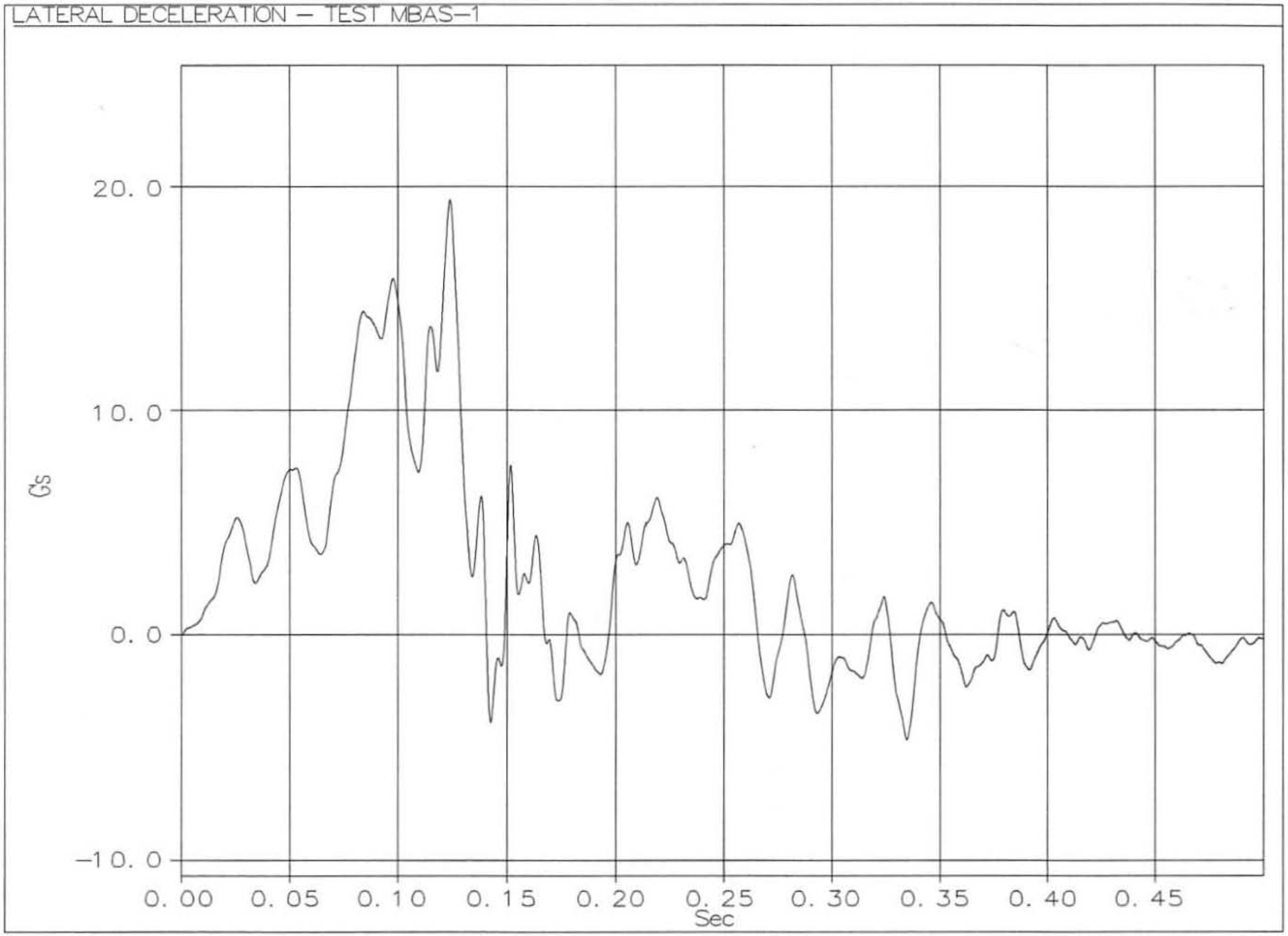


Figure D-4 Graph of Lateral Deceleration, Acc. #2

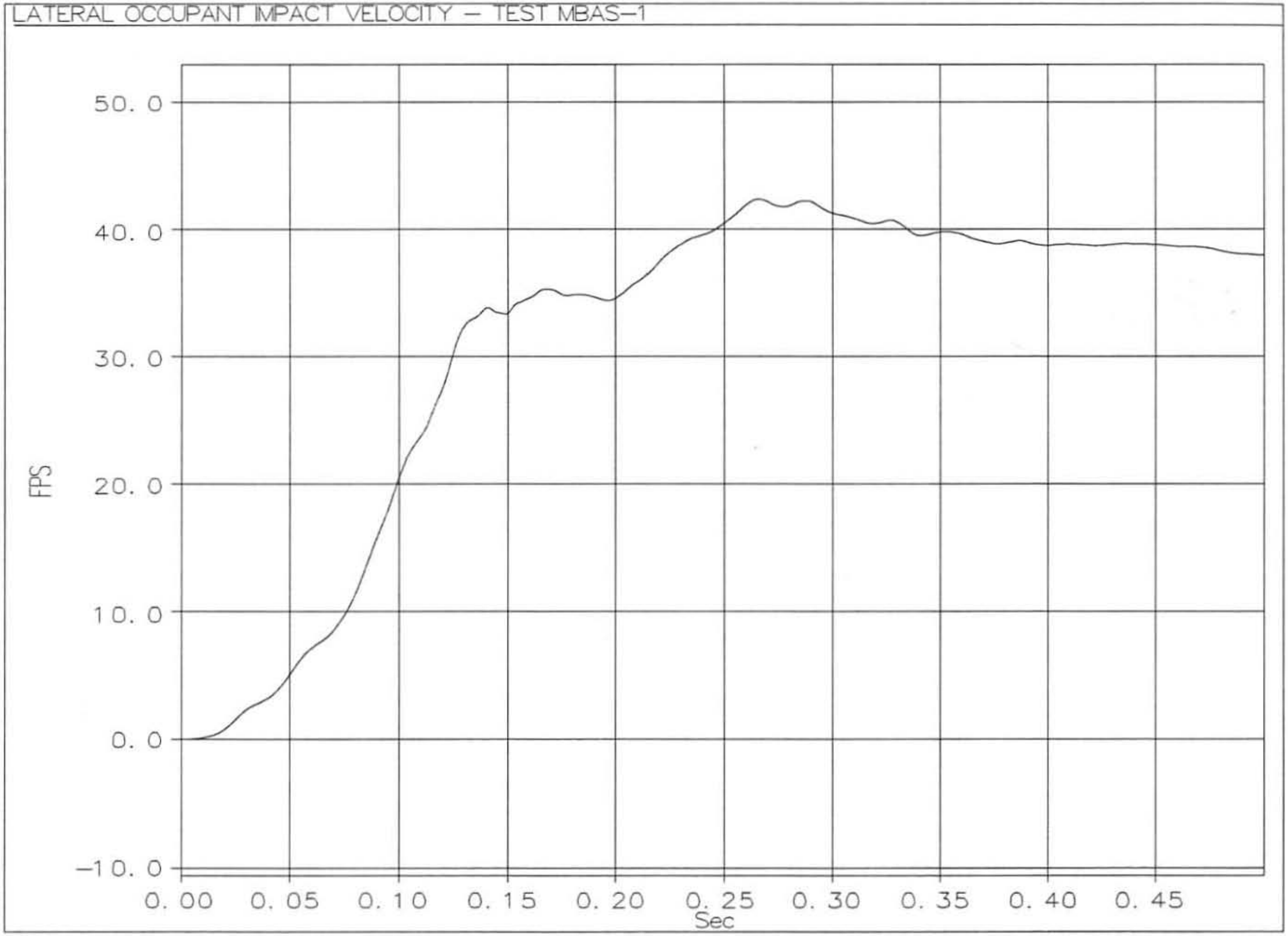


Figure D-5 Graph of Lateral Occupant Impact Velocity, Acc. #2

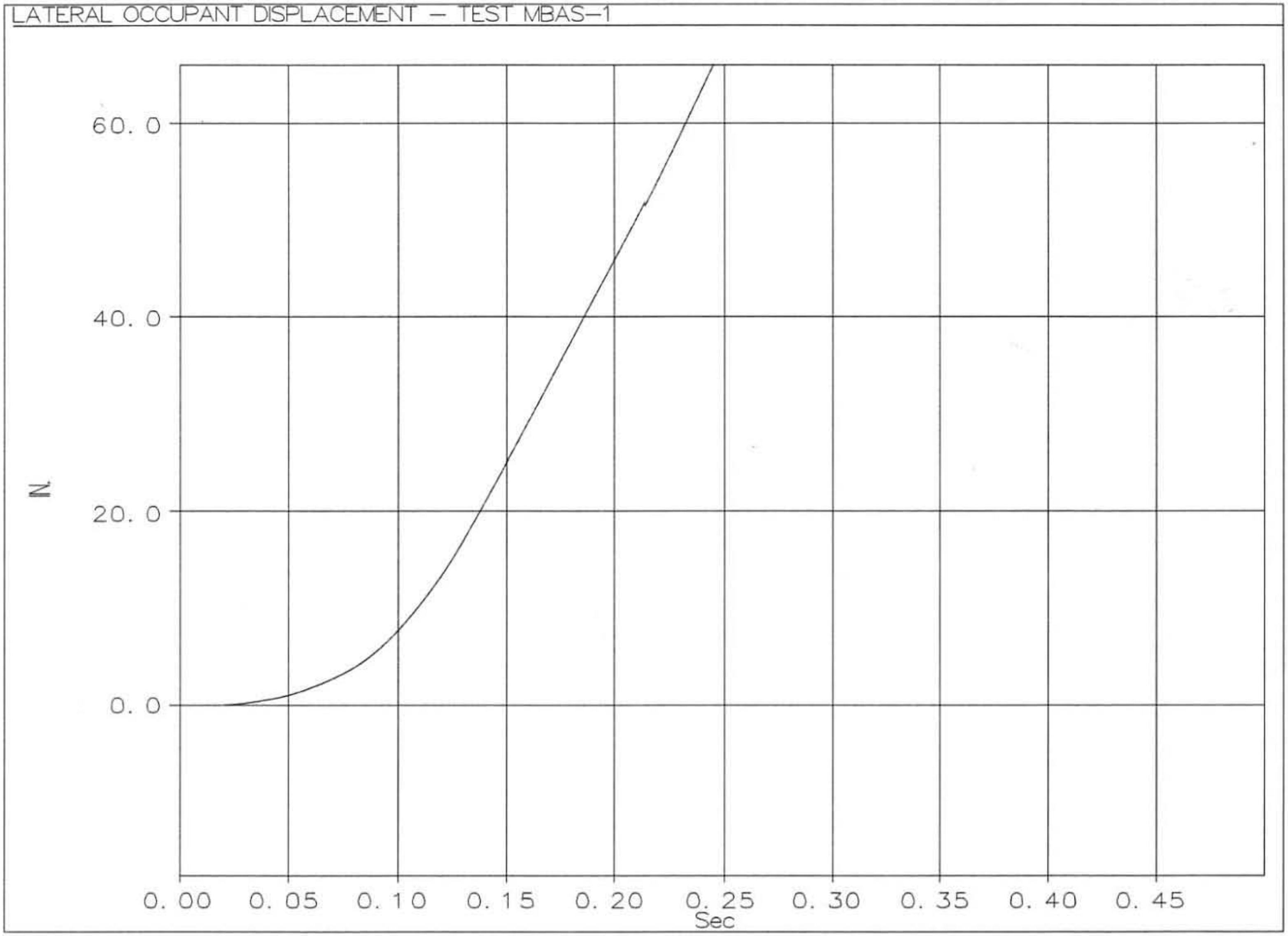


Figure D-6 Graph of Lateral Occupant Displacement, Acc. #2