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DEVELOPMENT AND TESTING OF AN APPROACH GUARDRAIL TRANSITION TO A SINGLE SLOPE CONCRETE MEDIAN BARRIER

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9. Abstract An approach guardrail transition for use with the single slope concrete median barrier (CMB) was developed and crash tested. The transition was constructed with 10-gauge thrie beam guardrails and supported by nine W6x9 steel posts. A single slope connector plate was developed to connect the thrie beam to the single slope CMB and structural tube spacer blocks (TS $7x4x^3/_{16}$) were incorporated for use with the thrie beam guardrail transition. Two full-scale vehicle crash tests were performed on Missouri's approach guardrail transition attached to a single slope concrete median barrier (CMB). The tests were conducted and reported in accordance with the requirements specified in the National Cooperative Highway Research Program (NCHRP) Report No. 350, *Recommended Procedures for the Safety Performance Evaluation of Highway Features*. The safety performance of the approach guardrail transition attached to a single slope CMB was determined to be acceptable according to Test Level 3 of the NCHRP 350 criteria.			
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1 INTRODUCTION

1.1 Problem Statement

According to Section 1058 of the 1991 Intermodal Surface Transportation Efficiency Act (ISTEA), all State Highway Agencies are required to certify annually that a minimum of 2.5 percent of the total kilometers of new or replacement permanent median barriers constructed with Federal - Aid Funds are of an innovative design. An innovative median barrier was defined as either being experimental by a State or as not already in use (or in limited use) by a State and differs significantly in material, size, shape, performance level, or operational characteristics from median barriers commonly used elsewhere. Eight different types of barriers were considered innovative by various certifying States and are as follows: (1) single slope concrete median barrier (CMB); (2) tall New Jersey CMB; (3) tall F-shape CMB; (4) Ontario tall wall; (5) Quick-Change median barrier; (6) International Barrier Corporation (IBC) Mark VII barrier; (7) modified thrie beam barrier; and (8) painted CMB.

Proper protection is required when the end of a CMB is placed within the clear zone. This protection may be provided by attaching an approach guardrail transition to the CMB installation. The Missouri Highway and Transportation Department (MHTD) elected to use the single slope CMB as its innovative median barrier on a new bridge replacement project, specifically, for the I-70 Rocheport Bridge located in Boone and Cooper Counties. However, no approach guardrail transition had been previously developed for use with the single slope CMB. Therefore if MHTD wished to install the single slope CMB on new or reconstruction projects, an approach guardrail transition needed to be developed and crash tested using current safety performance criteria.

1.2 Objective

The objective of the research project was to develop a new approach guardrail transition attached to a single slope CMB that meets the safety performance criteria set forth in the National Cooperative Highway Research Program (NCHRP) Report No. 350, *Recommended Procedures for the Safety Performance Evaluation of Highway Features* (2).

1.3 Scope

The research objective was achieved by performing several tasks, which included redesigning and modifying the reinforcement in Missouri's Type C single slope CMB, revising the end of the single slope CMB, designing the connection between the single slope CMB and the approach guardrail transition, and developing the post and rail configuration for the approach guardrail transition. Two full-scale vehicle crash tests were performed using 1985 Chevrolet C-20 pickup trucks, weighing approximately 2,000 kg (4,409 lbs). The target impact speed and angle were 100 km/h (62.14 mph) and 25 degrees, respectively. Finally, the test results were analyzed, evaluated and documented, with conclusions and recommendations formed regarding the safety performance of the developed approach guardrail transition.

2 SINGLE SLOPE CMB

2.1 Background

In 1988, the Texas Transportation Institute (TTI) and the Texas Department of Transportation developed a single slope CMB. The single slope CMB was developed and tested according to NCHRP Report No. 230 (3) and was designed for both temporary and permanent applications. Four full-scale vehicle crash tests were performed, two tests each on the temporary and permanent configurations. All full-scale vehicle crash tests met the NCHRP Report No. 230 criteria. However, no crashworthy approach guardrail transition was developed for use with the single slope CMB.

The TTI single slope CMB measures 1,066-mm (42-in.) high by 203-mm (8-in.) and 610-mm (24-in.) wide at the top and bottom surfaces, respectively, as shown in Figure 1. The steel reinforcement consisted of ten No. 5 longitudinal bars and No. 4 vertical bars spaced at 305-mm (12-in.) centers. Additional design details are provided in the Transportation Research Record (TRR) No. 1302 (4).

2.2 Reinforcement Modifications

An ultimate strength analysis or "yield-line analysis" was performed on the original single slope CMB to determine if any economy could be achieved by reducing the longitudinal and vertical steel reinforcement (5,6). The analysis indicated that No. 4 vertical bars, spaced on 610-mm (24-in.) centers, in conjunction with adequate longitudinal reinforcement, would produce a single slope CMB that could sustain almost all vehicular impacts with only superficial barrier damage. Longitudinal steel requirements are also controlled by barrier maintenance considerations. Although some states have reported reasonably good barrier maintenance history with only one No. 5 longitudinal bar or welded wire mesh reinforcements, the increase in barrier strength and durability associated with additional longitudinal reinforcement is probably well worth the additional cost (7). A yield line and temperature steel analysis indicated that a single slope CMB with four No. 5 or six No. 4 longitudinal bars would be capable of withstanding most vehicular impacts with little or no barrier damage. Thus, the recommended steel reinforcement for the single slope CMB consisted of four No. 5 longitudinal bars and No. 4 vertical bars spaced on 610-mm (24-in.) centers, as shown in Figure 2 and discussed in Appendix A.

2.3. End-Section Details

The end-section of the single slope CMB was also modified to prevent vehicle snagging and increase its structural capacity. First, it was necessary to decrease the potential for wheel-hub snagging on the upstream end at the CMB's base as well as prevent the front hood and quarter panel from snagging at the top of the CMB. The end-sections of the CMB were designed to include various beveled sections, as shown in Figures 3 and 4. The top surface of the CMB incorporated a 2:1 slope in the longitudinal direction over the last 559 mm (22 in.). The base of the CMB end-section was beveled inward, resulting in a 400-mm (15 ¾-in.) barrier width at the upstream end. This beveled portion included the first 559 mm (22 in.) of CMB length and reached up to 279 mm (11 in.) at the CMB's end and tapered to the ground.

A concrete foundation was placed below the single slope CMB end-section and measured 610-mm (24-in.) thick by 813-mm (32-in.) wide by 3,658-mm (12-ft) long. This foundation was incorporated to simulate a rigid bridge endsection. A L4000 concrete mix, with a minimum 28-day concrete compressive strength of 27.58 MPa (4,000 psi), was used for the single slope CMB and foundation.

High lateral forces imparted to the CMB by the transition required additional longitudinal and vertical reinforcement at the end. The CMB's longitudinal reinforcement in the last 1,524 mm (5 ft) was increased from four to twelve No. 5 bars. The spacing of the No. 4 vertical bars was gradually decreased from 610-mm (24-in.) to 102-mm (4-in.) centers. Two rows of 305-mm (12-in.) long, No. 8 deformed dowel bars were used to attach the single slope CMB to a concrete foundation. Over the last 3.05 m (10 ft), the dowel bar spacing was reduced from 610-mm (24-in.) to 457-mm (18-in.) centers. Each row of bars was spaced 178 mm (7 in.) away from the longitudinal centerline of the CMB. The dowel bar extended 152 mm (6 in.) into the foundation and 152 mm (6 in.) into the CMB's base. All reinforcing and dowel bars used Grade 60 reinforcing steel. Additional reinforcement details are provided in Figure 5.

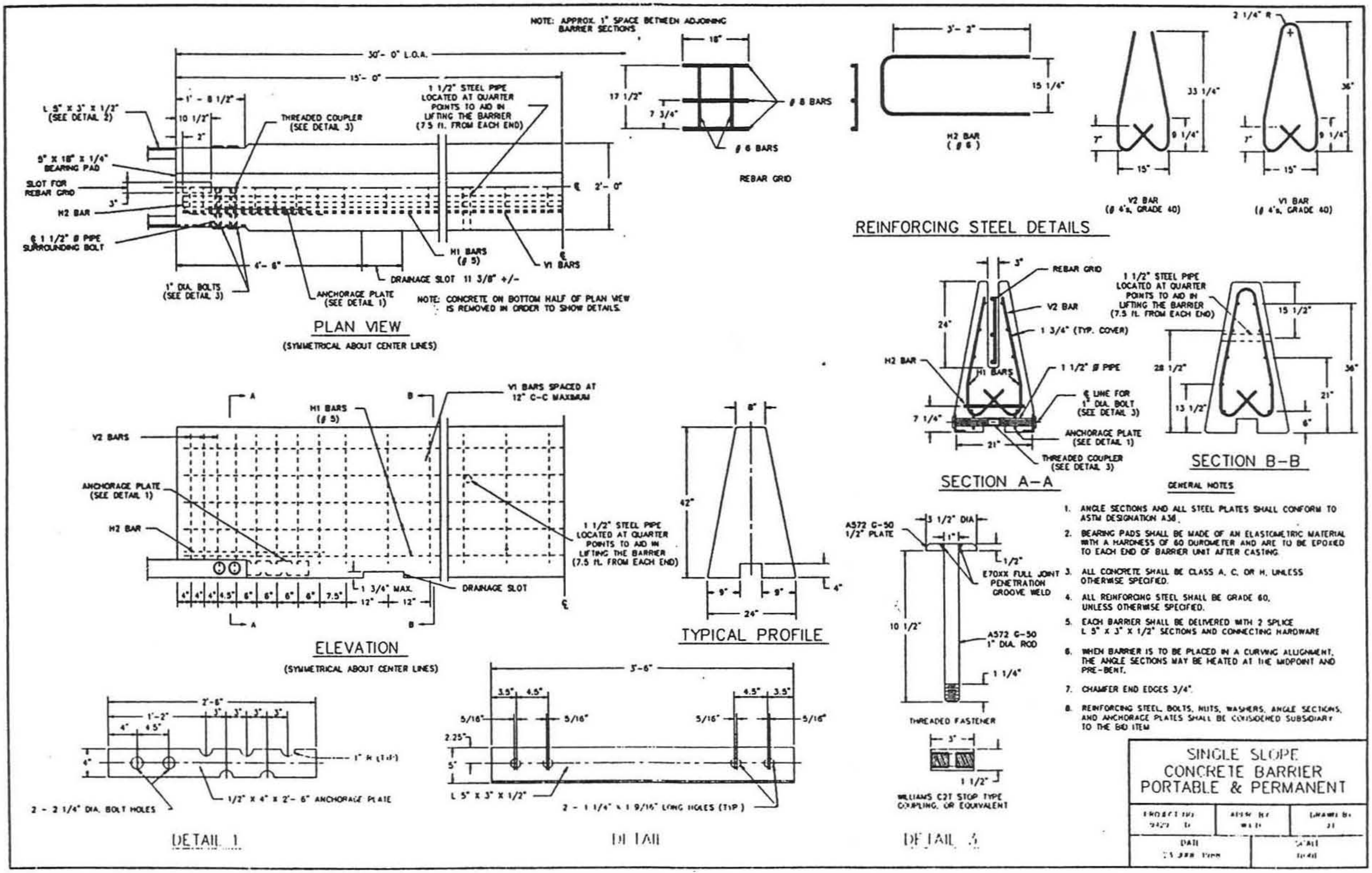

Figure 1. TTI Single Slope CMB Design Details.

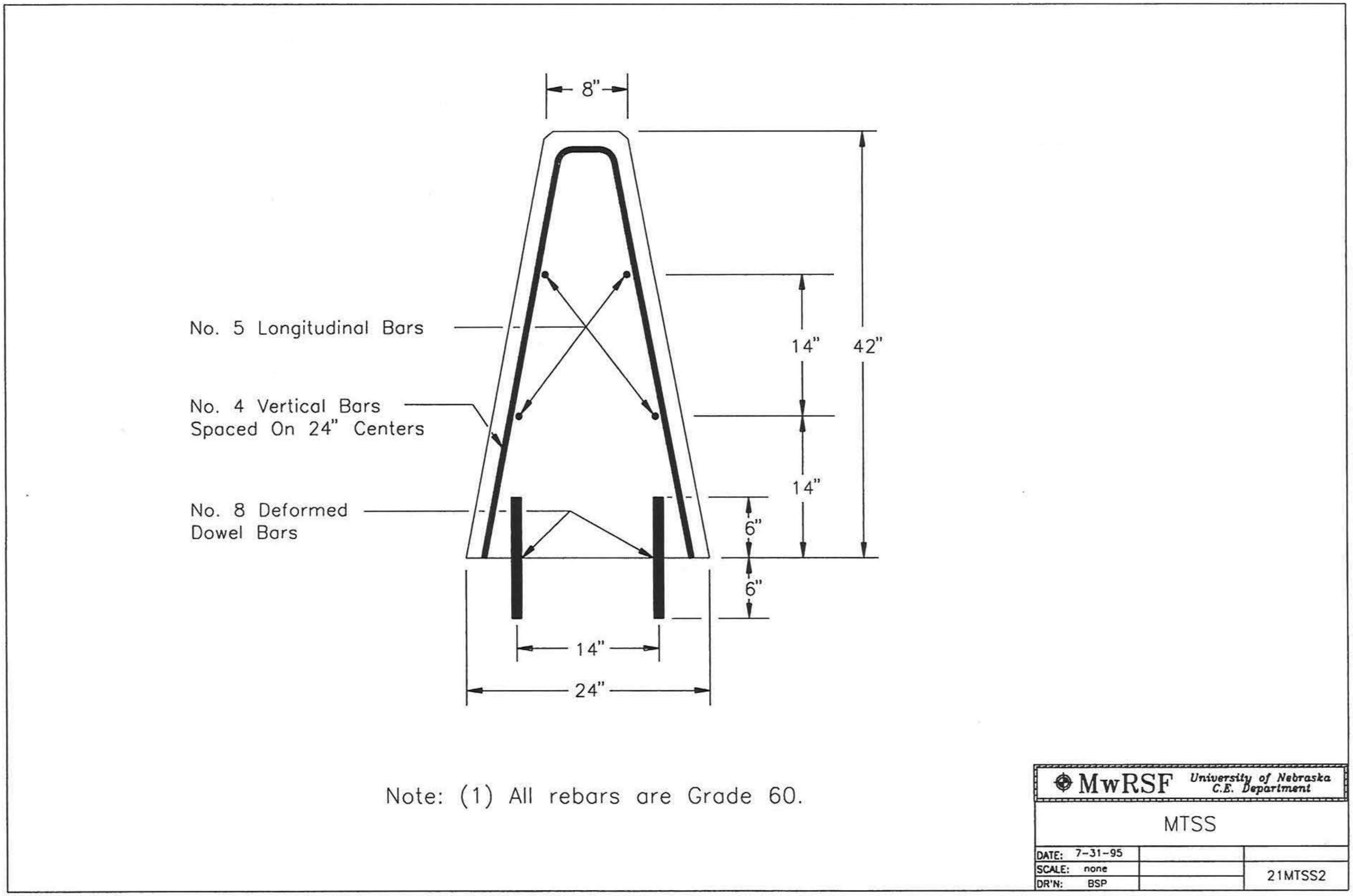

Figure 2. Cross Section of Single Slope CMB with Reduced Longitudinal Reinforcement.

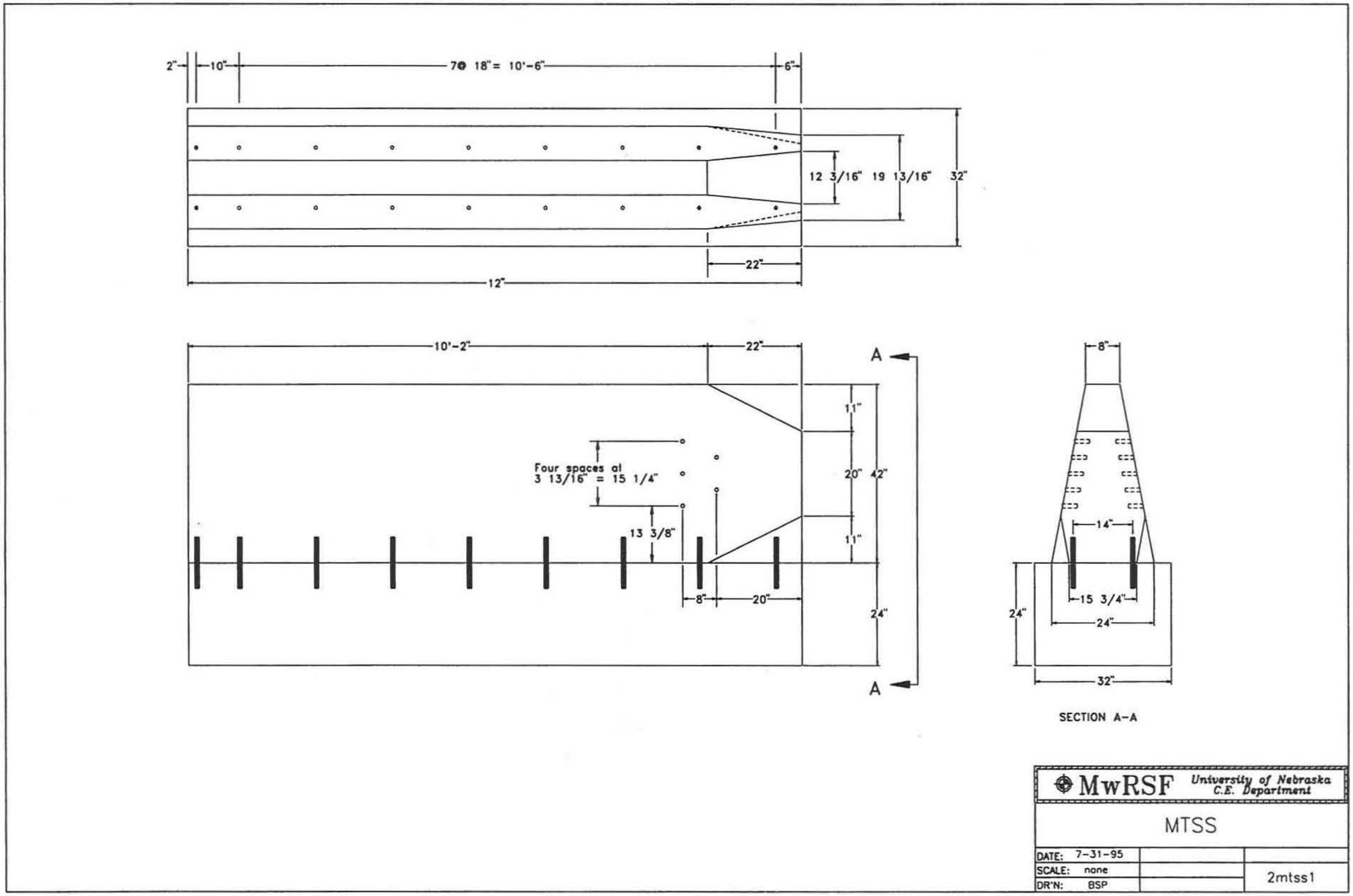

Figure 3. Cross Section and Dowel Configuration of the Single Slope CMB

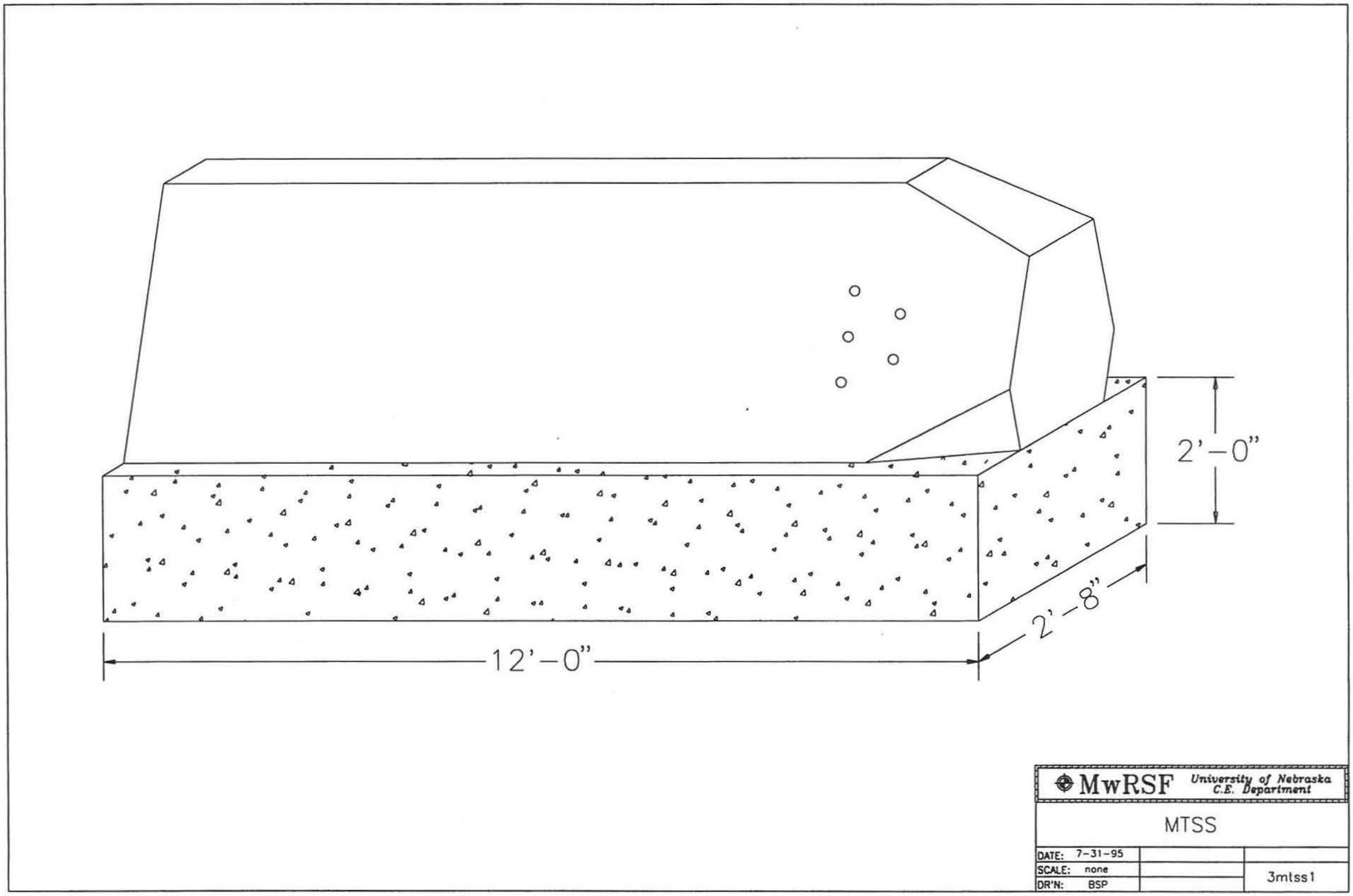

Figure 4. Orthographic Projection of the Single Slope CMB End-Section.

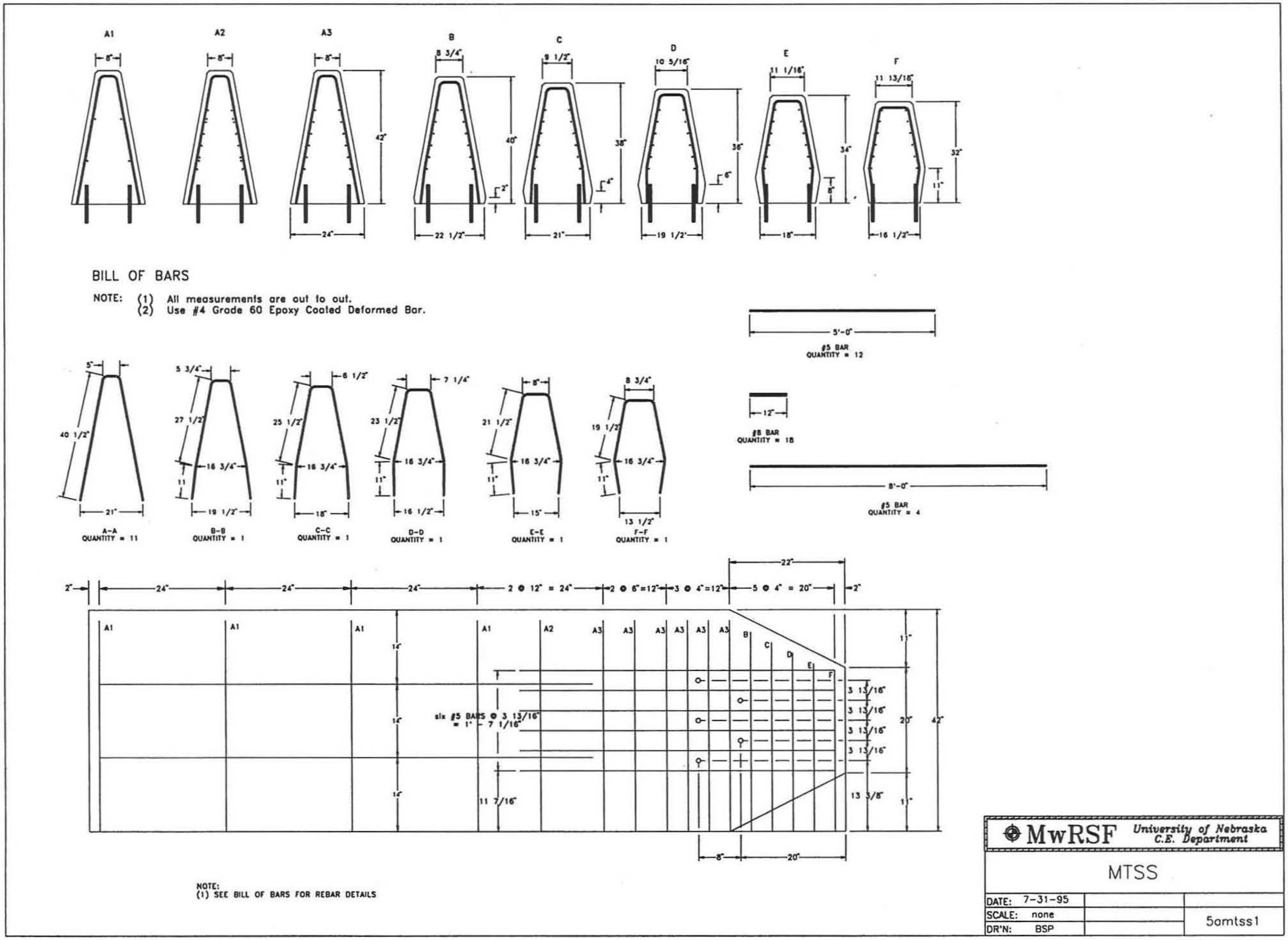

Figure 5. Reinforcement Scheme for the Single Slope CMB and Rebar Details.

3 APPROACH GUARDRAIL TRANSITION (DESIGN NO. 1)

The total length of the test installation was 24.43 m (80-ft 1 ¾-in.) long, as shown in Figure 6. Photographs of the test installation are shown in Figures 7 through 11. The test installation consisted of five major structural components: (1) a 3,658-mm (12-ft) long single slope CMB; (2) a 1,276-mm (4-ft 2 ¼-in.) long steel thrie beam to single slope CMB connector plate (or referred to as the single slope connector plate); (3) a 3,810-mm (12-ft 6-in.) long standard thrie beam rail; (4) a 1,905-mm (6-ft 3-in.) long W-beam to thrie beam transition section; and (5) a 15.2-m (50-ft) long standard W-beam guardrail attached to a simulated anchorage device.

A painted, single slope connector plate connected the thrie beam rail to the CMB was fabricated with 6.3-mm (¼-in.) thick ASTM A36 steel. External dimensions were 1,276-mm (50 ¼-in.) long by 508-mm (20-in.) deep as shown in Figures 12a through 12c. Five 22-mm (⅞-in.) diameter ASTM A325 (Grade 5) bolts, consisting of 127-mm, 114-mm, 102-mm, 83-mm, and 70-mm (5-in., 4 ½-in., 4-in., 3 ¼-in., and 2 ¾-in.) lengths, connected the single slope connector plate to the CMB. Five 22-mm (⅞-in.) diameter self-drilling anchors were placed in the CMB for use with the 22-mm (⅞-in.) diameter bolts.

The system was constructed with seventeen guardrail posts. Post Nos. 1 through 15 consisted of galvanized, ASTM A36 steel W6x9 sections measuring 1,829-mm (6-ft) long. Post Nos. 16 and 17 were timber posts measuring 139.7-mm wide x 190.5-mm deep x 1,079.5-mm long (5½-in. wide x 7½-in. deep x 3-ft 6½-in. long) and were placed in steel foundation tubes. The timber posts and foundation tubes were part of an anchorage system used to develop the required tensile capacity of the guardrail, as shown in Figures 6 and 11.

The spacing from the concrete end to Post No. 1 was 292 mm (11 ½ in.) while the spacing between Post Nos. 1 through 6 was 476 mm (1 ft - 6 ¾ in.), as shown in Figure 6. Post Nos. 6 through 9 were spaced on 953-mm (3-ft 1½-in.) centers, and Post Nos. 9 through 17 were spaced on 1,905-mm (6-ft 3-in.) centers. The soil embedment depths for Post Nos. 1 through 7, 8, and 9 through 15 were 1,030 mm (40 9/16 in.), 1,080 mm (42 ½ in.), and 1,132 mm (44 9/16 in.), respectively, as shown in Figure 16. A structural tube spacer block was utilized on Post Nos. 1 through 7, as shown in Figure 13, to prevent torsional collapse commonly observed to occur with open section W-shape blockouts. The TS 7x4x3/16 by 530-mm (1-ft 8 7/8-in.) long spacer block was fabricated with ASTM A500 Grade B steel. Thrie beam backup plates, measuring 305-mm (12-in.) long, were used at Post Nos. 1 through 6. At Post No. 8, W6x9 by 435-mm (1-ft 5 1/8-in.) long spacer blocks were used, as shown in Figure 14. For Post Nos. 9 through 15, W6x9 by 336.6-mm (1-ft 1¼-in.) long spacer blocks and steel W-Beam backup plates were used at all post locations except at rail splices, as shown in Figure 15. The steel posts were placed in 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 or the weak soil defined in NCHRP Report No. 350 (2).

On each side of the CMB, a standard 10-gauge thrie beam rail, measuring 3,810-mm (12-ft 6-in.) long, was placed between the upstream end of the CMB and Post No. 7. The thrie beam rail, with a top mounting height of 787 mm (2 ft - 7 in.), was connected to the CMB with a standard 10-gauge thrie beam terminal connector. Twelve-gauge W-beam to thrie beam transition sections, measuring 1,905-mm (6-ft 3-in.) long, were placed between Post Nos. 7 and 9, attaching the thrie beam rails to the W-beam guardrails. Between Post Nos. 9 through 17, 15.24 m (50 ft) of standard 12-gauge W-beam rail was placed on each side of the guardrail posts with a top mounting height of 689 mm (2 ft - 3 in.).

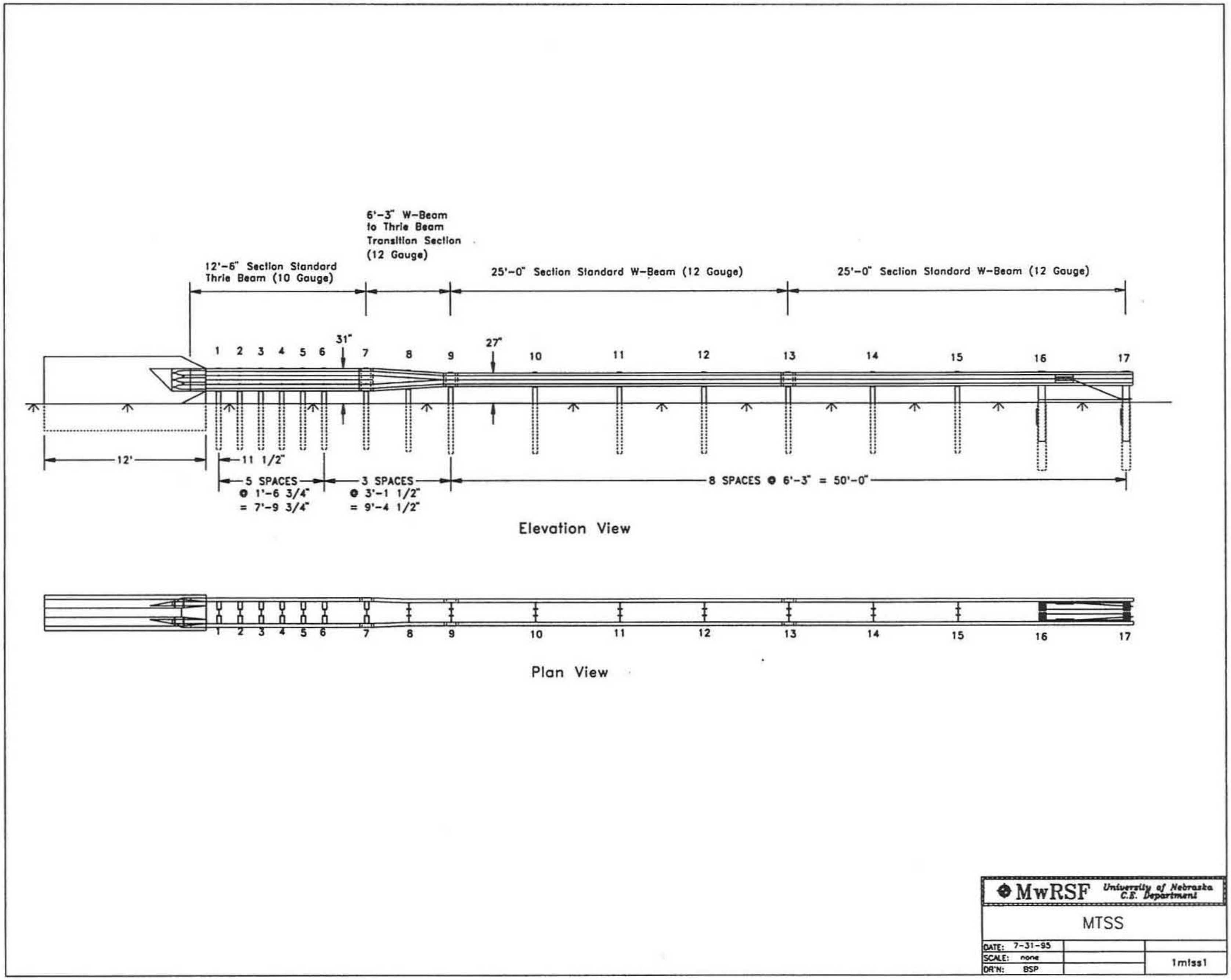

Figure 6. Test Installation Configuration.

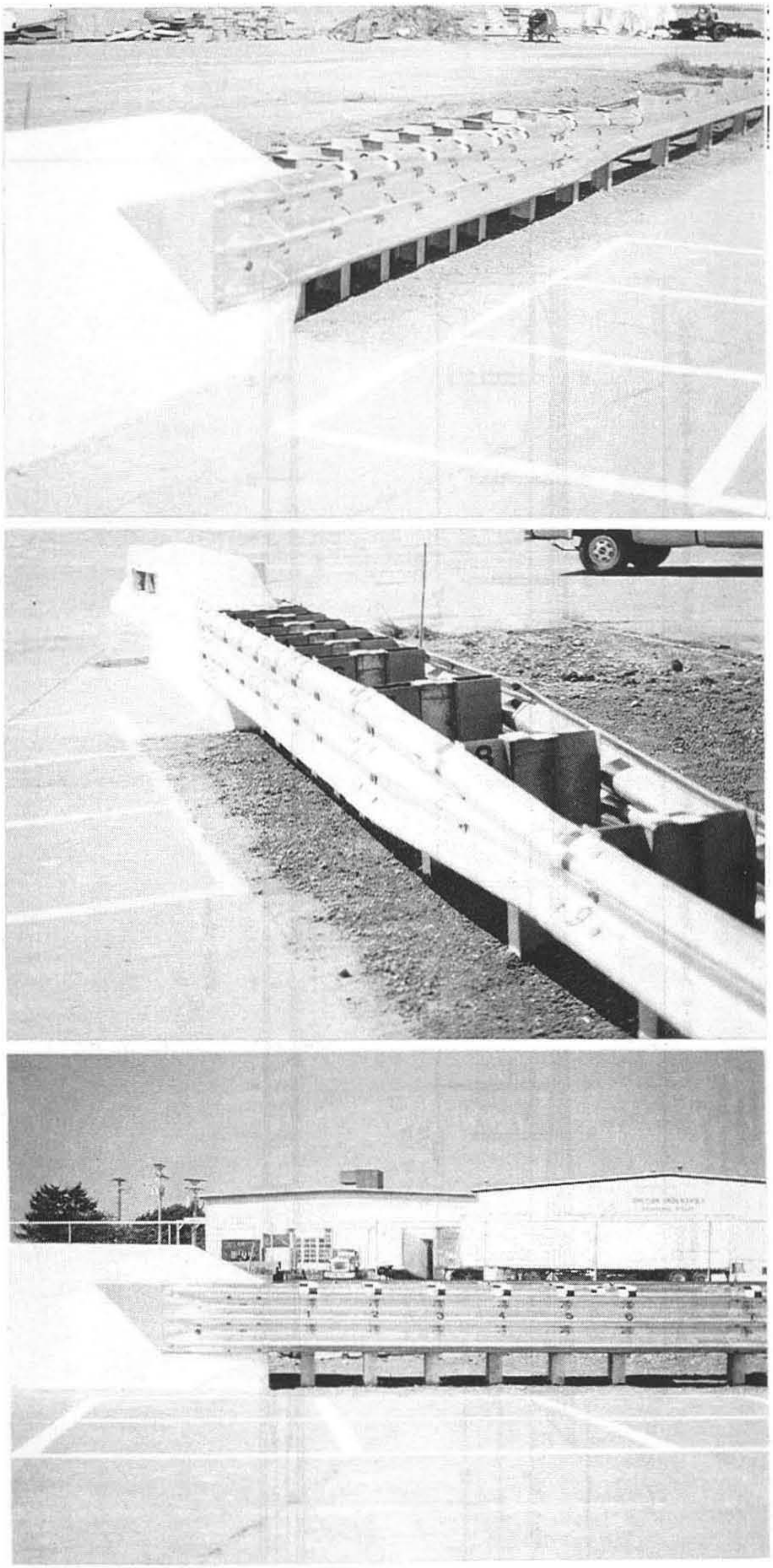

Figure 7. Approach Guardrail Transition, Design No. 1

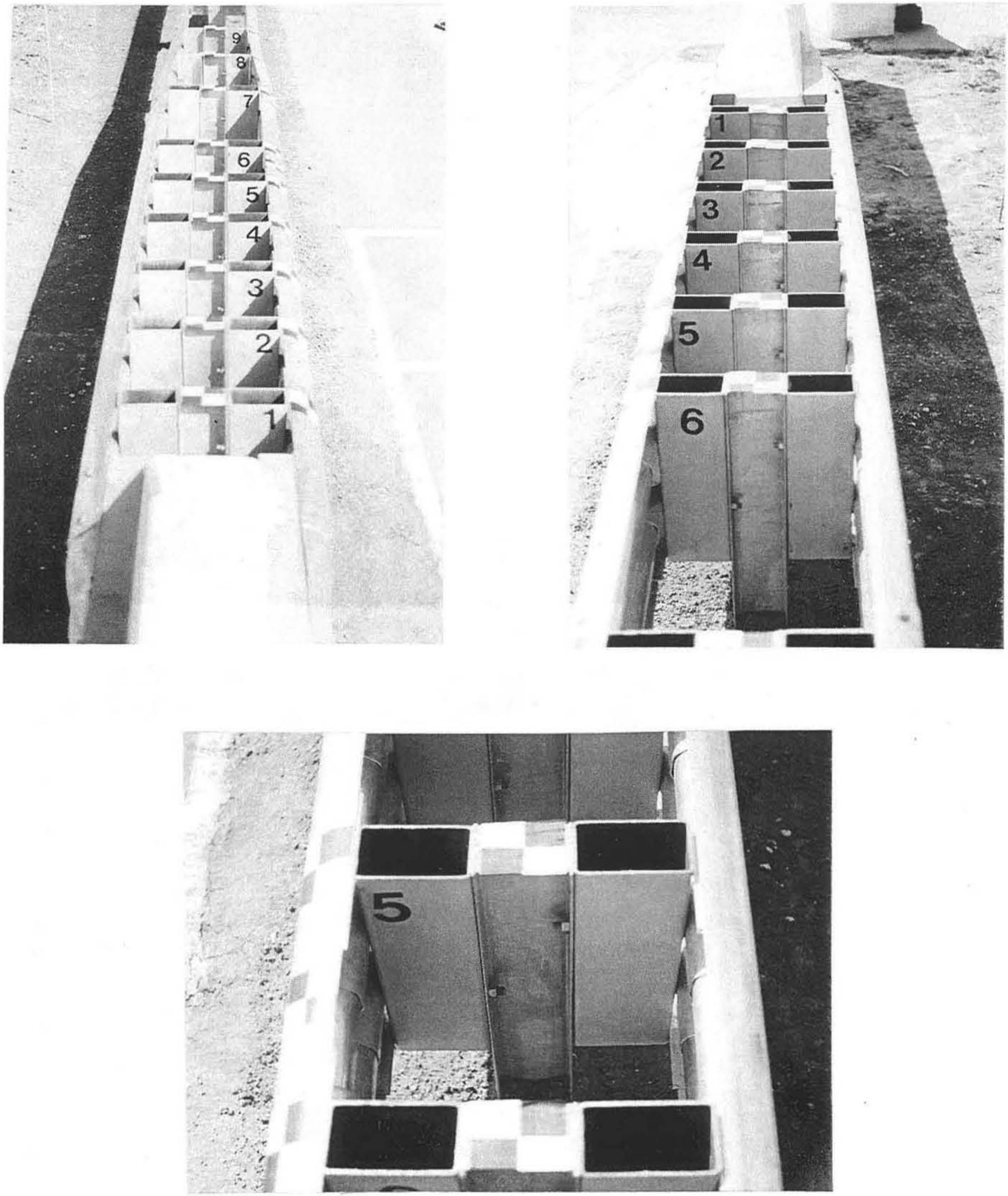

Figure 8. Approach Guardrail Transition - Median Application, Design No. 1

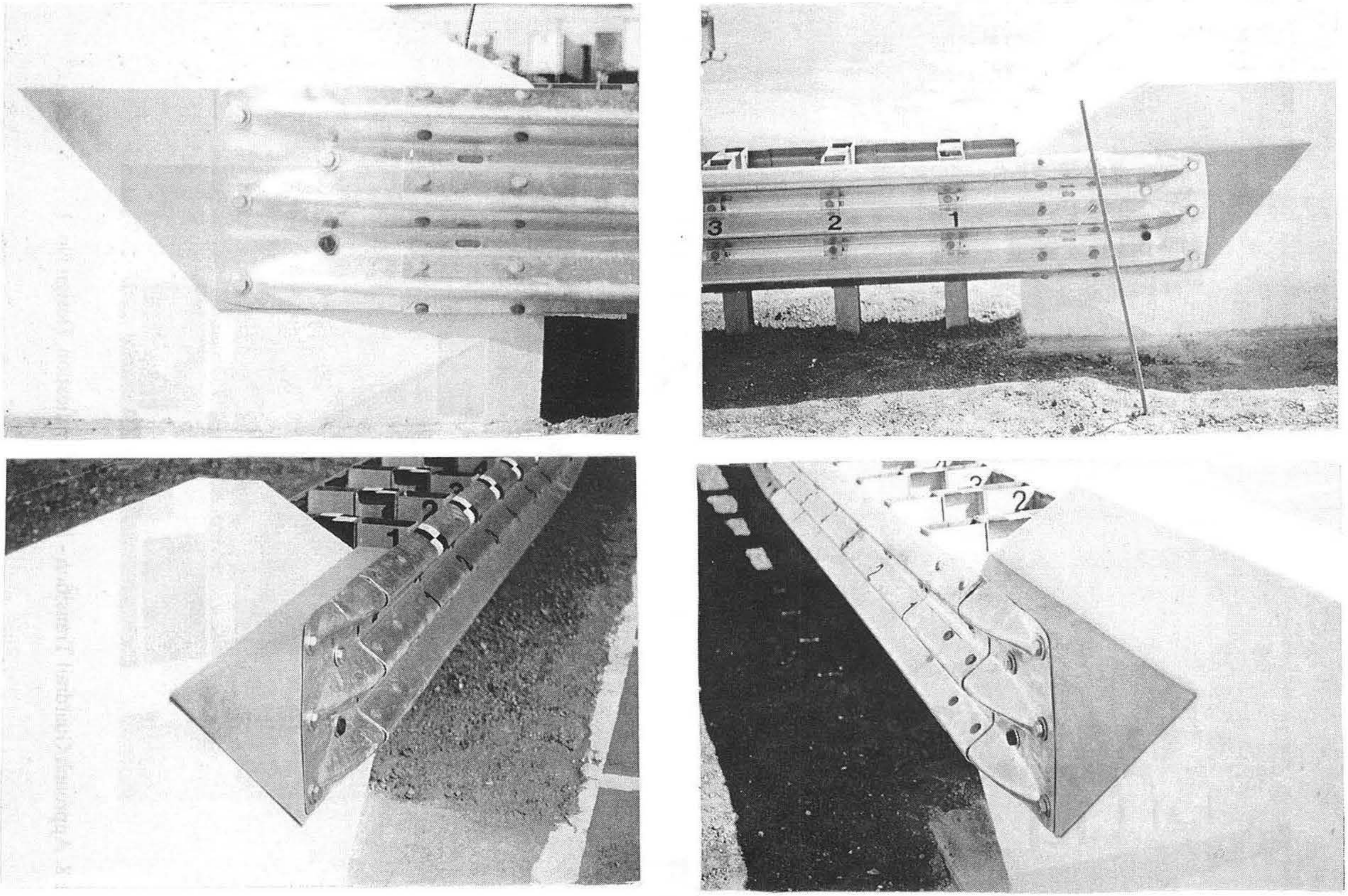

Figure 9. Connection between Single Slope and Approach Guardrail, Design No. 1

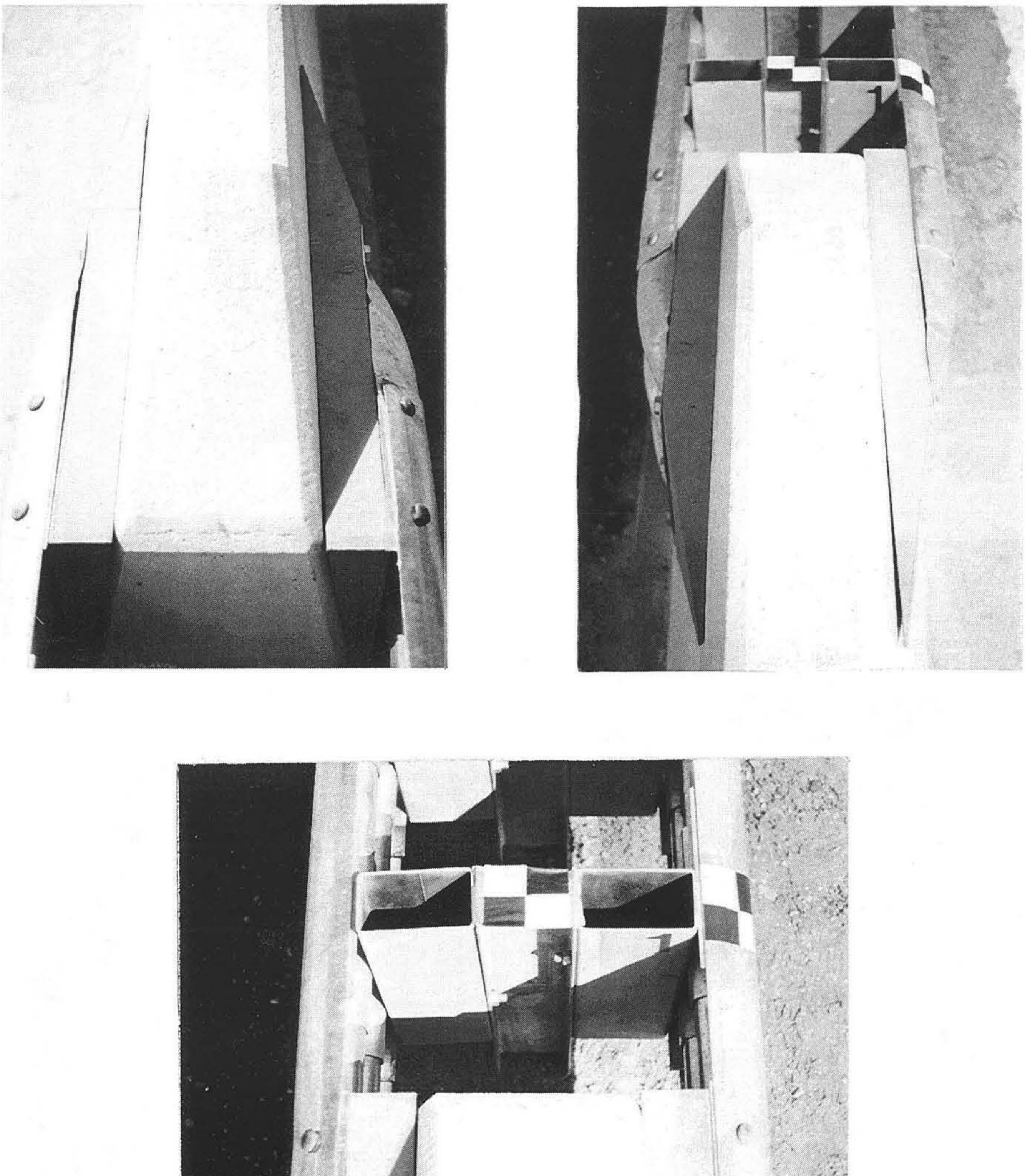

Figure 10. Single Slope CMB - End Section, Design No. 1

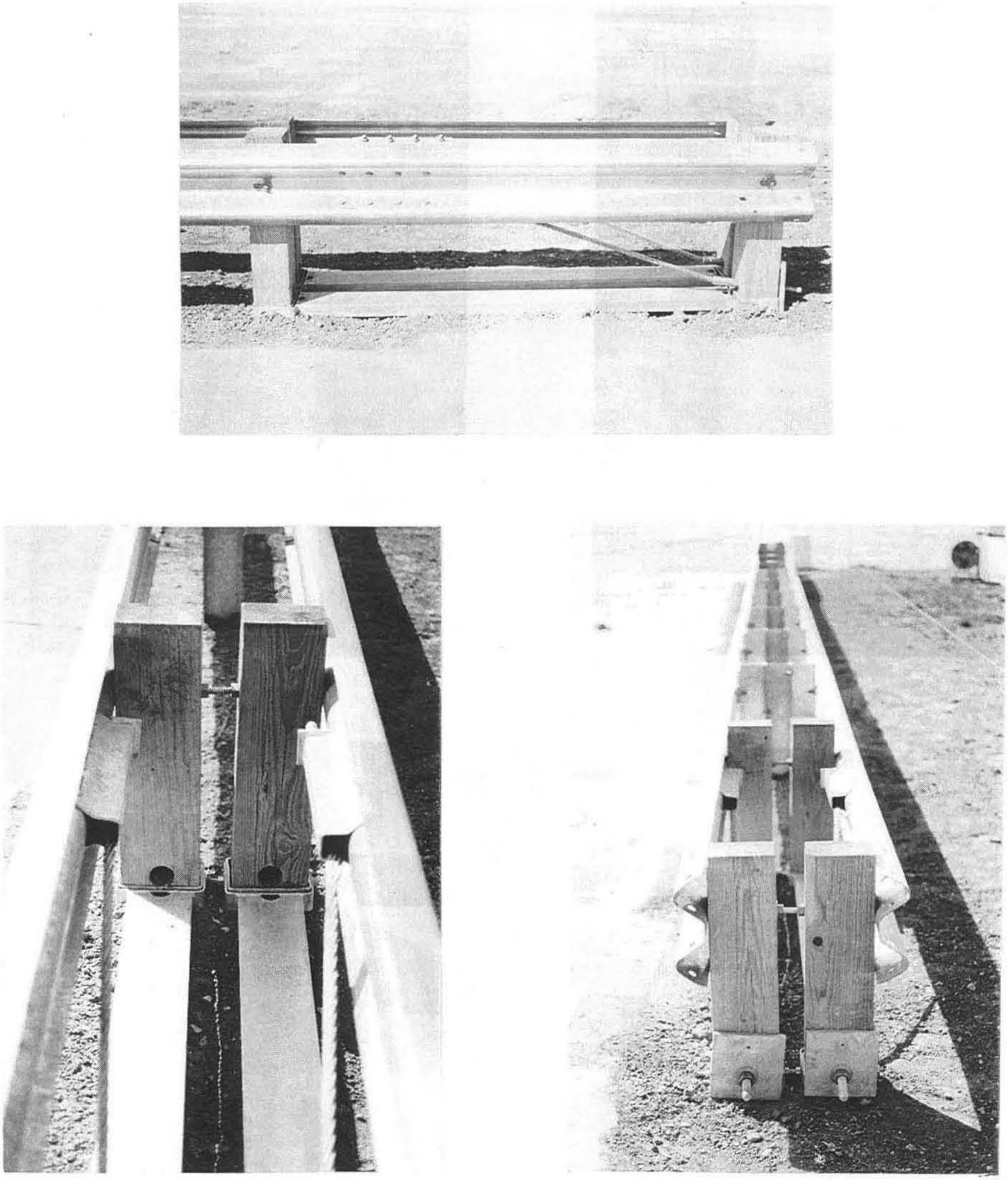

Figure 11. Guardrail Anchorage, Design No. 1

NOTES:

1. All steel shall conform to ASTM A36
2. Flat plate panels are 3/16" thick.
3. Stiffners are 1/4" thick.
4. All hole diameters are 1"
5. Weld components with E60 rod.
6. Galvanize or paint.

WELDING INSTRUCTIONS:

(a) Stiffeners located on the outside edges of the cover plates shall be welded as follows: 3/16" continuous back weld on external sides and 3/16" fillet weld by 1" long spaced at 2" on internal sides.
(b) Stiffeners located on the inside of the cover plates shall be welded as follows: 3/16" fillet weld by 1" long spaced at 2"
(c) Rectangular and triangular cover plates shall be welded together with a 3/16" continuous back weld on both sides.

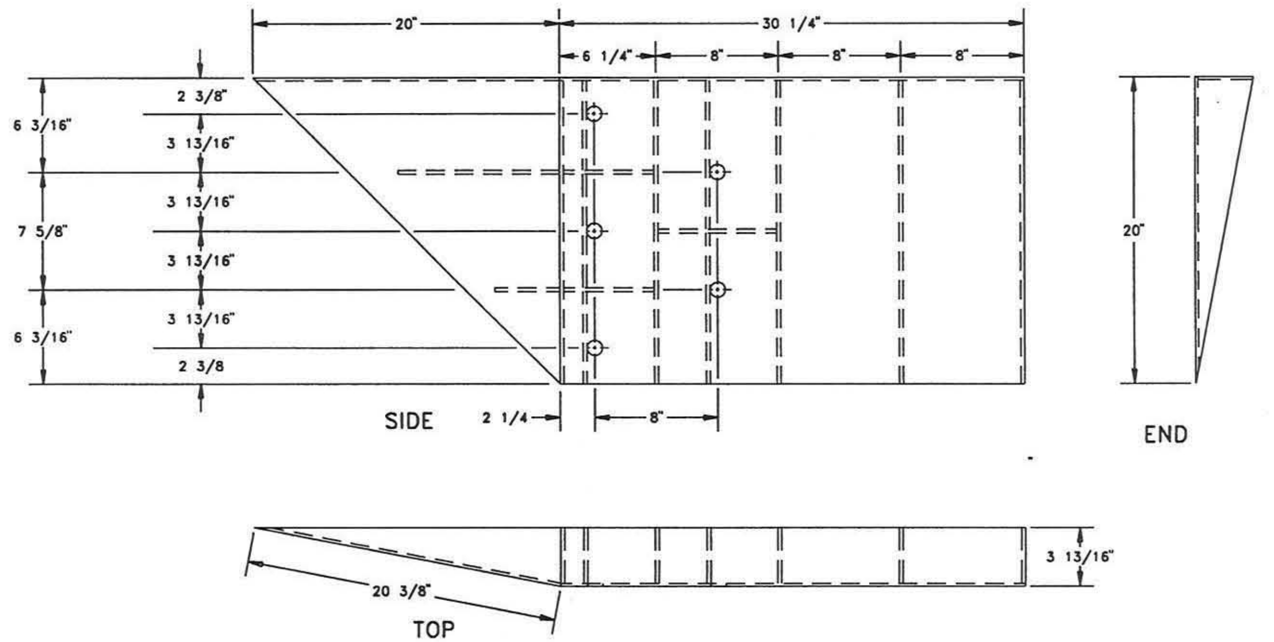

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Figure 12 a. Single Slope Connector Plate, Design No. 1

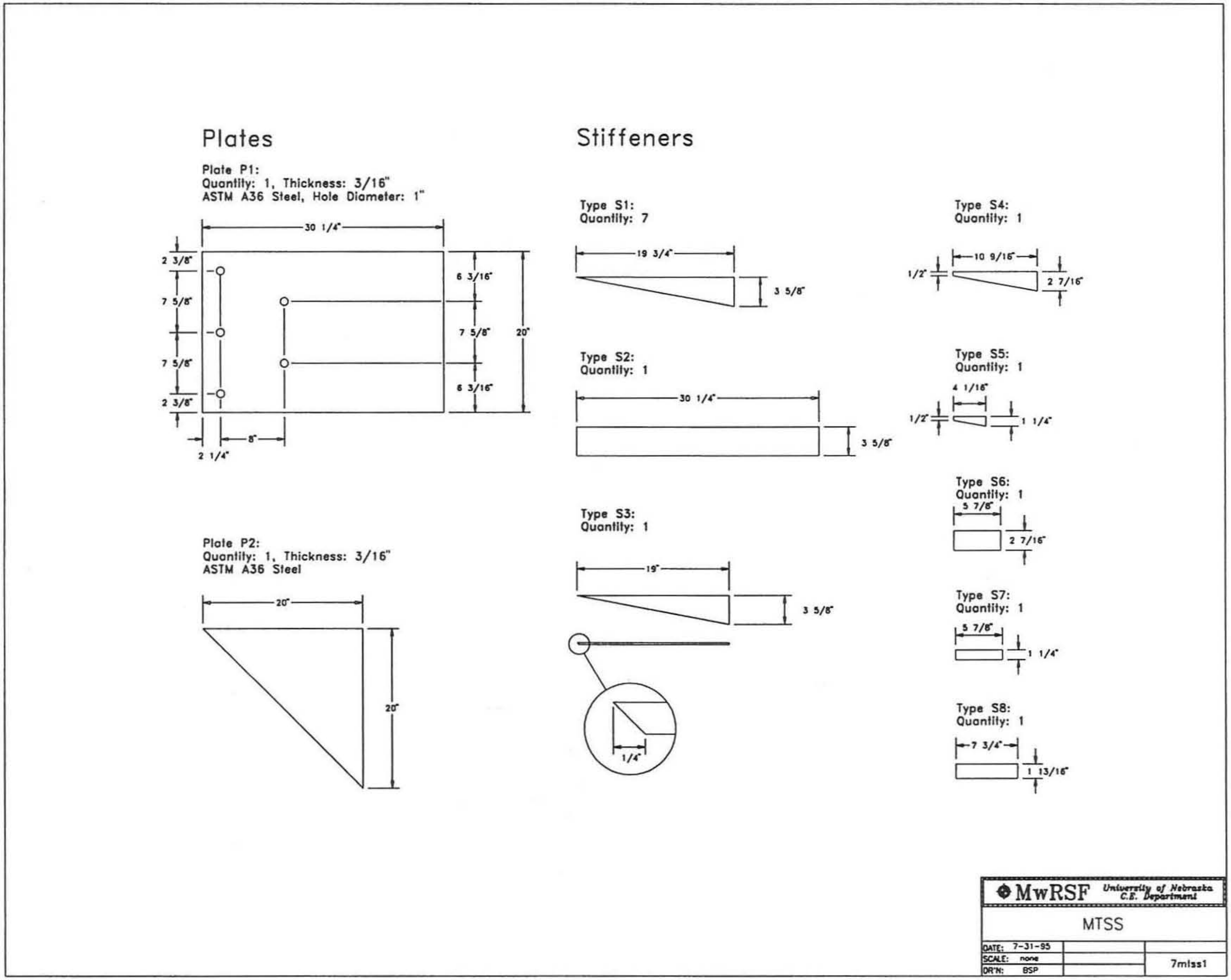


Figure 12 b. Single Slope Connector Plate, Design No. 1 (Con't)

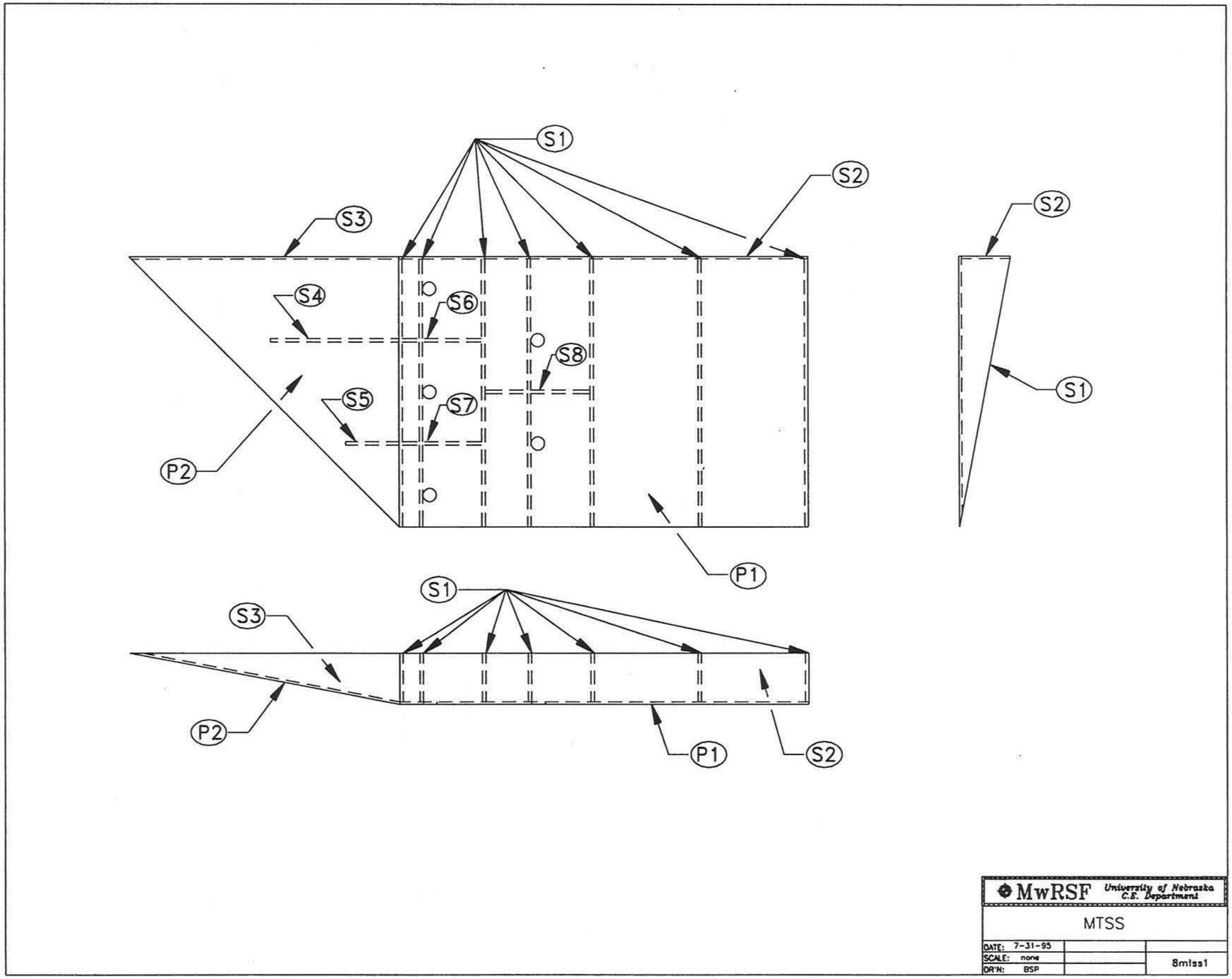


Figure 12 c. Single Slope Connector Plate, Design No. 1

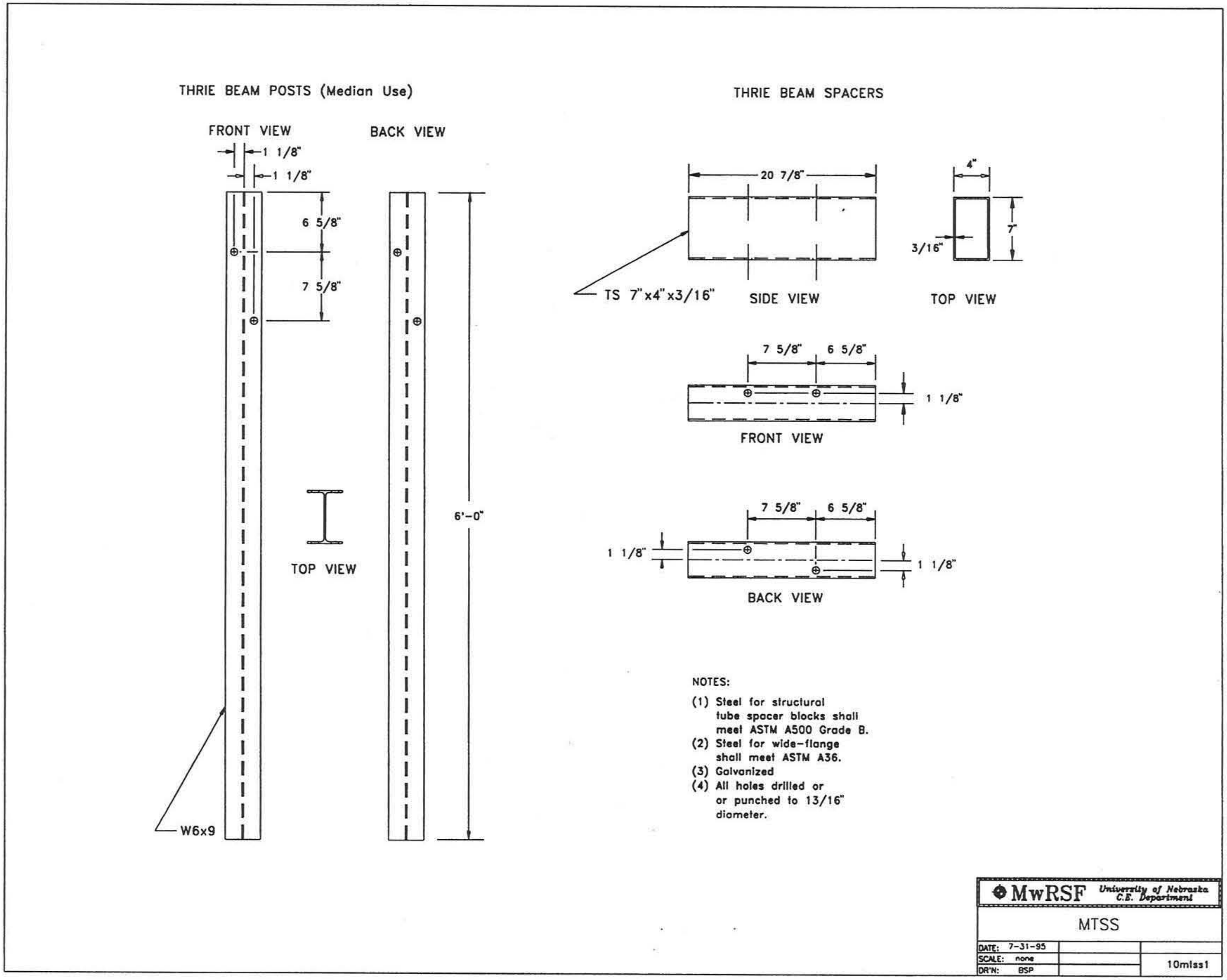


Figure 13. Thrie beam Post and Spacer Details, Design No. 1

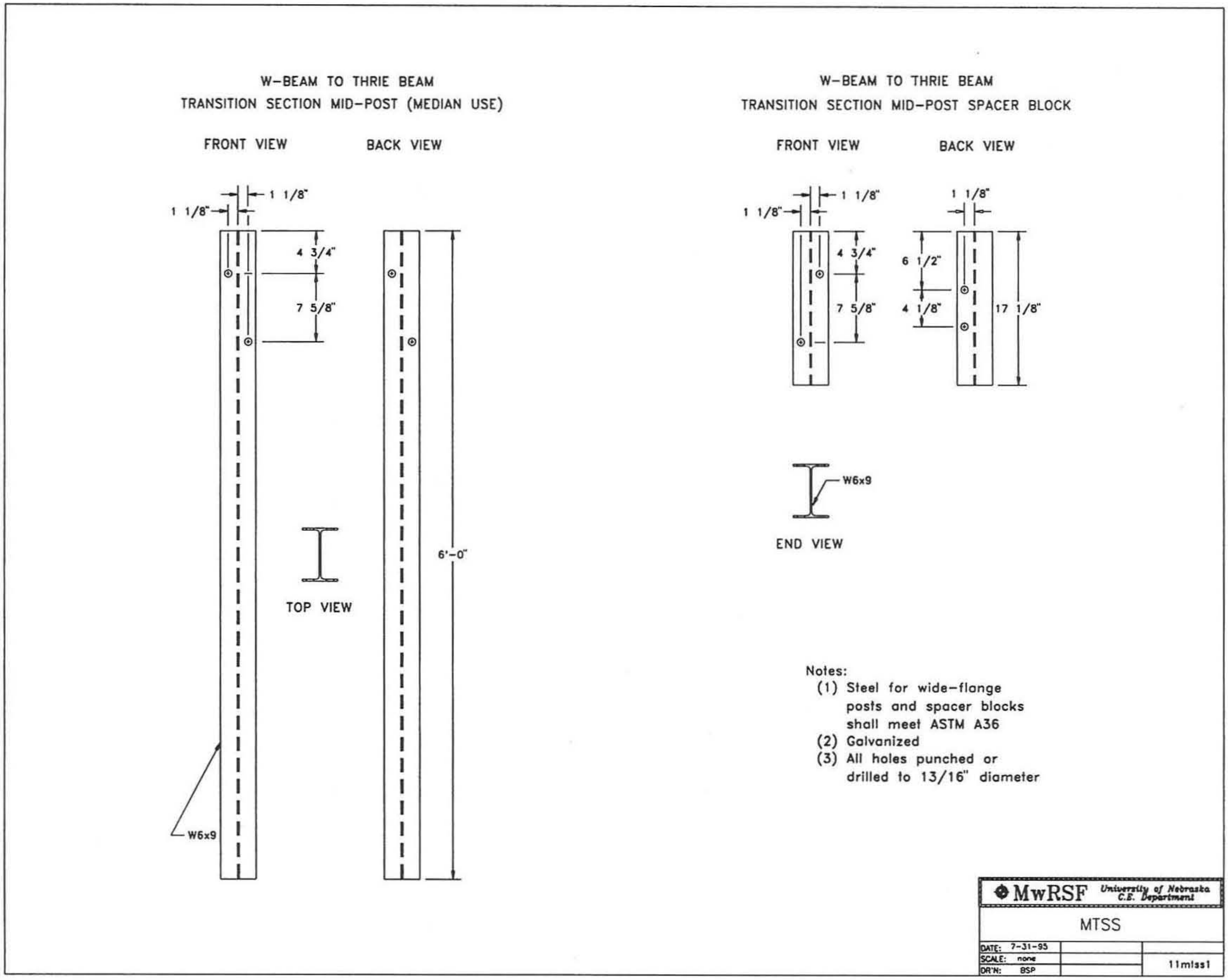


Figure 14. W-Beam to Thrie Beam Post and Spacer Details, Design No. 1

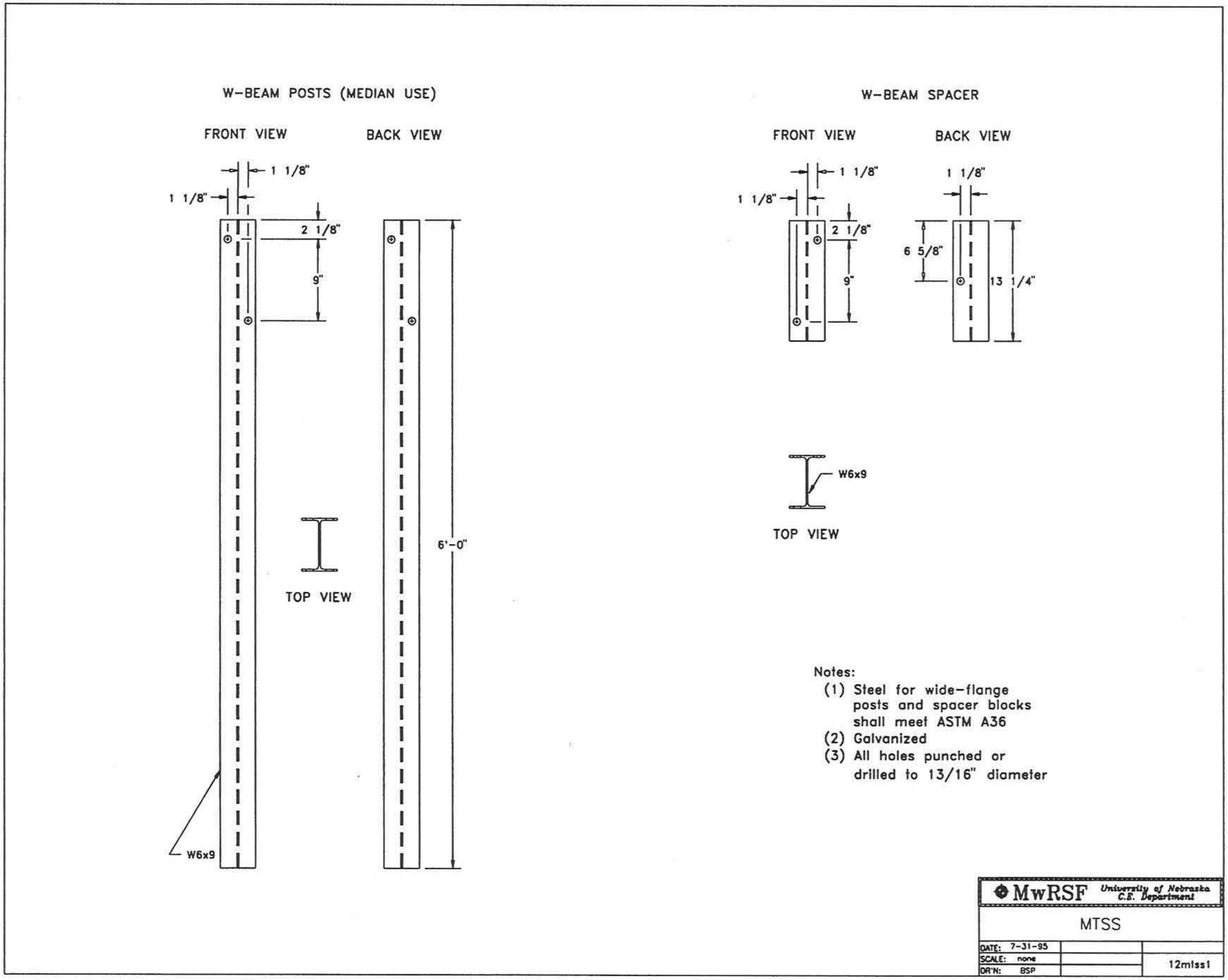


Figure 15. W-Beam Post and Spacer Details, Design No. 1

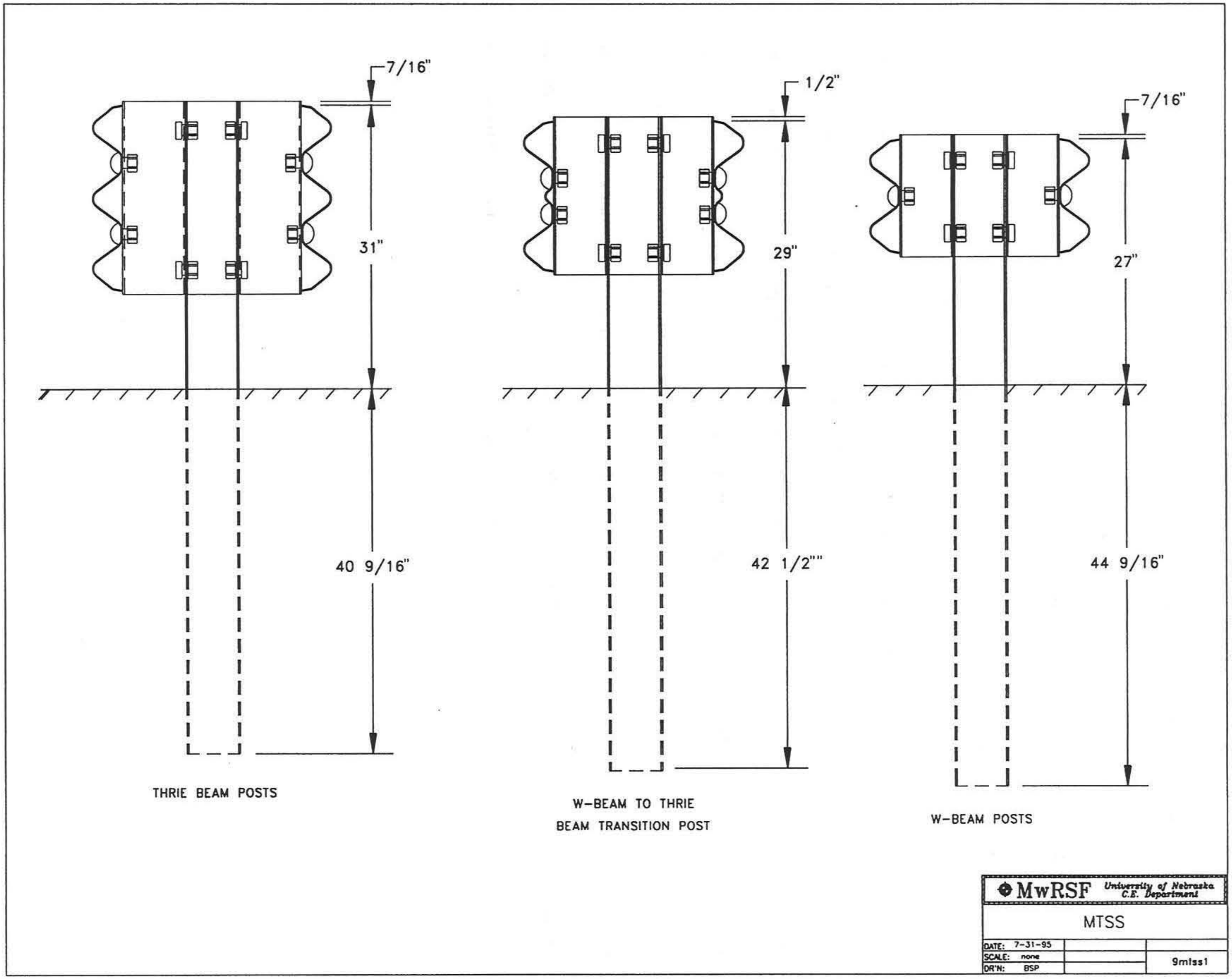


Figure 16. Typical Post Configuration, Design No. 1

4 PERFORMANCE EVALUATION CRITERIA

Roadside safety hardware, including approach guardrail transitions, must satisfy the requirements provided in NCHRP Report No. 350 (2), in order to be accepted for use on new construction projects or as a replacement for existing transition designs. NCHRP Report 350 requires that approach guardrail transitions be subjected to two full-scale vehicle crash tests: (1) a 2,000-kg (4,409-lb) pickup truck impacting at a speed of 100 km/h (62.14 mph) and at an angle of 25 degrees; and (2) an 820-kg (1,808-lb) minicompact vehicle impacting at an speed of 100 km/h (62.14 mph) and at an angle of 20 degrees. However, the 820-kg (1808-lb) minicompact crash test was considered unnecessary since thrie beam barriers have been shown to meet safety performance standards and to be essentially rigid when impacted by minicompact vehicles.

Three major factors were used to evaluate the safety performance of Missouri's approach guardrail transition to a single slope CMB and are as follows: (1) structural adequacy; (2) occupant risk; and (3) vehicle trajectory after collision. These three evaluation criteria are defined in Table 1. The full-scale vehicle crash tests were conducted and reported in accordance with the procedures provided in NCHRP Report No.350 (2).

Table 1. NCHRP Report 350 Evaluation Criteria (Test Designation 3-21)

Structural Adequacy	A.	Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.
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.
Vehicle Trajectory	K.	After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.
	L.	The occupant impact velocity in the longitudinal direction should not exceed 12 m/s and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 g's.
	M.	The exit angle from the test article preferably should be less than 60 percent of test impact angle, measured at time of vehicle loss of contact with test devise.

5 COMPUTER SIMULATION

5.1 Background

Computer simulation modeling with BARRIER VII (8), was performed to analyze and predict the dynamic performance of various approach guardrail transition alternatives attached to the single slope CMB prior to full-scale vehicle crash testing. Computer simulation was also used to determine the critical impact point (CIP) for the approach guardrail transition. 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 (2). The simulations were conducted modeling a 2,000-kg (4,409-lb) pickup truck impacting at a speed of 100 km/h (62.14 mph) and at an angle of 25 degrees. The BARRIER VII finite element model of the approach guardrail transition and the idealized finite element, 2-dimensional vehicle model for the 2,000-kg pickup truck are shown in Appendix B. A typical computer simulation input datafile is shown in Appendix C.

5.2 Design Options

BARRIER VII computer simulation modeling was performed on three design options (Options A, B, and C). The first design option (*Option A*) consisted of the same post configuration as that used in the evaluation and testing of Missouri's bridge anchor section (9). However, the approach guardrail transition developed for this research study was intended for median applications. Therefore one 10-gauge thrie beam guardrail section was placed on each side of the concrete median barrier. *Option A* consisted of seven reduced post spacings - one at 292 mm (11½ in.), one at 476 mm (1 ft - 6¾ in.), and five at 952 mm (3 ft - 1½ in.). *Option B* consisted of eight reduced post spacings - one at 292 mm (11½ in.), three at 476 mm (1 ft - 6 ¾ in.), and four at 952 mm (3 ft - 1½ in.). *Option C* consisted of nine reduced post spacings - one at 292 mm (11½ in.), five at 476 mm

(1 ft - 6 ¾ in.), and three at 952 mm (3 ft - 1½ in.). The finite element models for these design options are provided in Appendix B.

5.3 BARRIER VII Results

Ten computer simulation runs were performed for both *Options A and B* at different impact locations, as provided in Tables 2 and 3. For *Option C*, only four computer simulation runs were performed, as shown in Table 4. 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 CMB. As previously mentioned, the size of the blunt-end face was minimized by incorporating a bevel at the upstream end of the CMB's base. Therefore, the potential for wheel-hub snagging would only exist with significant rail deflections or rail flattening near the end of the CMB.

The results of the computer simulations indicated a potential for wheel-hub snagging on the upstream end of the CMB. Simulations of *Option A* produced the greatest snag potential with a lateral wheel-hub snag distance of 74 mm (2.9 in.) for an impact 2,673 mm (8 ft - 9¼ in.) from the upstream end of the CMB. Subsequently, *Option B*, consisting of one additional post, produced a wheel-hub snag distance of 56 mm (2.2 in) for impacts 2,435 mm (7 ft - 11 ⅞ in.) and 2,673 mm (8 ft - 9¼ in.) from the upstream end of the CMB. Computer simulations were then performed on *Option C*, which utilized two additional posts. These simulations produced a wheel-hub snag distance of 53 mm (2.1 in) for an impact 2,435 mm (7 ft - 11⅞ in.) from the upstream end of the CMB. Although *Option B and C* provided similar wheel-hub snag distances, *Option C* was selected as the final design due to the additional reduction in maximum permanent set and dynamic deflections, as shown in Tables 3 and 4. In addition, *Option C* provided a more conservative transition design than *Option B* for a slight increase in material cost.

The critical impact point (CIP) for *Option C*, as determined by the simplified procedures for Test No. 21 found in NCHRP 350 (2), was determined to be less than 1,494 mm (4.9 ft) for post spacings equal to 476 mm (1 ft - 6 ¾ in.). The CIP values from BARRIER VII computer simulation (2,435 mm (7 ft - 11 ⅞ in.)) and NCHRP 350 (1,494 mm (4.9 ft)) were found to be in disagreement. Therefore it appeared that there may be a problem with the CIP graphs developed for Test No. 21 (Figure 3.14 of NCHRP 350). However, the CIP location, as determined by our BARRIER VII computer simulation, was based upon the impact scenario that provided the greatest potential for wheel hub snagging and not necessarily the greatest dynamic rail/post deflection. Following the CIP comparison, it was determined that the CIP equal to 2,435 mm (7 ft - 11 ⅞ in.), as determined from BARRIER VII, would be used for the full-scale vehicle crash test.

Table 2. Computer Simulation Test Matrix and Results for Option No. A

Test No.	Impact Node	Impact Distance[1]	Maximum Tensile Force @ Thrie Beam Connector (kips)	Maximum Dynamic Rail Deflection (in.)	Maximum Permanent Set Deflection (in.)	Lateral Wheel-Hub Snag Distance[2] (in.)
1	19	11 ft - 10 ¾ in.	98.2	11.05	9.75	0.7
2	20	11 ft - 1 ⅜ in.	98.0	10.89	9.47	1.3
3	21	10 ft - 4 in.	98.0	10.79	9.47	2.0
4	22	9 ft - 6 ⅝ in.	101.6	9.69	8.36	2.2
5	23	8 ft - 9 ¼ in.	108.6	10.03	8.68	2.9[3]
6	24	7 ft - 11 ⅞ in.	101.8	8.85	7.31	2.4
7	25	7 ft - 2 ½ in.	88.5	7.19	5.83	2.1
8	26	6 ft - 5 ⅛ in.	85.1	6.12	4.86	2.0
9	27	5 ft - 7 ¾ in.	78.3	5.14	3.9	1.8
10	28	4 ft - 10 ⅜ in.	49.1	3.76	2.84	1.5

[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).

Table 3. Computer Simulation Test Matrix and Results for Option No. B

Test No.	Impact Node	Impact Distance[1]	Maximum Tensile Force @ Thrie Beam Connector (kips)	Maximum Dynamic Rail Deflection (in.)	Maximum Permanent Set Deflection (in.)	Lateral Wheel-Hub Snag Distance[2] (in.)
1B	19	11 ft - 10 ¾ in.	93.0	10.31	9.08	NA
2B	20	11 ft - 1 ⅜ in.	88.6	9.51	8.29	NA
3B	21	10 ft - 4 in.	87.5	8.30	7.07	0.8
4B	22	9 ft - 6 ⅝ in.	91.3	7.64	6.49	1.3
5B	23	8 ft - 9 ¼ in.	93.1	8.08	6.77	2.2[3]
6B	24	7 ft - 11 ⅞ in.	95.1	7.71	6.43	2.2[3]
7B	25	7 ft - 2 ½ in.	80.2	5.99	4.94	1.8
8B	26	6 ft - 5 ⅛ in.	75.1	5.20	4.06	1.6
9B	27	5 ft - 7 ¾ in.	61.0	4.31	3.33	1.5
10B	28	4 ft - 10 ⅜ in.	33.0	2.90	2.25	1.2

NA - Not Applicable

[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).

Table 4. Computer Simulation Test Matrix and Results for Option No. C

Test No.	Impact Node	Impact Distance[1]	Maximum Tensile Force @ Thrie Beam Connector (kips)	Maximum Dynamic Rail Deflection (in.)	Maximum Permanent Set Deflection (in.)	Lateral Wheel-Hub Snag Distance[2] (in.)
4C	22	9 ft - 6 ⅝ in.	84.5	6.85	5.77	1.0
5C	23	8 ft - 9 ¼ in.	88.8	6.47	5.36	1.4
6C	24	7 ft - 11 ⅞ in.	91.6	6.50	5.38	2.1[3]
7C	25	7 ft - 2 ½ in.	80.8	5.56	4.51	1.7

[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).

6 TEST MTSS-1 (2,043 kg (4,504 lbs), 104.0 km/h (64.6 mph), 24.2 deg)

The pickup impacted the approach guardrail transition attached to the single slope CMB approximately 2.44 m (8 ft) from the upstream end of the CMB (Figures 17 and 18). A summary of the test results and the sequential photographs is presented in Figure 19. Additional sequential photographs are shown in Figure 20.

6.1 Test Description

After the initial impact with the approach guardrail transition, the right-front corner of the bumper and quarter panel crushed inward. At 0.026 sec, the right-front corner of the vehicle was at Post No. 4, and the left-front wheel started to steer to the left 0.030 sec after impact. At 0.044 sec and 0.058 sec, the right-front corner of the vehicle was near Post Nos. 3 and 2, respectively. The left-front wheel steered quickly to the right at 0.080 sec. At 0.090 sec, the right-front corner of the vehicle was at the upstream end of the single slope CMB. At 0.100 sec after impact, the maximum dynamic rail deflection of 251 mm (9.9 in.) occurred at Post No. 4. The roof of the vehicle buckled at 0.106 sec after impact. After 0.134 sec, the windshield fractured as the A-pillar of the vehicle was at the upstream end of the single slope CMB. The left-rear wheel lost contact with the ground and the vehicle became parallel to the transition at 0.220 sec with a velocity of 66.0 km/h (41.0 mph). At 0.234 sec after impact, the right-front corner of the vehicle was near the downstream end of the single slope CMB. The vehicle exited the test installation at approximately 0.320 sec after impact at a speed of 64.9 km/h (40.3 mph) and an angle of 3.2 degrees. The vehicle's post impact trajectory is shown in Figure 19. The vehicle came to rest approximately 61.0 m (200 ft) downstream from impact and 17.7 m (58 ft) laterally behind a line projected parallel to the traffic-side face of the rail.

Figure 17. Impact Location, Test MTSS-1

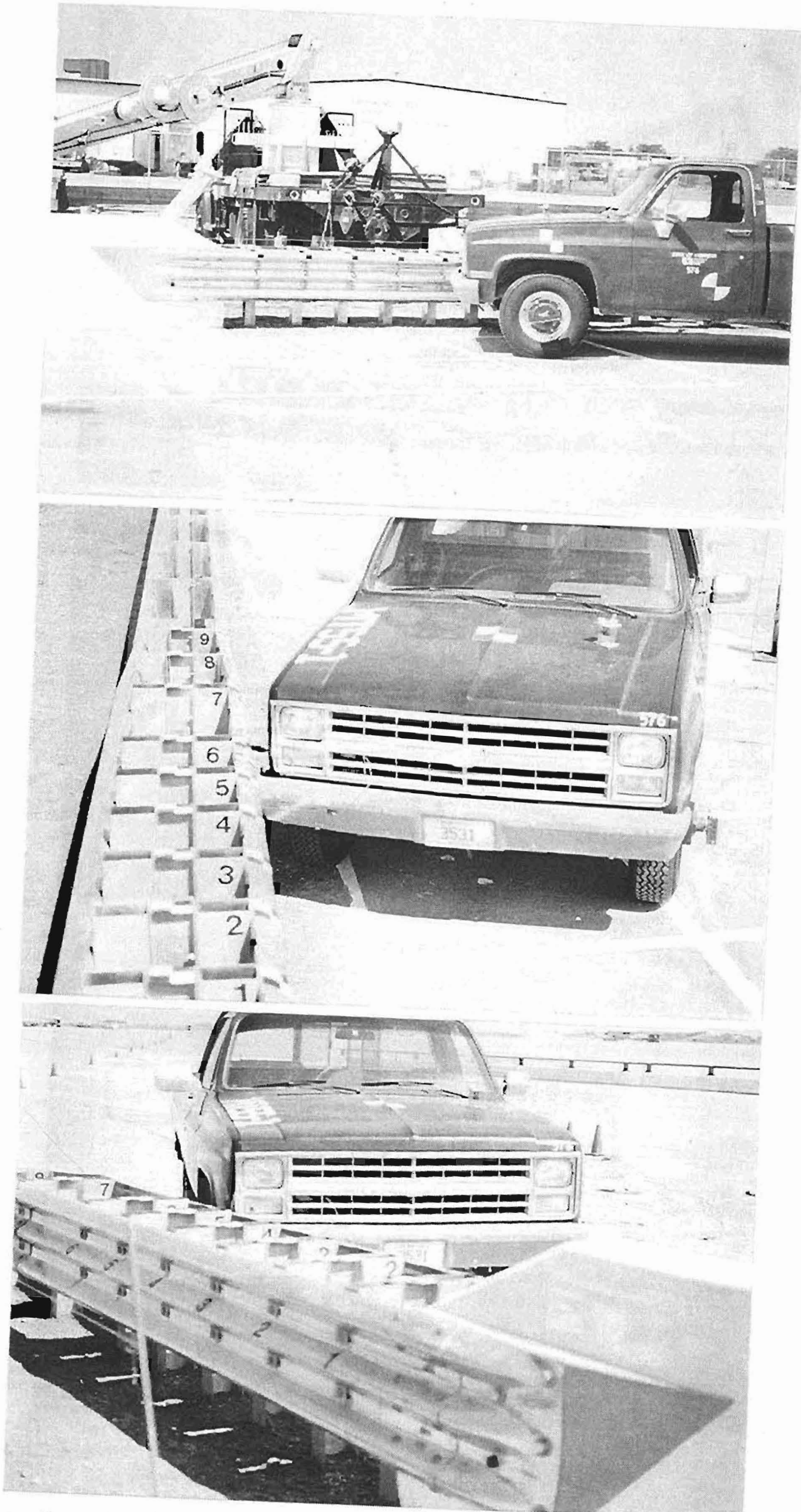
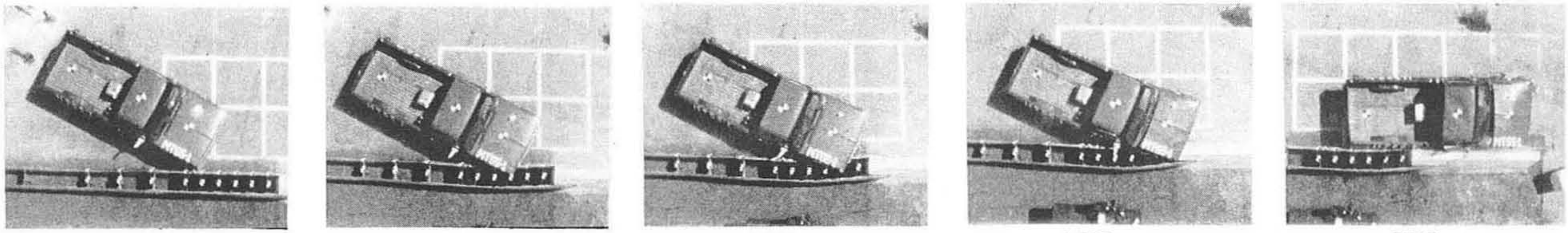
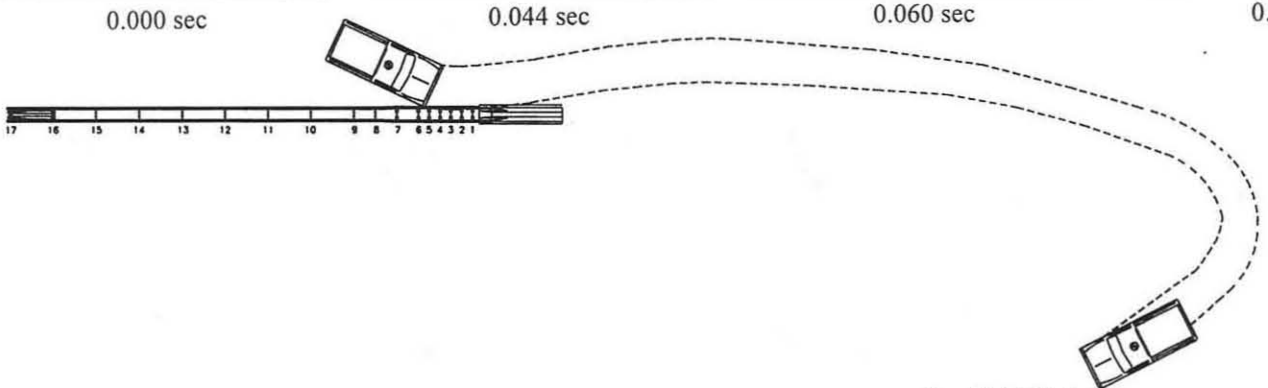
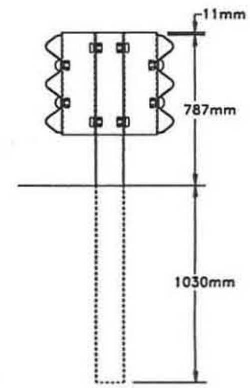


Figure 18. Impact Location, Test MTSS-1 (Con't)



0.000 sec 0.044 sec 0.060 sec 0.106 sec 0.220 sec





- Test Number MTSS-1
- Date 8/22/94
- Appurtenance .... Missouri's approach guardrail transition to a single slope CMB
- Total Length .... 21.1 m
- Steel Thrie Beam (10 Gauge)
  - Top Mounting Height .... 787 mm
- Steel Posts
  - Post Nos. 1 - 15 .... W6x9 by 1829 mm long
- Steel Spacer Blocks
  - Post Nos. 1 - 7 .... TS 7x4x3/16 by 530-mm long
  - Post Nos. 8 .... W6x9 by 435-mm long
  - Post Nos. 9 - 15 .... W6x9 by 337-mm long
- Soil Type .... Silty-Clay (SL) (Dry)
- Vehicle Model .... 1985 Chevrolet C-20 2WD
  - Curb Weight .... 1,912 kg
  - Test Inertial Weight .... 2,043 kg
  - Gross Static Weight .... 2,043 kg
- Vehicle Speed
  - Impact .... 104.0 km/h
  - Exit .... 64.9 km/h
- Vehicle Angle
  - Impact .... 24.2 deg
  - Exit .... 3.2 deg
- Vehicle Snagging .... Contact at top end of CMB and top of posts/spacer blocks
- Vehicle Stability .... Satisfactory
- Occupant Ridedown Deceleration
  - Longitudinal .... 10.23 G's < 20 G's
  - Lateral .... 17.84 G's < 20 G's
- Occupant Impact Velocity (Normalized)
  - Longitudinal .... 9.48 m/s < 12 m/s
  - Lateral .... 8.14 m/s < 9 m/s
- Vehicle Damage .... Extensive
  - TAD[10] 1-RBQ-5, 1-RD-4
  - SAE[11] 01RDAW3
- Vehicle Stopping Distance .... 61.0 m downstream 17.7 m lateral
- Barrier Damage .... Moderate
- Maximum Post Deflections
  - Permanent Set .... 127 mm
  - Dynamic .... 251 mm

Figure 19. Summary of Test Results, Test MTSS-1

IMPACT

0.030 sec

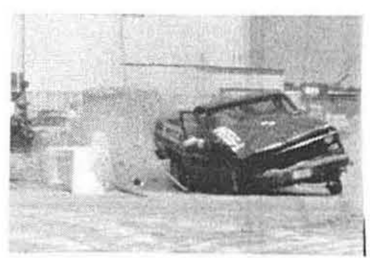
0.080 sec

0.100 sec

0.200 sec

0.220 sec

0.400 sec



0.590 sec

Figure 20. Additional Sequential Photographs, Test MTSS-1

6.2 Vehicle Damage

Exterior vehicle damage was extensive and occurred to several body locations, including the right-side door and quarter panels, front and rear bumpers, right-side wheels and rims, engine hood, roof, windshield, occupant compartment, and steel frame, as shown in Figures 21 through 29. The right-side door was severely deformed and had evidence of the vehicle-rail interlock, as shown in Figures 21 and 22. The right-front quarter panel received extensive deformation due to contact with the top of the upstream end of the single slope CMB and vehicle-rail interlock, as shown in Figures 21 and 22. The right-front bumper was crushed inward and deformed over its entire length, as shown in Figure 23. During the impact sequence, the right-front tire was deflated. In addition, the right-front steel rim was deformed due to localized contact with the lower thrie beam corrugation and pushed backward into the engine firewall, as shown in Figure 22. Minor deformation and scrapes were observed on the right-rear steel rim and rear bumper, as shown in Figure 21. Evidence of vehicle-rail interlock occurred over the entire length of the right-side of the pickup box, as shown in Figure 21. Figures 21 through 23 show the deformed engine hood with the right-side attaching hardware fractured. The front windshield was also fractured, as shown in Figures 23 and 24. Figures 25 through 27 show the severe occupant compartment deformation to the right-side and center of the floorboard as well as the transversely buckled and deformed front dashboard. The back vertical wall of the right-side of the truck compartment was also deformed, as shown in Figure 27. The deformation of the floorboard, dashboard, and the truck compartment walls was judged to be sufficient to cause injury to vehicle occupants. Other vehicle damage consisted of slight deformation to the left-front quarter panel. The frame and engine housing were also shifted toward the left, away from the longitudinal center line of the vehicle. Significant vehicle undercarriage damage is shown in Figures 28 and 29.

Seven measurements were made detailing the occupant compartment deformations throughout the truck cab's interior. The front dashboard was deformed upward approximately 152 mm (6 in.). Two measurements were taken adjacent to the longitudinal centerline of the floorboard. At the midpoint and at the firewall, the floor was pushed upward approximately 76 mm and 25 mm (3 in. and 1 in.), respectively. Two additional measurements were taken at the firewall located on the right-side of the vehicle, resulting in a maximum upward and downward firewall movement of 102 mm and 190 mm (4 in. and 7.5 in.), respectively. On the right-side floorboard, two measurements revealed that the floor was deformed downward approximately 108 mm (4.25 in.).

6.3 Barrier Damage

Damage to the barrier was moderate, as shown in Figures 30 through 39. Actual vehicle impact occurred midway between Post Nos. 5 and 6 in the thrie beam guardrail section, as shown in Figure 30. No damage occurred to the W-beam and the W-beam to thrie beam transition sections. Continuous contact marks were observed from the impact location through 279 mm (11 in.) from the downstream end of thrie beam terminal connector, as shown in Figures 30 and 34. Evidence of rail gouging was found on the lower corrugation of the thrie beam between Post Nos. 4 and 5, as shown in Figures 32 and 34. The permanent set of the guardrail and posts is shown in Figures 35 through 38. The maximum lateral permanent set deflection was approximately 127 mm (5 in.) at Post No. 3, as measured in the field. The maximum lateral dynamic deflection was 251 mm (9.9 in.) at Post No. 4, as determined from the high-speed film analysis. These maximum deflections are presented graphically in Figure 39.

The thrie beam terminal connectors on both sides of the single slope CMB were deformed. The single slope connector plate on the traffic-side face of the single slope CMB was deformed at the upstream end, as shown in Figure 31. The traffic-side spacer block at Post No. 2 was slightly deformed, as shown in Figure 36. No significant post deformation occurred except near the upper regions of Post Nos. 1 and 2, as shown in Figures 36 and 37.

The upstream end of the single slope CMB experienced concrete spalling along the vertical and top edges on the traffic-side face, as shown in Figure 31. Vehicle contact marks were evident on the top slope at the end of the CMB over the entire 22 in. No evidence of vehicle contact was found on the lower upstream end of the CMB. In addition, no barrier cracking was observed. However, the foundation shifted approximately 2 mm ($^1/_{16}$ in.) and 8 mm ($^5/_{16}$ in.) at the downstream and upstream ends of the longitudinal construction joint of the concrete foundation, respectively, as shown in Figure 40. It was judged that this movement did not significantly affect the performance of the approach guardrail transition.

6.4 Occupant Risk Values

The normalized longitudinal and lateral occupant impacmt velocities were determined to be 9.48 m/s (31.09 ft/s) and 8.14 m/s (26.70 ft/s), respectively. The maximum 0.010-sec average occupant ridedown decelerations in the longitudinal and lateral directions were 10.2 g's and 17.8 g's, respectively. The results of the occupant risk, determined from accelerometer data, are summarized in Figure 19. Results are shown graphically in Appendix D.

Figure 21. Vehicle Damage, Test MTSS-1

Figure 22. Vehicle Damage, Test MTSS-1 (Con't)

Figure 23. Vehicle Damage, Test MTSS-1 (Con't)

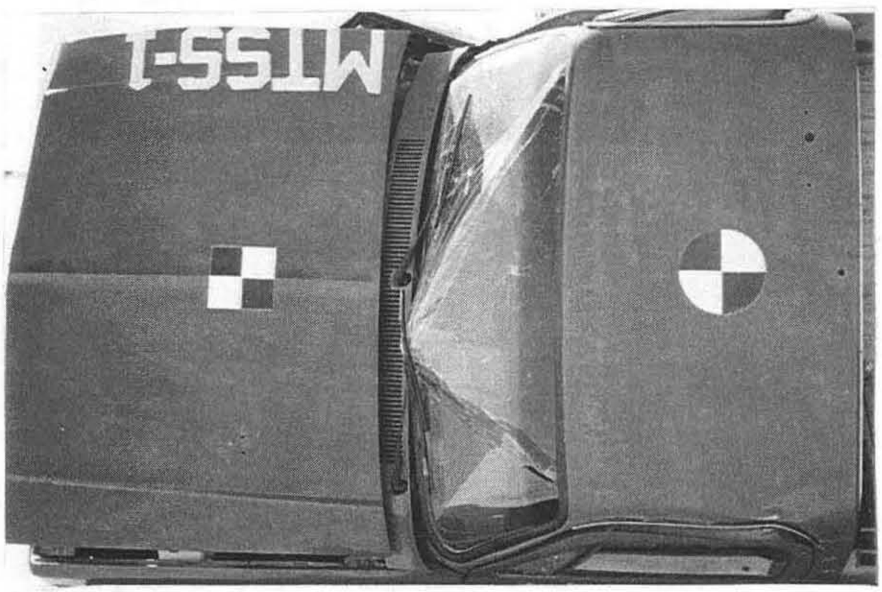


Figure 24. Front Windshield Damage, Test MTSS-1

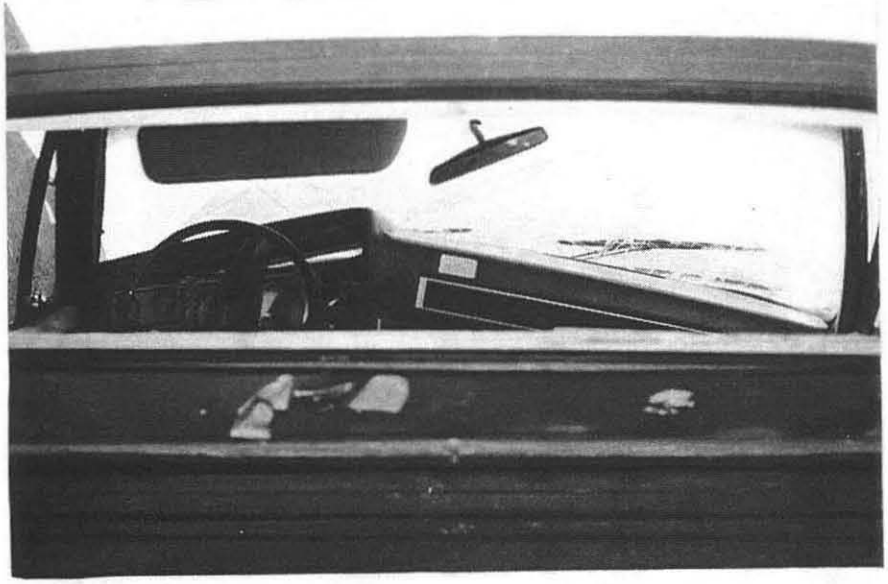


Figure 25. Front Dashboard Buckling, Test MTSS-1

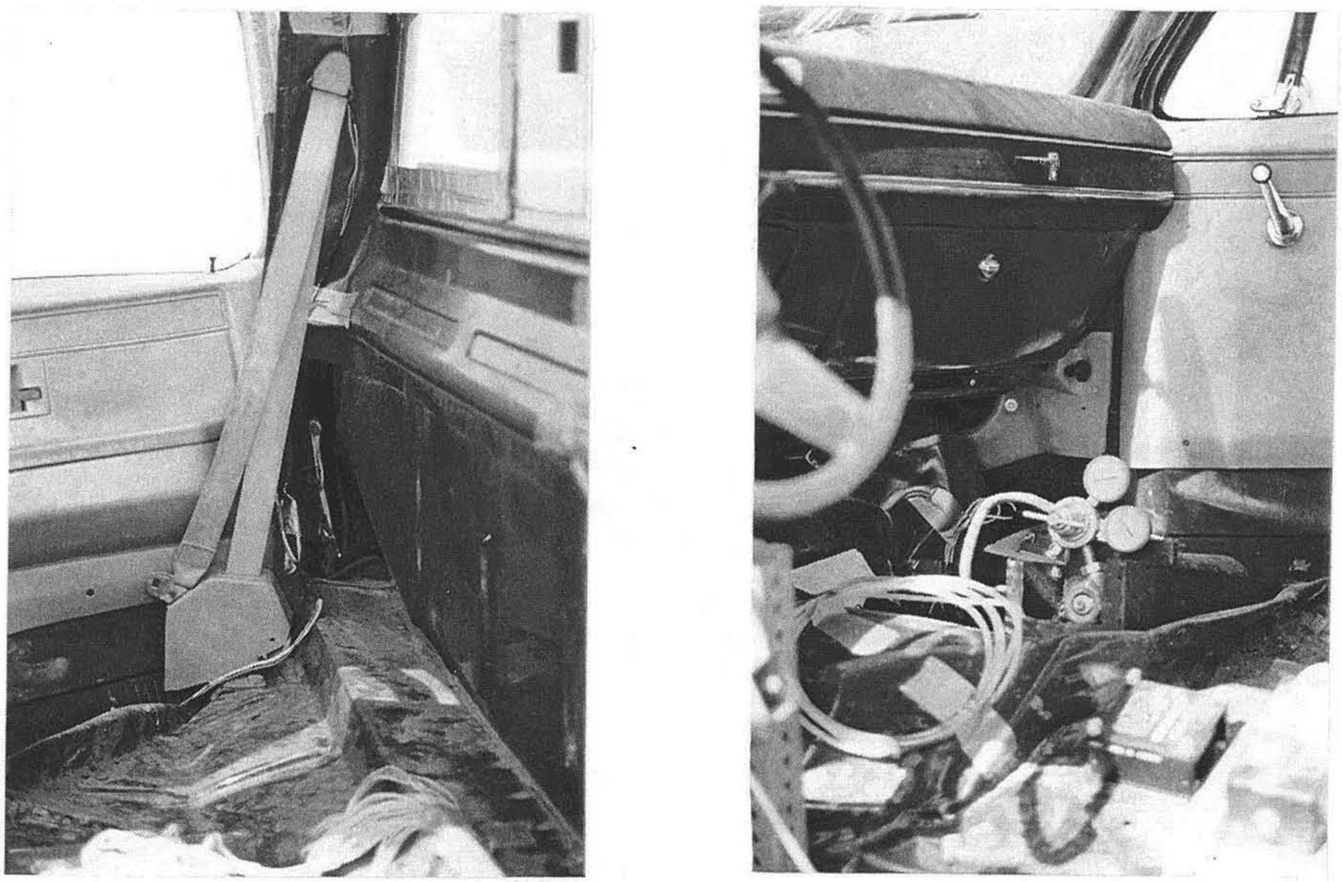


Figure 26. Occupant Compartment Deformation, Test MTSS-1

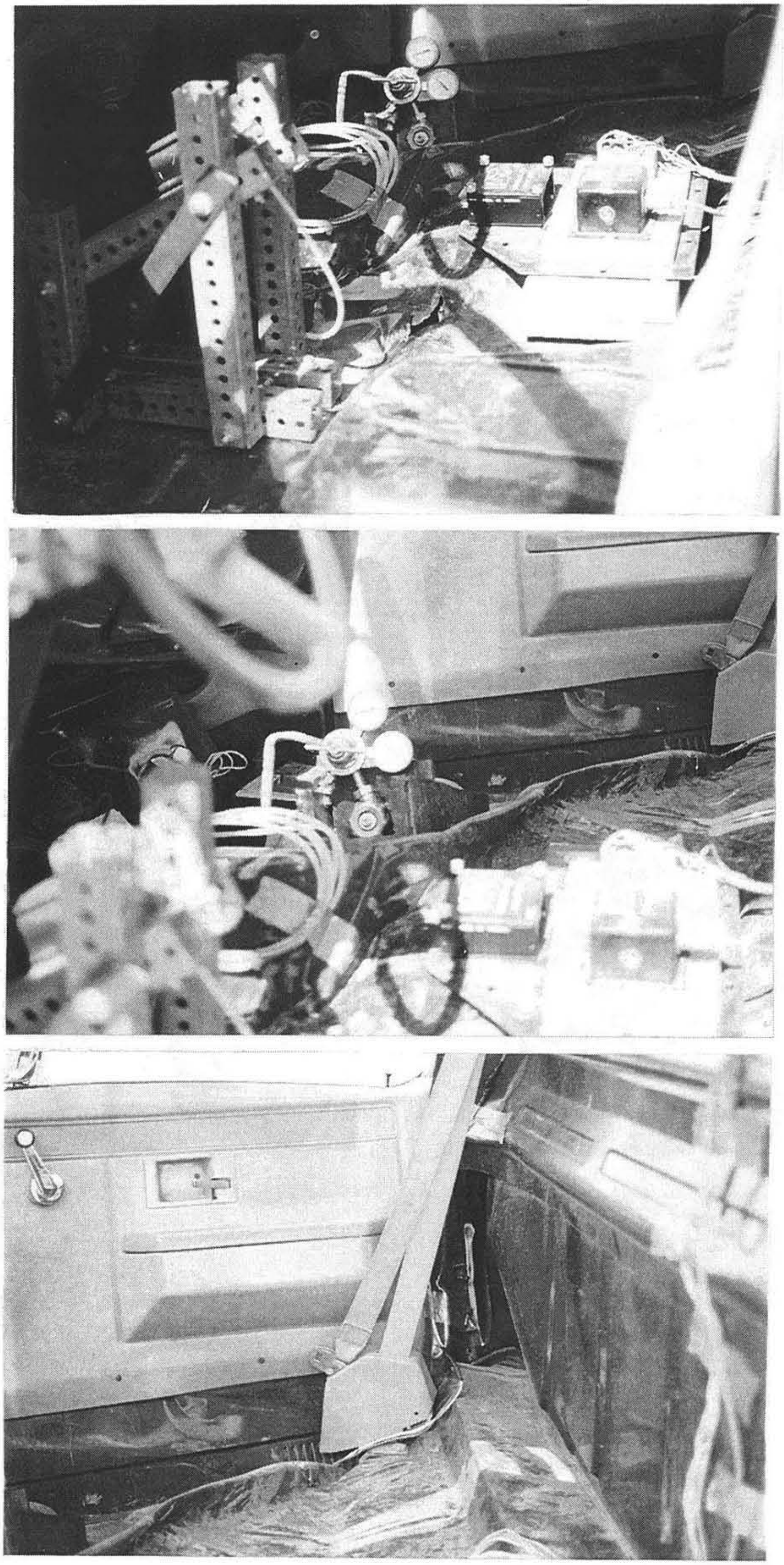


Figure 27. Occupant Compartment Deformation, Test MTSS-1 (Con't)

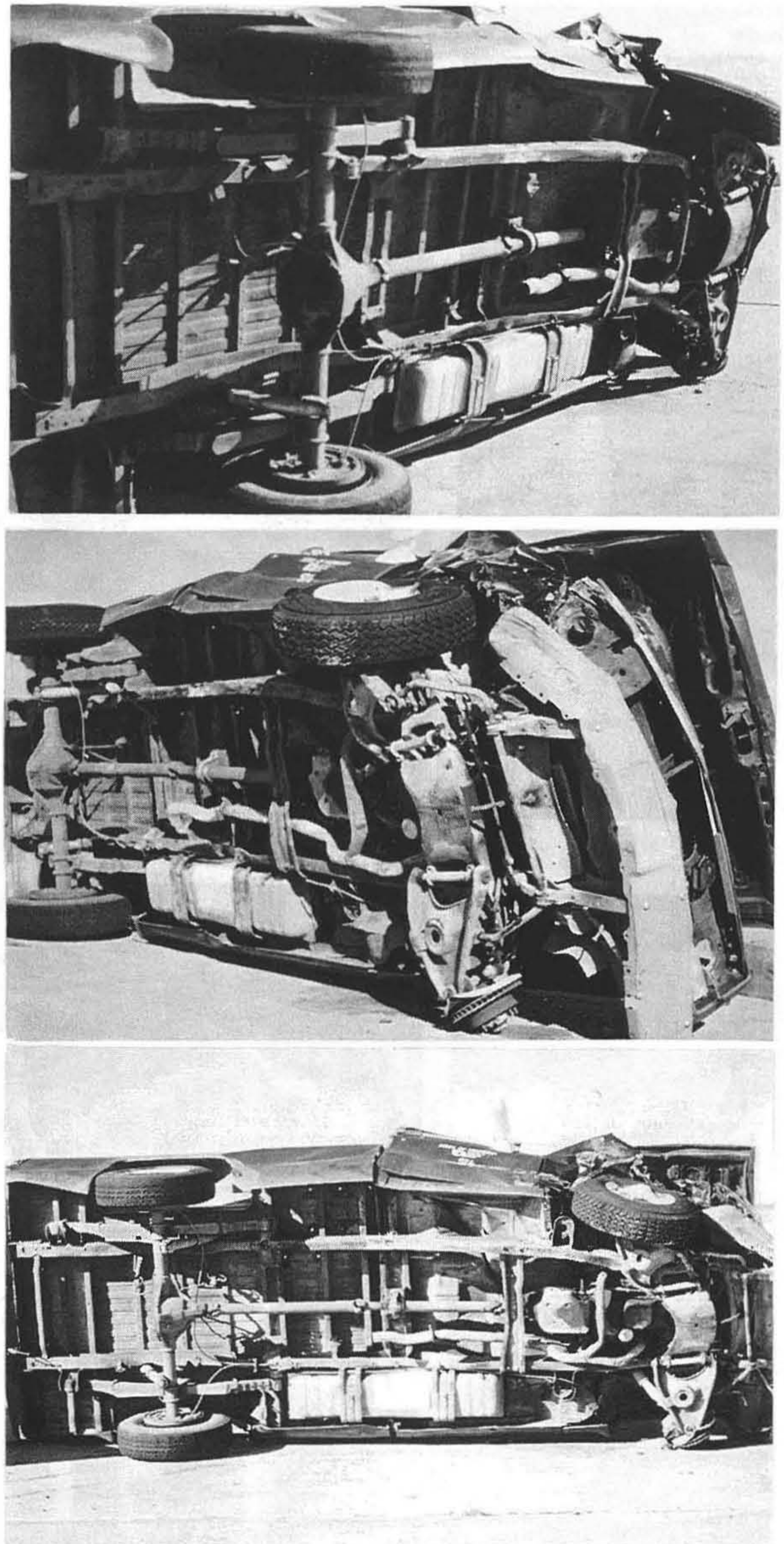


Figure 28. Vehicle Undercarriage Damage, Test MTSS-1

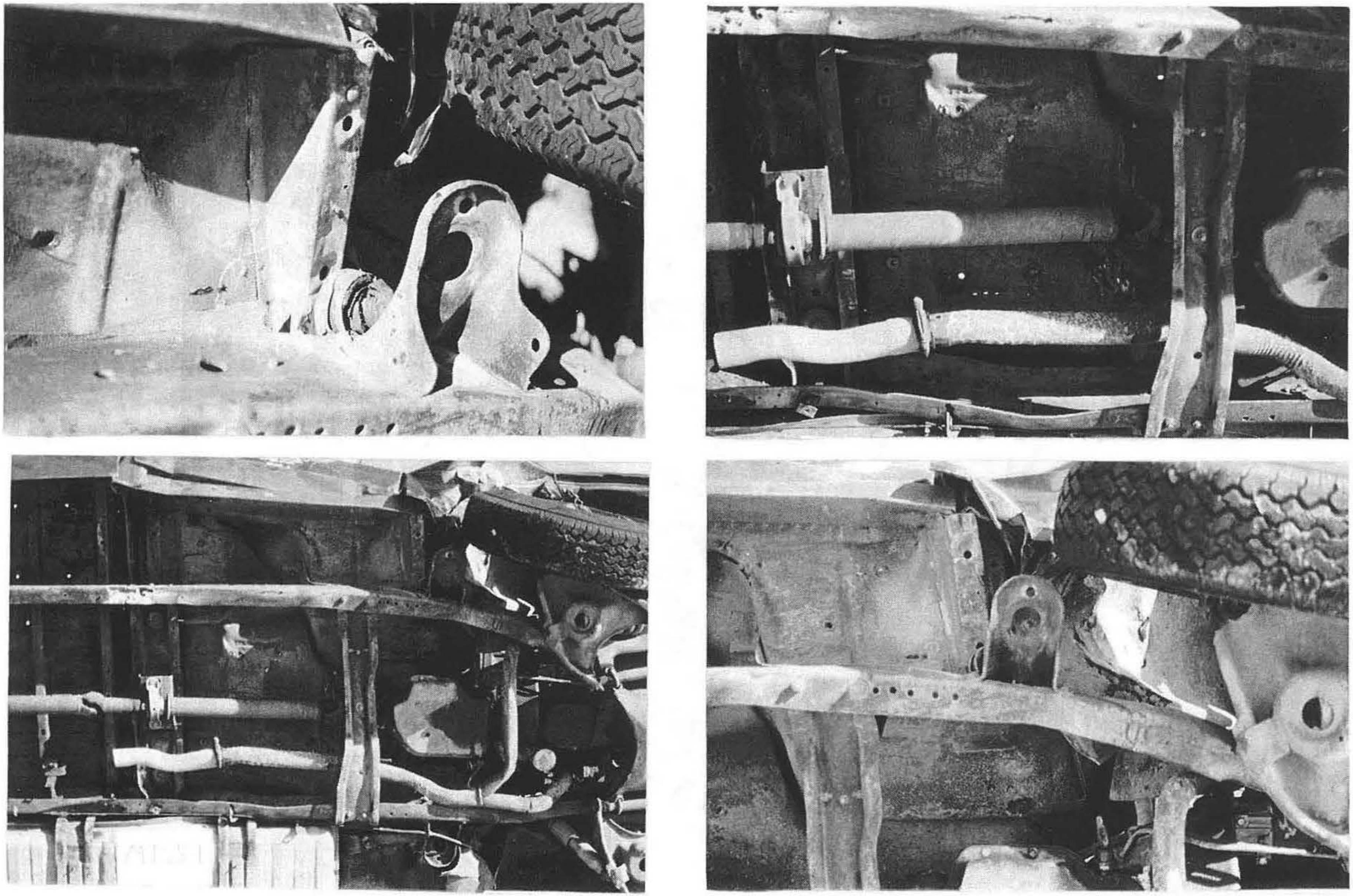


Figure 29. Frame Deformation, Test MTSS-1

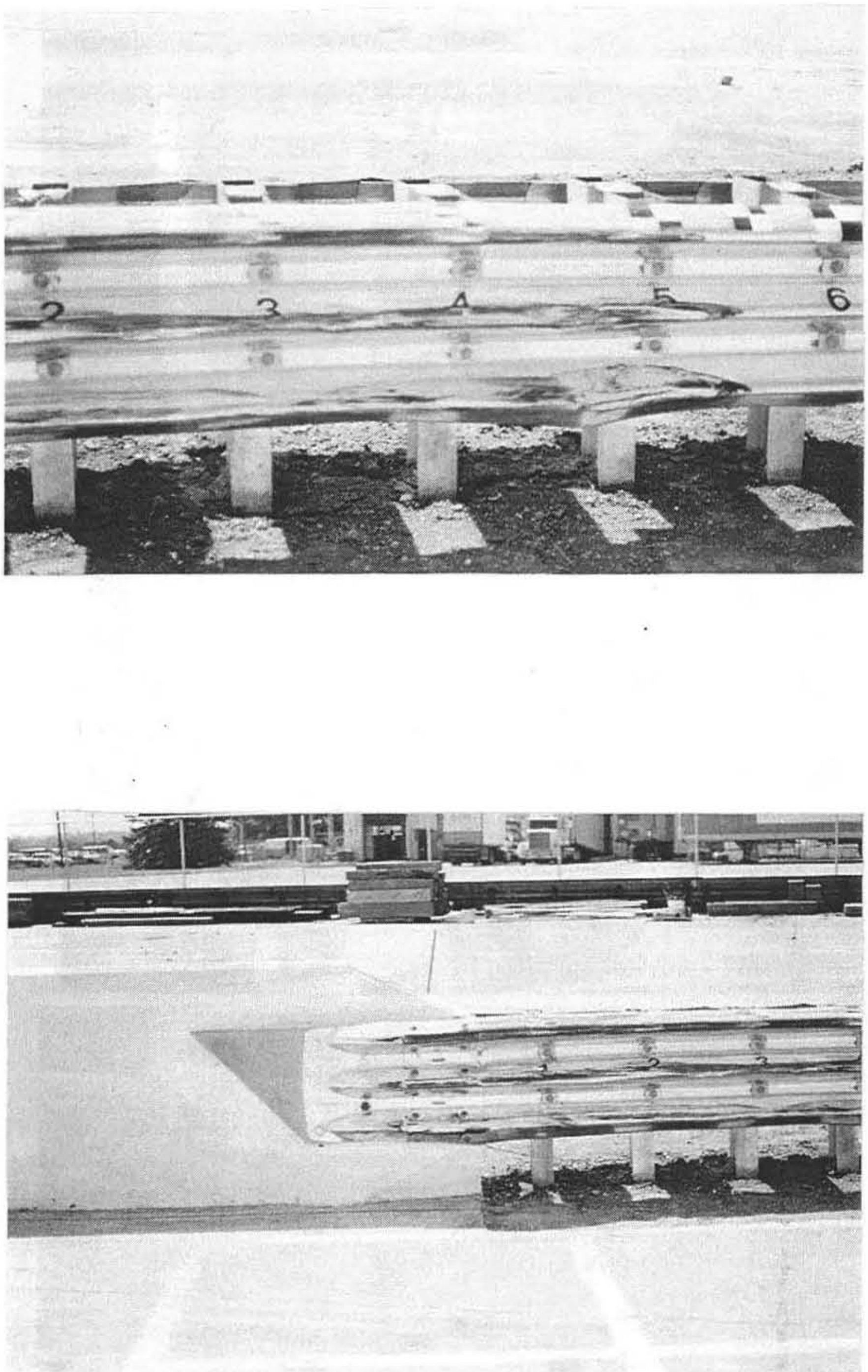


Figure 30. Approach Guardrail Transition Damage, Test MTSS-1

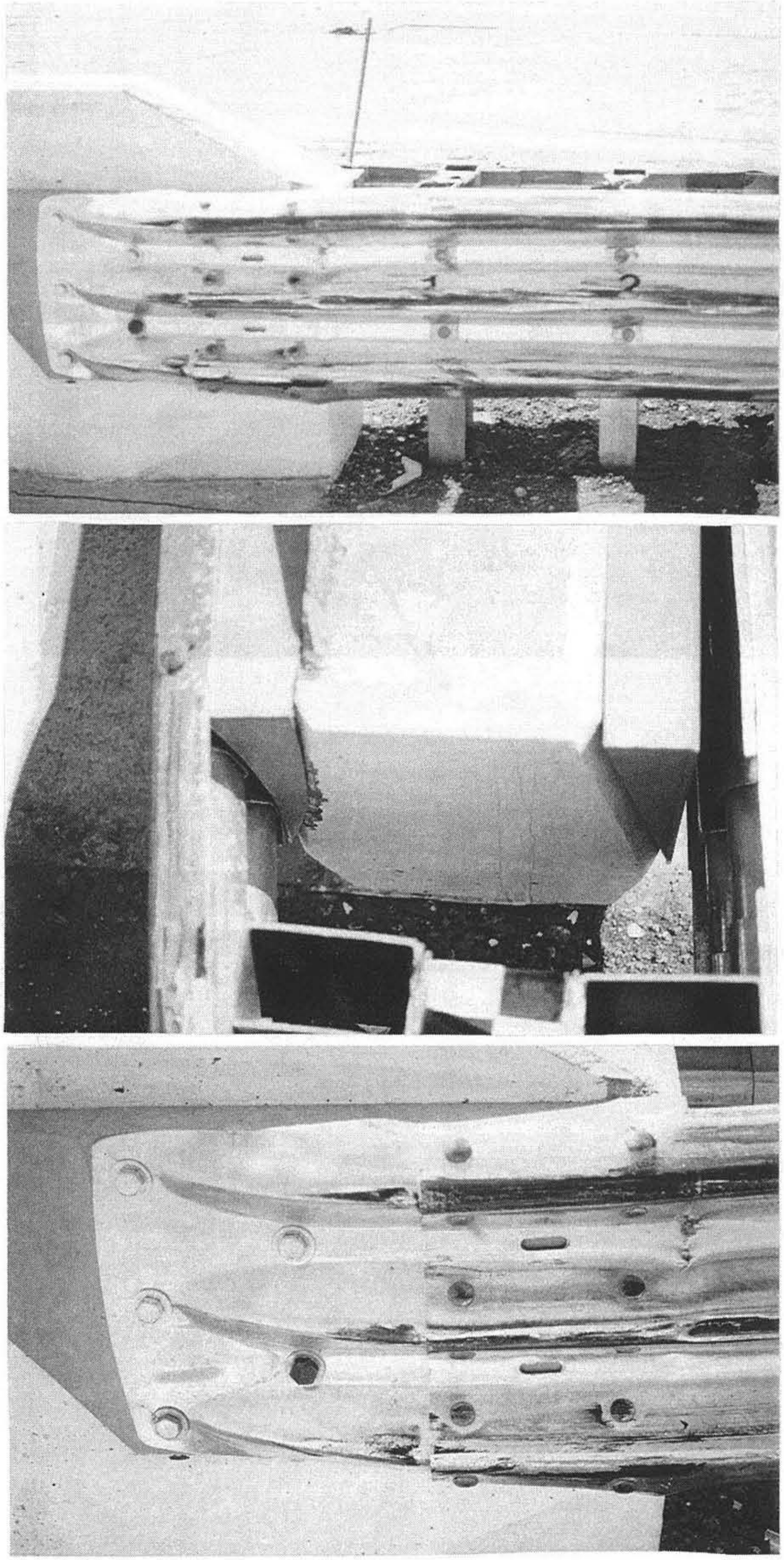


Figure 31. Approach Guardrail Transition Damage, Test MTSS-1 (Con't)

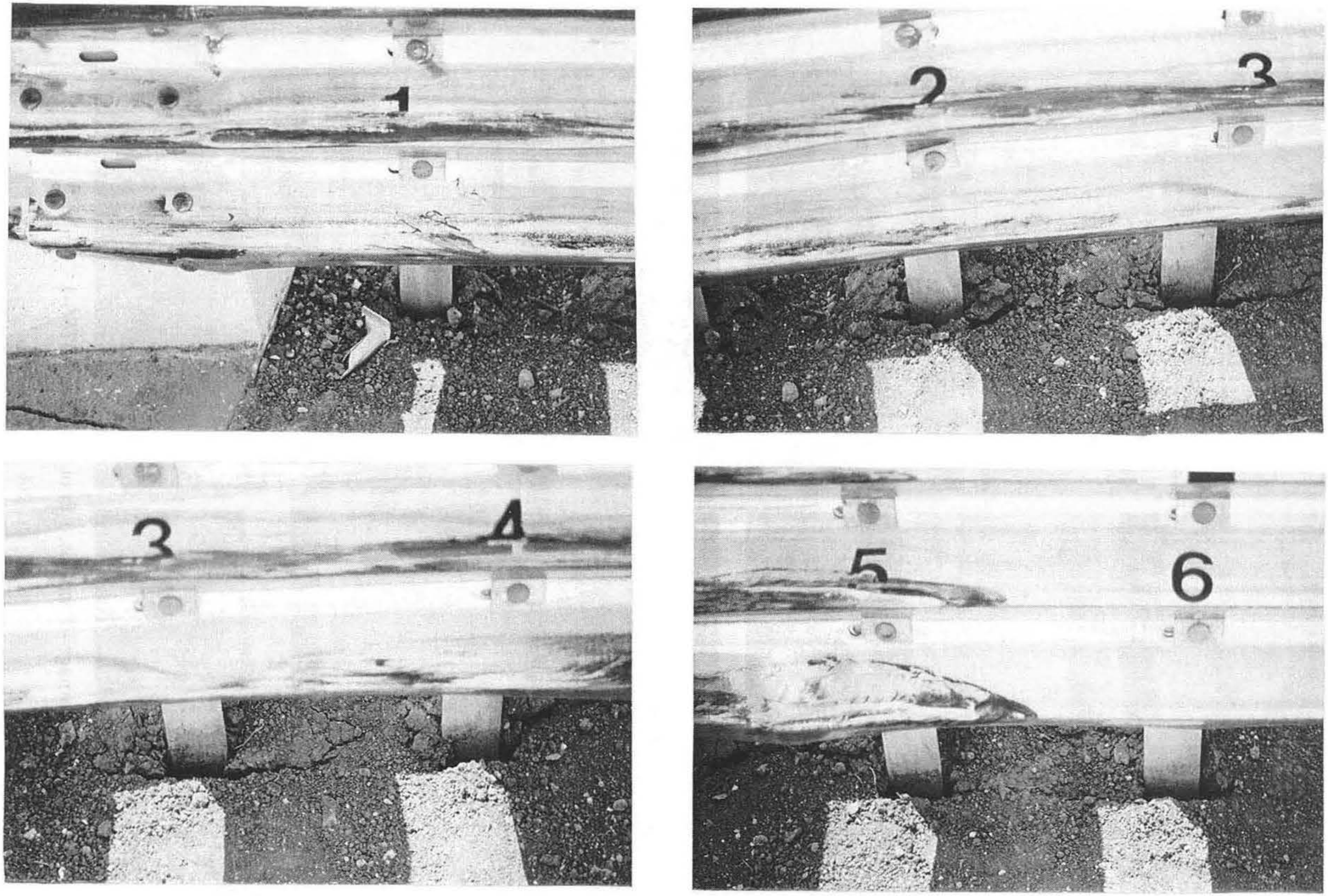


Figure 32. Thrie Beam Damage - Post Nos. 1 through 6, Test MTSS-1

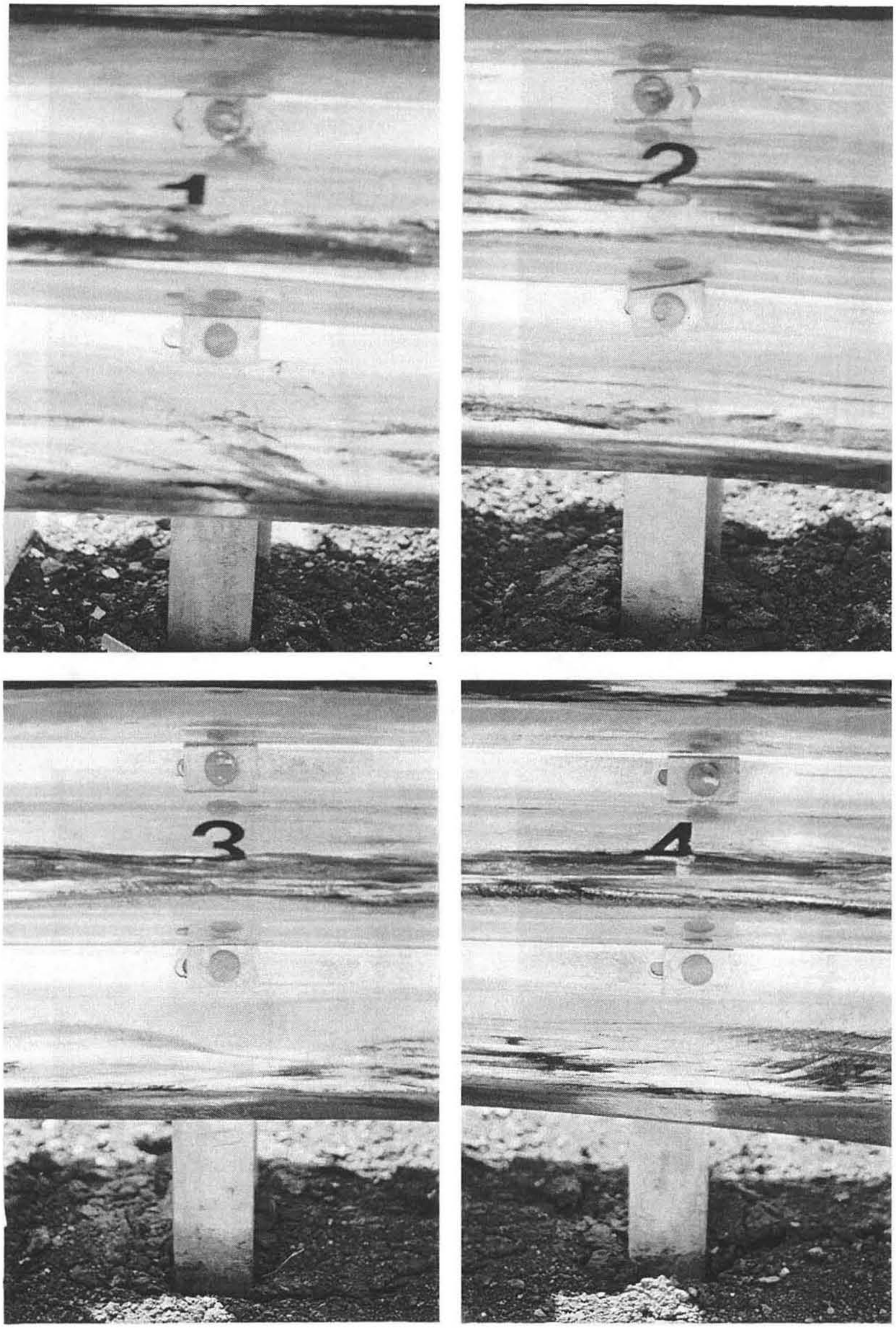


Figure 33. Thrie Beam Damage - Post Nos. 1 through 4, Test MTSS-1

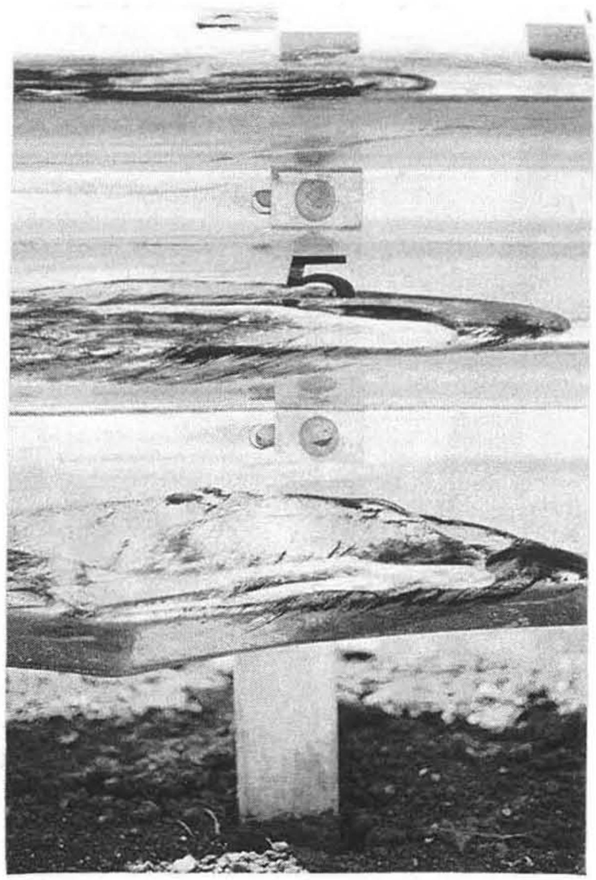


Figure 34. Thrie Beam Damage - Post No. 5, Test MTSS-1

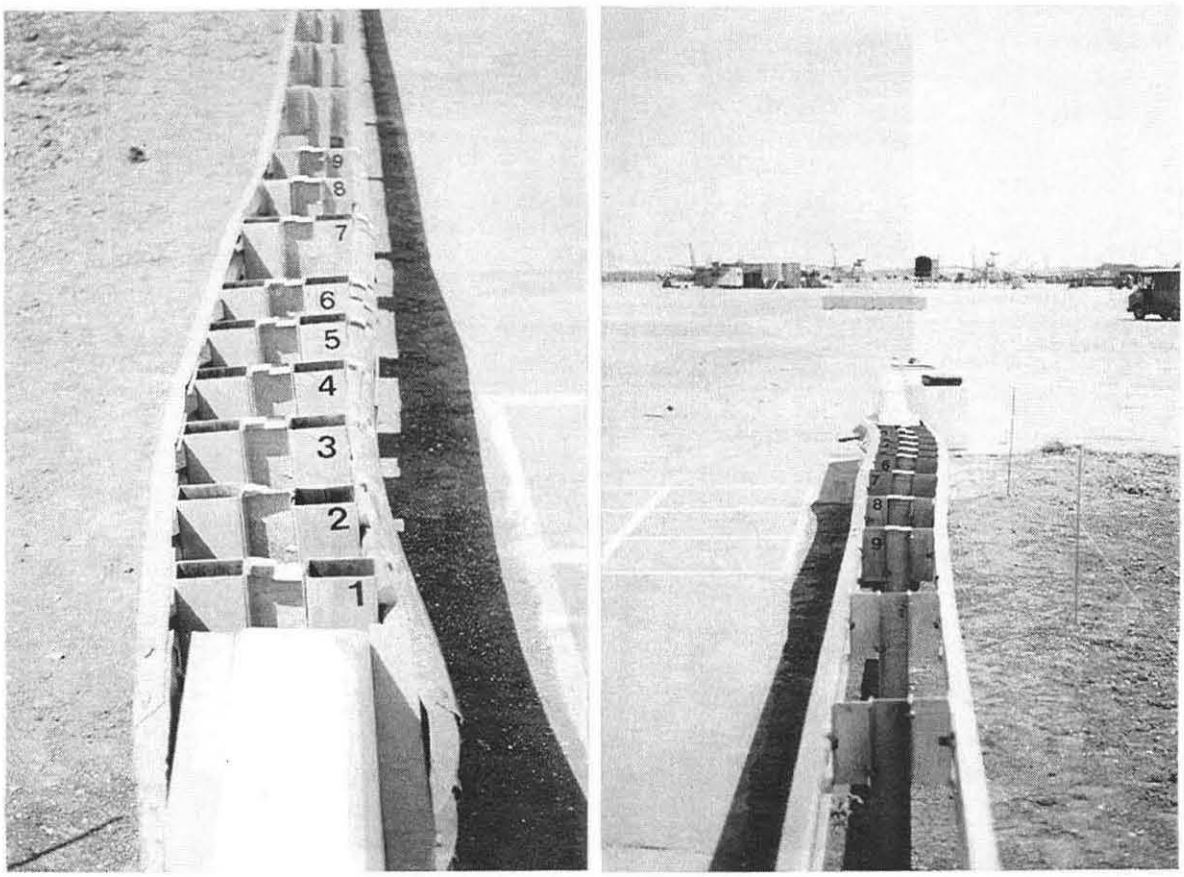


Figure 35. Permanent Set Deflection, Test MTSS-1

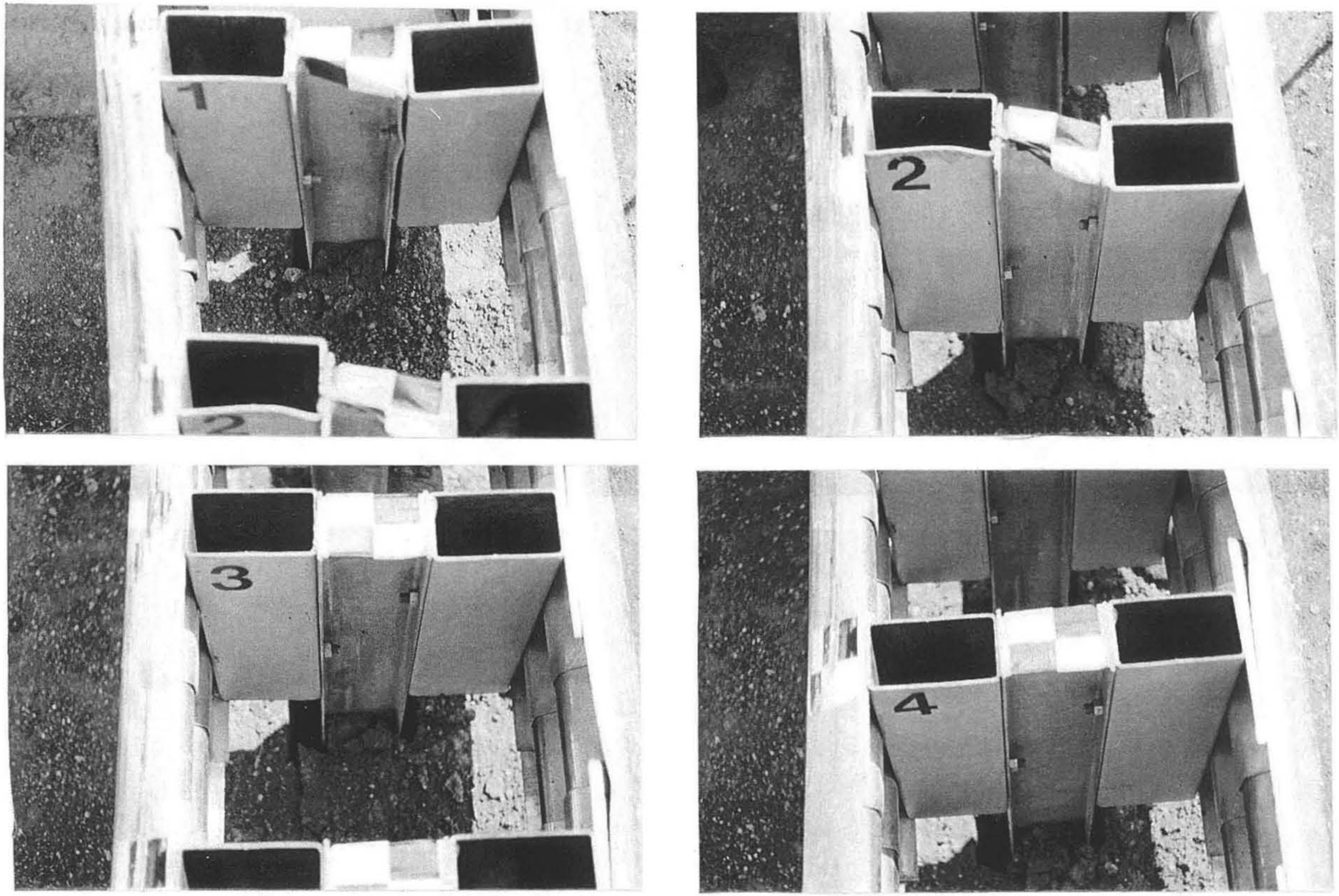


Figure 36. Permanent Set Deflections- Post Nos. 1 through 4, Test MTSS-1

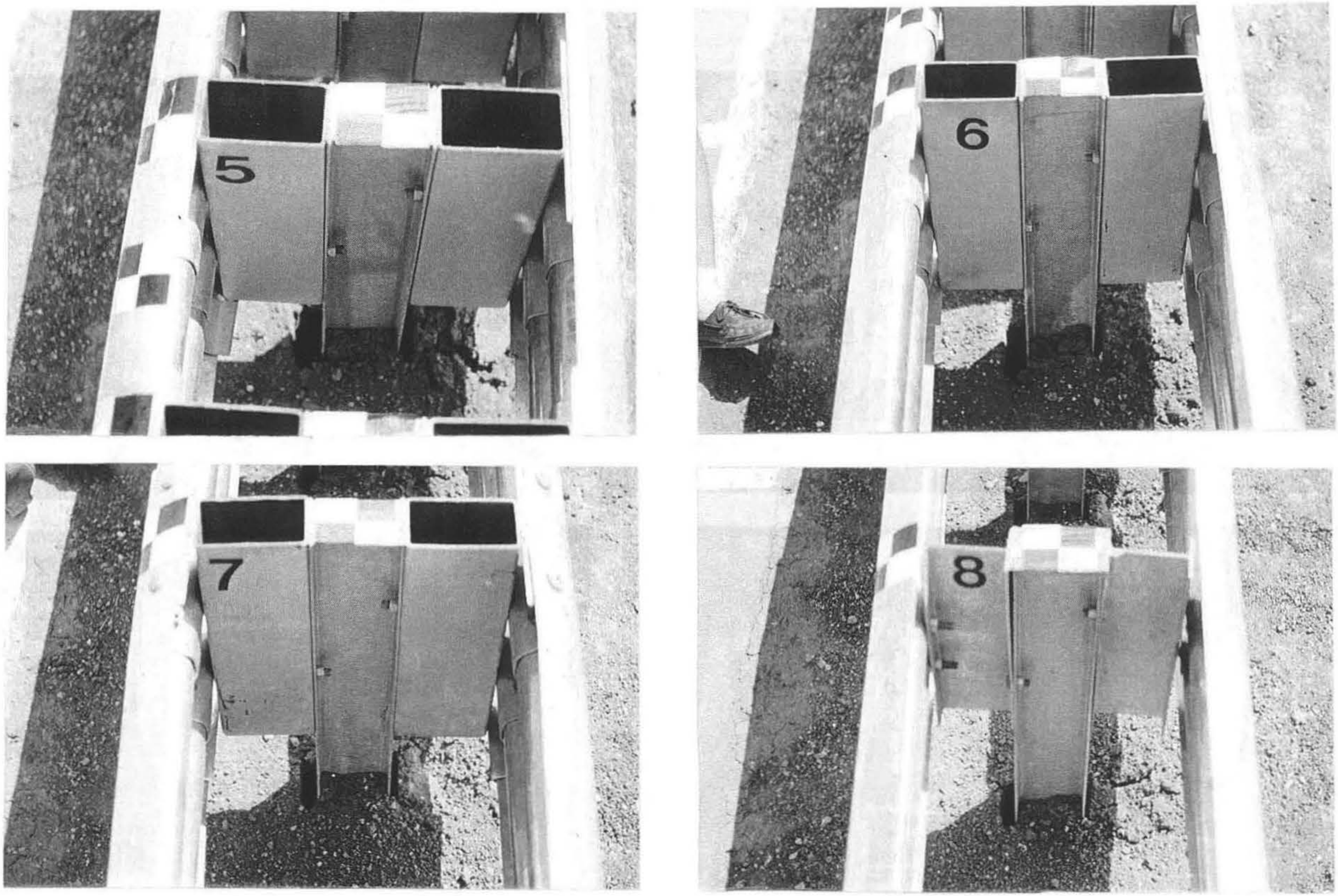


Figure 37. Permanent Set Deflections - Post Nos. 5 through 8, Test MTSS-1

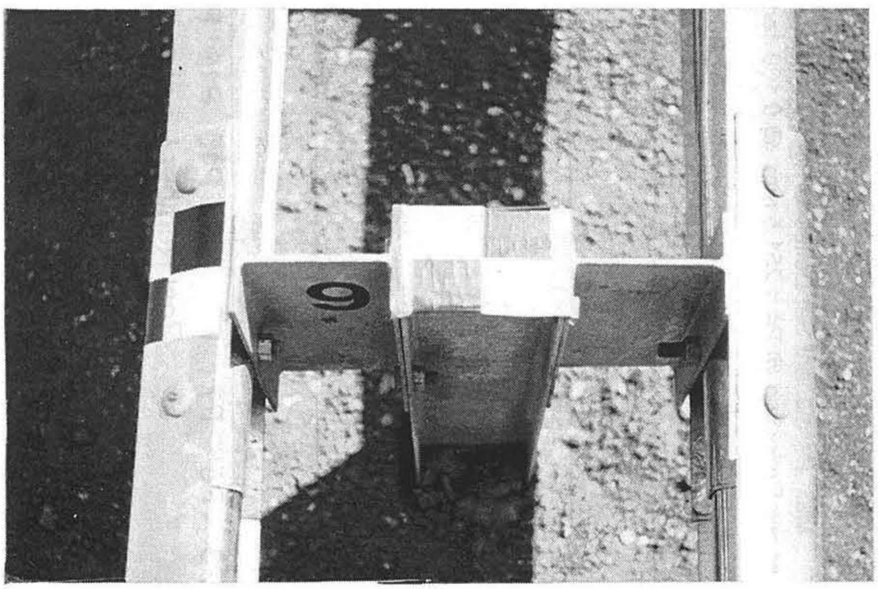


Figure 38. Permanent Set Deflections - Post No. 9, Test MTSS-1

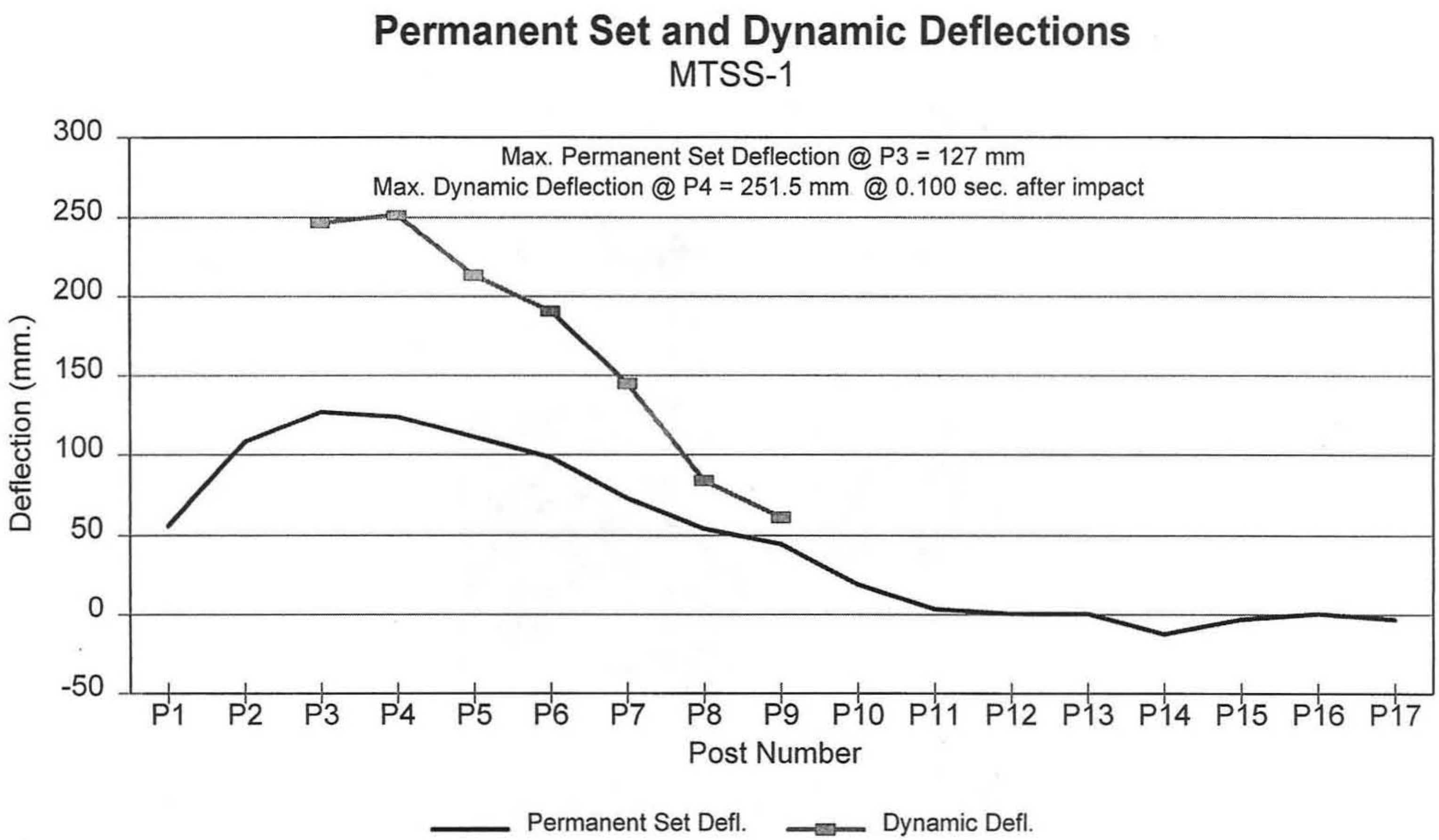


Figure 39. Permanent Set and Dynamic Deflections, Test MTSS-1

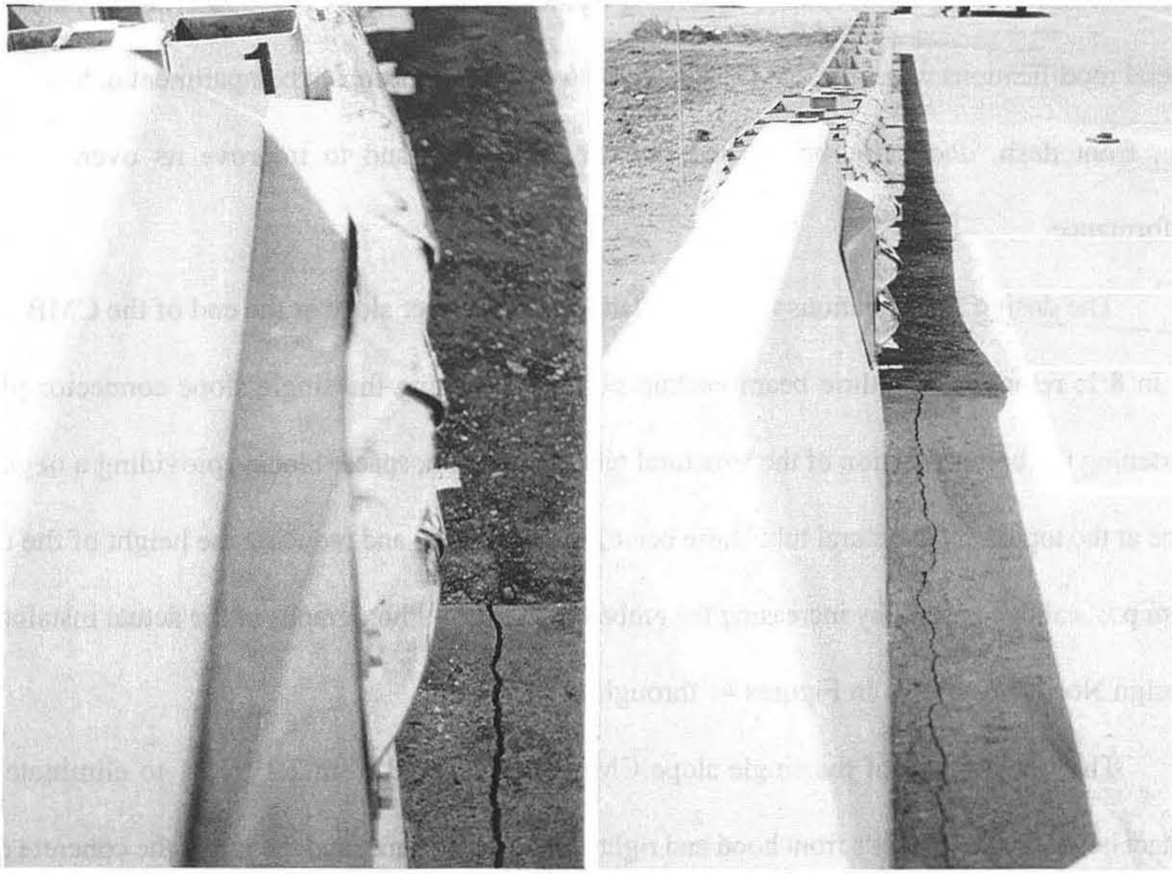


Figure 40. Cracking of Concrete Foundation, Test MTSS-1

7 APPROACH GUARDRAIL TRANSITION (DESIGN NO. 2)

Following test MTSS-1, a safety performance evaluation was conducted, and Design No. 1 was determined to be unacceptable according to the NCHRP Report No. 350 criteria. Therefore, several modifications were made to Design No. 1 to reduce the occupant compartment deformations (i.e., front dash, door, floorboard, and interior cab walls) and to improve its overall safety performance.

The design modifications included: flattening the upper slope at the end of the CMB from 2:1 to 8:1; removing the thrie beam backup plates; shortening the single slope connector plate; shortening the bottom section of the structural tube, thrie beam, spacer blocks; providing a negative slope at the top of the structural tube, thrie beam, spacer blocks; and reducing the height of the thrie beam posts above ground by increasing the embedment depth. Photographs of the actual installation (Design No. 2) are shown in Figures 41 through 43.

The upper slope of the single slope CMB was flattened from 2:1 to 8:1 to eliminate the contact between the vehicle's front hood and right-front quarter panel and the top of the concrete end-section, as shown in Figures 41, 44, and 45. The thrie beam backup plates, located at Post Nos. 1 through 6, were removed to reduce the flexural stiffness of the lower thrie beam corrugation and decrease the potential for the right-front wheel assembly to push inward into the floorboard of the occupant compartment. The length of the single slope connector plate was also reduced from 1,276 mm (50¼ in.) to 1,016 mm (40 in.) to decrease the plastic deformation at the upstream end of the connector plate and any potential for pocketing or snagging at the end of the single slope CMB, as shown in Figures 45 and 46.

The structural tube spacer blocks, located at Post Nos. 1 through 7, were shortened from 530-

mm (1-ft 8 $^7/_8$-in.) to 443-mm (1-ft 5 $^7/_{16}$-in.) long, reducing the spacer block length by 87 mm (3 $^7/_{16}$ in.), as shown in Figures 45, 47, and 48. The reduction in length was intended to allow the lower thrie corrugation to fold inward when impacted by the wheel hub. In addition, the top of the thrie beam spacer blocks were modified to include a negative slope over a vertical distance of 62 mm (2 $^7/_{16}$ in.). This change decreased the potential for contact between the front hood and quarter panel and the top of the thrie beam spacer blocks and posts. The embedment depth for Post Nos. 1 through 7 was also increased from 1,041 mm (41 in.) to 1,103 mm (43 $^7/_{16}$ in.), as shown in Figure 48.

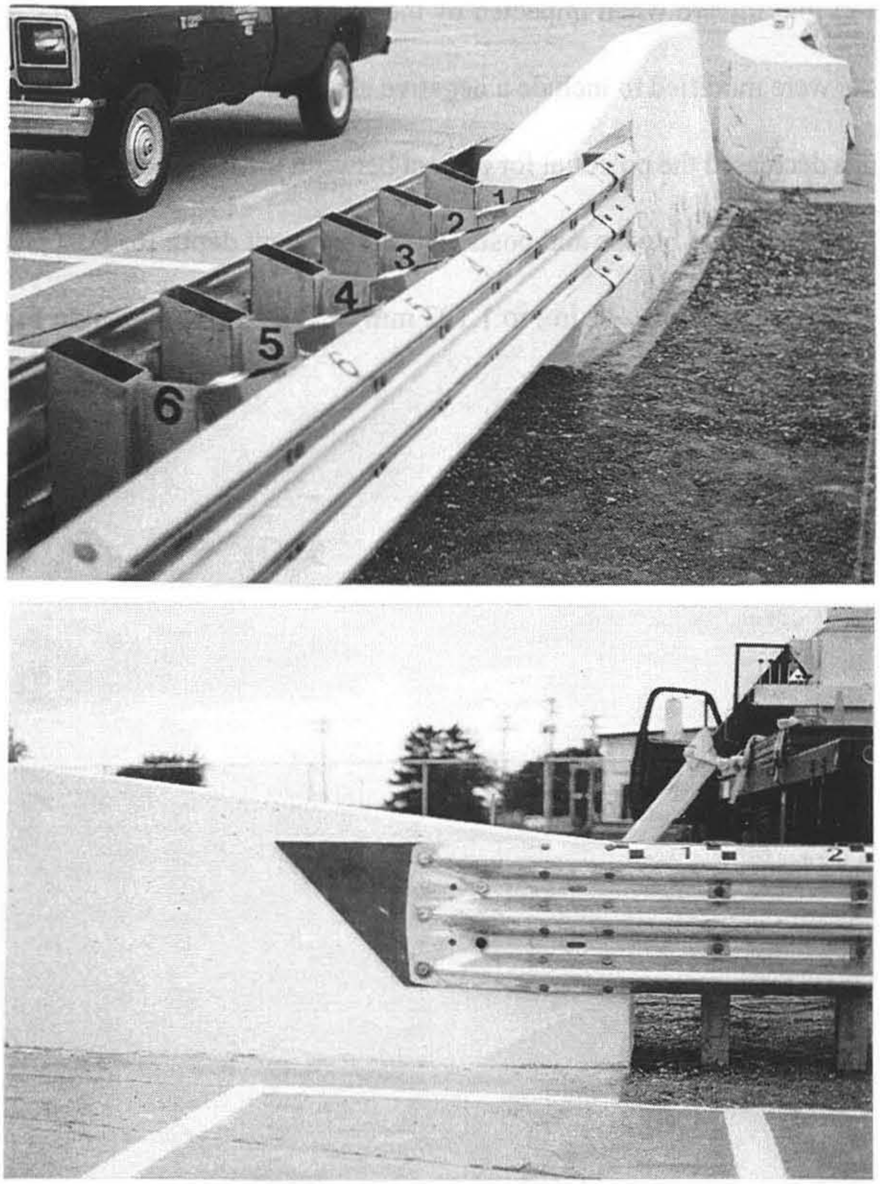


Figure 41. Approach Guardrail Transition, Design No. 2

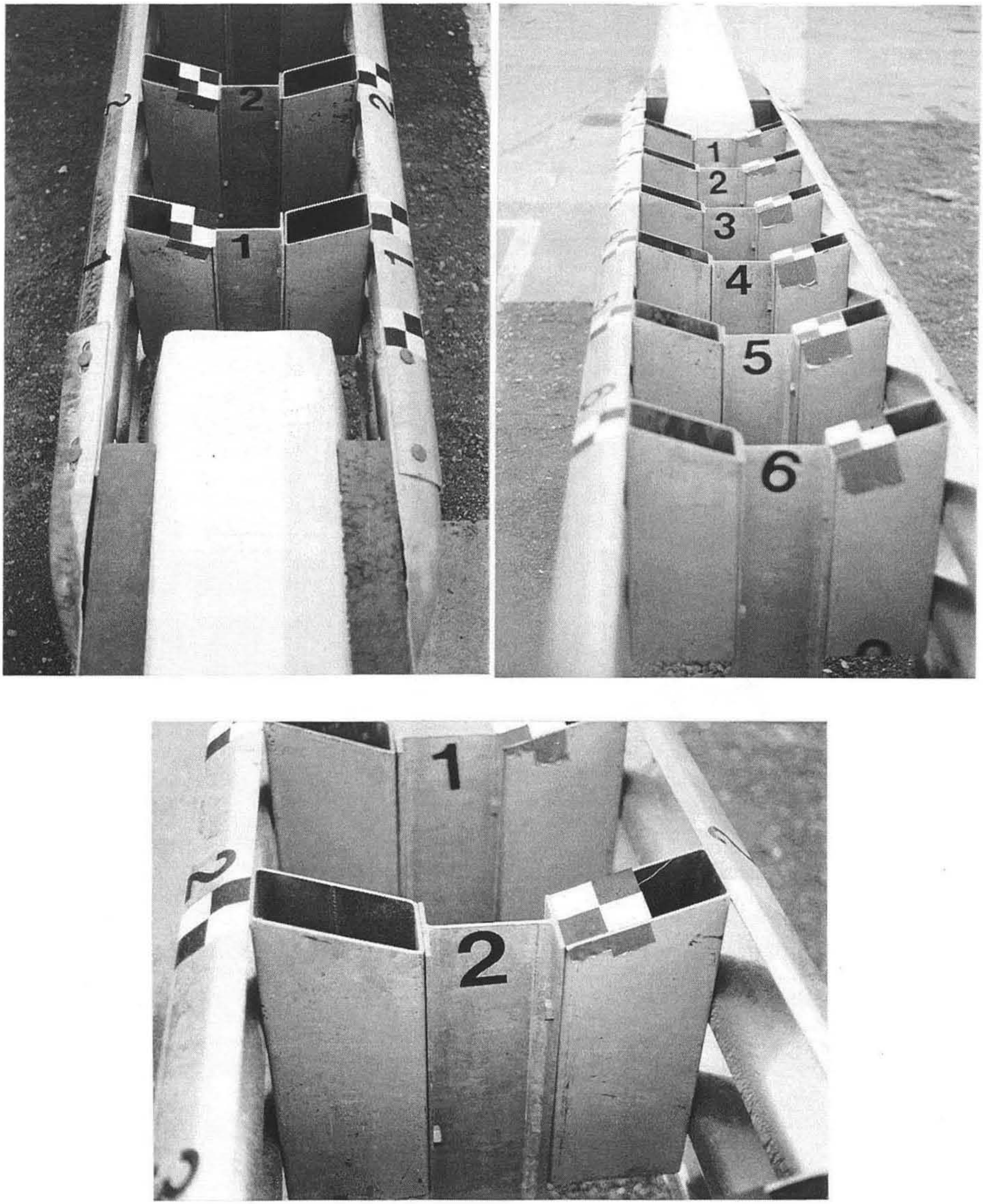


Figure 42. Approach Guardrail - Median Application, Design No. 2

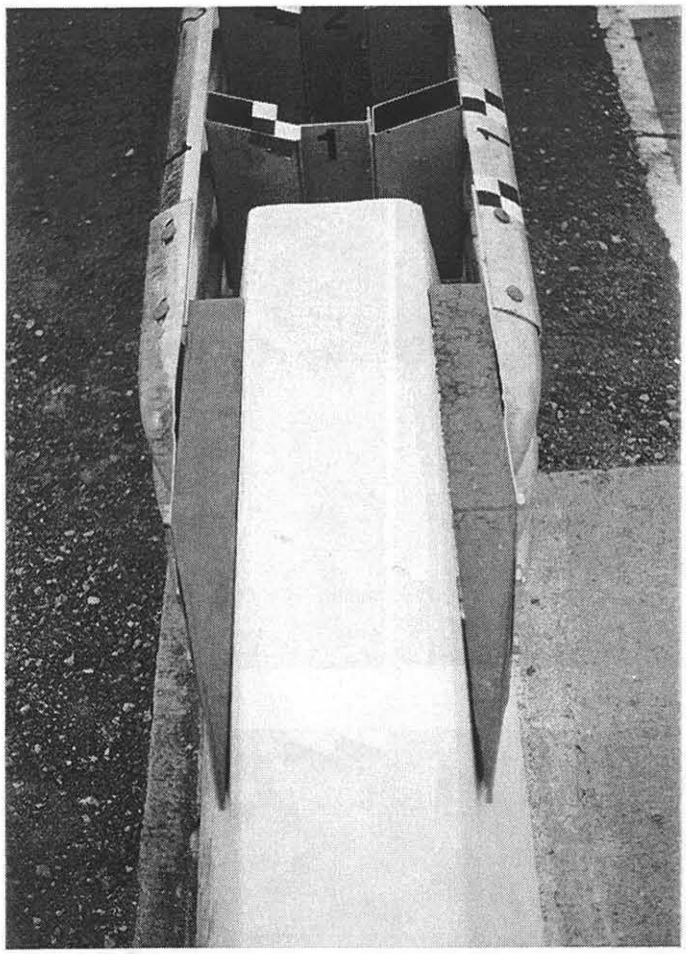
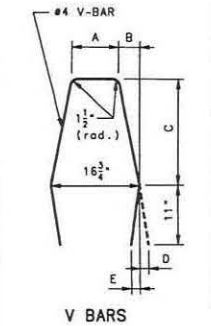
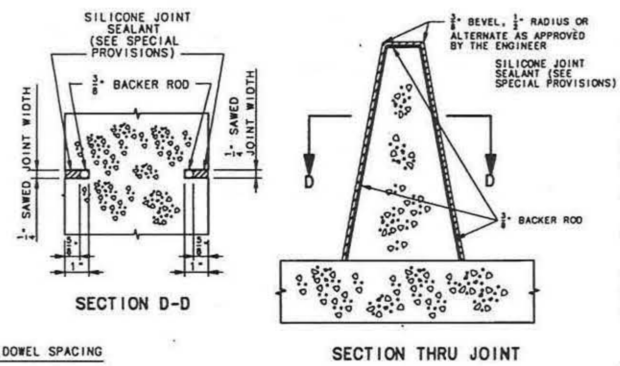


Figure 43. Single Slope End Section, Design No. 2



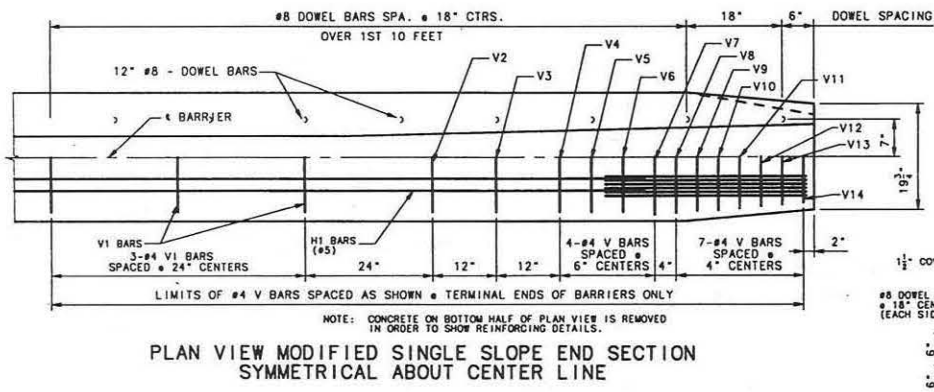
BAR DIMENSIONS OUT - OUT											
V BARS	A	B	C	D	E	V BARS	A	B	C	D	E
V1	5"	$5\frac{7}{8}$"	$29\frac{1}{2}$"	$2\frac{1}{8}$"	---	V8	8"	$4\frac{3}{8}$"	$21\frac{3}{4}$"	$2\frac{1}{8}$"	---
V2	$5\frac{3}{4}$"	$5\frac{1}{2}$"	$27\frac{1}{2}$"	$2\frac{1}{8}$"	---	V9	$8\frac{1}{8}$"	$4\frac{5}{16}$"	$21\frac{1}{4}$"	$2\frac{1}{8}$"	---
V3	$6\frac{3}{8}$"	$5\frac{3}{16}$"	26"	$2\frac{1}{8}$"	---	V10	$8\frac{3}{8}$"	$4\frac{3}{16}$"	$20\frac{3}{4}$"	$1\frac{3}{8}$"	---
V4	$6\frac{7}{8}$"	$4\frac{15}{16}$"	$24\frac{1}{2}$"	$2\frac{1}{8}$"	---	V11	$8\frac{1}{2}$"	$4\frac{1}{8}$"	$20\frac{1}{4}$"	$\frac{5}{8}$"	---
V5	$7\frac{1}{4}$"	$4\frac{3}{4}$"	$23\frac{3}{4}$"	$2\frac{1}{8}$"	---	V12	$8\frac{3}{4}$"	4"	$19\frac{3}{4}$"	---	$\frac{1}{4}$"
V6	$7\frac{1}{2}$"	$4\frac{5}{8}$"	23"	$2\frac{1}{8}$"	---	V13	$8\frac{7}{8}$"	4"	$19\frac{1}{4}$"	---	$\frac{7}{8}$"
V7	$7\frac{3}{4}$"	$4\frac{1}{2}$"	$22\frac{1}{4}$"	$2\frac{1}{8}$"	---	V14	$9\frac{1}{8}$"	$3\frac{13}{16}$"	$18\frac{3}{4}$"	---	$1\frac{5}{8}$"

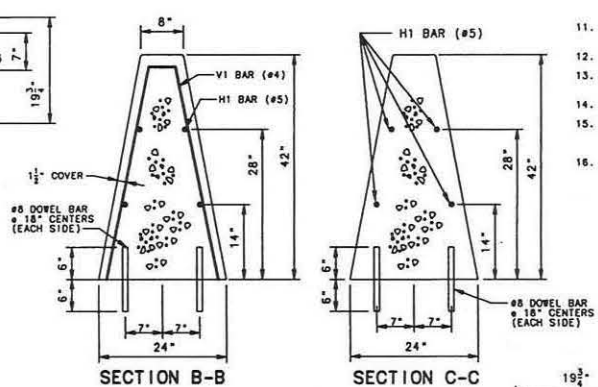


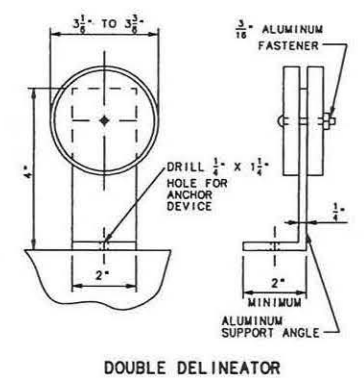
STATE	JOB NO.	SHEET NO.
MO		
DIST NO.	PROJECT NO.	ROUTE
	COUNTY	

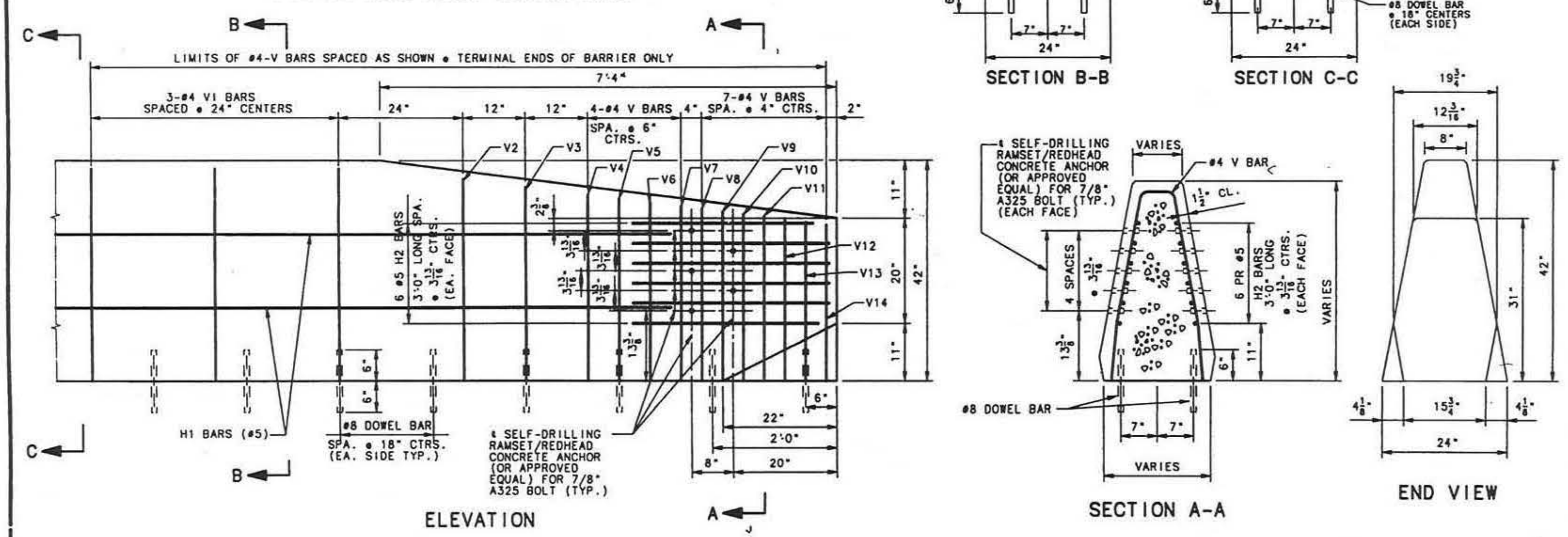
GENERAL NOTES

1. ALL CONCRETE AND REINFORCING STEEL SHALL CONFORM TO SECTION 617 OF THE MISSOURI STANDARD SPECIFICATIONS FOR HIGHWAY CONSTRUCTION.
2. CHAMFER TOP AND END EDGES 3/4 INCH.
3. BAR SPLICES FOR ROADWAY BARRIER SHALL BE A MINIMUM OF 24 TIMES THE NOMINAL DIAMETER OF THE BAR.
4. ANY METHOD DEVISED BY THE CONTRACTOR AND APPROVED BY THE ENGINEER THAT WILL ASSURE THE LONGITUDINAL ROADWAY STEEL WILL BE POSITIONED +/- 1/2 INCH AS DIMENSIONED WILL BE SATISFACTORY.
5. THE CONTRACTOR HAS THE OPTION TO SLIP-FORM THE BARRIER, IN WHICH CASE, ADDITIONAL REINFORCEMENT MAY BE TIED TO THE UPPER TWO-THIRDS OF THE REINFORCING CAGE TO PROVIDE BRACING.
6. THIS BARRIER SHALL NOT BE USED TO SUPPORT HIGHWAY LIGHTING POLES.
7. THIS BARRIER IS NOT TO BE USED FOR BRIDGE ROADWAY APPLICATIONS.
8. DELINEATORS TO BE MOUNTED ON MEDIAN BARRIERS SHALL BE YELLOW WHERE THE BARRIER IS ON THE LEFT IN THE DIRECTION OF TRAFFIC; SHALL BE WHITE WHERE THE BARRIER IS ON THE RIGHT IN THE DIRECTION OF TRAFFIC; AND SHALL BE DOUBLE YELLOW WHERE THE BARRIER IS IN THE MEDIAN WITH TRAFFIC IN EACH DIRECTION.
9. ALL MATERIALS FOR SUPPORTING DELINEATORS SHALL BE ALUMINUM EXCEPT ANCHOR DEVICES.
10. ANCHOR DEVICES FOR DELINEATORS SHALL BE EITHER ALUMINUM OR GALVANIZED STEEL AND SHALL BE EXPANSIVE BOLTS OR ADHESIVE SELF-GROUTING BOLTS. IF GALVANIZED STEEL BOLTS ARE USED, A NON-CONDUCTIVE WASHER SHALL BE USED BETWEEN THE ALUMINUM ALLOY SUPPORT ANGLE AND THE HEAD OF THE BOLT.
11. DELINEATORS SHALL HAVE A MAXIMUM OF 100' SPACING FOR A 0° TO 2°45' CURVE AND 60' MAXIMUM SPACING FOR A 3° TO 6° CURVE.
12. NO DIRECT PAYMENT IS MADE FOR DELINEATORS.
13. THE COST OF SILICONE JOINT SEALANT AND BACKER ROD COMPLETE IN PLACE IS TO BE INCLUDED IN THE CONTRACT UNIT PRICE FOR BARRIER CURB.
14. LOCATE SAWED JOINTS AT 30'-0" CENTERS, MAXIMUM.
15. ALL REINFORCING STEEL SHALL BE GRADE 60 EPOXY-COATED IN ACCORDANCE WITH SECTION 1036 OF THE MISSOURI STANDARD SPECIFICATIONS FOR HIGHWAY CONSTRUCTION.
16. NO DIRECT PAYMENT WILL BE MADE FOR FURNISHING, GROUTING AND INSTALLING 12"-#8 DEFORMED BARS.









MISSOURI HIGHWAY AND TRANSPORTATION COMMISSION

CONCRETE TRAFFIC BARRIER

MODIFIED TYPE C

WITH THRIE BEAM ANCHOR ATTACHMENT

SPECIAL SHEET

SHEET 1 OF 3

Figure 44. Modified Single Slope Design Details, Design No. 2

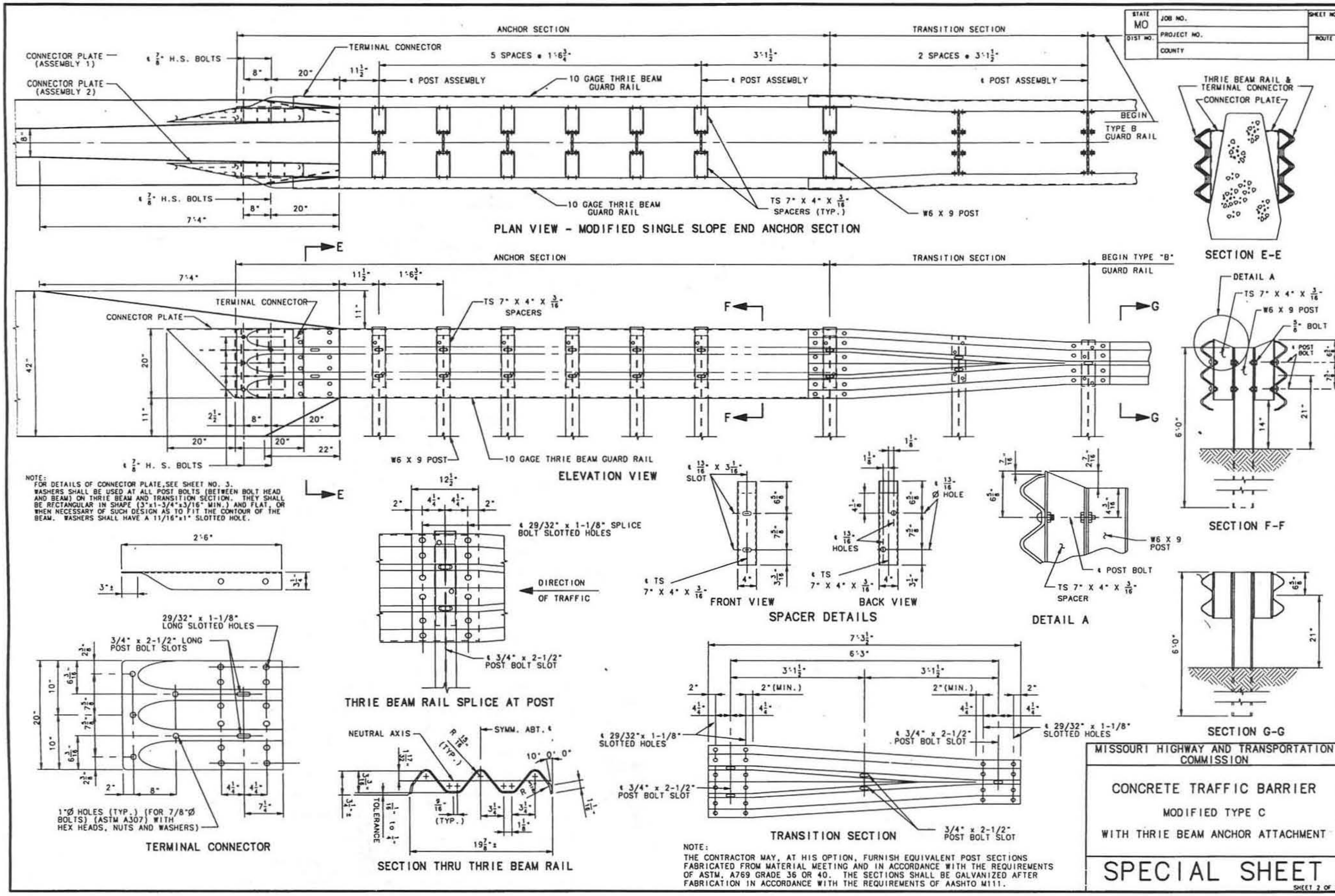
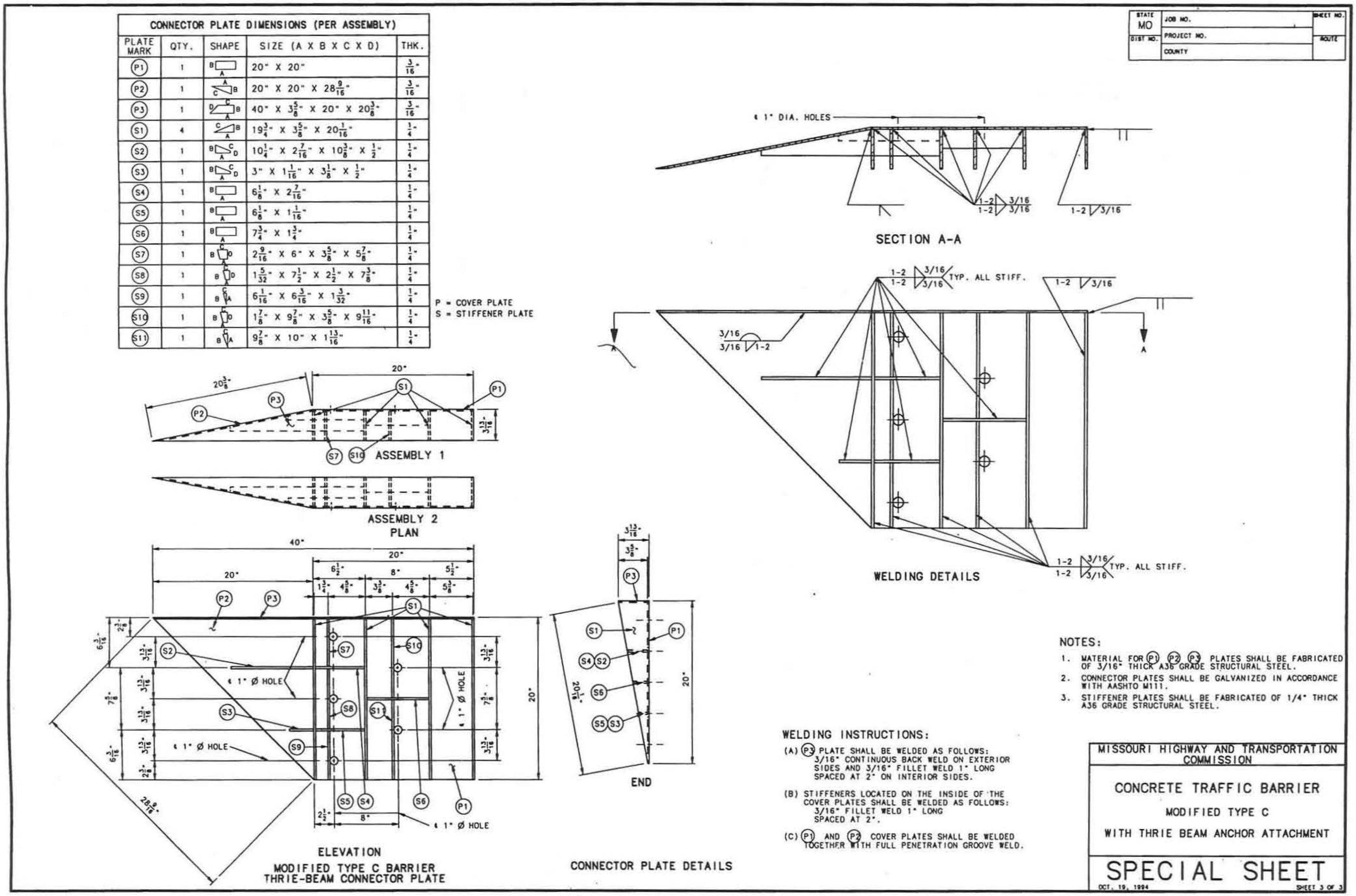


Figure 45. Modified Single Slope End Anchor Design, Design No. 2



CONNECTOR PLATE DIMENSIONS (PER ASSEMBLY)				
PLATE MARK	QTY.	SHAPE	SIZE (A X B X C X D)	THK.
P1	1		20" X 20"	3/16"
P2	1		20" X 20" X 28 9/16"	3/16"
P3	1		40" X 3 5/8" X 20" X 20 3/8"	3/16"
S1	4		19 3/4" X 3 5/8" X 20 1/16"	1/4"
S2	1		10 1/4" X 2 7/16" X 10 3/8" X 1/2"	1/4"
S3	1		3" X 1 1/16" X 3 1/8" X 1/2"	1/4"
S4	1		6 1/8" X 2 7/16"	1/4"
S5	1		6 1/8" X 1 1/16"	1/4"
S6	1		7 3/4" X 1 3/4"	1/4"
S7	1		2 9/16" X 6" X 3 5/8" X 5 7/8"	1/4"
S8	1		1 5/32" X 7 1/2" X 2 1/2" X 7 3/8"	1/4"
S9	1		6 1/16" X 6 3/16" X 1 3/32"	1/4"
S10	1		1 7/8" X 9 7/8" X 3 5/8" X 9 11/16"	1/4"
S11	1		9 7/8" X 10" X 1 13/16"	1/4"

Figure 46. Single Slope Connector Plate Design, Design No. 2

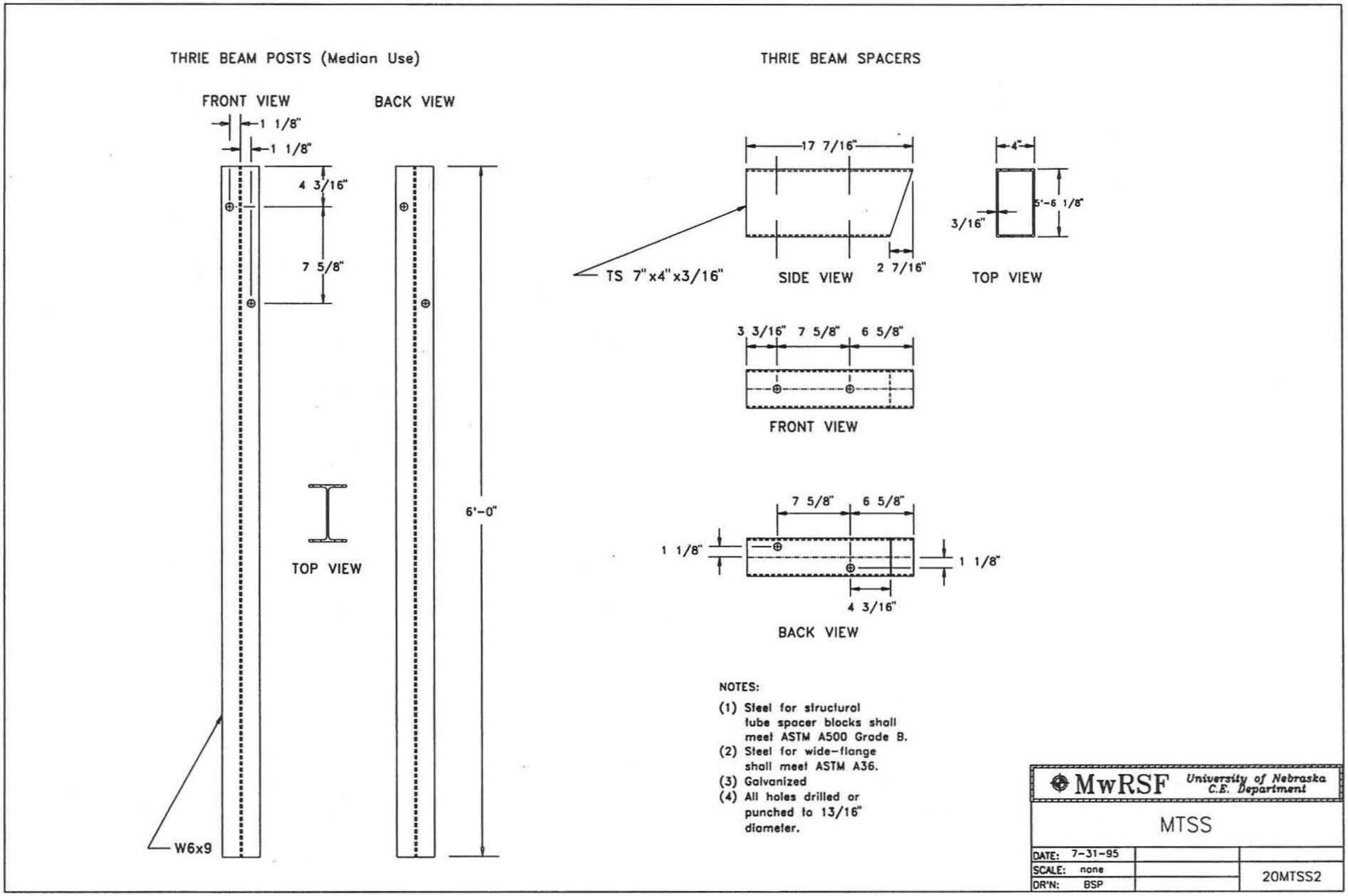


Figure 47. Thrie Beam Post and Spacer Details, Design No. 2

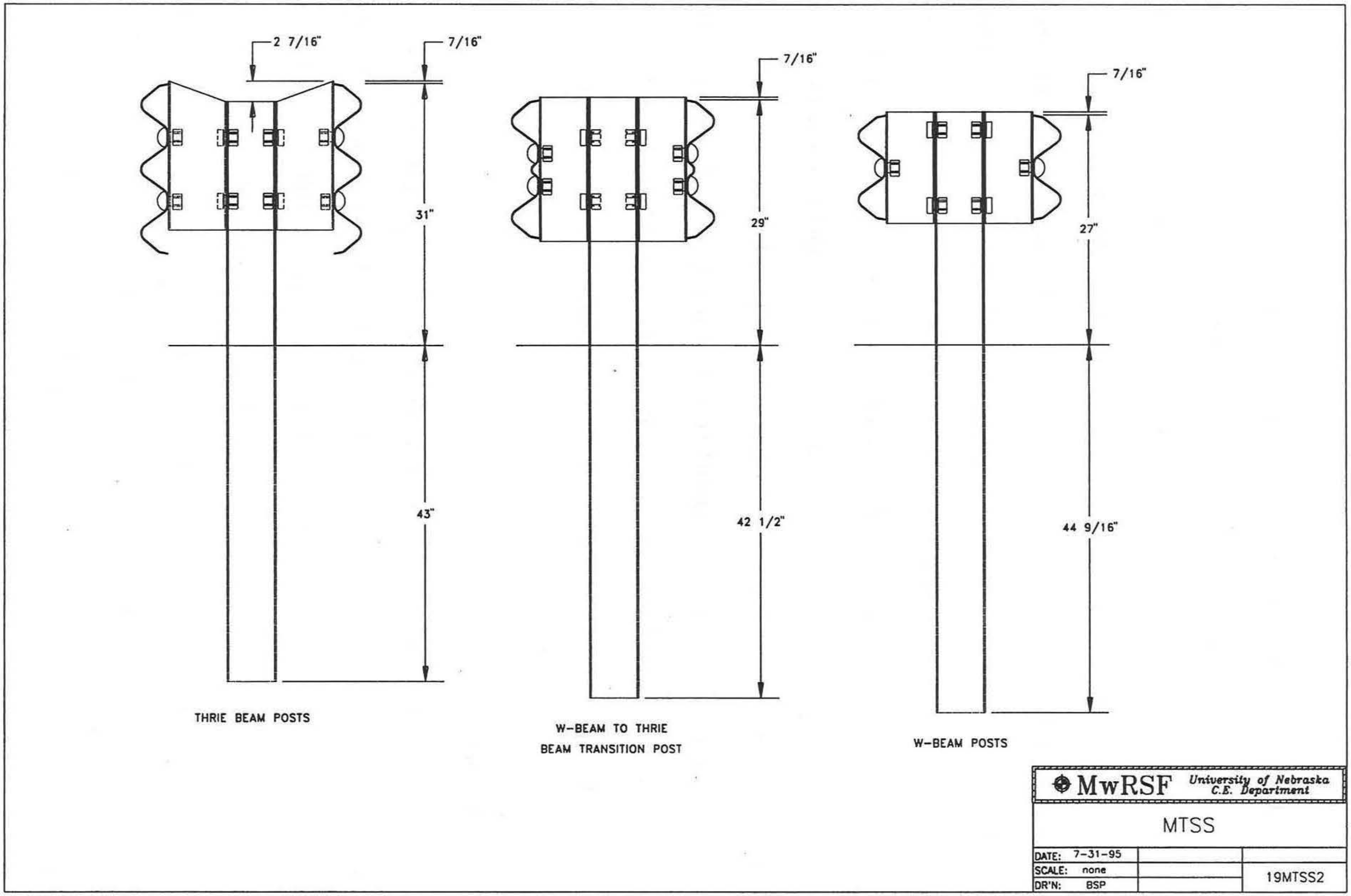


Figure 48. Post and Spacer Details, Design No. 2

8 TEST MTSS-2 (2,034 kg (4,484 lbs), 92.5 km/h (57.5 mph), 28.7 deg)

Test MTSS-2 impacted the approach guardrail transition attached to the single slope CMB approximately 3.08 m (10 ft - 1¼ in.) from the upstream end of the CMB (Figures 49 and 50). A summary of the test results and the sequential photographs is presented in Figure 51. Additional sequential photographs are shown in Figure 52. Documentary photographs of the crash test are shown in Figures 53 and 54. It is noted that technical difficulties were encountered near the end of the vehicle tow process, causing the actual impact conditions of 92.5 km/h and 28.7 degrees to deviate slightly from the target impact conditions of 100.0 km/h and 25 degrees. Although the actual impact conditions for test MTSS-2 deviated slightly from the target impact conditions, the actual impact severity (or a measure of the severity of the impact) of 155.5 kJ (114.7 kip-ft) was greater than the nominal impact severity of 138.3 kJ (102.0 kip-ft). Therefore, it was judged that test MTSS-2 was a valid indicator of the barrier's performance. Prior to testing, the CMB and foundation were realigned and compacted on the back-side to prevent foundation movement from occurring during the retest.

8.1 Test Description

After the initial impact with the approach guardrail transition, the right-front corner of the bumper and quarter panel crushed inward. At 0.040 sec, the right-front corner of the vehicle coincided with Post No. 5, while the grill and hood were disengaged. At 0.062 sec, the right-front corner of the vehicle coincided with Post No. 4, and the left-front wheel started to steer to the right. At 0.083 sec and 0.105 sec, the right-front corner of the vehicle was near Post Nos. 3 and 2, respectively. The maximum dynamic rail deflection of 193 mm (7.6 in) was observed at Post No. 3 at 0.119 sec. At 0.127 sec, the right-front corner of the vehicle was at Post No. 1 and at the upstream end of the single slope CMB at 0.143 sec. At 0.169 sec and 0.190 sec, the left-front and left-rear wheels lost contact with the ground, respectively. The vehicle became parallel to the transition at 0.298 sec with a velocity of 55.6 km/h (34.6 mph). At 0.324 sec, the right-front corner of the vehicle was at the downstream end of the single slope CMB. At 0.427 sec, the rear-end of the vehicle was at the upstream end of the CMB. The vehicle exited the system at approximately 0.456 sec after impact at a speed of 54.7 km/h (34.0 mph) and an angle of 9.8 degrees. The vehicle's post test trajectory is shown in Figure 51. The vehicle came to rest approximately 23.8 m (78 ft) downstream from impact and 5.5 m (18 ft) laterally in front of a line projected parallel to the traffic-side face of the rail.

8.2 Vehicle Damage

Vehicle damage was moderate and occurred to several body locations, including the right-side door and quarter panels, front and rear bumpers, right-front wheel and rim, engine hood, windshield, occupant compartment, and steel frame, as shown in Figures 55 through 60. The right-side door was deformed and has evidence of the vehicle-rail interlock, as shown in Figures 55 and 56. The right-front quarter panel received deformation due to contact with the top of the spacer blocks and/or posts and vehicle-rail interlock, as shown in Figures 55 and 56. The right-front bumper was crushed inward, and the center bumper region was buckled, as shown in Figure 55. During the impact sequence, the right-front tire was deflated and the rim was deformed due to localized contact with the lower thrie beam corrugation and pushed backward into the engine firewall, as shown in Figures 55 and 56. Minor deformation was observed at the right-rear corner of the rear bumper, and no damage occurred to the right-rear wheel, as shown in Figures 55 and 56. Evidence of vehicle-rail interlock occurred at the rear end of the right-side of the pickup box, as shown in Figure 55. Figure

55 shows the deformed hood with the right-side and the left-side attaching hardware fractured and deformed, respectively. The front windshield was also slightly cracked, as shown in Figures 55 and 57. Figure 57 shows the minor occupant compartment deformation to the right-side and center of the floorboard. No deformation or buckling occurred to the front dashboard or the back vertical wall of the truck cab. The deformation of the floorboard, was not judged to be sufficient to cause injury to vehicle occupants. Other vehicle damage consisted of slight deformation to the left-front quarter panel and to the front of the left-side door, as shown in Figure 55. The frame and engine housing were also shifted toward the left, away from the longitudinal centerline of the vehicle, as shown in Figure 58. Moderate vehicle undercarriage damage is shown in Figures 59 and 60.

During test MTSS-2, occupant compartment deformations were significantly reduced from those obtained in test MTSS-1. Unfortunately, an oversight was made in obtaining actual occupant compartment deformations for test MTSS-2. These measurements were inadvertently not taken prior to salvaging the vehicle.

8.3 Barrier Damage

Damage to the barrier was minor, as shown in Figures 61 through 67. Actual vehicle impact occurred 406 mm (16 in.) upstream from Post No. 6 in the thrie beam guardrail section, as shown in Figure 61. No damage occurred to the W-beam and the W-beam to thrie beam transition sections. Contact marks were observed from the impact location through 178 mm (7 in.) from the downstream end of the thrie beam terminal connector, as shown in Figures 61 and 63. Evidence of rail gouging was found on the lower thrie beam corrugation upstream and downstream of Post No. 6, as shown in Figures 61 and 62. A gouge was also observed in the middle corrugation of the thrie beam at Post No. 5, as shown in Figure 61 and 62.

The thrie beam terminal connector on the traffic-side face of the single slope CMB contained superficial scraping. No damage occurred to the single slope connector plates, as shown in Figure 64. The traffic-side spacer blocks at Post Nos. 1, 3, and 4 were slightly deformed, as shown in Figures 65 and 66. Bolts were also partially pulled through the back-side rail at Post No. 8. The only significant post deformation occurred near the upper region of Post No. 3, as shown in Figure 65.

The permanent set of the approach guardrail transition is shown in Figure 67. The maximum lateral permanent set deflections were approximately 84 mm (3.3 in.) at Post No. 5, as measured in the field. The maximum lateral dynamic deflection was 193 mm (7.6 in.) at Post No. 3, as determined from the high-speed film analysis. These maximum deflections are presented graphically in Figure 68.

The upstream end of the single slope CMB experienced minor concrete spalling along the top edge, as shown in Figure 64. Vehicle contact marks were evident on the top slope at the end of the CMB over 1,778 mm (70 in.). No evidence of vehicle contact was found on the lower upstream end of the CMB. In addition, no barrier cracking or foundation movement was observed.

8.4 Occupant Risk Values

The normalized longitudinal and lateral occupant impact velocities were determined to be 9.2 m/s (30.1 ft/s) and 7.2 m/s (23.6 ft/s), respectively. The maximum 0.010-sec average occupant ridedown decelerations in the longitudinal and lateral directions were 10.5 g's and 4.6 g's, respectively. The results of the occupant risk, determined from accelerometer data, are summarized in Figure 51. Results are shown graphically in Appendix E.

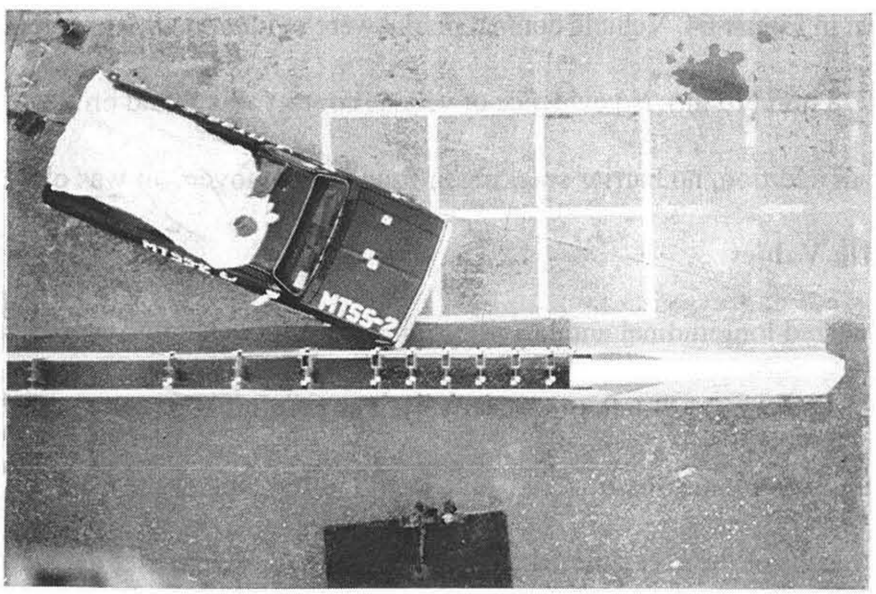
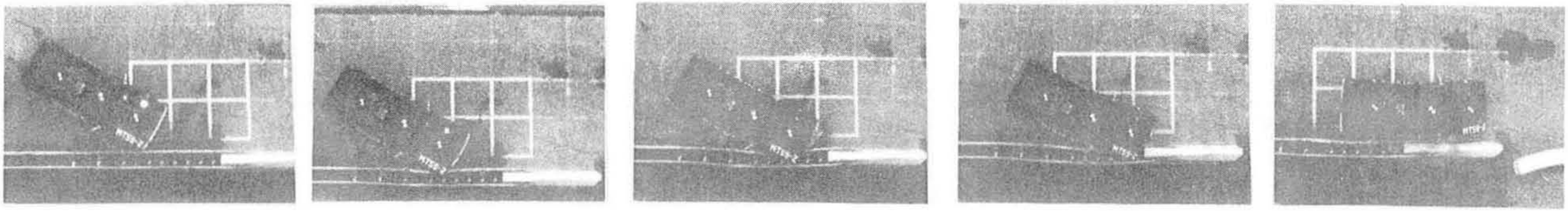
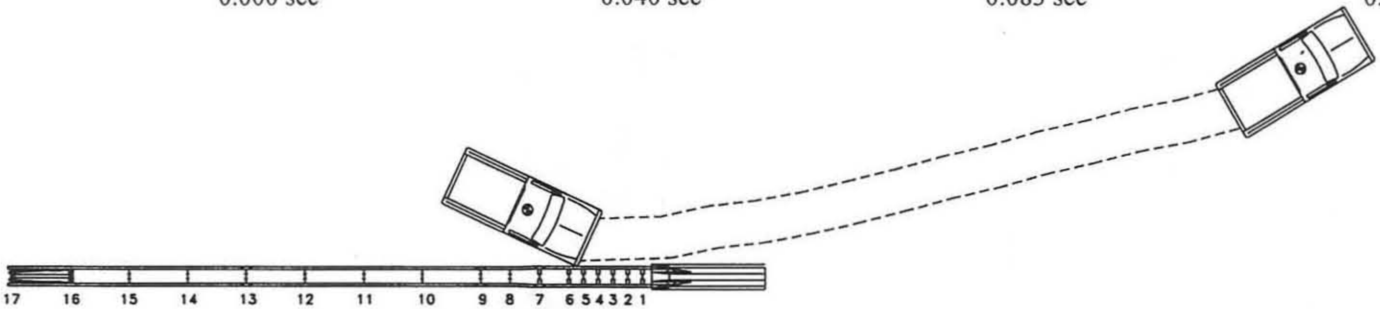


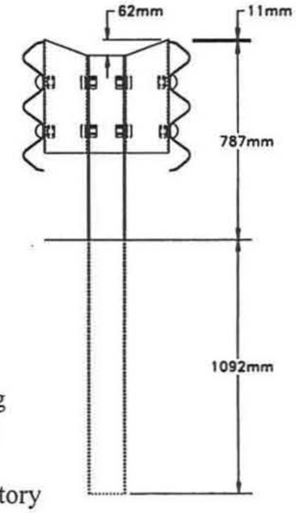
Figure 49. Impact Location, Test MTSS-2

Figure 50. Impact Location, Test MTSS-2 (Con't)



0.000 sec　　0.040 sec　　0.083 sec　　0.127 sec　　0.298 sec





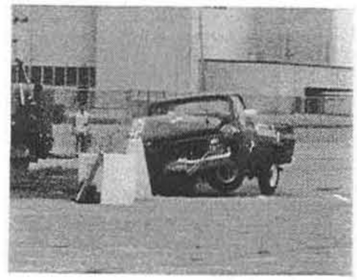
- Test Number MTSS-2
- Date 9/15/94
- Appurtenance .... Missouri's approach guardrail transition to a single slope CMB
- Total Length .... 21.1 m
- Steel Thrie Beam (10 Gauge)
  - Top Mounting Height .... 787 mm
- Steel Posts
  - Post Nos. 1 - 15 .... W6x9 by 1829-mm long
- Steel Spacer Blocks
  - Post Nos. 1 - 7 .... TS 7x4x3/16 by 530-mm long
  - Post Nos. 8 .... W6x9 by 435-mm long
  - Post Nos. 9 - 15 .... W6x9 by 337-mm long
- Soil Type .... Silty-Clay (SL) (Dry)
- Vehicle Model .... 1985 Chevrolet C-20 2WD
  - Curb Weight .... 1,919 kg
  - Test Inertial Weight .... 2,034 kg
  - Gross Static Weight .... 2,034 kg
- Vehicle Speed
  - Impact .... 92.5 km/h
  - Exit .... 54.7 km/h
- Vehicle Angle
  - Impact .... 28.7 deg
  - Exit .... 9.8 deg
- Vehicle Snagging .... None
- Vehicle Stability .... Satisfactory
- Occupant Ridedown Deceleration
  - Longitudinal .... 10.53 G's < 20 G's
  - Lateral .... 4.59 G's < 20 G's
- Occupant Impact Velocity (Normalized)
  - Longitudinal .... 9.16 m/s < 12 m/s
  - Lateral .... 7.20 m/s < 9 m/s
- Vehicle Damage .... Moderate
  - TAD[10] 1-RBQ-4, 1-RD-2
  - SAE[11] 01RYEW3
- Vehicle Stopping Distance .... 23.8 m downstream
  5.5 m lateral
- Barrier Damage .... Minor
- Maximum Post Deflections
  - Permanent Set .... 84 mm
  - Dynamic .... 193 mm

Figure 51. Summary of Test Results, Test MTSS-2

IMPACT

0.030 sec

0.060 sec

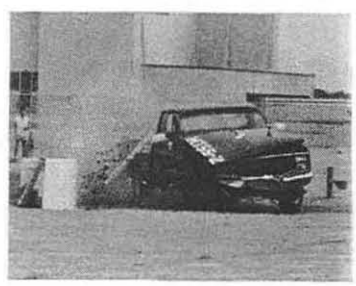


0.160 sec

0.190 sec

0.280 sec

0.400 sec



0.600 sec

Figure 52. Additional Sequential Photographs, Test MTSS-2

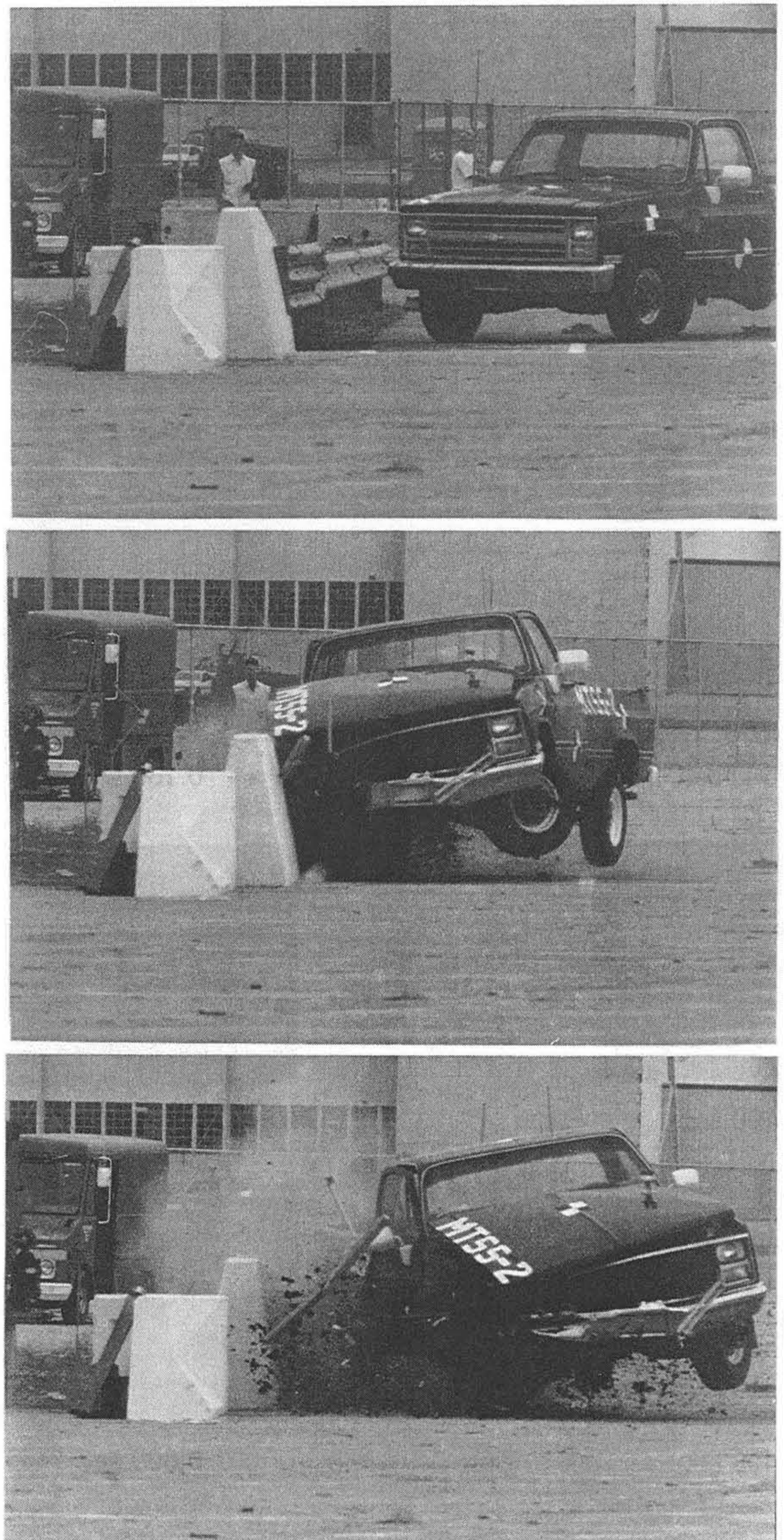


Figure 53. Impact Sequence, Test MTSS-2

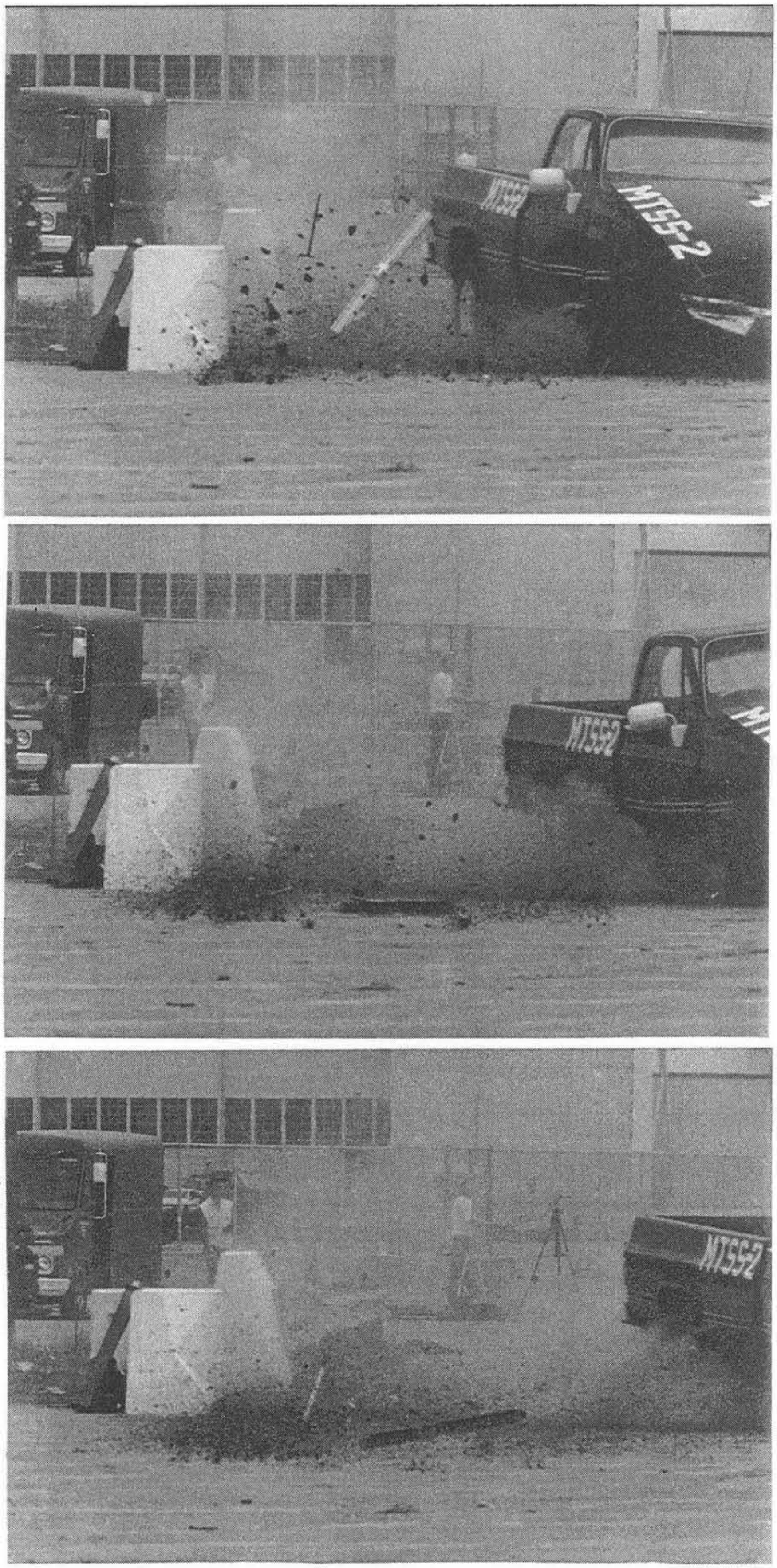


Figure 54. Impact Sequence, Test MTSS-2 (Con't)

Figure 55. Vehicle Damage, Test MTSS-2

Figure 56. Vehicle Damage, Test MTSS-2 (Con't)

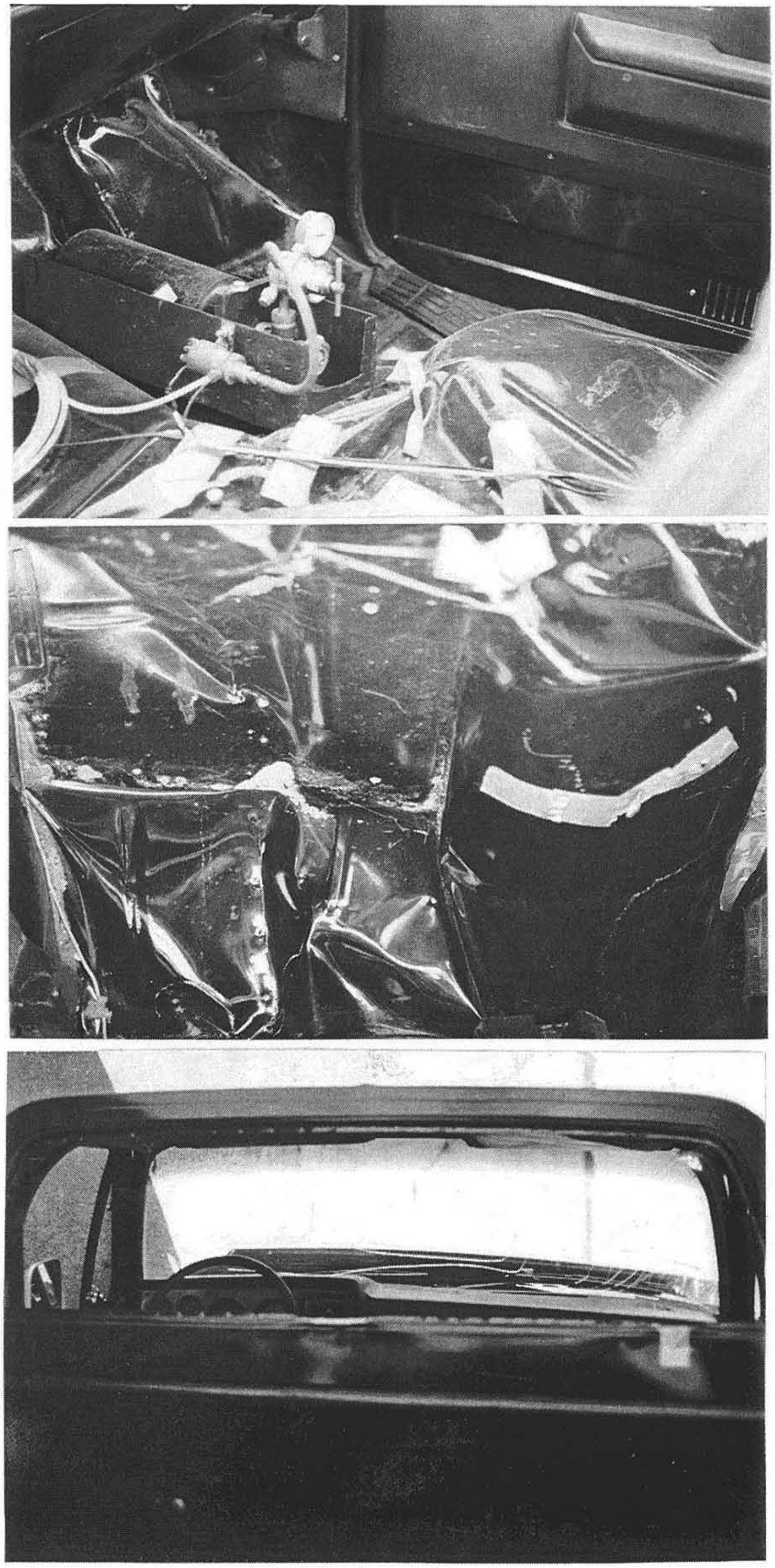


Figure 57. Occupant Compartment Deformation, Test MTSS-2

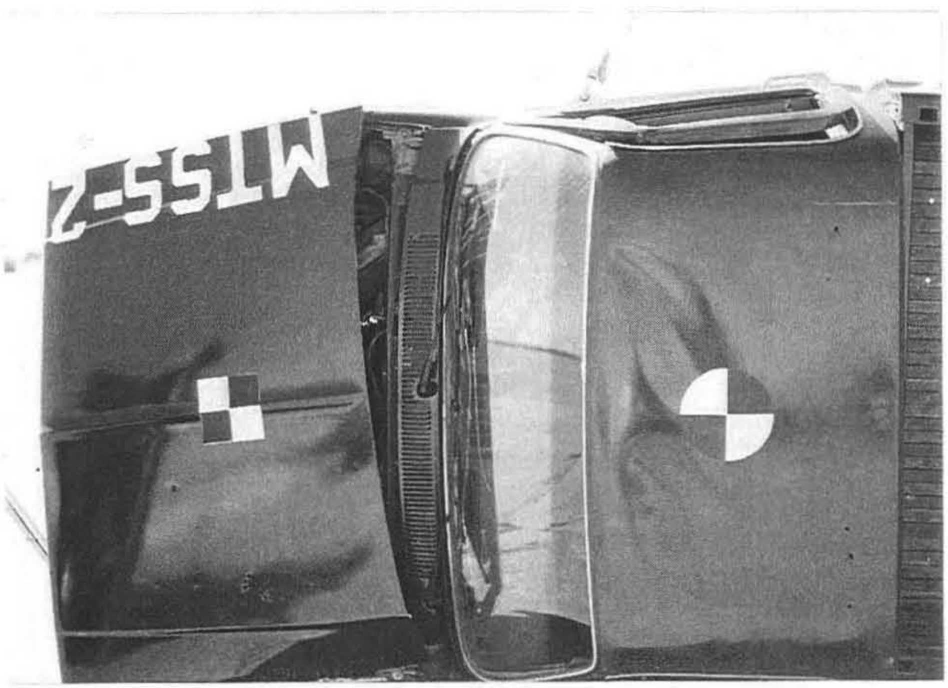


Figure 58. Front Windshield Damage, Test MTSS-2

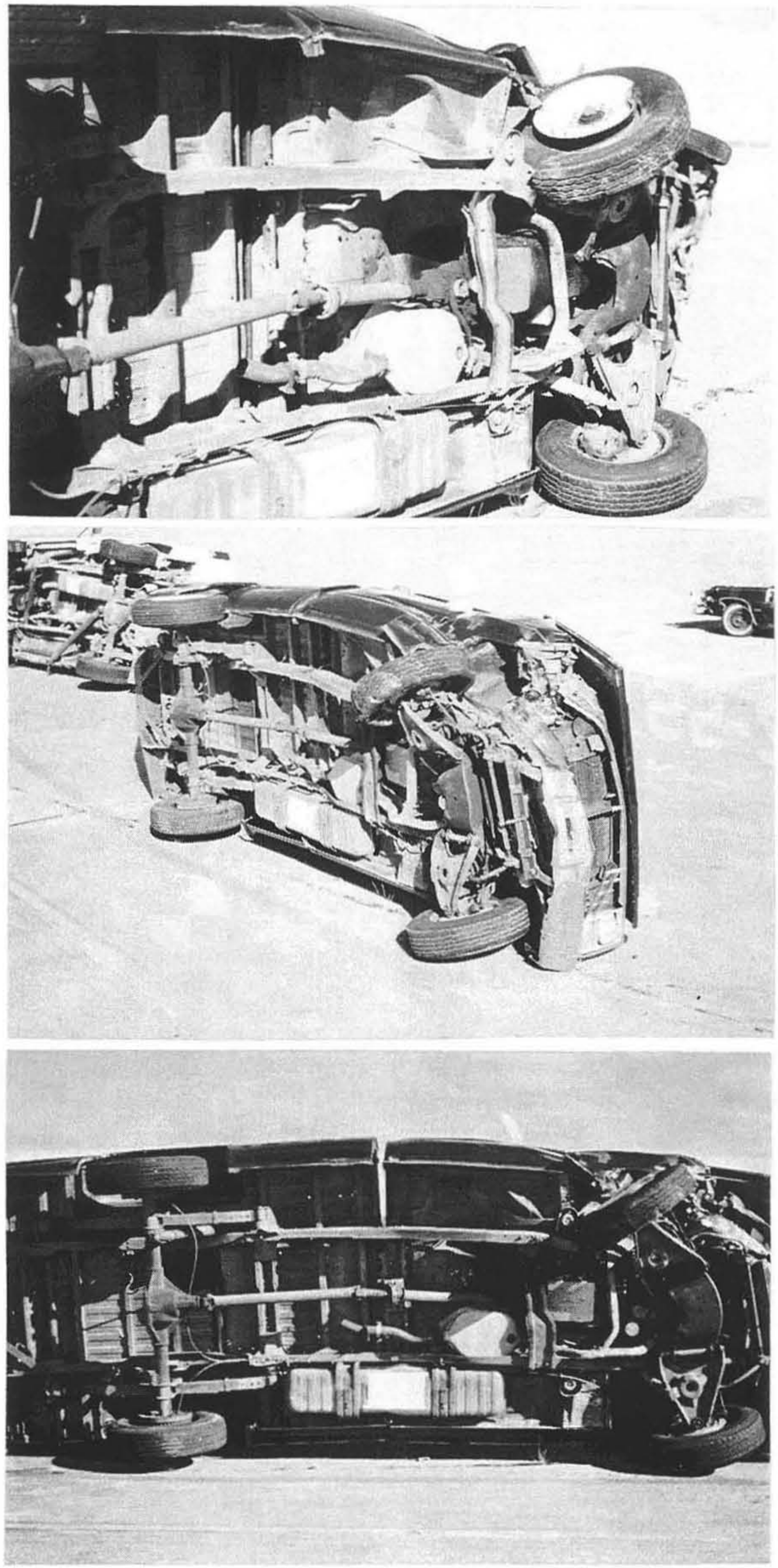
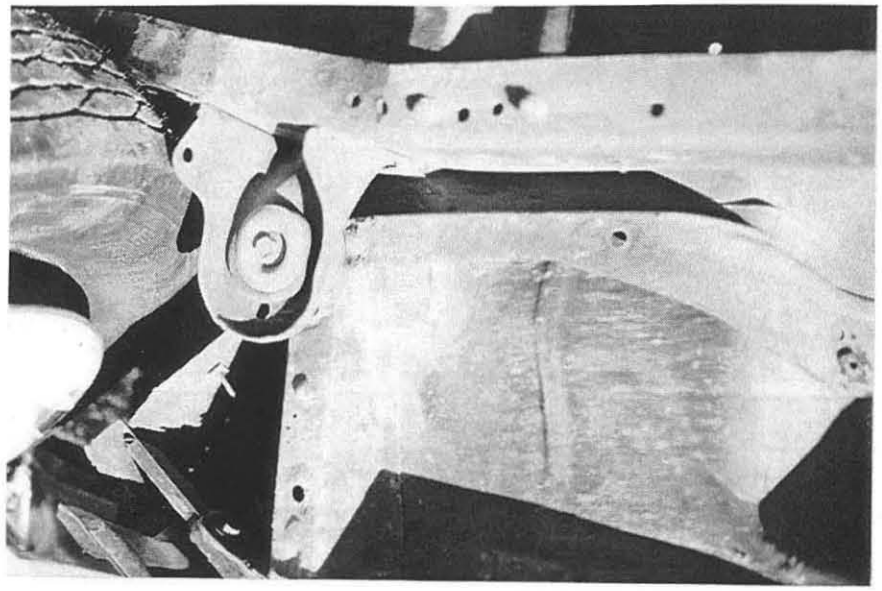


Figure 59. Vehicle Undercarriage Damage, Test MTSS-2 (Con't)



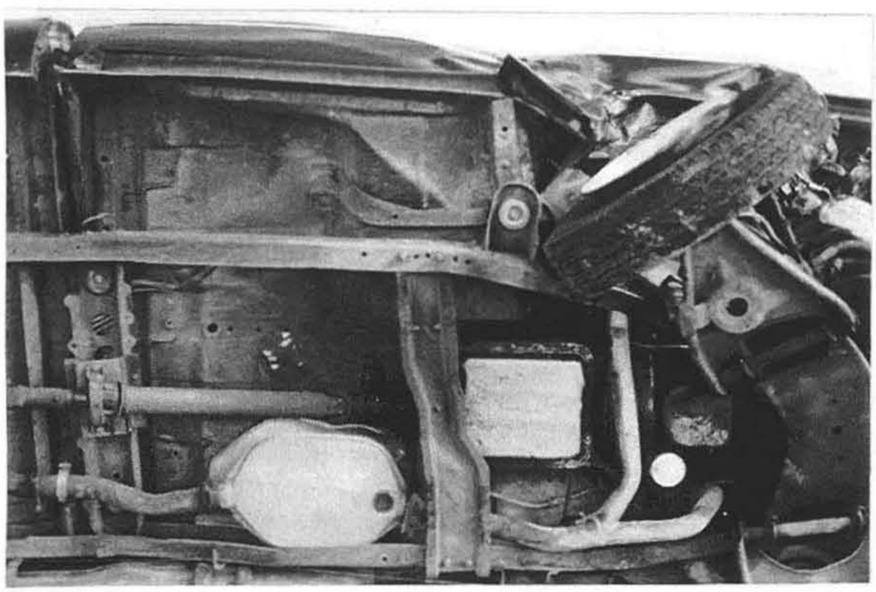


Figure 60. Vehicle Undercarriage Damage, Test MTSS-2 (Con't)

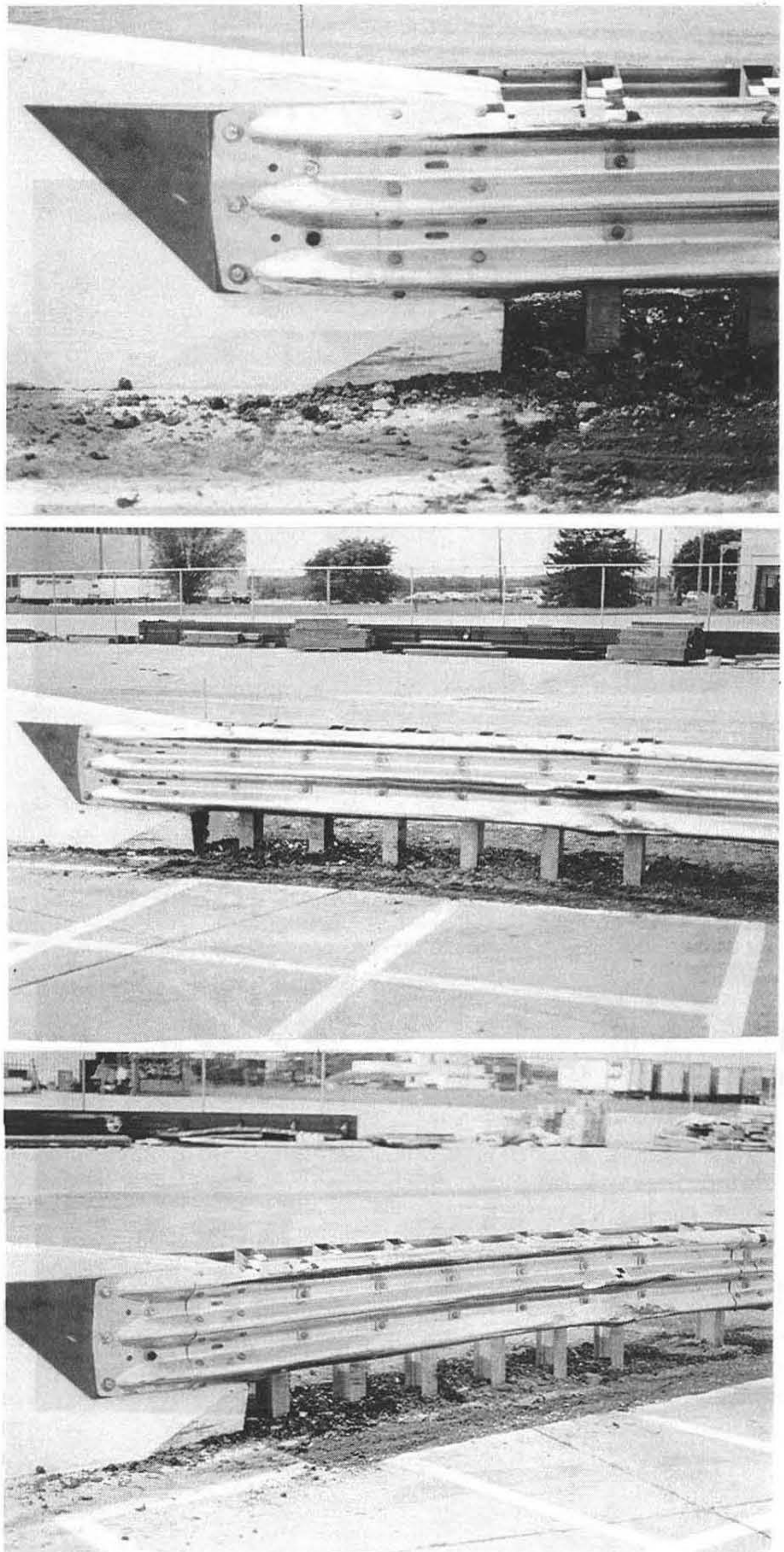


Figure 61. Approach Guardrail Transition Damage, Test MTSS-2

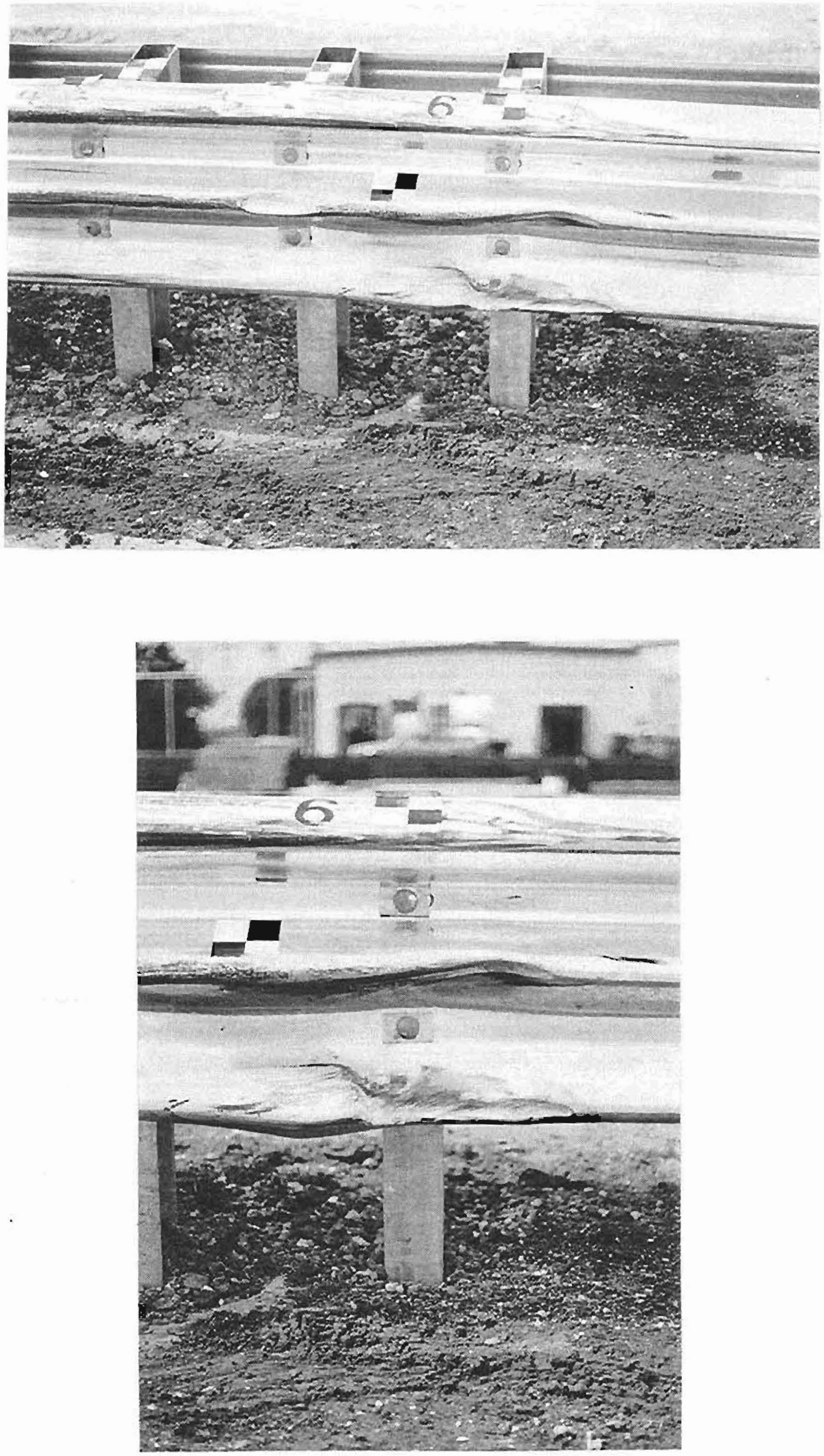
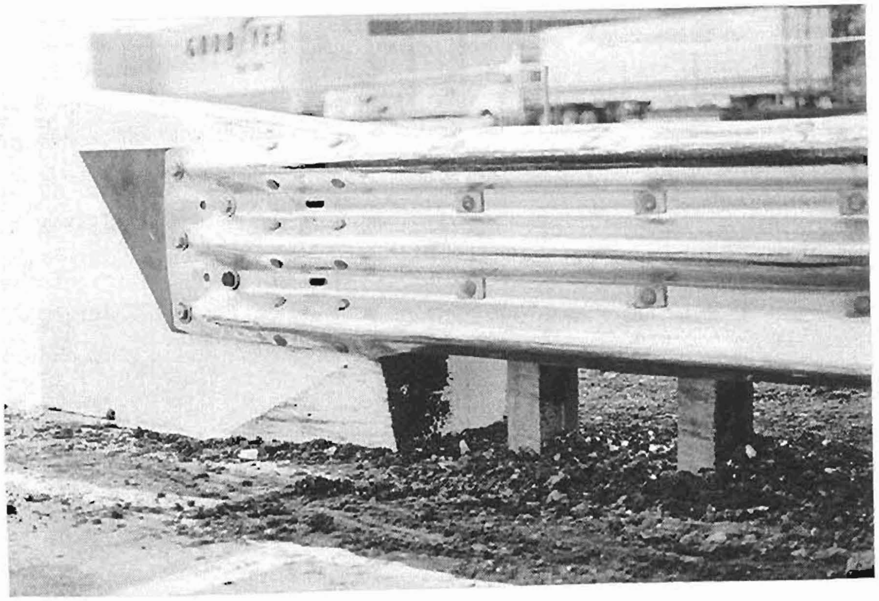


Figure 62. Impact Location, Test MTSS-2



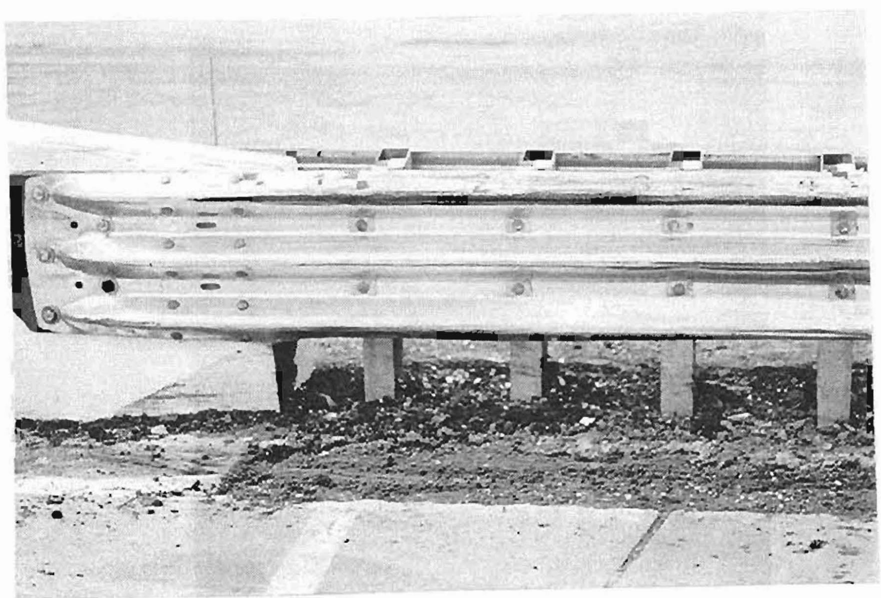


Figure 63. Transition Damage, Test MTSS-2 MTSS-2

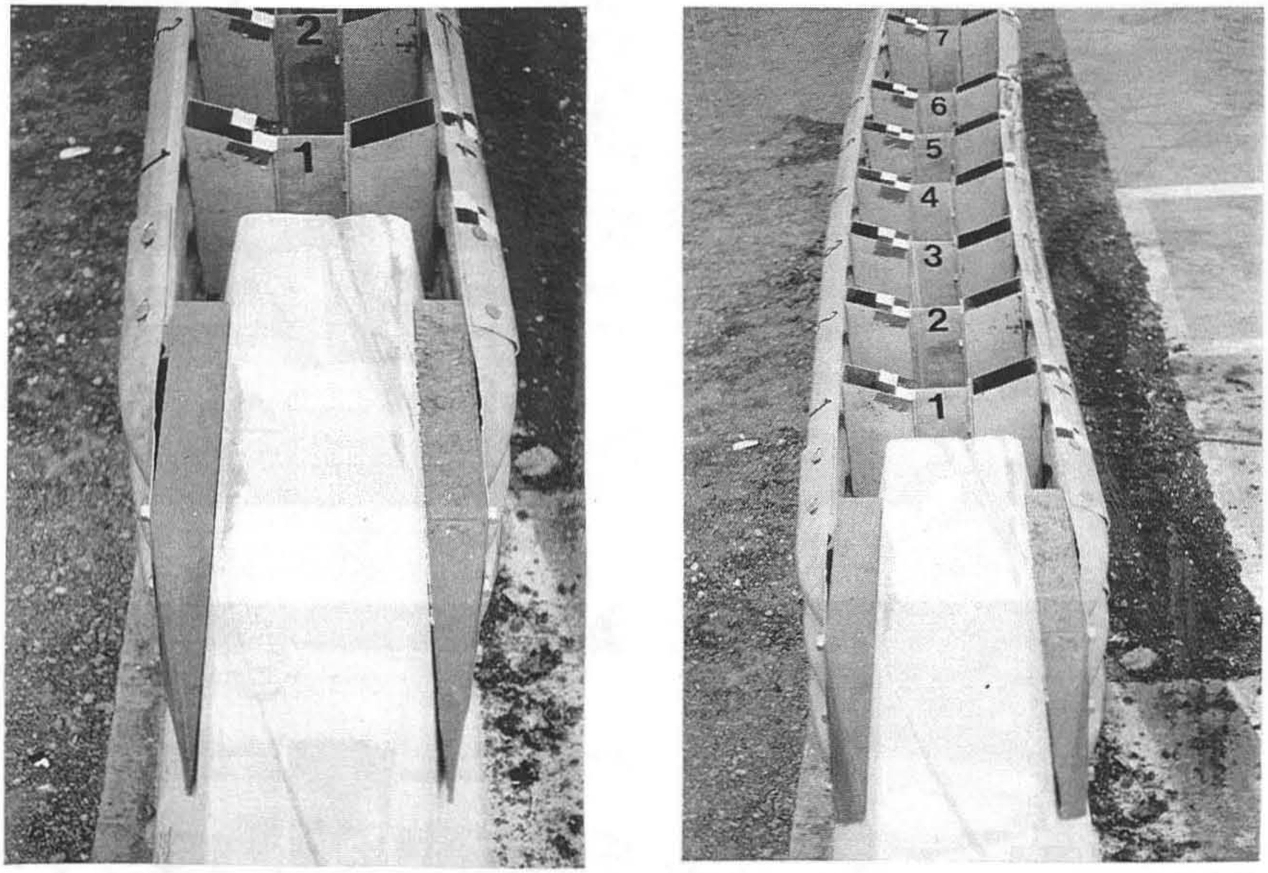


Figure 64. Single Slope Connector Plate Damage, Test MTSS-2

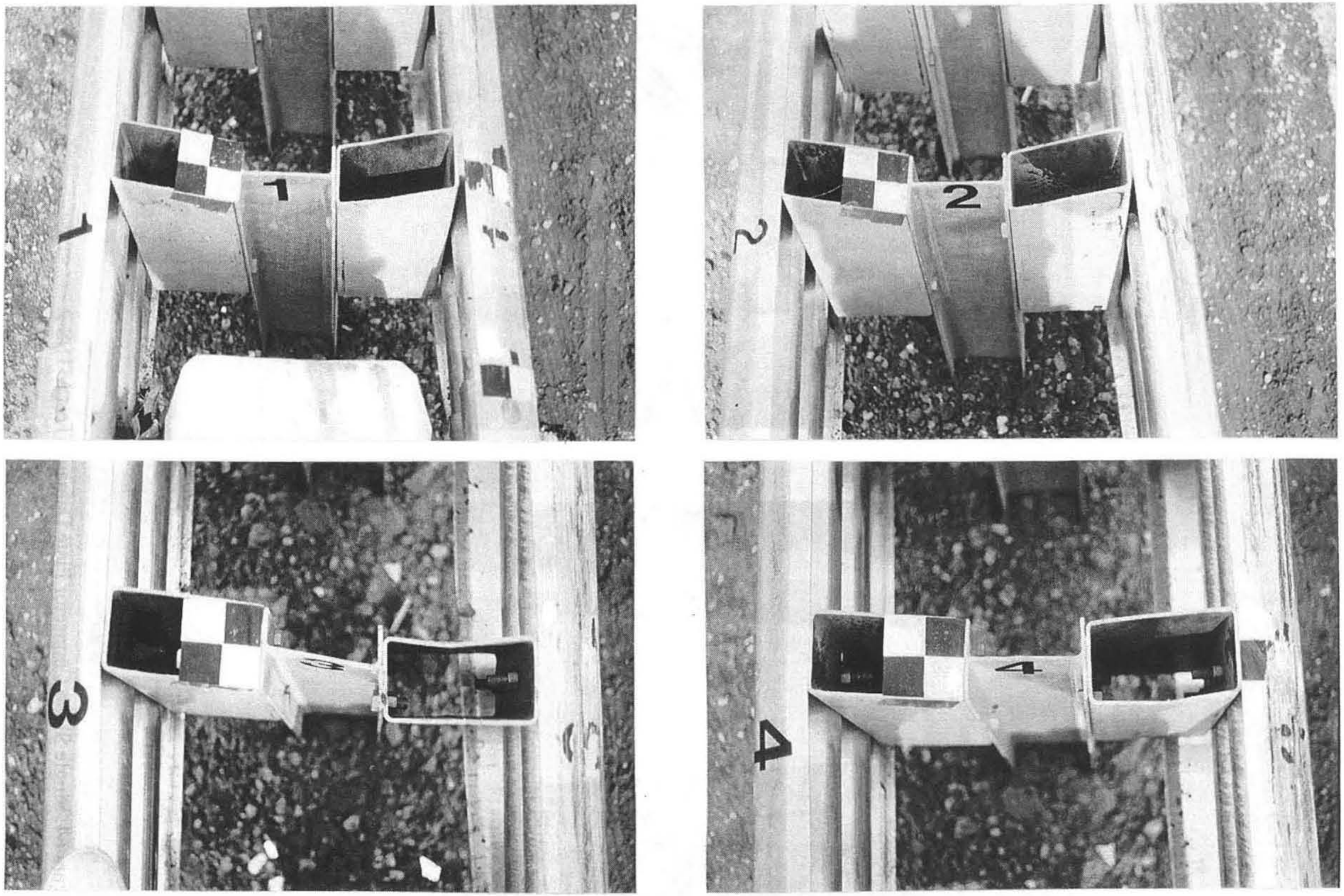


Figure 65. Permanent Set Deformations - Post Nos. 1 through 4, Test MTSS-2

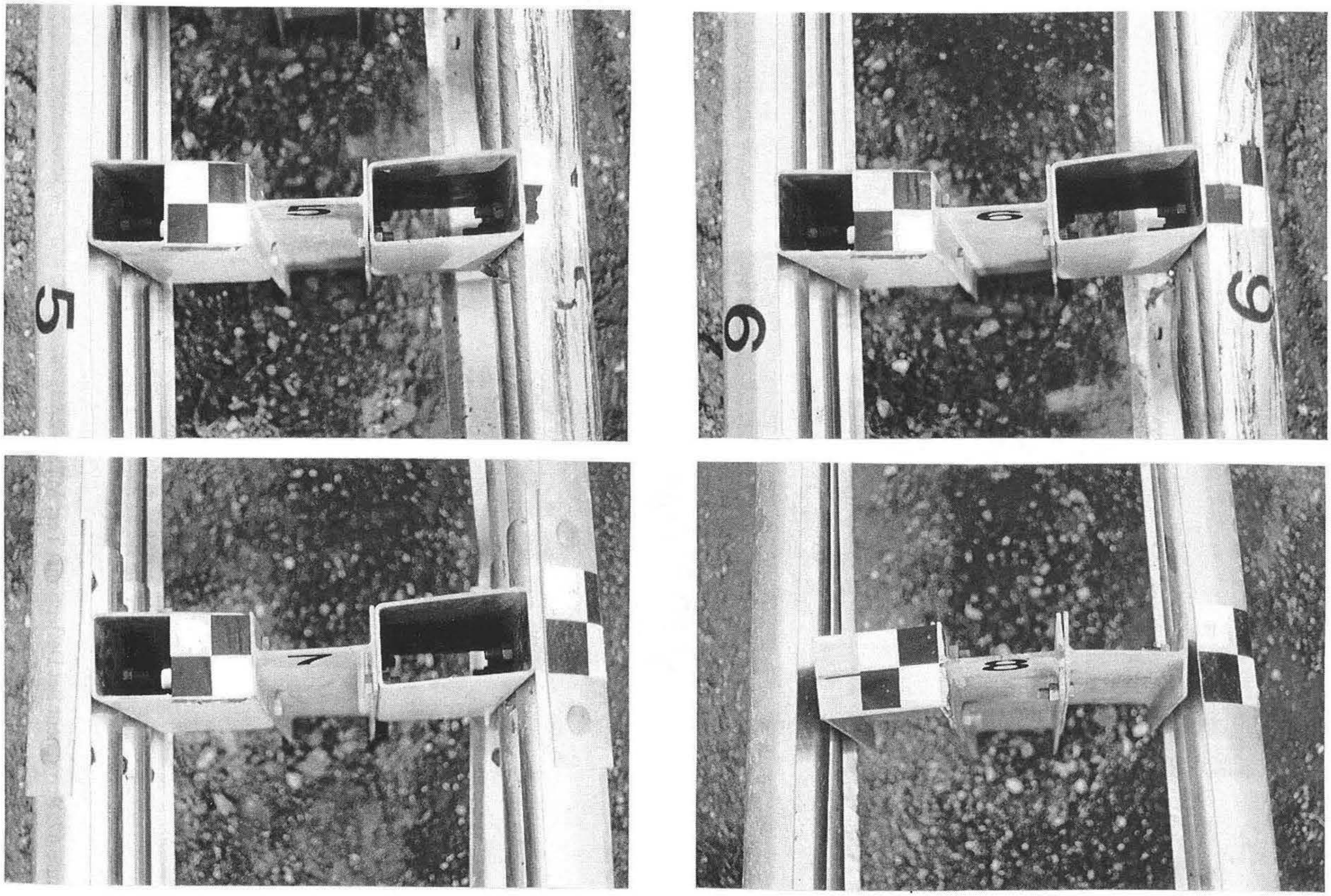
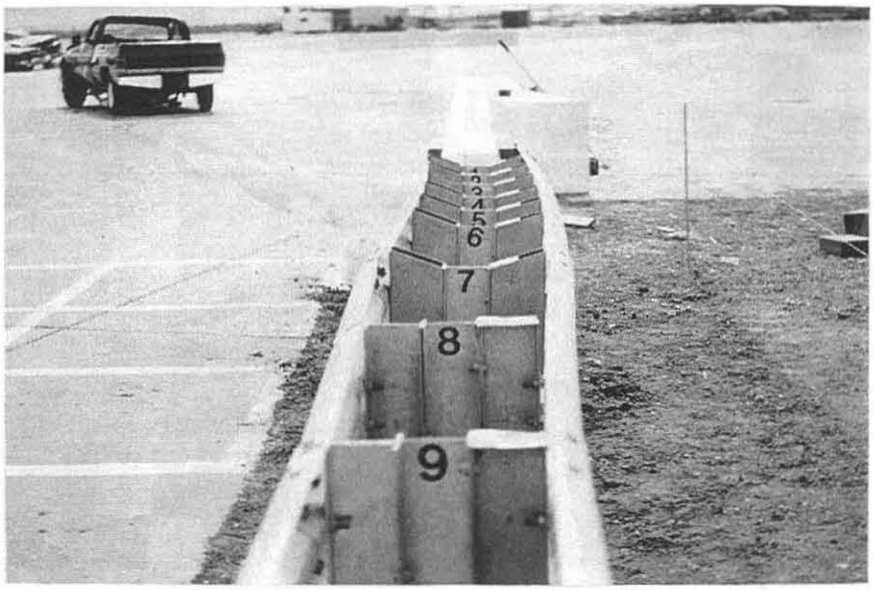


Figure 66. Permanent Set Deflections - Post Nos. 5 through 8, Test MTSS-2



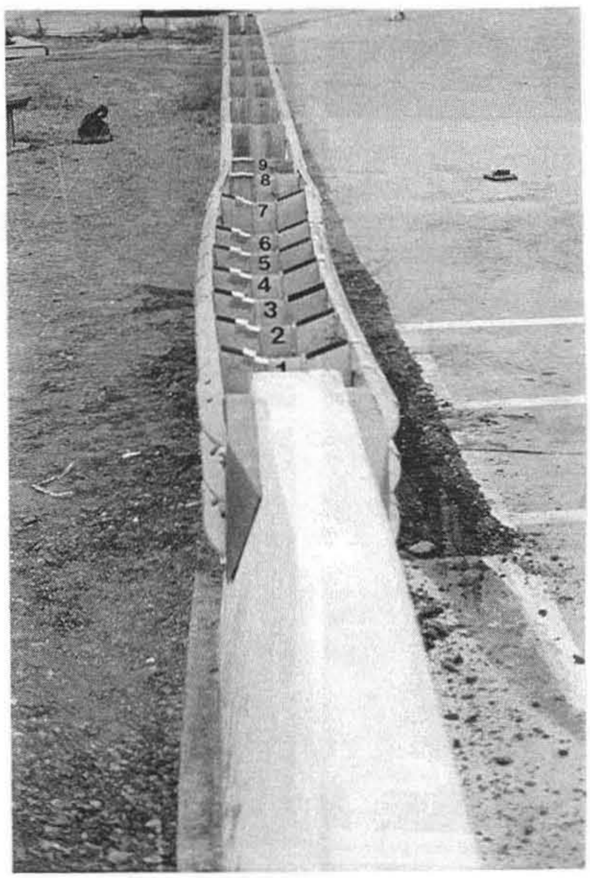


Figure 67. Permanent Set Deflections, Test MTSS-2

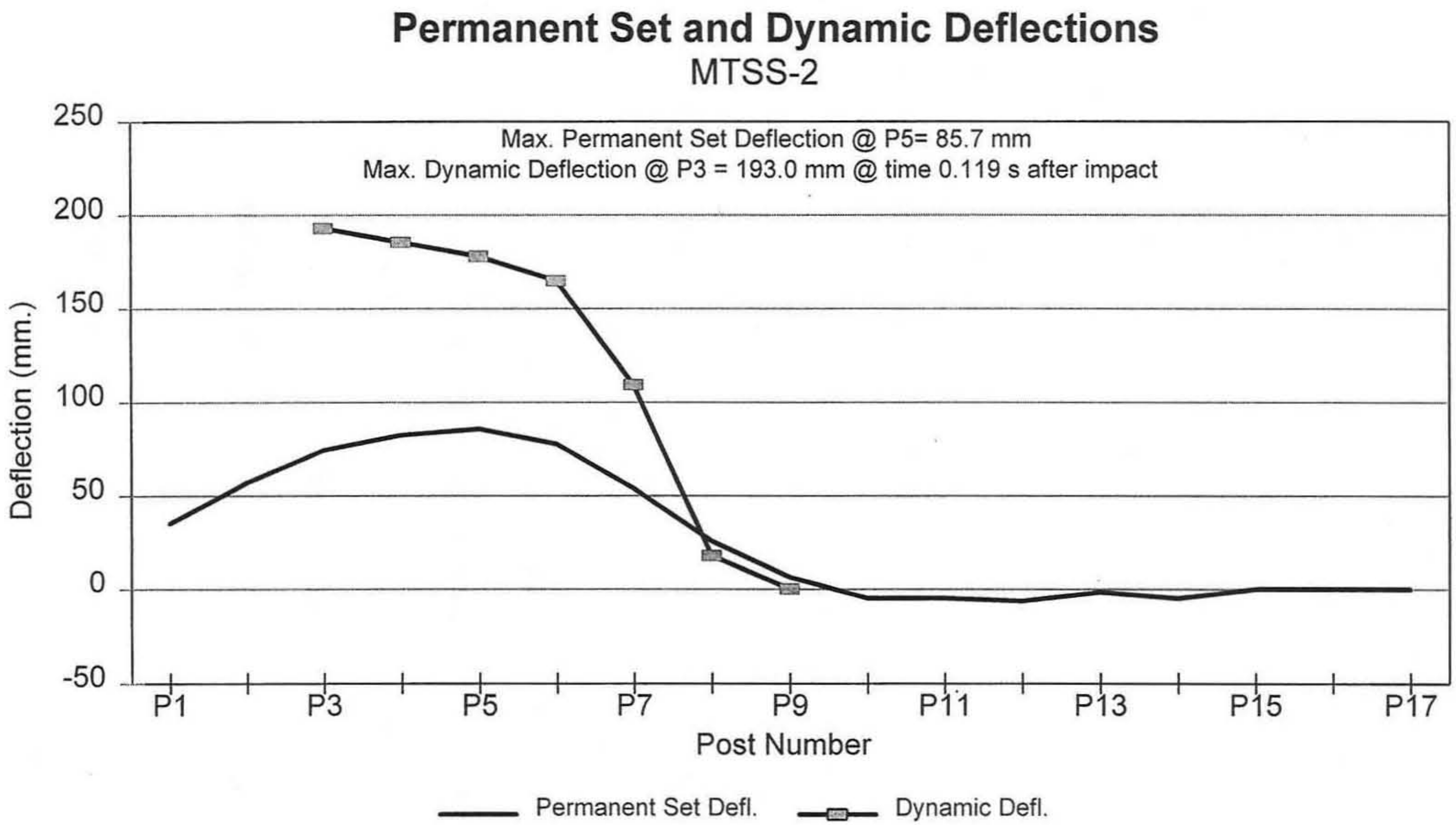


Figure 68. Permanent Set and Dynamic Deflections, Test MTSS-2

9 SUMMARY AND CONCLUSIONS

Two full-scale vehicle crash tests, were performed according to Test Level 3 (Test Designation 3-21) of NCHRP Report No. 350 (2). The first crash test, test MTSS-1, failed due to excessive occupant compartment deformations. Following this crash test, the approach guardrail transition and single slope CMB end section were redesigned by flattening the upper slope at the end of the CMB from 2:1 to 8:1, removing the thrie beam backup plates, shortening the steel single slope connector plate, shortening the bottom section of the structural tube, thrie beam, spacer blocks, providing a negative slope at the top of the structural tube, thrie beam, spacer blocks, and reducing the height of the thrie beam post above ground by increasing the embedment depth. A retest, test MTSS-2, was performed on the modified system and was determined to be acceptable according to the safety performance criteria presented in TL-3 of NCHRP Report No. 350 (2). A summary of the safety performance evaluation is provided in Table 5 and discussed below.

The analysis of the MTSS-2 test results indicated that the approach guardrail transition contained and redirected the test vehicle. The vehicle did not penetrate, underride, or override the barrier system. Detached elements, fragments, or other debris from the barrier system did not penetrate or show potential for penetrating the occupant compartment, or did not present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment were not considered to be sufficient to cause serious injury to the vehicle occupants. The test vehicle remained upright during and after the collision. After collision, the vehicle's trajectory did not intrude into adjacent traffic lanes. The occupant impact velocity in the longitudinal direction did not exceed 12 m/s and the occupant ridedown deceleration in the longitudinal direction did not exceed 20 g's. The exit angle from the barrier system was 9.8 degrees or less than 60% of the impact angle of 25 degrees or 15 degrees. Therefore, the Missouri's approach guardrail transition has successfully passed all of the safety performance criteria, and in nearly all the cases the values were near to the "preferred values" as opposed to the "maximum threshold limits".

This research revealed that the pickup truck rim has a tendency to gouge on the lower thrie beam corrugation shortly after impact. This gouging can push the tire backward into the firewall, causing significant occupant compartment deformations. Severe occupant compartment deformation occurred without the wheel snagging on the guardrail posts. However this problem was significantly reduced by decreasing the spacer block depth and eliminating the backup plates, thus allowing the lower thrie beam corrugation to bend back when impacted by the front wheel hub. The crash tests also revealed the tendency for the pickup truck's front hood and quarter panel to extend over the thrie beam and snag on the top of the steel posts and spacer blocks, causing extensive vehicle damage. This problem was reduced by providing a negative slope on top of the thrie beam spacer blocks, thus recessing the top of the posts below the thrie beam.

The results of this research study indicate that Missouri's approach guardrail transition attached to a single slope CMB meets NCHRP Report 350 Test Level 3 performance standards. The success of this research study has resulted in a safe approach guardrail transition to a single slope CMB, and has allowed the MHTD to make use of the innovative single slope CMB.

Table 5. Summary of Safety Performance Evaluation Results

Evaluation Factors	Evaluation Criteria	Test MTSS-1	Test MTSS-2
Structural Adequacy	A. Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.	S	S
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.	U	S
	F. The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	S	S
Vehicle Trajectory	K. After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	S	S
	L. The occupant impact velocity in the longitudinal direction should not exceed 12 m/s and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 g's.	S	S
	M. The exit angle from the test article preferably should be less than 60 percent of test impact angle, measured at time of vehicle loss of contact with test devise.	S	S

S (Satisfactory)   U (Unsatisfactory)

8 REFERENCES

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4. Beason, W. L ,. Ross, H.E., Jr.,Perera, H.S., and Marek M., Single-Slope Concrete Median Barrier, Transportation Research Record (TRR) No. 1302, Transportation Research Council, Washington, D.C., 1991.

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6. *AASHTO LRFD Bridge Design Specifications*, Customary U.S. Units - First Edition, American Association of State Highway and Transportation Officials (AASHTO), 1994.

7. Bronstad, M.E., Calcote, L.R., and Kimball, C.E., Jr., *Concrete Median Barrier Research - Vol. 2 Research Report*, Report No. FHWA-RD-77-4, Submitted to the Offices of Research and Development, Federal Highway Administration, Performed by Southwest Research Institute, March 1976.

8. 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.

9. Faller, R.K., Sicking, D.L., Rosson, B.T., Pfeifer, B.G., and Holloway, J.C., *Dynamic Evaluation of Missouri's Modified Bridge Anchor Section*, Transportation Research Report No. TRP-03-38-93, Final Report to the Missouri Highway and Transportation Department, Performed by the Midwest Roadside Safety Facility, University of Nebraska-Lincoln, February 1994.

10. *Vehicle Damage Scale for Traffic Investigators*, Second Edition, Technical Bulletin No. 1, Traffic Accident Data (TAD) Project, National Safety Council, Chicago, Illinois, 1971.

11. *Collision Deformation Classification - Recommended Practice J224 March 1980*, Handbook Volume 4, Society of Automotive Engineers (SAE), Warrendale, Pennsylvania, 1985.

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

9 APPENDICES

APPENDIX A - RELEVANT CORRESPONDENCE

University of
Nebraska
Lincoln

Midwest Roadside Safety Facility
Civil Engineering Department
W348 Nebraska Hall
P.O. Box 880531
Lincoln, NE 68588-0531

December 17, 1993

Mr. Pat McDaniel
Design Division
Missouri Highway and Transportation Department
P.O. Box 270
Jefferson City, Missouri 65102

Dear Mr. McDaniel:

As you requested, we have reviewed concrete reinforcement requirements for slip formed concrete barriers. There are two very different questions that need to be addressed, safety and maintenance. A number of research studies have demonstrated that conventional slip formed concrete median barriers require very little reinforcement to provide adequate levels of safety. In a 1976 study, Bronstad found that safety shaped concrete barriers could perform adequately with a minimum amount of longitudinal reinforcement and no shear reinforcement. Further, a study by the Texas Transportation Institute (TTI) demonstrated that an unreinforced slip formed concrete barrier can withstand impacts from 80,000 lb tractor-trailer trucks. Thus, the safety performance of slip formed concrete barriers can meet NCHRP Report 230 performance standards with very little reinforcement.

Therefore, the remaining question is how much reinforcement is required to keep barrier maintenance to a reasonable level. Vertical shear reinforcement is not necessarily required to prevent barrier damage during most highway impacts. The previously mentioned study by Bronstad found that a number of state highway agencies were obtaining reasonably good barrier durability from slip formed barriers with no shear reinforcement. In these situations vertical steel is still required at the barrier ends and at construction joints. A yield line analysis of the single slope barrier indicates that shear reinforcements recommended by TTI should be incorporated within 12 ft. of a barrier end or a construction joint. Although not required for safety performance, additional vertical steel may be advantageous for minimizing barrier maintenance requirements at high impact locations or along truck corridors. A yield line analysis indicates that No. 4 vertical bars, spaced on 24 in. centers, in conjunction with adequate longitudinal reinforcement, would produce a single sloped concrete barrier that could sustain almost all vehicular impacts with only superficial barrier damage.

Longitudinal steel requirements are also controlled by barrier maintenance considerations. Although some states have reported reasonable barrier maintenance history with only one No. 5 longitudinal rebar or welded wire mesh reinforcements, the increase in barrier strength and durability associated with additional longitudinal reinforcement is probably well worth the additional cost. Yield line and temperature steel analyses indicates that a single slope barrier with four No. 5 or six No. 4 longitudinal rebars would be capable of withstanding most vehicular impacts with little or no barrier damage.

I apologize for the delay in conducting this analysis and hope that it did not inconvenience you in any way. Please call me if you would like to discuss this further or would like to see details of the above analysis.

Sincerely,

Dean Sicking

Dean L. Sicking, Ph.D., P.E.
Director and Assistant Professor

x.c.: Ronald K. Faller, P.E., Research Associate Engineer

APPENDIX B - BARRIER VII COMPUTER MODEL

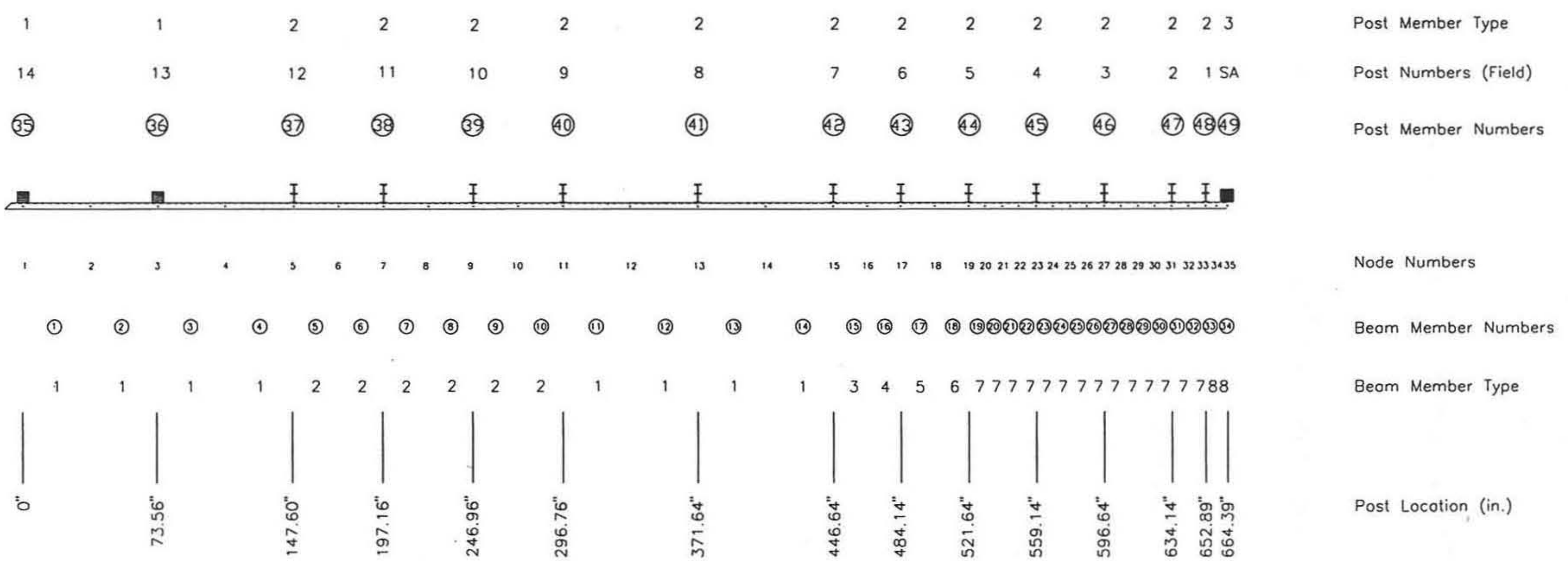


Figure B-1. Model of the Bridge Anchor Section, Option A

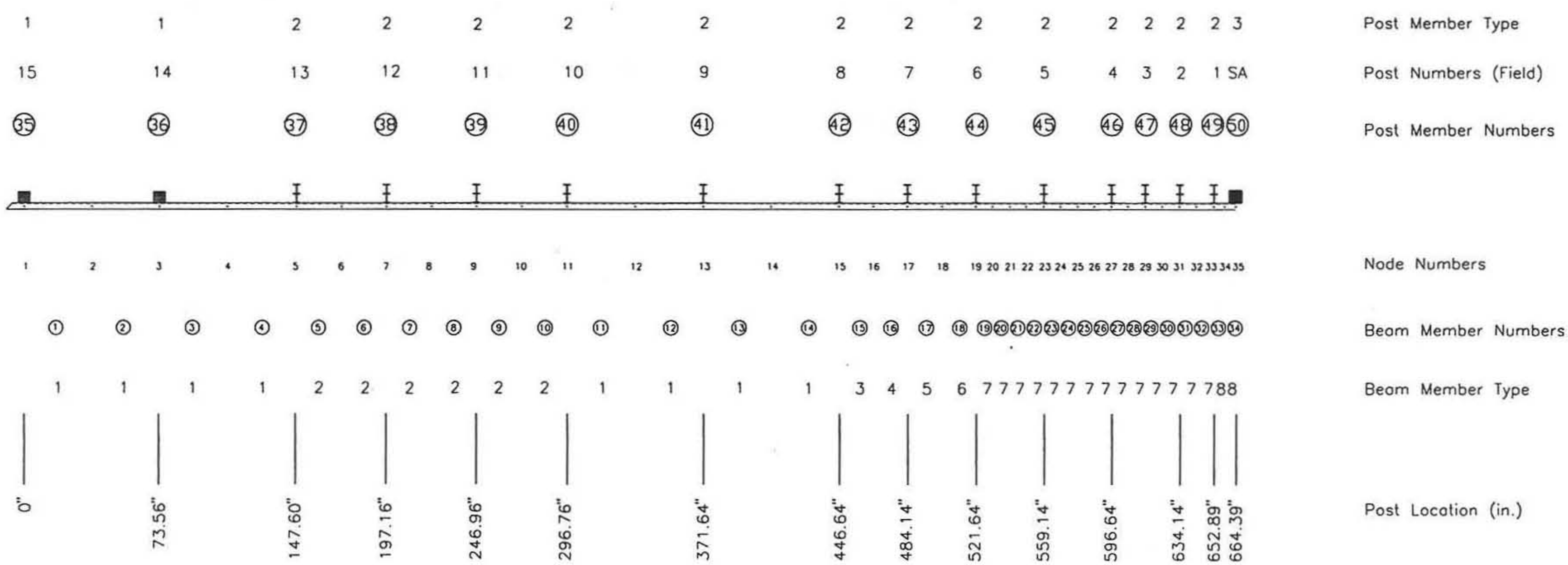


Figure B-2. Model of the Bridge Anchor Section, Option B

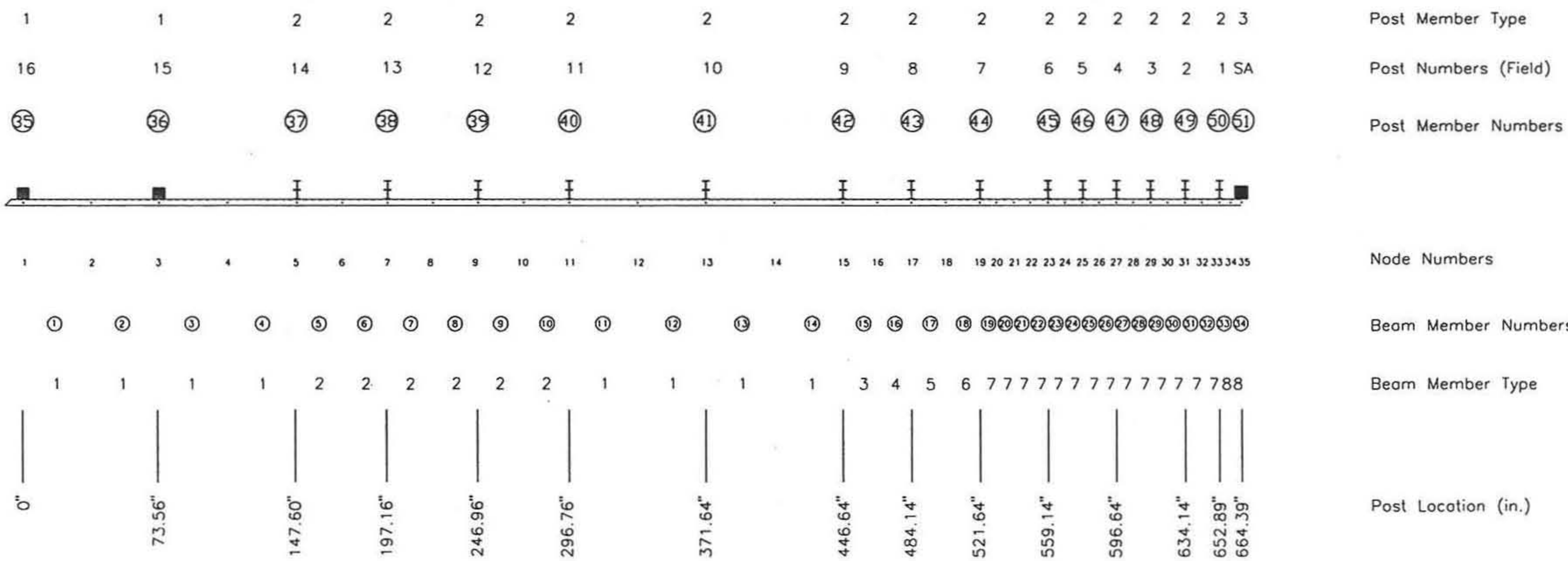


Figure B-3. Model of the Bridge Anchor Section, Option C

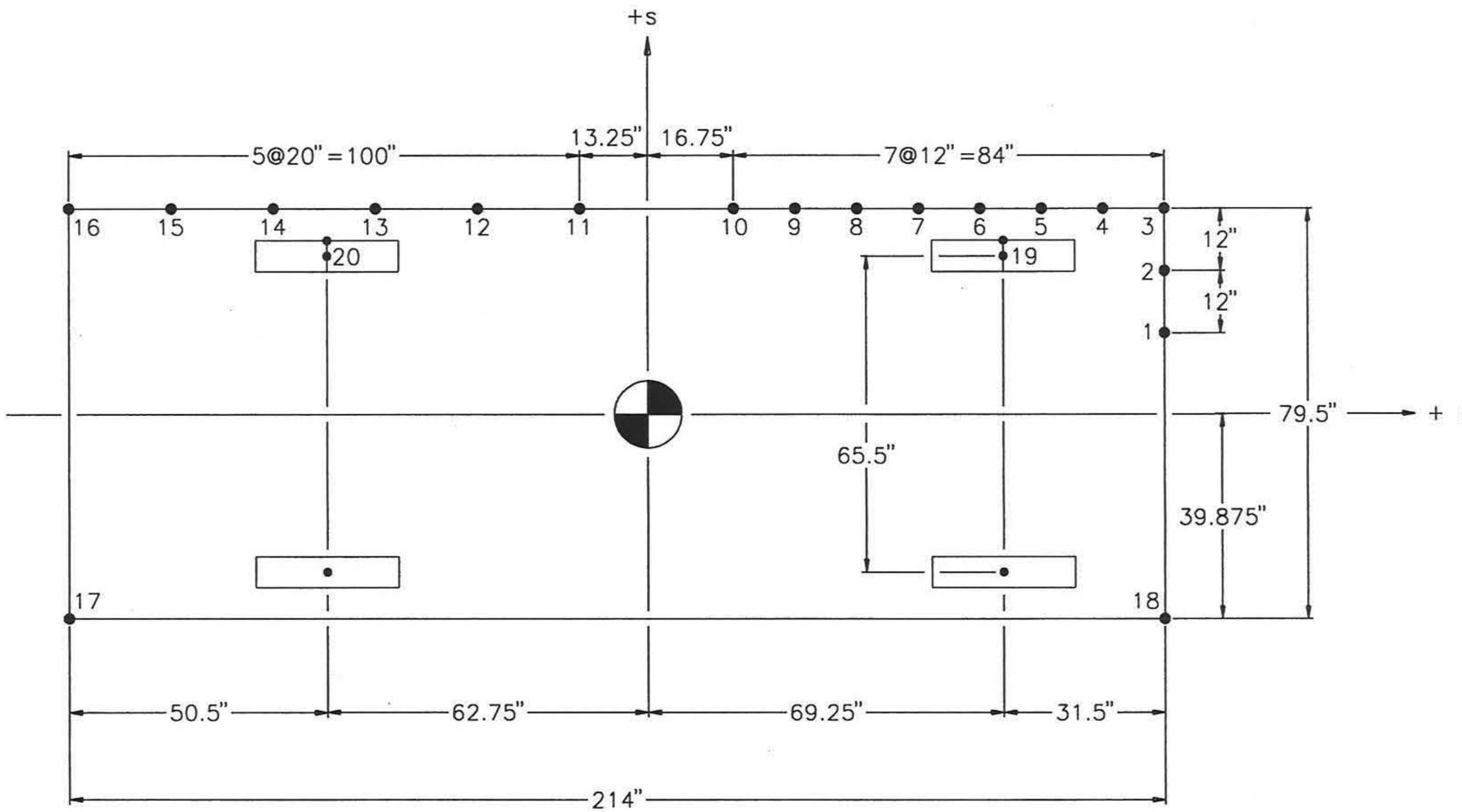


Figure B-4. Idealized Finite Element, 2 Dimensional Vehicle Model for the 2,000-kg Pickup Truck

APPENDIX C - TYPICAL BARRIER VII INPUT FILE

```
 TRANSITION TO SINGLE SLOPE MEDIAN BARRIER 4400-LB PICKUP TRUCK, 62.14 MPH, 25
DEG, NODE 24
   35   12   11    1   51   13    2    0
    0.0010    0.0010       0.75  200    0        1.0    1
    1    5    5    5    5    5    1
    1      0.0        0.0
    3     73.56       0.0
    5    147.60       0.0
    7    197.16       0.0
    9    246.96       0.0
   11    296.76       0.0
   13    371.64       0.0
   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      4.60        3.98       37.50   30000.0      13.84       199.0       137.0 0.10
    2      4.60        3.98       25.00   30000.0      13.84       199.0       137.0 0.10
    3      4.95        4.25       18.75   30000.0      14.81       212.5       147.5 0.10
    4      5.68        4.80       18.75   30000.0      16.75       240.0       168.0 0.10
    5      6.41        5.36       18.75   30000.0      18.70       268.0       188.0 0.10
    6      7.15        5.92       18.75   30000.0      20.65       296.0       208.5 0.10
    7      9.64        8.00       9.375   30000.0      27.90       400.0       280.0 0.10
    8      9.64        8.00        5.75   30000.0      27.90       400.0       280.0 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       2.0       2.0
    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          50     2  302       0.0        0.0        0.0        0.0        0.0
51    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     568.52        0.0       25.0      62.14        0.0        0.0        1.0
```

APPENDIX D - ACCELEROMETER DATA ANALYSIS

ACCELEROMETER DATA ANALYSIS, MTSS-1

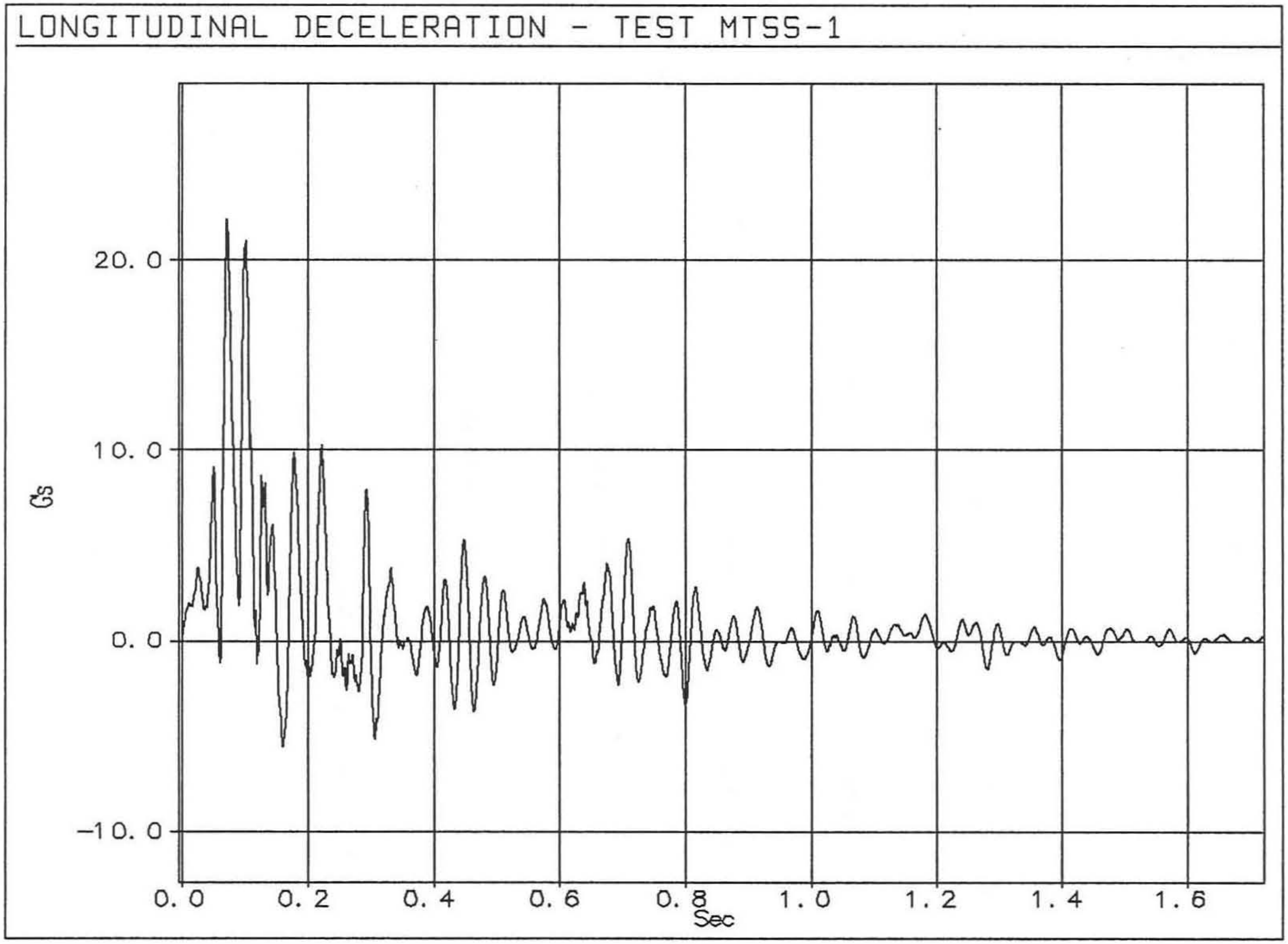


Figure D-1. Graph of Longitudinal Deceleration

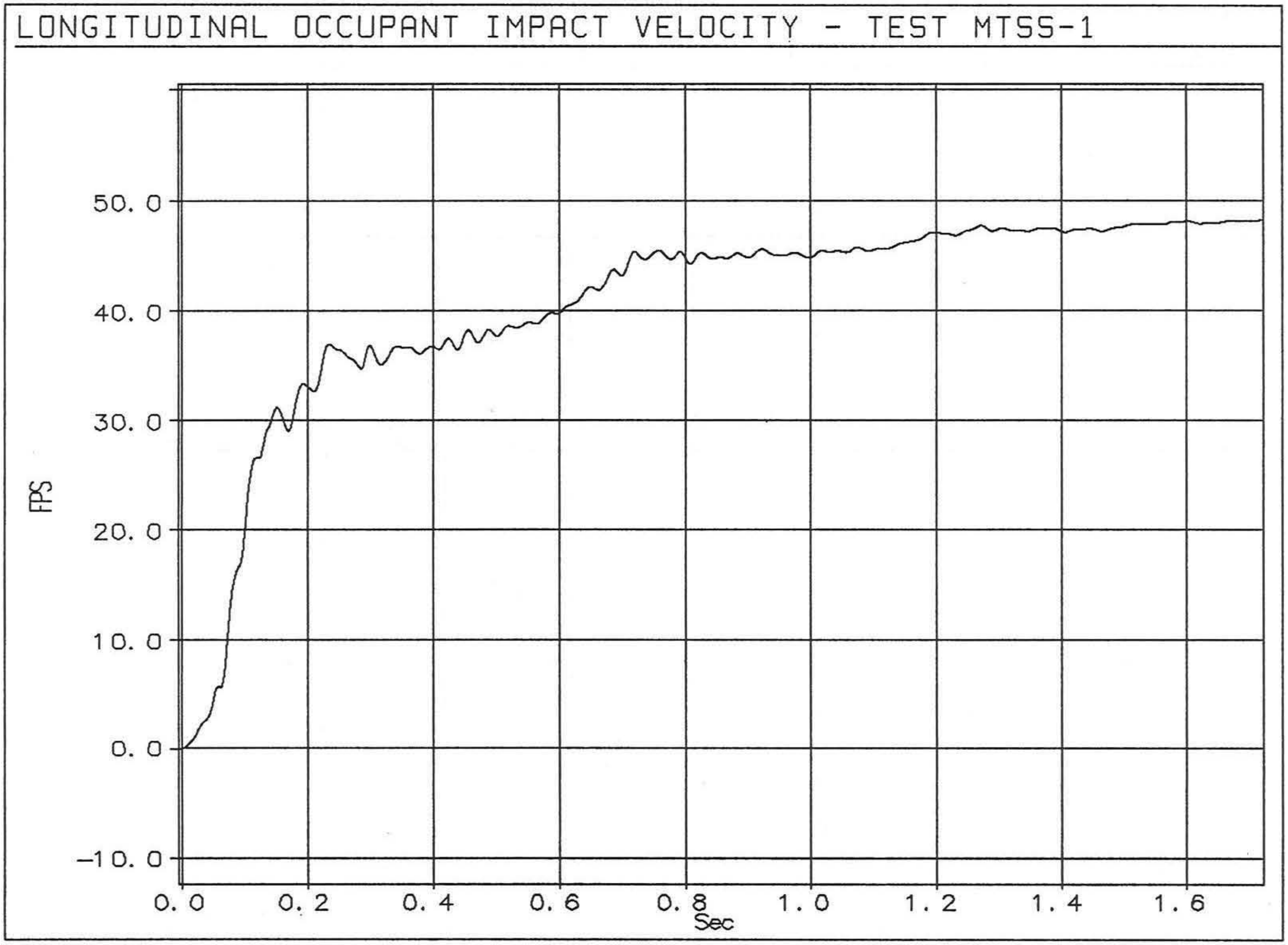


Figure D-2. Graph of Longitudinal Occupant Impact Velocity

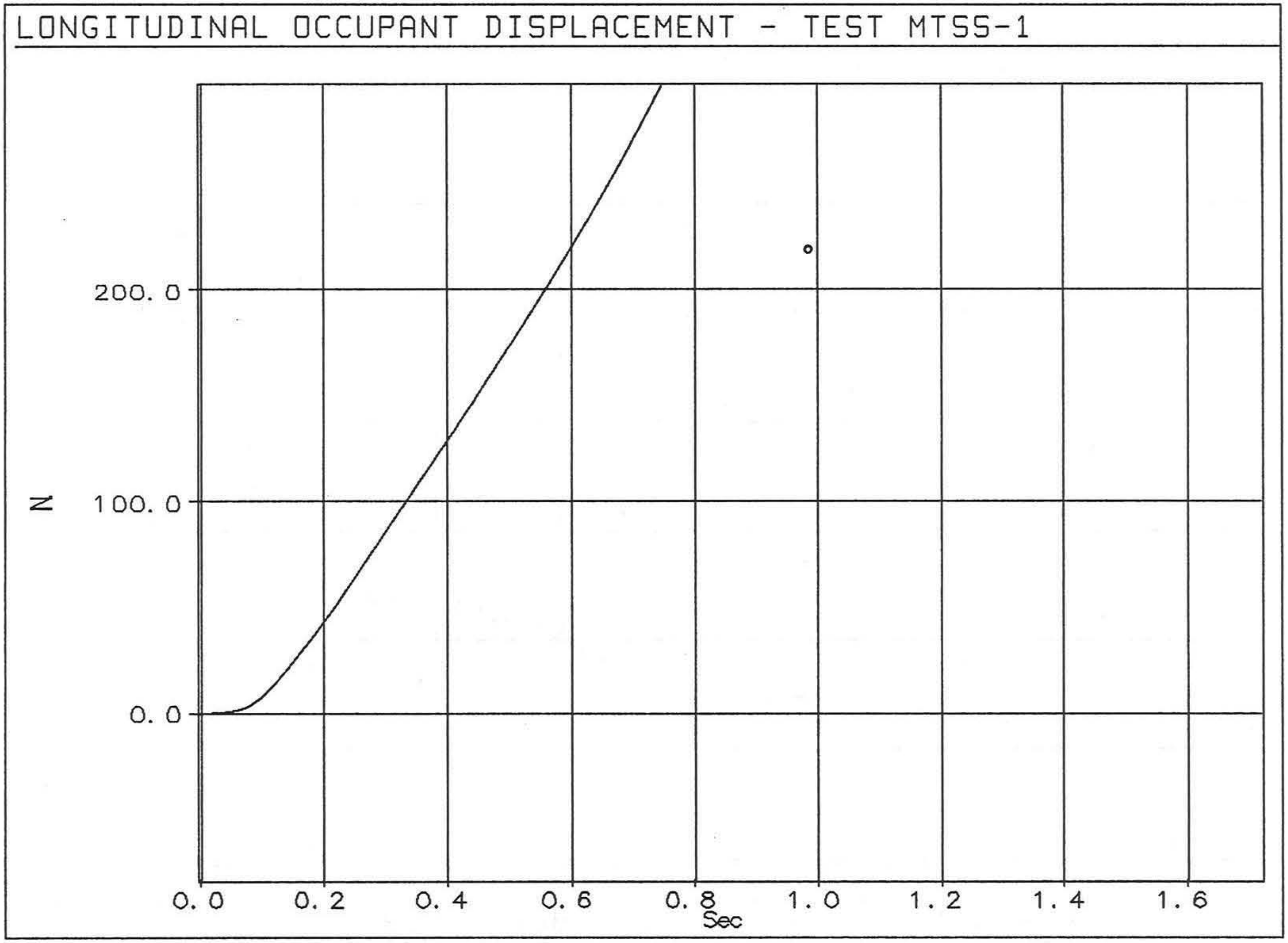


Figure D-3. Graph of Longitudinal Occupant Displacement

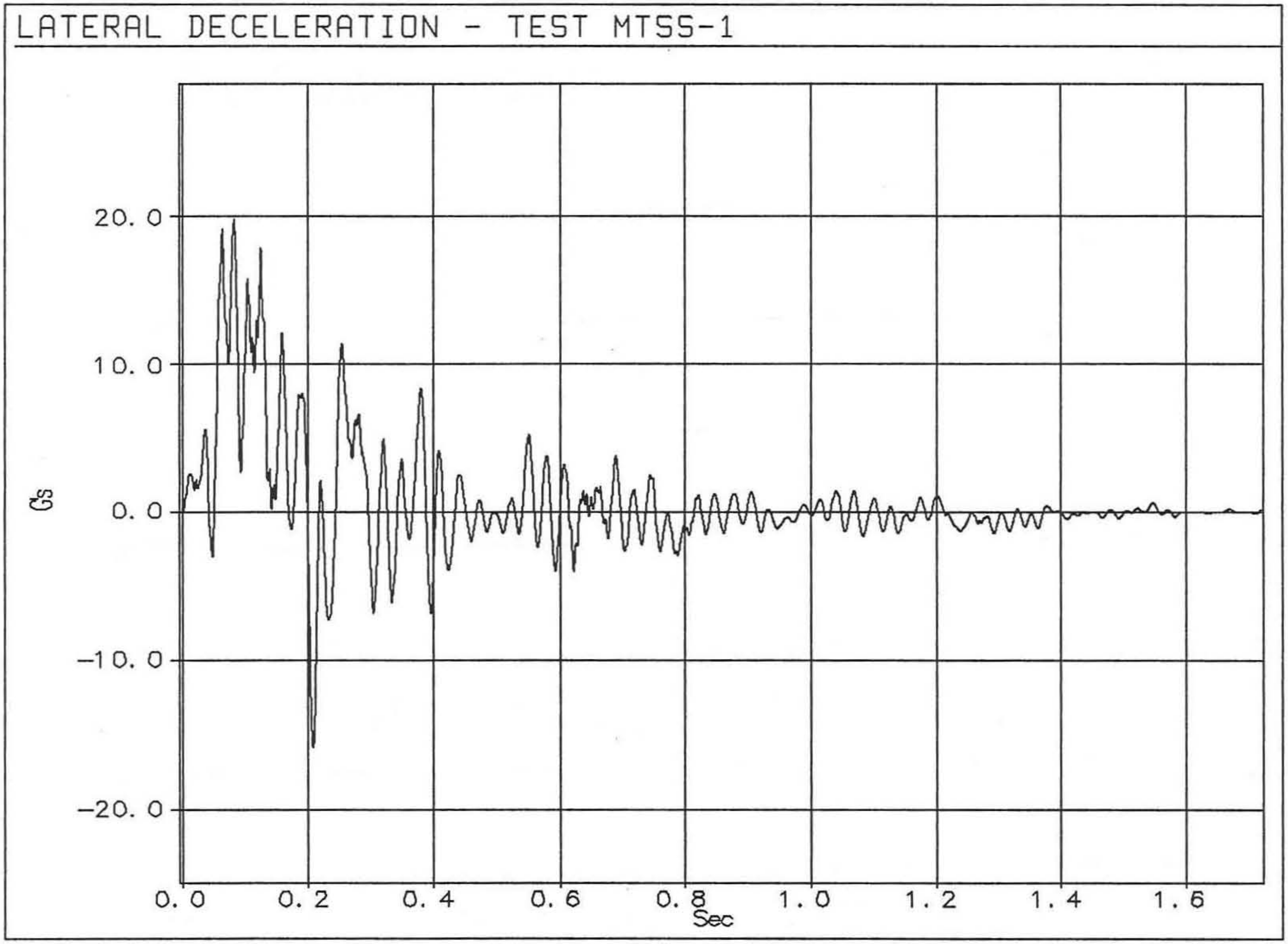


Figure D-4. Graph of Lateral Deceleration

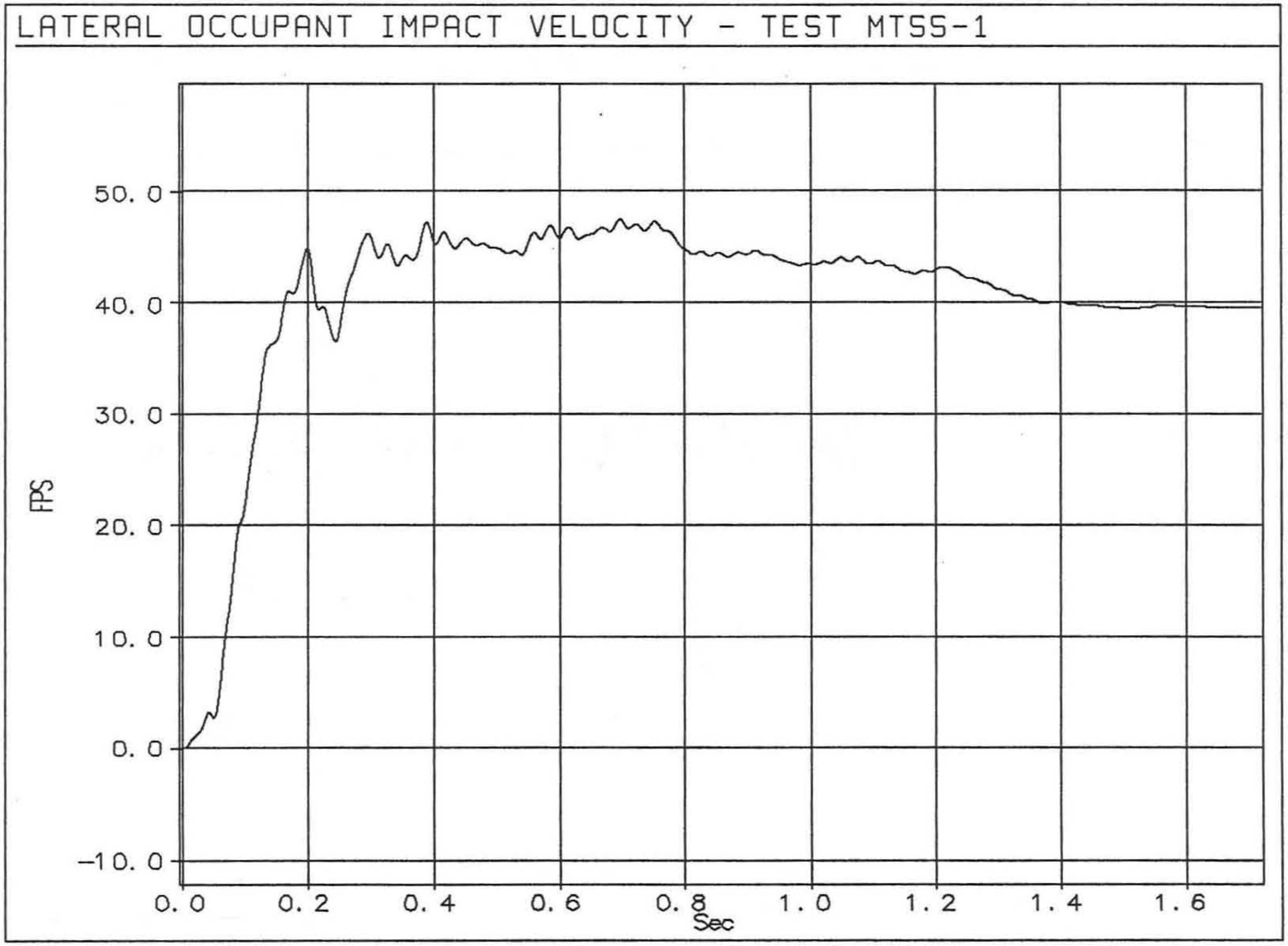


Figure D-5. Graph of Lateral Occupant Impact Velocity

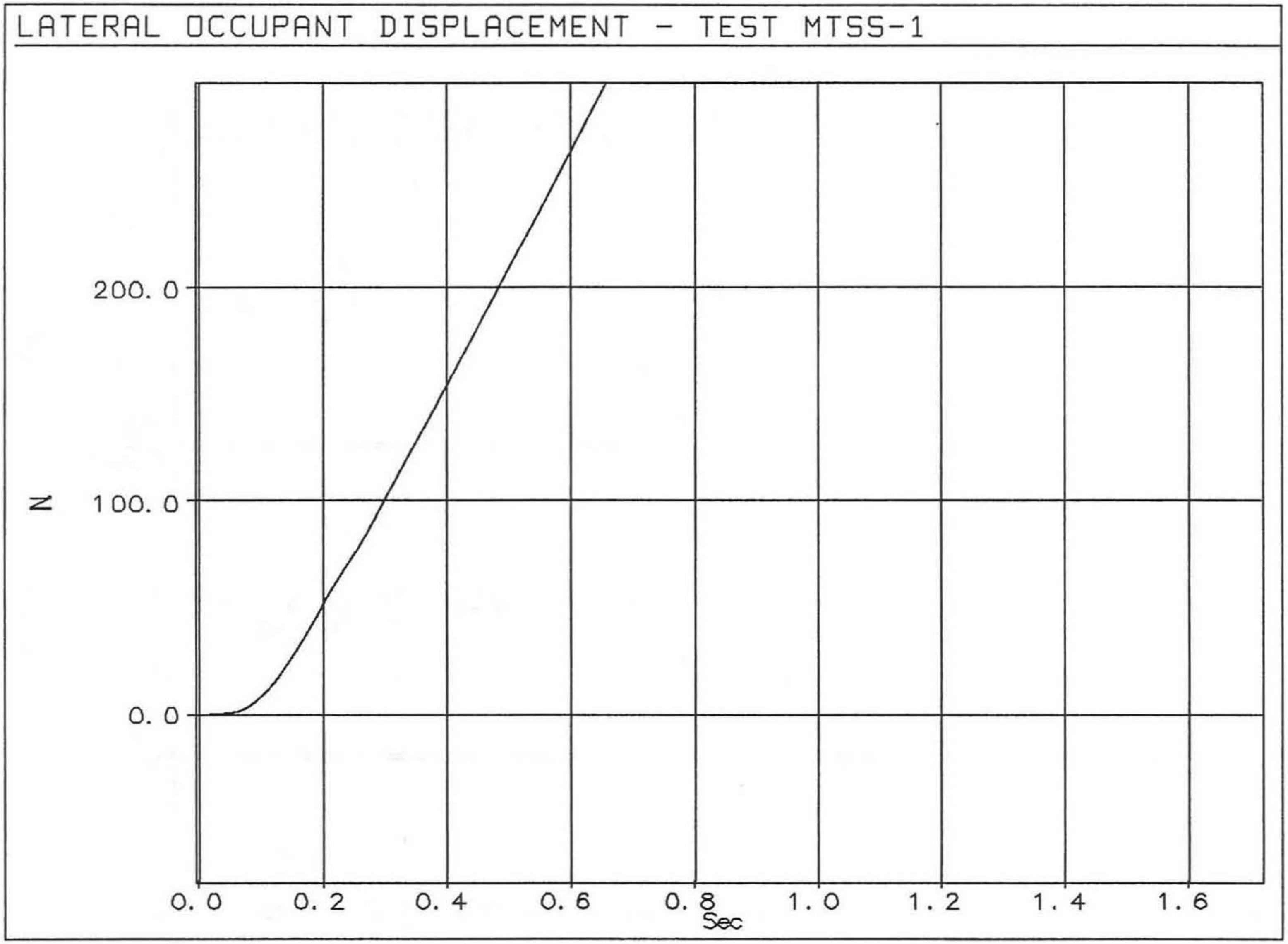


Figure D-6. Graph of Lateral Occupant Displacement

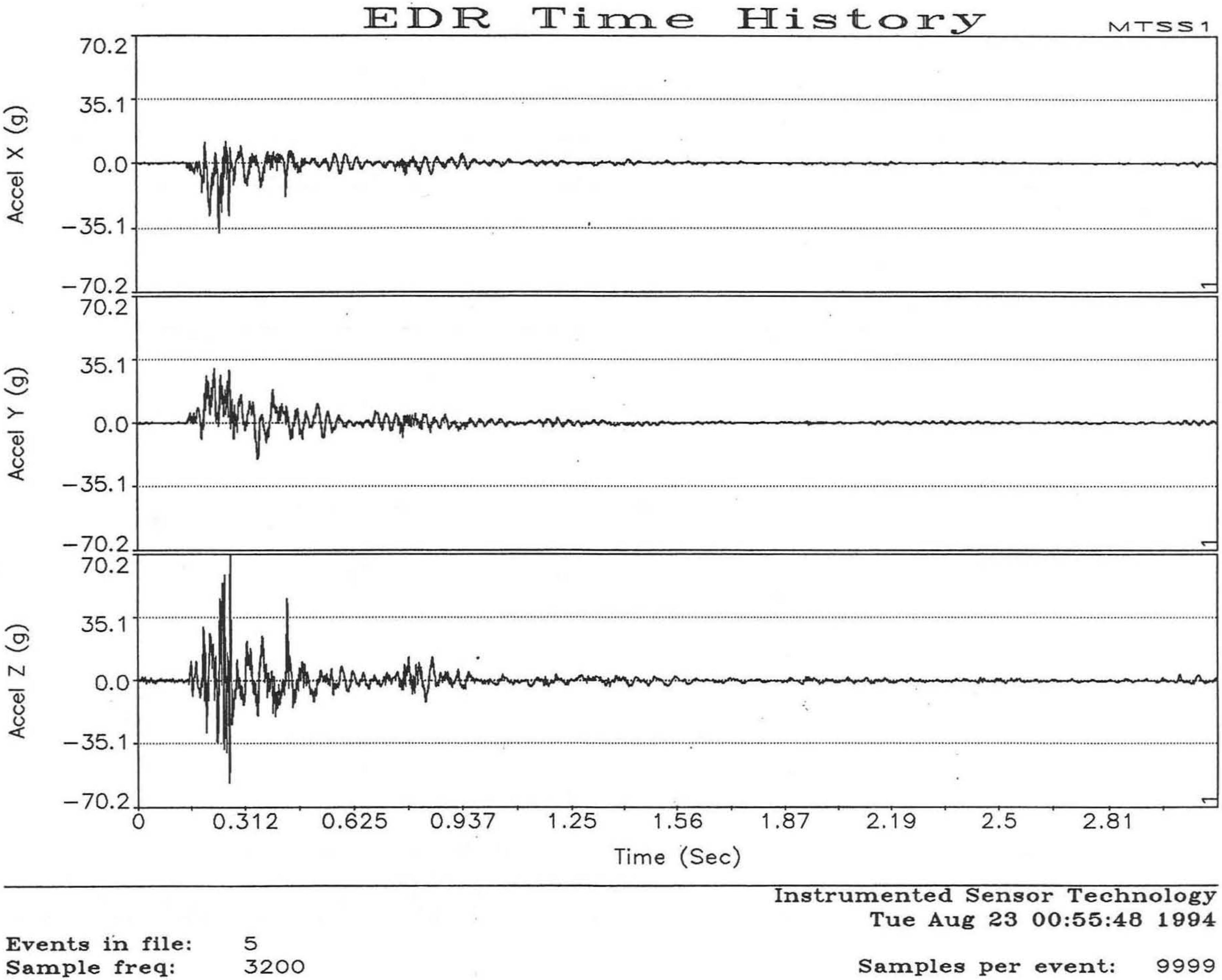


Figure D-7. EDR Time History, MTSS-1

ACCELEROMETER DATA ANALYSIS, MTSS-2

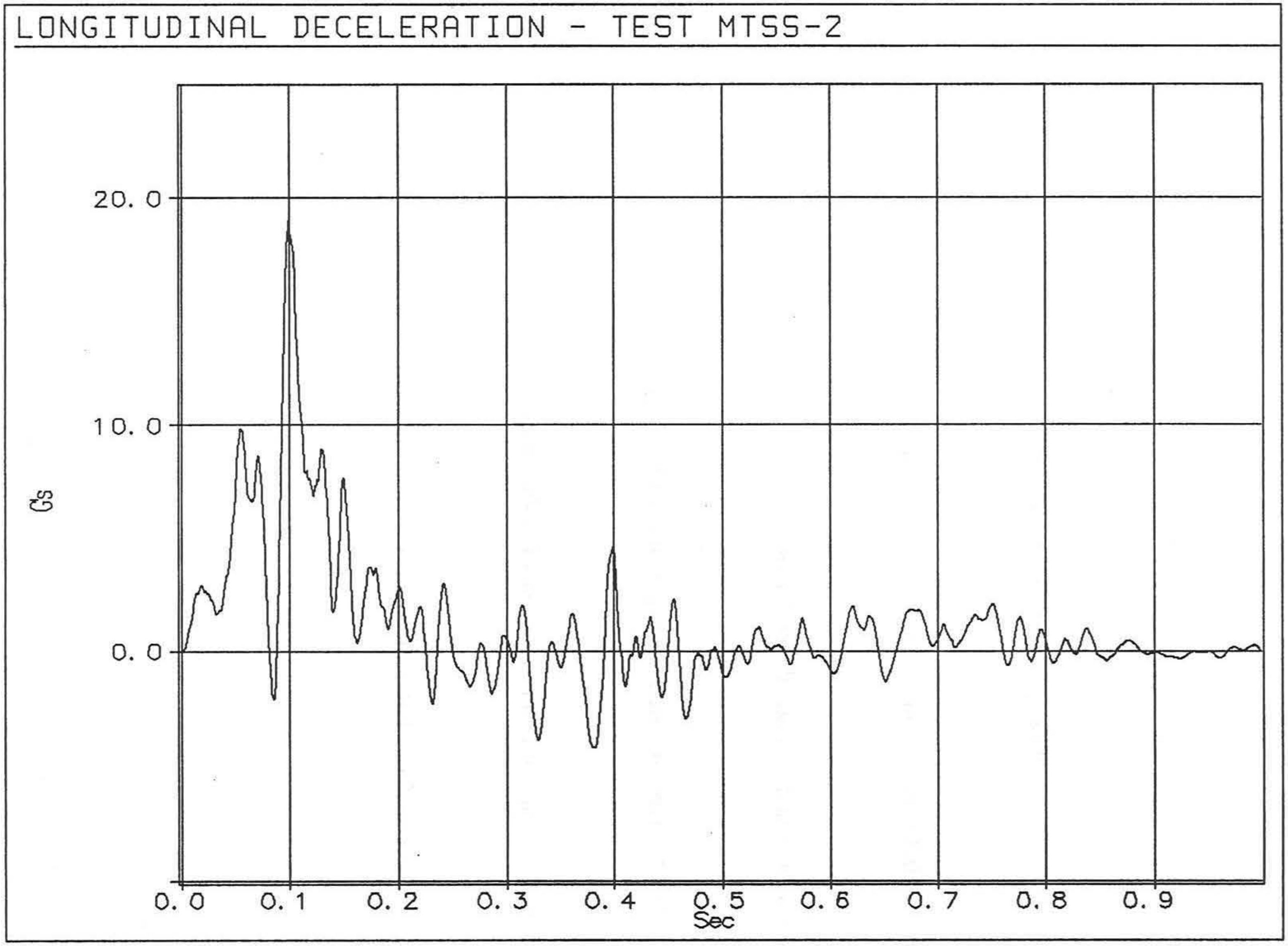


Figure D-8. Graph of Longitudinal Deceleration

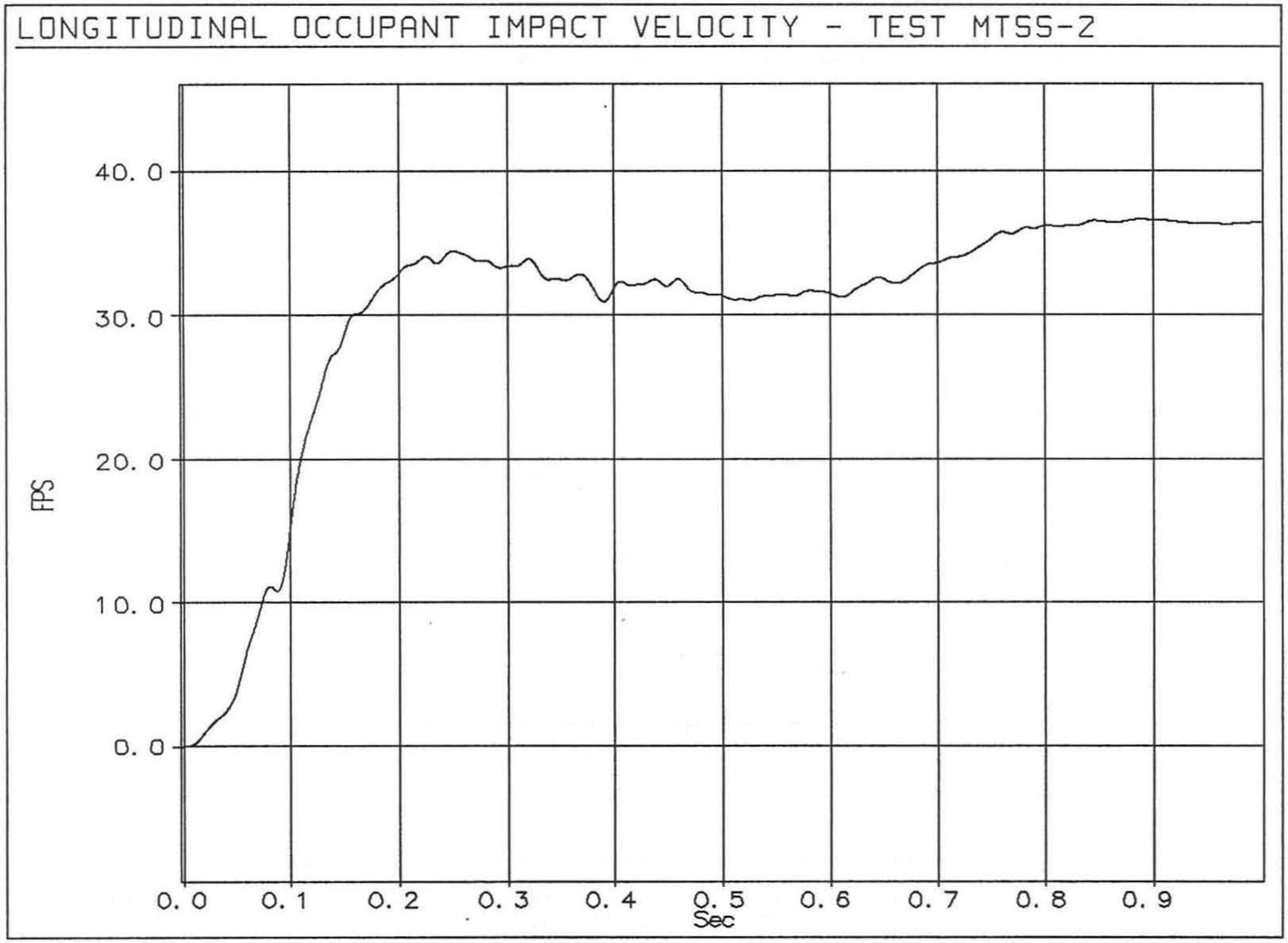


Figure D-9. Graph of Longitudinal Occupant Impact Velocity

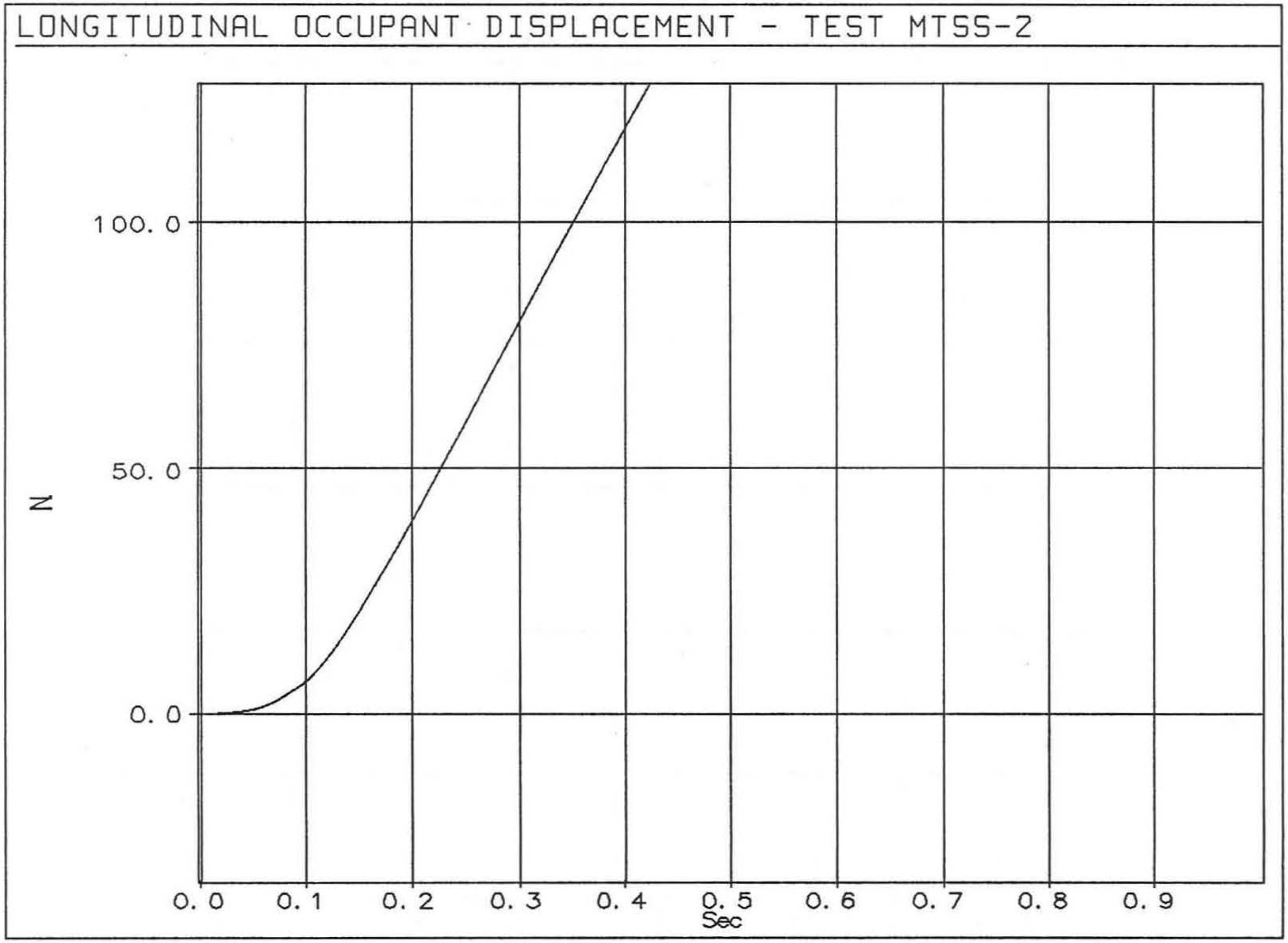


Figure D-10. Graph of Longitudinal Occupant Displacement

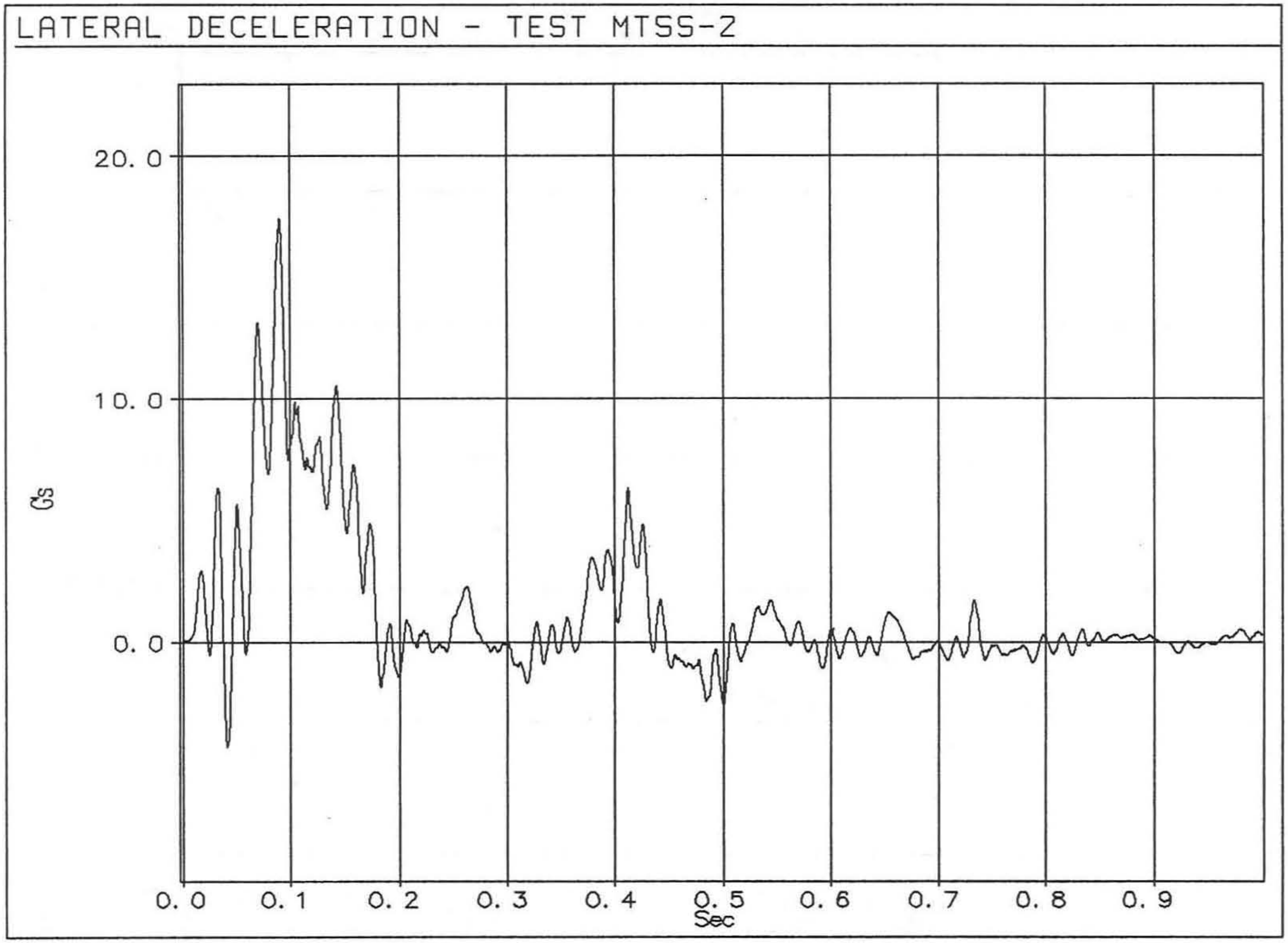


Figure D-11. Graph of Lateral Deceleration

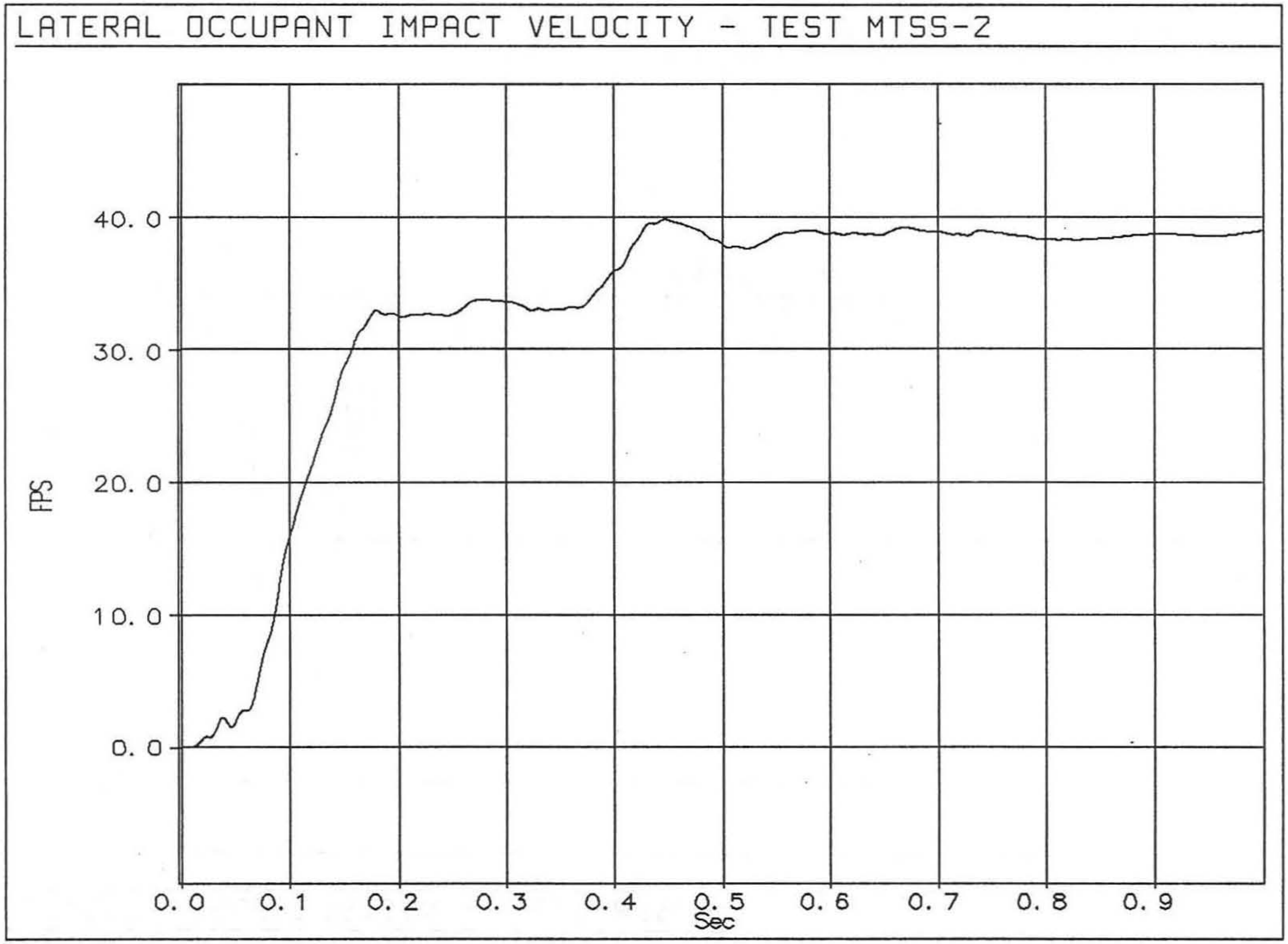


Figure D-12. Graph of Lateral Occupant Impact Velocity

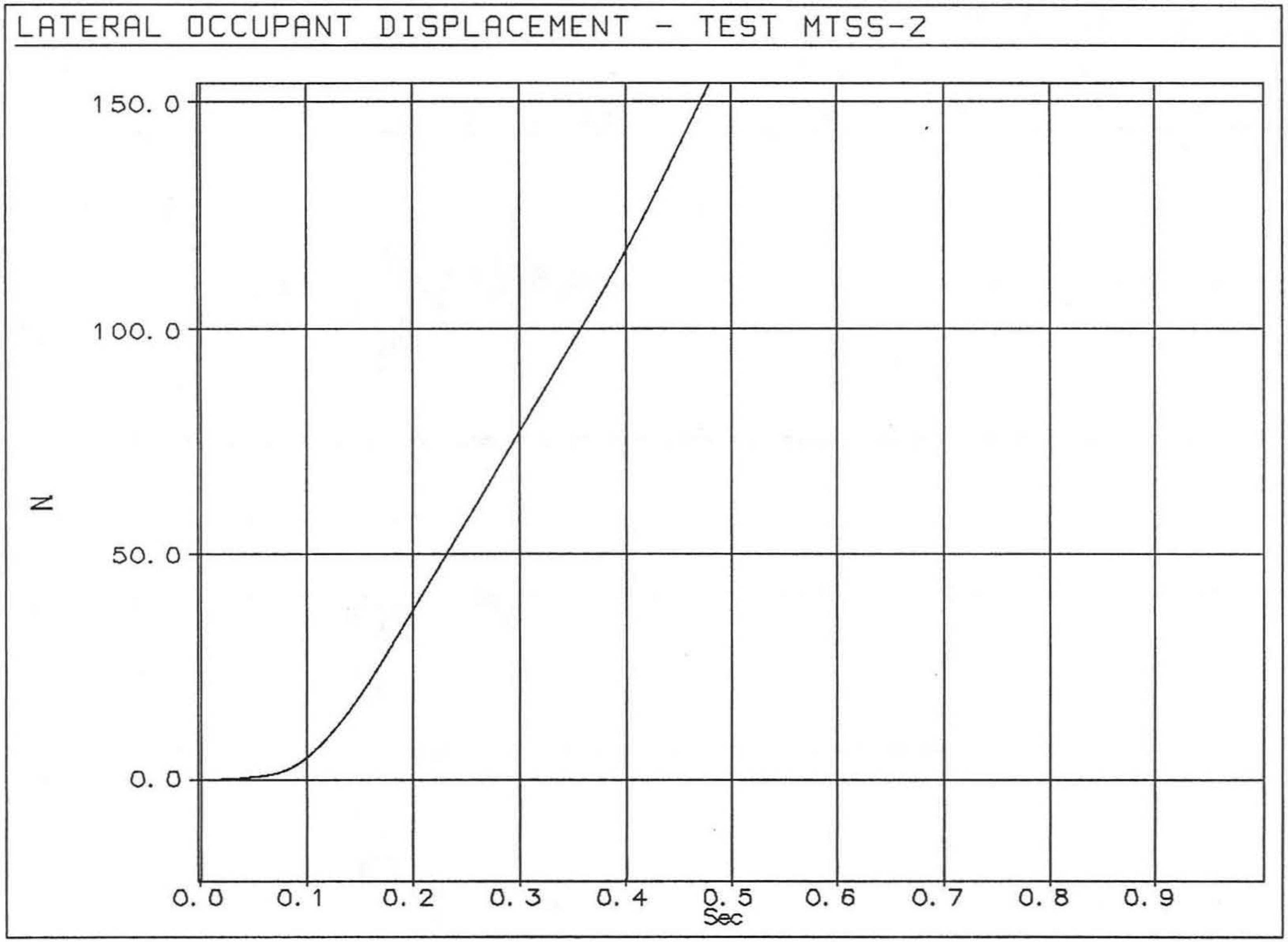


Figure D-13. Graph of Lateral Occupant Displacement

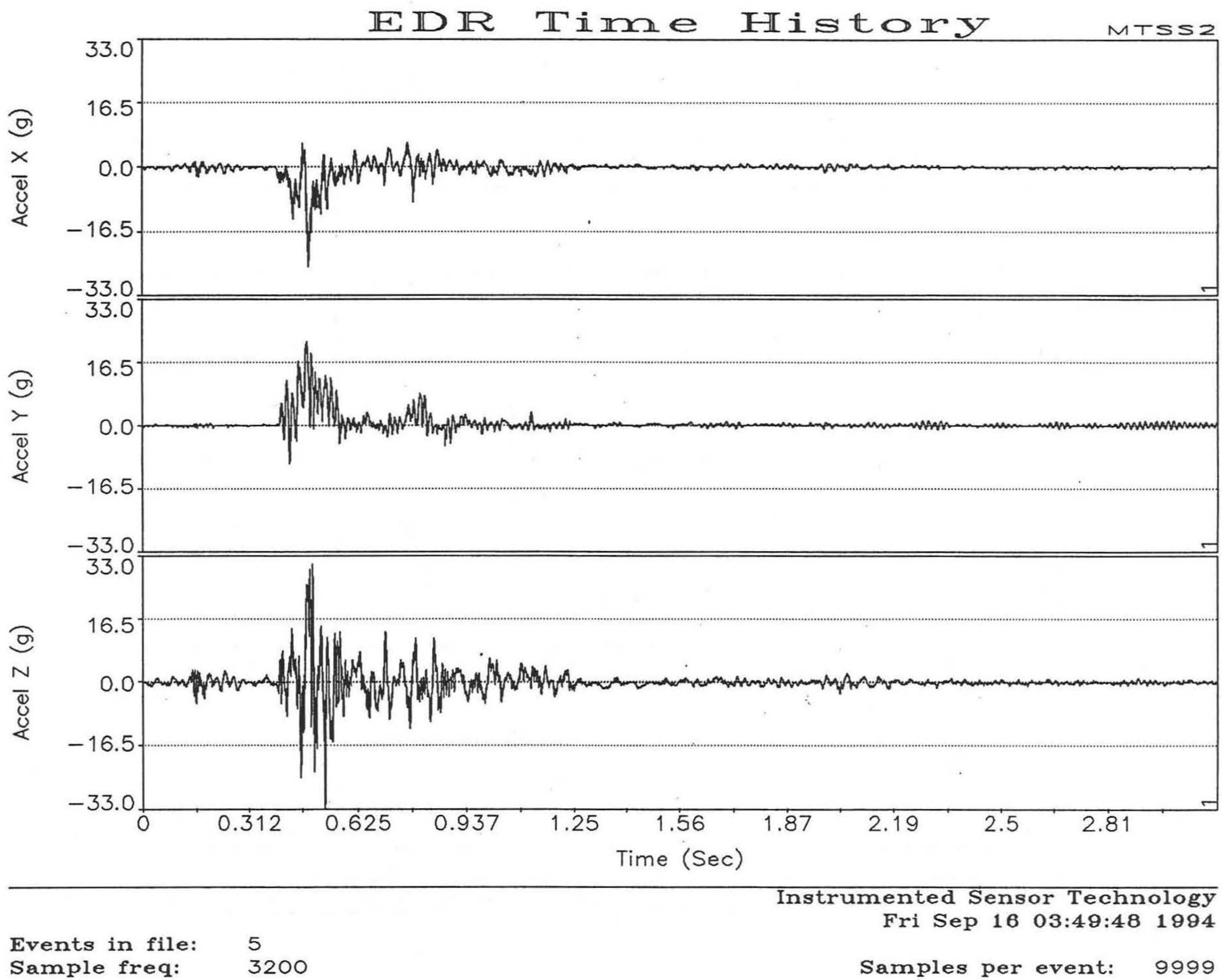


Figure D-14. EDR Time History, MTSS-2

APPENDIX E - TESTING EQUIPMENT

E.1 Vehicle Tow and Guidance System

A reverse cable tow system with a 1:2 mechanical advantage was used to propel the test vehicles. 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 (12) 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 9.5-mm (⅜-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 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 457 m (1,500-ft) long.

E.2 Test Vehicles

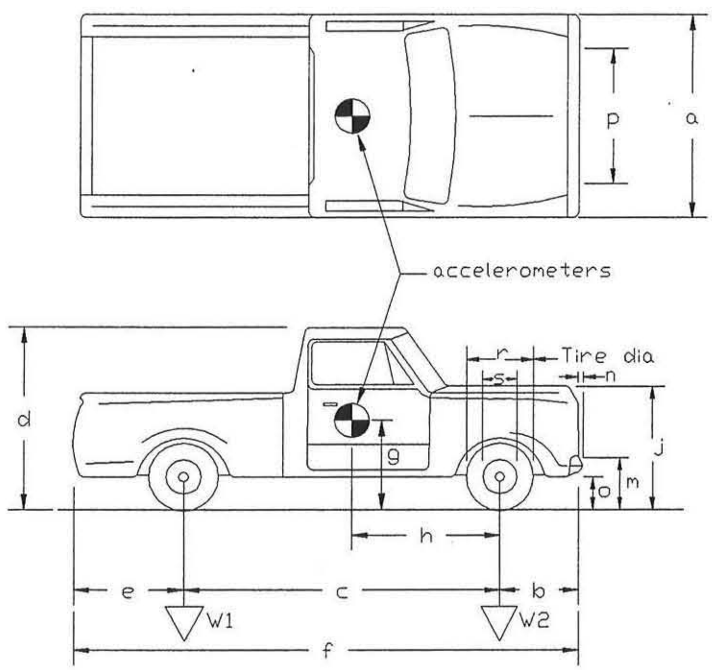
For test MTSS-1 and MTSS-2, 1985 Chevrolet C-20 2WD pickup trucks were used as the test vehicles. For tests MTSS-1 and MTSS-2, the test inertial and gross static weights were 4,504 lbs (2043 kg) and 4,484 lbs (2034 kg), respectively. The test vehicles are shown in Figure E-1 and vehicle dimensions are shown in Figure E-3 and E-4.

Figure E-1. Test Vehicles, MTSS-1 and MTSS-2

Date: 8/22/94 Test No.: MTSS-1 Model: C-20

Make: CHEVROLET Vehicle I.D.#: 1GCGC24MXF311219

Tire Size: P235/85R16 Year: 1985 Odometer: 132989



Vehicle Geometry - inches

a	77.5	b	33.5
c	132.0	d	72.5
e	49.5	f	215
g	29	h	57.5
i	———	j	45
k	———	l	———
m	27	n	4
o	18.5	p	66
r	31.5	s	18

Engine Type: V-8

Engine Size: 350 cu.in.(5.7L)

Transmission Type:

Automatic or Manual

FWD or RWD or 4WD

4 - wheel weight: lf____ rf____ lr____ rr____

Weight - pounds	Curb	Test Inertial	Gross Static
W1	1845	1963	1963
W2	2370	2541	2541
Wtotal	4215	4504	4504

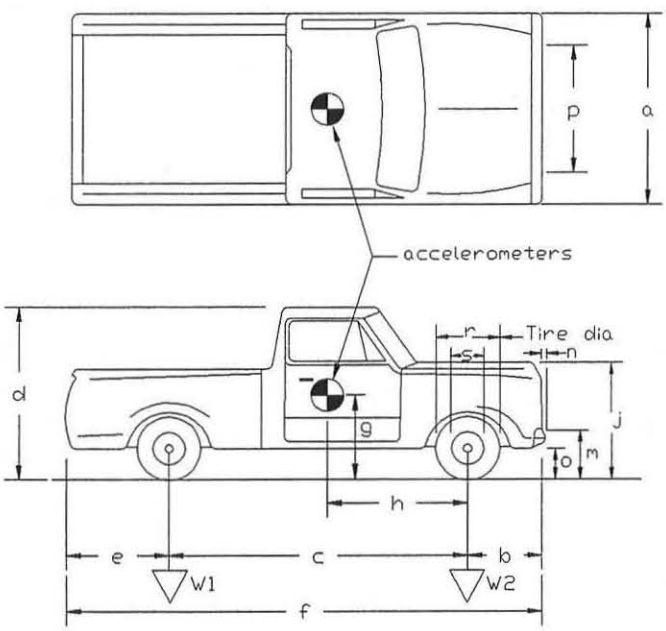
Note any damage prior to test: none

Figure E-2. Vehicle Dimensions and Weights, MTSS-1

Date: 9/15/94 | Test No.: MTSS-2 | Model: C-20

Make: CHEVROLET | Vehicle I.D.#: 1GCFC24H4FJ169065

Tire Size: P215/85R16 | Year: 1985 | Odometer: 132571



Vehicle Geometry - inches

a	77	b	28
c	133	d	71
e	47	f	212
g	28	h	55
i	—	j	48.5
k	—	l	—
m	25.75	n	4
o	17.5	p	66
r	29.5	s	17.5

Engine Type: V-8

Engine Size: 350 cu in(5.7L)

Transmission Type:

Automatic or Manual

FWD or RWD or 4WD

4 - wheel weight: lf____ rf____ lr____ rr____

Weight - pounds	Curb	Test Inertial	Gross Static
W1	1760	1866	1866
W2	2470	2618	2618
Wtotal	4230	4484	4484

Note any damage prior to test: none

Figure E-3. Vehicle Dimensions and Weights, MTSS-2

Vehicle ballast consisted of steel plates rigidly attached to the floor of the test vehicles. Eight square, black and white-checkered targets were placed on the vehicles to aid in the analysis of the high-speed film, as shown in figures 1 through 3. Two targets were placed on the center of gravity, one on the top and one on the driver's side of the vehicles. 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 vehicles were aligned for camber, caster, and toe-in values of zero so that the vehicles would track properly along the guide cable. Two 5B flash bulbs were mounted on the hood of the vehicles 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.

E.3 Data Acquisition Systems

E.3.1 Accelerometers

Two triaxial piezoresistive accelerometer systems with a range of ±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 by radiotelemetry to the Honeywell 101 Analog Tape Recorder. Computer software, "EGAA" and "DSP" were used to digitize, analyze, and plot the accelerometer data.

E.3.2 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 vehicles. The rate transducer was rigidly attached to the vehicles 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.

E.3.3 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 for test MTSS-1 and MTSS-2 is shown in Figures E-4 and E-5 respectively. A Bolex camera, with an operating speed of approximately 64 frames/sec, was used as a documentary camera. A 3.05-m (10-ft) wide by 4.57-m (15-ft) long, white-colored grid was painted on the surface on the traffic side of the bridge rail. This grid was incremented in 1.52-m (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.

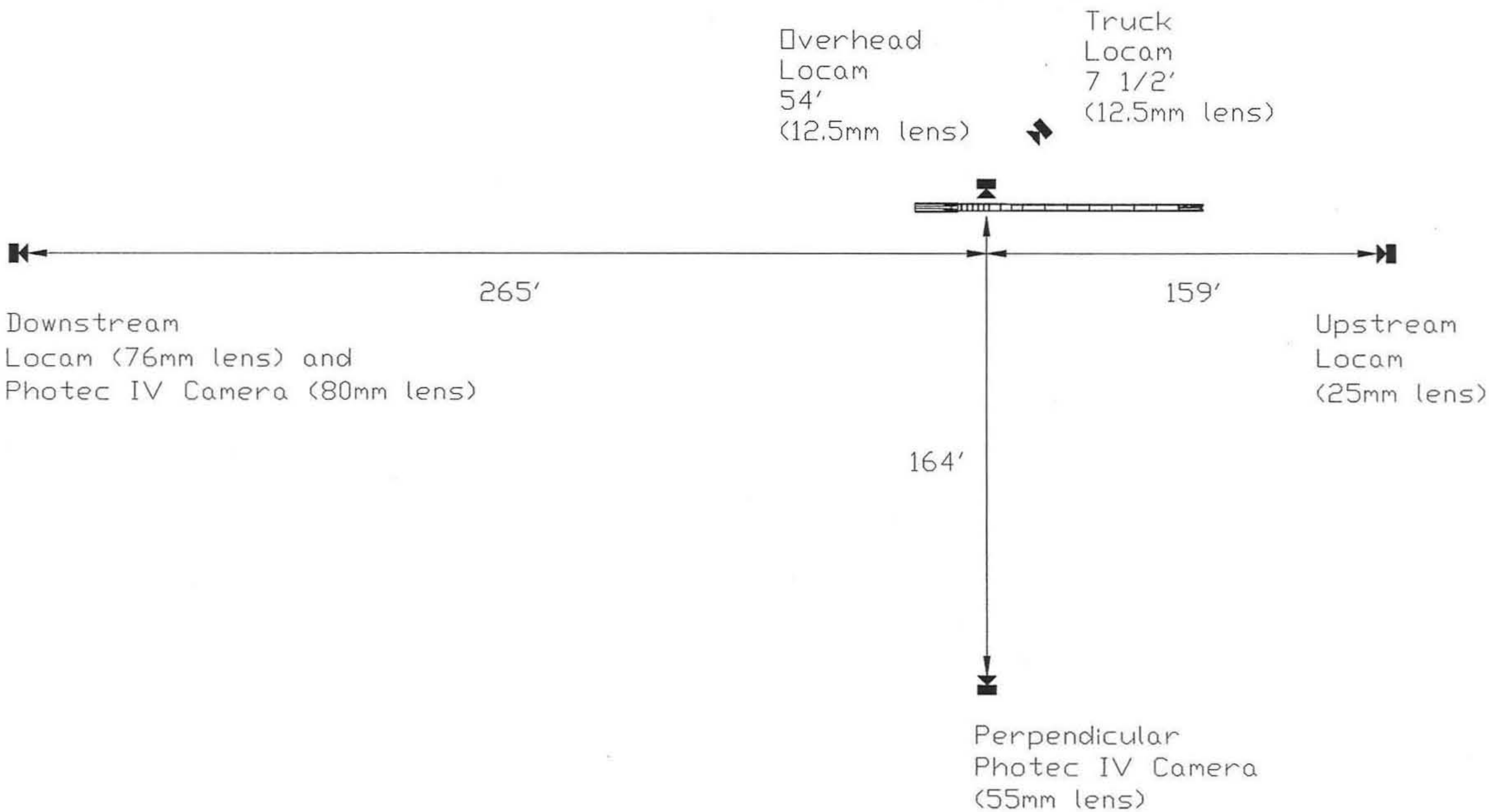


Figure E-4. Location of High-Speed Cameras, Test MTSS-1

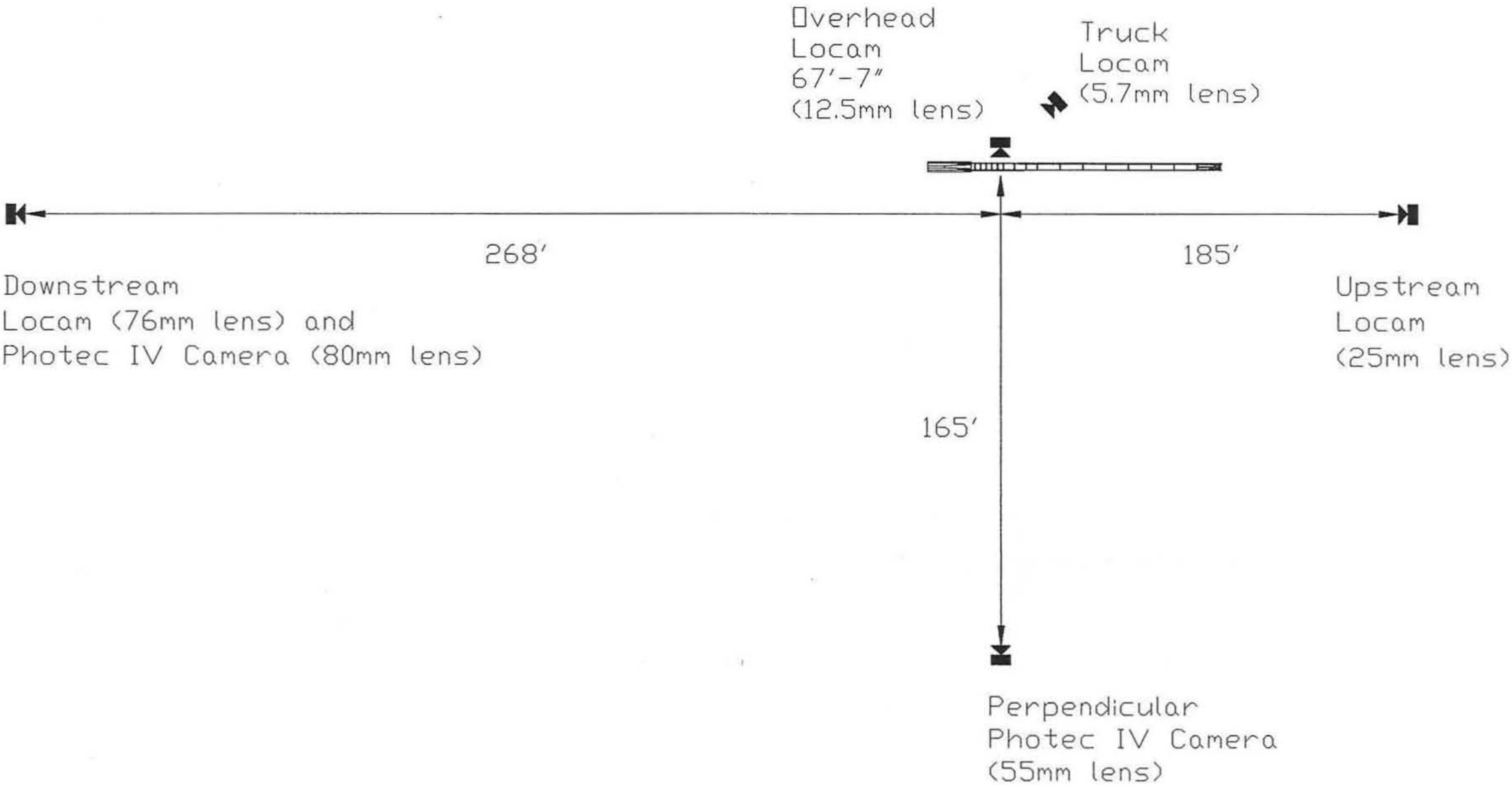


Figure E-5. Location of High-Speed Cameras, Test MTSS-2

E.3.4 Speed Trap Switches

Seven pressure-activated tape switches, spaced at 1,520-mm (5-ft) intervals, were used to determine the speed of the vehicles 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.