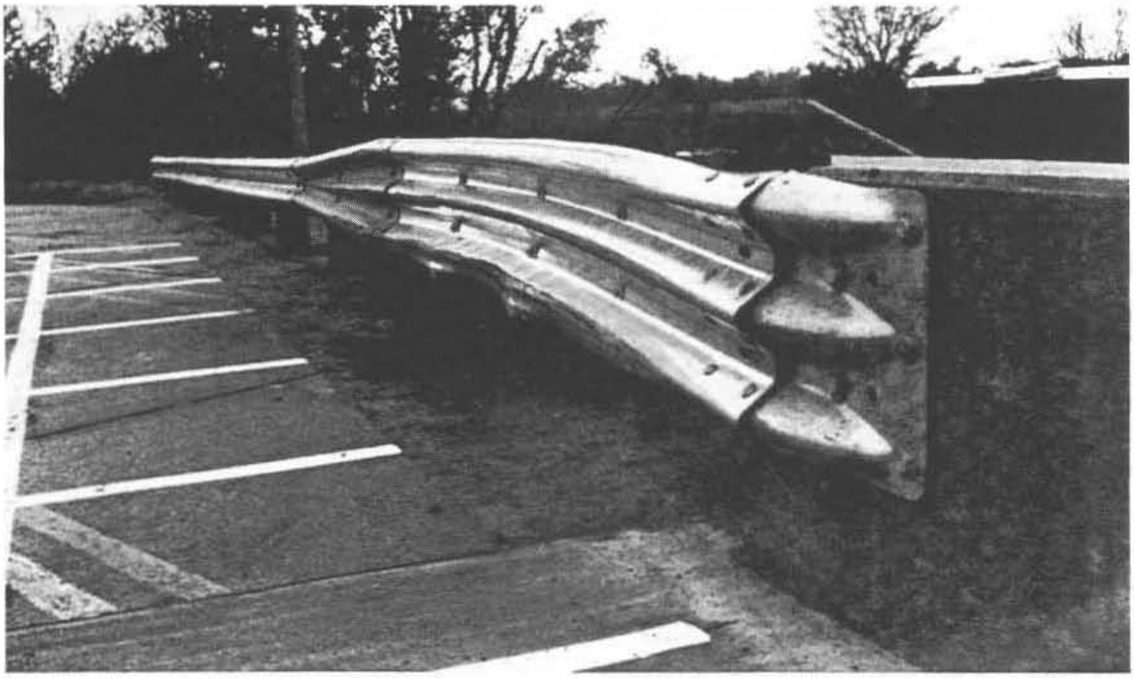
# FULL-SCALE VEHICLE CRASH TESTS
# on
# GUARDRAIL-BRIDGERAIL TRANSITION DESIGNS
# with
# SPECIAL POST SPACING



by
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*Sponsored by*
Nebraska Department of Roads
HP&R 86-2

*in cooperation with*
U.S. Department of Transportation
Federal Highway Administration

TRANSPORTATION RESEARCH REPORT TRP-03-008-87

Civil Engineering Department
W348 Nebraska Hall
University of Nebraska–Lincoln
Lincoln, Nebraska
68588-0531

May 1987

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.
NE-DOR-R87-2

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
Full-Scale Vehicle Crash Tests on Guardrail-Bridgerail Transition Design With Special Post Spacing

5. Report Date
May 1987

6. Performing Organization Code

7. Author(s)
Dr. Edward R. Post, P.E.

8. Performing Organization Report No.
TRP-03-008-87

9. Performing Organization Name and Address
Civil Engineering Department
W348 Nebraska Hall
University of Nebraska-Lincoln
Lincoln, NE 68588-0531

10. Work Unit No.

11. Contract or Grant No.
HPR 86-2

12. Sponsoring Agency Name and Address
Roadway Design Division
Nebraska Department of Roads
P.O. Box 94759
Lincoln, NE 68509

13. Type of Report and Period Covered
Final Report

14. Sponsoring Agency Code

15. Supplementary Notes
Prepared in cooperation with U.S. Department of Transportation, Federal Highway Administration

16. Abstract

Full-scale 4,500 lb. vehicle impact tests at 60 mph and 25 deg. were conducted on four new guardrail-bridgerail "transition" designs for use in Nebraska in which the first wood post from the bridge end was left out. The post was left out to represent a common field problem in which a concrete footing prevents the installation of the post. To compensate for the post left out, a stronger beam member and heavier wood posts were used in addition to a 4:1 tapered-end on the end of the concrete bridgerail. The tapered-end was used to (1) reduce the unsupported span length, and (2) provide a smooth guardrail deflection curve during vehicle redirection. All of the transition designs were identical except for the transition beam member. The designs consisted of 2 heavy 10 in. x 10 in. posts followed by 4 heavy 8 in. x 8 in. posts. The remaining posts were standard 6 in. x 8 in. posts. Over a guardrail length of 18 ft.-9 in., the posts were spaced 3 ft.-1 1/2 in. centers, whereas, over the remaining length, a standard post spacing of 6 ft.-3 in. was used. The posts were installed in a "native" silty-clay (type CL) soil. In terms of the evaluation guidelines in NCHRP 230, the overall performance of the transition designs were: .

- * Single Thrie Beam Transition . . . . . Unsatisfactory
- * Double Thrie Beam Transition . . . . . Satisfactory
- * Tubular Thrie Beam Transition . . . . Satisfactory
- * Double W-Beam Transition . . . . . . . . Unsatisfactory

17. Key Words
Guardrail Transitions, Crash Tests, Roadside Safety

18. Distribution Statement

19. Security Classif. (of this report)
Unclassified

20. Security Classif. (of this page)
Unclassified

21. No. of Pages
140

22. Price

Form DOT F 1700.7 (8-69)

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# NOMENCLATURE

AASHTO ... American Association of State Highway and Transportation Officials

NCHRP .... National Cooperative Highway Research Program

NDR ..... Nebraska Department of Roads

NSC ..... National Safety Council

# ACKNOWLEDGEMENTS

As the principal investigator, I would like to acknowledge and thank the following people who made a contribution to the successful outcome of this research project.

## Nebraska Department of Roads

Mark Borgmann (Bridge Design Division)
Kenneth Cheney (Materials and Test Division)
Leona Kolbet (Materials and Test Division and Research Coordinator)
Robert Miller (Manager of Purchasing and Supply)
Ron Morton (Materials and Tests Division)
Dalyce Ronnau (Materials and Test Division and Research Engineer)
Richard Ruby (Roadway Design Division and Project Manager)
Dan Sharp (Bridge Design Division)
Walter Witt (Roadway Design Division)
George Woolstrum (Materials and Tests Division)

## Federal Highway Administration

Milo Cress (Lincoln Division Office)
Charles McDevitt (Wash. D.C. Office of Research)
William Wendling (Kansas City Regional Office)

## University of Nebraska

Mike Cacak (Manager-Automobile Support Services)
Jerry Delhay (Manager-Maintenance)
Jim Dunlap (Manager-Photographic Productions)
Gerald Fritz (E.E. Technician)
Tom Grady (E.E. Technician)
William Kelly (Professor and C.E. Chairman)
Steve King (C.E. Student)
Eugene Matson (C.E. Technician)
Mary Lou Tomka (C.E. Administrative Assistant)
Vince Ullman (Photographic Technician)
Bruce Wacker (C.E. Student)
Mary Lou Wegener (C.E. Secretary)

# I.

# INTRODUCTION

## A. PROBLEM STATEMENT

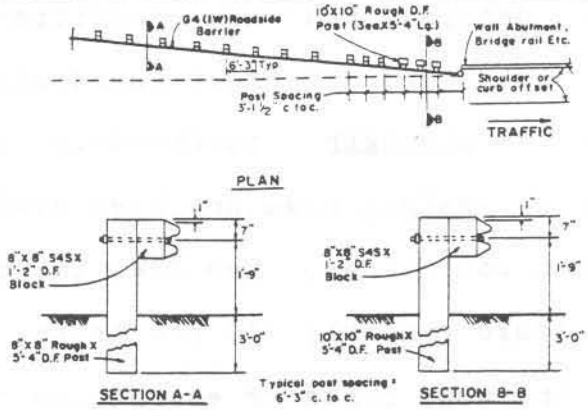
The majority of the bridgerail designs in current use are rigid traffic barriers, whereas, the guardrail designs on the approaches to the bridge structure are semi-rigid traffic barriers. In restraining and redirecting a large size 4,500 lb. automobile at 60 mph and 25 deg., a rigid and semi-rigid traffic barrier will typically undergo deflections of 0 to 6 in. and 30 in., respectively. To provide structural stiffness compatibility between the semi-rigid guardrail and the rigid bridgerail, a guardrail transition section consisting of reduced post spacings and larger size posts is used adjacent to the bridgerail end. A current AASHTO (1)[a] transition section is shown in Figure 1. Referring to Figure 1, it is to be noted that the first 6 wood posts back from the bridgerail end are installed on a reduced spacing of 3 ft-1 1/2 in., and the first 3 wood posts are larger size 10 in. x 10 in. posts.

Many of the bridge structures in the State of Nebraska were constructed with concrete footings that extend back from the end of the bridgerail. The footing has created a field problem in that the first required 10 in. x 10 in. wood post located 3 ft.-1 1/2 in. from the bridgerail end connection as shown in Figure 1 cannot be installed in the ground. In order to compensate for the first post left out or installed further back, the Nebraska Department of Roads

---

[a] Underlined number is a reference source

**Table III-B-3. Operational Roadside Barrier Transition Sections**

|  |  |  |
|---|---|---|
| **Metric Conversions**<br>1 ft. = 0.305 m<br>1 in. = 25.4 mm<br>1 mph = 1.61 km/hr<br>1 lb. = 0.454 kg |  |  |
| SYSTEM | T1<br>G4(1W) Approach Rail to Concrete Parapet |  |
| BARRIER DESCRIPTION | POST SPACING - as shown on sketch; POST TYPE - 8"x8" and 10"x10" Douglas Fir; BEAM TYPE - steel "W" section, 12 GA.; OFFSET BRACKETS - 8"x8" Douglas Fir block; MOUNTINGS - 1" diameter steel bolt; FOOTINGS - none. |  |
| IMPACT PERFORMANCE | IMPACT ANGLE = 15° | IMPACT ANGLE = 25° |
| IMPACT CONDITIONS |  |  |
| Speed (mph) | NO TEST | 58.8 |
| Vehicle Weight (lb.) |  | 4297 |
| BARRIER |  |  |
| Dynamic Deflection (ft.) |  | UNAV |
| VEHICLE ACCELERATIONS (G's)[1] |  |  |
| Lateral |  | 19.0 |
| Longitudinal |  | 8.8 |
| Total |  | UNAV |
| VEHICLE TRAJECTORY |  |  |
| Exit Angle (deg.) |  | UNAV |
| Roll Angle (deg.) |  | UNAV |
| Pitch Angle (deg.) |  | UNAV |
| BARRIER DAMAGE |  | UNAV |
| REFERENCES |  | 18 |
| FIELD PERFORMANCE DATA[2] | NO |  |
| REMARKS | Severe vehicle damage. System that was tested had no flare. |  |

UNAV — unavailable

[1] 50 millisecond average unless otherwise noted

[2] If available, see summary in Appendix A

Figure 1

AASHTO APPROVED GUARDRAIL-BRIDGERAIL TRANSITION DESIGN

(NDR) has designed four new transition sections consisting of longer 6 ft. posts and stronger guardrail beam members. Because the structural strength performance characteristics of the new transition designs have not been evaluated under full-scale vehicle crash test conditions, the FHWA is concerned that an out-of-control vehicle could possibly (1) penetrate, (2) vault, or (3) pocket and snag on the wood posts or end of the bridgerail.

## B. OBJECTIVES OF RESEARCH STUDY

The primary objective of this study was to select the most cost-effective of four new guardrail-bridgerail transition designs based on the findings obtained from conducting full-scale vehicle crash tests. In all tests, the first 10 in. x 10 in. wood post located 3 ft.-1 1/2 in. back from the bridgerail end connection was left out. The four new transition designs under consideration were:

1. Single Thrie Beam (Figure 2a)
2. Double Thrie Beam (Figure 2b)
3. Tubular Thrie Beam (Figure 2c)
4. Double W-Beam (Figure 2d)

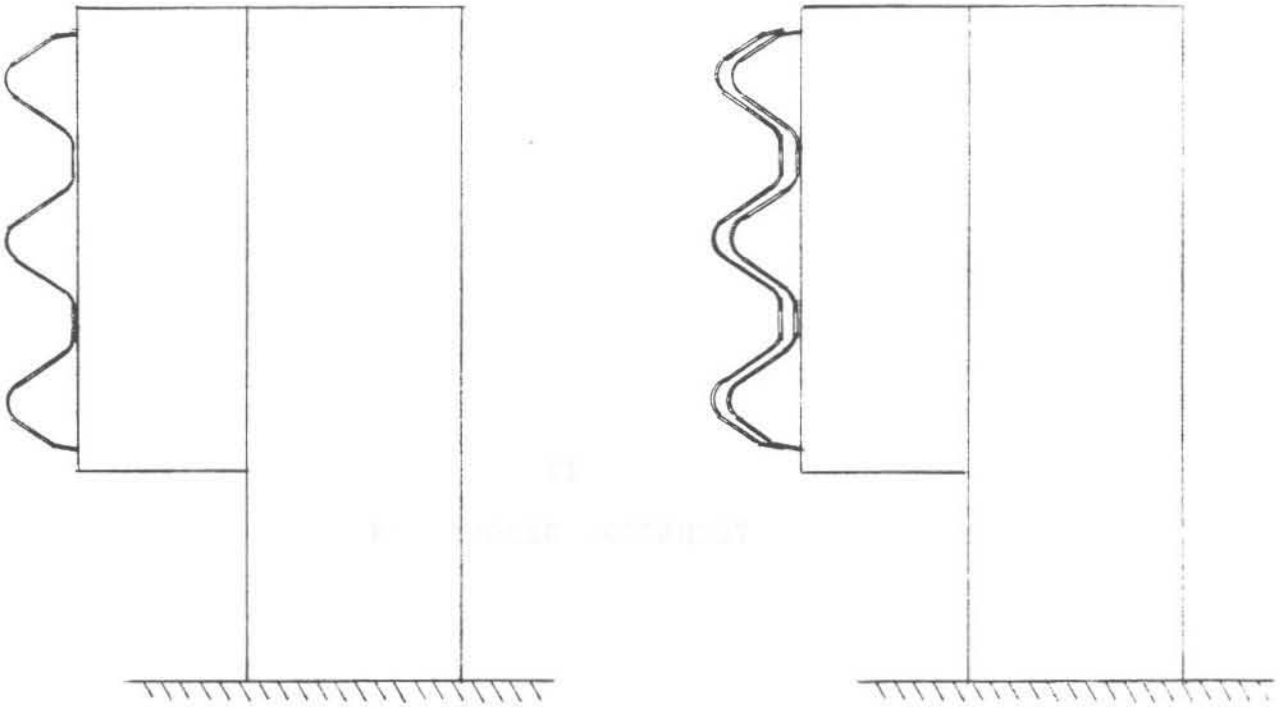


Figure 2a
SINGLE THRIE BEAM

Figure 2b
DOUBLE THRIE BEAM

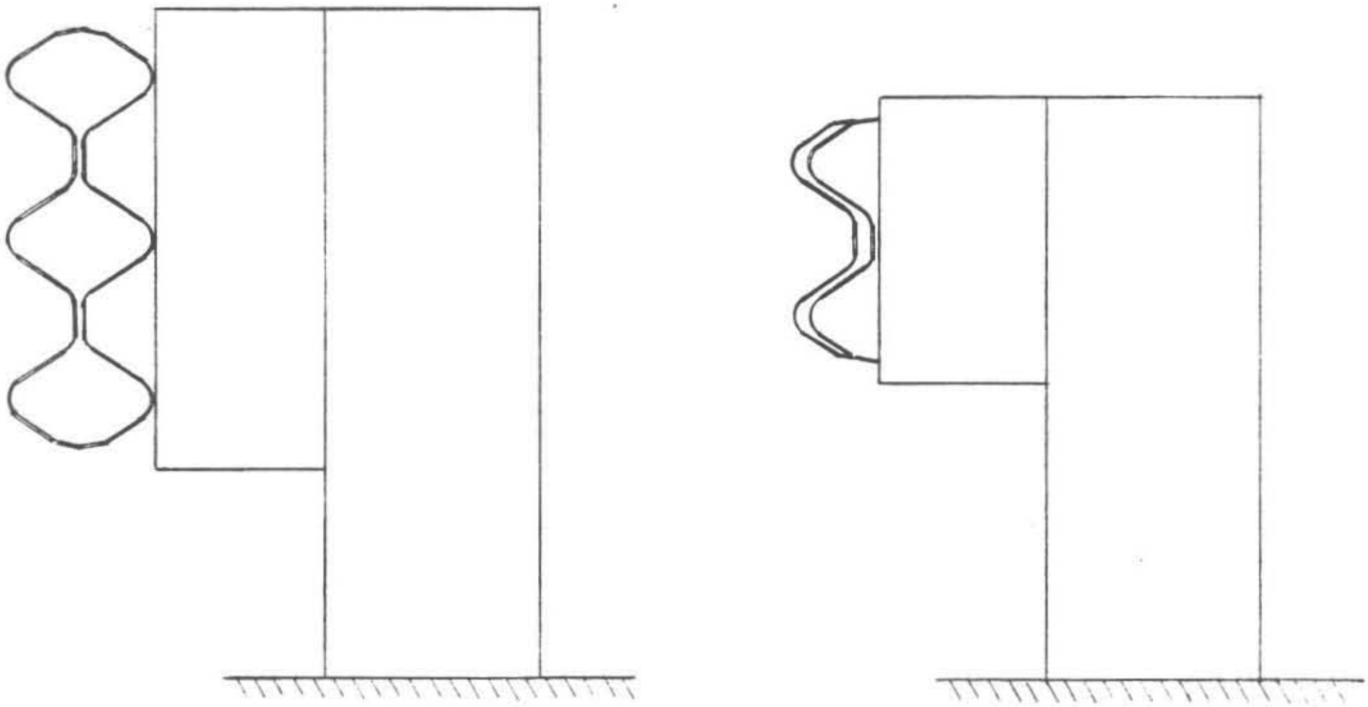


Figure 2c
TUBULAR THRIE BEAM

Figure 2d
DOUBLE W-BEAM

FIGURE 2
TRANSITION DESIGNS

# II

# TECHNICAL DISCUSSION

# A. TEST CONDITIONS

## A.1. TEST FACILITY

### Location

The full-scale vehicle crash test site was located at the Lincoln Municipal Airport near Rwy 14. The airport is approximately 7 mi. NW from the University. The test site consisted of a smooth level 30 ft. wide section of an abandoned concrete roadway.

### Cable Tow System

A cable tow system having a 2:1 mechanical advantage was used to tow the crash test vehicle. Photographs of the system are shown in Figure 3, and a detailed sketch of the system is shown in Figure 4. In this type of system, the test vehicle is travelling at a speed and distance that are exactly two times that of the tow vehicle.

One end of the tow cable was attached to a smooth vertical rod bolted to the front cross-frame member under the engine of the test vehicle, whereas, the other end was clamped to a dead-end anchor. The cable loop attached to the rod on the test vehicle was held-up in place with a piece of soft 18 Ga. wire. The tow cable was pulled down off the rod as the test vehicle passed over the pulley with a chute which was located about 25 ft. in advance of the barrier.

The towing vehicle was a 1981 Chevrolet Pickup truck with a large "454 cubic-inch" engine and a no-spin differential rear-end.

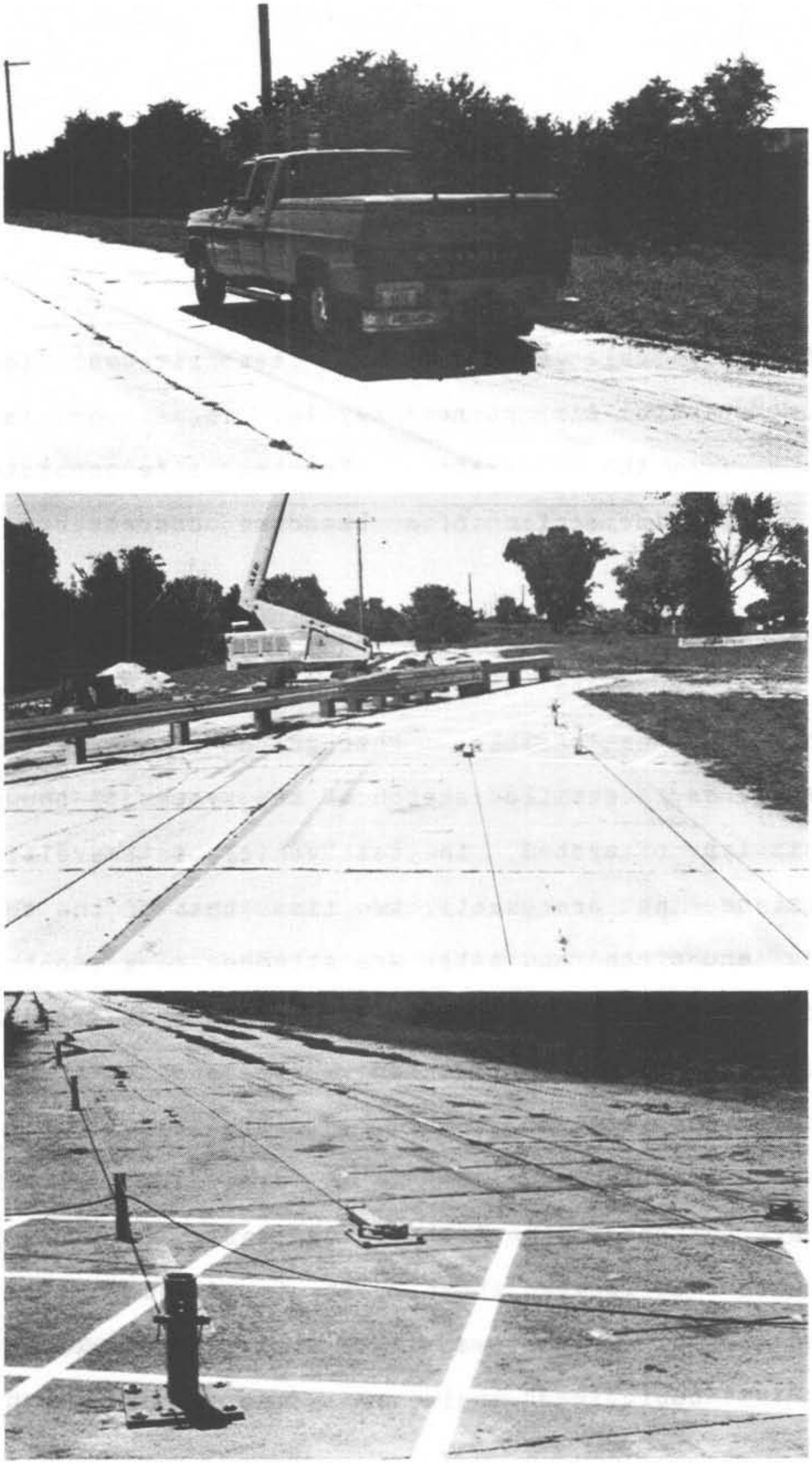


Figure 3
PHOTOGRAPHS OF CABLE TOW SYSTEM

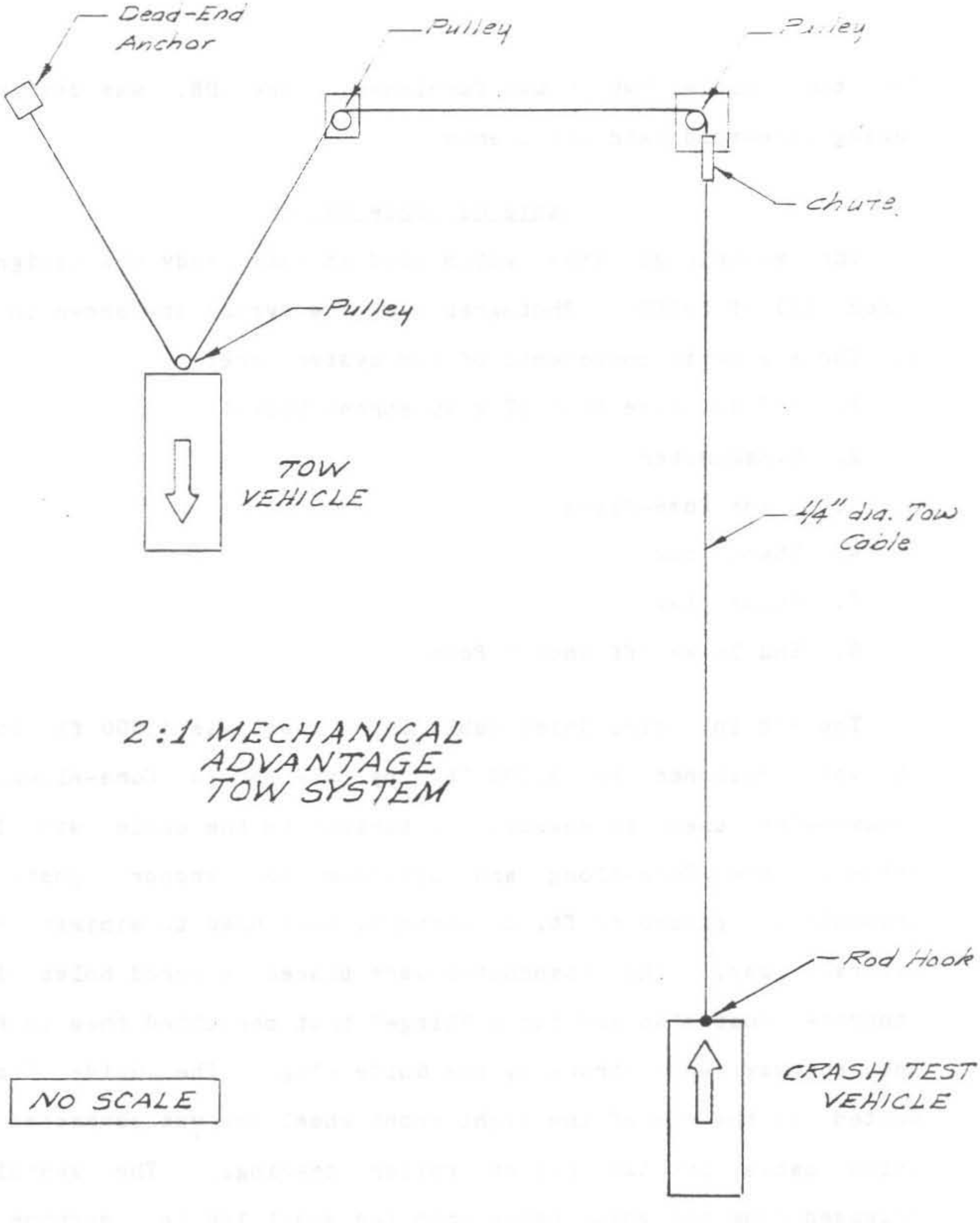


Figure 4

DETAILED SKETCH OF CABLE TOW SYSTEM

The tow vehicle, which was furnished by the NDR, was designed for making tire-road skid measurements.

## Cable Guidance System

The vehicle guidance system used in this study was designed by Hinch (2) of ENSCO. Photographs of the system are shown in Figure 5. The six basic components of the system were:

1. 3/8 in. Wire Rope (7 x 19 strand Galv.)
2. Dynamometer
3. 3-Ton Come-Along
4. Stanchions
5. Guide Flag
6. End Break-off Anchor Post

The 3/8 in. dia. Guide Cable (wire rope) was 1,000 ft. long and it was tensioned to 3,000 lb. by use of a Come-Along. The Dynamometer used to measure the tension in the cable was located between the Come-Along and upstream end anchor post. The stanchions, placed 50 ft. on centers, were used to minimize sag and lateral sway. The Stanchions were placed in cored holes in the concrete road slab and had a "hinge" that permitted them to fall to the roadway when struck by the Guide Flag. The Guide Flag was bolted to the rim of the right front wheel and was connected to the guide cable by two sets of roller bearings. The vehicle was released from the guide cable when two small 1/8 in. machine screws were sheared-off as the guide flag impacted the downstream end anchor post. The end anchor post was located so that the vehicle was

Figure 5
PHOTOGRAPHS OF CABLE GUIDANCE SYSTEM

"free-wheeling" for a distance of about 25 ft. before impacting the barrier.

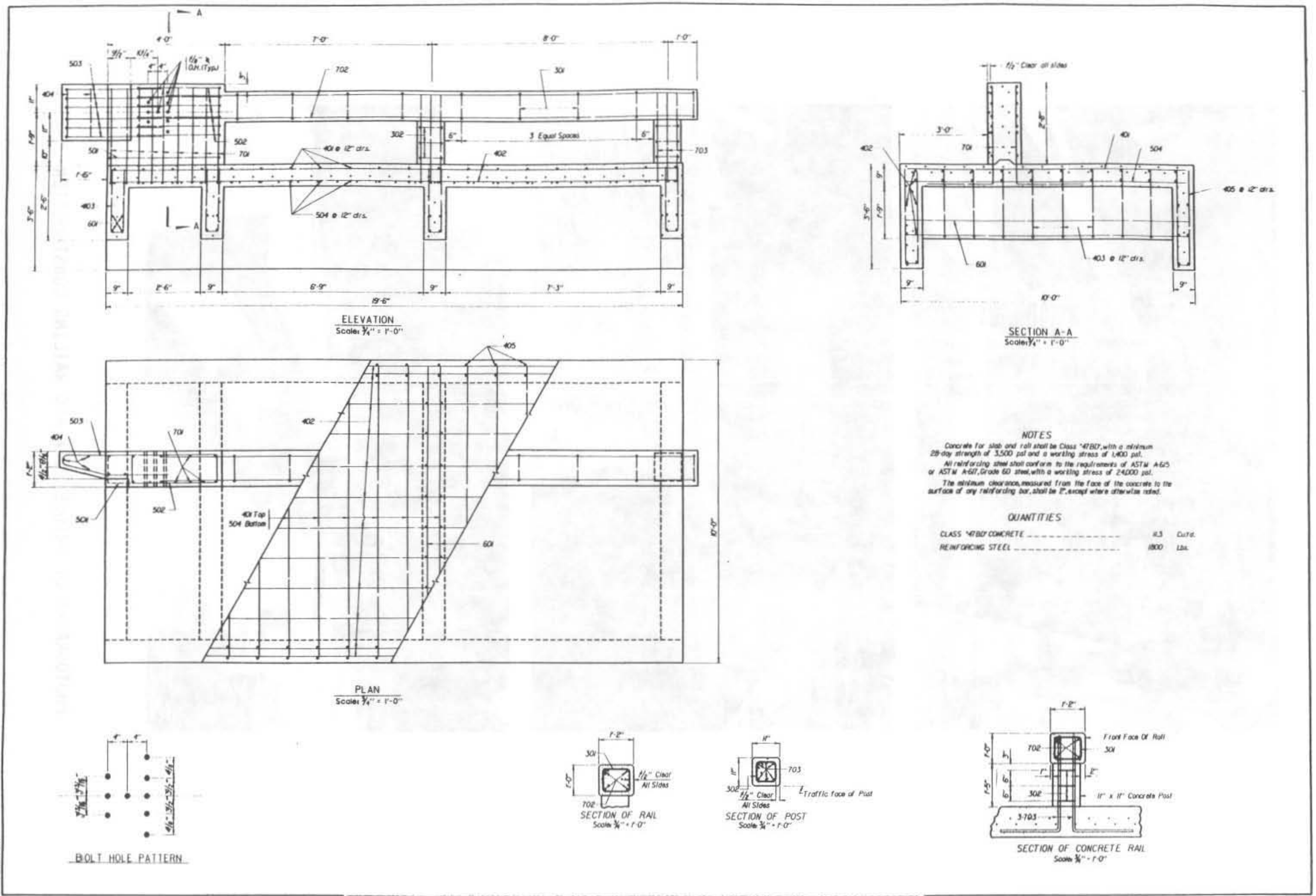
## A.2. DESIGN AND CONSTRUCTION OF TEST ARTICLE

### Simulated Bridge Deck and Railing

The simulated concrete bridge railing and deck were designed by the NDR Bridge Division. Design details of the bridge railing and deck are shown in Figure 6 and Appendix B, whereas, photographs of the construction are shown in Figure 7. The railing and deck were constructed by a private contractor who was qualified to bid on NDR bridge contracts. The name of the contractor was M.E. Collins Construction Co. of Wahoo, Nebraska.

The open bridge railing design is a recent design currently in use in Nebraska to help keep the roadway clear of blowing and drifting snow and to facilitate snow removal operations. The cantilevered 4:1 tapered end section was a totally new design feature that was recommended by McDevitt (4) of the FHWA as a method to (1) provide a smooth guardrail deflection curve in redirecting the test vehicle, and (2) reduce the effective unsupported span length to help compensate for the first wood post (Post No. 1) that was left out.

The concrete bridge railing and deck were designed to carry dynamic impact loads computed by the FHWA computer model, named BARRIER VII (5). The input and output data of the model are presented in Appendix C. The simultaneour peak impact loads were 120 kips perpendicular to the barrier and 50 kips parallel to the



### NOTES

Concrete for slab and rail shall be Class "47BD", with a minimum 28-day strength of 3,500 psi and a working stress of 1,400 psi.

All reinforcing steel shall conform to the requirements of ASTM A-615 or ASTM A-617, Grade 60 steel, with a working stress of 24,000 psi.

The minimum clearance, measured from the face of the concrete to the surface of any reinforcing bar, shall be 1", except where otherwise noted.

### QUANTITIES

| | | |
|---|---|---|
| CLASS "47BD" CONCRETE | 11.3 | Cu.Yd. |
| REINFORCING STEEL | 1800 | Lbs. |

Figure 6
DESIGN DETAILS OF SIMULATED

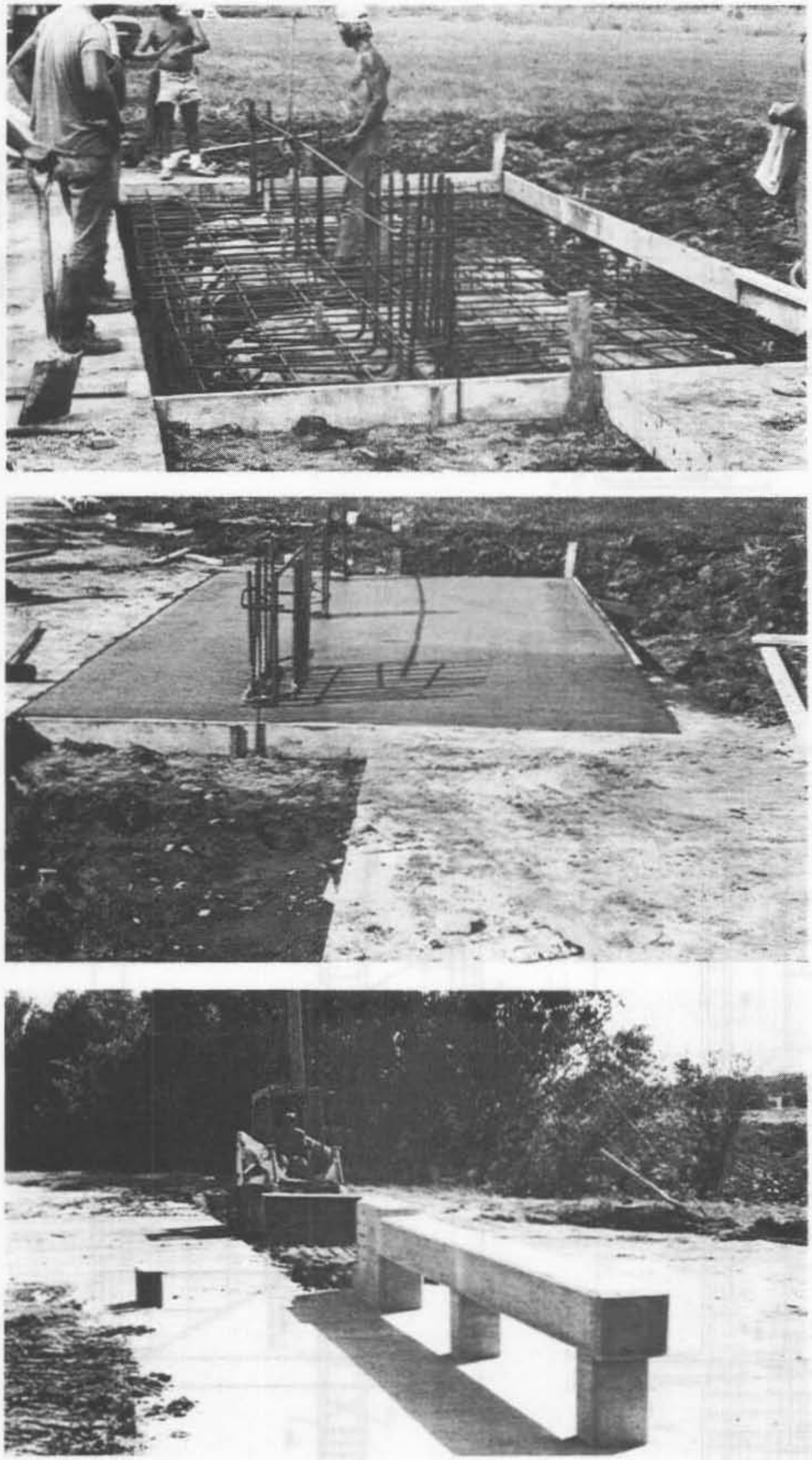


Figure 7

PHOTOGRAPHS OF BRIDGE DECK AND RAILING CONSTRUCTION barrier. It is to be noted that the perpendicular impact load is on the order of 12 times higher than the design load of 10 kips specified in the AASHTO Standard Specifications for Highway Bridges (6).

The concrete bridge deck slab was 9-in. deep, 10.0 ft. wide, and 19.5 ft. long. The two longitudinal floor beams were 42 in. deep, whereas, the four transverse floor beams were 21 in. deep. The deck slab and floor beams were reinforced with No. 6 and smaller size rebar (Grade 60) to carry the vehicle impact loads. The deck was constructed in a portion of an area where the concrete roadway slab had been sawcut and removed.

The concrete bridge railing, including the cantilevered 4:1 tapered end section, was 21.5 ft. long. The solid wall portion of the railing was 32 in. high, whereas, the beam portion was 29 in. high. The opening between the deck and railing was 17 in. in the vertical dimension. The two concrete posts, located 7 and 15 ft. from the solid wall portion, were setback 2 in. from the traffic face of the railing to minimize vehicle snagging. The 1 1/8 in. dia. bolt hole pattern in the railing wall was designed to accomodate the end shoes of both the Thrie Beam and the standard W-Beam guardrail sections. The 3 1/4 in. recessed area adjacent to the 4:1 tapered end section was designed to accomodate the added width of the tubular thrie beam guardrail. On the other hand, a 3 1/4 in. wide wood filler block was cut to fill the recessed area and to extend along the length of the tapered end section to accomodate the other non-tubular guardrail designs. The railing was reinforced with No. 7 and smaller size rebar (Grade 60) to carry the vehicle impact loads.

The compressive strength of concrete bridge deck at 14 days and the railing at 21 days exceeded the NDR specified minimum 28 day strength of 3,500 psi. The concrete cylinder strengths are presented in Table 1.

TABLE 1

CONCRETE COMPRESSIVE STRENGTH

| DAY | STRENGTH (psi) | |
|---|---|---|
| | Deck | Railing |
| 14 | 4,952 | 3,067 |
| | 5,164 | |
| 21 | | 4,174 |
| | | 4,025 |
| 25 | 5,801 | |
| | 5,518 | |

## Approach Guardrail

Design details of the combination W-Beam and Thrie Beam approach guardrail system are shown in Figure 8, and photographs of the installation are shown in Figure 9. The overall length of the guardrail installation was 56 ft.-3 in. A 6 ft. wide strip of the concrete roadway slab was sawcut and removed for the installation of

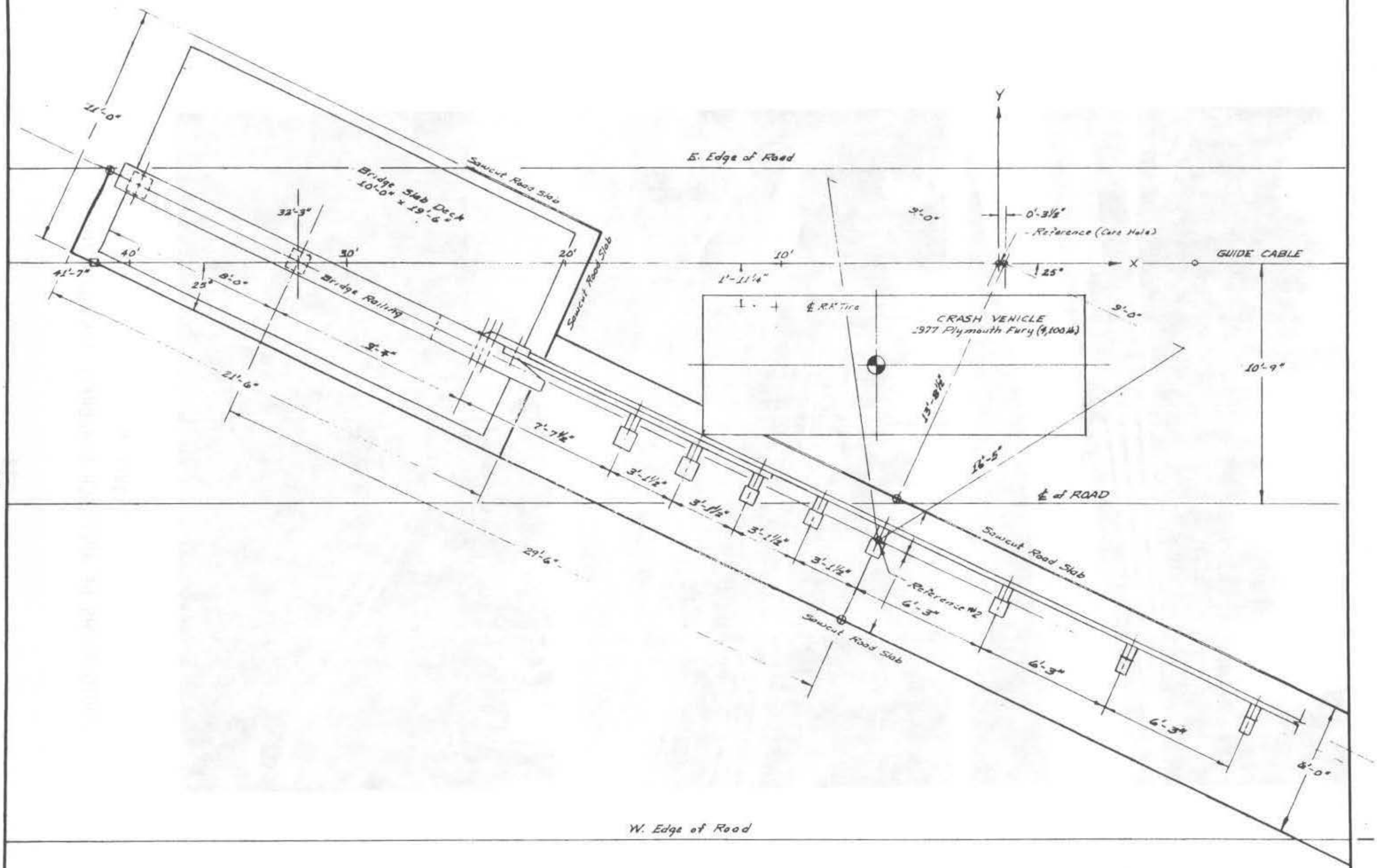


Figure 8
DESIGN DETAILS of APPROACH GUARDRAIL

TRAFFIC BARRIER LAYOUT

| | | |
|---|---|---|
| | SCALE 3/16" = 1'-0" | DRAWN BY E.K. Post<br>REVISED |
| DATE 6-20-86 | APPROVED BY | DRAWING NUMBER |

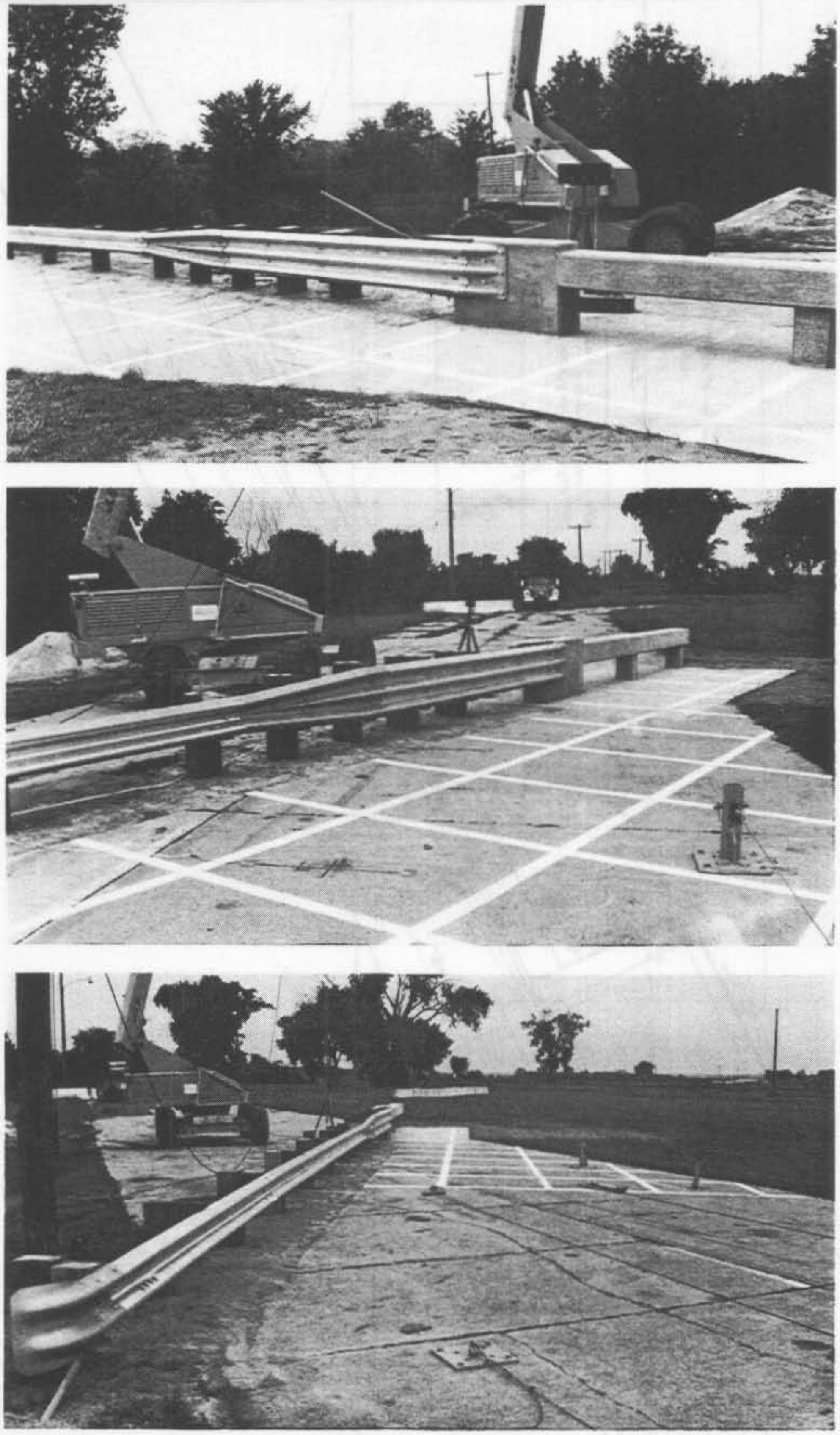


Figure 9
PHOTOGRAPHS OF APPROACH GUARDRAIL INSTALLATION

the guardrail in native soil. The guardrail was installed at an angle of 25 deg. relative to the centerline of the roadway.

The 12 Ga. Thrie Beam guardrail transition section adjacent to the end of the concrete bridge railing was 12 ft.-6 in. in length. A 12 Ga. 6 ft.-3 in. Adapter section was used to transition from the Thrie Beam section to the upstream standard 12 Ga. W-Beam section. The Thrie Beam was mounted at a height of 31 in., whereas, the standard W-Beam was mounted at a height of 27 in. The upstream end of the W-Beam guardrail was anchored into an 18 in. dia. by 6 ft. deep reinforced concrete shaft.

The first wood guardrail post (Post #2) was installed 7 ft.-7 1/2 in. from the centerline of the bolt hole pattern in the concrete bridge end. The unsupported span length from the 4:1 tapered concrete bridge end to the center of Post No. 2 was 4 ft.-7 in. The post spacings between Post No. 2 and Post No. 6 were 3 ft.-1 1/2 in. on centers, whereas, the post spacings of the remaining posts were 6 ft.-3 in. on centers. The posts were all 6 ft. in length. The size of the first 2 posts were 10 in. x 10 in.; the size of the next 4 posts were 8 in. x 8 in., and the size of the remaining posts were 6 in. x 8 in. The rail blockouts were all 6 in. x 8 in. in size.

## Soil

The soil, in which the guardrail wood posts were installed, was a "native" silty-clay topsoil. The soil was not in conformance with either the strong soil (S-1) or the weak soil (S-2) defined in NCHRP 230 (3). The decision to deviate from the recommended testing procedures in NCHRP 230 was made by engineers of the NDR because of the desire to evaluate the guardrail-bridgerail transition designs under typical soil conditions encountered in most of Nebraska. The properties of the soil are shown in Table 2.

TABLE 2

NATIVE SOIL PROPERTIES

| | |
|---|---|
| Unified Classification (ASTM D-2487) . . . | CL |
| Liquid Limit (LL) . . . . . . . . . . . . . . | 31 |
| Plastic Limit (PL). . . . . . . . . . . . . . | 20 |
| Plasticity Index (LL-PL) . . . . . . . . . . | 11 |
| Optimum Moisture Content . . . . . . . . . . | 17.6% |
| Unconfined Shear Strength . . . . . . . . . . | 1,900 psf |

The wood posts were placed in 18 to 20 in. dia. holes. The backfill soil around the posts was compacted by hand (as shown in Figure 10) in 6-in. layers to a density of approximately 92%. The soil tests conducted by the NDR and a private soil testing agency (Geotechnical Services, Inc.) are presented in Appendix A. The field density of the soil was measured by a Troxler Nuclear Density Meter.

Figure 10
PHOTOGRAPHS OF WOOD POST INSTALLATION

## A.3. TEST VEHICLES

The six test vehicles used in the full-scale crash tests were 1977 Plymouth Fury 4-door sedans. Ballast was added to bring the weight of the vehicles in conformance with the 4,500 ± 200 lb. requirement in NCHRP 230 (3). The ballast was equally distributed fore and aft of the vehicle center-of-gravity. The ballasted weights of the vehicles are presented in Table 3.

Referring to Figure 5 (p11), the two reference targets used in the analysis of the high-speed film and mounted on the centerline of the roof of the vehicle were spaced 5 ft. on centers. The forward target was mounted directly above the center-of-gravity of the vehicle.

The braking system installed in the test vehicle was bolted to the floor of the rear compartment area. The system consisted of a ram that was operated by high-pressure bottled nitrogen gas. A 1/8 in. dia. cable was attached to the ram and the vehicle brake pedal. In turn, the cable ran under the front seat and around a pulley that was bolted to the floor directly under the brake pedal. The cable pulled the brake pedal downward in the same manner that a driver would apply the brakes. The brakes were applied when the test vehicle was about 50 ft. clear of the test barrier.

## TABLE 3

## TEST VEHICLE WEIGHTS

| Test No. | Curb Weight$^{(1)}$ (lb) | Equipment Weight$_{(2)}$ (lb) | Ballast Weight (lb) | Test Weight$^{(3)}$ (lb) |
|---|---|---|---|---|
| 1 | 4,060 | 64 | 260 | 4,384 |
| 2 | 3,940 | 64 | 336 | 4,340 |
| 3 | 4,000 | 64 | 336 | 4,400 |
| 4 | 3,960 | 64 | 336 | 4,360 |
| 5 | 3,920 | 64 | 336 | 4,320 |
| 6 | 4,160 | 64 | 336 | 4,560 |

Notes:

(1) Rear seat removed

(2) Weight includes brake system, roof reference targets, and accelerometer hardware.

(3) Weight of 160 lb. Anthropometric Dummy not included.

## A.4. DATA ACQUISITION SYSTEMS

### High-Speed Photography System

Four high-speed cameras were used to film the crash tests at a film rate of approximately 500 frames/sec. One camera (Photex IV) was located at a distance of 300 ft. perpendicular to the barrier. A second camera (Photex IV) was located 200 ft. downstream and offset 6 ft. from an extended centerline of the traffic barrier. The downstream camera (see Figure 32) was protected by a row of Concrete Median Barriers to prevent the test vehicle from hitting the camera. In the first three crash tests, a third camera (Redlake Lo-Cam) was located at a distance of 50 ft. perpendicular to the barrier, and a fourth camera (Photex IV) was located 50 ft. overhead in the basket of the Cherry-Picker, whereas, in the remaining three crash tests, both of these cameras were located overhead.

Each camera was equipped with an electronic internal timing device for determining the exact operating speed of the camera. The timing device placed a red mark on the edge of the film every 10 msec.

A Vanguard Motion Analyzer was used to analyze the high-speed film frame by frame.

### Electronic Speed Trap System

Three electronic pressure tape switches were used to determine the impact speed of the vehicle. The tape switches were mounted exactly 3.00, 15.00, and 30.00 ft. from the point of barrier impact. As the left front tire of the vehicle rode over the pressure switch, the switch would close the circuit and a 6-volt battery would fire a blue 5-B flashbulb which was mounted in the field of view of all four high-speed cameras. The vehicle speed between two switches was determined by the following equation:

$$\text{Veh. Speed (fps)} = \frac{\begin{matrix}\text{Distance Between} \\ \text{Switches (ft)}\end{matrix} \quad \begin{matrix}\text{Calibrated Camera} \\ \text{Speed (fr/sec)}\end{matrix}}{\begin{matrix}\text{Number of Film Frames} \\ \text{Between Flashes (fr.)}\end{matrix}}$$

## Metraplex Accelerometer System

Photographs of the 160 lb. Anthropometric Dummy in the test vehicle, the tri-axial accelerometer unit on the C.G. of the test vehicle, and the data acquisition system placed in a van vehicle are shown in Figure 11. A schematic diagram of the electronic data acquisition system is presented in Figure 12. In addition to the accelerometers on the vehicle, a tri-axial accelerometer unit was placed inside the head of the dummy. The data from the six accelerometers on-board the test vehicle was transmitted to the Metraplex System and Honeywell Magnetic Recorder through a 1,200 ft. length of a an 18 pair, 36 conductor cable.

The analytical method described in NCHRP 230 for analyzing the accelerometer data was used in this study to determine the occupant risk factors of impact velocity and ridedown accelerations.

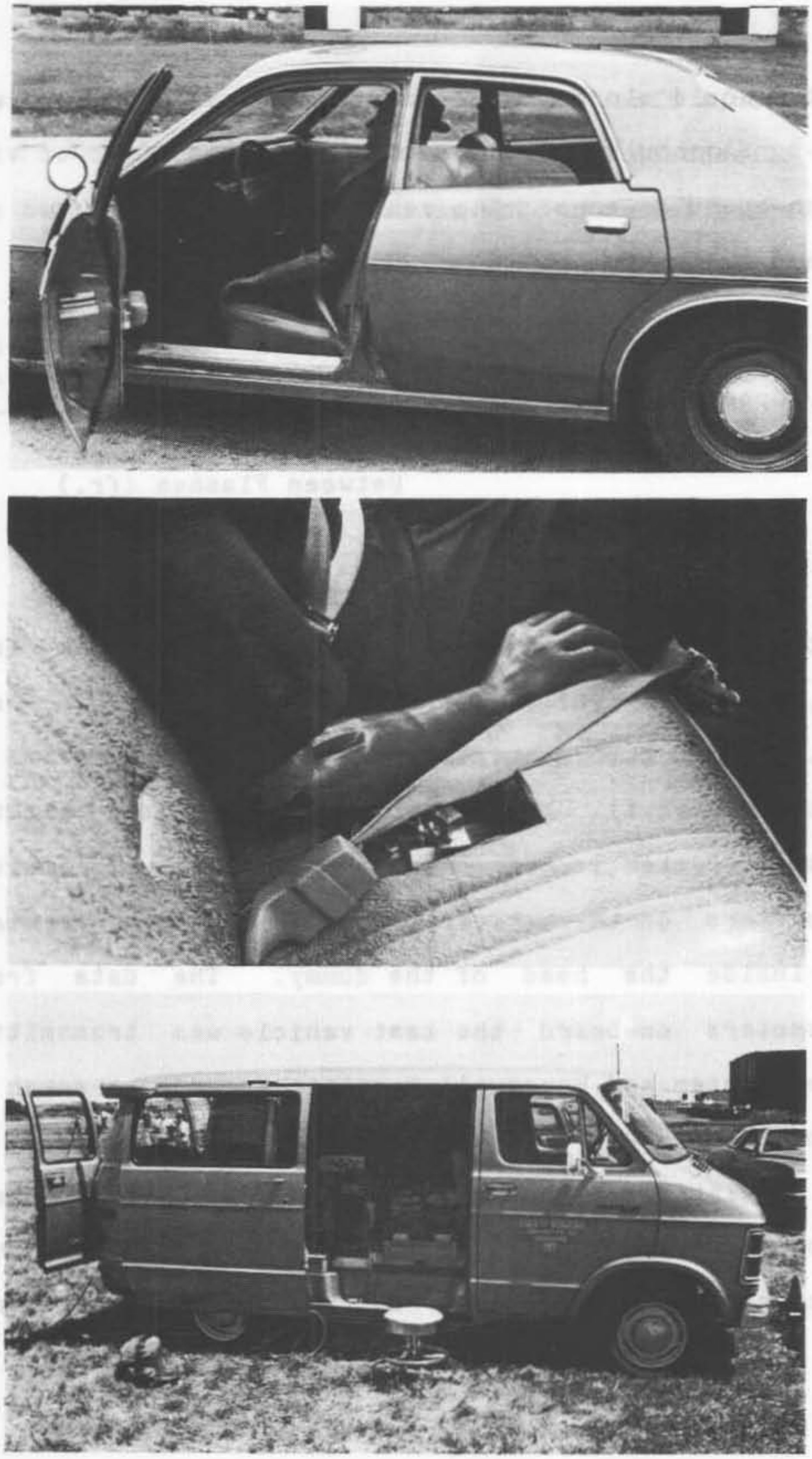


Figure 11

PHOTOGRAPHS OF DUMMY AND ELECTRONIC EQUIPMENT

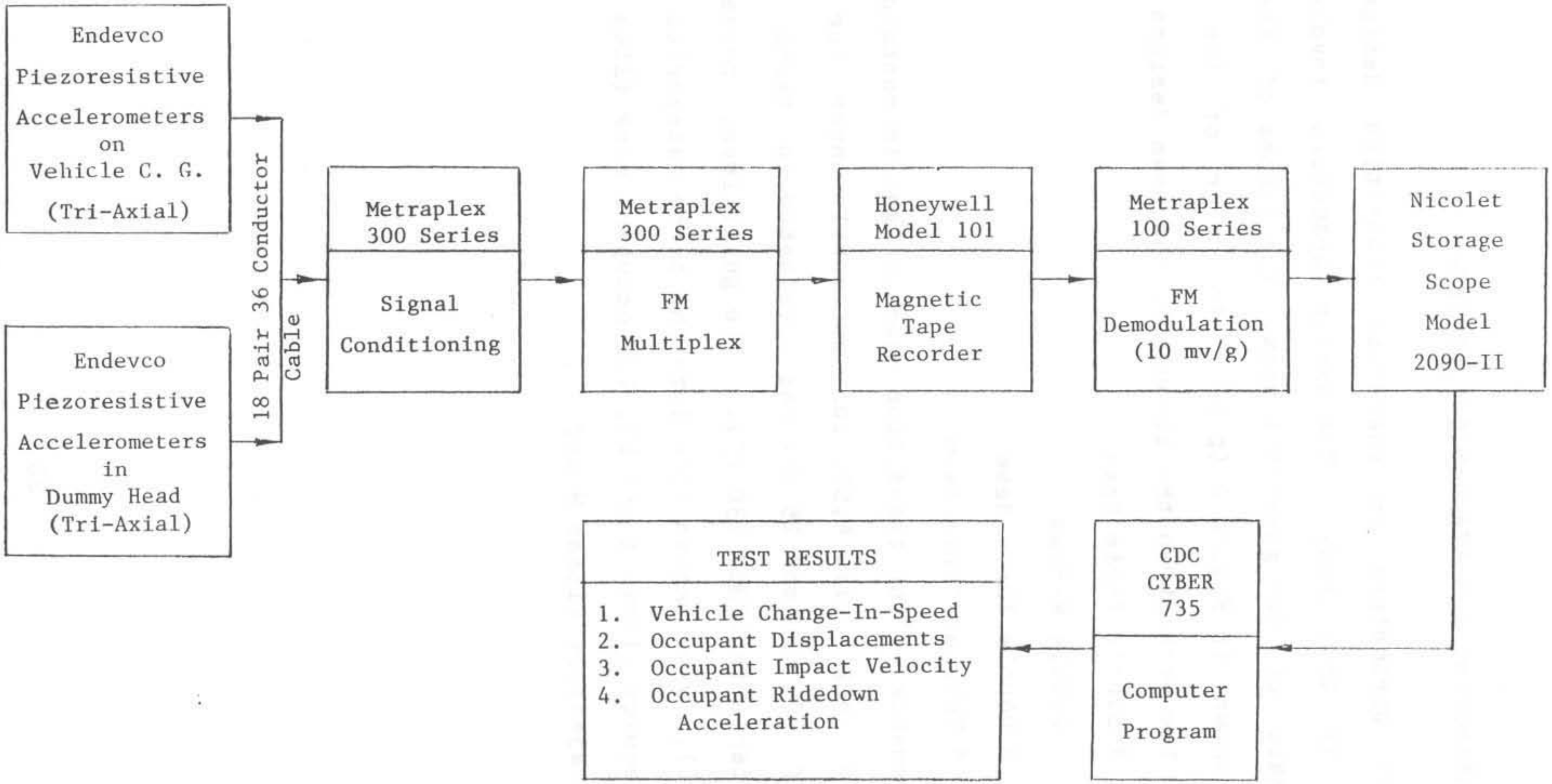


Figure 12 ELECTRONIC DATA ACQUISITION SYSTEM

## A.5. TEST PARAMETERS AND EVALUATION CRITERIA

Four test parameters on guardrail transition designs were investigated in this study. The design parameters involved the geometric shape of the guardrail beam. The shapes of the beams tested are shown in Figure 2 (p 5). In order of the bending strength from the weakest to the strongest, the beam designs were:

- Single Thrie Beam
- Double W-Beam
- Double Thrie Beam
- Tubular Thrie Beam

The performance of the transition beam designs in containing and redirecting a large size 4,500 lb. automobile under the impact conditions of 60 mph and 25 deg was evaluated in terms of the guideline criteria in NCHRP 230 (3). The guidelines, presented in Table 18 (p 86), were broken down into the three categories of: (1) structural adequacy (Items A and D), (2) occupant risk (Item E), and (3) vehicle trajectory (Items H and I).

## B. TEST RESULTS

*** Special Note ***

Due to electronic technical problems, no valid accelerometer data was obtained to evaluate the occupant risk factors in NCHRP 230 (Item F). However, the occupant risk factors of impact velocity and ridedown accelerations were obtained from the backup high-speed film analysis data acquisition system in conjunction with an analytical method in NCHRP 86 (see Appendix D). It is to be noted that the occupant risk factor in NCHRP 230 is <u>not a required</u> item for testing a guardrail transition.

## B.1. TEST NO. 1: TUBULAR THRIE BEAM TRANSITION

A summary of the full-scale vehicle crash test on the Tubular Thrie Beam Transition is presented in Table 4. Due to technical problems with the tow vehicle, the impact speed was 13 mph below the recommended target speed of 60 mph in NCHRP 230. The point of impact was between Post Nos. 2 and 3.

Sequential photographs of Test No. 1 are shown in Figure 13, and a description of the sequential events is presented in Table 5. At a time of 76 msec after impact, the vehicle reached its greatest depth of crushing into the guardrail. At a time of 194 msec, the "lateral" velocity component of the vehicle was zero as the vehicle became parallel to an extended centerline of the traffic barrier. Somewhere in between 76 and 194 msec, an occupant would have moved laterally 12 in. and struck the side of the vehicle.

Photographs of the guardrail damage are shown in Figure 14, and measurements of the guardrail permanent set deflections are shown in Figure 15. The tubular thrie beam was fabricated by a local steel manufacturer by shop welding two thrie beams back-to-back (see Figure 2c). The end shoe was welded on the outside of the tubular thrie beam. As evident, the damage to the guardrail was very minor with a maximum guardrail permanent set of only 2 1/2 in. Due to a technical problem with the overhead camera, no measurement was made of the maximum guardrail dynamic deflection. Assuming a typical impact factor of 1.5, an estimate of the maximum dynamic deflection would be 4 in.

# TABLE 4

## SUMMARY OF CRASH TEST NO. 1

### TEST VEHICLE

| | |
|---|---|
| Make | 1977 Plymouth Fury |
| Weight (excluding dummy) | 4,384 lb. |

### TRAFFIC BARRIER INSTALLATION

| | |
|---|---|
| Concrete Bridgerail | |
| Type | Open Rail/Post; Tapered End |
| Length | 21 ft.-6 in. |
| Guardrail Beam Members (12 Ga) | |
| Transition | |
| Type | Tubular Thrie Beam |
| Length | 12 ft.-6 in. |
| Adapter | |
| Length | 6 ft.-3 in. |
| Approach | |
| Type | Standard W-Beam |
| Length | 37 ft.-6 in. |
| Guardrail Wood Posts | |
| Post No. 1 | Left Out |
| Post Nos. 2 and 3 | 10 x 10 x 72 in. |
| Post Nos. 4 thru 7 | 8 x 8 x 72 in. |
| Post Nos. 8 thru 12 | 6 x 8 x 72 in. |
| Native Soil | |
| Type | Silty-Clay (CL) |
| Optimum Moisture | 18% |
| Relative Compaction | 92% |
| Test Conditions | Dry |

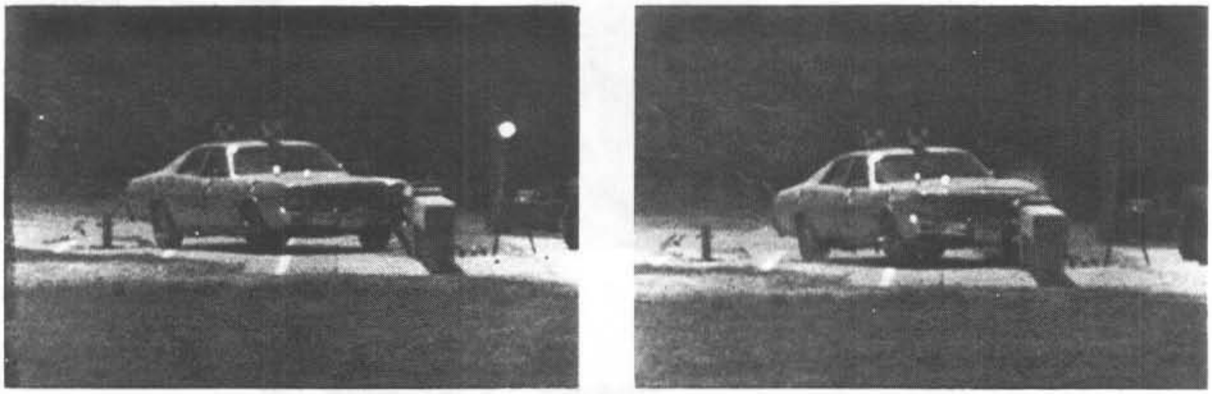
### TEST RESULTS

| | |
|---|---|
| Vehicle Speed | |
| Impact | 47 mph |
| Exit | 38 mph |
| Vehicle Angle | |
| Impact | 25 deg. |
| Exit | 15 deg. |
| Vehicle Rebound Distance | 72 ft. |
| Vehicle Damage | TAD LFQ-3 |
| Traffic Barrier | |
| Impact Location | Between Post Nos. 2 and 3 |
| Max. Dynamic Deflection | 4 in. (est.) |
| Max. Permanent Set | 2 1/2 in. |
| Snagging | None |
| Occupant Risk (NCHRP 230) | |
| Lateral Impact Velocity | Not Measured |
| Ridedown Accelerations | Not Measured |
| Occupant Risk (NCHRP 86) | |
| Injury Accident Probability | 18% |

## TABLE 5

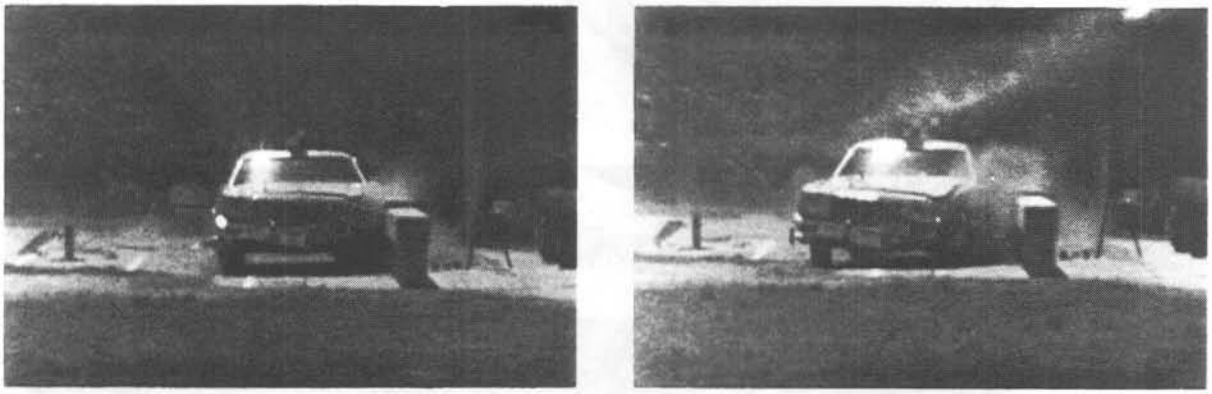
## DESCRIPTION OF TEST NO. 1 SEQUENTIAL EVENTS

| Time (msec) | EVENT |
|---|---|
| 0 | Vehicle Impact |
| 76 | Max. Vehicle Crushing of 22 in. |
| 194 | Vehicle Becomes Parallel to Center Line of Traffic Barrier |
| 294 | Vehicle Exit |



Impact

76 msec



194 msec

294 msec

Figure 13

SEQUENTIAL PHOTOGRAPHS OF TEST NO. 1

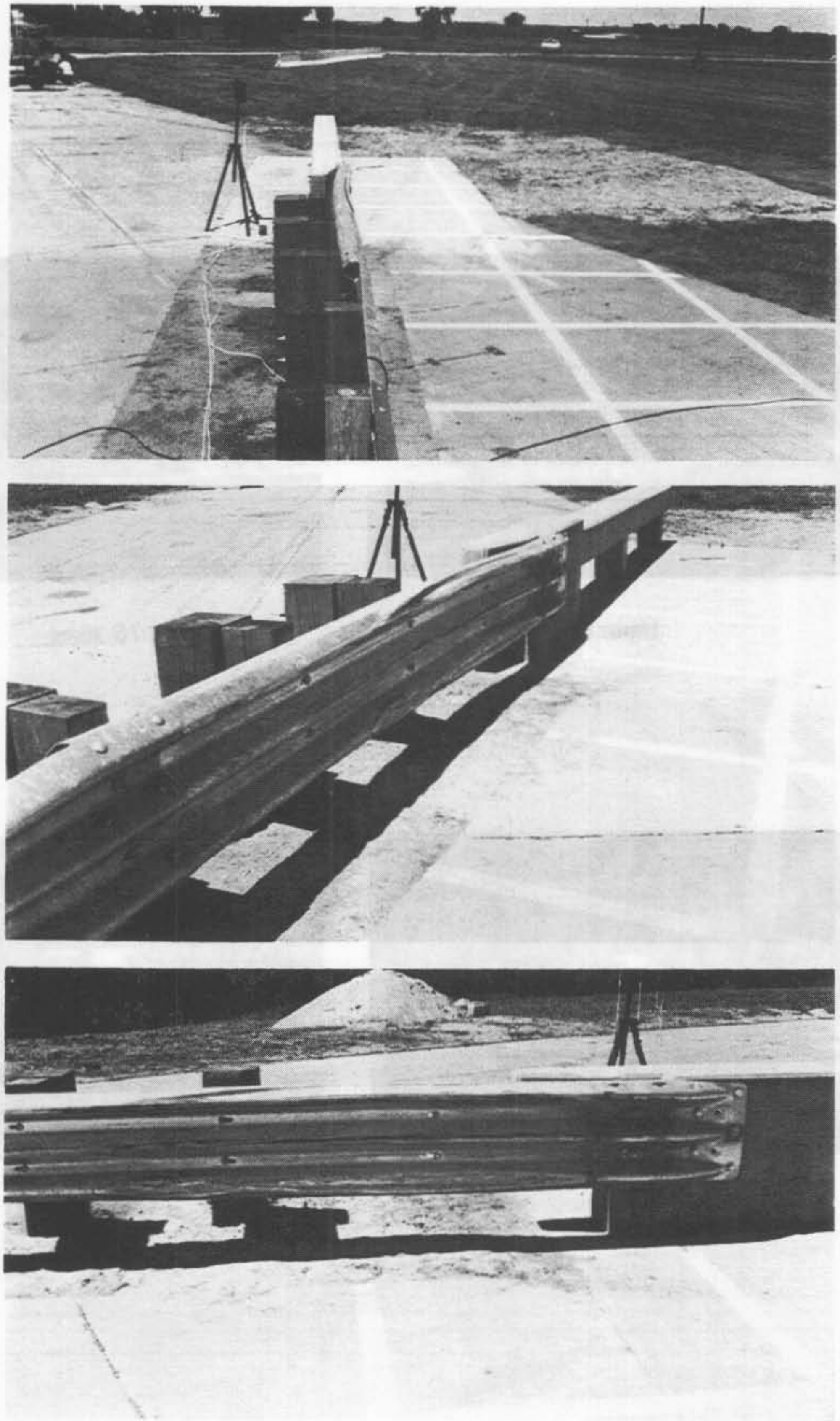
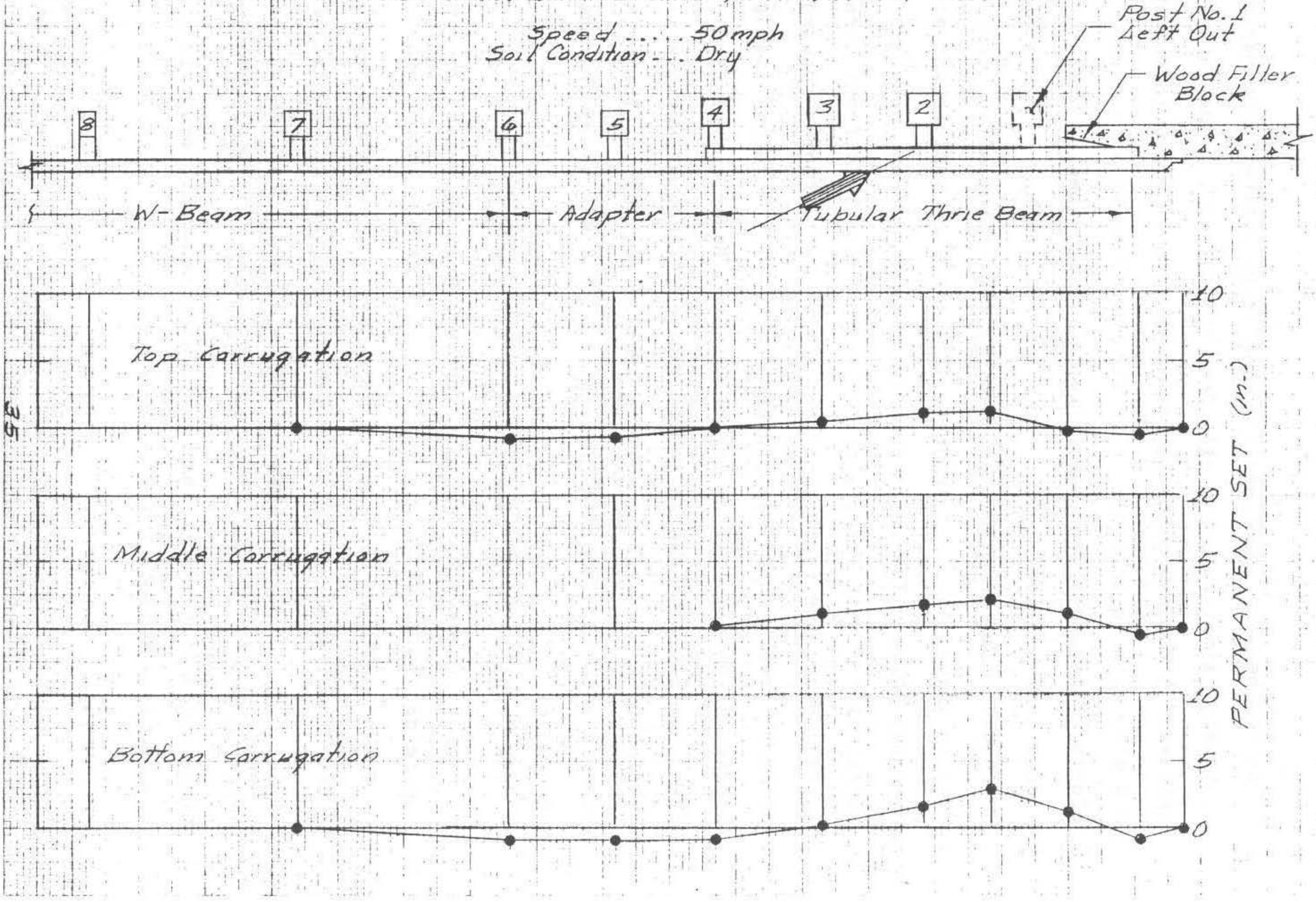


Figure 14
PHOTOGRAPHS OF TEST NO. 1 GUARDRAIL DAMAGE

Figure 15
TEST 1 ... GUARDRAIL PERMANENT SET

Speed ..... 50 mph
Soil Condition ... Dry



As can be seen in Figure 14, the vehicle tire scuff marks were relatively straight after exit from the barrier. The vehicle exit angle was 15 deg, and the vehicle travelled 270 ft. before it came to a stop with no braking. The tire scuff marks were caused by the deformed inward alignment of the two front wheels. The vehicle rebound distance was 72 ft.

Photographs of the test vehicle before and after impact are shown in Figure 16. As evident, damage to the vehicle was moderate and repairable. The left front door was not sprung open under the lateral side impact loading of the dummy. The left front corner was crushed 15 in. and the right front corner was deformed outward 3 in. The left rear corner was crushed 4 in. The vehicle damage was assigned a NSC (7) TAD rating of LFQ-3. Based on the findings in NCHRP 86 (8), the damage rating indicates that injuries will occur in 18% of the vehicles damaged to this extent that. The method to determine injury accident probability in NCHRP 86 is presented in Appendix E.

The vehicle impact speed was 47 mph and the exit speed was 38 mph. The change-in-speed of 9 mph was well below the 15 mph limit recommended in NCHRP 230 (3).

The results of Test No. 1 were used to determine "equivalent" impact conditions presented in Table 6 by equating lateral kinetic energy. At an impact angle of about 20 deg, the same guardrail damage shown in Figures 14 and 15 would have occurred under an impact speed of 60 mph. The equation to determine equivalent speeds is presented in Table 6.

Figure 16

PHOTOGRAPHS OF TEST VEHICLE BEFORE AND AFTER TEST NO. 1

## TABLE 6

## EQUIVALENT TEST NO. 1 IMPACT CONDITIONS

Actual Test Speed . . . 47 mph

Actual Test Angle . . . 25 deg

| Impact Angle (deg) | Equivalent Impact Speed (mph) |
|---|---|
| 15 | 77 |
| 16 | 72 |
| 17 | 68 |
| 18 | 64 |
| 19 | 61 |
| 20 | 58 |

$$\frac{1}{2}\frac{W}{g}(V\sin\theta)^2 = \left[\frac{1}{2}\frac{W}{g}(V\sin\theta)^2\right]_{test}$$

$$V^2 = \frac{(V\sin\theta)^2_{test}}{\sin^2\theta}$$

$$V^2 = \frac{394.5}{\sin^2\theta}$$

In a similar manner, the results of Test No. 1 were used to estimate that a dynamic deflection of 6 to 7 in. would have occurred in a 60 mph impact. This estimate is based on the assumption that the guardrail deflection is directly proportional to the vehicle lateral kinetic energy as follows:

$$\frac{D}{\frac{1}{2}\frac{W}{g}(V\sin\theta)^2} = \frac{D}{\frac{1}{2}\frac{W}{g}(V\sin\theta)^2}_{test}$$

$$D = \frac{V^2}{V^2_{test}} D_{test}$$

$$D = 1.63\, D_{test}$$

Based on the estimate that the guardrail dynamic deflections would have only been on the order of 6 to 7 in. under a 60 mph impact, the decision was made by NDR to not rerun the test because the test would most likely be successful. It is interesting to note that the BARRIER VII Computer Model (see Appendix C) predicted a dynamic deflection of 9 in. No attempt was made to "fine tune" the computer model in this study.

## B.2. TEST NO. 2: SINGLE THRIE BEAM TRANSITION

A summary of the full-scale vehicle crash test on the Single Thrie Beam Transition is presented in Table 7. The vehicle impact point was between Post Nos. 2 and 3. Due to technical problems with the tow vehicle, the vehicle impact speed of 46 mph was 14 mph below the speed of 60 mph recommended in NCHRP 230.

Sequential photographs of Test No. 2 are shown in Figure 17, and a description of the sequential events is presented in Table 8. The maximum vehicle crushing of 16 in. occurred at a time of 70 msec after impact. At a time of 193 msec, the "lateral" velocity component of the vehicle was zero as the vehicle became parallel to the centerline of the traffic barrier. The vehicle exit from the barrier occurred at a time of about 331 msec.

Photographs of the guardrail damage are shown in Figure 18, and measurements of the guardrail permanent set deflections are shown in Figure 19. As evident, the damage was relatively minor and there was evidence of vehicle snagging. The maximum permanent set was approximately 6 in. Due to technical problems with the overhead camera, no measurements were made of the guardrail dynamic deflections. Assuming an impact factor of 1.5, it was estimated that the maximum dynamic deflection was 9 in.

Photographs of the vehicle before and after the test are shown in Figure 20. To reemphasize, the line of concrete median barriers (CMB) were set in place to protect the downstream camera from the possibility of being struck by the vehicle. It was estimated that

## TABLE 7

## SUMMARY OF CRASH TEST NO. 2

### TEST VEHICLE

| | |
|---|---|
| Make | 1977 Plymouth Fury |
| Weight (excluding dummy) | 4,340 lb. |

### TRAFFIC BARRIER INSTALLATION

| | |
|---|---|
| Concrete Bridgerail | |
| Type | Open Rail/Post; Tapered End |
| Length | 21 ft.-6 in. |
| Guardrail Beam Members (12 Ga) | |
| Transition | |
| Type | Single Thrie Beam |
| Length | 12 ft.-6 in. |
| Adapter | |
| Length | 6 ft.-3 in. |
| Approach | |
| Type | Standard W-Beam |
| Length | 37 ft.-6 in. |
| Guardrail Wood Posts | |
| Post No. 1 | Left Out |
| Post Nos. 2 and 3 | 10 x 10 x 72 in. |
| Post Nos. 4 thru 7 | 8 x 8 x 72 in. |
| Post Nos. 8 thru 12 | 6 x 8 x 72 in. |
| Native Soil | |
| Type | Silty-Clay (CL) |
| Optimum Moisture | 18% |
| Relative Compaction | 92% |
| Test Conditions | Dry |

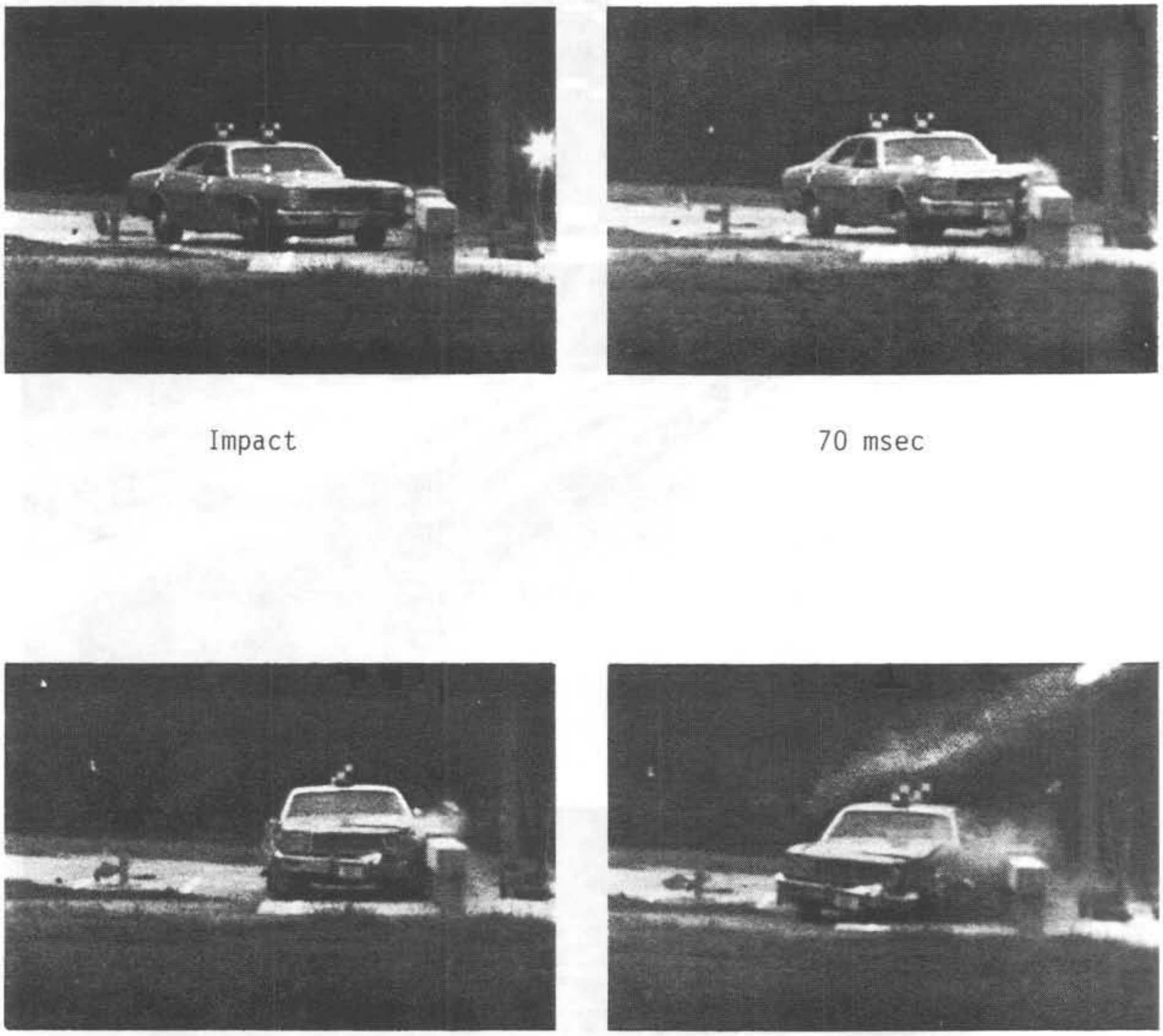
### TEST RESULTS

| | |
|---|---|
| Vehicle Speed | |
| Impact | 46 mph |
| Exit | 35 mph |
| Vehicle Angle | |
| Impact | 25 deg. |
| Exit | 15 deg. |
| Vehicle Rebound Distance | 20 ft. |
| Vehicle Damage | TAD LFQ-3 (moderate) |
| Traffic Barrier | |
| Impact Location | Between Post Nos. 2 and 3 |
| Max. Dynamic Deflection | 9 in. (est.) |
| Max. Permanent Set | 6 in. |
| Snagging | None |
| Occupant Risk (NCHRP 230) | |
| Lateral Impact Velocity | Not Measured |
| Ridedown Accelerations | Not Measured |
| Occupant Risk (NCHRP 86) | |
| Injury Accident Probability | 18% |

## TABLE 8

## DESCRIPTION OF TEST NO. 2 SEQUENTIAL EVENTS

| Time (msec) | EVENT |
|---|---|
| 0 | Vehicle Impact |
| 70 | Max. Vehicle Crushing of 16 in. |
| 193 | Vehicle Becomes Parallel to Center Line of Traffic Barrier |
| 331 | Vehicle Exit |



Impact

70 msec

193 msec

331 msec

Figure 17

SEQUENTIAL PHOTOGRAPHS OF TEST NO. 2

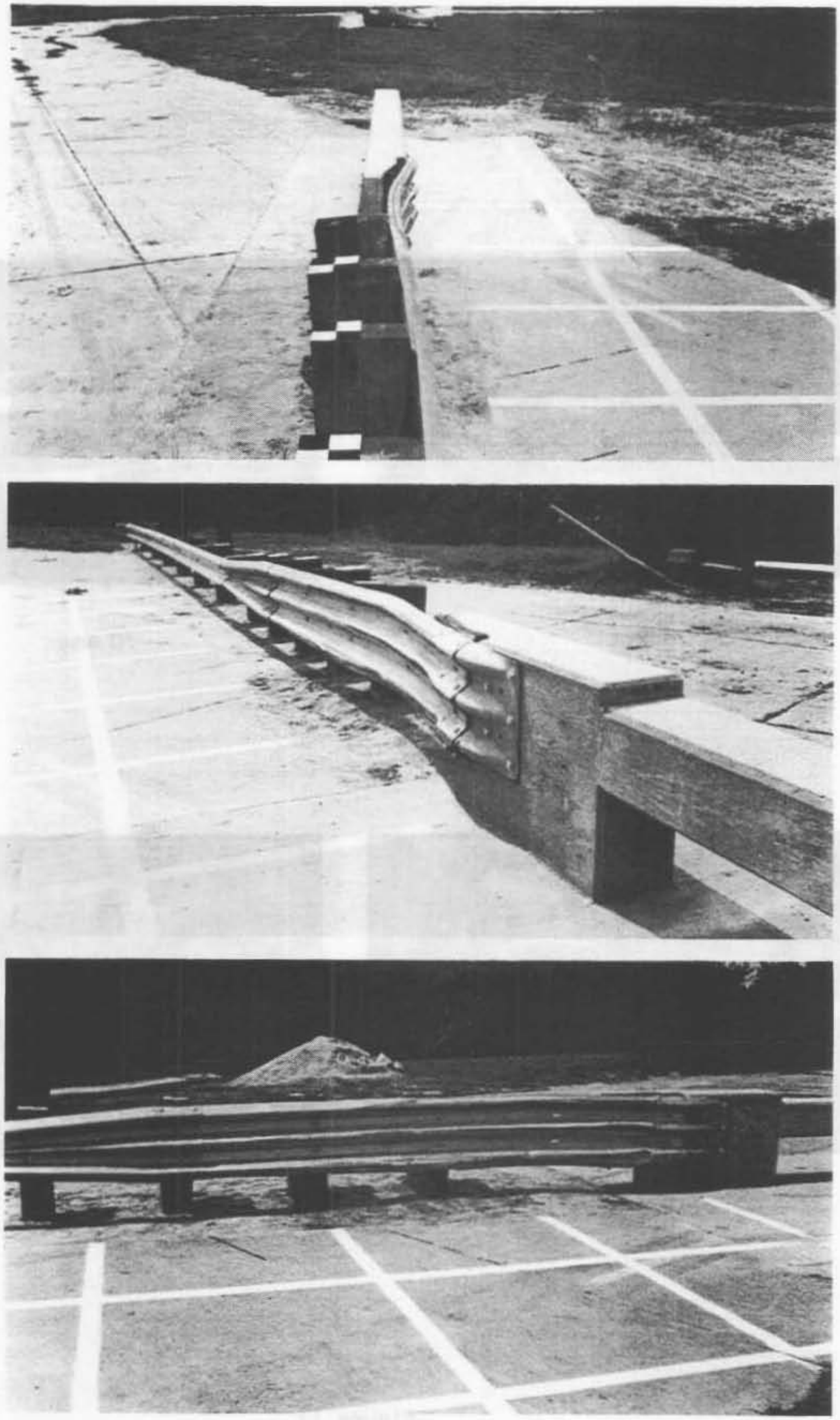
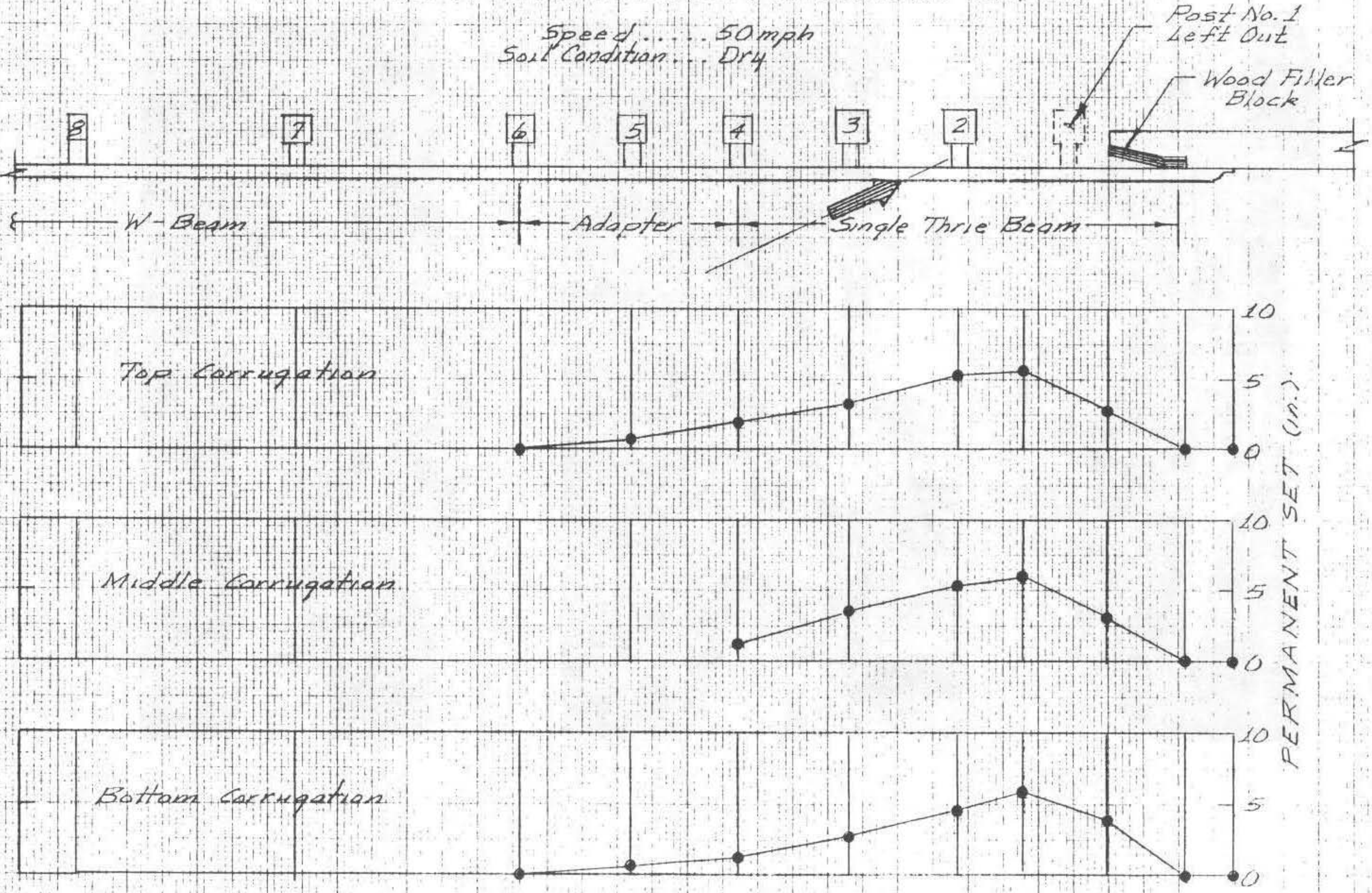


Figure 18

PHOTOGRAPHS OF TEST NO. 2 GUARDRAIL DAMAGE

Figure 19
TEST 2 ... GUARDRAIL PERMANENT SET

Speed ..... 50 mph
Soil Condition ... Dry



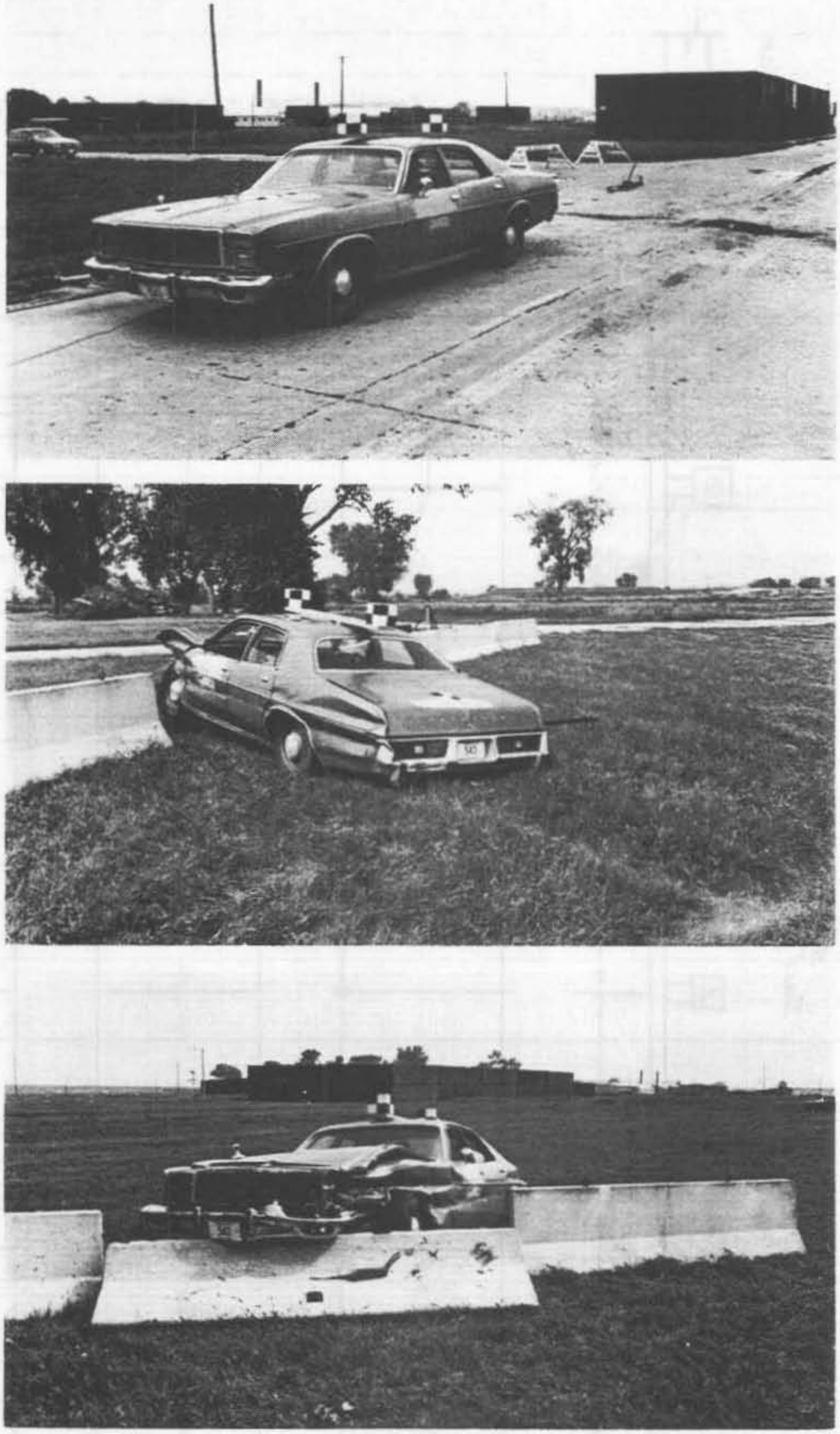


Figure 20

PHOTOGRAPHS OF TEST VEHICLE BEFORE AND AFTER TEST NO. 2

the vehicle was travelling at a speed of 10 mph or less when it was stopped by the CMB. Because the 20 ft. CMB sections were not connected and were free to slide and rotate as an individual section, it was assumed that most of the damage to the vehicle had occurred during impact with the traffic barrier. As evident, the damage to the vehicle was moderate and repairable. The damage was assigned a NSC (7) TAD rating of LFQ-3. Based on the findings in NCHRP 86 (8), it was predicted that in vehicles damaged to this extent that injuries would occur in 18% of the accidents.

Based upon the methodology discussed earlier in Test No. 1, it was estimated that under a 60 mph and 25 deg impact that the dynamic deflections of the guardrail would have been on the order of 6 to 7 in. greater than at the impact speed of 46 mph. Due to the uncertainty of the larger deflections on the performance of the guardrail at a higher impact speed of 60 mph, and due to the simple fact that the test speed was not in conformance with NCHRP 230, the decision was made by NDR to rerun the test.

## B.3. TEST NO. 3: SINGLE THRIE BEAM TRANSITION

A summary of the full-scale vehicle crash test on the Single Thrie Beam Transition is presented in Table 9. The point of impact was between Post Nos. 2 and 3. The vehicle impact speed was 60 mph and the exit speed was 39 mph.

Sequential photographs of Test No. 3 are shown in Figure 21, and a description of the sequential events is presented in Table 10. During the primary (vehicle front-end) impact stage at a time of 89 msec, the maximum guardrail deflection was 13 in. At a time of 108 msec, the lateral occupant displacement of 12 in. occurred nearly simultaneously to the time in which the front door sprung open under a dummy side impact loading force of 10 g's. The methodology used to determine occupant lateral displacement, impact velocity, and ridedown accelerations by high-film analyses is presented in Appendix D. It was interesting to observe that the largest guardrail deflection of 14 in. occurred during the secondary (vehicle rear-end) impact stage at a time of 231 msec. Vehicle exit from the barrier occurred at a time of about 280 msec.

Photographs of the guardrail damage are shown in Figure 22 (2 pages), and measurements of the guardrail permanent set deflections are shown in Figure 23. The area where the upstream end anchor was bolted to the W-Beam guardrail buckled inward under the tensile loading of about 48 kips. as computed by the BARRIER VII model (see Appendix C). As clearly visible in the photographs, a "moderate" amount of vehicle snagging occurred in the lower half of the thrie beam in the area of the tapered end of the concrete bridgerail. The

## TABLE 9

## SUMMARY OF CRASH TEST NO. 3

### TEST VEHICLE

| | |
|---|---|
| Make | 1977 Plymouth Fury |
| Weight (excluding dummy) | 4,400 lb. |

### TRAFFIC BARRIER INSTALLATION

| | |
|---|---|
| Concrete Bridgerail | |
| Type | Open Rail/Post; Tapered End |
| Length | 21 ft.-6 in. |
| Guardrail Beam Members (12 Ga) | |
| Transition | |
| Type | Single Thrie Beam |
| Length | 12 ft.-6 in. |
| Adapter | |
| Length | 6 ft.-3 in. |
| Approach | |
| Type | Standard W-Beam |
| Length | 37 ft.-6 in. |
| Guardrail Wood Posts | |
| Post No. 1 | Left Out |
| Post Nos. 1 and 2 | 10 x 10 x 72 in. |
| Post Nos. 3 thru 6 | 8 x 8 x 72 in. |
| Post Nos. 7 thru 12 | 6 x 8 x 72 in. |
| Native Soil | |
| Type | Silty-Clay (CL) |
| Optimum Moisture | 18% |
| Relative Compaction | 92% |
| Test Conditions | Dry |

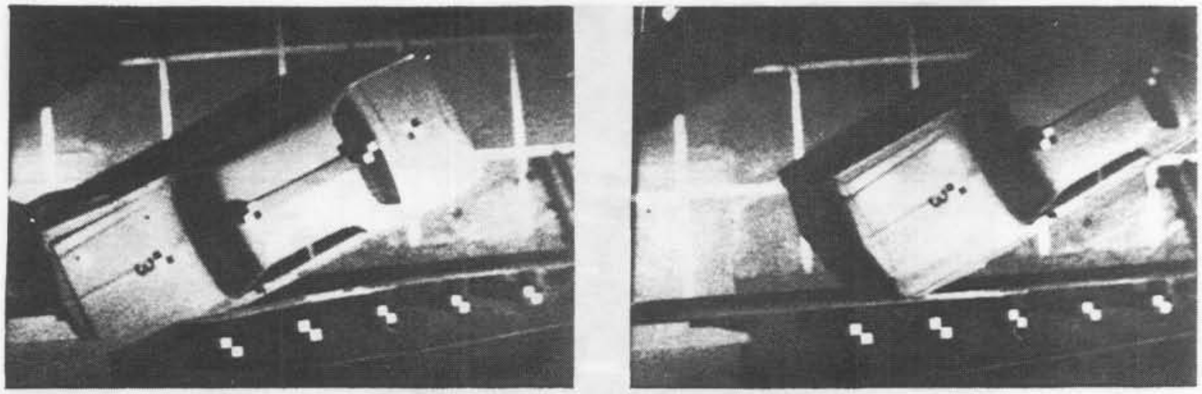
### TEST RESULTS

| | |
|---|---|
| Vehicle Speed | |
| Impact | 60 mph |
| Exit | 39 mph |
| Vehicle Angle | |
| Impact | 25 deg. |
| Exit | 11 deg. |
| Vehicle Rebound Distance | 20 ft. |
| Vehicle Damage | TAD FLQ-6 1/2 (major) |
| Traffic Barrier | |
| Impact Location | Between Post Nos. 2 and 3 |
| Max. Dynamic Deflection | 14 in. |
| Max. Permanent Set | 10 in. |
| Snagging | Moderate |
| Occupant Risk (NCHRP 230) | |
| Lateral Impact Velocity | 21 fps |
| Ridedown Accelerations | 10 g |
| Occupant Risk (NCHRP 86) | |
| Injury Accident Probability | 86% |

## TABLE 10

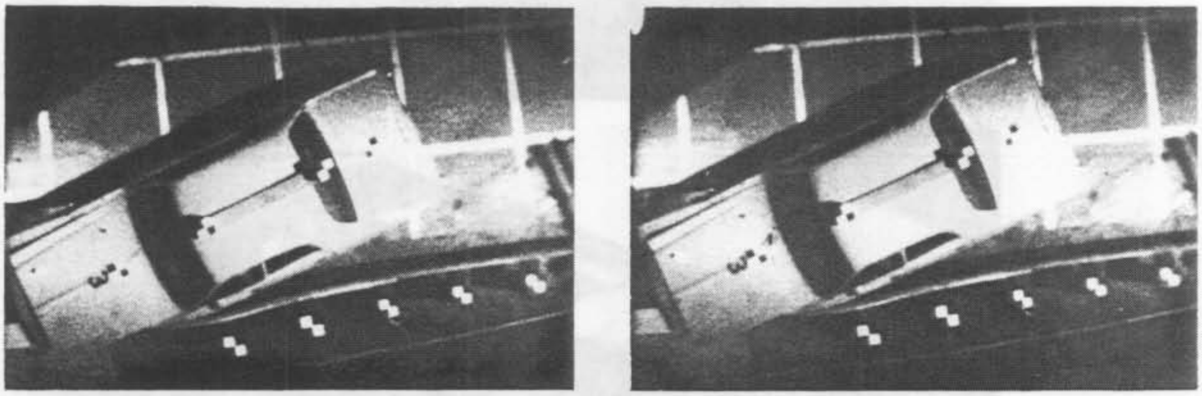
## DESCRIPTION OF TEST NO. 3 SEQUENTIAL EVENTS

| Time (msec) | EVENT |
|---|---|
| 0 | Vehicle Impact |
| 89 | Max. Guardrail Deflection of 13 in. During Primary Impact Stage |
| 108 | Lateral Occupant Displacement of 12 in. |
| 109 | Front Door Springs Open Under Dummy Side Loading |
| 185 | Vehicle Becomes Parallel to Center Line of Traffic Barrier |
| 231 | Max. Guardrail Deflection of 14 in. During Secondary Impact Stage |
| 280 | Vehicle Exit |



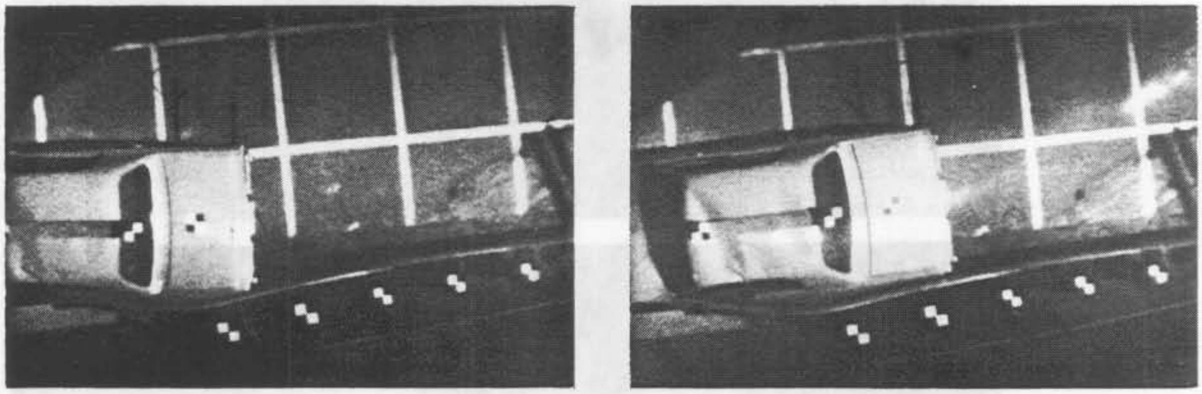
89 msec

Impact



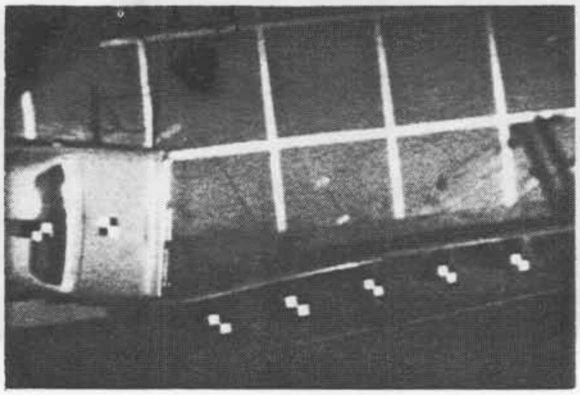
109 msec

108 msec



231 msec

185 msec



280 msec

Figure 21

SEQUENTIAL PHOTOGRAPHS OF TEST NO. 3

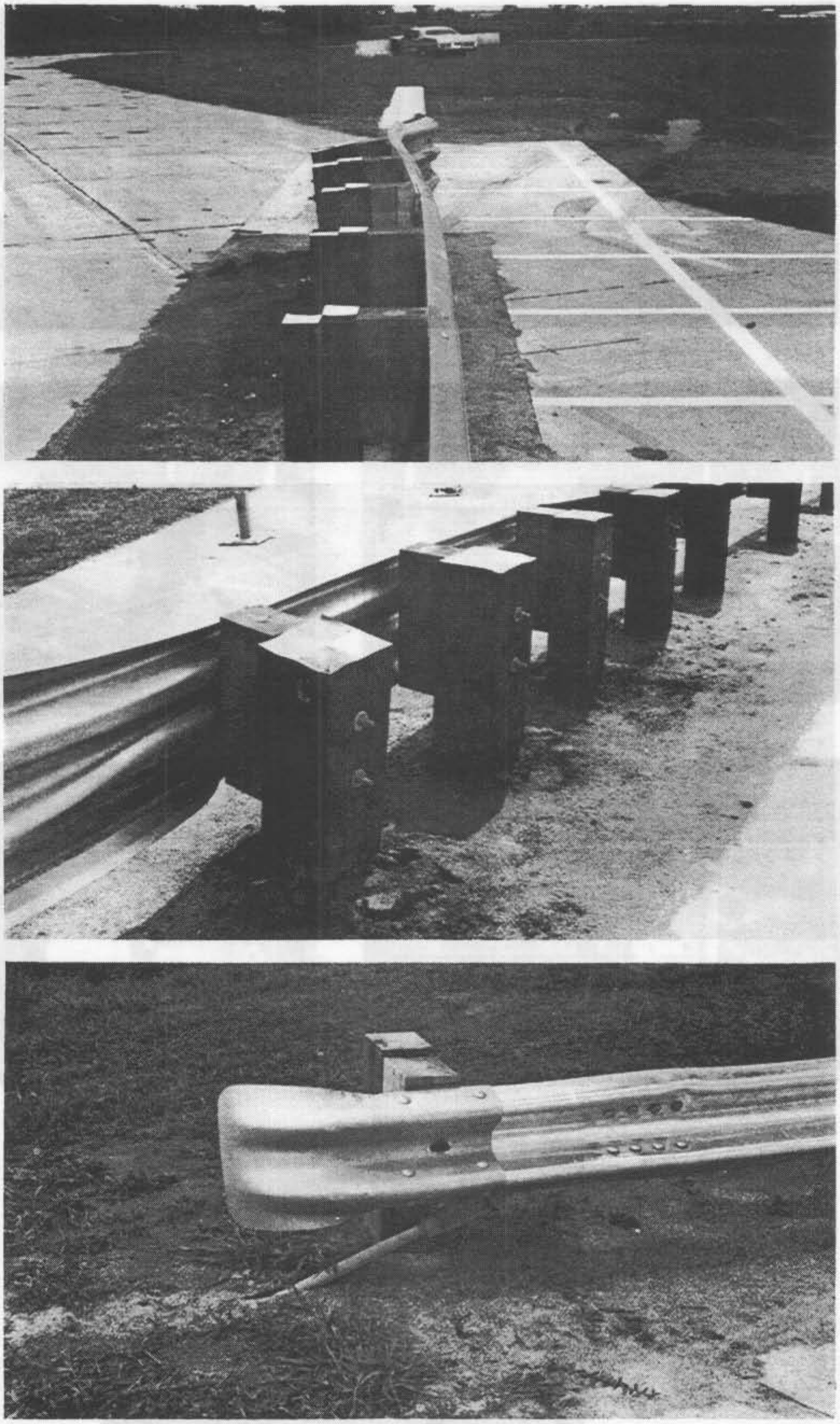


Figure 22

PHOTOGRAPHS OF TEST NO. 3 GUARDRAIL DAMAGE

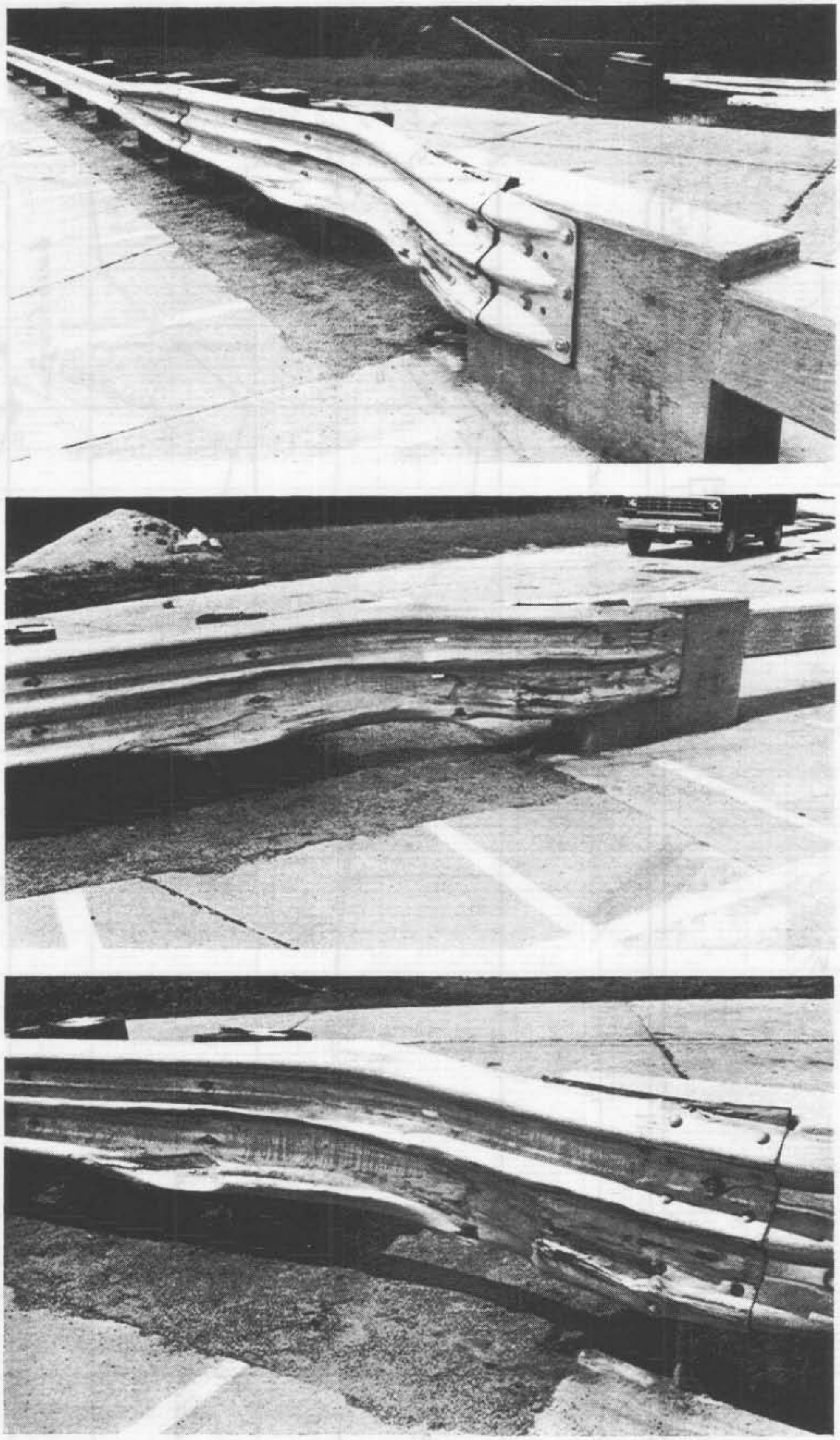
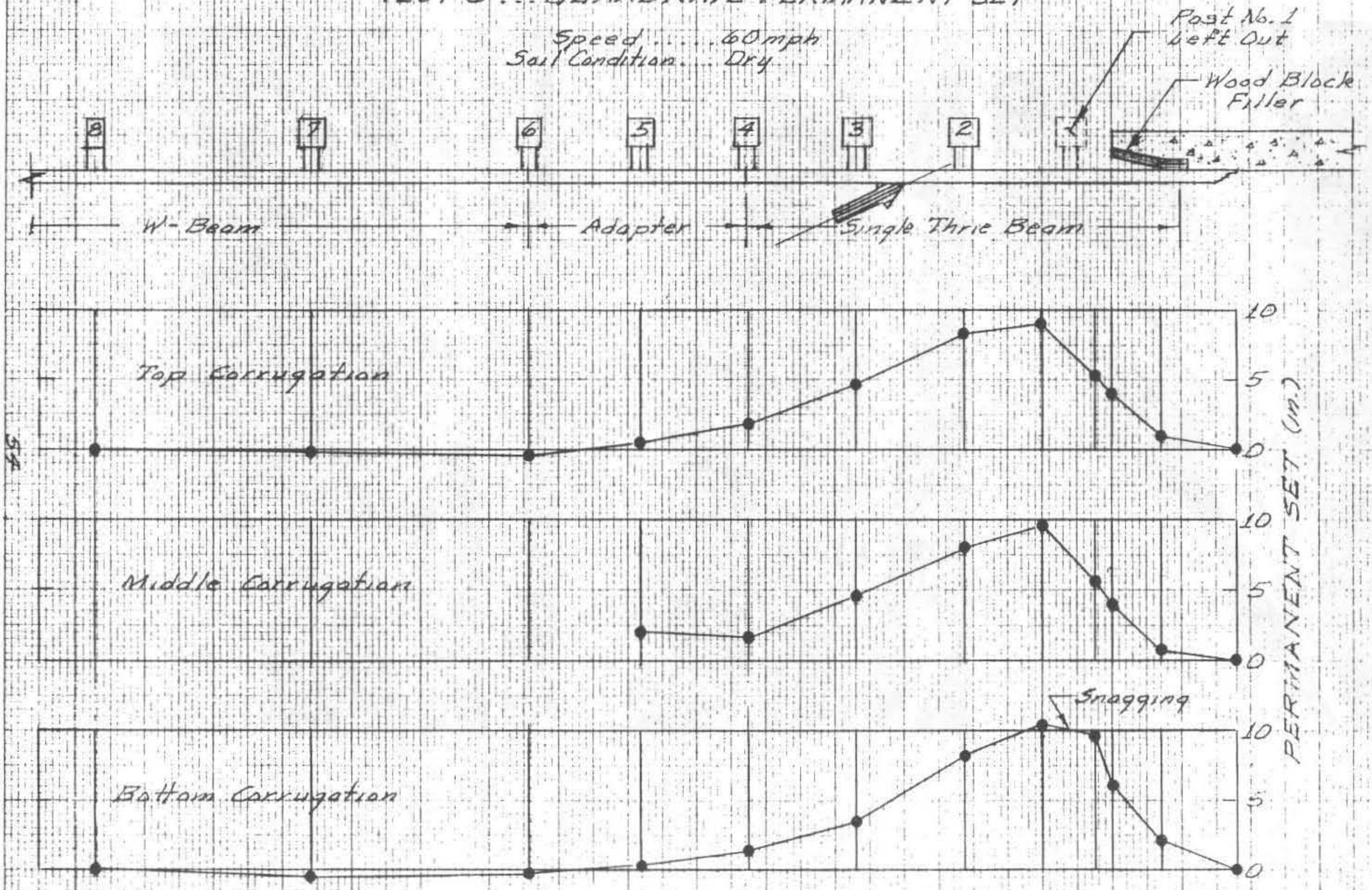


Figure 22

PHOTOGRAPHS OF TEST NO. 3 GUARDRAIL DAMAGE

Figure 23
TEST 3 ... GUARDRAIL PERMANENT SET

Speed ..... 60 mph
Soil Condition ..... Dry



The vehicle change-in-speed of 21 mph was also a clear indication of a moderate amount of snagging as the change-in-speed was greatly in excess of the 15 mph limit specified in NCHRP 230.

The vehicle exit angle, as visible in one of the photographs in Figure 22, was 11 deg. Due to the high drag forces from the badly damaged left front wheel, the vehicle turned back-in toward an extended centerline of the traffic barrier after it had travelled a distance of 78 ft. The maximum rebound distance of the vehicle C.G. path was 20 ft.

Photographs of the vehicle before and after the test are shown in Figure 24. It was assumed that the vehicle was travelling at a speed of 10 to 15 mph when it was stopped by the CMB protecting the downstream high-speed camera visible in the background. Due to the snagging, the damage to the vehicle was major and not repairable. Most of the damage was incurred during impact with the traffic barrier. The vehicle damage was assigned a NSC TAD rating of LFQ-6 1/2. Based on the findings in NCHRP 86 (8), the damage rating indicates that injuries will occur in 86% of the vehicles damaged to this extent.

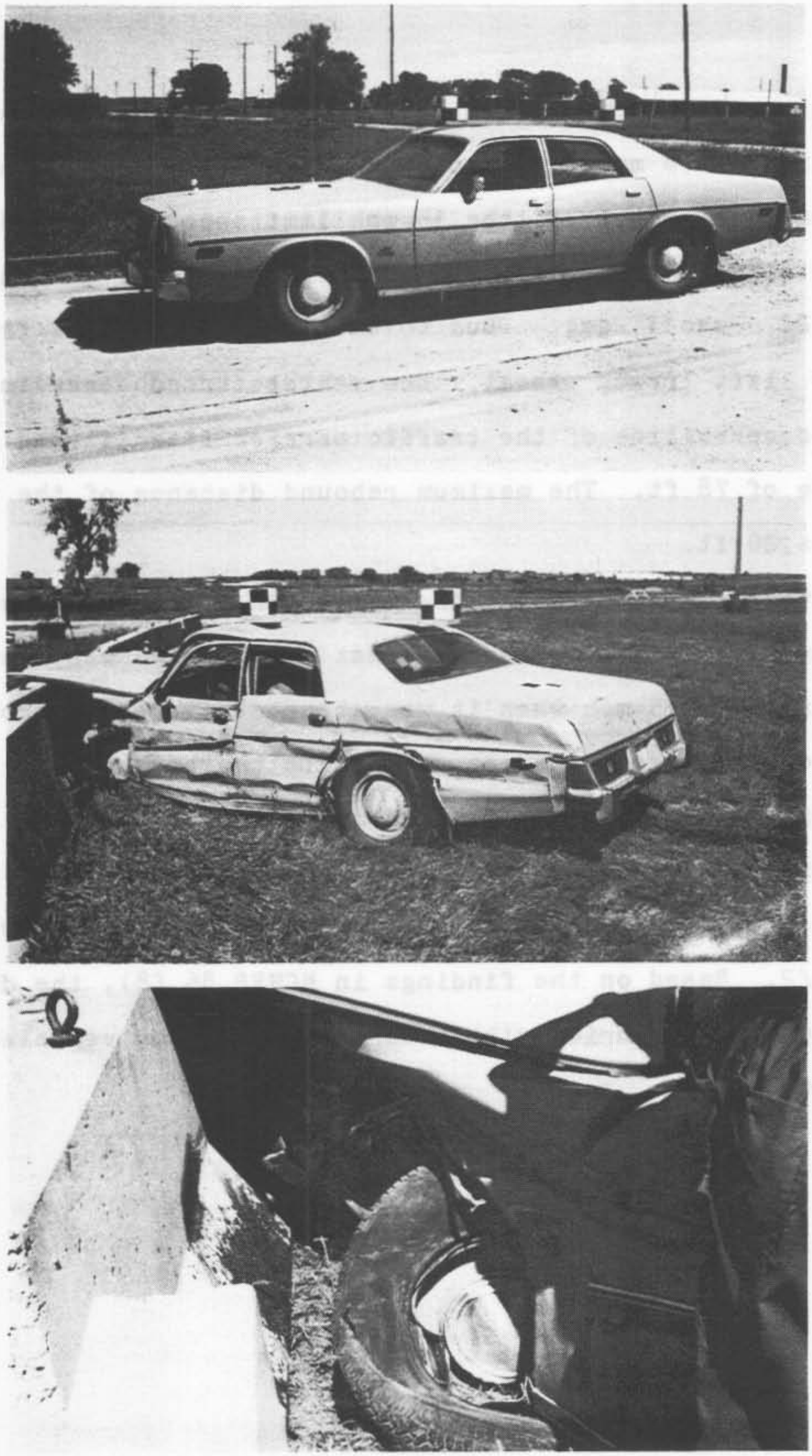


Figure 24

PHOTOGRAPHS OF TEST VEHICLE BEFORE AND AFTER TEST NO. 3

## B.4. TEST NO. 4: DOUBLE THRIE BEAM TRANSITION

A summary of the full-scale vehicle crash test on the Double Thrie Beam Transition is presented in Table 11. The point of impact was between Post Nos. 2 and 3. The vehicle impact speed was 61 mph and the exit speed was 47 mph.

Sequential photographs of Test No. 4 are shown in Figure 25, and a description of the sequential events is presented in Table 12. During the primary (vehicle front-end) impact stage at a time of 86 msec, the maximum guardrail deflection was 9 in. At a time of 114 msec, the lateral occupant displacement of 12 in. occurred nearly simultaneously to the time in which the front door sprung open under a dummy side impact loading force of 10 g's. The methodology used to determine occupant lateral displacement, impact velocity, and ridedown accelerations by high-speed analyses is presented in Appendix D. It was interesting to observe that the largest guardrail deflection of 10 in. occurred during the secondary (vehicle rear-end) impact stage at a time of 194 msec. Vehicle exit from the barrier occurred at a time of about 250 msec.

Photographs of the guardrail damage are shown in Figure 26, and measurements of the guardrail permanent set deflections are shown in Figure 27. The damaged guardrail shows no indication of vehicle snagging. The vehicle change-in-speed of 14 mph was also supportive of the fact that no snagging occurred as the change-in-speed was below the 15 mph limit specified in NCHRP 230. Overall, the guardrail "smoothly" redirected the vehicle. The maximum permanent set in the guardrail was 7 1/2 in.

## TABLE 11

## SUMMARY OF CRASH TEST NO. 4

### TEST VEHICLE

| | |
|---|---|
| Make | 1977 Plymouth Fury |
| Weight (excluding dummy) | 4,360 lb. |

### TRAFFIC BARRIER INSTALLATION

| | |
|---|---|
| Concrete Bridgerail | |
| Type | Open Rail/Post; Tapered End |
| Length | 21 ft.-6 in. |
| Guardrail Beam Members (12 Ga) | |
| Transition | |
| Type | Double Thrie Beam |
| Length | 12 ft.-6 in. |
| Adapter | |
| Length | 6 ft.-3 in. |
| Approach | |
| Type | Standard W-Beam |
| Length | 37 ft.-6 in. |
| Guardrail Wood Posts | |
| Post No. 1 | Left Out |
| Post Nos. 2 and 3 | 10 x 10 x 72 in. |
| Post Nos. 4 thru 7 | 8 x 8 x 72 in. |
| Post Nos. 8 thru 12 | 6 x 8 x 72 in. |
| Native Soil | |
| Type | Silty-Clay (CL) |
| Optimum Moisture | 18% |
| Relative Compaction | 92% |
| Test Conditions | Dry |

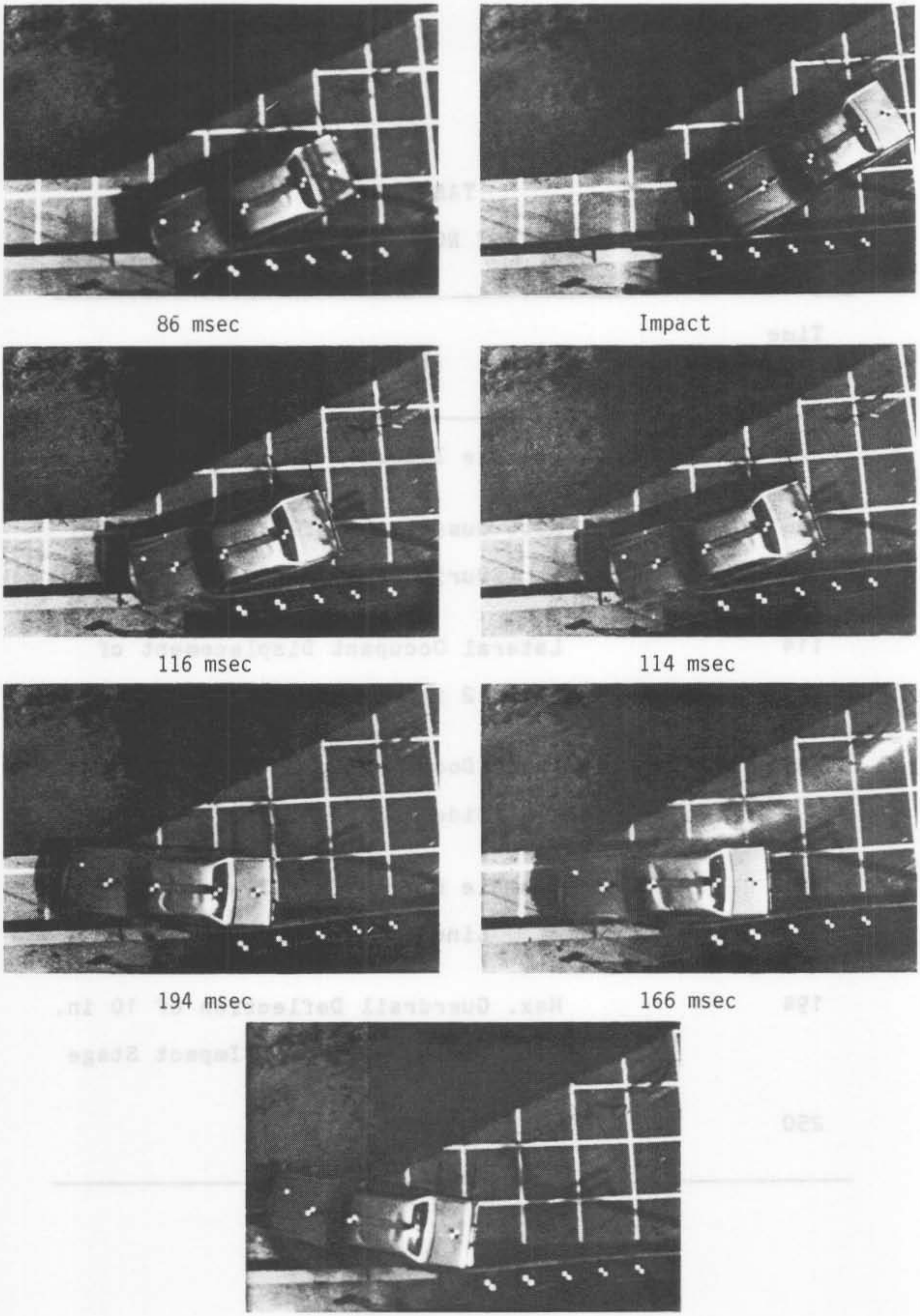
### TEST RESULTS

| | |
|---|---|
| Vehicle Speed | |
| Impact | 61 mph |
| Exit | 47 mph |
| Vehicle Angle | |
| Impact | 25 deg. |
| Exit | 11 deg. |
| Vehicle Rebound Distance | 20 ft. |
| Vehicle Damage | TAD FLQ-4 1/2 |
| Traffic Barrier | |
| Impact Location | Between Post Nos. 2 and 3 |
| Max. Dynamic Deflection | 10 in. |
| Max. Permanent Set | 7 1/2 in. |
| Snagging | None |
| Occupant Risk (NCHRP 230) | |
| Lateral Impact Velocity | 19 fps |
| Ridedown Accelerations | 10 g |
| Occupant Risk (NCHRP 86) | |
| Injury Accident Probability | 41% |

## TABLE 12

## DESCRIPTION OF TEST NO. 4 SEQUENTIAL EVENTS

| Time (msec) | EVENT |
|---|---|
| 0 | Vehicle Impact |
| 86 | Max. Guardrail Deflection of 9 in. During Primary Impact Stage |
| 114 | Lateral Occupant Displacement of 12 in. |
| 116 | Front Door Springs Open Under Dummy Side Loading |
| 166 | Vehicle Becomes Parallel to Center Line of Traffic Barrier |
| 194 | Max. Guardrail Deflection of 10 in. During Secondary Impact Stage |
| 250 | Vehicle Exit |



86 msec

Impact

116 msec

114 msec

194 msec

166 msec

250 msec

Figure 25

SEQUENTIAL PHOTOGRAPHS OF TEST NO. 4

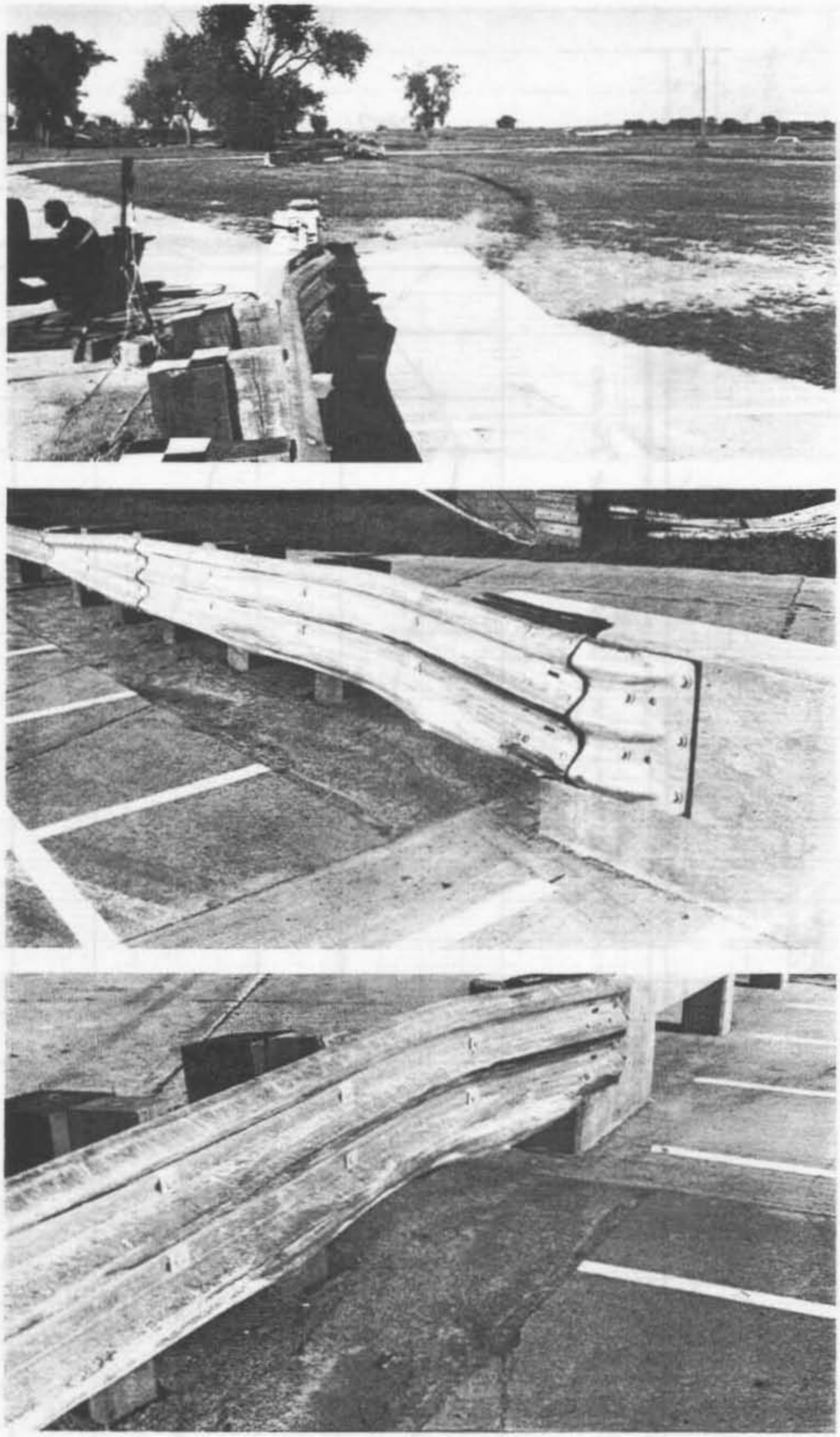
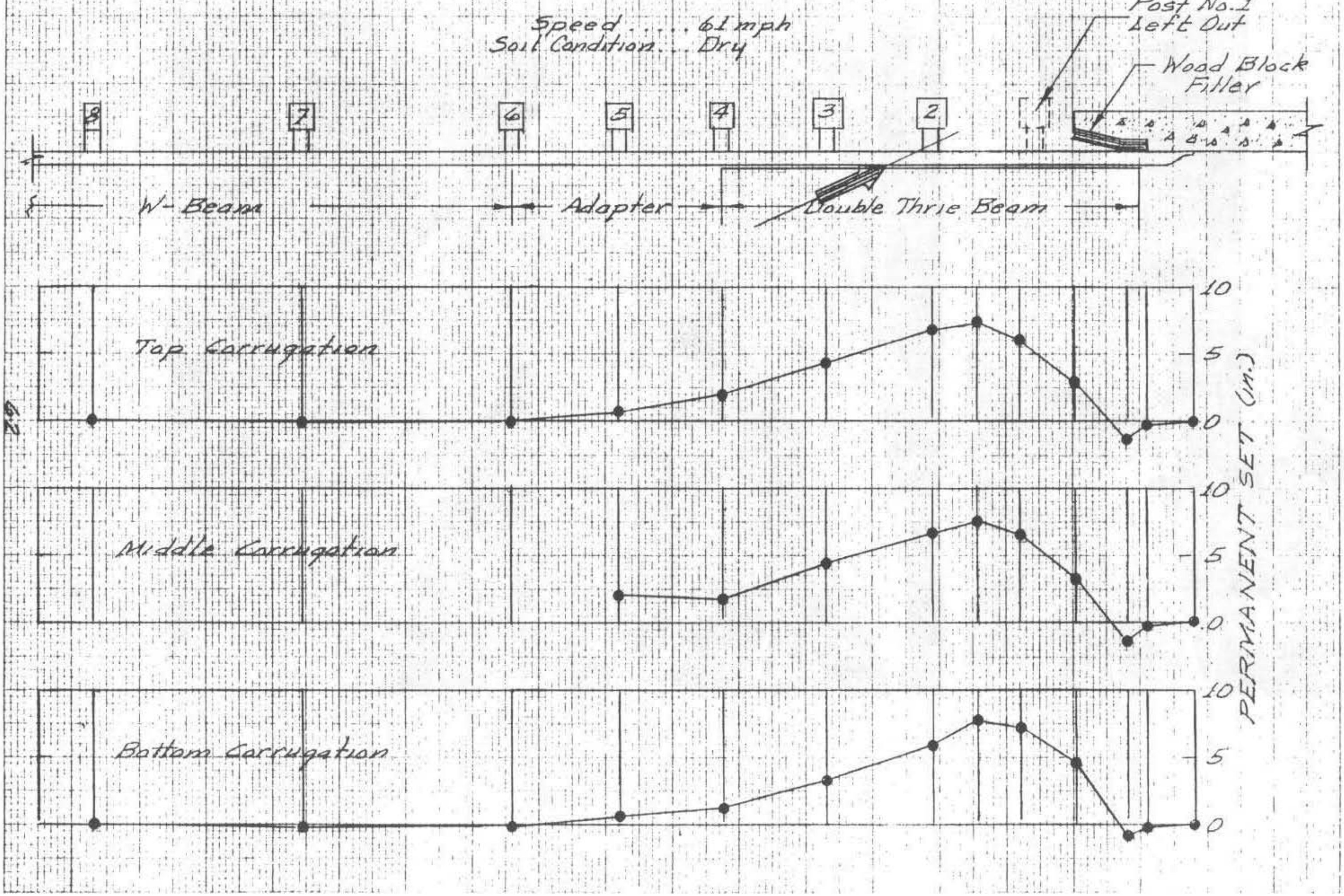


Figure 26
PHOTOGRAPHS OF TEST NO. 4 GUARDRAIL DAMAGE

Figure 27
TEST 4 ... GUARDRAIL PERMANENT SET



The vehicle exit angle, as measured from the high-speed film analyses of the overhead camera and the tire scuff marks, was 11 deg. which is well below the limit of 15 deg. recommended in NCHRP 230. Due to slight damage of the left front wheel, the vehicle turned slowly back-in toward an extended centerline of the traffic barrier. The maximum rebound distance of the vehicle C.G. path was approximately 20 ft.

Photographs of the vehicle before and after the test are shown in Figure 28. It was estimated that the vehicle was travelling at a speed of 10 to 15 mph when it was stopped by the CMB protecting the downstream high-speed camera. Most of the damage was incurred during impact with the Double Thrie Beam Transition. The vehicle damage was assigned a NSC TAD rating of LFQ-4 1/2. Based on the findings in NCHRP 86 (8), it was predicted that injuries would occur in vehicles damaged to this extent in 41% of the accidents.

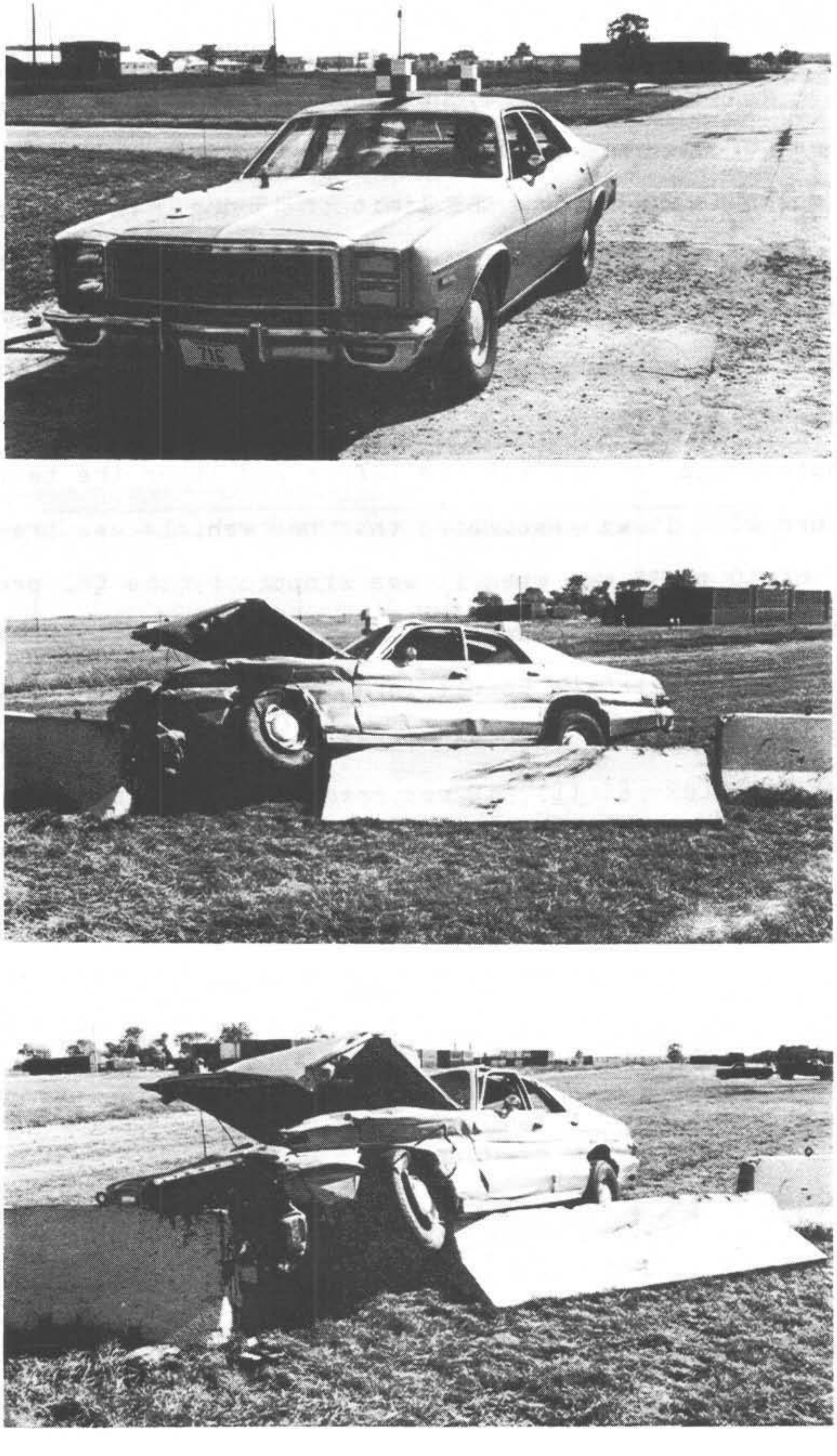


Figure 28
PHOTOGRAPHS OF TEST VEHICLE BEFORE AND AFTER TEST NO. 4

## B.5. TEST NO. 5: DOUBLE THRIE BEAM TRANSITION

A summary of the full-scale vehicle crash test on the Double Thrie Beam Transition is presented in Table 13. The point of impact was at Post No. 4; whereas, in the preceding test (Test No. 4) on the identical guardrail design, the impact point was between Post Nos. 2 and 3. The decision to run the second test was based on the need to determine the most critical impact location in terms of guardrail performance. The vehicle impact speed was 61 mph and the exit speed was 48 mph.

Sequential photographs of Test No. 5 are shown in Figure 29, and a description of the sequential events is presented in Table 14. During the primary (vehicle front-end) impact stage at a time of 90 msec, the maximum guardrail deflection was 16 in. At a time of 99 msec, the lateral occupant displacement of 12 in. occurred nearly simultaneously to the time in which the front door sprung open under a dummy side impact loading force of 8 g's. The methodology used to determine occupant lateral displacement, impact velocity, and ridedown accelerations by high-speed film analyses is presented in Appendix D. It was interesting to observe that the largest guardrail deflection of 17 in. occurred during the secondary (vehicle rear-end) impact stage at a time of 201 msec. Vehicle exit from the barrier occurred at a time of about 283 msec.

Photographs of the guardrail damage are shown in Figure 30 (2 pages), and measurements of the guardrail permanent set deflections are shown in Figure 31. The soil was <u>saturated</u> from a heavy 2 day storm preceding the day of the test. The decision to test under a

# TABLE 13

## SUMMARY OF CRASH TEST NO. 5

### TEST VEHICLE

| | |
|---|---|
| Make | 1977 Plymouth Fury |
| Weight (excluding Dummy | 4,320 lb. |

### TRAFFIC BARRIER INSTALLATION

| | |
|---|---|
| Concrete Bridgerail | |
| Type | Open Rail/Post; Tapered End |
| Length | 21 ft.-6 in. |
| Guardrail Beam Members (12 Ga) | |
| Transition | |
| Type | Double Thrie Beam |
| Length | 12 ft.-6 in. |
| Adapter | |
| Length | 6 ft.-3 in. |
| Approach | |
| Type | Standard W-Beam |
| Length | 37 ft.-6 in. |
| Guardrail Wood Posts | |
| Post No. 1 | Left Out |
| Post Nos. 2 and 3 | 10 x 10 x 72 in. |
| Post Nos. 4 thru 7 | 8 x 8 x 72 in. |
| Post Nos. 8 thru 12 | 6 x 8 x 72 in. |
| Native Soil | |
| Type | Silty-Clay (CL) |
| Optimum Moisture | 18% |
| Relative Compaction | 92% |
| Test Conditions | Wet |

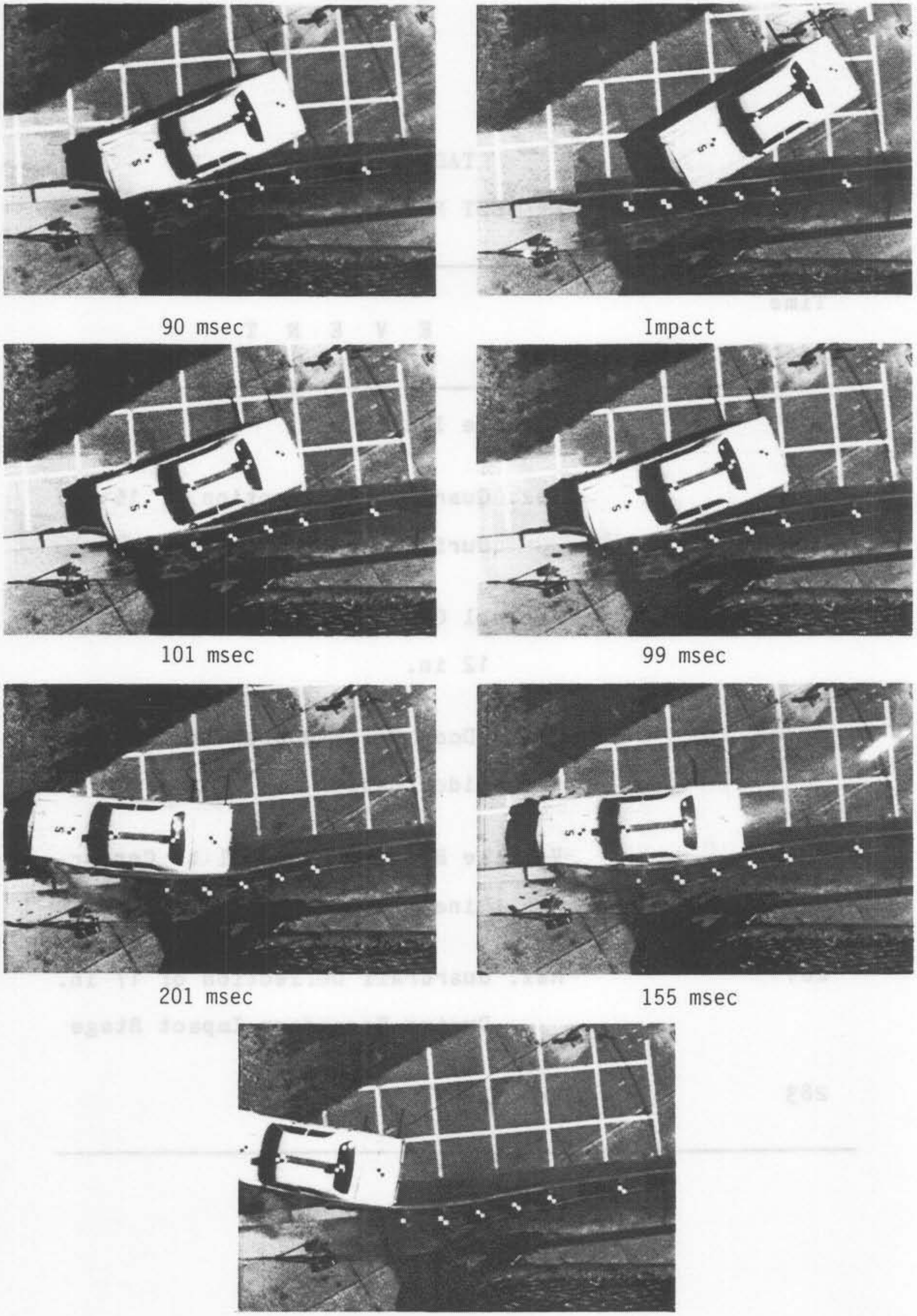
### TEST RESULTS

| | |
|---|---|
| Vehicle Speed | |
| Impact | 61 mph |
| Exit | 48 mph |
| Vehicle Angle | |
| Impact | 25 deg. |
| Exit | 15 deg. |
| Vehicle Rebound Distance | 20 ft. |
| Vehicle Damage | TAD LFQ-4 |
| Traffic Barrier | |
| Impact Location | Post No. 4 |
| Max. Dynamic Deflection | 17 in. |
| Max. Permanent Set | 11 in. |
| Snagging | None |
| Occupant Risk (NCHRP 230) | |
| Lateral Impact Velocity | 17 fps |
| Ridedown Accelerations | 8 g |
| Occupant Risk (NCHRP 86) | |
| Injury Accident Probability | 33% |

## TABLE 14

## DESCRIPTION OF TEST NO. 5 SEQUENTIAL EVENTS

| Time (msec) | EVENT |
|---|---|
| 0 | Vehicle Impact |
| 90 | Max. Guardrail Deflection of 16 in. During Primary Impact Stage |
| 99 | Lateral Occupant Displacement of 12 in. |
| 101 | Front Door Springs Open Under Dummy Side Loading |
| 155 | Vehicle Becomes Parallel to Center Line of Traffic Barrier |
| 201 | Max. Guardrail Deflection of 17 in. During Secondary Impact Stage |
| 283 | Vehicle Exit |



90 msec

Impact

101 msec

99 msec

201 msec

155 msec

283 msec

Figure 29

SEQUENTIAL PHOTOGRAPHS OF TEST NO. 5

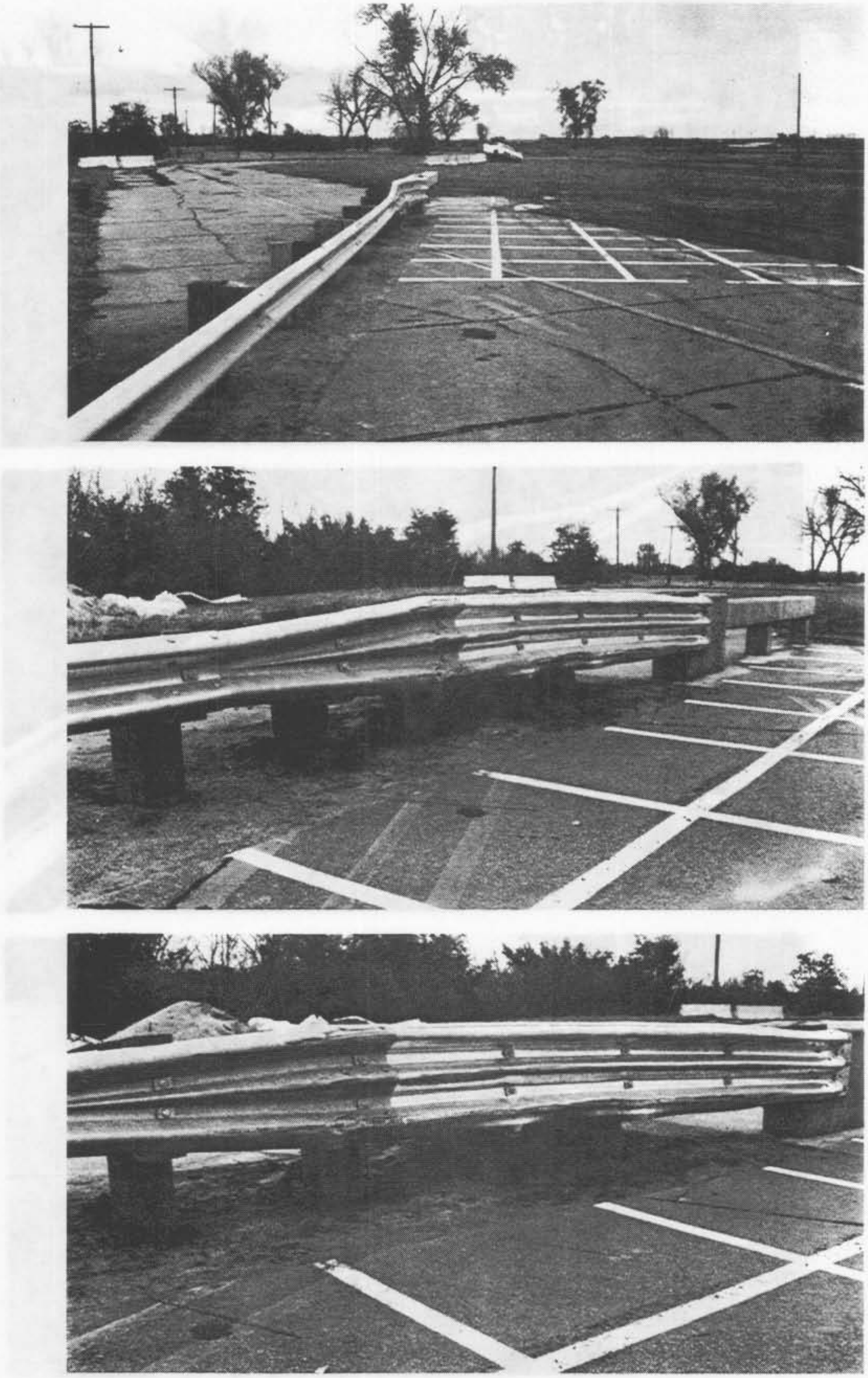


Figure 30

PHOTOGRAPHS OF TEST NO. 5 GUARDRAIL DAMAGE

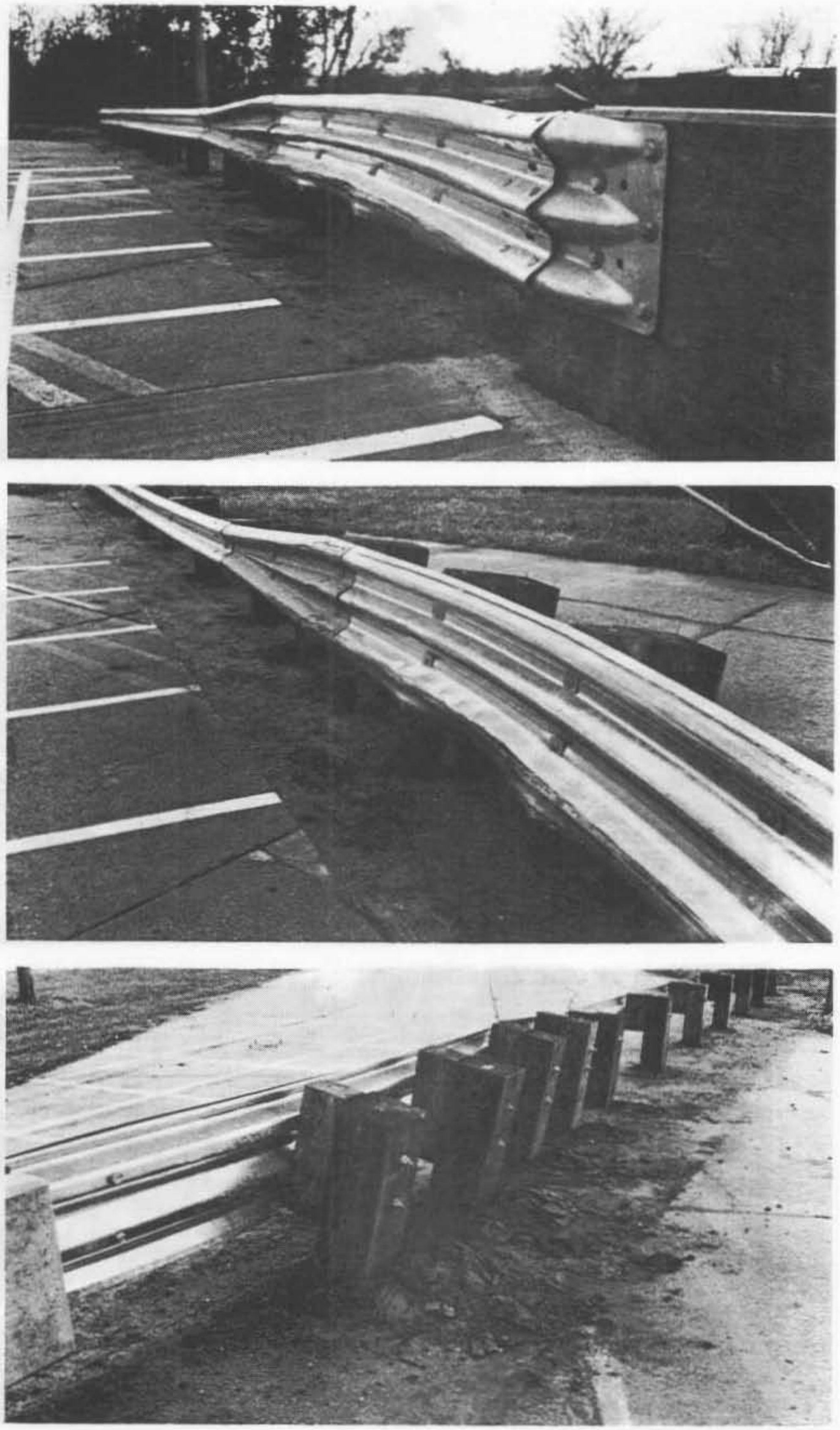
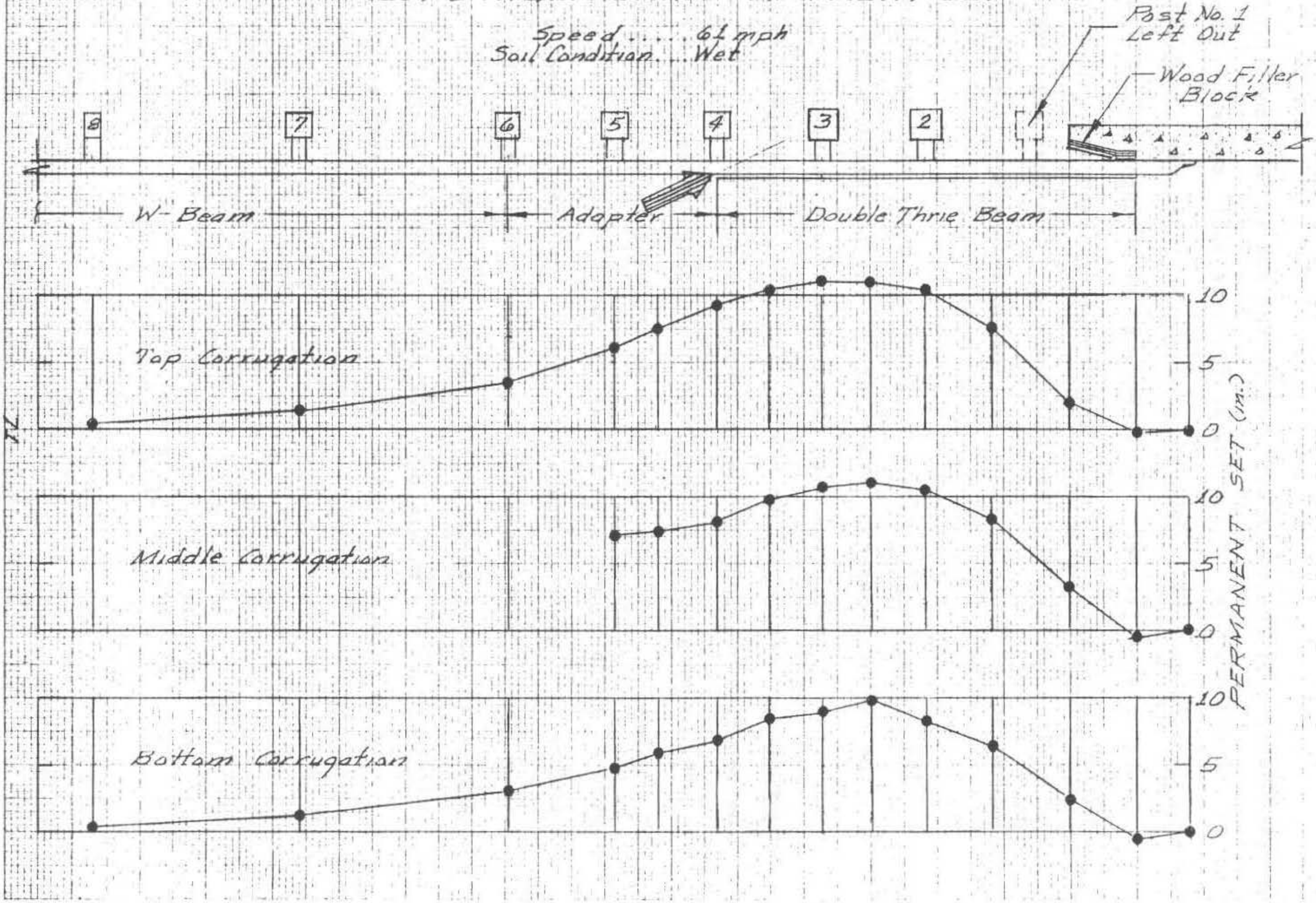


Figure 30

PHOTOGRAPHS OF TEST NO. 5 GUARDRAIL DAMAGE

Figure 31
TEST 5 . . . GUARDRAIL PERMANENT SET

Speed . . . . . 61 mph
Soil Condition . . . Wet



saturated soil condition was made by the NDR as this condition would be representative of the lowest possible soil shearing strength. The damaged guardrail shows no indication of vehicle snagging. The vehicle change-in-speed of 13 mph was also supportive of the fact that no snagging occurred as the change-in-speed was below the 15 mph limit specified in NCHRP 230. Overall, the guardrail "smoothly" redirected the vehicle. The maximum permanent set in the guardrail was 11 in.

The vehicle exit angle, as measured from the high-speed analysis of the overhead camera, was 15 deg. Due to slight damage of the left front wheel, the vehicle turned slowly back-in toward an extended centerline of the traffic barrier. The maximum rebound of the vehicle C.G. path was approximately 20 ft.

Photographs of the vehicle before and after the test are shown in Figure 32. It was assumed that the vehicle was travelling at a speed of 10 to 15 mph when it was stopped by the CMB protecting the downstream high-speed camera. Most of the damage was incurred during impact with the Double Thrie Beam Transition. The vehicle damage was assigned a NSC TAD rating of LFQ-4. Based on the findings in NCHRP 86 (8), it was predicted that injuries would occur in vehicles damaged to this extent in 33% of the accidents.

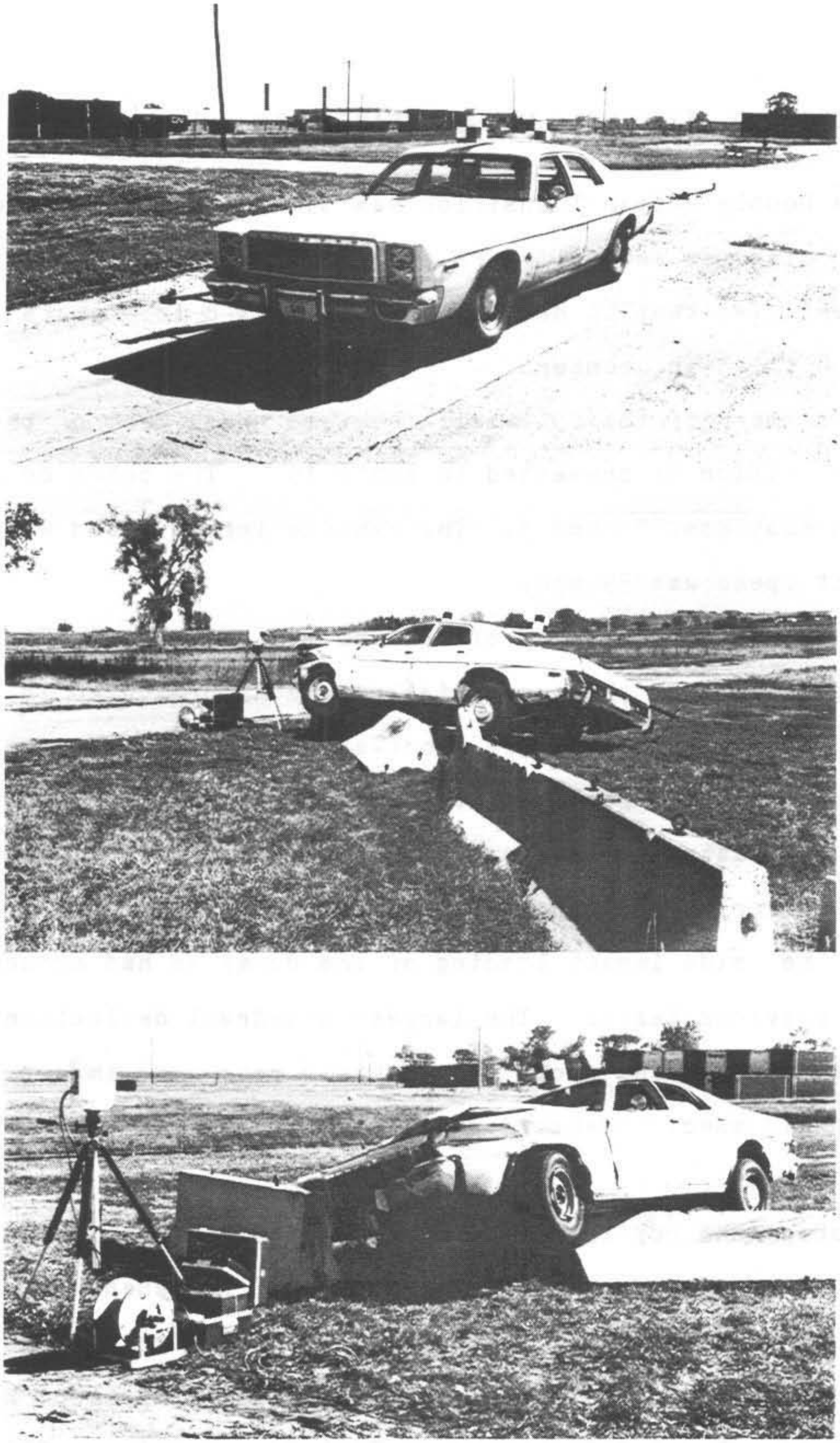


Figure 32

PHOTOGRAPHS OF TEST VEHICLE BEFORE AND AFTER TEST NO. 5

## B.6. TEST NO. 6: DOUBLE W-BEAM TRANSITION

The Double W-Beam Transition was similar to an "old" design that was in wide use several years ago in Nebraska. The old design was different in that it had smaller size 6 x 8 in. posts spaced on longer 6 ft.-3 in. centers.

A summary of the full-scale vehicle crash test on the Double W-Beam Transition is presented in Table 15. The point of impact was between Post Nos. 2 and 3. The vehicle impact speed was 62 mph and the exit speed was 39 mph.

Sequential photographs of Test No. 6 are shown in Figure 33, and a description of the sequential events is presented in Table 16. During the primary (vehicle front-end) impact stage at a time of 75 msec, the maximum guardrail deflection was 9 in. At a time of 113 msec, the lateral displacement of an occupant would have been 12 in., however, there was no sign of the front door being sprung open under the side impact loading of the dummy as had occurred in the three previous tests. The largest guardrail deflection of 10 in. occurred during the secondary (vehicle rear-end) impact stage at a time of 212 msec. Vehicle exit from the barrier occurred at a time of 262 msec.

Photographs of the guardrail damage are shown in Figure 34 (2 pages), and measurements of the guardrail permanent set deflections are shown in Figure 35. The soil was frozen to a depth of 8 to 10 in. The effect of the frozen soil was readily apparent by comparing the permanent set deflections in Test No. 4 (Figure 27) with this

TABLE 15

SUMMARY OF CRASH TEST NO. 6

### TEST VEHICLE

| | |
|---|---|
| Make | 1977 Plymouth Fury |
| Weight (excluding Dummy) | 4,560 lb. |

### TRAFFIC BARRIER INSTALLATION

| | |
|---|---|
| Concrete Bridgerail | |
| Type | Open Rail/Post; Tapered End |
| Length | 21 ft.-6 in. |
| Guardrail Beam Members (12 Ga) | |
| Transition | |
| Type | Double W-Beam |
| Length | 12 ft.-6 in. |
| Adapter | |
| Length | 6 ft.-3 in. |
| Approach | |
| Type | Standard W-Beam |
| Length | 37 ft.-6 in. |
| Guardrail Wood Posts | |
| Post No. 1 | Left Out |
| Post Nos. 2 and 3 | 10 x 10 x 72 in. |
| Post Nos. 4 thru 7 | 8 x 8 x 72 in. |
| Post Nos. 8 thru 12 | 6 x 8 x 72 in. |
| Native Soil | |
| Type | Silty-Clay (CL) |
| Optimum Moisture | 18% |
| Relative Compaction | 92% |
| Test Conditions | Ground Frozen 8 to 10 in. |

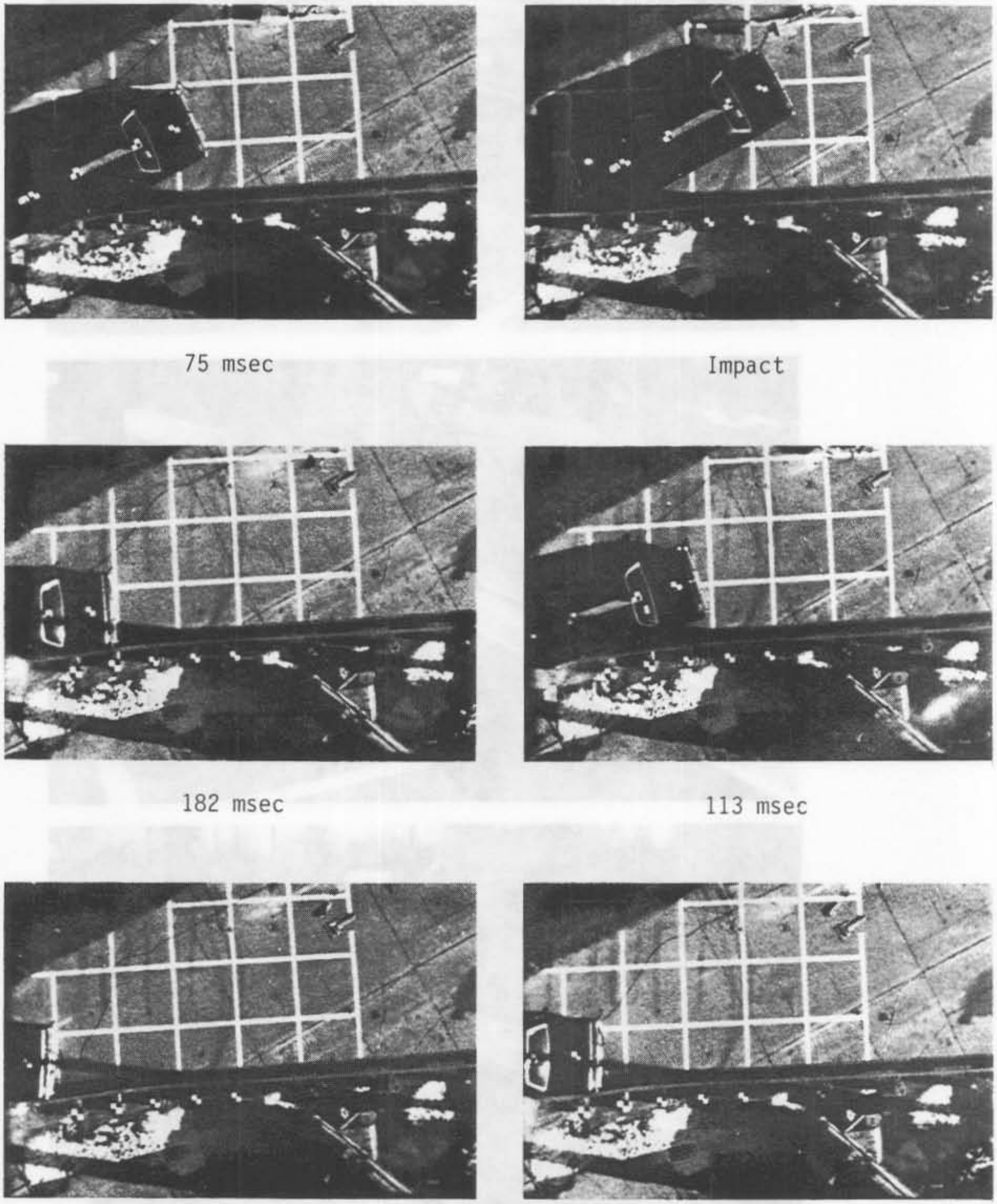
### TEST RESULTS

| | |
|---|---|
| Vehicle Speed | |
| Impact | 62 mph |
| Exit | 39 mph |
| Vehicle Angle | |
| Impact | 25 deg. |
| Exit | 9 deg. |
| Vehicle Rebound Distance | 20 ft. |
| Vehicle Damage | TAD FLQ-7 (extensive) |
| Traffic Barrier | |
| Impact Location | Between Post Nos. 2 and 3 |
| Max. Dynamic Deflection | 10in. |
| Max. Permanent Set | 6 in. |
| Snagging | severe |
| Occupant Risk (NCHRP 230) | |
| Lateral Impact Velocity | 24 fps |
| Ridedown Accelerations | 6 g |
| Occupant Risk (NCHRP 86) | |
| Injury Accident Probability | 100% |

## TABLE 16

## DESCRIPTION OF TEST NO. 6 SEQUENTIAL EVENTS

| Time (msec) | EVENT |
|---|---|
| 0 | Vehicle Impact |
| 75 | Max. Guardrail Deflection of 9 in. During Primary Impact |
| 113 | Lateral Occupant Displacement of 12 in. |
| 182 | Vehicle Becomes Parallel to Center Line of Traffic Barrier |
| 212 | Max. Guardrail Deflection of 10 in. During Secondary Impact |
| 262 | Vehicle Exit |



75 msec

Impact

182 msec

113 msec

262 msec

212 msec

Figure 33

SEQUENTIAL PHOTOGRAPHS OF TEST NO. 6

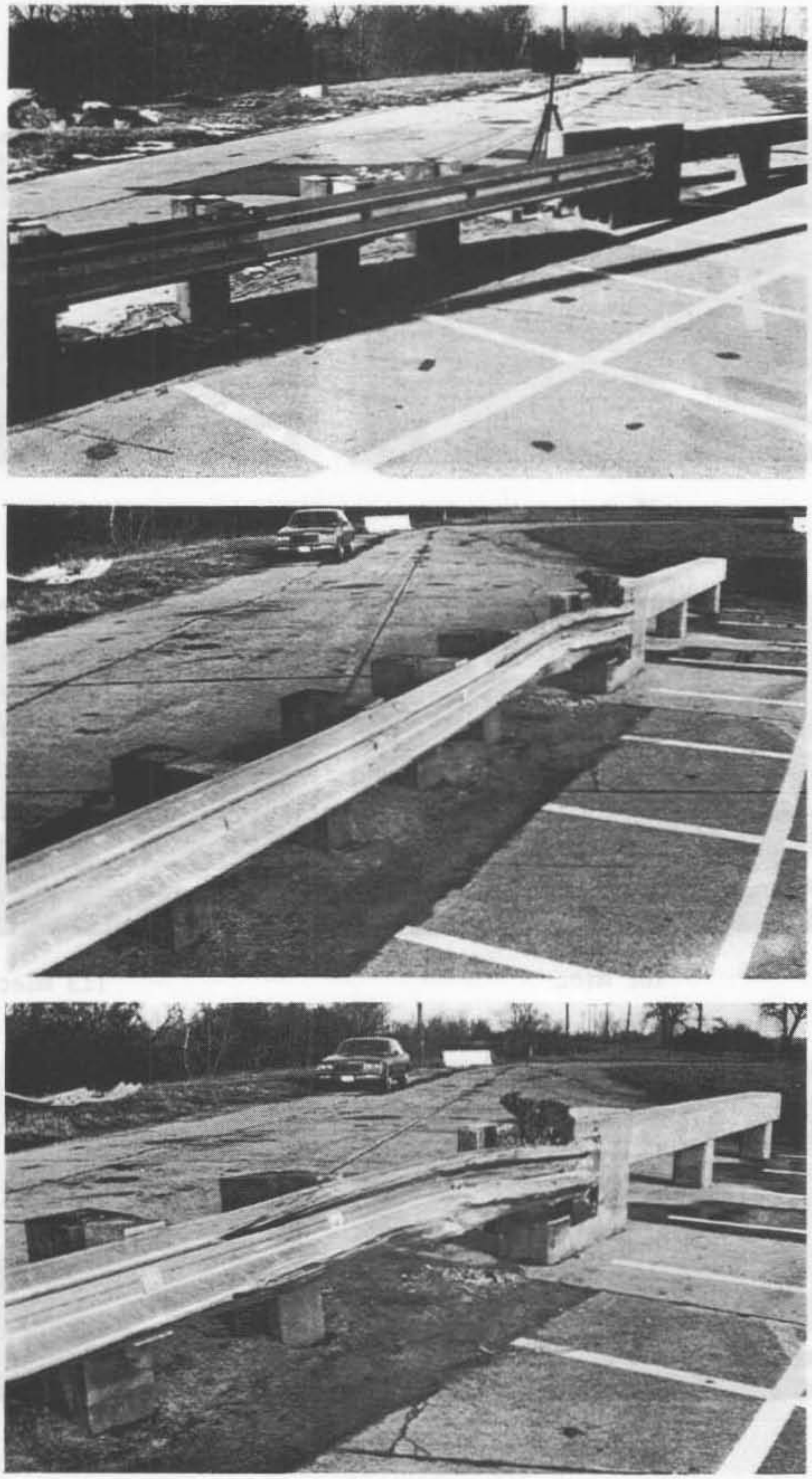


Figure 34
PHOTOGRAPHS OF TEST NO. 6 GUARDRAIL DAMAGE

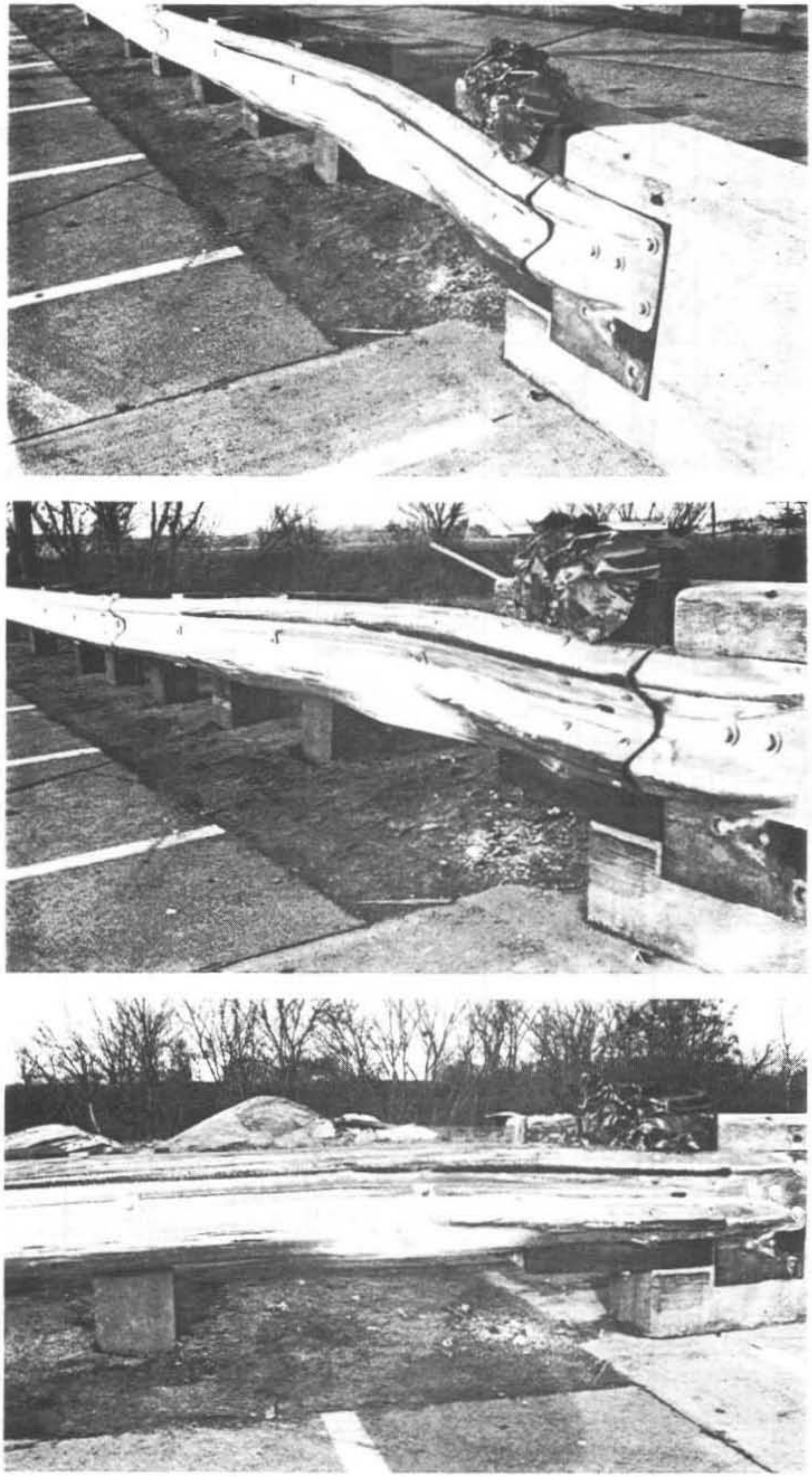
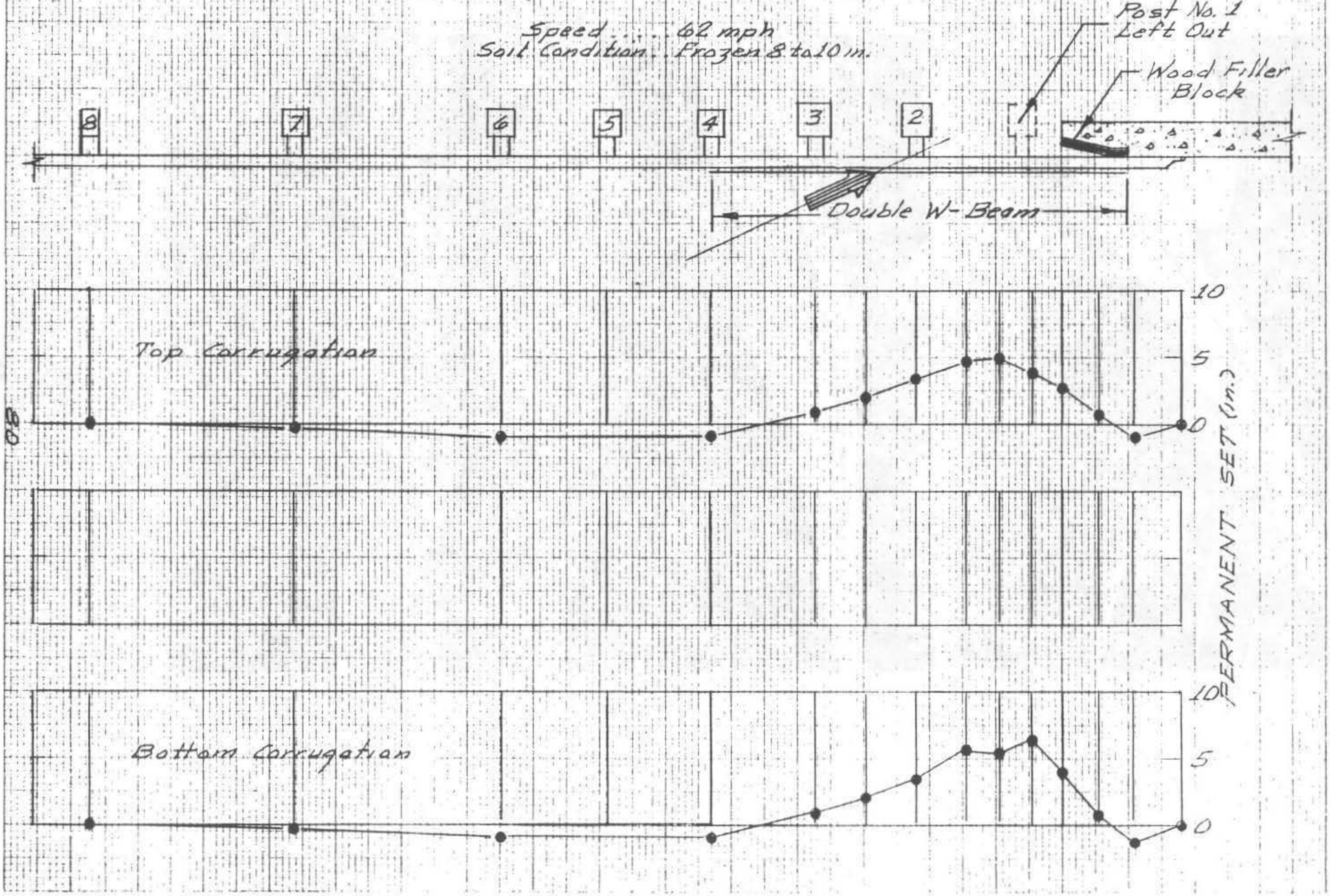


Figure 34
PHOTOGRAPHS OF TEST NO. 6 GUARDRAIL DAMAGE

Figure 35
TEST 6 ... GUARDRAIL PERMANENT SET

Speed ..... 62 mph
Soil Condition .. Frozen 8 to 10 in.



test. Aside from the fact that the strength of the Double Thrie Beam in Test No. 4 was much stronger than the strength of the Double W-Beam, the permanent set deflections of the Double W-Beam were much less. The damaged guardrail in Figure 34 shows severe vehicle snagging. The vehicle change-in-speed of 23 mph was also supportive of the fact that severe snagging occurred as the change-in-speed greatly exceeded the 15 mph limit specified in NCHRP 230. The snagging was the result of the vehicle frame and wheel assembly getting under the guardrail and impacting the tapered-end of the concrete bridgerail. As can be seen in Figure 34, sheet metal was torn from the vehicle and wedged in between the guardrail and the wood filler block in the recessed area of the bridgerail tapered-end.

The vehicle exit angle, as measured from an analysis of the high-speed film of the overhead camera, was 9 deg. Due to the badly damaged left front wheel, the vehicle turned rapidly back-in toward an extended centerline of the traffic barrier.

Photographs of the vehicle before and after the test are shown in Figure 36. It was estimated that the vehicle was travelling at a speed of 10 to 15 mph when it was stopped by the CMB protecting the downstream high-speed camera. Most of the damage was incurred during impact with the Double W-Beam Transition. As evident, the vehicle was extensively damaged as a result of the severe snagging. The vehicle damage was assigned a NSC TAD rating of LFQ-7. Based on the findings in NCHRP 86 (8), it was predicted that injuries would occur in vehicles damaged to this extent in 100% of the accidents.

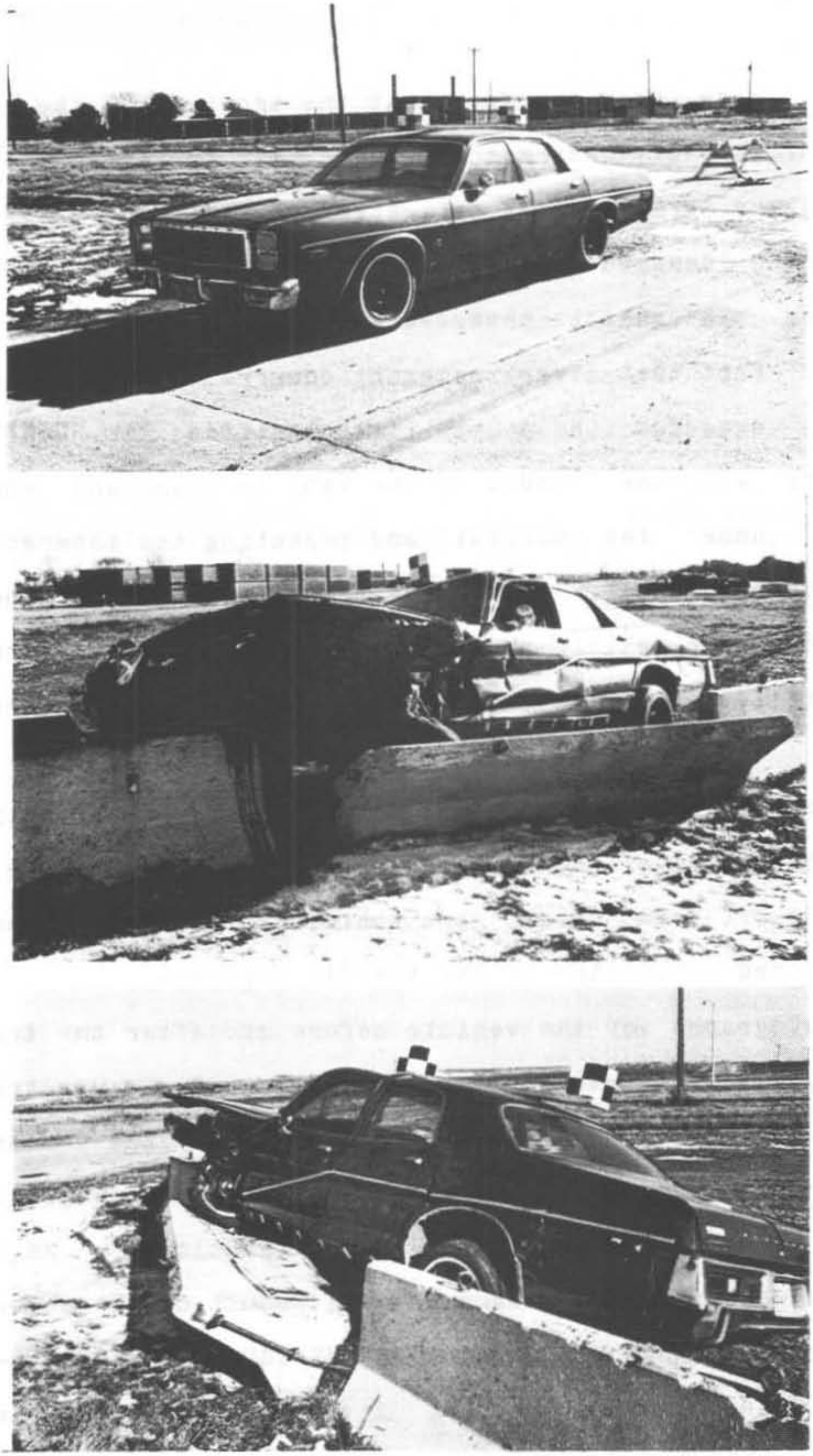


Figure 36

PHOTOGRAPHS OF TEST VEHICLE BEFORE AND AFTER TEST NO. 6

# III

# SUMMARY AND CONCLUSIONS

A comparative summary of the crash test results is presented in Table 17, and the performance of the traffic barrier measured in terms of the NCHRP 230 (3) safety evaluation guidelines is presented in Table 18.

Due to technical problems with the tow vehicle, the impact speeds in Test No. 1 and Test No. 2 were approximately 14 mph below the recommended target speed of 60 mph in NCHRP 230. Test No. 1 on the Tubular Thrie Beam transition was not rerun because it was estimated that the dynamic deflection would have only been on the order of 3 in. greater at the higher 60 mph impact speed, and hence, the 60 mph test would have most likely been satisfactory. On the other hand, Test No. 2 on the Single Thrie Beam transition was rerun (1) because of the uncertainty that existed due to an estimated dynamic deflection on the order of 7 in. greater at the higher 60 mph impact speed, (2) due to the simple fact that the test speed was not in conformance with NCHRP 230. The estimated deflections were determined on the assumption that the deflection of the guardrail was directly proportional to the lateral kinetic energy of the vehicle.

After impact with the guardrail transition, the vehicle trajectory (C.G. path) in each of the six tests was unsatisfactory in accordance with NCHRP 230 (Item H) as each vehicle would have been redirected back into the adjacent lanes of traffic. In order to compensate for this type of situation, it is specified in NCHRP 230 (Item I) that (1) the change-in-speed of the vehicle should be less than 15 mph, and (2) the exit angle should be less than 15 deg.

## TABLE 17

## COMPARATIVE SUMMARY OF CRASH TEST RESULTS

| TEST NO. | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| TRANSITION BEAM DESIGN | Tubular Thrie | Single Thrie | Single Thrie | Double Thrie | Double Thrie | Double W-Beam |
| SOIL (Silty-Clay) | Dry | Dry | Dry | Dry | Wet | Frozen(a) |
| VEHICLE WEIGHT (lb) | 4,384 | 4,340 | 4,400 | 4,360 | 4,320 | 4,560 |
| VEHICLE SPEED | | | | | | |
| Impact (mph) | 47 | 46 | 60 | 61 | 61 | 62 |
| Exit (mph | 38 | 35 | 39 | 47 | 48 | 39 |
| Change (mph) | 9 | 11 | 21 | 14 | 13 | 23 |
| VEHICLE ANGLE | | | | | | |
| Impact (deg) | 25 | 25 | 25 | 25 | 25 | 25 |
| Exit (deg) | 15 | 15 | 11 | 11 | 15 | 9 |
| VEHICLE REBOUND DISTANCE (ft) | 72 | 20 | 20 | 20 | 20 | 20 |
| VEHICLE DAMAGE (TAD LFQ) | 3 (moderate) | 3 (moderate) | 6 1/2 (major) | 4 1/2 (moderate) | 4 (moderate) | 7 (extensive) |
| TRAFFIC BARRIER | | | | | | |
| Impact Post Location | Bet. 2&3 | Bet. 2&3 | Bet. 2&3 | Bet. 2&3 | 4 | Bet. 2&3 |
| Max. Dynamic Deflection (in) | 4 | 9 | 14 | 10 | 17 | 10 |
| Max. Permanent Set (in) | 2½ | 6 | 10 | 7½ | 11 | 6 |
| Snagging | None | None | Moderate | None | None | Severe |
| OCCUPANT RISK (NCHRP 230) | | | | | | |
| Lateral Impact Velocity (fps) | 12[b] | 12[b] | 21 | 19 | 17 | 24 |
| Ridedown Accelerations (g) | - | - | 10 | 10 | 8 | 6 |
| OCCUPANT RISK (NCHRP 86) | | | | | | |
| Injury Accident Probability | 18 | 18 | 86 | 41 | 33 | 100 |

Notes: (a) Soil Frozen to Depth of 8 to 10 in.

(b) Estimated . . . See Figure 37

## TABLE 18

## NCHRP 230 SAFETY EVALUATION GUIDELINES

Appurtenance . . . . Longitudinal Barrier
Test Designation . . . . No. 30 (Transition)

| | | TRANSITION DESIGN(1) | | | | | |
|---|---|---|---|---|---|---|---|
| Evaluation Factor | Evaluation Criteria | Tubular Thrie Beam (Test 1) | Single Thrie Beam (Test 2) | Single Thrie Beam (Test 3) | Double Thrie Beam (Test 4) | Double Thrie Beam (Test 5) | Double Safety Beam (Test 6) |
| Impact Conditions | 58 to 60 mph/25 deg | U | U | S | S | S | S |
| Structural | A. Test article shall smoothly redirect the vehicle. | S | S | U | S | S | U |
| | The vehicle shall not penetrate or go over the installation although controlled lateral deflection of the test article is acceptable. | S | S | S | S | S | S |
| | D. Detached elements, fragments or other debris from the test article shall not penetrate or show potential for penetrating the passenger compartment or present undue hazard to other traffic. | S | S | S | S | S | S |
| Occupant Risk | E. The vehicle shall remain upright during and after collision although moderate roll, pitching and yawing are acceptable. | S | S | S | S | S | S |
| | Integrity of the passenger compartment must be maintained with essentially no deformation or intrusion. | S | S | M | S | S | M |
| Vehicle Trajectory | H. After collision, the vehicle trajectory and final stopping position shall intrude a minimum distance, if at all, into adjacent traffic lanes. | U | U | U | U | U | U |
| | I. In test where the vehicle is judged to be redirected into or stopped while in adjacent traffic lanes, vehicle speed change during test article collision should be less than 15 mph and the exit angle from the test article should be less than 60 percent of test impact angle, both measured at time of vehicle loss of contact with test device. | S | S | U | S | S | U |

In Test No. 3 on the Single Thrie Beam transition, a moderate amount of vehicle snagging occurred in the lower half of the thrie beam adjacent to the tapered end of the concrete bridgerail. As a result, the test was considered to be unsatisfactory because the vehicle change-in-speed of 21 mph was significantly higher than the limit of 15 mph specified in NCHRP 230. Due to vehicle snagging on the Single Thrie Beam transition, a decision was made by the NDR to run the next test on a Double Thrie Beam transition in favor of the much stronger and costly Tubular Thrie Beam transition that was used earlier in the study.

In Test No. 6 on the Double W-Beam transition, an extensive amount of vehicle snagging occurred under the guardrail on the tapered end of the concrete bridgerail. As a result, the test was considered to be unsatisfactory because the vehicle change-in-speed of 23 mph greatly exceeded the limit of 15 mph specified in NCHRP 230. In addition, the integrity of the passenger compartment area in terms of occupant risk (Item E) was considered to be marginal as the engine firewall was pushed backward on the side of the driver. The last item of concern was the soil that was frozen to a depth of 5 to 6 in. It is predicted that if the soil had not been frozen that the vehicle would have penetrated deeper under the flexible guardrail, and as a result, the vehicle would most-likely have been abruptly stopped and spunout on the tapered end of the concrete bridgerail.

From an overall consideration, the Double Thrie Beam transition in Test Nos. 4 and 5 was satisfactory in terms of the NCHRP 230 performance categories of structural adequacy (Items A and D), occupant risk (Item E), and vehicle trajectory (Item I). Two tests were conducted at different points of impact to be certain that the transition design was tested under the most critical condition of impact. Also, in Test No. 5 the soil was saturated from a heavy 2 day storm preceding the day of the test. The decision to test under a saturated soil condition was made by the NDR as this condition would be representative of the lowest possible soil shearing strength.

In NCHRP 230, it is to be noted that no evaluation guidelines are specified for conducting tests on a guardrail transition in regard to the "Impact Velocity of a Hypothetical Front Seat Passenger Against the Vehicle Interior". However, data on occupant impact velocity was presented in this study because it was felt that the data provided further insight into the evaluation of the transition designs tested. To supplement the NCHRP 230 data on occupant impact velocity, data on "Injury Accident Probability" contained in NCHRP 86 (8) was also presented in this study. The two sets of data on the tests are presented in Table 17, and a graphical relationship between the two sets of data is presented in Figure 37. An occupant impact velocity of 20 fps is recommended in NCHRP 230 as an "acceptable" design value, whereas, a value of 30 fps is a recommended design "limit". The effects of vehicle snagging are very evident in Figure 37.

In Test No. 6, severe snagging on the Double W-Beam transition would result in an injury accident probability of 100%; whereas, in

Test No. 3, moderate snagging on the Single Thrie Beam transition would result in an injury accident probability of 86%. In Test Nos. 4 and 5, an impact with the Double Thrie Beam transition in which no snagging occurred would result in an injury accident probability of 35 to 40%. Lastly, in Test Nos. 1 and 2 at a lower impact speed of 47 mph, an impact into either the Single Thrie Beam transition or the Tubular Thrie Beam transition in which no snagging occurred would result in an injury accident probability of about 20%.

In summary, the following conclusions were reached in regard to the overall performance of the four new guardrail-bridgerail transition designs in restraining and smoothly redirecting a large size 4,500 lb. automobile under the impact conditions of 60 mph and 25 deg.

1. Tubular Thrie Beam Transition . . . . . Satisfactory
2. Single Thrie Beam Transition . . . . . Unsatisfactory
3. Double Thrie Beam Transition . . . . . Satisfactory
4. Double W-Beam Transition . . . . . . . Unsatisfactory

It is to be emphasized that the above conclusions are based on the condition that a new design in the field will be constructed to the same exact design details under which the full-scale vehicle crash tests were conducted. In particular careful attention must be given to insure that: (1) the soil has the properties of a type "CL" soil, (2) the wood posts are of the proper size, spacing and clear of knots, (3) the 4:1 tapered-end is installed to the dimensions tested, and (4) the size and quantity of rebar in the concrete bridge end are adequate to carry a lateral impact load of 120 kips and a longitudinal load of 50 kips.

# IV

# REFERENCES

1. AASHTO, "Guide for Selecting, Locating, and Designing Traffic Barriers", American Association of State Highway and Transportation Officials, 1977.
2. Hinch, J., Yang, T-L, and Owings, R., "Guidance Systems for Vehicle Testing", ENSCO Inc., Springfield, VA, 1986.
3. NCHRP Report 230, "Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances", National Cooperative Highway Research Program Report, Transportation Research Board, March 1981.
4. McDevitt, C.F., Structural Research Engineer, Federal Highway Administration, Office of Research, Fairbank Highway Research Station, Washington, D.C. 20590.
5. Powell, G.H. "BARRIER VII: A Computer Program for Evaluation of Automobile Barrier Systems", Report No. FHWA-RD-73-51, Final Report, April 1973.
6. AASHTO, "Standard Specifications for Highway Bridges", American Association of State Highway and Transportation Officials, Sect. 1.1.8-Railings, 12th. Edition, 1977.
7. National Safety Council, "Vehicle Damage Scale for Traffic Accident Investigators", TAD Project Technical Bulletin No. 1, 1971.
8. Olson, R.M., Post, E.R., and McFarland, W.F., "Tentative Service Requirements for Bridge Rail Systems", National Cooperative Highway Research Board, NCHRP 86, 1970.

# APPENDICIES

# APPENDIX A

# SOIL TESTS

DEPARTMENT OF ROADS
INTER-OFFICE CORRESPONDENCE

DATE August 19, 1986

TO Richard Ruby

FROM Kenneth Cheney

THRU

SUBJECT Guard Rail Post Backfill

A bag of material used for backfill around guard rail posts was submitted to Materials and Tests. Tests performed were moisture-density and unconfined compression to determine shear strength.

The results are listed below.

Moisture - Density Tests
Maximun dry density 1.71 gm/cc
Optimum Moisture 17.9%

Unconfined Compression Test

| Moisture % | Dry Density gm/cc | Shear Strength P.S.F. |
|---|---|---|
| 16.6 | 1.76 | 3575 |
| 18.8 | 1.70 | 1900 |
| 20.6 | 1.66 | 1230 |

A shear strength of 1900 P.S.F. would best represent maximum density-optimum moisture condition.

The moisture content around the guard rail post was 21.0% on August 13, 1986 which may have been affected by recent rains.

Kenneth Cheney
Kenneth Cheney
Soils and Aggregates Engineer

KC/pr

xc: W. Ramsey

# COMPACTION TEST REPORT

**GEOTECHNICAL SERVICES, INC.**

CONSULTING GEOTECHNICAL ENGINEERS AND GEOLOGISTS

Lincoln, Grand Island & Omaha, Nebraska
Salina, Kansas
Ames, Iowa

| | |
|---|---|
| PROJECT | Existing Traffic Barrier Test Site |
| TYPE OF TEST | Backfill |
| JOB NUMBER | 335AL14 |
| LOCATION | NW 38th Street & W. Webster Street |
| CONTRACTOR | University of Nebraska-Lincoln |

| TEST NO. | DATE TESTED | LOCATION | DEPTH OF FILL (ft.) | SOIL DESCRIPTION | M.D. RESULTS | | REQUIREMENTS | | TEST RESULTS | | RESULTS | | | REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | MAX. DENS. (pcf) | OPT MOIST (%) | COMP (%) | MOIST ± OPT | DENSITY (pcf) | MOIST (%) | COMP (%) | MOIST ± OPT | PASS FAIL | |
| D895<br>1 | 10/30/86 | Post #2 3"NW of Northwest face of post | at grade | Dark Brown Silty Clay | 112.5* | 18.0* | 95 std | | 107.0 | 18.9 | 95 | +0.9 | PASS | |
| D896<br>2 | " | Post #1 3"NW of Northwest face of post | " | " | " | " | " | | 100.5 | 21.9 | 89 | +2.9 | | |
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COPIES 1-Post
ORIGINAL File
NOTE Test numbers followed by an alphabetical letter indicates a RETEST

SUBMITTED BY Wm. C. Arnson
[illegible], P.E.

**GEOTECHNICAL SERVICES, INC.**

*Soil and Foundation Consultants*

OMAHA, LINCOLN &
GRAND ISLAND, NEBRASKA
SALINA, KANSAS

# MOISTURE - DENSITY RELATIONSHIP REPORT

TYPE OF TEST: ASTM D 698 Method "A"

OPTIMUM DRY DENSITY (pcf): 109.5

OPTIMUM WATER CONTENT (%): 17.3

JOB NO.: 335AL14

LAB NO.: A-333

DATE TESTED: 11/6/86

SUBMITTED BY: Wm. C. Arneson, P.E. Wm. C. Arneson

LOCATION SAMPLED: Base of Guard Rail Post

SAMPLE NO.: MD02-126

SAMPLE DEPTH: 0-3'

SOIL DESCRIPTION: Brown Black Silty Clay

ATTERBERG LIMITS: LL 31 PL 20 PI 11

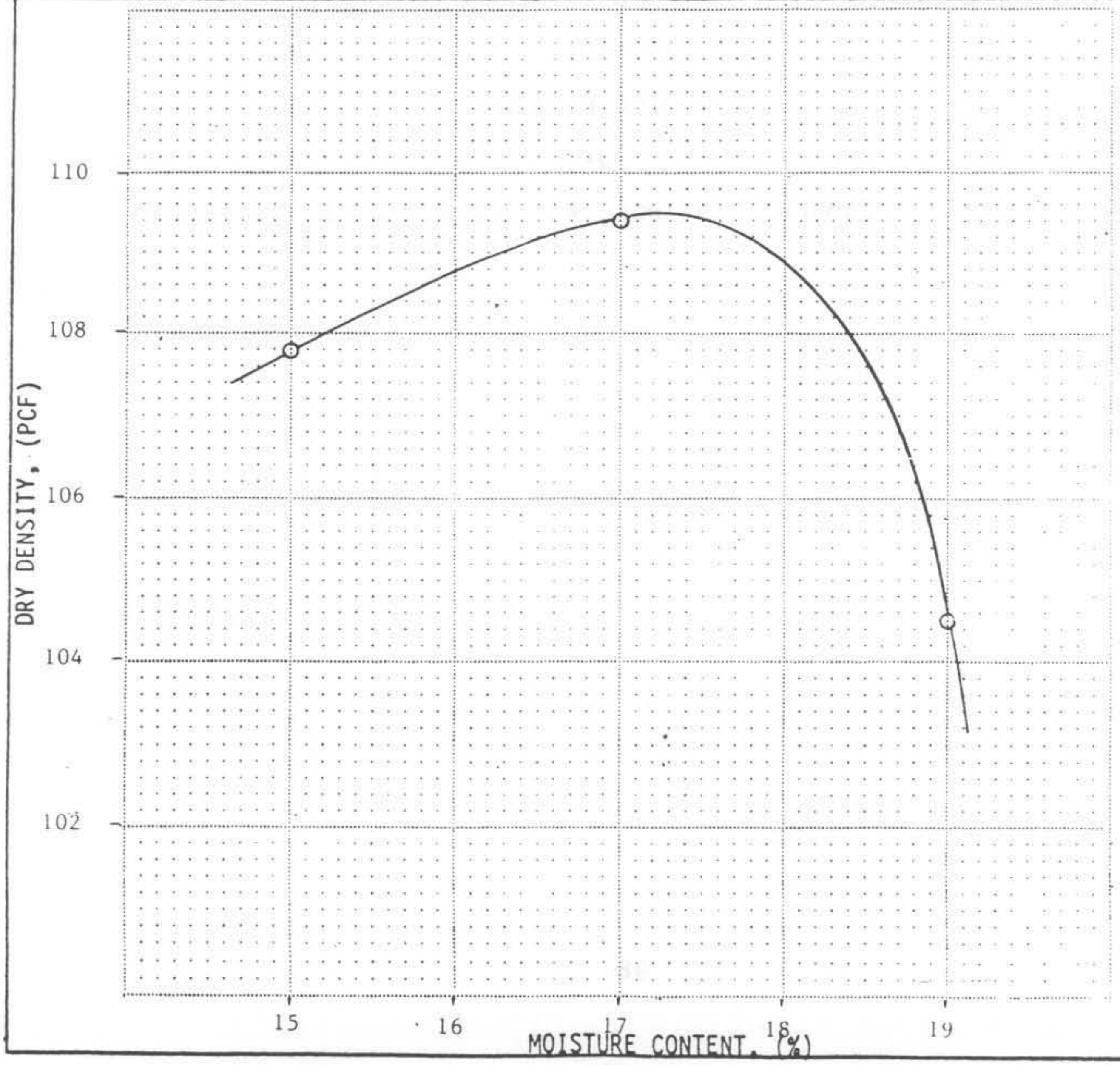
SOIL CLASSIFICATION: CL

PROJECT: Barrier Crash Site

ARCHITECT/ENGINEER/CONTRACTOR: Dr. Post-College of Engineering Science and Technologies

LOCATION OF PROJECT: Air Park, Lincoln, Nebraska

OWNER: University of Nebraska-Lincoln

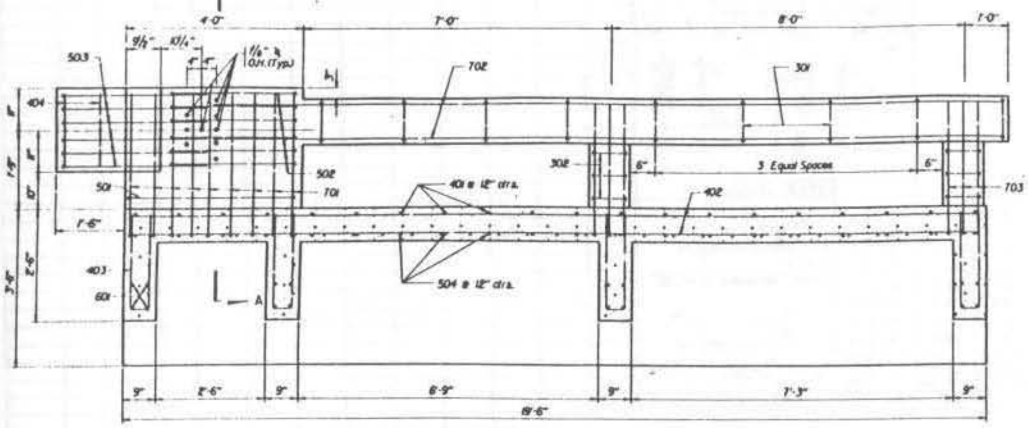


# APPENDIX B

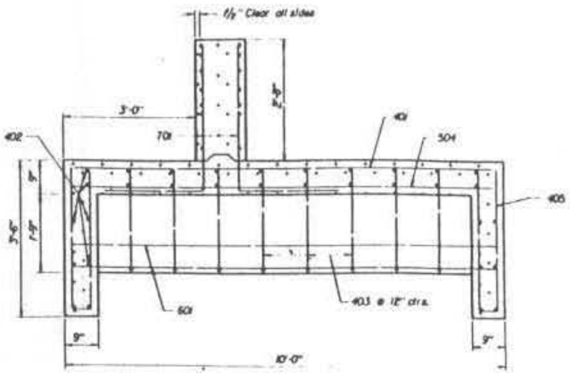
# DESIGN DETAILS

# OF

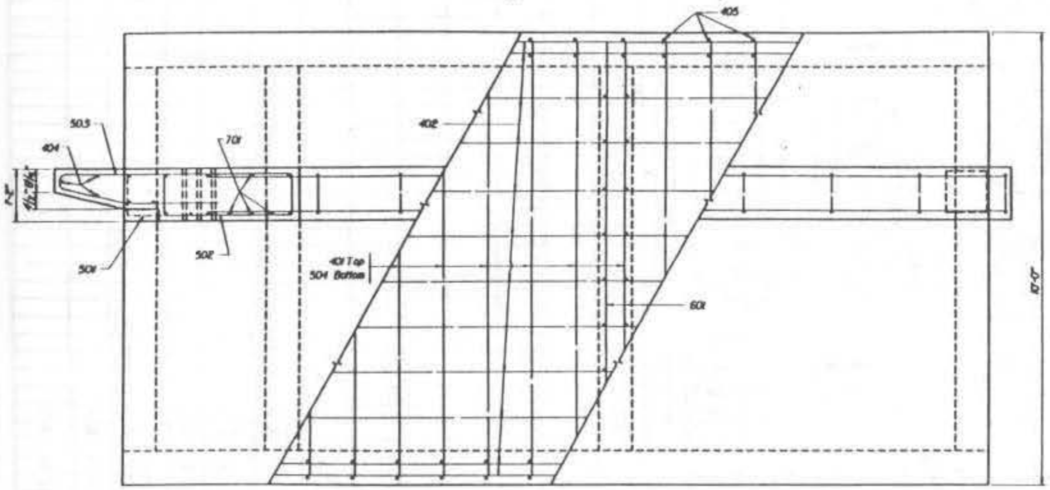
# SIMULATED BRIDGE DECK AND RAILINGS



ELEVATION
Scale: ¼" = 1'-0"



SECTION A-A
Scale: ¼" = 1'-0"



PLAN
Scale: ¼" = 1'-0"

### NOTES

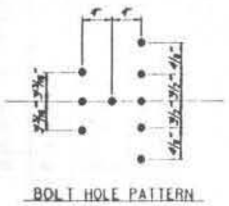
Concrete for slab and rail shall be Class '47BD', with a minimum 28-day strength of 3,500 psi and a working stress of 1,400 psi.

All reinforcing steel shall conform to the requirements of ASTM A-615 or ASTM A-617, Grade 60 steel, with a working stress of 24,000 psi.

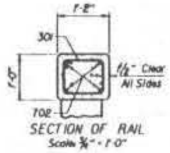
The minimum clearance, measured from the face of the concrete to the surface of any reinforcing bar, shall be 2", except where otherwise noted.

### QUANTITIES

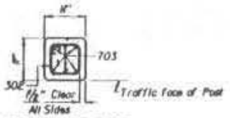
| | | |
|---|---|---|
| CLASS '47BD' CONCRETE | 8.3 | Cu.Yd. |
| REINFORCING STEEL | 1800 | Lbs. |



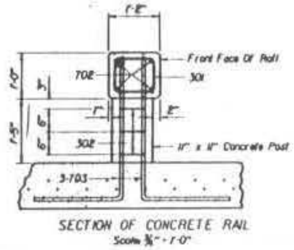
BOLT HOLE PATTERN



SECTION OF RAIL
Scale: ¾" = 1'-0"



SECTION OF POST
Scale: ¾" = 1'-0"



SECTION OF CONCRETE RAIL
Scale: ¾" = 1'-0"

Sheet A

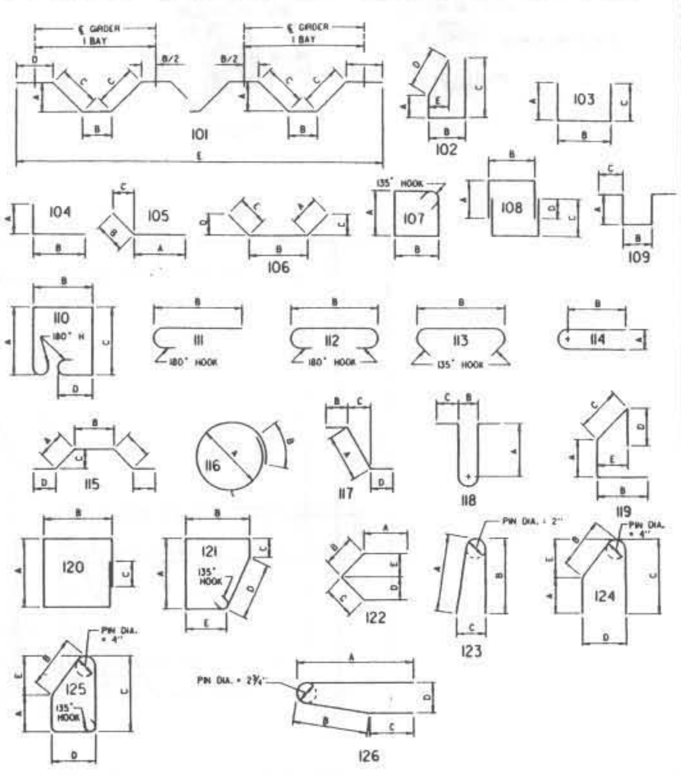
## BILL OF BARS

| MARK | NO. | LENGTH | TYPE | "A" | "B" | "C" | "D" | "E" | | | | HOOK |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 701 | 14 | 5'-1" | 104 | 3'-1" | 2'-0" | | | | | | | |
| 702 | 4 | 17'-6" | Str. | | | | | | | | | |
| 703 | 12 | 4'-10" | 104 | 2'-10" | 2'-0" | | | | | | | |
| | | | | | | | | | | | | |
| 601 | 16 | 9'-6" | Str. | | | | | | | | | |
| | | | | | | | | | | | | |
| 501 | 1 | 10'-3" | 107 | 0'-11" | 3'-9" | | | | | | | 5½" |
| 502 | 6 | 8'-8" | 107 | 0'-11" | 2'-11½" | | | | | | | 5½" |
| 503 | 6 | 5'-5" | 126 | 2'-8" | 1'-5" | 1'-3" | 0'-11" | | | | | |
| 504 | 20 | 9'-6" | Str. | | | | | | | | | |
| | | | | | | | | | | | | |
| 401 | 20 | 9'-6" | Str. | | | | | | | | | |
| 402 | 32 | 19'-6" | Str. | | | | | | | | | |
| 403 | 40 | 4'-7" | 103 | 2'-1" | 0'-5" | 2'-1" | | | | | | |
| 404 | 3 | 1'-7" | Str. | | | | | | | | | |
| 405 | 40 | 6'-7" | 103 | 3'-1" | 0'-5" | 3'-1" | | | | | | |
| | | | | | | | | | | | | |
| 301 | 10 | 3'-11" | 107 | 0'-11" | 0'-9" | | | | | | | 3½" |
| 302 | 6 | 3'-3" | 107 | 0'-8" | 0'-8" | | | | | | | 3½" |

## BENDING DIAGRAMS

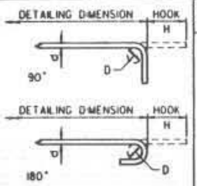
ALL DIMENSIONS ARE OUT TO OUT

NOT TO SCALE



## STANDARD HOOKS

(PRIMARY STRESS BARS)

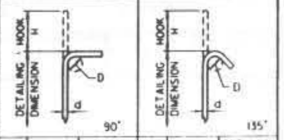


| BAR SIZE | D | 90° HOOK | 180° HOOK |
|---|---|---|---|
| | | HOOK H | HOOK H |
| 4 | 3" | 6 ¾" | 6" |
| 5 | 3 ¾" | 8 ⅛" | 7" |
| 6 | 4 ½" | 10 ¼" | 8 ¼" |
| 7 | 5 ¼" | 1' - 0" | 9 ¾" |
| 8 | 6" | 1' - 1⅛" | 11" |
| 9 | 9" | 1' - 4" | 1' - 3" |
| 10 | 10 ¼" | 1' - 6" | 1' - 4 ¾" |
| 11 | 11¼" | 1' - 8" | 1' - 6 ½" |

## BAR SETS

| MARK | MAX. LENGTH | MIN. LENGTH | NO. OF SETS | BARS PER SET |
|---|---|---|---|---|
| | | | | |

## STIRRUP DETAILS



| BAR SIZE | D | 90° HOOK | BAR SIZE | D | 135° HOOK |
|---|---|---|---|---|---|
| | | HOOK H | | | HOOK H |
| 3 | 1 ½" | 2 ¾" | 3 | 1 ½" | 3 ½" |
| 4 | 2" | 3 ½ | 4 | 2" | 4 ½" |
| 5 | 2 ½" | 4 ½" | 5 | 2 ½" | 5 ½" |

# APPENDIX C

# BARRIER VII COMPUTER MODEL SIMULATIONS

The BARRIER VII computer simulation model developed by Powell (5) was used in this study to determine (1) design impact loading on the end of the concrete bridgerail, and (2) the most critical point-of-impact on the guardrail transition. The "input" data on the vehicle crushing properties and the cohesive soil were obtained from results published by other research agencies. It is to be noted that no attempt was made to "fine tune" or calibrate the model after the full-scale testing was underway because the results on the dynamic deflections in Test No. 1 were in good agreement with the model.

The traffic barrier was idealized as a plane framework composed of inelastic one-dimensional elements of a variety of types. The automobile was idealized as a plane rigid body surrounded by a cushion of springs. A large-displacement dynamic structural analysis problem was solved by numerical methods.

The analysis is two-dimensional in the horizontal plane. Out-of-plane effects, which include vertical displacements of both the automobile and the barrier, are not considered. The automobile slides along the barrier, and the effects of normal force, friction forces, and wheel draG forces are considered in determining its motion. The necessary input data consist of the barrier configuration, the properties of the barrier members and the automobile, and the velocity and trajectory of the automobile before impact. Output consists of barrier member forces, barrier deflections, time histories of automobile positions, and velocities and accelerations of the automobile.

A final comment should be made about the BARRIER VII program. It is a two-dimensional program and it therefore has limitations. BARRIER VII cannot predict the roll motion of the vehicle, wheel snagging, or vehicle vaulting, nor will it predict situations in which the vehicle could break through the guardrail.

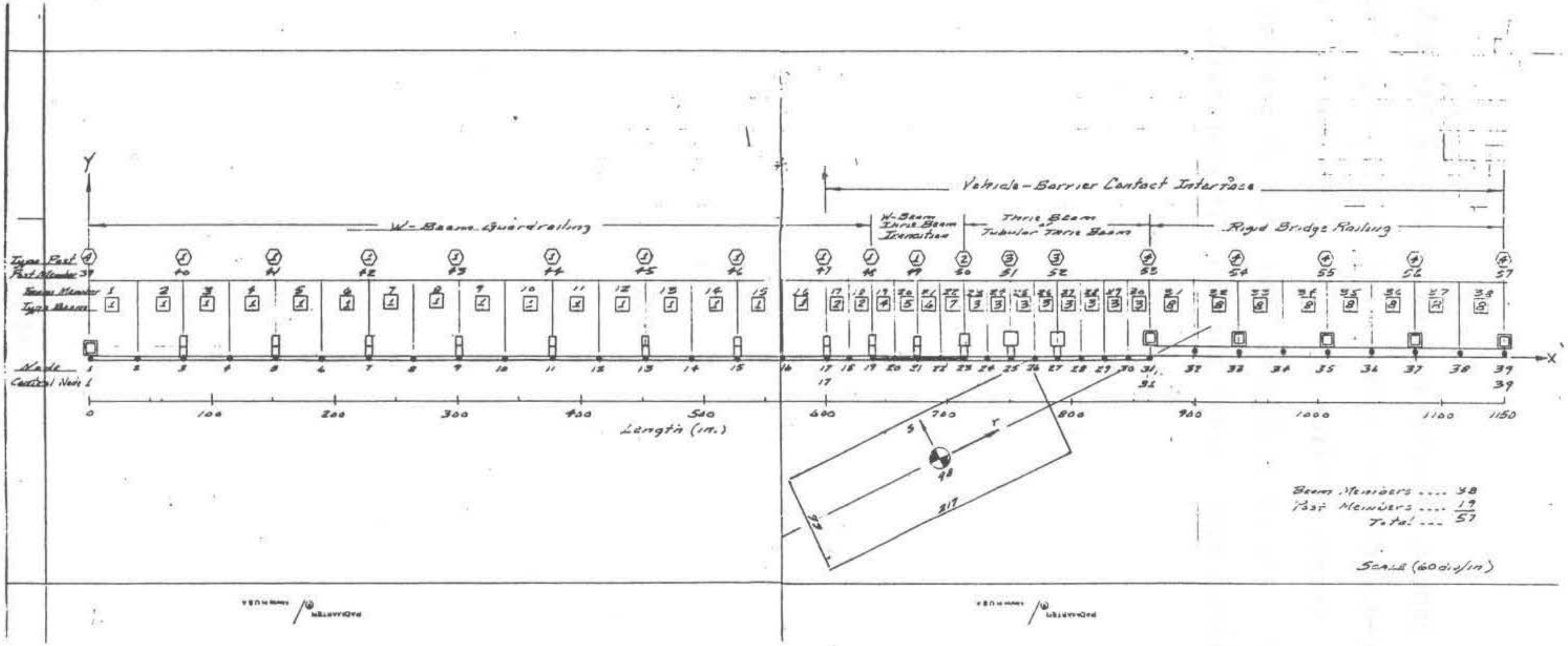


Figure C1

TRAFFIC BARRIER SETUP

ER Post

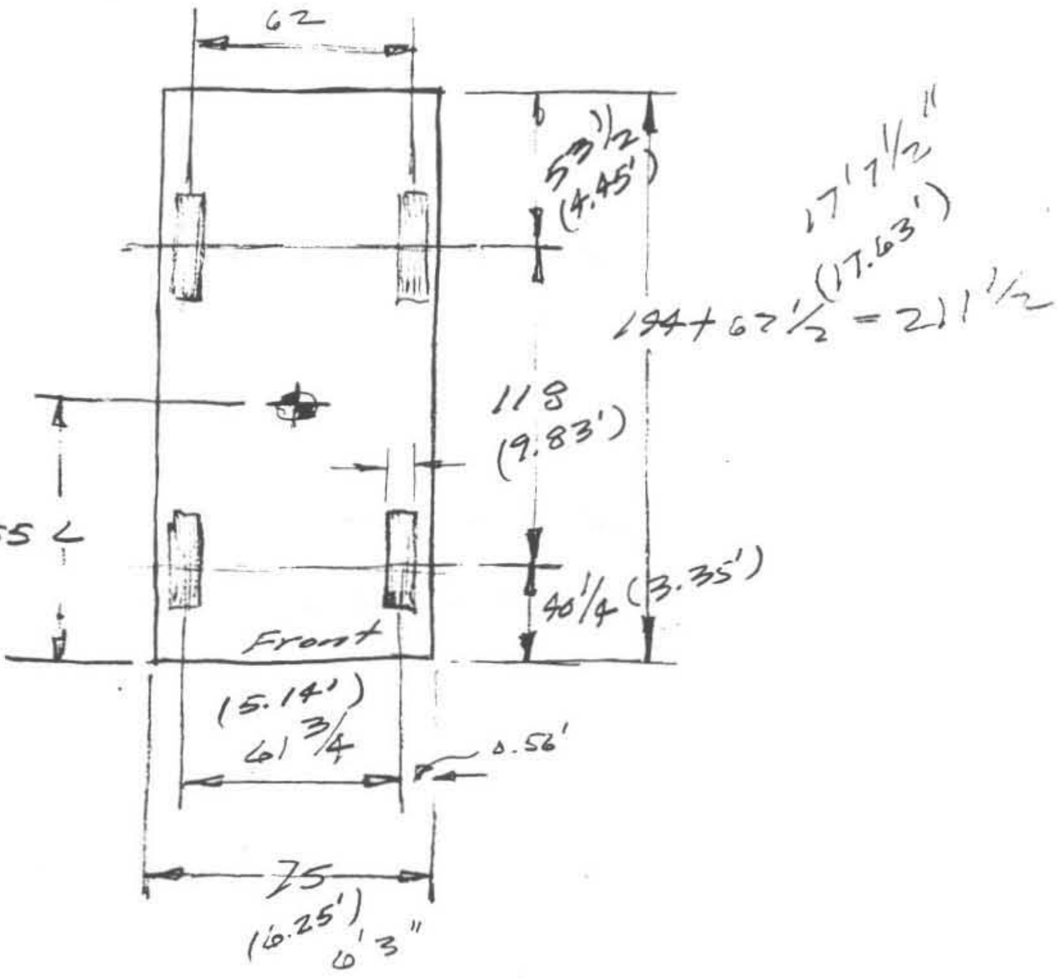
2(3)

HP & R 86-02

CRASH
VEHICLES

## AUTOMOBILE

1. Vehicle Dimensions



$W_t = 4{,}100$ lb

2. Vehicle Yaw Moment-of-Inertia

$$I_{z_t}^{cgt} = (1.26\, W_t - 1750)\, 12$$
$$= [1.26(4100) - 1750]\, 12$$
$$= 40{,}992 \text{ in-lb-sec}$$

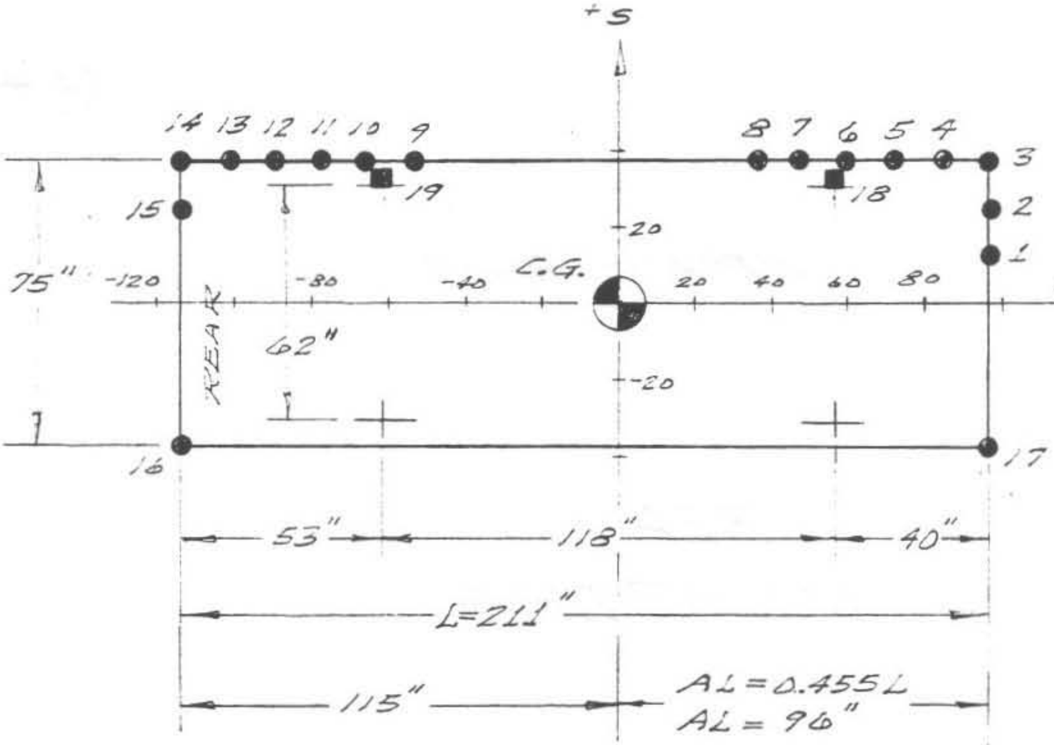
3. Weight Distribution

$$2W_F\,(118'') = W_t\,(62'')$$
$$W_F = \frac{4100 \text{ lb}\,(62'')}{2\,(118'')} = 1{,}077.1 \text{ lb}$$
$$2W_R = 4100 - 2(1077.1)$$
$$W_R = 972.9 \text{ lb}$$

AUTOMOBILE
1977 Plymouth Fury

(3/3)

3. Contact Points



SCALE 50 div/in

| | Contact Point No. | Coordinates | | Stiffnesses | | | Deflection Before Bottoming | Length |
|---|---|---|---|---|---|---|---|---|
| | | r (in.) | s (in.) | Before Bottoming (K/in/in) | After Bottoming (K/in/in) | Unloading (K/in/in) | (in.) | (in) |
| Sheet Metal (Unit #1) | 1 | 96.0 | 13.5 | 0.04 | 0.24 | 0.33 | 15.0 | 12.0 |
| | 2 | 96.0 | 25.5 | | | | | 12.0 |
| | 3 | 96.0 | 37.5 | | | | | 12.0 |
| | 4 | 84.0 | 37.5 | | | | | 12.0 |
| | 5 | 72.0 | 37.5 | | | | | 12.0 |
| | 6 | 60.0 | 37.5 | | | | | 12.0 |
| | 7 | 48.0 | 37.5 | | | | | 12.0 |
| | 8 | 36.0 | 37.5 | | | | | 12.0 |
| | 9 | - 55.0 | 37.5 | | | | | 12.0 |
| | 10 | - 67.0 | 37.5 | | | | | 12.0 |
| | 11 | - 79.0 | 37.5 | | | | | 12.0 |
| | 12 | - 91.0 | 37.5 | | | | | 12.0 |
| | 13 | -103.0 | 37.5 | | | | | 12.0 |
| | 14 | -115.0 | 37.5 | | | | | 12.0 |
| | 15 | -115.0 | 25.5 | | | | | 12.0 |
| | 16 | -115.0 | -37.5 | | | | | 1.0 |
| | 17 | 96.0 | -37.5 | ↓ | ↓ | ↓ | ↓ | 1.0 |
| Wheel Hubs (Unit #2) | 18 | 56.0 | 33.0 | 1.00 | 2.00 | 1.50 | 10.0 | 1.0 |
| | 19 | - 62.0 | 33.0 | 1.00 | 2.00 | 1.50 | ↓ | 1.0 |

E.R. Post

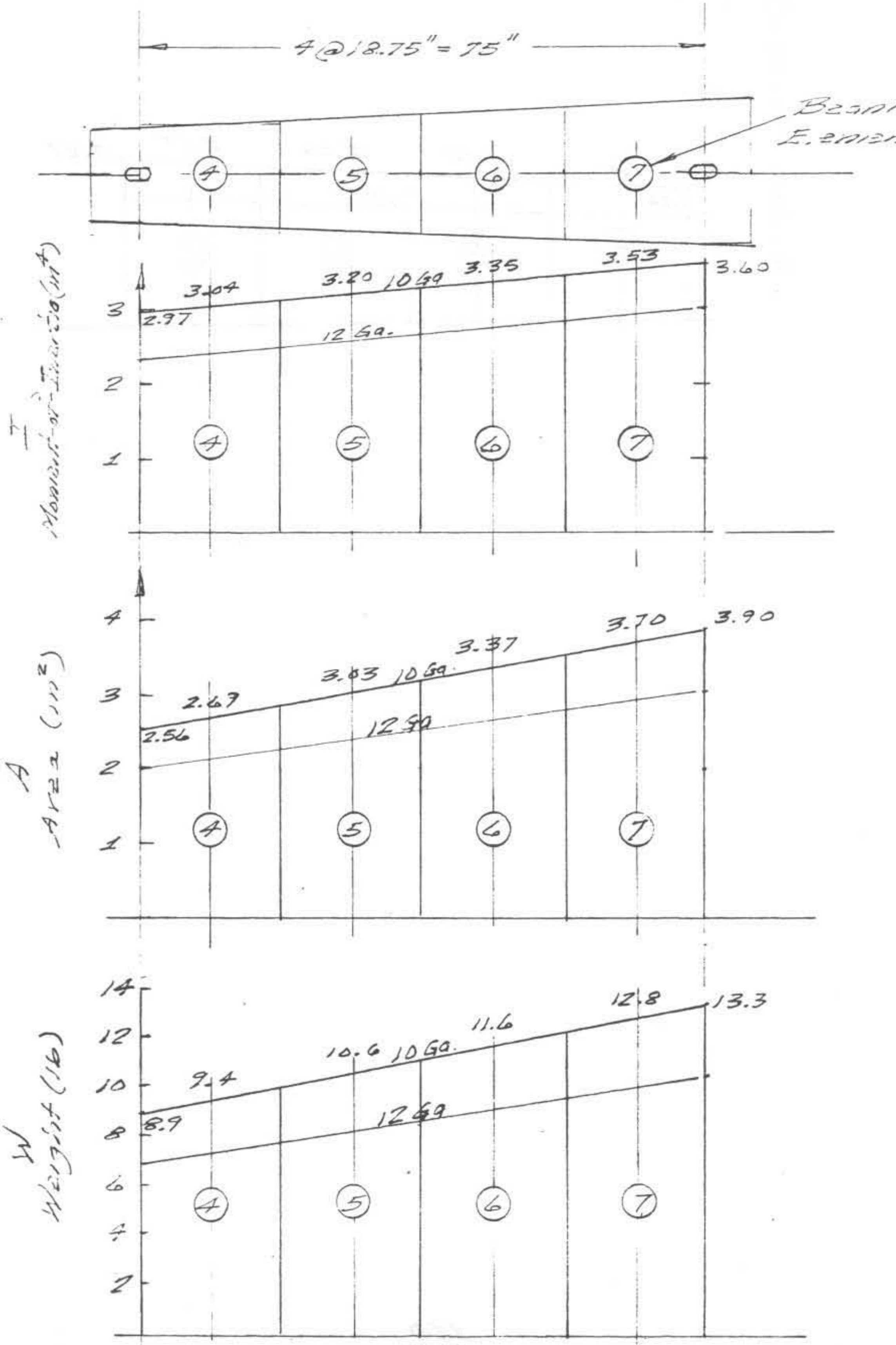
29 Apr 83

(14)

# HP&R 86-2

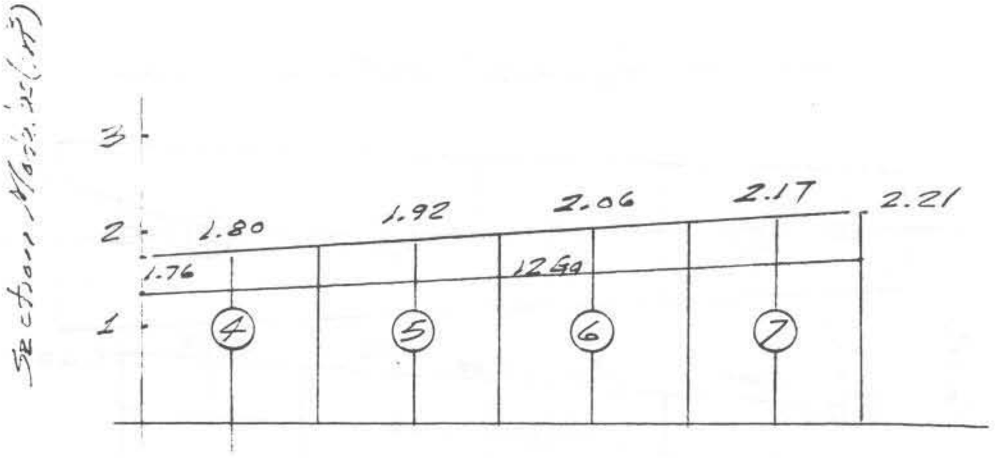
# BEAM
# MEMBERS

1. THRIE BEAM TRANSITION (10Ga.)



(3,4)

1. Thick Bm. Transition (10 Ga)



$$I_{tabular} = 2 \left\{ I_{yy} + A d^2 \right\}$$

$$23.35 = 2 \left\{ 3.60 + 3.9 d^2 \right\}$$

$$2(3.9) d^2 = 16.15$$

$$d = 1.44 \text{ in.}$$

$$I_{1250} = 2 \left\{ 2.89 + 3.0 (1.44)^2 \right\}$$

$$= 18.22$$

$$S_{1250} = \frac{18.22}{3.25} =$$

E. K. Post

29 Apr 86

(1/2)

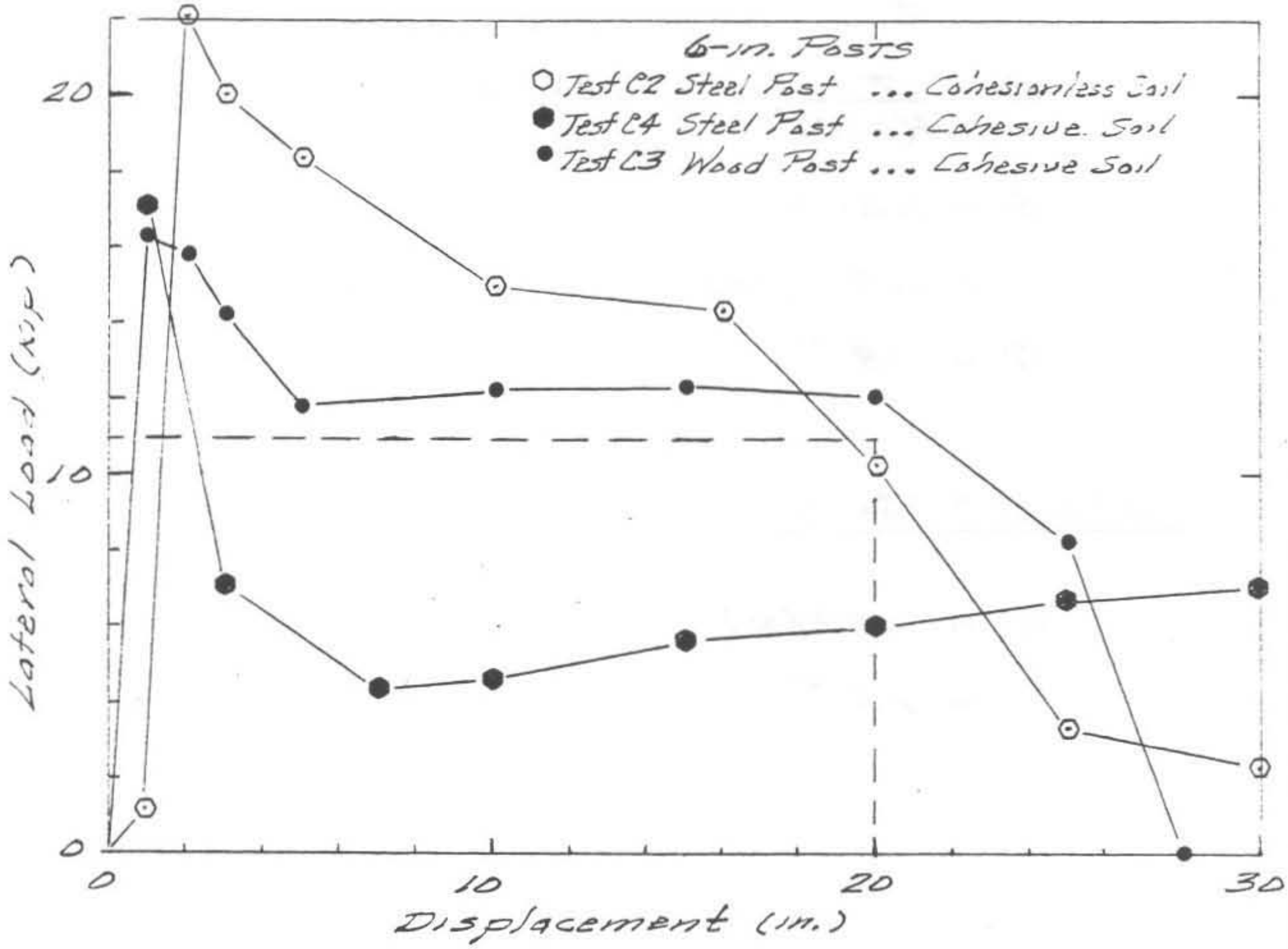
HP&R 86-2

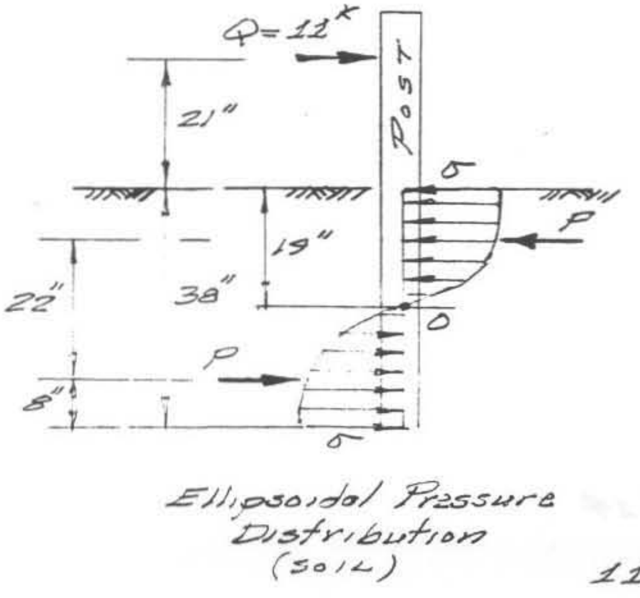
# POST
# MEMBERS

# DYNAMIC TESTS
# ON
# GUARDRAIL POSTS

(1/4)

(TTI...TRR 970)





Ellipsoidal Pressure Distribution (SOIL)

ΣM=0 $P = (\frac{40}{22}) Q = 1.82 Q$

also, $P = \frac{\pi}{4}(19)(\sigma)(b)$

$= \frac{\pi}{4}(19'')(6'')\sigma$

$P = 89.5 \sigma$

thus, $\sigma = \frac{1.82 Q}{89.5} = \frac{1.82(11)}{89.5}$

$\sigma = 0.224$ ksi

(2.4)

10" x 10" POSTS

$$1.82\,Q = \frac{\pi}{4}(19)(b)(\sigma)$$

$$Q = \frac{\pi}{4(1.82)}(19)(0.224)\,b$$

$$Q = 1.84\,b$$

$$= 1.84(10)$$

$$Q = 18^{K}$$

8" x 8" POSTS

$$Q = 1.84(8)$$

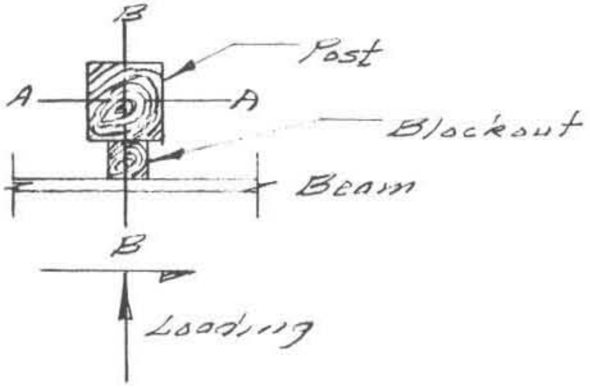
$$= 15^{K}$$

E. R. Post

27 Apr '86
(3/4)

# POST MEMBERS

| Post Position | Type No. | Beam Height | | Stiffness | | Effective Weight[2] (lb) | Base Moment | | Yield Accuracy | Shear Force[1] | | Deflection | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Node 1 (in) | Node 2 (in) | A-axis (K/in) | B-axis (K/in) | | B-axis (K-in) | A-axis (K-in) | | A-axis (K) | B-axis (K) | A-axis (in) | B-axis (in) |
| Approach GR End (stiff)[3] | 1 | 21.0 | 0.0 | 2955.0 | 2955.0 | 200.0 | 2670.0 | 2670.0 | 0.10 | 127.0 | 127.0 | 1.0 | 1.0 |
| 6"×8" | 2 | ↓ | ↓ | 15.0 | 11.0 | 50.0 | 315.0 | 231.0 | ↓ | 18.8 | 13.8 | 20.0 | 20.0 |
| 8"×8" | 3 | ↓ | ↓ | 15.0 | 15.0 | 77.0 | 315.0 | 315.0 | ↓ | 18.8 | 18.8 | 20.0 | 20.0 |
| 10"×10" | 4 | ↓ | ↓ | 18.0 | 18.0 | 121.0 | 378.0 | 378.0 | ↓ | 22.5 | 22.5 | 20.0 | 20.0 |
| Bridge (stiff)[3] | 1 | ↓ | ↓ | 2955.0 | 2955.0 | 200.0 | 2670.0 | 2670.0 | ↓ | 127.0 | 127.0 | 1.0 | 1.0 |



Notes

1. Shear values increased 25% above yield in order to suppress post failure in shear at base
2. Effective Weights

$$W_2 = (0.022 \text{ pci})(6'')(8'')(47'') = 50.0 \text{ lbs}$$
$$W_3 = (0.022)(8'')(8'')(47''+8'') = 77.0 \text{ lbs}$$
$$W_4 = (0.022)(10)(10)(47+8) = 121.0 \text{ lbs}$$

3. Stiff Posts (End GR & Bridge)

TS 10×10×0.6250

$$M_p = \sigma_y (1.22 S_e) = 36(1.22)(60.7)$$
$$= 2,670 \text{ K-in.}$$
$$P_u = \frac{M_p}{\ell} = \frac{2670}{21} = 127^K$$
$$k = \frac{P}{\Delta} = \frac{3EI}{\ell^3} = \frac{3(30)(10^6)(304)}{(21)^3} = 2,954,325 \frac{lb}{in}$$

$$W_4 = 74 \frac{lb}{ft} (2.7 \text{ ft}) = 200.0 \text{ lb}$$

# INPUT
# DATA

```
1BARRIER VII  -  ANALYSIS OF AUTOMOBILE BARRIERS  -  U.C. BERKELEY,  1972

 ***********************************************************************

 UNL RUN NO. 2E  12 GA. TUBULAR THRIE  BEAM  GUARDRAIL TRANSITION

 ***********************************************************************


0CONTROL INFORMATION


 NUMBER OF BARRIER NODES                    =      39
 NUMBER OF CONTROL NODES                    =       4
 NUMBER OF NODE GENERATIONS                 =       3

 NUMBER OF INTERFACES                       =       1

 NUMBER OF MEMBERS                          =      57
 NUMBER OF MEMBER GENERATIONS               =      14
 NUMBER OF DIFFERENT MEMBER SERIES          =       2

 NUMBER  OF ADDITIONAL WEIGHT SETS          =       0

0BASIC TIME STEP (SEC)                      =      .00250
 LARGEST ALLOWABLE TIME STEP (SEC)          =      .00250
 MAXIMUM TIME SPECIFIED (SEC)               =      .60000
 MAX. NO. OF STEPS WITH NO CONTACT          =      50

 OVERSHOOT INDEX                            =       0
 ROTATIONAL DAMPING MULTIPLIER              =    1.00

 STEP-BY-STEP INTEGRATION TYPE              =       1



 OUTPUT FREQUENCIES

 AUTOMOBILE DATA       =      5
 BARRIER DEFLECTIONS   =      5
 BARRIER FORCES        =      5

 ENERGY BALANCE        =      5

 CONTACT INFORMATION   =      5

 PUNCHED JOINT DATA    =      0
 PUNCHED TRAJECTORY    =      0
1CONTROL NODE COORDINATES (IN)

 NODE            X-ORD              Y-ORD

    1              .00                .00
   17           500.00                .00
   31           862.50                .00
   39          1150.50                .00


 COORDINATE GENERATION COMMANDS

 FIRST    LAST    NO. OF    NODE      DISTANCE
  NODE    NODE     NODES    DIFF
```

```
    1       17         15          1                .00
   17       31         13          1                .00
   31       39          7          1                .00
1NODE  COORDINATES (IN)

 NODE           X-ORD            Y-ORD

    1              .00             .00
    2            37.50             .00
    3            75.00             .00
    4           112.50             .00
    5           150.00             .00
    6           187.50             .00
    7           225.00             .00
    8           262.50             .00
    9           300.00             .00
   10           337.50             .00
   11           375.00             .00
   12           412.50             .00
   13           430.00             .00
   14           487.50             .00
   15           525.00             .00
   16           562.50             .00
   17           600.00             .00
   18           618.75             .00
   19           637.50             .00
   20           656.25             .00
   21           675.00             .00
   22           693.75             .00
   23           712.50             .00
   24           731.25             .00
   25           750.00             .00
   26           768.75             .00
   27           787.50             .00
   28           806.25             .00
   29           825.00             .00
   30           843.75             .00
   31           862.50             .00
   32           898.50             .00
   33           934.50             .00
   34           970.50             .00
   35          1006.50             .00
   36          1042.50             .00
   37          1078.50             .00
   38          1114.50             .00
   39          1150.50             .00
1CONTACT INTERFACES


  INTERFACE  1

  NO. OF NODES =  23,  FRICTION COEFF. =  .350

  LIST OF NODES
           39        38        37        36        35        34        33        32        31        30
           29        28        27        26        25        24        23        22        21        20
           19        18        17
1BEAM ELEMENTS, 100 SERIES

  TYPE NUMBER                 =          1          2          3          4          5          6          7          8
  M. OF I. (IN4)              =  .231E+01  .231E+01  .182E+02  .238E+01  .257E+01  .273E+01  .290E+01  .304E+03
  AREA (IN2)                  =  .199E+01  .199E+01  .600E+01  .212E+01  .240E+01  .267E+01  .292E+01  .218E+02
  LENGTH (IN)                 =  .375E+02  .186E+02  .188E+02  .188E+02  .188E+02  .188E+02  .188E+02  .375E+02
```

```
 YOUNGS MODULUS (KSI)         =    .300E+05   .300E+05   .300E+05   .300E+05   .300E+05   .300E+05   .300E+05   .300E+05
 WEIGHT (LB/FT)               =    .692E+01   .692E+01   .207E+02   .730E+01   .820E+01   .900E+01   .990E+01   .740E+02
 YIELD FORCE (K)              =    .995E+02   .995E+02   .300E+03   .106E+03   .120E+03   .134E+03   .146E+03   .785E+03
 YIELD MOMENT (K.IN)          =    .685E+02   .685E+02   .280E+03   .650E+02   .750E+02   .785E+02   .840E+02   .279E+04
 YIELD ACCURACY LIMIT         =    .100E+00   .100E+00   .100E+00   .100E+00   .100E+00   .100E+00   .100E+00   .100E+00
  9 1 21.0   .0  15.0  11.0 50.0  315.0  231.0   .1  18.8  13.8  20.0  20.0
 10 2 21.0   .0  15.0  15.0 77.0  315.0  315.0   .1  18.8  18.8  20.0  20.0
 11 3 21.0   .0  18.0  18.0121.0  378.0  378.0   .1  22.5  22.5  20.0  20.0
 12 4 21.0  .02955.02955.0200.0 2670.0 2670.0   .1 127.0 127.0   1.0   1.0
1POSTS, 300 SERIES

 TYPE NUMBER                  =           1          2          3          4
 HEIGHT OF NODE I (IN)        =    .210E+02   .210E+02   .210E+02   .210E+02
 HEIGHT OF NODE J (IN)        =    .750E+02   .785E+02   .840E+02   .279E+04
 A AXIS STIFFNESS (K/IN)      =    .411E+04   .437E+04   .464E+04   .243E+06
 B AXIS STIFFNESS (K/IN)      =    .384E+04   .427E+04   .467E+04   .174E+05
 EFFECTIVE WEIGHT (LB)        =    .820E+01   .900E+01   .990E+01   .740E+02
 B AXIS YIELD MOMENT (K.IN)   =    .120E+03   .134E+03   .146E+03   .785E+03
 A AXIS YIELD MOMENT (K.IN)   =    .000E+00   .000E+00   .000E+00   .000E+00
 YIELD ACCURACY LIMIT         =    .100E+00   .100E+00   .100E+00   .100E+00
 A SHEAR AT FAILURE (K)       =    .825E+02   .864E+02   .924E+02   .307E+04
 B SHEAR AT FAILURE (K)       =    .675E+02   .707E+02   .756E+02   .251E+04
 A DEFLN AT FAILURE (IN)      =    .000E+00   .000E+00   .000E+00   .000E+00
 B DEFLN AT FAILURE (IN)      =    .000E+00   .000E+00   .000E+00   .000E+00
1MEMBER GENERATION COMMANDS

  FIRST     NODE      NODE      LAST      NODE     TYPE                               PRESTRESS DATA
 MEMBER       I         J      MEMBER     DIFF      NO.           1           2              3             4            5

     1        1         2        16        1        101          .000        .000          .000          .000         .000
    17       17        18        18        1        102          .000        .000          .000          .000         .000
    19       19        20         0        0        104          .000        .000          .000          .000         .000
    20       20        21         0        0        105          .000        .000          .000          .000         .000
    21       21        22         0        0        106          .000        .000          .000          .000         .000
    22       22        23         0        0        107          .000        .000          .000          .000         .000
    23       23        24        30        1        103          .000        .000          .000          .000         .000
    31       31        32        36        1        108          .000        .000          .000          .000         .000
    39        1         0         0        0        304          .000        .000          .000          .000         .000
    40        3         0        47        2        301          .000        .000          .000          .000         .000
    48       19         0        49        2        301          .000        .000          .000          .000         .000
    50       23         0         0        0        302          .000        .000          .000          .000         .000
    51       25         0        52        2        303          .000        .000          .000          .000         .000
    53       31         0        57        2        304          .000        .000          .000          .000         .000
1COMPLETE MEMBER DATA

 BEAMS, 100 SERIES

 MEMBER    NODE I    NODE J     TYPE        FORCE     I-MOMENT     J-MOMENT

    1         1         2        101          .00         .00          .00
    2         2         3        101          .00         .00          .00
    3         3         4        101          .00         .00          .00
    4         4         5        101          .00         .00          .00
    5         5         6        101          .00         .00          .00
    6         6         7        101          .00         .00          .00
    7         7         8        101          .00         .00          .00
    8         8         9        101          .00         .00          .00
    9         9        10        101          .00         .00          .00
   10        10        11        101          .00         .00          .00
   11        11        12        101          .00         .00          .00
   12        12        13        101          .00         .00          .00
   13        13        14        101          .00         .00          .00
   14        14        15        101          .00         .00          .00
   15        15        16        101          .00         .00          .00
```

```
   16       16        17       101           .00           .00          .00
   17       17        18       102           .00           .00          .00
   18       18        19       102           .00           .00          .00
   19       19        20       104           .00           .00          .00
   20       20        21       105           .00           .00          .00
   21       21        22       106           .00           .00          .00
   22       22        23       107           .00           .00          .00
   23       23        24       103           .00           .00          .00
   24       24        25       103           .00           .00          .00
   25       25        26       103           .00           .00          .00
   26       26        27       103           .00           .00          .00
   27       27        28       103           .00           .00          .00
   28       28        29       103           .00           .00          .00
   29       29        30       103           .00           .00          .00
   30       30        31       103           .00           .00          .00
   31       31        32       108           .00           .00          .00
   32       32        33       108           .00           .00          .00
   33       33        34       108           .00           .00          .00
   34       34        35       108           .00           .00          .00
   35       35        36       108           .00           .00          .00
   36       36        37       108           .00           .00          .00
   37       37        38       108           .00           .00          .00
   38       38        39       108           .00           .00          .00

 POSTS, 300 SERIES

 MEMBER   NODE I    NODE J    TYPE      A-SHEAR       B-SHEAR     B-MOMENT     A-MOMENT        ANGLE

   39        1         0       304           .00           .00          .00          .00          .00
   40        3         0       301           .00           .00          .00          .00          .00
   41        5         0       301           .00           .00          .00          .00          .00
   42        7         0       301           .00           .00          .00          .00          .00
   43        9         0       301           .00           .00          .00          .00          .00
   44       11         0       301           .00           .00          .00          .00          .00
   45       13         0       301           .00           .00          .00          .00          .00
   46       15         0       301           .00           .00          .00          .00          .00
   47       17         0       301           .00           .00          .00          .00          .00
   48       19         0       301           .00           .00          .00          .00          .00
   49       21         0       301           .00           .00          .00          .00          .00
   50       23         0       302           .00           .00          .00          .00          .00
   51       25         0       303           .00           .00          .00          .00          .00
   52       27         0       303           .00           .00          .00          .00          .00
   53       31         0       304           .00           .00          .00          .00          .00
   54       33         0       304           .00           .00          .00          .00          .00
   55       35         0       304           .00           .00          .00          .00          .00
   56       37         0       304           .00           .00          .00          .00          .00
   57       39         0       304           .00           .00          .00          .00          .00

 STIFFNESS MATRIX STORAGE

 REQUIRED   =   702
 ALLOCATED  =  6000
1AUTOMOBILE PROPERTIES

 WEIGHT (LB)                      =    4100.0
 MOMENT OF INERTIA (LB.IN.SEC2)   =   40992.0
 NO. OF CONTACT POINTS            =     19
 NO. OF UNIT STIFFNESSES          =      2
 NO. OF WHEELS                    =      4
 BRAKE CODE (1=ON, 0=OFF)         =      0
 NO. OF OUTPUT POINTS             =      1
```

```
 UNIT STIFFNESSES (K/IN/IN)

 NO.        BEFORE          AFTER                          BOTTOMING
          BOTTOMING      BOTTOMING     UNLOADING          DISTANCE

  1          .040           .240          .330              15.00
  2         1.000          2.000         1.500              10.00


 CONTACT POINT DATA

 POINT          R             S         STIFFNESS        TRIBUTARY             INTERFACE CONTACTS
              COORD         COORD          NO.             LENGTH

   1          96.00         15.50           1               12.00              1       0       0       0
   2          96.00         25.50           1               12.00              1       0       0       0
   3          96.00         37.50           1               12.00              1       0       0       0
   4          84.00         37.50           1               12.00              1       0       0       0
   5          72.00         37.50           1               12.00              1       0       0       0
   6          60.00         37.50           1               12.00              1       0       0       0
   7          48.00         37.50           1               12.00              1       0       0       0
   8          36.00         37.50           1               12.00              1       0       0       0
   9         -55.00         37.50           1               12.00              1       0       0       0
  10         -67.00         37.50           1               12.00              1       0       0       0
  11         -79.00         37.50           1               12.00              1       0       0       0
  12         -91.00         37.50           1               12.00              1       0       0       0
  13        -103.00         37.50           1               12.00              1       0       0       0
  14        -115.00         37.50           1               12.00              1       0       0       0
  15        -115.00         25.50           1               12.00              1       0       0       0
  16        -115.00        -37.50           1                1.00              0       0       0       0
  17          96.00        -37.50           1                1.00              0       0       0       0
  18          56.00         33.00           2                1.00              1       0       0       0
  19         -62.00         33.00           2                1.00              1       0       0       0

OWHEEL COORDINATES (IN), STEER ANGLES (DEG), AND DRAG FORCES (LB)

 POINT          R-ORD             S-ORD    STEER ANGLE      DRAG FORCE

   1            56.00             31.00         .00           430.00
   2            56.00            -31.00         .00           430.00
   3           -62.00             31.00         .00           390.00
   4           -62.00            -31.00         .00           390.00

OOUTPUT POINT COORDINATES (IN)

 POINT          R-ORD          S-ORD

   1              .00            .00
1INITIAL POSITION AND VELOCITIES OF AUTO

 SPECIFIED BOUNDARY POINT                  =          3
 X ORDINATE OF POINT                       =        750.00
 Y ORDINATE OF POINT                       =           .00

 ANGLE FROM X AXIS TO R AXIS (DEG)         =         25.00
 VELOCITY IN R DIRECTION (M.P.H)           =         60.00
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 VELOCITY IN S DIRECTION (M.P.H)          =          .00
 ANGULAR VELOCITY (RAD/SEC)               =          .000

 MINIMUM RESULTANT VELOCITY (M.P.H)       =        10.00

 TRANSLATIONAL KINETIC ENERGY (K.IN)      =      5922.35
 ROTATIONAL KINETIC ENERGY (K.IN)         =          .00

 TOTAL INITIAL KINETIC ENERGY (K.IN)      =      5922.35


 AUTO TRAJECTORY RESULTS
 PT   X-ORD   Y-ORD  ANGLE  X-VEL  Y-VEL  R-VEL   S-VEL  T-VEL  ANGLE  X-ACC  Y-ACC  R-ACC  S-ACC  T-ACC  ANGLE
   TIME =  .0000 SECS
  1   678.8   -74.6   25.0  54.38  25.36  60.00     .00  60.00   25.0    .00    .00    .00    .00    .00     .0


 BARRIER DEFLECTIONS, TIME =  .0000 SECS
  NODE     X-DEFL     Y-DEFL       X-ORD       Y-ORD
     1        .00        .00          .0          .0
     2        .00        .00        37.5          .0
     3        .00        .00        75.0          .0
     4        .00        .00       112.5          .0
     5        .00        .00       150.0          .0
     6        .00        .00       187.5          .0
     7        .00        .00       225.0          .0
     8        .00        .00       262.5          .0
     9        .00        .00       300.0          .0
    10        .00        .00       337.5          .0
    11        .00        .00       375.0          .0
    12        .00        .00       412.5          .0
    13        .00        .00       450.0          .0
    14        .00        .00       487.5          .0
    15        .00        .00       525.0          .0
    16        .00        .00       562.5          .0
    17        .00        .00       600.0          .0
    18        .00        .00       618.8          .0
    19        .00        .00       637.5          .0
    20        .00        .00       656.3          .0
    21        .00        .00       675.0          .0
    22        .00        .00       693.8          .0
    23        .00        .00       712.5          .0
    24        .00        .00       731.3          .0
    25        .00        .00       750.0          .0
    26        .00        .00       768.8          .0
    27        .00        .00       787.5          .0
    28        .00        .00       806.2          .0
    29        .00        .00       825.0          .0
    30        .00        .00       843.7          .0
    31        .00        .00       862.5          .0
    32        .00        .00       898.5          .0
    33        .00        .00       934.5          .0
    34        .00        .00       970.5          .0
    35        .00        .00      1006.5          .0
    36        .00        .00      1042.5          .0
    37        .00        .00      1078.5          .0
```

# CRITICAL
# DESIGN LOADING
# FOR
# CONCRETE BRIDGERAIL

Impact Node . . . 28

#21

```
ENERGY BALANCE, TIME =  .0875 SECS

TYPE OF                          PERCENT OF
ENERGY                          ORIG AUTO KE

TRANSLATIONAL K.E. OF AUTO =      60.2
ROTATIONAL K.E. OF AUTO    =       2.4
BARRIER K.E.               =        .0

ELASTIC ENERGY IN MEMBERS

:::      BE        .0
              ::::::OL\ -ZN1&7B?

:::      PO********
              ::::::OM*_;MN2H7"S

INELASTIC WORK ON MEMBERS

:::      BE        .0
              ::::::OQ5K)∂N6ZX>N

:::      PO********
              ::::::OK\U4ENO$#.%

ELASTIC ENERGY IN AUTO     =       7.5
INELASTIC WORK ON AUTO     =       6.9

DAMPING LOSSES             =        .1

AUTO-BARRIER FRICTION LOSS =      21.4
AUTO-PAVEMENT FRICTION LOSS=        .3

SUM OF ALL CONTRIBUTIONS   =     101.3



DATA ON AUTO-BARRIER CONTACT, TIME =  .0875 SECS

 AUTO     CONTACT    CONTACT BETWEEN          X              Y              NORMAL          X            Y
 POINT   INTERFACE   NODE  AND  NODE      COORDINATE     COORDINATE         FORCE         FORCE        FORCE

   1         1        32         31        892.06            .02             2.13          -.77         -2.12
   2         1        32         31        877.61            .02            12.36         -4.81        -12.18
   3         1        32         31        862.36            .05            46.19        -19.22        -45.01
   4         1        31         30        858.61            .54            29.54        -12.27        -28.79
   5         1        31         30        854.22           1.13            14.51         -6.01        -14.15
   6         1        31         30        849.01           1.84             5.91         -2.44         -5.76
   7         1        30         29        842.62           2.53             3.30         -1.34         -3.23
   8         1        30         29        834.43           2.45             1.16          -.43         -1.15
  18         1        31         30        850.69           1.61             6.69         -2.77         -6.53
                                                                                        ________     ________
                                                                                        50.06 K      118.95 K

AUTO TRAJECTORY RESULTS

PT   X-ORD   Y-ORD  ANGLE  X-VEL  Y-VEL  R-VEL  S-VEL  T-VEL  ANGLE  X-ACC  Y-ACC  R-ACC  S-ACC  T-ACC  ANGLE

  TIME =  .1000 SECS
 1  825.4   -42.9   19.2  43.10  -2.11  40.00 -16.19  43.15   -2.8  -9.96 -23.94 -17.29 -19.32  25.93 -112.6
```

# CRITICAL
# TRAFFIC BARRIER
# IMPACT LOCATION

TABLE ___ (1/1)

# BARRIER VII SIMULATIONS

## NDR HP&R 86-2

Vehicle Weight ..... 4,100 lb.
Impact Speed ..... 60 mph
Impact Angle ..... 25 deg.
Barrier Transition ..... 12 Ga. Tubular Thrie Beam

| Run No. | Impact Node | Maximum Barrier Railing Deflections (in.) | | | | | | | | | | | | Max. Veh. C.G. Decel. (G's) | | Max. Veh. Forces (kips) | | Veh. Exit Conditions | | Veh. Hwy Angle (deg) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Node ⑰ | Node 20 | Node ㉑ | Node 22 | Node ㉓ | Node 24 | Node ㉕ | Node 26 | Node ㉗ | Node 28 | Node 29 | Node 30 | Long. (R) | Lat. (S) | X | Y | Speed (mph) | Angle (deg) | |
| | 19 | | | | | | | | | | | | | | | | | | | |
| | 20 | | | | | | | | | | | | | | | | | | | |
| 2FF | 21 | 0.63 | 1.64 | 2.80 | 6.08 | 8.79 | 10.13 | 9.77 | 7.85 | 5.62 | 4.33 | 2.93 | 1.48 | 12.09 | 11.36 | 27.94 | 63.24 | 40 | -19 | |
| 2DD | 22 | 0.19 | 0.50 | 1.00 | 3.23 | 5.71 | 8.16 | 8.88 | 8.41 | 6.26 | 4.69 | 3.10 | 1.50 | 12.31 | 11.99 | 27.99 | 65.36 | 41 | -20 | |
| 2GG | 23 | 0.05 | 0.16 | 0.35 | 1.21 | 2.21 | 4.98 | 7.50 | [redacted] | 8.30 | 7.10 | 4.68 | 2.32 | 11.20 | 11.74 | 25.99 | 61.93 | 41 | -23 | -1 |
| 2CC | 24 | -0.06 | -0.08 | 0.15 | 0.31 | 0.69 | 2.91 | 5.21 | 7.71 | 8.27 | 8.13 | 5.96 | 3.04 | 11.44 | 12.01 | 27.26 | 63.33 | 41 | -23 | |
| 2EE | 25 | -0.04 | -0.08 | -0.11 | 0.16 | 0.45 | 2.01 | 3.66 | 5.51 | 7.23 | [redacted] | 7.56 | 3.94 | 14.76 | 14.04 | 39.27 | 74.4 | 39.01 | -30. | -33 |
| 2AA | 26 | -0.04 | -0.07 | -0.11 | -0.12 | 0.05 | 0.69 | 1.39 | 3.18 | 4.75 | 7.58 | 7.37 | 5.11 | 19.50 | 17.97 | 52.42 | 96.06 | 38.1 | -38 | -45 |
| 2HH | 27 | -0.04 | -0.11 | -0.20 | -0.27 | -0.20 | 0.28 | 0.73 | 1.92 | 5.30 | 4.79 | 6.74 | 4.66 | 23.69 | 21.47 | 60.37 | 117.21 | 38 | -42 | -44 |
| 1BB | 28 | -0.03 | -0.09 | -0.18 | -0.26 | -0.22 | -0.07 | 0.24 | 0.64 | 1.35 | 2.47 | 3.62 | 3.44 | 24.52 | 23.05 | 57.93 | 126.04 | 40 | -37 | -43 |
| 1II | 29 | -0.01 | -0.01 | -0.02 | -0.02 | -0.01 | 0.03 | 0.07 | 0.13 | 0.18 | 0.23 | 0.23 | 0.16 | 19.35 | 21.05 | 34.20 | 111.27 | 43 | -30 | -37 |
| 1JJ | 30 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.02 | 0.03 | 0.04 | 0.0 | 0.02 | 19.10 | 21.06 | 38.55 | 110.26 | 44 | -4 | -39 |

Notes: (a) ○ Circled node represents location of post (see Fig. __ for numbering of Posts).

TABLE __ (—/—)

# BARRIER VII SIMULATIONS

NDR HP&R 86-2

Vehicle Weight ..... 4,100 lb.
Impact Speed ..... 60 mph
Impact Angle ..... 25 deg.
Barrier Transition ..... 10 Ga. Tubular Thrie Beam

| Run No. | Impact Node | Maximum Barrier Railing Deflections (in.) | | | | | | | | | | | | Max. Veh. C.G. Decel. (G's) | | Max. Veh. Forces (kips) | | Veh. Exit Conditions | | Veh. Hwy Angle (deg) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Node ⑲ | Node 20 | Node ㉑ | Node 22 | Node ㉓ | Node 24 | Node ㉕ | Node 26 | Node ㉗ | Node 28 | Node 29 | Node 30 | Long. (R) | Lat. (S) | X | Y | Speed (mph) | Angle (deg) | |
| | 19 | | | | | | | | | | | | | | | | | | | |
| | 20 | | | | | | | | | | | | | | | | | | | |
| 1FF | 21 | 0.76 | 2.12 | 3.75 | 6.46 | 5.74 | 9.27 | 8.94 | 1.05 | 5.03 | 3.77 | 2.49 | 1.24 | [illegible] | 12.21 | 25.47 | [illegible] | 41 | -20 | |
| 1DD | 22 | 0.27 | 0.68 | 1.31 | 3.59 | 6.16 | 7.55 | 8.30 | 7.92 | 5.79 | 4.50 | 3.00 | 1.50 | 11.99 | 11.62 | 26.0 | 64.04 | 41 | -20 | |
| 1GG | 23 | -0.12 | 0.16 | 0.49 | 1.44 | 2.66 | 4.82 | 6.82 | [redacted] | 6.85 | 5.40 | 3.62 | 1.73 | 11.75 | 12.20 | 24.27 | 65.83 | 41 | -21 | |
| 1CC | 24 | -0.09 | -0.11 | 0.12 | 0.35 | 0.82 | 2.88 | 5.01 | 7.19 | [redacted] | 6.93 | 4.76 | 2.59 | 11.43 | 11.95 | 27.82 | 65.97 | 41 | -23 | |
| 1EE | 25 | -0.07 | -0.11 | -0.14 | 0.18 | 0.51 | 2.06 | 3.70 | 5.45 | 7.07 | [redacted] | 6.30 | 3.20 | 13.89 | 13.84 | 36.35 | 72.49 | 39.5 | -29 | -31.5 |
| 1AA | 26 | 0.07 | 0.14 | 0.24 | 0.32 | 0.22 | 1.1 | 2.1 | 3.6 | 5.3 | 7.2 | 6.4 | 3.70 | 19.1 | 17.4 | 48.5 | 94.9 | 39 | -37 | -43 |
| 1HH | 27 | -0.07 | -0.15 | -0.25 | -0.33 | -0.23 | 0.32 | 0.99 | 1.97 | 3.05 | 4.21 | 5.79 | 3.71 | 21.60 | 20.28 | 53.95 | 111.29 | 40 | -40 | -45 |
| 1BB | 28 | -0.04 | -0.10 | -0.18 | -0.21 | -0.21 | 0.08 | 0.26 | 0.66 | 1.20 | 1.87 | 2.56 | 2.64 | 21.98 | 22.25 | 50.06 | 118.95 | 41 | [illegible] | -42 |
| 1II | 29 | 0.00 | -0.01 | -0.01 | -0.01 | -0.01 | 0.02 | 0.04 | 0.08 | 0.11 | 0.14 | 0.13 | 0.09 | 19.25 | 21.01 | 38.13 | 110.75 | 43 | -27 | -37 |
| 1JJ | 30 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | -0.01 | -0.01 | -0.02 | -0.03 | -0.04 | -0.04 | -0.02 | [illegible] | 20.89 | 38.55 | 110.25 | 43 | -27 | -37 |
| | | | | | | | | | | | | | | | | | | | | |

Notes (a) ○ Circled node represents location of post (see Fig. __ for numbering of Posts) -

IMPACT NODE 25

```
TYPE OF                              PERCENT OF
ENERGY                              ORIG AUTO KE

TRANSLATIONAL K.E. OF AUTO =       71.0
ROTATIONAL K.E. OF AUTO    =        1.4
BARRIER K.E.               =         .0

ELASTIC ENERGY IN MEMBERS

:::     BE        .0
              ::::::0072'#N41=:F

:::     PO********
              ::::::00,V9"N4G?T$

INELASTIC WORK ON MEMBERS

:::     BE        .0
              ::::::0P@(YMN5w0QQ

:::     PO********
              ::::::0Q=58IN6U^<E

ELASTIC ENERGY IN AUTO     =        2.2
INELASTIC WORK ON AUTO     =        3.9

DAMPING LOSSES             =         .3

AUTO-BARRIER FRICTION LOSS =       14.8
AUTO-PAVEMENT FRICTION LOSS=         .3

SUM OF ALL CONTRIBUTIONS   =       99.9


DATA ON AUTO-BARRIER CONTACT, TIME =   .0875 SECS
 AUTO     CONTACT     CONTACT BETWEEN         X               Y                NORMAL         X            Y
 POINT   INTERFACE    NODE   AND  NODE    COORDINATE      COORDINATE            FORCE        FORCE        FORCE
   1         1         30          29       838.03           3.69                3.33        -1.64        -3.13
   2         1         30          29       826.10           5.49                7.26        -3.52        -6.84
   3         1         29          28       812.56           7.24               27.24       -11.56       -26.44
   4         1         29          28       808.34           7.78               13.11        -5.29       -12.84
   5         1         28          27       802.93           7.87                4.96        -1.85        -4.92
   6         1         28          27       796.37           7.59                4.02        -1.35        -4.04
   7         1         28          27       788.79           7.27                1.83         -.53        -1.86
  18         1         28          27       798.46           7.68                1.99         -.69        -2.00


AUTO TRAJECTORY RESULTS
PT   X-ORD   Y-ORD  ANGLE  X-VEL  Y-VEL  R-VEL  S-VEL  T-VEL  ANGLE  X-ACC  Y-ACC  R-ACC  S-ACC  T-ACC  ANGLE
   TIME =  .1000 SECS
 1   770.9   -39.8   20.2  47.16   7.05  46.69  -9.70  47.69    8.5  -8.14 -16.94 -13.49 -13.07  18.79 -115.7

BARRIER DEFLECTIONS, TIME =  .1000 SECS
```

```
   NODE      X-DEFL      Y-DEFL        X-ORD       Y-ORD

     1          .02         .00           .0          .0
     2          .05         .00         37.5          .0
     3          .08         .00         75.1          .0
     4          .11         .00        112.6          .0
     5          .14         .00        150.1          .0
     6          .17         .00        187.7          .0
     7          .20         .00        225.2          .0
     8          .24         .00        262.7          .0
     9          .27         .00        300.3          .0
    10          .31         .00        337.8          .0
    11          .35         .00        375.3          .0
    12          .39         .00        412.9          .0
    13          .42         .00        450.4          .0
    14          .47         .00        488.0          .0
    15          .51         .00        525.5          .0
    16          .56         .00        563.1          .0
    17          .61         .00        600.6          .0
    18          .64        -.01        619.4          .0
    19          .66        -.02        638.2          .0
    20          .82        -.03        657.1          .0
    21          .85        -.02        675.8          .0
    22          .87         .04        694.6          .0
    23          .89         .20        713.4          .2
    24          .86        1.59        732.1         1.6
    25          .82        3.06        750.8         3.1
    26          .74        5.02        769.5         5.0
    27          .66        6.96        788.2         7.0
    28          .63        8.61        806.9         8.6   Max. Deflection
    29          .61        7.19        825.6         7.2
    30          .30        3.62        844.0         3.6
    31         -.02         .02        862.5          .0
    32         -.01         .00        898.5          .0
    33         -.01         .00        934.5          .0
    34         -.01         .00        970.5          .0
    35         -.01         .00       1006.5          .0
    36          .00         .00       1042.5          .0
    37          .00         .00       1078.5          .0
    38          .00         .00       1114.5          .0
    39          .00         .00       1150.5          .0


 MEMBER FORCES, TIME =  .1000 SECS                          Anchor Force (approx.)

 BEAMS, 100 SERIES
 MEMBER    NODE I     NODE J      TYPE        FORCE     I-MOMENT     J-MOMENT   F-CODE   M-CODE
     1         1          2        101        48.36          .00          .00       1        1
     2         2          3        101        48.35          .00          .00       1        1
     3         3          4        101        49.46          .00          .00       1        1
     4         4          5        101        49.45          .00          .00       1        1
     5         5          6        101        51.46          .00          .00       1        1
     6         6          7        101        51.44          .00          .00       1        1
     7         7          8        101        54.39          .00          .00       1        1
     8         8          9        101        54.36          .00          .00       1        1
     9         9         10        101        58.31          .00          .00       1        1
    10        10         11        101        58.27          .00          .00       1        1
    11        11         12        101        63.31          .00          .01       1        1
    12        12         13        101        63.26         -.01         -.01       1        1
    13        13         14        101        69.47          .01         -.03       1        1
    14        14         15        101        69.42          .03         -.02       1        1
    15        15         16        101        76.93          .02          .22       1        1
    16        16         17        101        76.88         -.22          .80       1        1
    17        17         18        102        85.85         -.80          .46       1        1
```

```
   18        18        19        102       85.82        -.46          .46      1        1
   19        19        20        104       95.61        -.46        -3.94      2        1
   20        20        21        105       95.62        3.94        -9.83      1        1
   21        21        22        106      108.34        9.83       -23.77      1        1
   22        22        23        107      108.34       23.77       -47.82      1        1
   23        23        24        103      121.73       47.82      -148.82      1        1
   24        24        25        103      121.74      148.82      -252.87      1        1
   25        25        26        103      137.22      252.87      -255.96      1        1
   26        26        27        103      137.27      255.96      -257.40      1        4
   27        27        28        103      150.18      257.39       -42.07      1        2
   28        28        29        103      139.95       42.07       269.02      1        3
   29        29        30        103      125.31     -269.02        77.05      1        2
   30        30        31        103      122.39      -77.05      -279.12      1        3
   31        31        32        108       64.86      279.12      -128.65      1        1
   32        32        33        108       64.87      128.65        20.55      1        1
   33        33        34        108       35.73      -20.55         9.87      1        1
   34        34        35        108       35.73       -9.87         -.77      1        1
   35        35        36        108       18.69         .77         -.43      1        1
   36        36        37        108       18.69         .43         -.08      1        1
   37        37        38        108        7.99         .08         -.04      1        1
   38        38        39        108        7.99         .04          .00      1        1

 POSTS, 300 SERIES
 MEMBER    NODE I    NODE J    TYPE      A-SHEAR     B-SHEAR     B-MOMENT    A-MOMENT    CODE
   39         1         0      304       48.38         .00      1016.01         .00       1
   40         3         0      301        1.16         .00        24.29         .00       1
   41         5         0      301        2.09         .00        43.86         .00       1
   42         7         0      301        3.06         .00        64.22         .00       1
   43         9         0      301        4.08         .00        85.74         .00       1
   44        11         0      301        5.18         .00       108.81         .01       1
   45        13         0      301        6.37         .00       133.85        -.04       1
   46        15         0      301        7.68         .00       161.33         .10       1
   47        17         0      301        9.13        -.05       191.77       -1.11       1
   48        19         0      301        9.94        -.25       208.75       -5.20       1
   49        21         0      301       12.69        -.23       266.58       -4.78       1
   50        23         0      302       13.42        3.06       281.82       64.34       1
   51        25         0      303       14.78        6.83       310.46      143.46       1
   52        27         0      303       11.95       14.37       251.02      301.69       1
   53        31         0      304      -51.11       48.20     -1073.36     1012.16       1
   54        33         0      304      -29.14       -4.44      -612.02      -93.24       1
   55        35         0      304      -17.04         .30      -357.77        6.40       1
   56        37         0      304      -10.70        -.01      -224.75        -.18       1
   57        39         0      304       -7.99         .00      -167.87        -.02       1


 ENERGY BALANCE, TIME =  .1000 SECS

 TYPE OF                            PERCENT OF
 ENERGY                            ORIG AUTO KE

 TRANSLATIONAL K.E. OF AUTO =        63.2
 ROTATIONAL K.E. OF AUTO    =         2.4
 BARRIER K.E.               =          .0

 ELASTIC ENERGY IN MEMBERS

:::       BE       .0
              ::::::OO(P,IN4)\!\

:::       PO********
              ::::::OO=<">N4$-^+

 INELASTIC WORK ON MEMBERS
```

# APPENDIX D

# METHOD TO DETERMINE OCCUPANT RISK

The time that a hypothetical unrestrained front seat passenger moved laterally a distance of 12 in. and struck the side of the vehicle door was determined by an analysis of the high-speed film from the overhead camera. During impact, it was assumed that the occupant maintained the same straight path and velocity of the vehicle just prior to impact as shown in Figure D1. When the distance between the C.G. path of the redirected vehicle and the straight path of the occupant was 12 in., the time was ocmputed by multiplying the camera speed (fr/sec) by the number of frames from the instant of impact. Plotting the vehicle C.G. path, as shown in Figure D1, was very tedious work. A much simpler and faster method was later used which consisted of taping a straight-edge along the path of the vehicle before impact and then checking the distance between the front target on the vehicle roof (vehicle C.G.) and the straight-edge until a distance of 12 in. was obtained. It is important to note in Figure D1 that practically no change in vehicle direction occurred while crushing sheet metal until a time of about 35 msec. after impact. The instant when the vehicle became parallel to the centerline of traffic barrier was the time in which the lateral velocity component of the vehicle was equal to zero.

The time-velocity data obtained was then plotted as shown in Figure D2 to measure the impact velocity of the occupant striking the side door of the vehicle. The vehicle lateral velocity component was taken perpendicular to the centerline of the traffic barrier. The velocity was assumed to be constant for a time of 20 msec. After a time of 20 msec, the velocity was assumed to decrease

TEST NO. 4
SPEED 61 mph
TRANSITION Double Thrie Beam
DATA POINT INTERVAL 23 msec

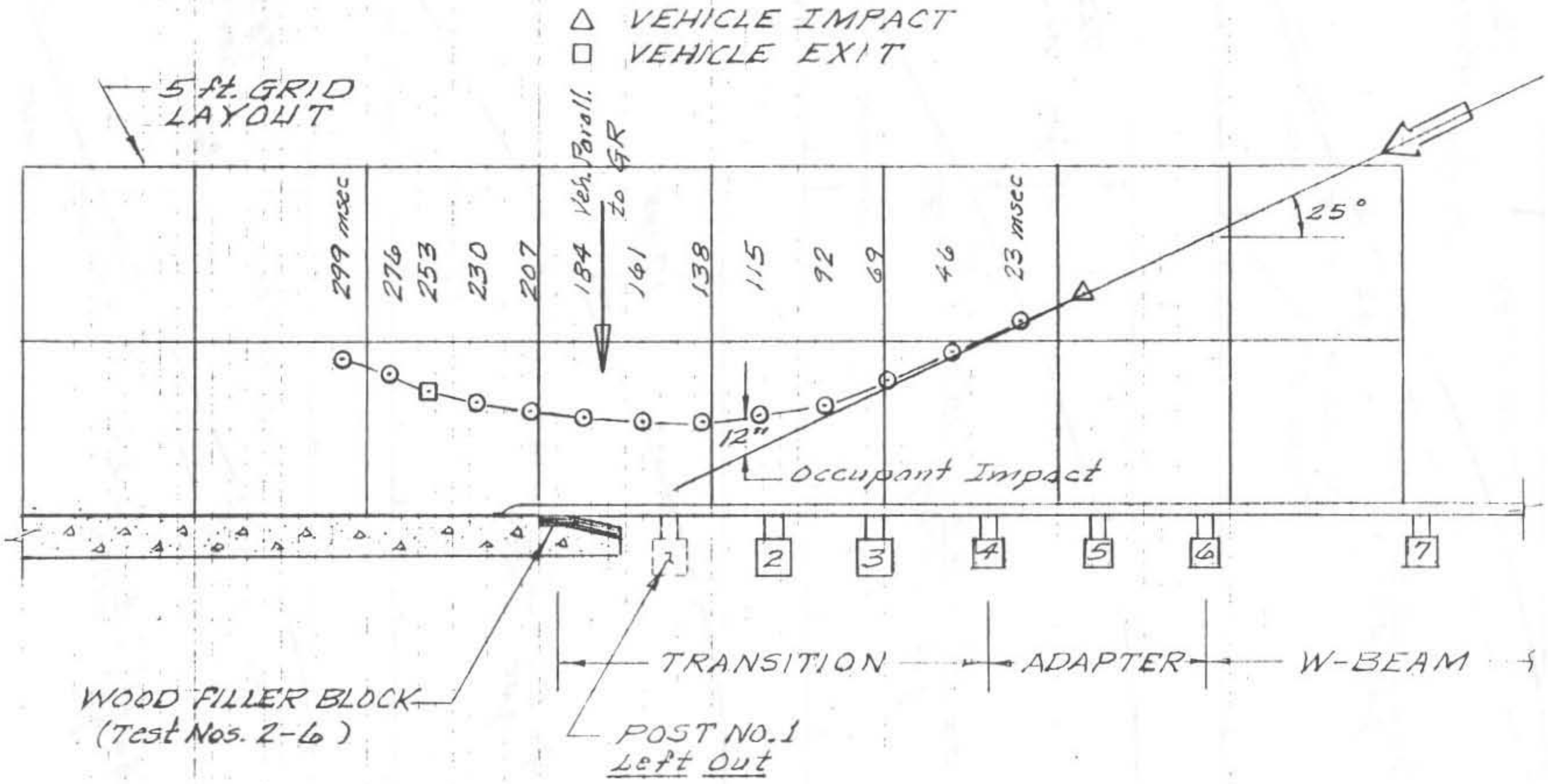

Figure D1

C.G. PATH OF VEHICLE

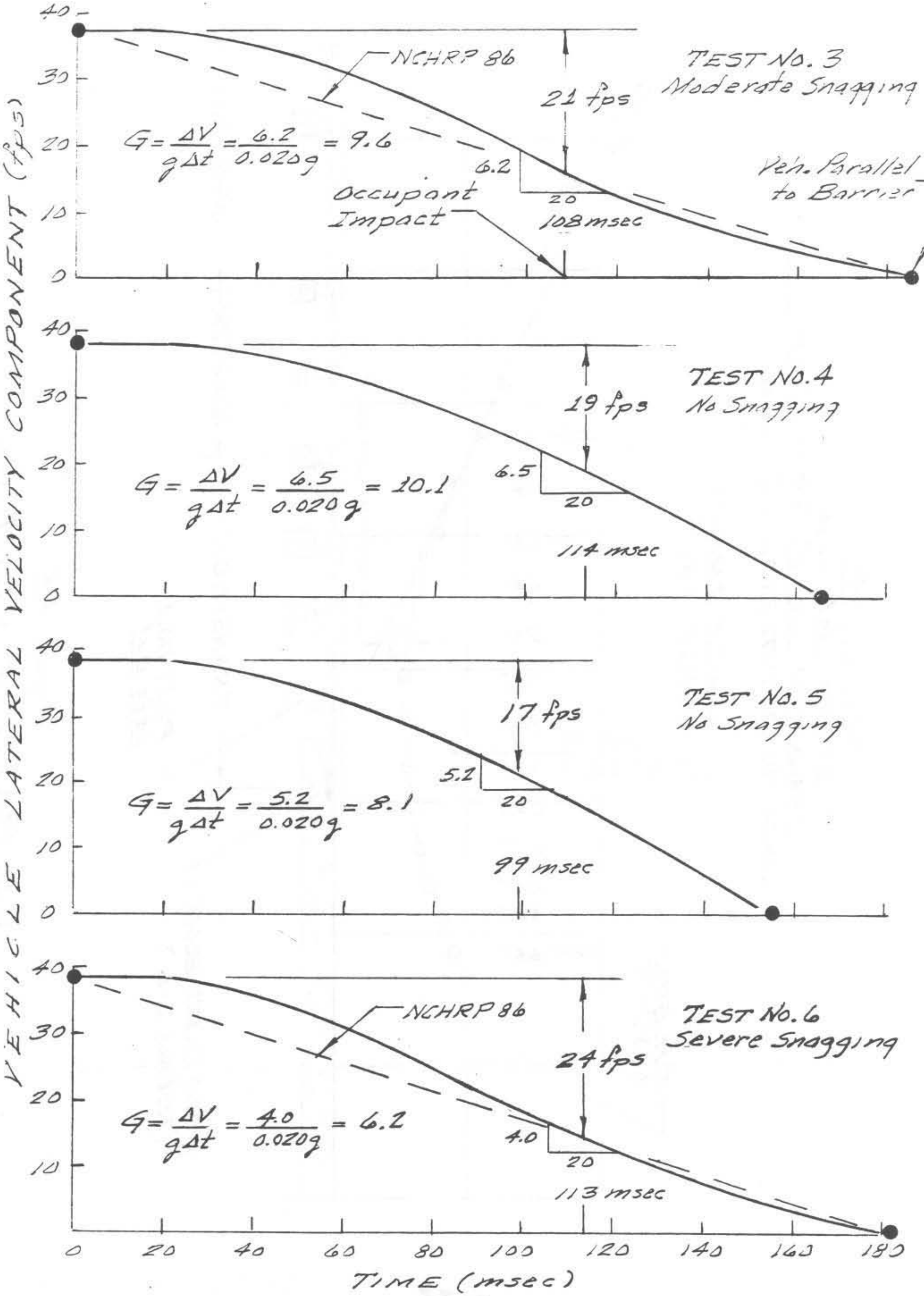
VEHICLE LATERAL VELOCITY COMPONENT (fps)
TIME (msec)
0
20
40
60
80
100
120
140
160
180
0
10
20
30
40
TEST No. 3
Moderate Snagging
NCHRP 86
21 fps
$G = \frac{\Delta V}{g \Delta t} = \frac{6.2}{0.020g} = 9.6$
6.2
20
108 msec
Occupant Impact
Veh. Parallel to Barrier
TEST No. 4
No Snagging
19 fps
$G = \frac{\Delta V}{g \Delta t} = \frac{6.5}{0.020g} = 10.1$
6.5
20
114 msec
TEST No. 5
No Snagging
17 fps
$G = \frac{\Delta V}{g \Delta t} = \frac{5.2}{0.020g} = 8.1$
5.2
20
99 msec
TEST No. 6
Severe Snagging
NCHRP 86
24 fps
$G = \frac{\Delta V}{g \Delta t} = \frac{4.0}{0.020g} = 6.2$
4.0
20
113 msec

Figure D2

in a slightly non-linear manner to a value of zero when the vehicle became parallel to the centerline of the traffic barrier. The occupant impact velocity was measured by taking the difference between the impact lateral velocity component of the vehicle and the lateral velocity component of the vehicle when a hypothetical passenger had moved 12 in. laterally.

A similar method was presented in NCHRP 86 (8) for validating a mathematical model by assuming a linear straight line decrease in velocity from the instant of impact to that time when the vehicle became parallel to the barrier. The straight line method in NCHRP 86, with an accuracy of + 20%, seems to compare well with the non-linear plots in Test Nos. 3 and 5 in which snagging occurred.

# APPENDIX E

# INJURY ACCIDENT PROBABILITY

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
REPORT **86**

# TENTATIVE SERVICE REQUIREMENTS FOR BRIDGE RAIL SYSTEMS

ROBERT M. OLSON, EDWARD R. POST,
AND WILLIAM F. McFARLAND
TEXAS A & M UNIVERSITY
COLLEGE STATION, TEXAS

RESEARCH SPONSORED BY THE AMERICAN ASSOCIATION
OF STATE HIGHWAY OFFICIALS IN COOPERATION
WITH THE BUREAU OF PUBLIC ROADS

SUBJECT CLASSIFICATION:
HIGHWAY DESIGN
BRIDGE DESIGN
HIGHWAY SAFETY

HIGHWAY RESEARCH BOARD
DIVISION OF ENGINEERING NATIONAL RESEARCH COUNCIL
NATIONAL ACADEMY OF SCIENCES—NATIONAL ACADEMY OF ENGINEERING 1970

signs tested. Barrier rail systems that deflected laterally were effective, as noted by the lower transverse readings. It is interesting to note that there was no significant difference between the vertical readings for the New Jersey barrier, which has a lower sloping face, and the W-beam guardrail when tested under the same impact conditions. Also of interest, the longitudinal decelerations of the anthropomorphic dummy in the majority of tests were approximately or equal to one-half of the lateral decelerations. As shown in Appendix A, a similar relationship was found to exist between the average lateral and longitudinal decelerations of vehicles involved in full-scale dynamic tests.

Thus, an occupant restrained by a seat belt and shoulder harness would most likely experience decelerations similar to the vehicle compartment area, whereas an unrestrained occupant might experience decelerations completely different from that of the vehicle. In any event, the severity of damage to the vehicle would appear to be a good indication of the vehicle decelerations and incidence of injury to unrestrained occupants. Based on the work of Michalski (*12*) and employing the mathematical model discussed previously, this hypothesis has been confirmed.

From the results of a 1967 field study conducted in Oregon involving 951 vehicles in traffic accidents of which there were 184 personal injuries and 7 fatalities, Michalski demonstrated, as shown in Figure 6, that the proportion of damaged vehicles in which injuries occurred was proportional to the square of the severity of damage to a vehicle as rated on a 7-point photographic scale (*17*) by police officers and others at the scene of an accident. Michalski indicates that the probability integral and parabolic curves in Figure 6 may be used with equal facility to predict incidence of injuries in relation to vehicle damage rating. Michalski has indicated verbally that less than 5 percent of the vehicle occupants were restrained by a seat belt and/or shoulder belt.

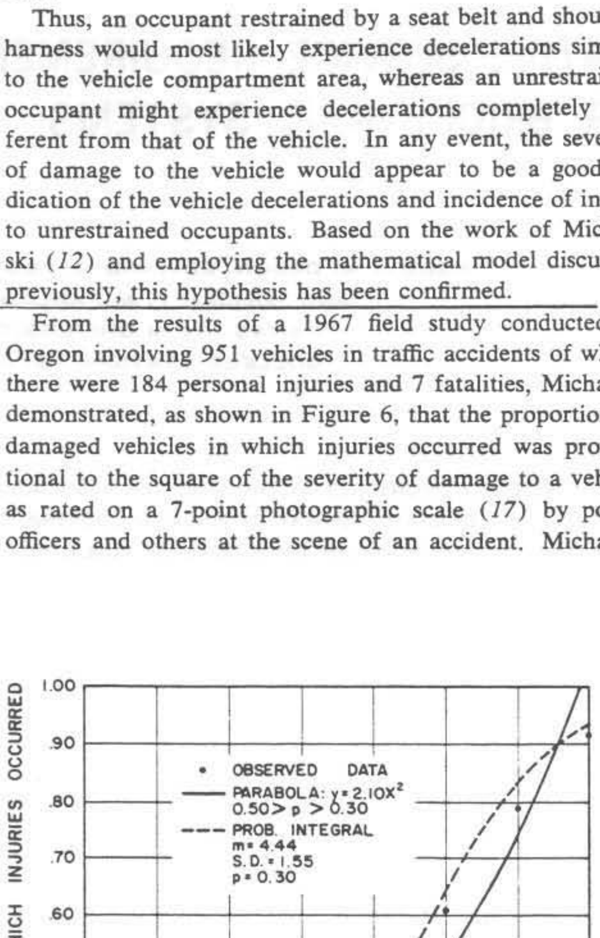

*Figure 6. Occurrence of personal injuries in relation to front-end damage rating* (12, p. 38).

To apply and extend the work of Michalski to include average vehicle decelerations, vehicles damaged in full-scale dynamic tests by various research agencies were selected for evaluation. As shown in Figures 7 and 8, the results of this study, which are developed in depth in Appendix B, indicate that the average vehicle decelerations are directly proportional to: (1) the proportion of damaged vehicles involved in traffic accidents in which occupant injuries occurred, and (2) the square of the vehicle damage rating. In mathematical notation, this relationship would be represented by the equations:

| *Type Vehicle Impact* | *Mathematical Equation* | |
|---|---|---|
| Front | $G_{\text{long.}} = 0.280\,R^2 = 13.7\,P$ | (10) |
| Angle | $G_{\text{lat.}} = 0.204\,R^2 = 10.0\,P$ | (11) |

in which

$G$ = average vehicle deceleration;
$R$ = vehicle damage rating; and
$P$ = proportion of vehicles in which injuries occurred.

It must be noted that the average lateral vehicle decelerations are based on the assumption that the vehicle is smoothly redirected by the barrier rail.

In addition to demonstrating that the proportion of vehicles in which personal injuries occurred in relation to damage rating was nearly parabolic in form, Michalski determined that at mean damage ratings * of: (1) 1.99—vehicles are drivable, (2) 4.08—vehicles are non-drivable, (3) 4.45 and 4.73—injuries occurred in front-end and side vehicle impacts, respectively, and (4) 2.32 and 2.49—no injuries occurred in front-end and side vehicle impacts, respectively. Based on the mathematical relationship established, Eqs. 10 and 11, the average vehicle decelerations and the percent of vehicles involved in an accident in which injuries would occur that correspond to the conditions for which mean damage ratings were determined by Michalski are given in Table 9.

Before attempting to predict the severity of a barrier rail accident, a study of vehicle encroachments on a barrier rail must be made. From accident data on the Ohio Turnpike for a period of five months during the summer and fall of 1967, Garrett (*13*) reported vehicle speeds and the departure angles as given in Table 10. For purposes of this study, it is assumed that the mean departure angles for various speeds as reported by Garrett would also be representative for an out-of-control vehicle striking a barrier railing.

From injury accident data involving guardrail on two-lane highways and four-lane divided highways, it was possible to estimate from the graph presented by Deleys (*2, p. 6*) that approximately 85 to 90 percent of the accidents (excluding inappropriate data) occurred at an angle of 20° and less.

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*** Unless noted, the mean damage ratings include all types of impacts.**

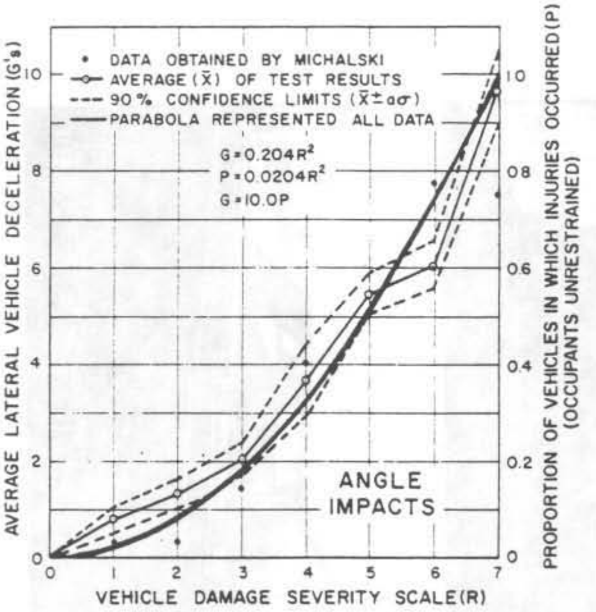


*Figure 7. Curve relating lateral deceleration, proportion of injuries, and damage rating scale.*

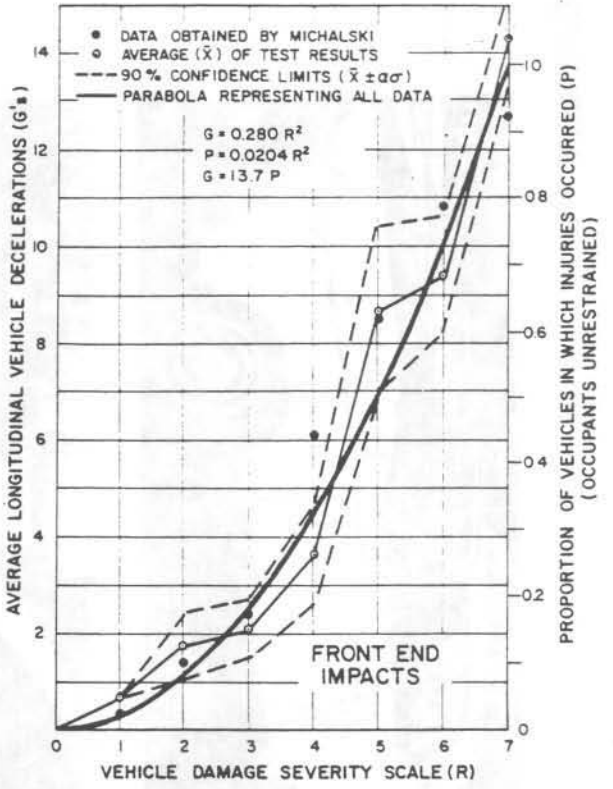


*Figure 8. Curve relating longitudinal deceleration, proportion of injuries, and damage rating scale.*

When the average lateral decelerations of the mathematical model, Eq. 5, are graphically plotted using the vehicle impact speed as the ordinate and the impact angle as the abscissa, it is evident as shown in Figure 9 that approximately 80 to 85 percent of the accident data reported by Deleys and the curve representing the information obtained by Garrett fall to the left (less than) of a 2-*G* level deceleration curve; whereas 85 to 90 percent of the accident data fall to the left of a 3-*G* deceleration curve.

Based on the information presented, and assuming that the hazardous conditions discussed in section "Accident Information" are eliminated, this agency-conducted study indicates that for approximately 85 percent of the accidents, a standard-size vehicle would be subjected to an average lateral deceleration (at the center of mass of the vehicle) of 3 *G*'s or less for various combinations of impact speed and angle. At this deceleration level, this study also indicates that 85 percent of the accidents would be non-fatal, and 60 percent of the accidents would not produce injuries to unrestrained occupants. As is evident from Table 9, a 3-*G* average deceleration level for angle impacts would correspond to a slightly lower rating than that at which vehicles are non-drivable.

TABLE 9

AVERAGE VEHICLE DECELERATIONS AS FUNCTION OF NSC MEAN DAMAGE VEHICLE RATINGS AND INJURY LEVELS

| | AVERAGE VEHICLE DECELERATIONS (G's) | | % OF VEHICLES IN WHICH INJURIES WOULD OCCUR | |
|---|---|---|---|---|
| CONDITIONS FOR WHICH MEAN DAMAGE RATINGS WERE DETERMINED BY MICHALSKI (*12*) | FRONT IMPACTS | ANGLE IMPACTS | FRONT IMPACTS | ANGLE IMPACTS |
| Vehicles drivable | 1.1 | 0.8 | 8 | 8 |
| Vehicles non-drivable | 4.7 | 3.4 | 34 | 34 |
| No injuries | 1.5 | 1.3 | 11 | 13 |
| Injuries | 5.5 | 4.6 | 40 | 46 |

TABLE 10

SPEED-MEAN DEPARTURE ANGLE

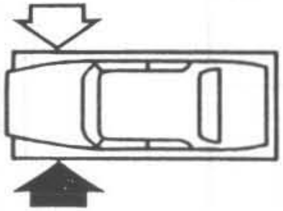
| Speed range (mph) | 10-19 | 20-29 | 30-39 | 40-49 | 50-59 | 60-69 |
|---|---|---|---|---|---|---|
| Mean departure angle[a] (degrees) | 48.5 | 8.8 | 7.9 | 7.1 | 2.0 | 3.7 |
| No. of observations | 2 | 5 | 8 | 30 | 78 | 126 |

[a] Departure angle was defined as the angle of the path of the vehicle as it left the paved roadway.

**SEVERITY SCALE**

# LFQ/RFQ

Front Quarter Damage
Angular Impact



This scale is applicable to damage to the left or right front quarter of subject vehicle (ahead of passenger compartment) resulting from an angular impact, by another vehicle or object.

**Damage Rating**

LFQ-1 or RFQ-1 ➧

LFQ-2 or RFQ-2 ➧

LFQ-3 or RFQ-3 ➧

LFQ-4 or RFQ-4 ➧

LFQ-5 or RFQ-5 ➧

LFQ-6 or RFQ-6 ➧

LFQ-7 or RFQ-7 ➧