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DEVELOPMENT OF A TL-3 F-SHAPE TEMPORARY CONCRETE MEDIAN BARRIER

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ABSTRACT

A temporary concrete median barrier (CMB) was designed and tested for compliance under the Test Level 3 (TL-3) guidelines specified in the *Recommended Procedures for the Safety Performance Evaluation of Highway Features*, National Cooperative Highway Research Program (NCHRP) Report No. 350. The barrier is built to the new metric standards and has a traditional pin and loop configuration for interconnection. The objective of this research project was to develop and evaluate a standardized, temporary concrete barrier design while addressing the concerns for safety, economy, structural integrity, constructability, ease of installation, and maintenance. The resulting F-shape barrier segment is 3,800-mm long, a length that reduced the number of connections while limiting the weight of the barriers to ease handling. Full-scale crash testing demonstrated several critical design features. First, the connections need to be tight initially as practicable to limit deformation and rotation of the barriers,. Secondly, the pin needs to restrain the longitudinal barrier forces. Full-scale compliance testing of the final design demonstrated that the barrier was capable of successfully redirecting the 2000-kg vehicle. The vehicle demonstrated significant roll after contact with the barrier, which is evidenced in a majority of other concrete barrier tests. This barrier provides economical work zone protection applicable in a variety of situations, where TL-3 test criteria is warranted.

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1 INTRODUCTION

1.1 Problem Statement

Several different temporary concrete median barrier (CMB) designs are currently in use throughout the United States, generally consisting of the New Jersey safety shape, and more recently the F-shape and single-slope barriers. Throughout the Midwest states, temporary concrete barrier configurations differ significantly in steel reinforcement, connection details at joints, segment length, and barrier handling features. Consequently, contractors that work in multiple states must either maintain inventories of several temporary concrete barrier designs, or they must seek approval to use alternate designs on a project-by-project basis. However, the structural adequacy, as well as the safety performance, of some of the current designs are questionable, and none of these designs have been evaluated to determine if they meet the crash test safety standards provided in the National Cooperative Highway Research Program (NCHRP) Report No. 350, *Recommended Procedures for the Safety Performance Evaluation of Highway Features* (1). Therefore, a need exists to develop and evaluate one, standardized, temporary concrete barrier design that meets safety standards, potentially reduces barrier costs by using only one configuration, and improves conditions for contractors to work in multiple states using the same barrier.

1.2 Objective and Scope

The objective of this research project was to develop and evaluate one, standardized, temporary concrete barrier design while addressing the concerns for safety, economy, structural integrity, constructability, ease of installation, and maintenance. The temporary concrete barrier

was developed to meet the Test Level 3 (TL-3) safety performance criteria provided in NCHRP Report No. 350.

The Midwest Roadside Safety Facility (MwRSF), in cooperation with the State Highway Departments of Iowa, Kansas, Minnesota, Missouri, Nebraska, and South Dakota, undertook the task of reviewing the literature, selecting a specific barrier shape, redesigning and/or modifying the barrier (i.e., steel reinforcement, connections), conducting static component tests, and performing compliance tests on the barrier. Two full-scale vehicle crash tests were performed using Chevrolet C-20 pickup trucks, weighing approximately 2,000 kg (4,409 lbs). The target impact speed and angle were 100 km/h (62.1 mph) and 25 degrees, respectively. Finally, the test results were analyzed, evaluated and documented, with conclusions and recommendations made that pertain to the safety performance of the temporary CMB.

2 BACKGROUND

Over the years, several research studies have been conducted to evaluate the safety performance of various temporary CMB designs, such as the New Jersey safety shape, F-shape, and single-slope barrier (2,3). Almost all of these designs incorporate precast concrete barrier units, many of which have successfully passed NCHRP Report No. 230 impact standards (4). Barrier designs were tested with segment lengths ranging from 2,438 to 9,144 mm with the 2,438 to 6,096 mm range as the most common lengths.

Crash tests on the different temporary barrier designs have been conducted with various connections at the joints with mixed results - such as pin and rebar, pin and wire rope, tongue and groove, hinge plates, and vertical I-beams. Structural analyses of these connection designs have also been performed to determine preferred configurations and ultimate capacities (5,6,7,8). The overall capacity of the temporary concrete barrier system is generally limited by the strength of the joint details, since the capacity of the connection is often less than that of the barrier section located away from the ends.

3 PERFORMANCE EVALUATION CRITERIA

Longitudinal barriers, such as temporary CMB's, must satisfy the requirements provided in NCHRP Report No. 350 (1) in order to be accepted for use on new construction projects or as a replacement for existing barriers not meeting current safety standards. According to Test Level 3 (TL-3) of NCHRP Report No. 350, longitudinal barriers must be subjected to two full-scale vehicle crash tests: (1) a 2,000-kg pickup truck impacting at a speed of 100.0 km/hr and at an angle of 25 degrees; and (2) an 820-kg small car impacting at an speed of 100.0 km/hr and at an angle of 20 degrees. However, the 820-kg small car crash test was deemed unnecessary for several reasons. First, rigid New Jersey safety shape barriers when impacted by small cars have been shown to meet safety performance standards (2,9). Second, small car crash tests conducted on temporary New Jersey safety shape CMB's have also resulted in little barrier movement (10). Third, computer simulation modeling of safety shape barriers has revealed that the F-shape CMB offers a slight improvement in safety performance over the New Jersey safety shape (11). Finally, a small car crash test was successfully conducted on a rigid, F-shape bridge rail; and therefore, it was reasoned to be a valid indicator of the safety performance of the F-shape temporary CMB (12).

Evaluation criteria for full-scale vehicle crash testing are based on three appraisal areas: (1) structural adequacy; (2) occupant risk; and (3) vehicle trajectory after collision. Criteria for structural adequacy are intended to evaluate the ability of the railing to contain, redirect, or allow controlled vehicle penetration in a predictable manner. Occupant risk evaluates the degree of hazard to occupants in the impacting vehicle. Vehicle trajectory after collision is a measure of the potential for the post-impact trajectory of the vehicle to cause subsequent multi-vehicle

accidents, thereby subjecting occupants of other vehicles to undue hazard or to subject the occupants of the impacting vehicle to secondary collisions with other fixed objects. These three evaluation criteria are defined in Table 1. The full-scale vehicle crash tests were conducted and reported in accordance with the procedures provided in NCHRP Report No. 350.

Table 1. NCHRP Report 350 Evaluation Criteria for 2000P Pickup Truck Crash Test (1).

Structural Adequacy	A.	Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.
Occupant Risk	D.	Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.
	F.	The vehicle should remain upright during and after collision although moderate roll, pitching, and yawing are acceptable.
Vehicle Trajectory	K.	After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.
	L.	The occupant impact velocity in the longitudinal direction should not exceed 12 m/sec and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 G's.
	M.	The exit angle from the test article preferably should be less than 60 percent of test impact angle, measured at time of vehicle loss of contact with test devise.

4 BARRIER DESIGN

The F-shape section was selected for use as the TL-3 temporary barrier; since, the F-shape offers a slight improvement in safety performance from the New Jersey safety shape with its slight reduction in vehicle roll angles, vehicular climb heights, and increased vehicle stability (11,12). In addition, the F-shape is becoming more widely used by the various States' Departments of Transportation. In order to comply with the recent Federal legislation to use the International System (SI) of units, the barrier was designed and tested using actual metric-sized steel reinforcement and also followed the metric cross-sectional dimensions as provided in the Task Force 13 report, *A Guide to Standardized Highway Barrier Hardware* (13).

A parametric study performed by the Texas Transportation Institute (TTI) determined barrier sensitivity to various factors, such as joint moment capacity, barrier length, static and sliding friction coefficients between ground and barrier, barrier mass, and connection slack (5). The research results showed that for larger joint moment capacities, lateral barrier deflections were smallest for segment lengths of 3,048 mm and 9,144 mm and largest for lengths approximately 6,096-mm long. Similarly, the 3,658 and 9,144-mm long segment lengths provided smaller lateral deflections than the 6,096 mm length for an increase in connection slack between barriers. Therefore, a 3,800-mm segment length was chosen for the F-shape barrier based on three factors. First, it provided an increased capability over 6,096-mm segment lengths for limiting lateral barrier deflections. Second, the 3,800-mm segment length should be easier to handle for temporary use than the longer length CMB's. Finally, a 3,800-mm long F-shape provided a 30% increase in weight above the 3,048-mm long New Jersey safety shape, but maintained contractor's ability to lift and install the barriers with currently used equipment.

A pin and rebar connection type was selected for joining the barrier segments. Prior research showed that the pin and rebar connection provided adequate structural capacity for resisting a 2,041-kg sedan impacting at a speed of 96.6 km/hr and an angle of 25 degrees (7). However, the strength of the connection is based on preventing the pin from deforming significantly and pulling out of the rebar loops while under load. In addition to providing load capacity, using a pin retainer was also considered important to eliminate the possibility of pin removal due to vandalism, resulting in a serious safety issue. Finally, this connection type was approximately 50% less expensive than other available connections that could provide the necessary required strength.

An objective of the research project was to develop a barrier that could be used in temporary as well as permanent applications. Therefore, additional features were included in the barrier segment allowing it to be used in both temporary and permanent applications.

5 DESIGN NO. 1 DETAILS

A 61.97-m long barrier system was constructed on a concrete surface located at the MwRSF outdoor test site, as shown in Figure 1. The barrier system consisted of sixteen F-shape CMB sections, each measuring 3,800-mm in length. Design details for the joint connections and steel reinforcement are shown in Figures 2 and 3, respectively. Photographs of the pin and rebar connection are shown in Figure 4. Note that the cavities located at the barrier ends in Design No. 1 were intended for making a rigid connection between barrier segments when the barrier was installed in permanent applications.

The actual 28-day concrete compressive strengths of the various barrier segments were all in excess of 41.37 MPa, while the minimum concrete compressive strength for the design mix was 31.03 MPa. All steel reinforcement complied with the ASTM A615M specification, resulting in a minimum yield stress of 400 MPa. The metric steel bars were obtained from Cowin Steel Co. Ltd. in Winnipeg, Manitoba, Canada.

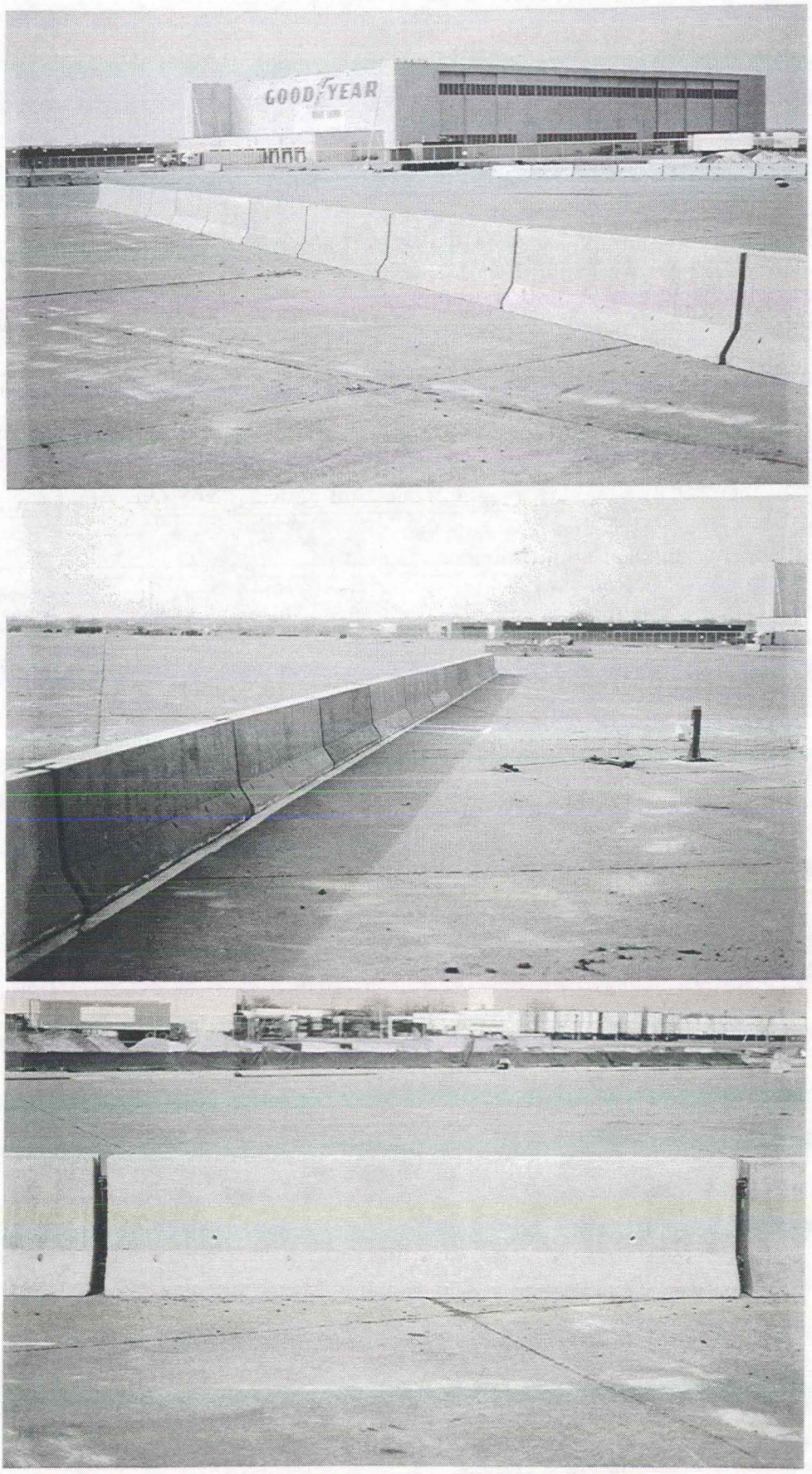
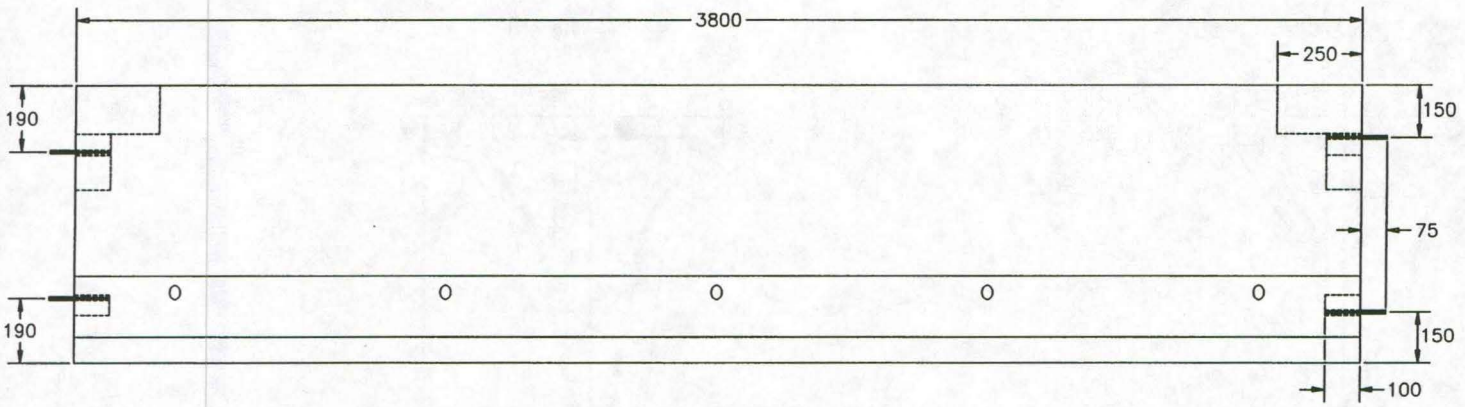
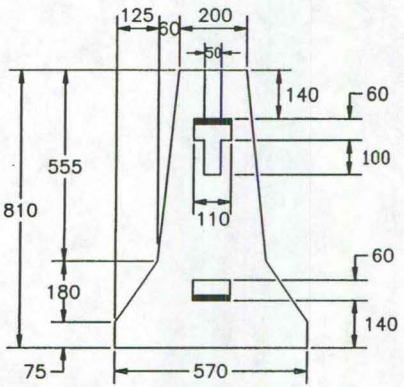


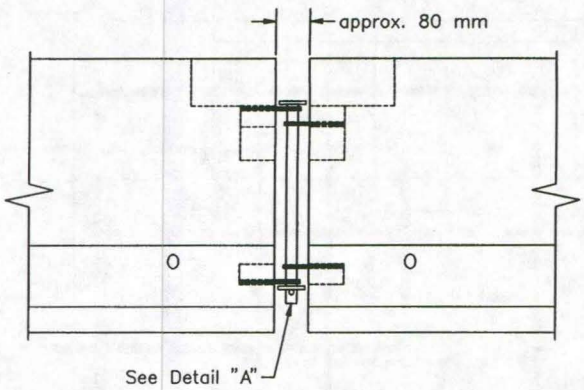
Figure 1. Temporary F-Shape CMB System, Design No. 1



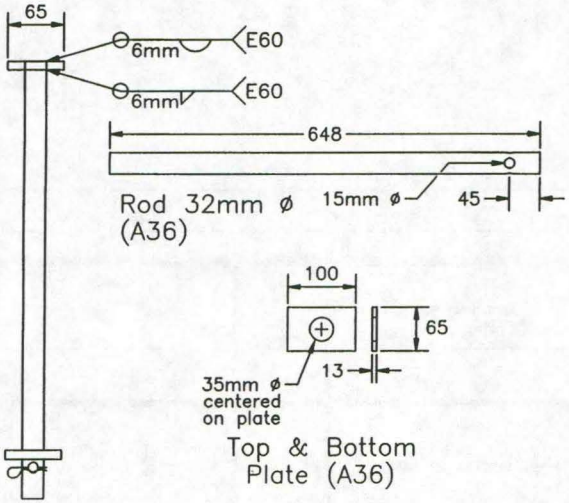
Side View



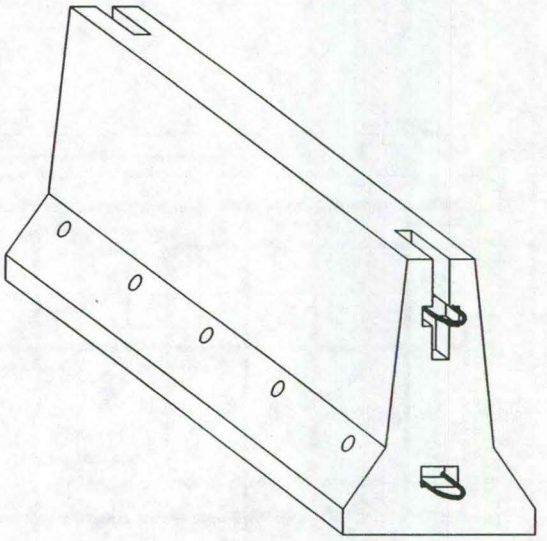
End View



Connection Detail

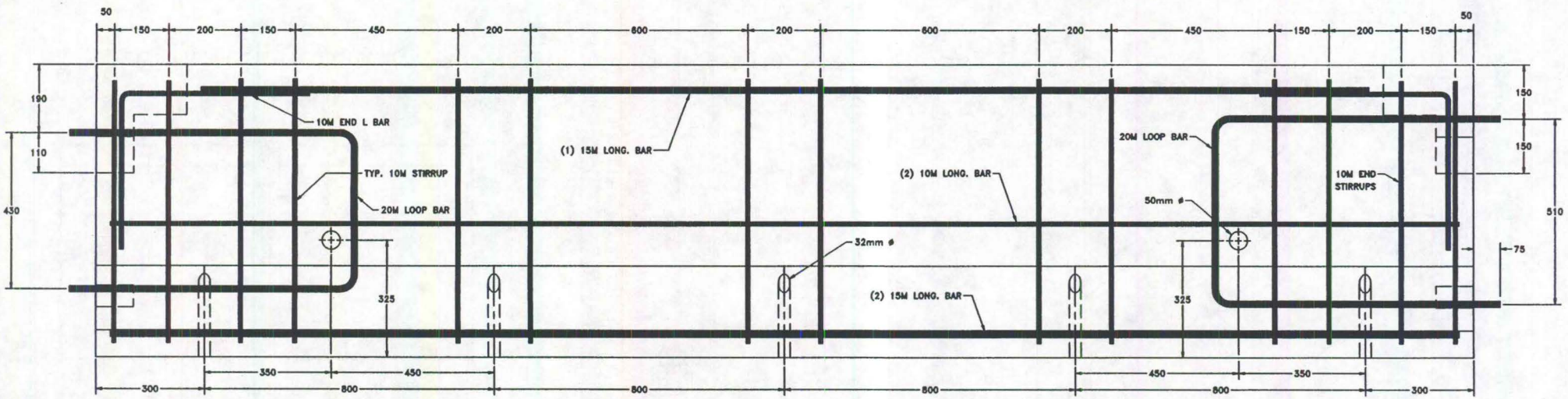


Detail "A"

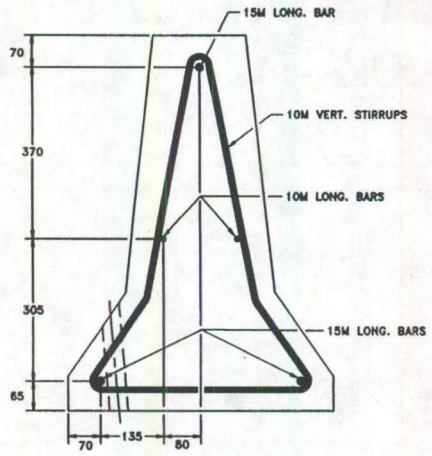


Isometric

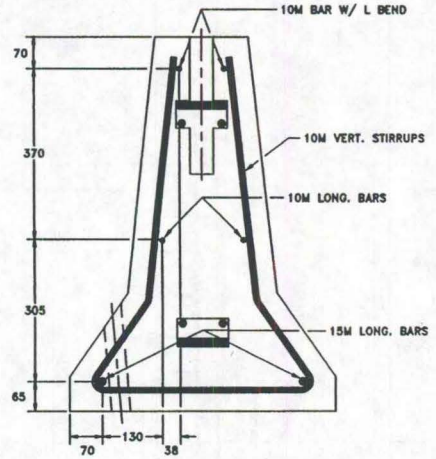
Figure 2. Connection Details, Design No. 1



NOTES:
1) All dimensions are in mm.
2) Minimum Cover of 40 mm.
3) All reinforcement is Grade 414MPa ASTM A615M.
4) Minimum lap of all longitudinal bars is 300 mm.



INTERIOR STIRRUP



END STIRRUP (first 2 each end)

Figure 3. Reinforcement Details, Design No. 1

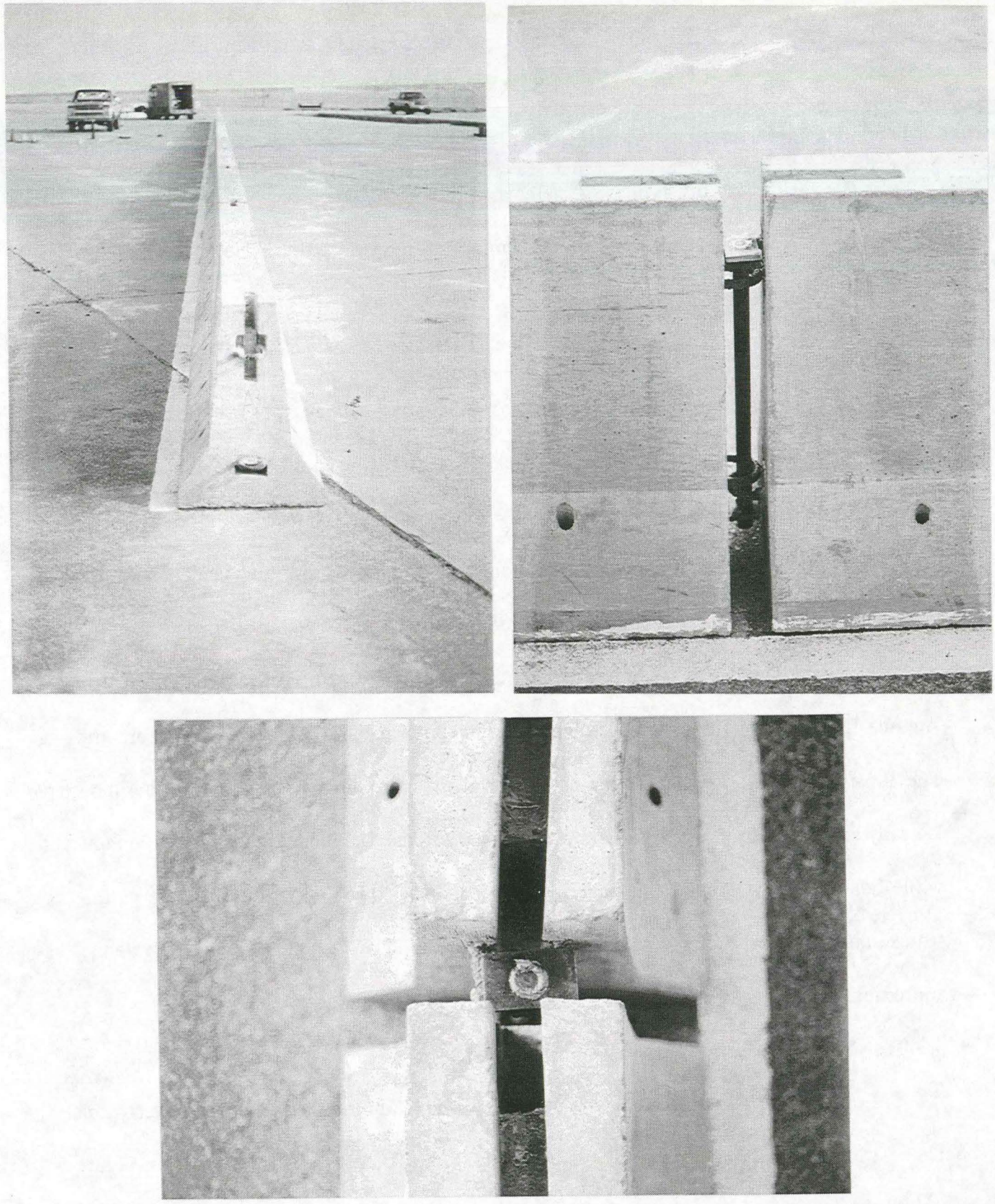


Figure 4. Pin and Rebar Connection, Design No. 1

6 TEST CONDITIONS

6.1 Test Facility

The testing facility is located at the Lincoln Air-Park on the NW end of the Lincoln Municipal Airport and is approximately 8.0 km NW of the University of Nebraska-Lincoln. The site is protected by an 2.44-m high chain-link security fence.

6.2 Vehicle Tow and Guidance System

A reverse cable tow system with a 1:2 mechanical advantage was used to propel the test vehicles. The distance traveled and the speed of the tow vehicle are one-half that of the test vehicle. The test vehicle was released from the tow cable before impact with the bridge rail. A fifth wheel, built by the Nucleus Corporation, was located on the tow vehicle and used in conjunction with a digital speedometer to increase the accuracy of the test vehicle impact speed.

A vehicle guidance system developed by Hinch (14) was used to steer the test vehicle. A guide-flag, attached to the front-left wheel and the guide cable, was sheared off before impact. The 9.5-mm diameter guide cable was tensioned to approximately 13.3 kN, and supported laterally and vertically every 30.48 m by hinged stanchions. The hinged stanchions stood upright while holding up the guide cable, but as the vehicle was towed down the line, the guide-flag struck and knocked each stanchion to the ground. The vehicle guidance system was approximately 457.2-m long.

6.3 Test Vehicles

For test ITMP-1, a 1985 Chevrolet C-20 ¾-ton pickup truck was used as the test vehicle. The test inertial and gross static weights were 2,000 kg. The test vehicle is shown in Figure 5, and vehicle dimensions are shown in Figure 6.

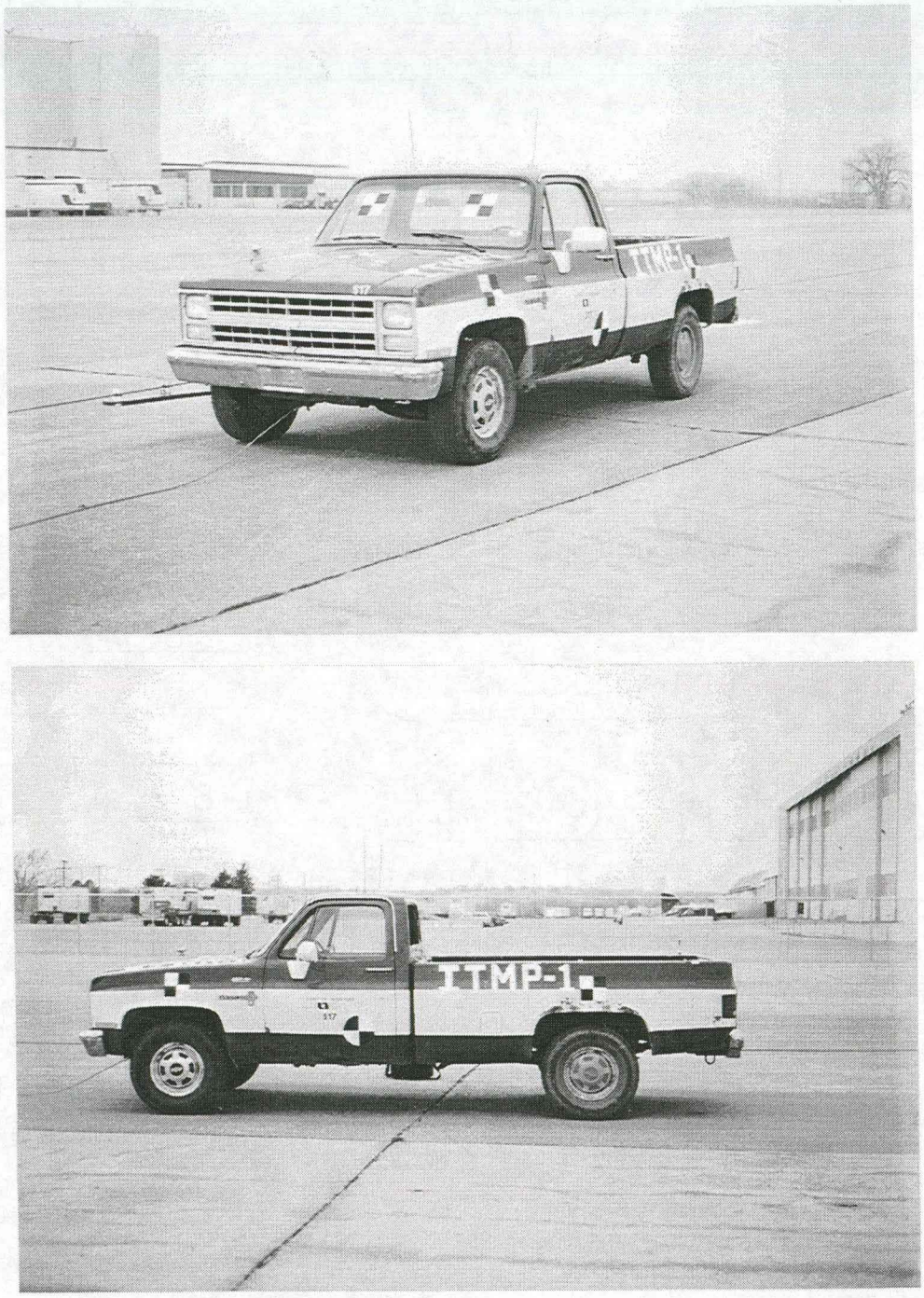
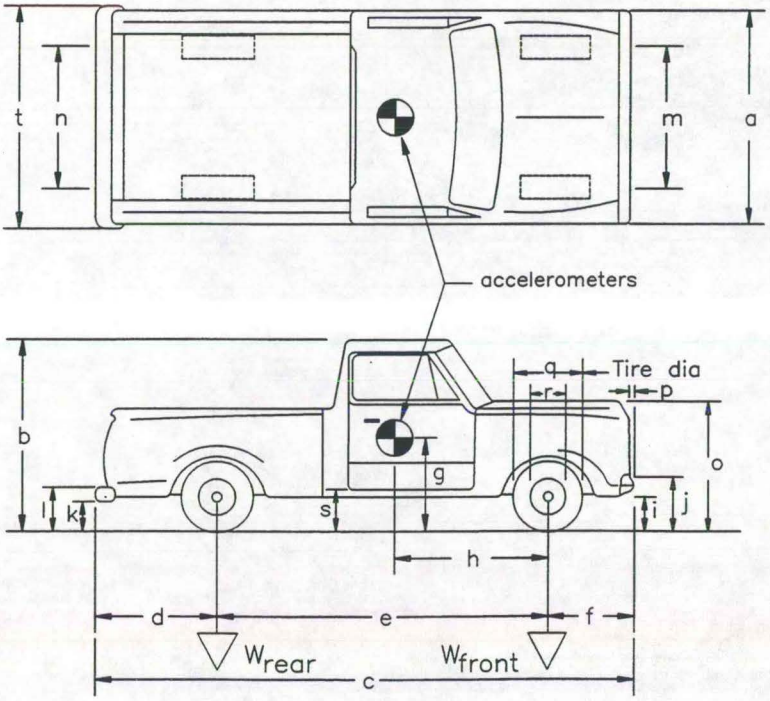


Figure 5. Test Vehicle, Test ITMP-1

Date: 3/5/96 Test Number: ITMP-1 Model: C-20

Make: Chevrolet Vehicle I.D.#: 1GCGC24M9FS189789

Tire Size: LT235/85R16 Year: 1985 Odometer: 74023



Vehicle Geometry – inches

a	76	b	73
c	210	d	50
e	131	f	29
g	28	h	58.2
i	12.5	j	27
k	20	l	28
m	66	n	66
o	50	p	3.5
q	31	r	17.5
s	19.75	t	78.5

Wheel Center Height 15

Engine Type V-8

Engine Size 350

Transmission Type:

Automatic or (Manual)

FWD or (RWD) or 4WD

Weight (Mass) – lbs (Kg)

	Curb	Test Inertial	Gross Static
Front	2640 (1198)	2446 (1109)	2446 (1109)
Rear	2260 (1025)	1964 (891)	1964 (891)
Total	4900 (2223)	4410 (2000)	4410 (2000)

Figure 6. Vehicle Dimensions, ITMP-1

For test ITMP-2, a 1986 Chevrolet C-20 ¾-ton pickup truck was used as the test vehicle. The test inertial and gross static weights were 2,005 kg. The test vehicle is shown in Figure 7, and vehicle dimensions are shown in Figure 8.

The Elevated Axle Method (15) was used to determine the vertical component of the center of gravity. This method converts measured wheel weights at different elevations to the location of the vertical component of the center of gravity. The longitudinal component of the center of gravity was determined using the measured axle weights. The location of the final centers of gravity are shown in Figures 6 and 8.

Square, black and white-checkered targets were placed on the vehicle to aid in the analysis of the high-speed film, as shown in Figures 5, 7, 9 and 10. One target was placed on the center of gravity at the driver's side door and on the roof of the vehicle. The remaining targets were located for reference so that they could be viewed from the high-speed cameras for film analysis.

The front wheels of the test vehicle were aligned for camber, caster, and toe-in values of zero so that the vehicles would track properly along the guide cable. Two 5B flash bulbs were mounted on the hood of the vehicles to pinpoint the time of impact with the bridge railing on the high-speed film. The flash bulbs were fired by a pressure tape switch mounted on the front face of the bumper. A remote controlled brake system was installed in the test vehicle so the vehicle could be brought safely to a stop after the test.

6.4 Data Acquisition Systems

6.4.1 Accelerometers

One biaxial piezoresistive accelerometer system with a range of ±200 g's (Endevco Model 7264) was used to measure the acceleration in the longitudinal and lateral directions. Two

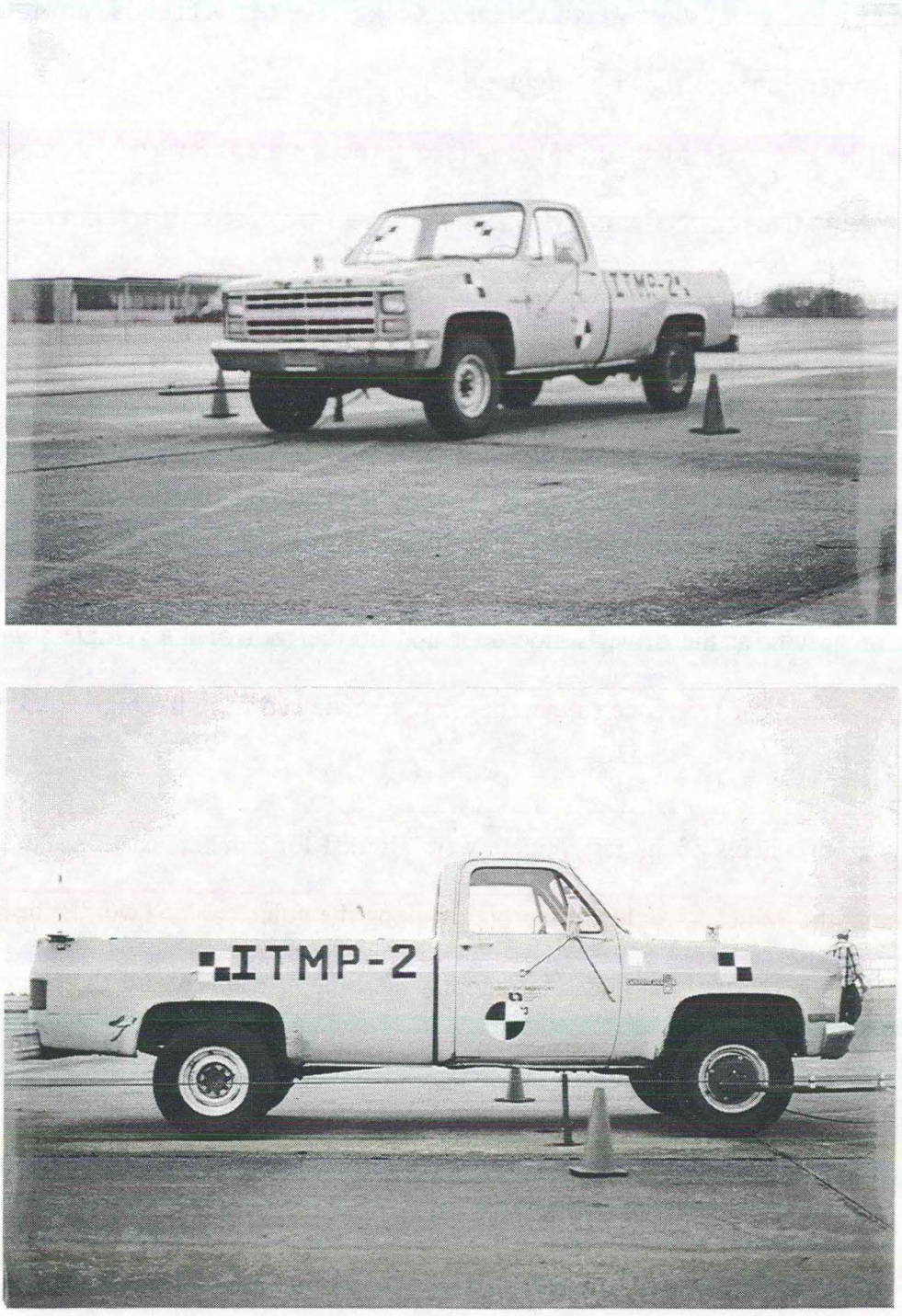
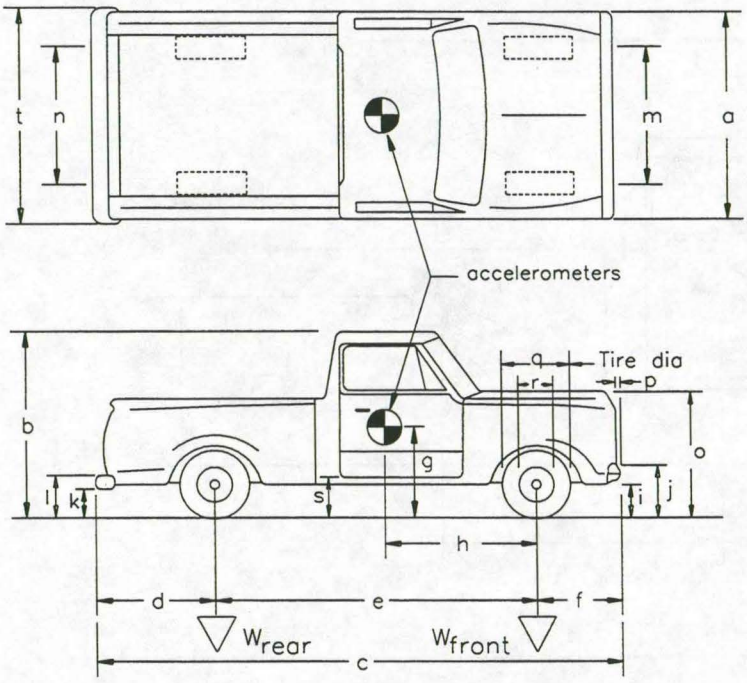


Figure 7. Test Vehicle, Test ITMP-2

Date: 5/9/96 Test Number: ITMP-2 Model: Custom Deluxe

Make: CHEVY Vehicle I.D.#: 1GCEC24H56F423544

Tire Size: LT235/85R16 Year: 1986 Odometer: 93561



Vehicle Geometry – inches

a	77.13	b	73.38
c	214.38	d	52
e	131.13	f	31.5
g	29	h	58.3
i	20	j	21.13
k	20	l	27
m	65.5	n	65.13
o	46	p	3.38
q	31.88	r	17.38
s	20.25	t	76.38

Wheel Center Height 15

Engine Type V-8

Engine Size 305

Transmission Type:

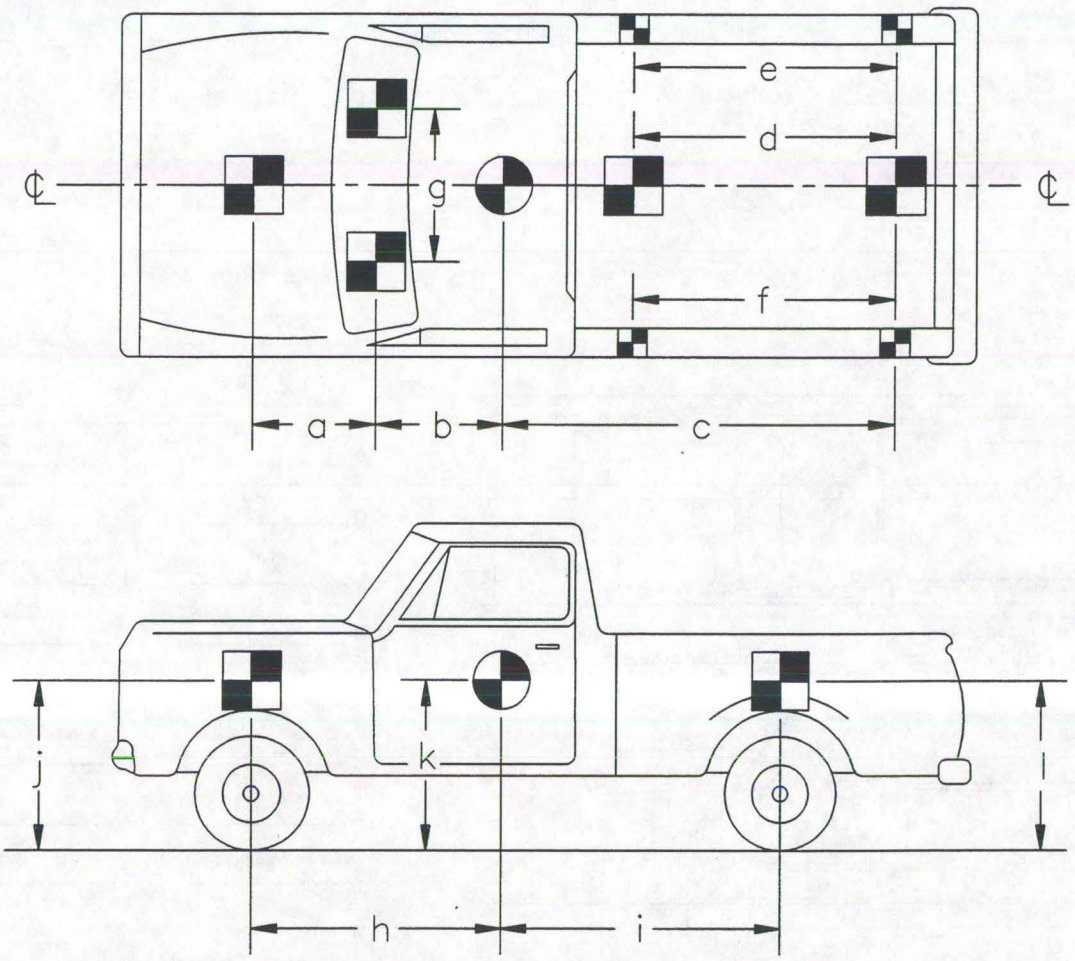
Automatic or (Manual)

FWD or (RWD) or 4WD

Weight (Mass) – lbs (Kg)

	Curb	Test Inertial	Gross Static
Front	2513 (1140)	2464 (1117)	2464 (1117)
Rear	1920 (871)	1957 (888)	1957 (888)
Total	4433 (2011)	4421 (2005)	4421 (2005)

Figure 8. Vehicle Dimensions, Test ITMP-2

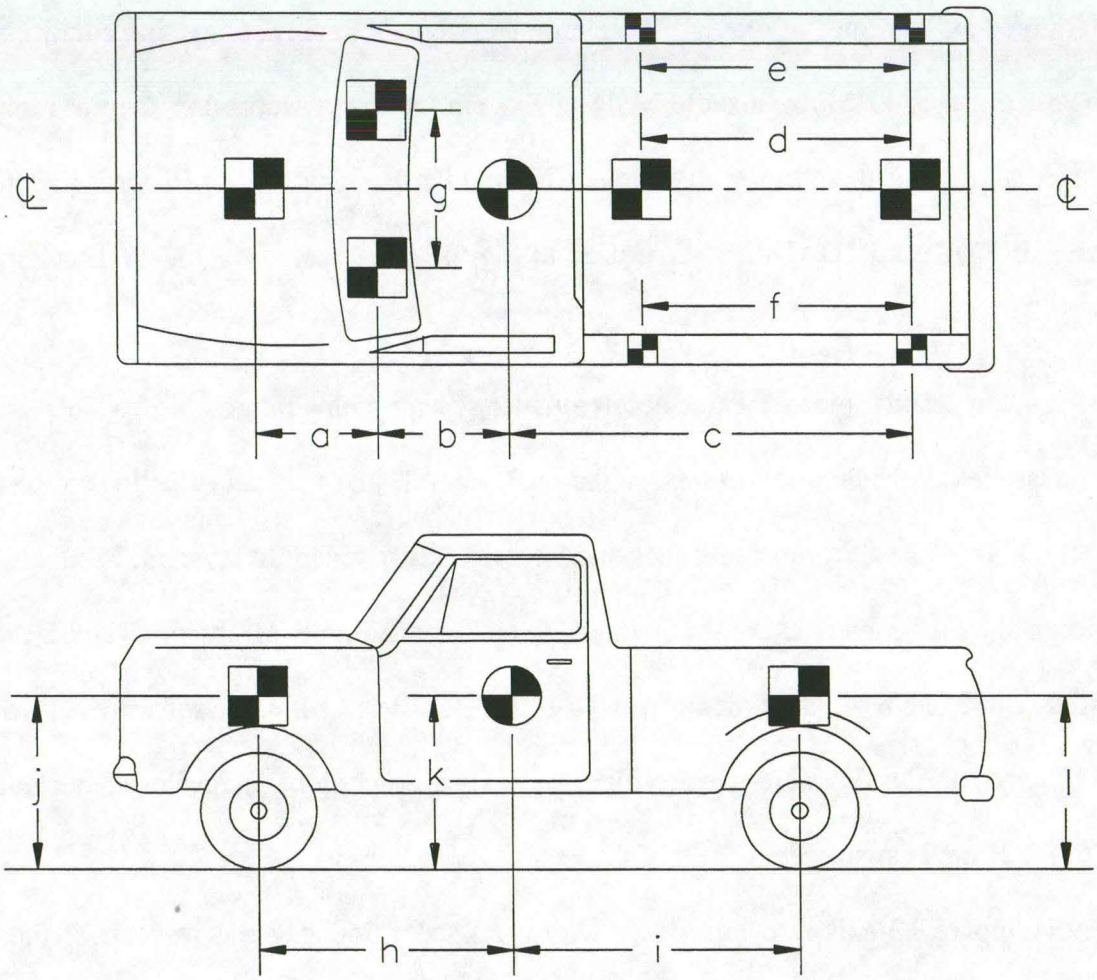


TEST No.: ITMP-1

TARGET GEOMETRY (inches)

a 32.25	b 26.5	c 104.5	d 48
e 48	f 48	g 33.75	h 58.2
i 73	j 42	k 28	l 42

Figure 9. Vehicle Target Locations, Test ITMP-1



TEST No.: ITMP-2

TARGET GEOMETRY (inches)

a 32.5	b 27	c --	d 41.5
e 67.25	f 68	g 38	h 58.3
i 72.75	j 42.5	k 29	l 43.5

Figure 10. Vehicle Target Locations, Test ITMP-2

accelerometers were mounted in each of the two directions and were rigidly attached to a metal block mounted at the center of gravity. Accelerometer signals were received and conditioned by an onboard Series 300 Multiplexed FM Data System built by Metraplex Corporation. The multiplexed signal was then transmitted to the Honeywell 101 Analog Tape Recorder. Computer software, "EGAA" and "DADiSP" were used to digitize, analyze, and plot the accelerometer data.

A backup triaxial piezoresistive accelerometer system with a range of $\pm$200 G's was also used to measure the acceleration in the longitudinal, lateral, and vertical directions at a sample rate of 3,200 Hz. The environmental shock and vibration sensor/recorder system, Model EDR-3, was developed by Instrumented Sensor Technology (IST) of Okemos, Michigan. The EDR-3 was configured with 256 Kb of RAM memory and a 1,120 Hz filter. Computer software, "DynaMax 1 (DM-1)" and "DADiSP" were used to digitize, analyze, and plot the accelerometer data.

6.4.2 Rate Transducer

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

6.4.3 High-Speed Photography

For test ITMP-1, five high-speed 16-mm cameras, with operating speeds of approximately 500 frames/sec, were used to film the crash test. A Red Lake Locam with a wide-angle 12.5-mm lens was placed above the test installation to provide a field of view perpendicular to the ground. A Red Lake Locam with a 76-mm lens was placed downstream from the impact point and had a field of view parallel to the barrier. A Red Lake Locam with a 12.5 to 75-mm zoom lens was placed on the traffic side of the barrier and had a field of view perpendicular to the barrier. A Red Lake Locam with a 12.5-mm lens was placed upstream and behind the barrier. A Red Lake Locam with a 12.5 to 75-mm zoom lens was placed on the back side of the bridge rail and had a field of view perpendicular to the barrier. A schematic of all five camera locations for test ITMP-1 is shown in Figure 11.

For test ITMP-2, five high-speed 16-mm cameras, with operating speeds of approximately 500 frames/sec, were used to film the crash test. A Red Lake Locam with a wide-angle 12.5-mm lens was placed above the test installation to provide a field of view perpendicular to the ground. A Red Lake Locam with a 76-mm lens was placed downstream from the impact point and had a field of view parallel to the barrier. A Red Lake Locam with a 12.5 to 75-mm zoom lens was placed on the traffic side of the barrier and had a field of view perpendicular to the barrier. A Red Lake Locam with a 12.5 to 75-mm lens was placed downstream and behind the barrier. A Red Lake Locam with a 12.5 to 75-mm zoom lens was placed on the back side of the bridge rail and had a field of view perpendicular to the barrier. A schematic of all five camera locations for test ITMP-2 is shown in Figure 12.

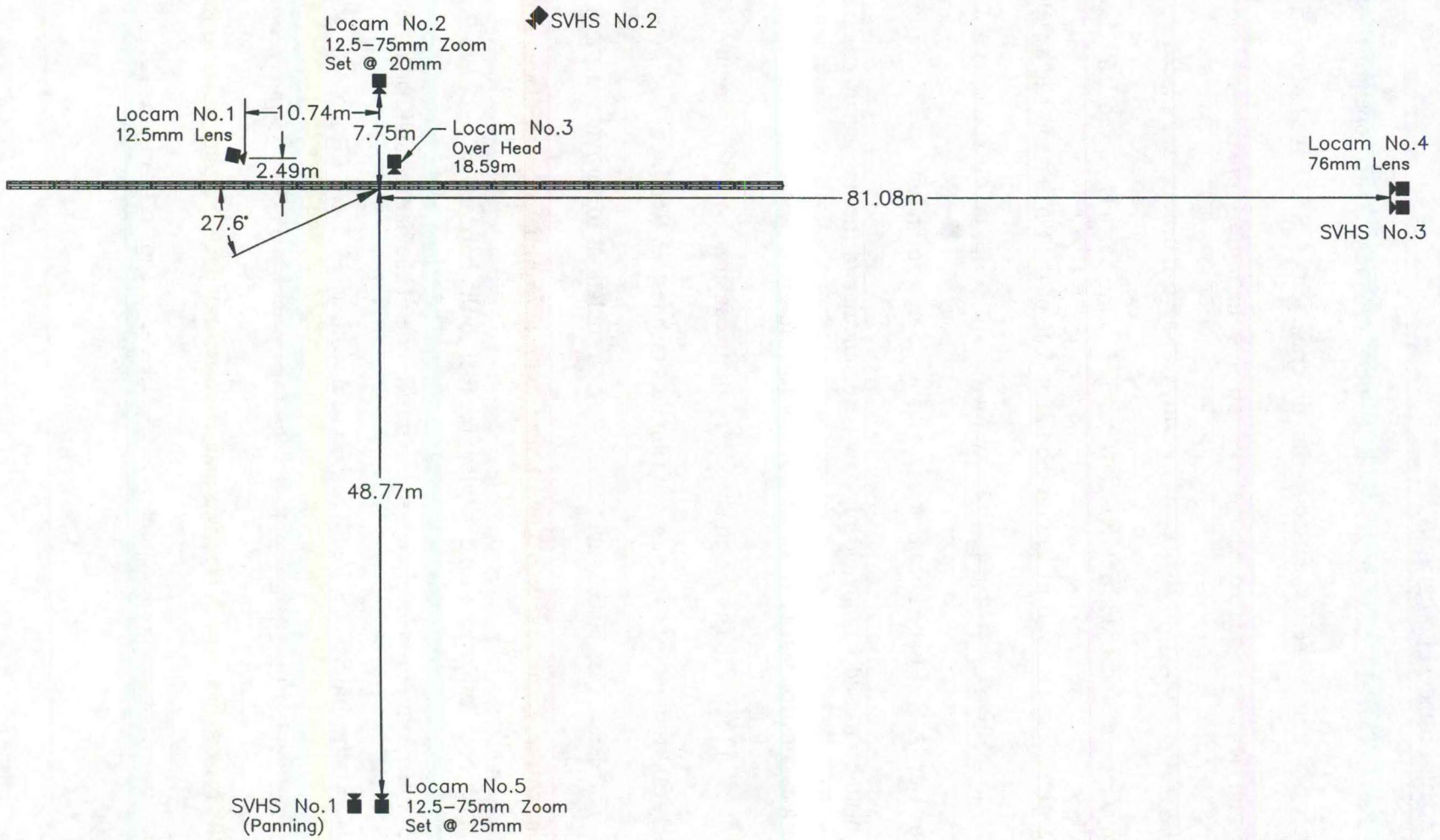


Figure 11. Location of High-Speed Cameras, Test ITMP-1

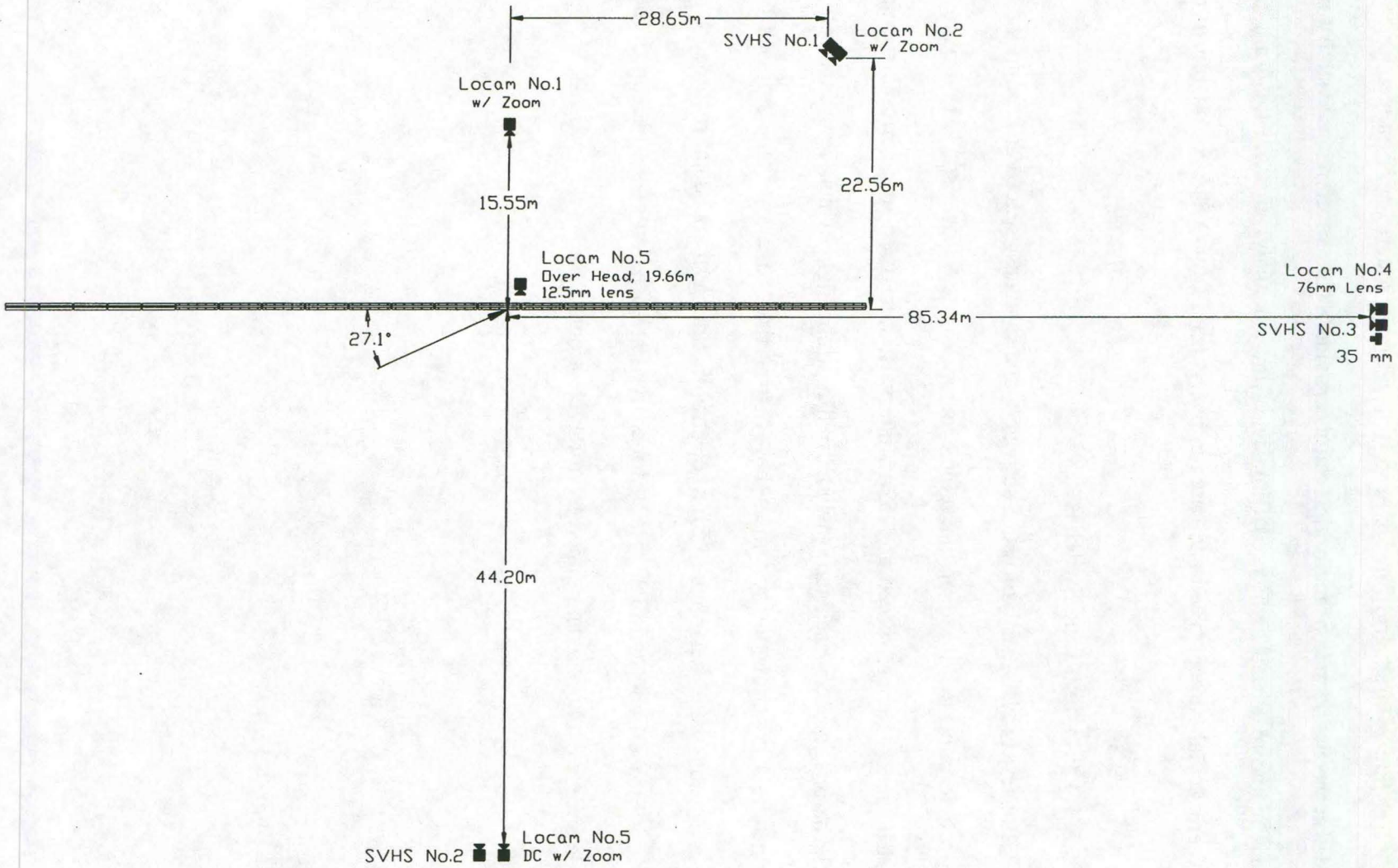


Figure 12. Location of High-Speed Cameras, Test ITMP-2

A white-colored grid, approximately 1,220-mm square, was painted on the concrete surface on the traffic side of the bridge rail to provide a visible reference system for use in the analysis of the overhead high-speed film. The film was analyzed using the Vanguard Motion Analyzer. Actual camera speed and camera divergence factors were considered in the analysis of the high-speed film.

6.4.4 Pressure Tape Switches

For test ITMP-1, five pressure-activated tape switches, spaced at 1.52-m intervals, were used to determine the speed of the vehicle before impact. For test ITMP-2, three pressure-activated tape switches, spaced at 1.52-m intervals, were used to determine the speed of the vehicle before impact. Each tape switch fired a strobe light which sent an electronic timing signal to the data acquisition system as the left front tire of the test vehicle passed over it. Test vehicle speeds were determined from electronic timing mark data recorded on "EGAA" software. Strobe lights and high-speed film analysis are used only as a backup in the event that vehicle speeds cannot be determined from the electronic data.

7 CRASH TEST NO. 1

7.1 Test ITMP-1

The 2,000-kg pickup truck impacted the concrete barrier (Design No. 1) at a speed of 103.1 km/hr and an angle of 27.6 degrees. A summary of the test results and the sequential photographs are shown in Figure 13. Additional sequential photographs are shown in Figure 14. Documentary photographs of the crash test are shown in Figures 15 and 16.

7.2 Test Description

Initial impact occurred 1.15 m upstream from the centerline of the gap between barrier nos. 8 and 9, as shown in Figure 17. After impact, the left-front tire of the vehicle became airborne as it began to climb the face of the barrier, and the left-front corner of the vehicle was crushed inward. In addition, the traffic-side face of barrier no. 9 was uplifted off the ground. Shortly thereafter, the left-front tire was deflated as it passed the gap between barrier nos. 8 and 9. The front tires then turned sharply left toward the barrier as the vehicle continued to climb the barrier's front face. The front bumper became dislodged as it neared the top of the barrier. Subsequently, the right-front tire became airborne. The left-rear tire was also deflated as it passed the gap between barrier nos. 8 and 9. At 0.284 sec, the vehicle was parallel to the barrier with the undercarriage positioned above the top of the barrier. The vehicle continued to travel parallel to and above the barrier, reaching an approximate maximum roll angle 47.5 deg at 0.587 sec. with the right-front tire on the front face of the barrier. The vehicle's undercarriage then contacted the top of the barrier and continued to travel on the barrier's top with the left-side tires behind the barrier. The vehicle came off the end of the barrier system with the left-rear tire contacting the ground behind the barrier, and the left-front wheel became dislodged. The vehicle

came to rest 33.90 m downstream from impact and 8.30 m behind the barrier, as shown in Figure 13.

7.3 Vehicle Damage

Vehicle damage was moderate, as shown in Figure 18. The front bumper and left-front quarter panel were crushed inward. The left-front wheel assembly was dislodged during the impact as the outer steel rim fractured from the inner region attached to the wheel hub. The steel frame was slightly bent inward near the front with a slight twist along its length from front to rear. Maximum occupant compartment deformations to the floorboard were 127 mm of longitudinal displacement near the center firewall region and a vertical displacement of 32 mm and 51 mm near left-side floorpan and center hump, respectively. The deformations to the floorboard were judged insufficient to cause serious injury to the vehicle occupants.

7.4 Barrier Damage

Barrier damage was extensive, as shown in Figures 19 through 22. Concrete damage consisted of tire marks, scrapes, gouges, spalling, and fractured concrete pieces. The ends of barriers nos. 7 through 10 were cracked and fractured at various locations, and two cracks were also observed to extend through barrier no. 9. Ten of the steel connector pins were also deformed, ranging from slight to extensive. The maximum permanent set deflection of the barrier was 0.99 m.

7.5 Occupant Risk Values

During the crash test, the data acquisition systems malfunctioned, and no electronic accelerometer data was obtained for the determination of occupant risk.

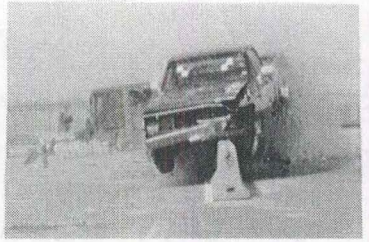
7.6 Discussion

The analysis of the test results for test ITMP-1 showed that the barrier did not adequately contain and redirect the vehicle; since, the vehicle overrode the barrier system and came off the barrier system's end with the left-rear wheel contacting the concrete surface behind the barrier. Deformations to the occupant compartment were evident but not considered excessive enough to cause serious injuries to the occupants. The vehicle remained upright both during and after the collision and with moderate vehicle roll. However, test ITMP-1 conducted on Design No. 1 was determined to be unacceptable according to the NCHRP Report No. 350 criteria.

0.000 sec

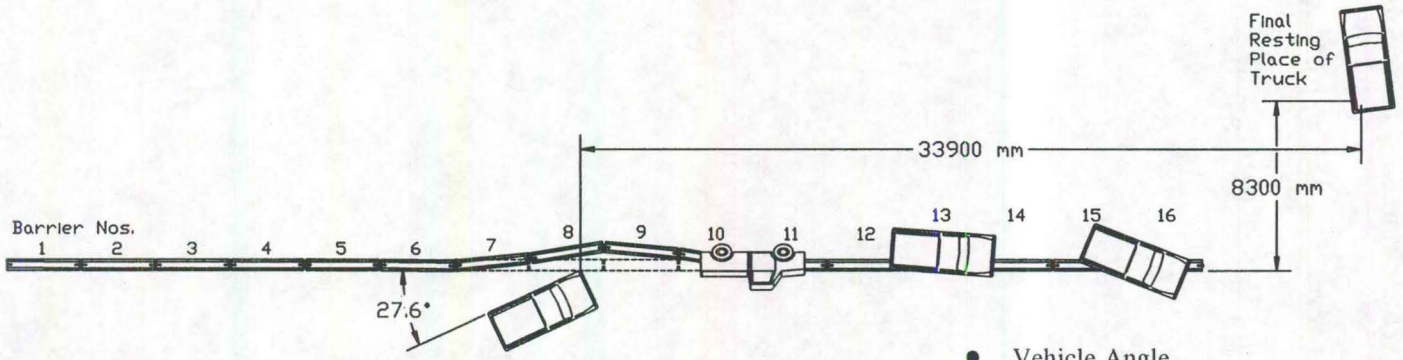
0.117 sec

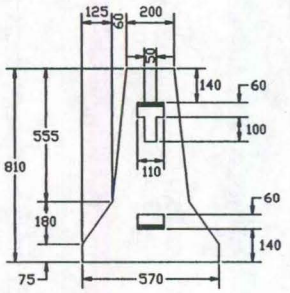
0.587 sec



1.076 sec

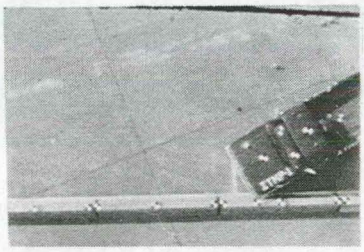
1.761 sec





- Test Number ITMP-1
- Date 3/5/96
- Appurtenance . . . . . F-Shape Concrete Median Barrier
- Total Length . . . . . 61.97 m
- Barrier
  - Length . . . . . 3800 mm
  - Height . . . . . 810 mm
  - Base Width . . . . . 570 mm
  - Top Width . . . . . 200 mm
- Connection
  - Type . . . . . Pin and Rebar
  - Pin Diameter . . . . . 31.8 mm
  - Rebar Diameter . . . . . 20 mm
- Vehicle Model . . . . . 1985 Chevrolet C-20 2WD
  - Curb Weight . . . . . 2,223 kg
  - Test Inertial Weight . . . . . 2,000 kg
  - Gross Static Weight . . . . . 2,000 kg
- Vehicle Speed
  - Impact . . . . . 103.1 km/hr
  - Exit . . . . . NA
- Vehicle Angle
  - Impact . . . . . 27.6 deg
  - Exit . . . . . NA
- Vehicle Snagging . . . . . Minor contact at gap between barrier nos. 8 and 9
- Vehicle Stability . . . . . Unsatisfactory
- Occupant Ridedown Deceleration
  - Longitudinal . . . . . NA < 20 G's
  - Lateral (not required) . . . . . NA
- Occupant Impact Velocity (Normalized)
  - Longitudinal . . . . . NA < 12 m/s
  - Lateral (not required) . . . . . NA
- Vehicle Damage . . . . . Moderate
  - TAD[15] 1-LFQ-5
  - SAE[16] 01LFEW3
- Vehicle Stopping Distance . . . . . 33.90 m downstream
  8.30 m behind
- Barrier Damage . . . . . Extensive
- Maximum Deflections
  - Permanent Set . . . . . 0.99 m
  - Dynamic . . . . . NA

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



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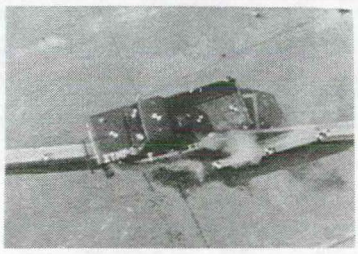

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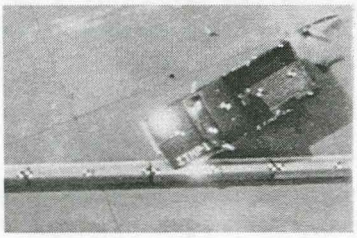

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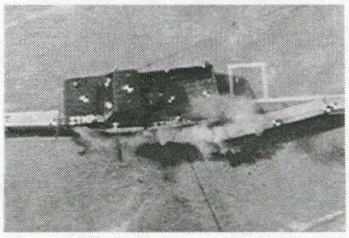

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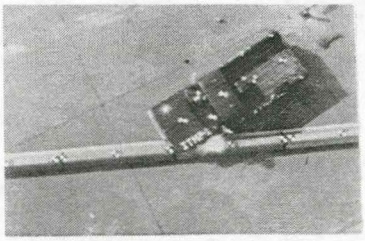
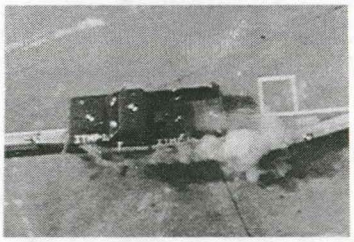


0.039 sec



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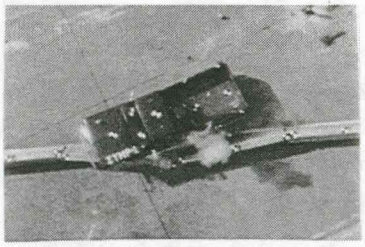
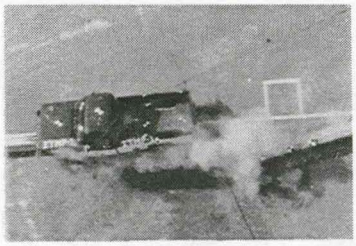
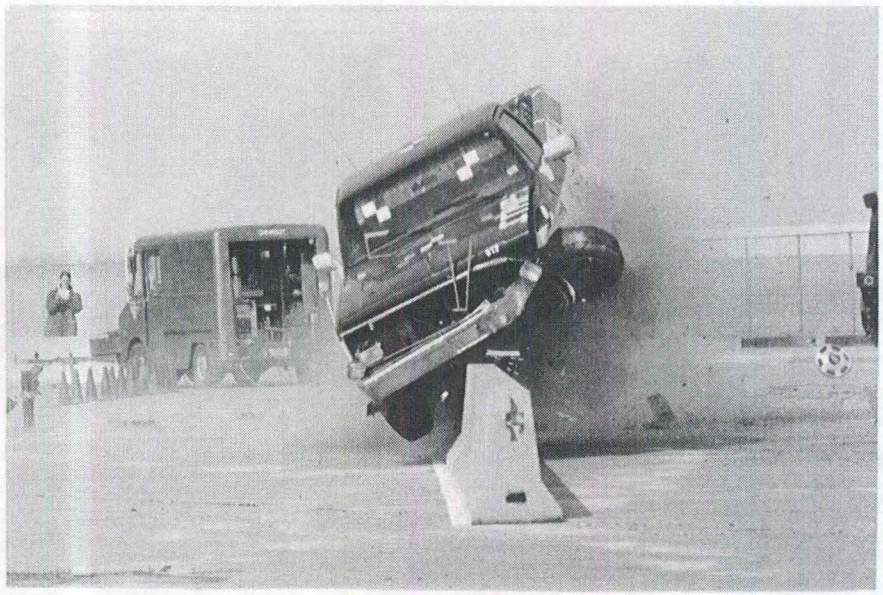


0.137 sec



0.343 sec

Figure 14. Additional Sequential Photographs, Test ITMP-1



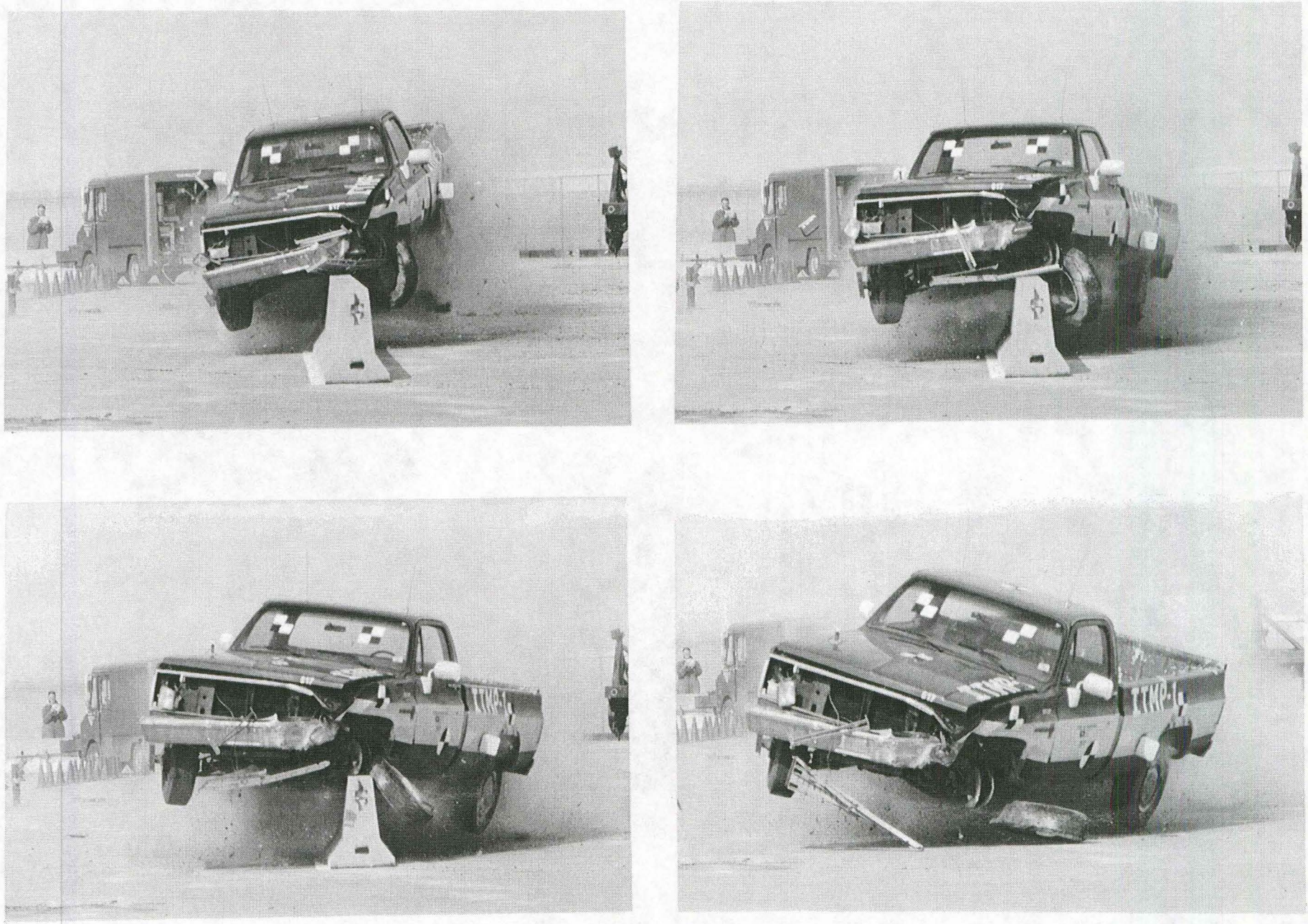


Figure 16. Documentary Photographs, Test ITMP-1

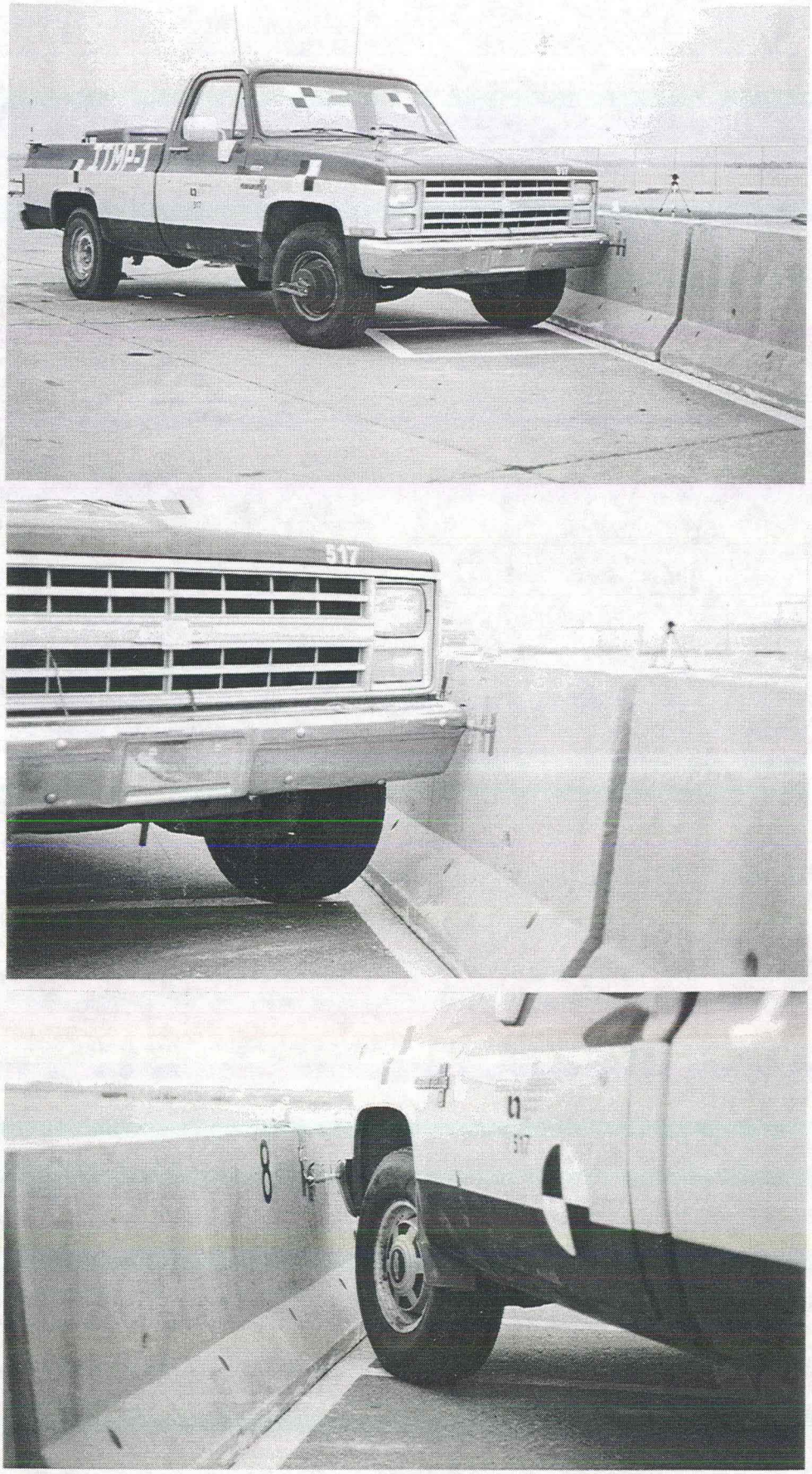
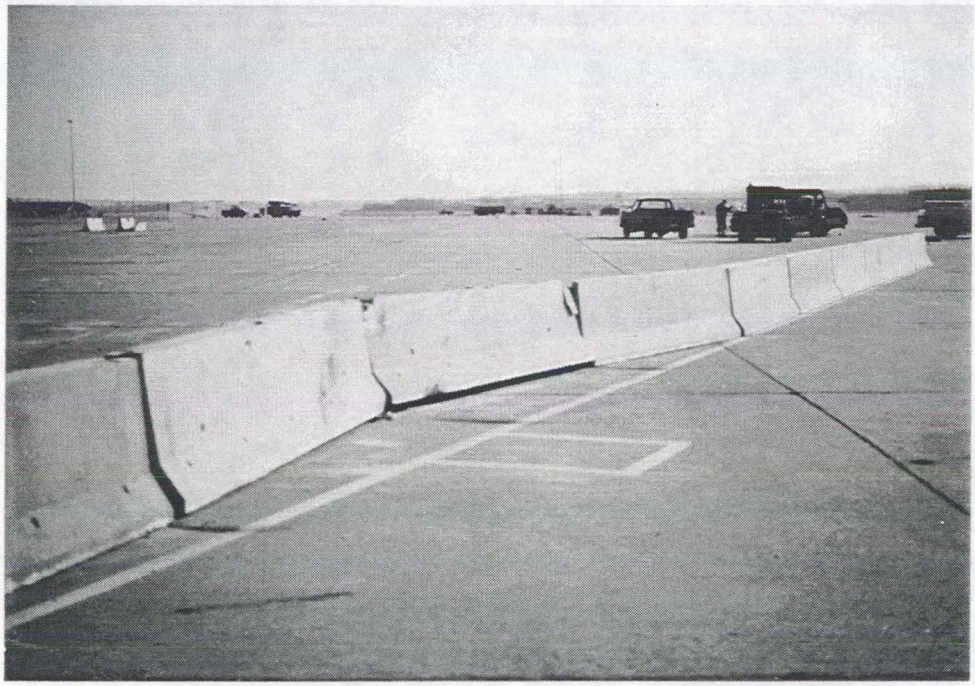


Figure 17. Impact Location, Test ITMP-1

Figure 18. Vehicle Damage, Test ITMP-1



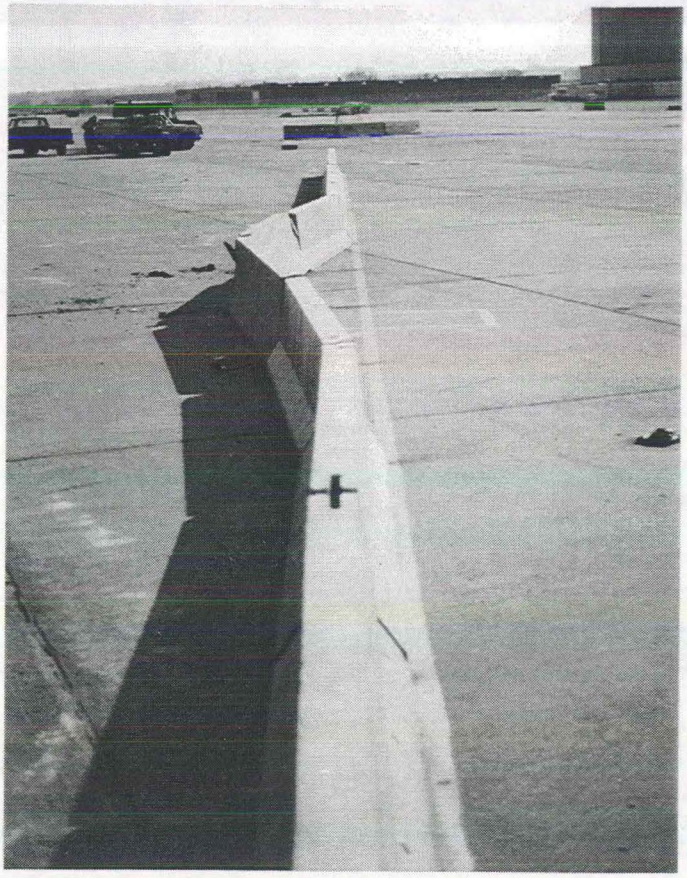


Figure 19. Barrier Damage, Test ITMP-1

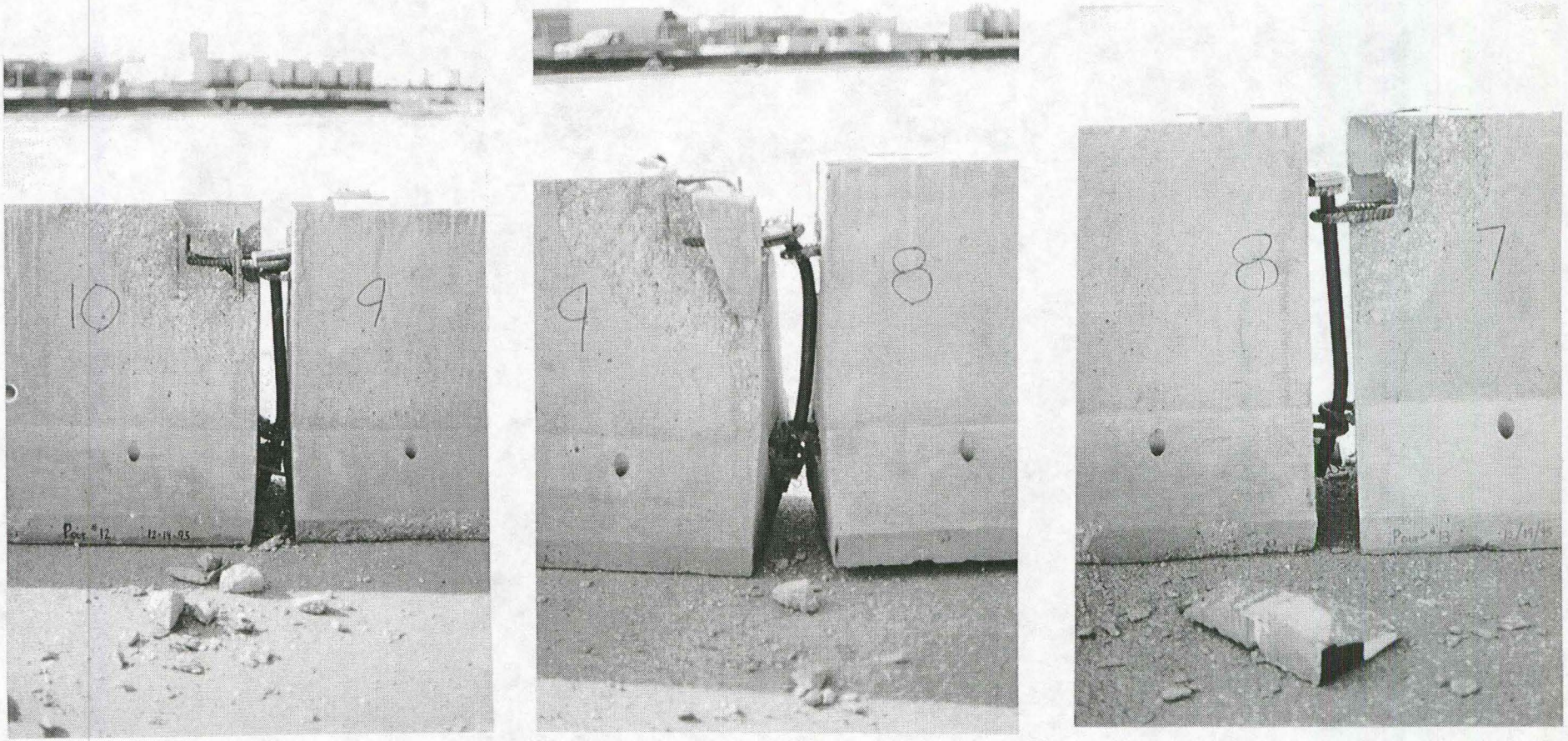


Figure 20. Damage at Barrier Ends (Back Side), Test ITMP-1

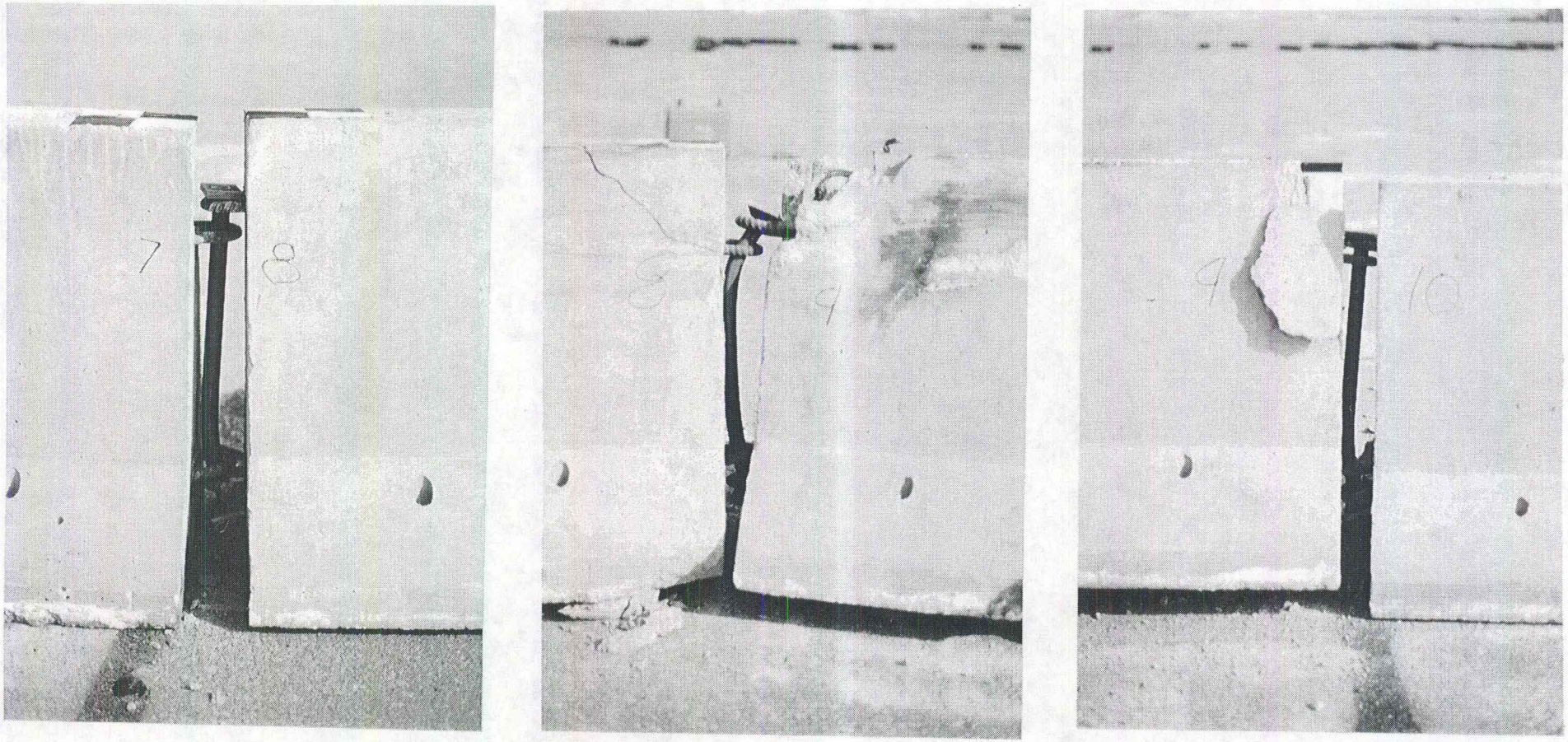


Figure 21. Damage at Barrier Ends (Traffic Side), Test ITMP-1

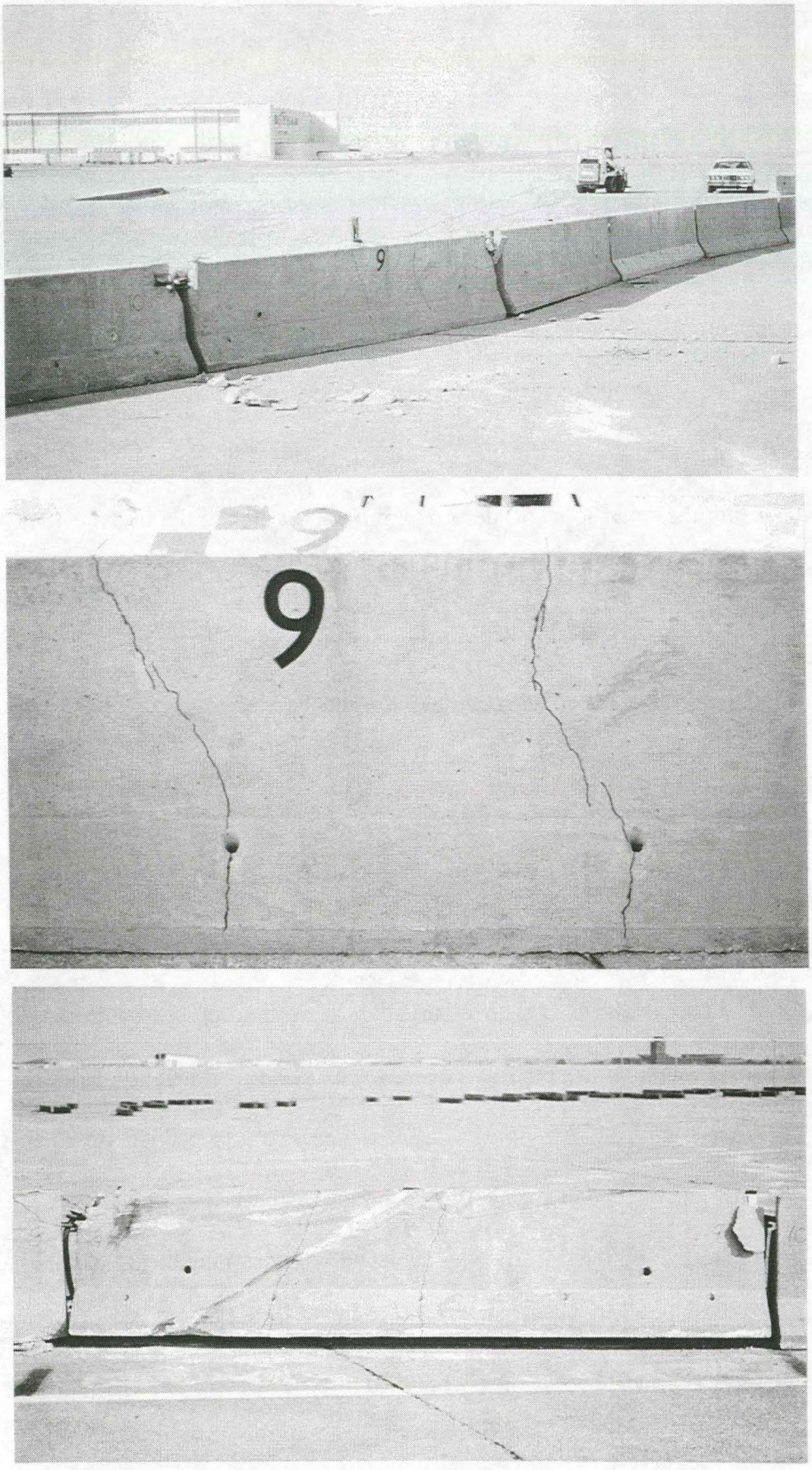
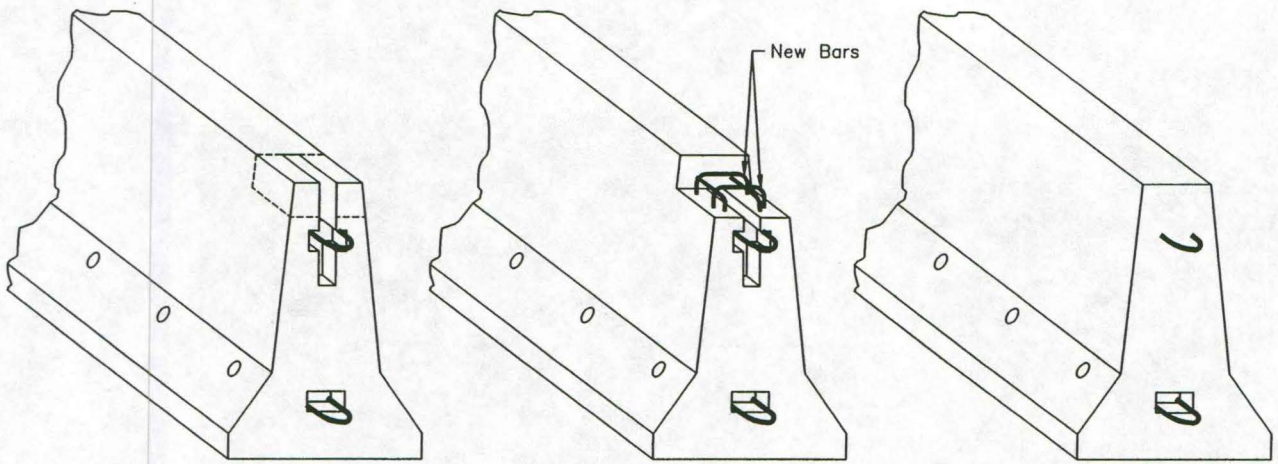


Figure 22. Cracks in Barrier Segment No. 9, Test ITMP-1

8 BARRIER MODIFICATIONS (DESIGN NO. 2)

Following the unsuccessful crash test on Design No. 1, it was necessary to determine the cause of the poor barrier performance so that design modifications could be made to the system. A careful examination of the damaged barrier system revealed that considerable damage occurred at the barrier joints, most likely resulting from the inherently weakened recessed areas located at the top end of each barrier. It is believed that the recessed areas weakened the pin and rebar connection causing the rebar loops to deform significantly during the impact, thus allowing for excessive joint rotations and barrier uplift. This joint and barrier movement led to increased vehicle climbing and penetration over the barrier system.

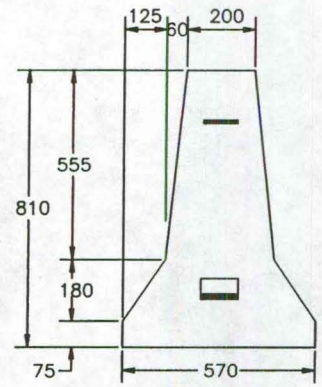
In order to reduce the joint rotations between barrier segments as well as to prevent barrier uplift, it was necessary to strengthen the barrier ends by eliminating the recessed areas. This retrofit was completed in a three step process, as shown in Figures 23 and 24. First, concrete was removed at the top end of each barrier to expose both the vertical shear and longitudinal reinforcement. Second, vertical holes were drilled in the exposed concrete region at each end of the barrier. Two U-shaped steel bars were then epoxied into the holes to close the tops of the two end-stirrups. Finally, concrete was placed at each end to return the barrier to its original shape. In addition, it was deemed necessary to reduce pin deformations by decreasing the clearance between the bottom of the lower rebar loop and the top of the bottom plate. This 25-mm reduction in clearance was achieved by shortening the 31.8-mm diameter steel pin and repositioning the 12.7-mm diameter hole near the base, as shown in Figure 23. A photograph of the modified pin and rebar connection is shown in Figure 25.



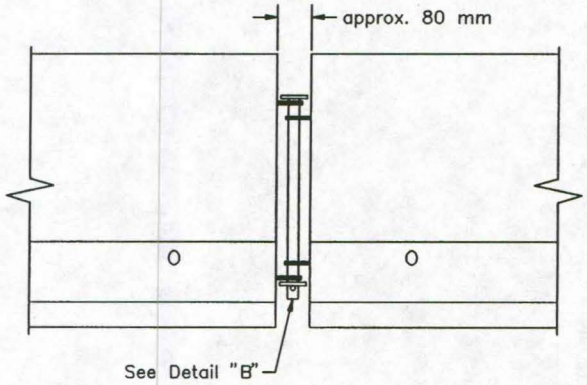
Retrofit Step One
Cut away concrete along dotted line (avoid rebar).

Retrofit Step Two
Drill holes and insert 2 "U"-shaped bars to "close" the end stirrups.

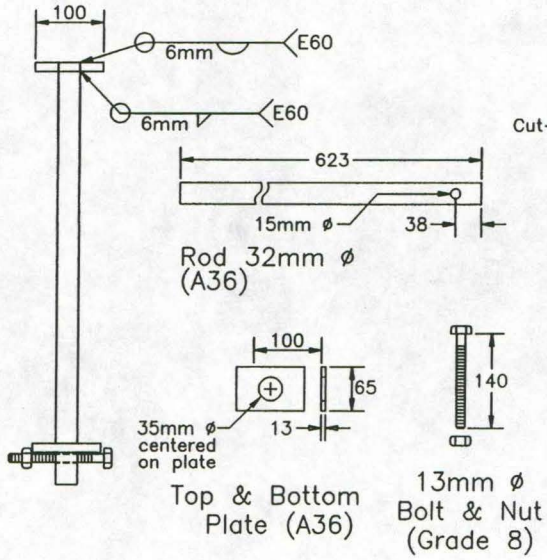
Retrofit Step Three
Fill with concrete to complete retrofit.



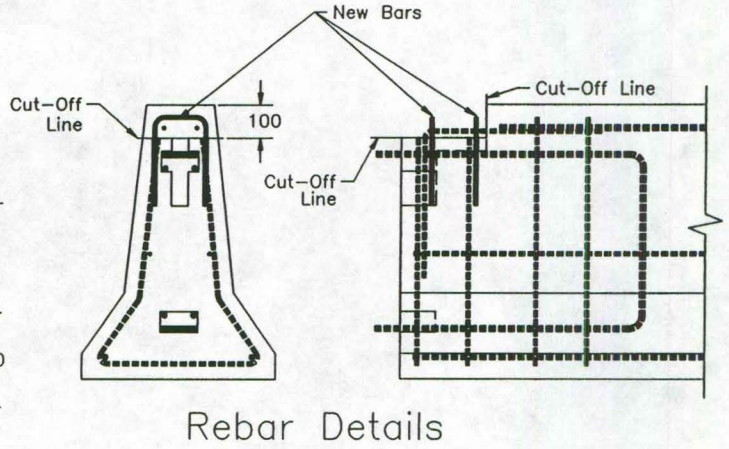
End View



Connection Detail



Detail "B"



Rebar Details

Figure 23. Barrier Modifications and Connections Details, Design No. 2

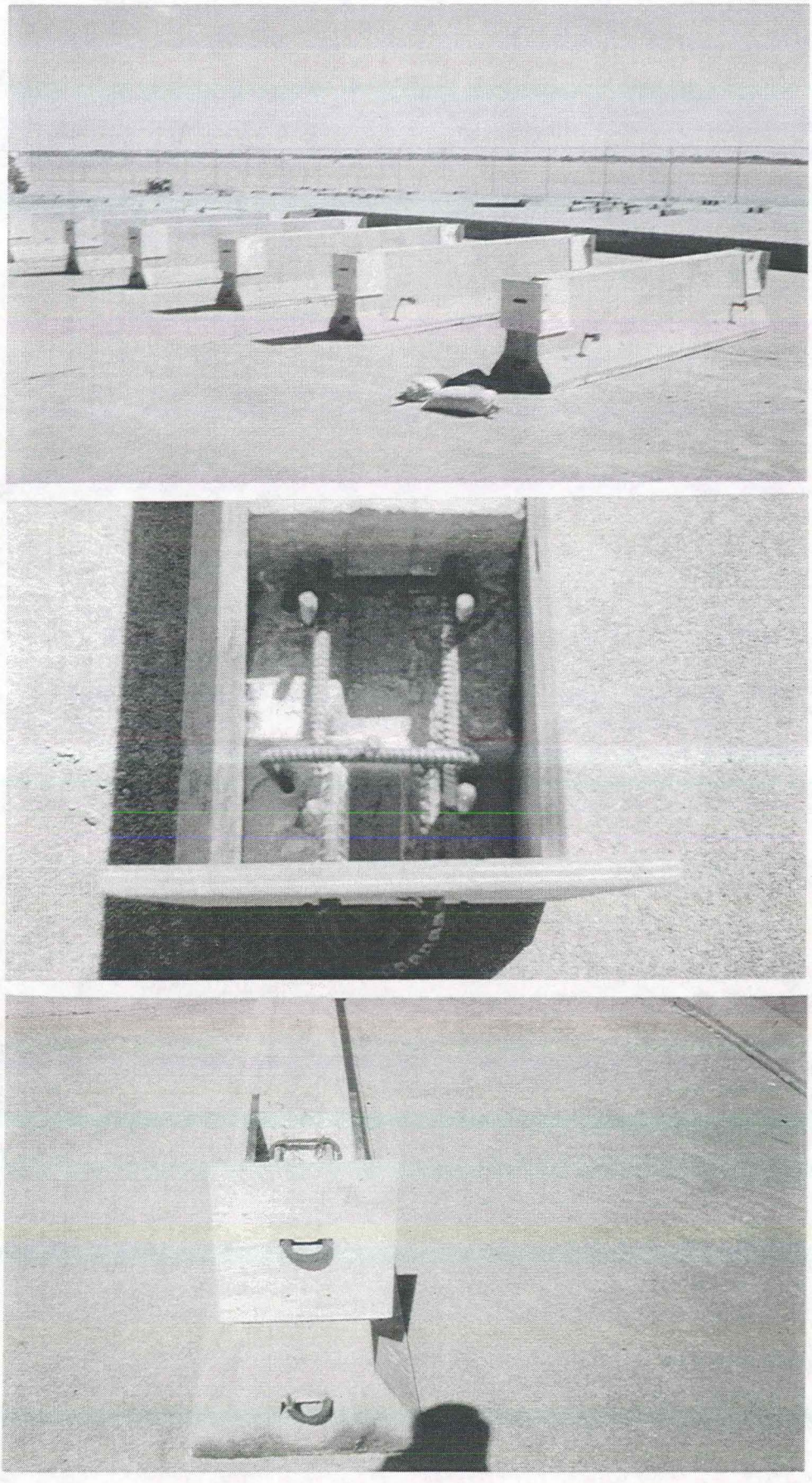


Figure 24. Barrier Retrofit, Design No. 2

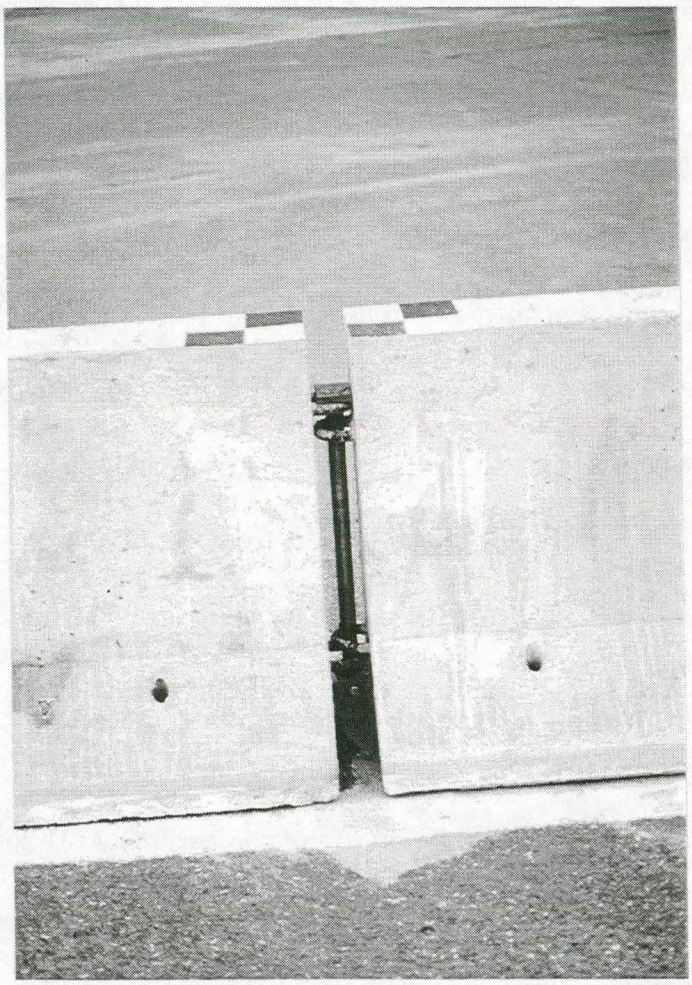


Figure 25. Modified Pin and Rebar Connection, Design No. 2

9 CRASH TEST NO. 2

9.1 Test ITMP-2

The 2,005-kg pickup truck impacted the concrete barrier (Design No. 2) at a speed of 100.3 km/hr and an angle of 27.1 degrees. A summary of the test results and the sequential photographs are shown in Figure 26. Additional sequential photographs are shown in Figure 27. Documentary photographs of the crash test are shown in Figures 28 and 29. It is noted that five additional barrier sections were placed on the upstream end of the installation to provide extra weight for resisting longitudinal barrier movement.

9.2 Test Description

Initial impact occurred 1.20 m upstream from the centerline of the gap between barrier nos. 8 and 9, as shown in Figure 30. After impact, the left-front tire of the vehicle became airborne as it began to climb the face of the barrier, and the left-front corner of the vehicle was crushed inward. Shortly thereafter, the left-front tire was deflated as it passed the gap between barrier nos. 8 and 9. The front tires then turned sharply left toward the barrier as the left-front corner continued to crush inward and extend over the top of the barrier. The right-front tire became airborne as the vehicle continued to climb up the barrier's front face. Subsequently, the left-front tire was observed to be on top of the barrier. At 0.268 sec, the vehicle was parallel to the barrier with the left-side of the vehicle's undercarriage positioned above the top of the barrier. The vehicle continued to travel above and on the traffic side of the barrier with the left-rear tire contacting the top of the barrier. After the vehicle became completely airborne with no barrier contact, it was evident that the left-front tire was dislodged from the vehicle. The vehicle then began to fall toward the ground with a moderate clockwise roll angle. At 0.695 sec, the

right-front tire contacted the ground, while at 0.804 sec, the vehicle experienced significant pitch and roll. The maximum roll, pitch, and yaw angles of 48.7, 22.8, and 64.3 deg occurred at 0.836, 1.61, and 1.34 sec after impact, respectively. The vehicle then became airborne as the right-front tire bounced into the air. The left-rear tire recontacted the barrier, and then the left-front wheel hub struck the ground. The vehicle came to rest 55.15 m downstream from impact and 19.86 m away from the traffic-side face of the barrier, as shown in Figure 26.

9.3 Vehicle Damage

Vehicle damage was moderate, as shown in Figure 31. The front bumper and left-front quarter panel were crushed inward. The left-front wheel assembly was dislodged during the impact as the outer steel rim fractured from the inner region attached to the wheel hub. The steel frame was bent inward near the front with a significant twist along its length from front to rear. Maximum occupant compartment deformations to the floorboard were 55 mm of lateral displacement near the firewall and both a vertical and longitudinal displacement of 38 mm near the center hump behind the gear shift. The deformations to the floorboard were judged to be insufficient to cause serious injury to the vehicle occupants.

9.4 Barrier Damage

Barrier damage was minor, as shown in Figures 32 through 34. Concrete damage was mostly cosmetic, consisting of tire marks, scrapes, gouges, and minor spalling. Nine steel pins were also deformed, ranging from slight to extensive. The maximum permanent set deflection of the barrier was 1.14 m.

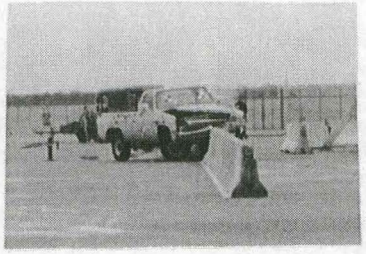
9.5 Occupant Risk Values

The normalized longitudinal and lateral occupant impact velocities were determined to be 7.2 m/sec and 5.3 m/sec, respectively. The maximum 0.010-sec average occupant ridedown decelerations in the longitudinal and lateral directions were 7.6 g's and 10.5 g's, respectively. It is noted that the occupant impact velocities and occupant ridedown decelerations were within the suggested limits provided in NCHRP Report No. 350. The results of the occupant risk, determined from accelerometer data, are summarized in Figure 26. Results are shown graphically in Appendix A. The results from the rate transducer are shown graphically in Appendix B.

9.6 Discussion

The analysis of the test results for test ITMP-2 showed that the barrier contained and redirected the vehicle with controlled lateral displacement of the barrier. Minor deformations to the occupant compartment were evident but not considered excessive enough to cause serious injuries to the occupants. The vehicle remained upright both during and after the collision and with significant vehicle roll, pitch, and yaw angular displacements. Therefore, test ITMP-2 conducted on Design No. 2 was determined to be acceptable according to the NCHRP Report No. 350 criteria.

0.000 sec



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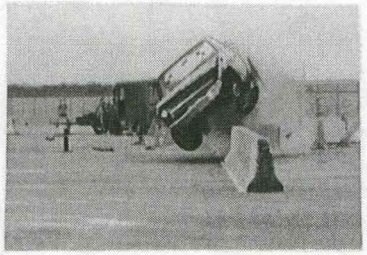
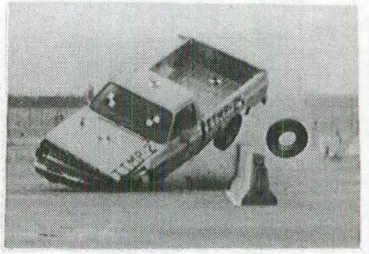
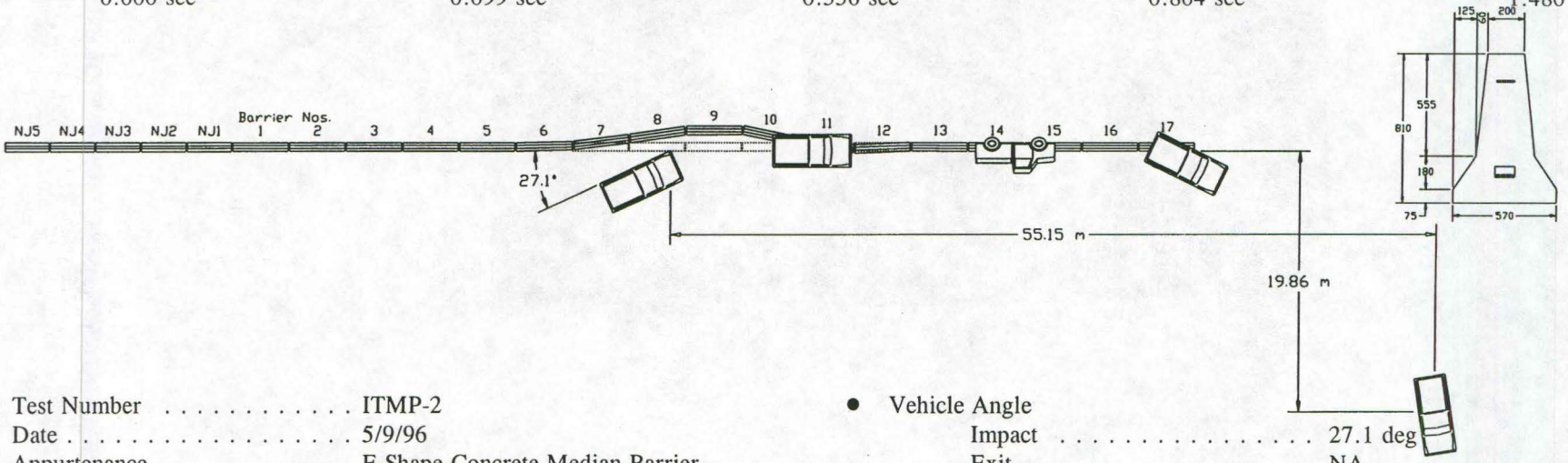


0.556 sec

0.804 sec

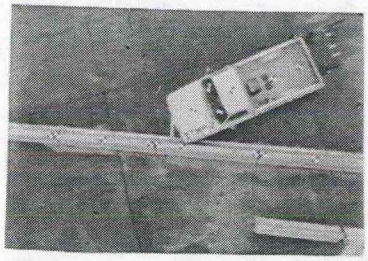


1.480 sec



- Test Number ITMP-2
- Date 5/9/96
- Appurtenance . . . . . F-Shape Concrete Median Barrier
- Total Length . . . . . 81.52 m
- Barrier
  - Length . . . . . 3800 mm
  - Height . . . . . 810 mm
  - Base Width . . . . . 570 mm
  - Top Width . . . . . 200 mm
- Connection
  - Type . . . . . Pin and Rebar
  - Pin Diameter . . . . . 31.8 mm
  - Rebar Diameter . . . . . 20 mm
- Vehicle Model . . . . . 1986 Chevrolet C-20 2WD
  - Curb Weight . . . . . 2,011 kg
  - Test Inertial Weight . . . . . 2,005 kg
  - Gross Static Weight . . . . . 2,005 kg
- Vehicle Speed
  - Impact . . . . . 100.3 km/hr
  - Exit . . . . . NA
- Vehicle Angle
  - Impact . . . . . 27.1 deg
  - Exit . . . . . NA
- Vehicle Snagging . . . . . None
- Vehicle Stability . . . . . Marginal
- Occupant Ridedown Deceleration
  - Longitudinal . . . . . 7.6 G's < 20 G's
  - Lateral (not required) . . . . . 10.5 G's
- Occupant Impact Velocity (Normalized)
  - Longitudinal . . . . . 7.2 m/s < 12 m/s
  - Lateral (not required) . . . . . 5.3 m/s
- Vehicle Damage . . . . . Moderate
  - TAD[15] 1-LFQ-5
  - SAE[16] 01LFEW3
- Vehicle Stopping Distance . . . . . 55.15 m downstream
  19.86 m lateral
- Barrier Damage . . . . . Minimal
- Maximum Deflections
  - Permanent Set . . . . . 1.14 m
  - Dynamic . . . . . 1.15 m

Figure 26. Summary of Test Results and Sequential Photographs, Test ITMP-2



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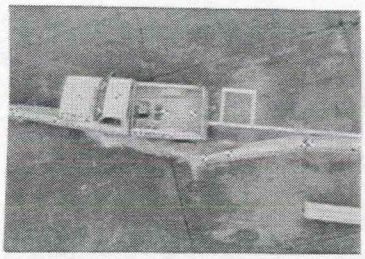

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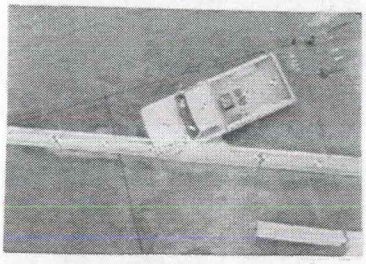

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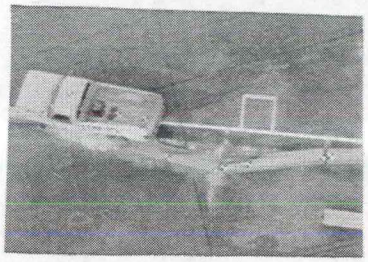

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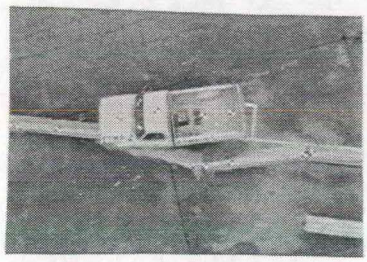

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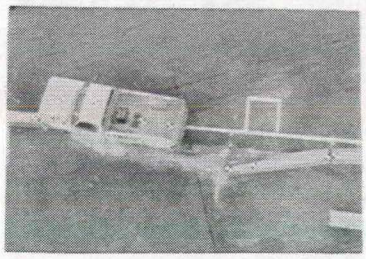


0.393 sec

Figure 27. Additional Sequential Photographs, Test ITMP-2

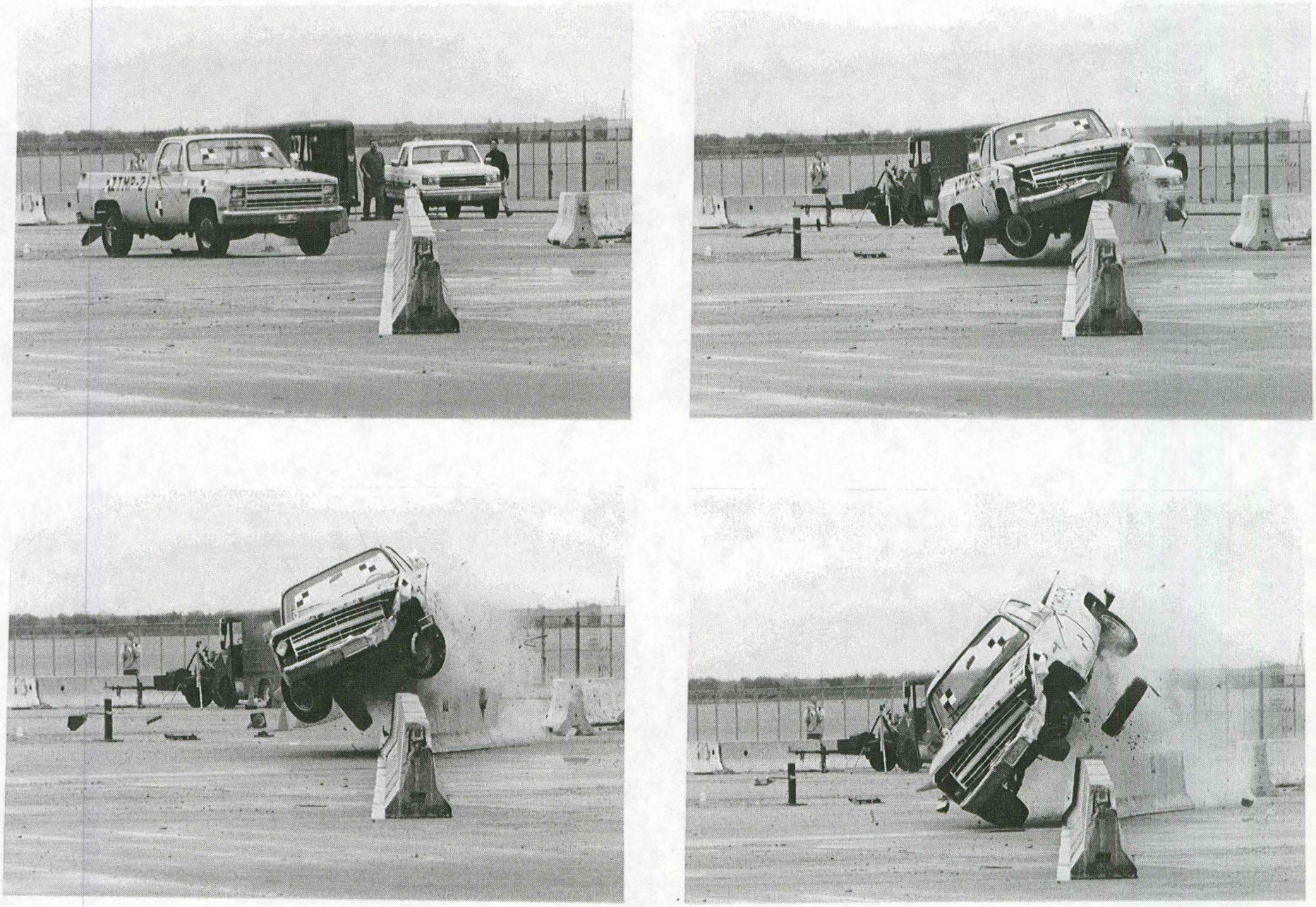
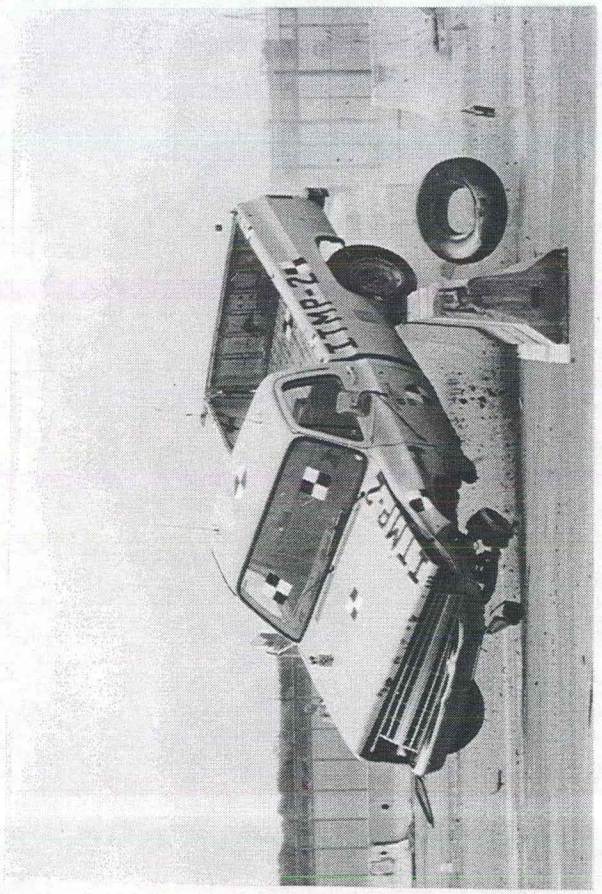
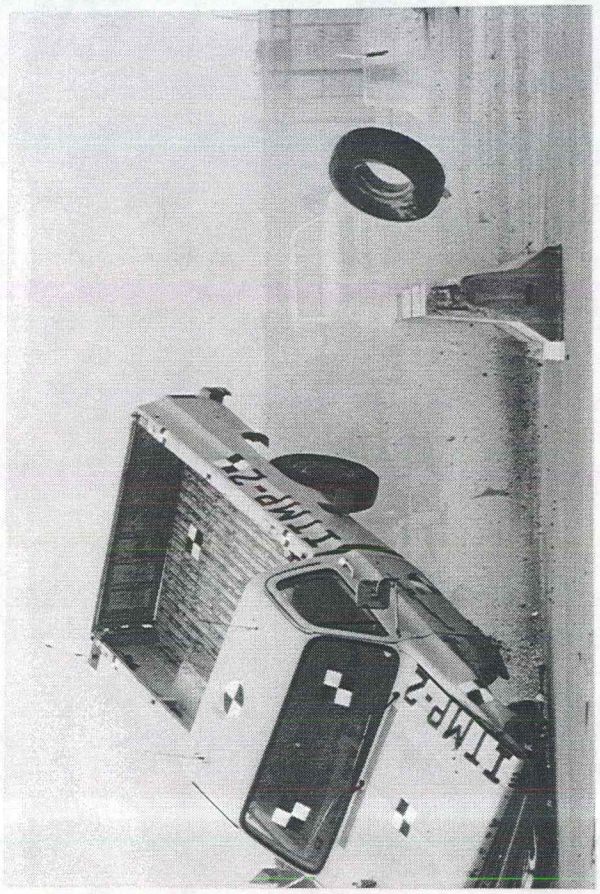
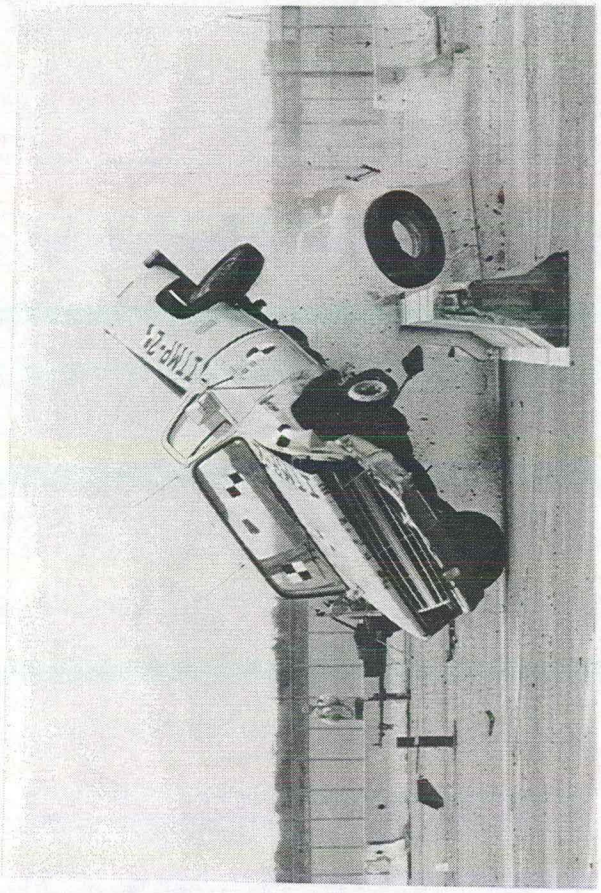
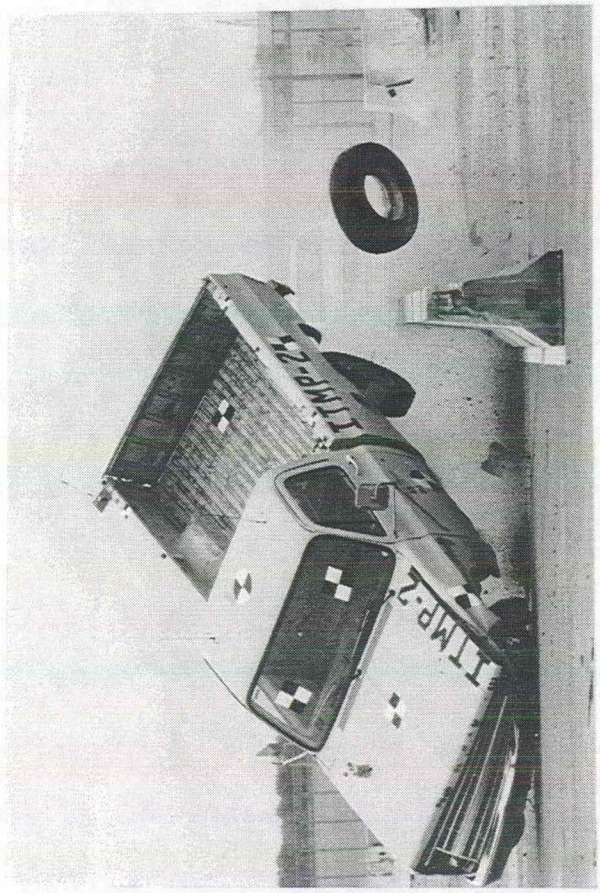


Figure 28. Documentary Photographs, Test ITMP-2


TIMP-2


TIMP-2


TIMP-2


TIMP-2

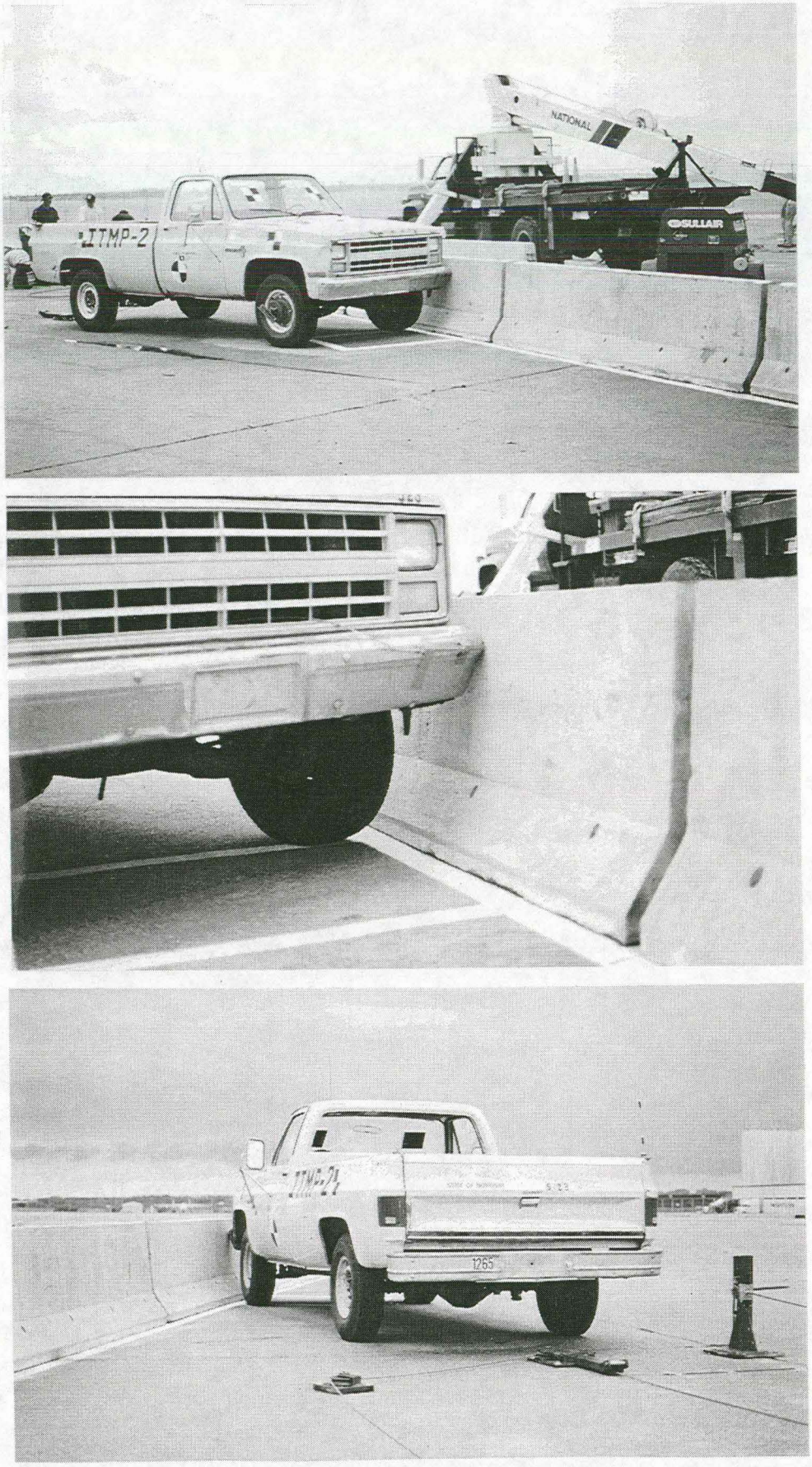


Figure 30. Impact Location, Test ITMP-2

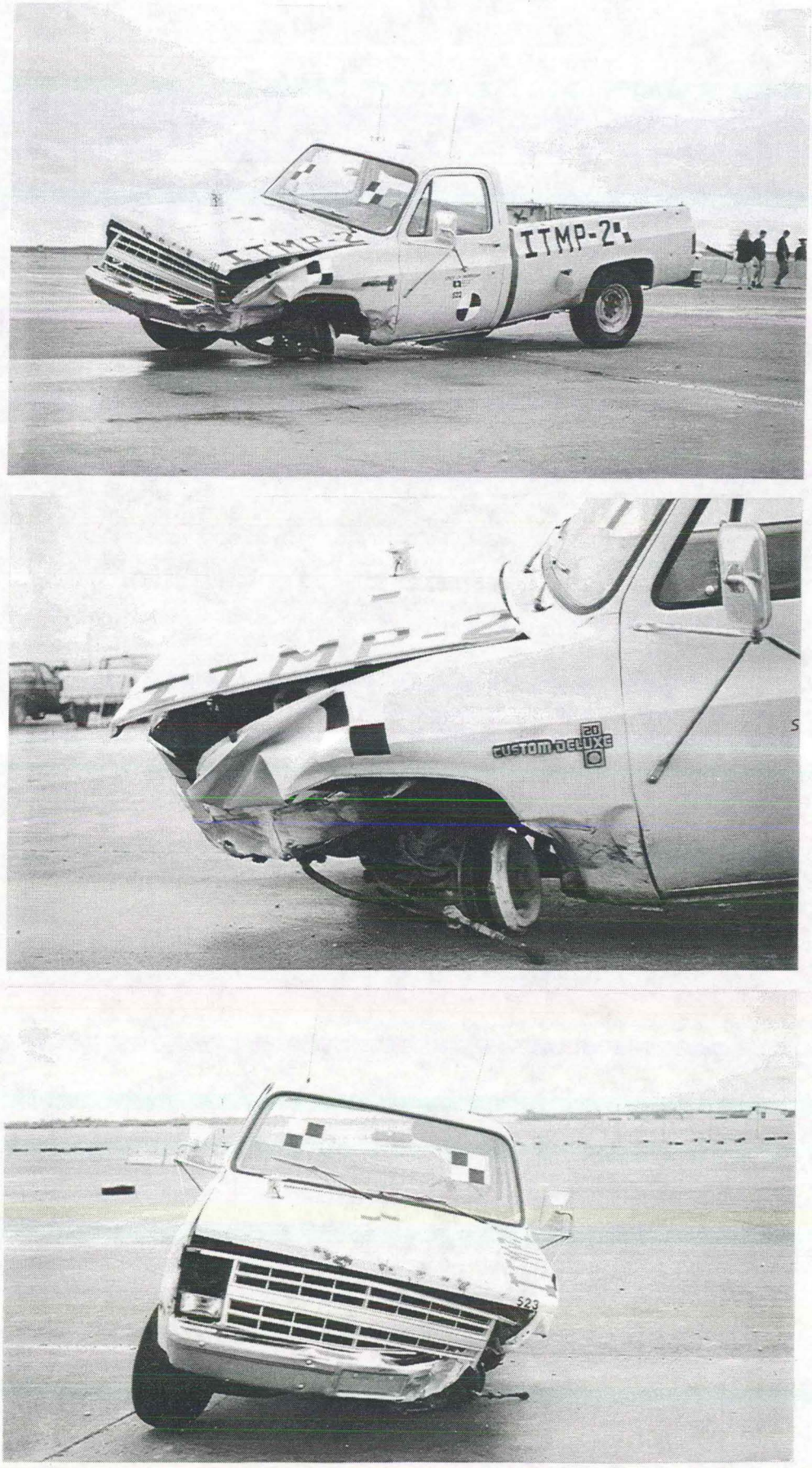


Figure 31. Vehicle Damage, Test ITMP-2

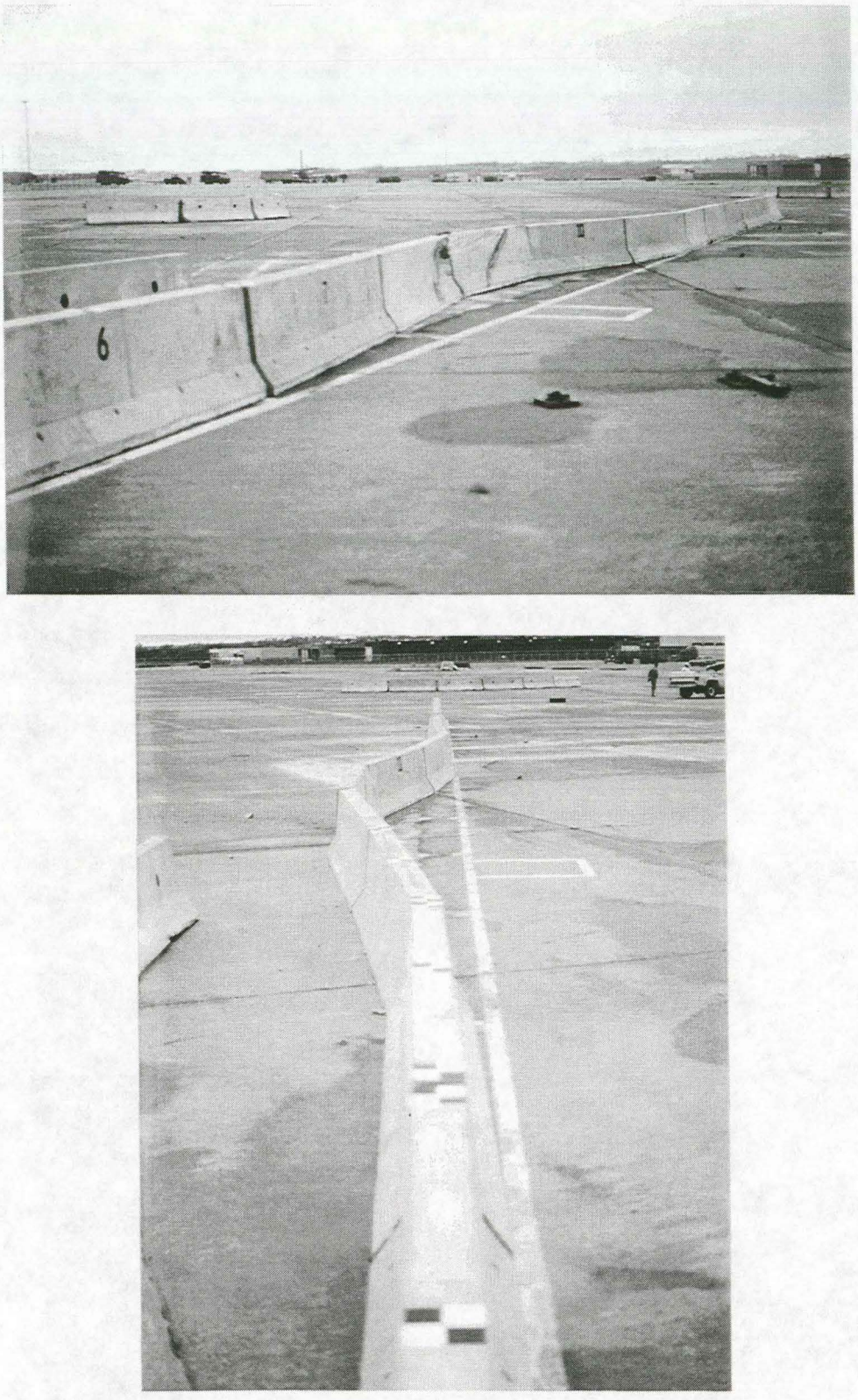


Figure 32. Barrier Damage, Test ITMP-2

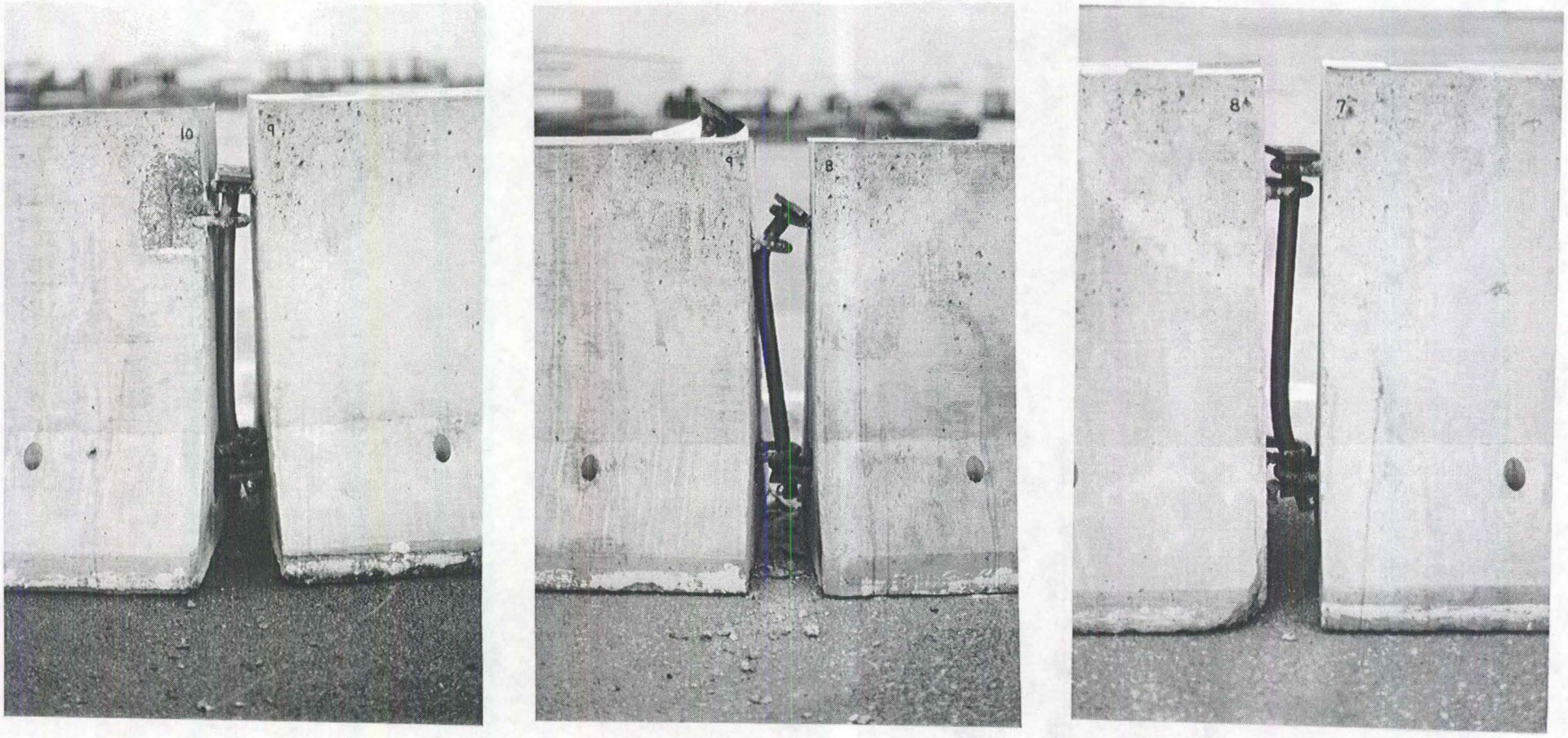


Figure 33. Damage at Barrier Ends (Back Side), Test ITMP-2

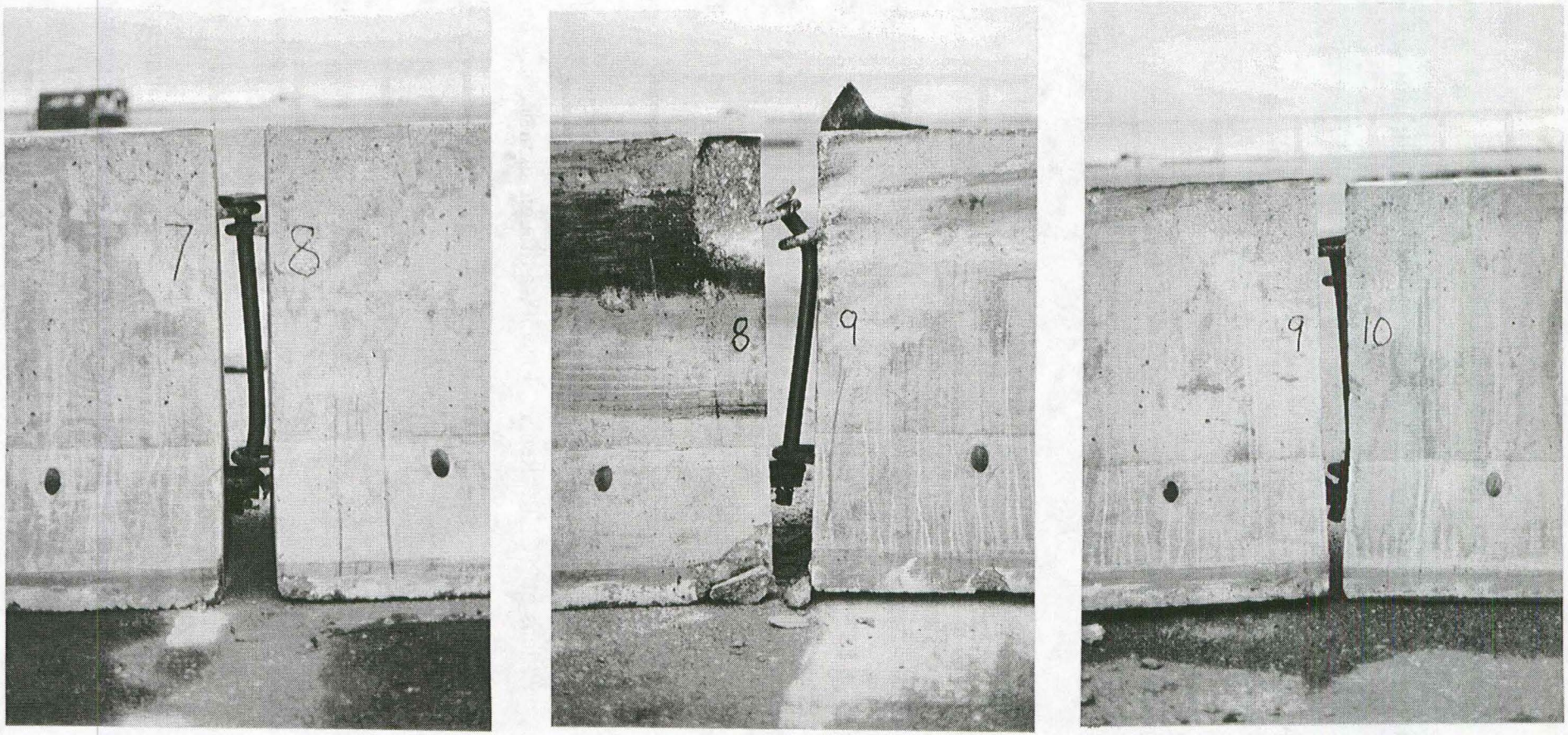


Figure 34. Damage at Barrier Ends (Traffic Side), Test ITMP-2

10 SUMMARY AND CONCLUSIONS

A standardized, temporary concrete median barrier was developed and full-scale crash tested while addressing the concerns for safety, economy, structural integrity, constructability, ease of installation, and maintenance. However, the compromise between economy and performance in the design of a temporary concrete median barrier is very difficult, since the Test Level 3 (TL-3) criteria of NCHRP Report No. 350 provide for a very stringent test of the barrier system. Therefore, the success of the barrier design was based largely on the capacity of the pinned connection and the subsequent reduction of the rotation of the barrier system.

Two crash tests were performed according to TL-3 of NCHRP Report No. 350. The first crash test, test ITMP-1, was performed with unsatisfactory results, resulting in extensive barrier damage. The barrier did not adequately contain and redirect the vehicle; since, the vehicle overrode the barrier system and came off the barrier system's end with the left-rear wheel contacting the concrete surface behind the barrier. Following this crash test, the temporary concrete barrier was modified, and a retest, test ITMP-2, was successfully performed on the modified barrier system. The temporary CMB was determined to be acceptable according to the TL-3 crash test conditions of NCHRP Report No. 350, although significant vehicle roll, pitch, and yaw motions were encountered and are typical of the majority of other concrete barrier tests. A summary of the safety performance evaluation is provided in Table 2.

The initial barrier design incorporated several features that allowed the barrier system to rotate excessively during impact. Two of these features were the open annulus adjacent to the rebar loops, and a gap between the retainer pin and the bottom loop of the system. The open annulus on the barrier ends were initially intended to provide space for steel reinforcement cast-

in-place, allowing the barrier to have incremental stiffness at the top of the joints of permanent installations. The rotation of the barrier caused the vehicle to intrude on the space immediately behind the barrier, a situation that was determined to cause the first test to be designated a failure.

System modifications for test ITMP-2 were not extensive, they included filling the open annulus on the ends of the barrier, and reducing the length of the pin to decrease the barrier deformation. With these two modifications, the barrier system was substantially stiffer, redirecting the vehicle with significantly less intrusion on the work space. Damage to the barriers was also substantially reduced, with the replacement of the pins and straightening of rebar loops being the only necessary requirement for continued use.

It cannot be overemphasized that the success of this barrier system is entirely based on limiting rotation of the barriers and assuring that the connection withstands the longitudinal loading. These criteria require that the connection be retained in a manner described in the report, and that the size of the loops and rods located on the ends of the barrier are not altered in a manner that increases barrier rotations.

Table 2. Summary of Safety Performance Evaluation Results

Evaluation Factors		Evaluation Criteria	Test ITMP-1	Test ITMP-2
Structural Adequacy	A.	Test article should contain and redirect the vehicle; the vehicle should not penetrate, underride, or override the installation although controlled lateral deflection of the test article is acceptable.	U	S
Occupant Risk	D.	Detached elements, fragments or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.	M	S
	F.	The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.	M	M
Vehicle Trajectory	K.	After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	S	S
	L.	The occupant impact velocity in the longitudinal direction should not exceed 12 m/sec and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 G's.	S	S
	M.	The exit angle from the test article preferably should be less than 60 percent of test impact angle, measured at time of vehicle loss of contact with test devise.	S	S

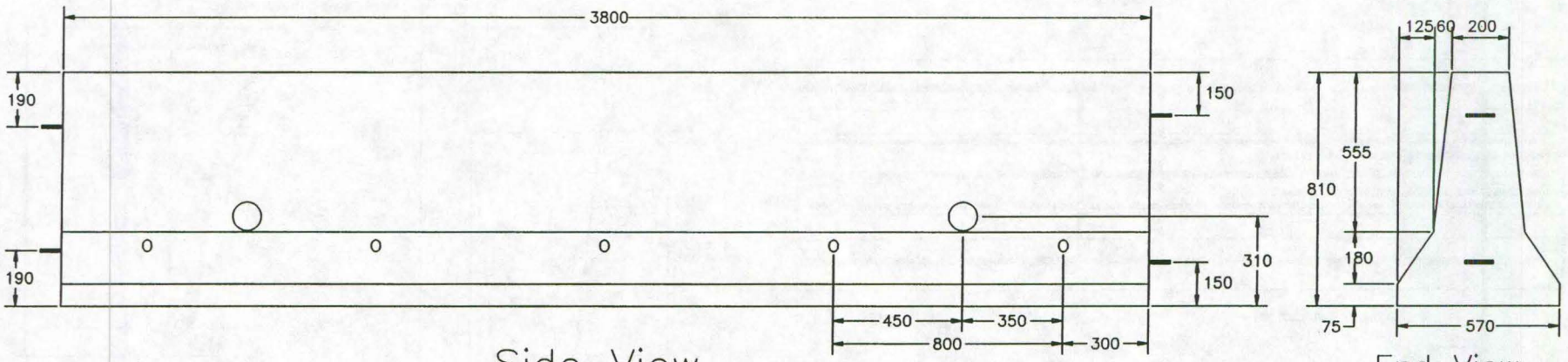
S - (Satisfactory)
M - (Marginal)
U - (Unsatisfactory)

11 RECOMMENDATIONS

Following the successful completion of the research objective, final design drawings (Design No. 3A) were developed for the TL-3 temporary concrete median barrier, as shown in Figures 35 through 37. It is noted that the retrofit procedure, used in Design No. 2 to fill the cavities at the barrier ends, is no longer needed for constructing new barriers. Therefore, modifications were made to the steel reinforcement located at the barrier ends. First, the end stirrups were closed at the upper end, and only one type of vertical stirrup was required throughout the entire barrier length. Second, the L-shaped bars were removed at the barrier ends and replaced by extending the top longitudinal bar to the full barrier length. In addition, the diameter of the transverse lifting holes was increased from 50 to 100 mm and constructed with a section of steel pipe cast into the concrete. However, this design contains the vertical dowel holes located at the barrier's base and the same quantity and location of vertical stirrups used in the original barrier design.

During the completion of the final design drawings, the Iowa Department of Transportation requested that consideration be given for the placement of transverse, rectangular slots in the middle region of the barrier's base. These open slots would be used for lifting the concrete barrier with standard, forklift-type construction equipment. Therefore, a second final design (Design No. 3B) was completed that included this feature, as shown in Figures 38 through 40. However, inclusion of such slots required that modifications be made to the steel reinforcement located near the barrier's base. First, the bottom longitudinal bars were raised 75 mm and the shape of the vertical stirrups was changed slightly to provide the necessary concrete

cover above the slots. Second, the vertical dowel holes were removed, thus allowing for a reduction in the vertical stirrups located around the three interior dowel holes.



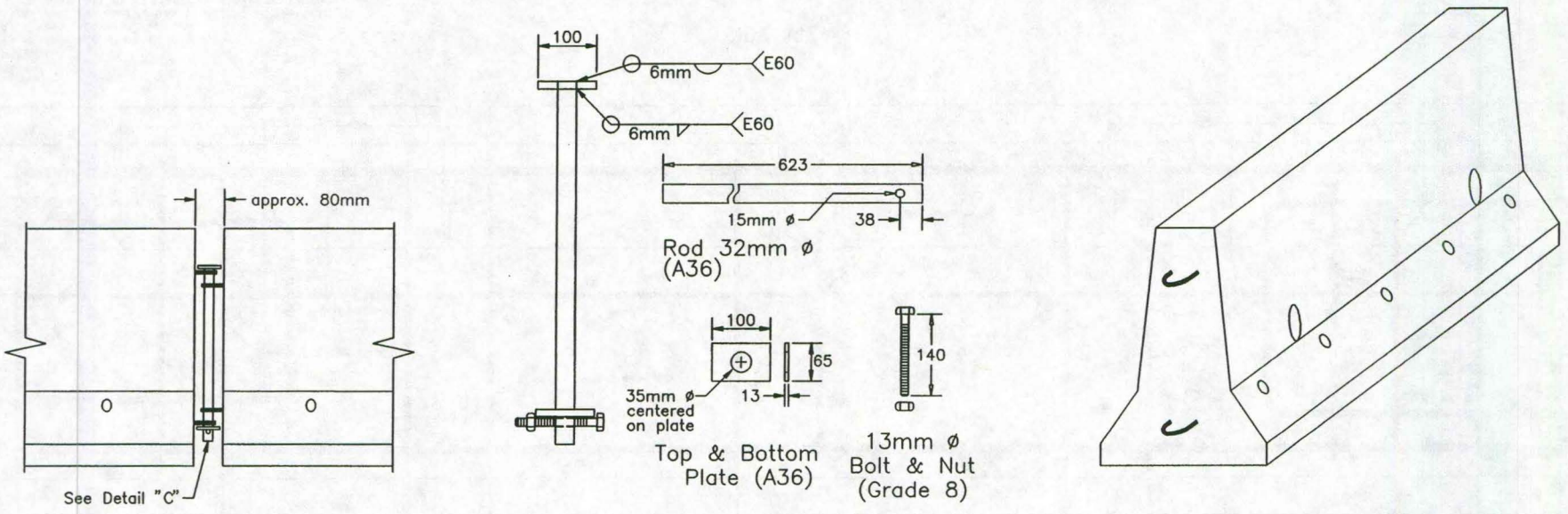
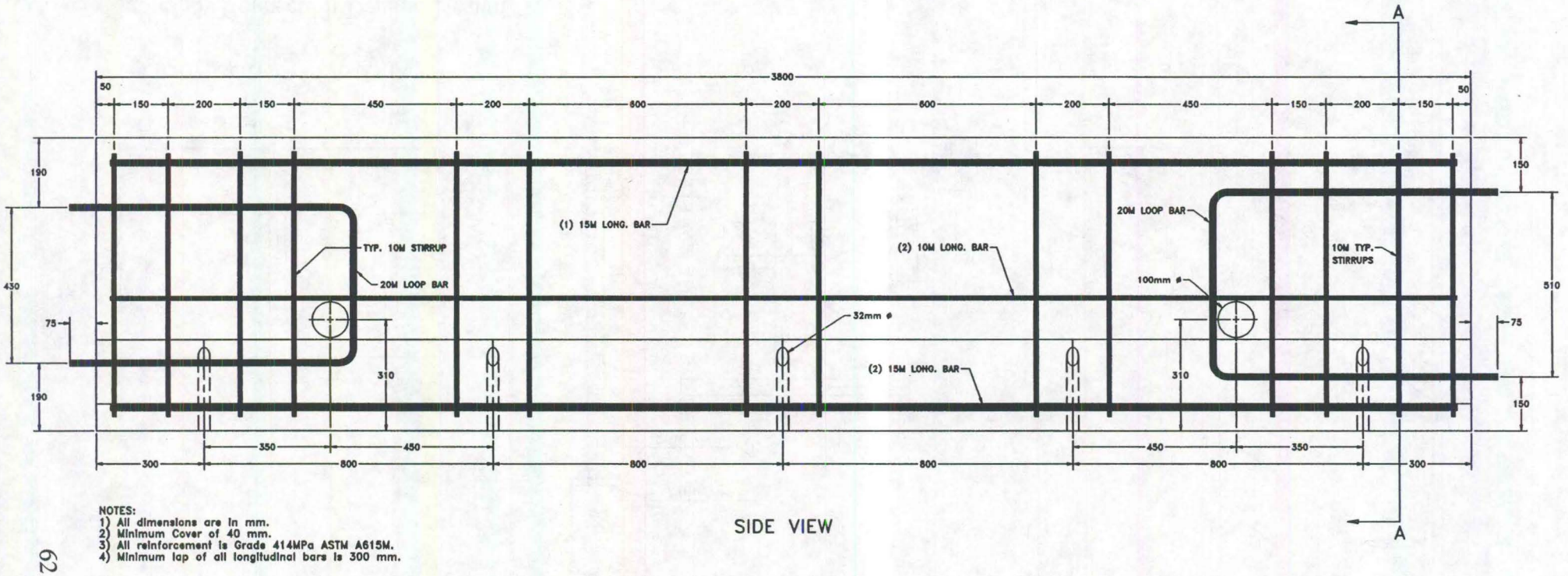
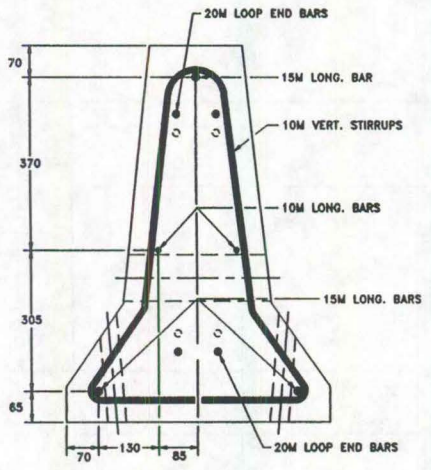


Figure 35. Connection Details, Design No. 3A

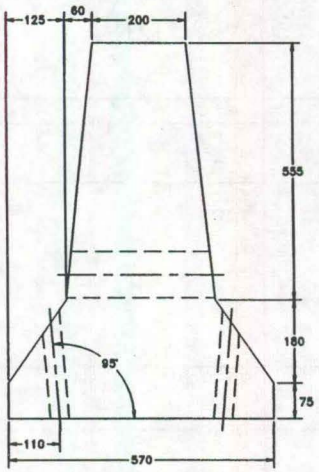


NOTES:
1) All dimensions are in mm.
2) Minimum Cover of 40 mm.
3) All reinforcement is Grade 414MPa ASTM A615M.
4) Minimum lap of all longitudinal bars is 300 mm.

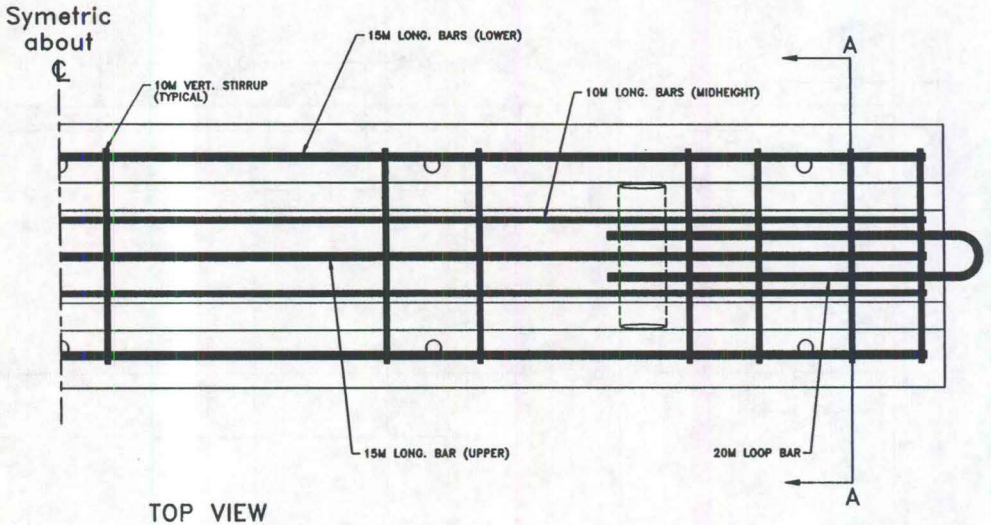
SIDE VIEW



TYPICAL STIRRUP
SECTION A–A



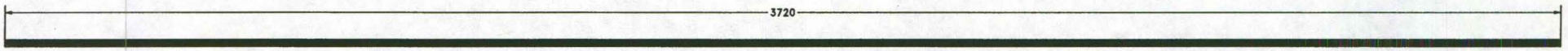
Anchor Hole Placement



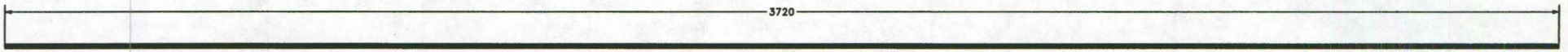
TOP VIEW

Figure 36. Reinforcement Details, Design No. 3A

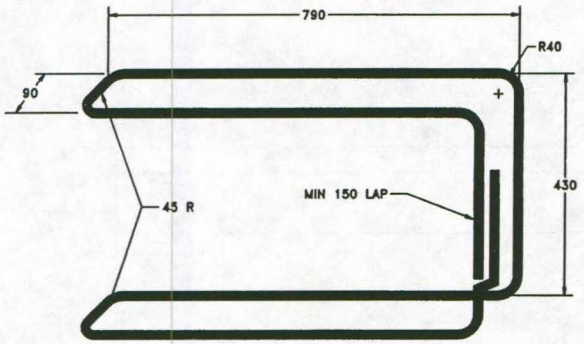
All measurements are in mm.



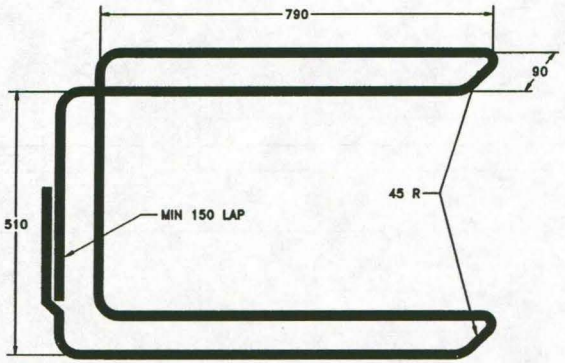
IA 15-1 @ 3720 mm



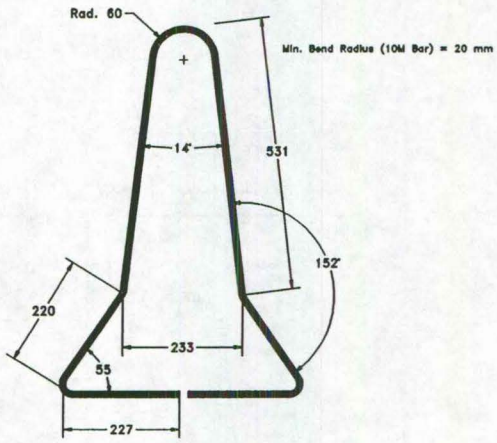
IA 10-2 @ 3720 mm



IA 20-1 @ 4630 mm

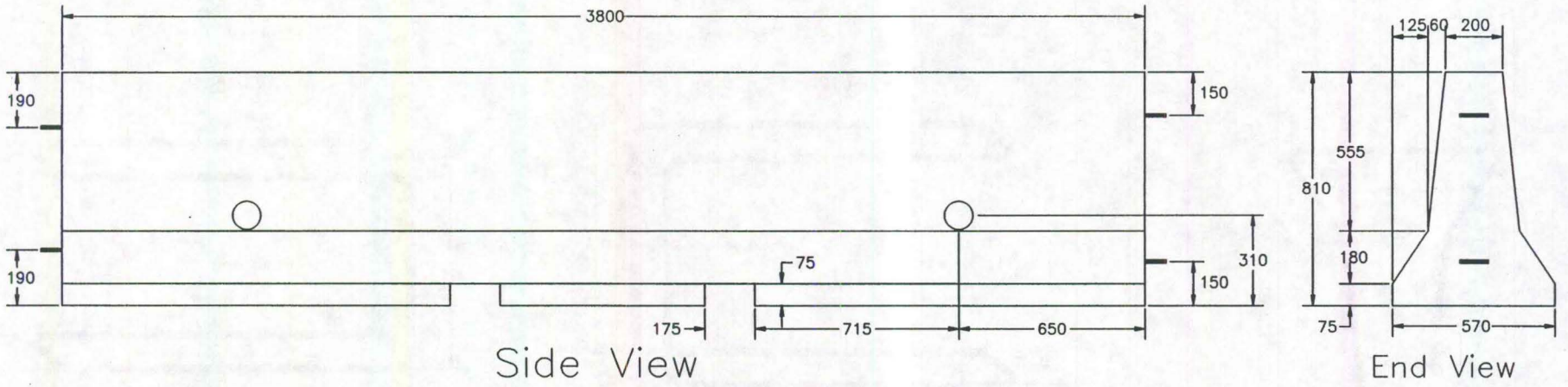


IA 20-2 @ 4860 mm



IA 10-1 @ 1990 mm

Figure 37. Reinforcement Bend Diagrams, Design No. 3A



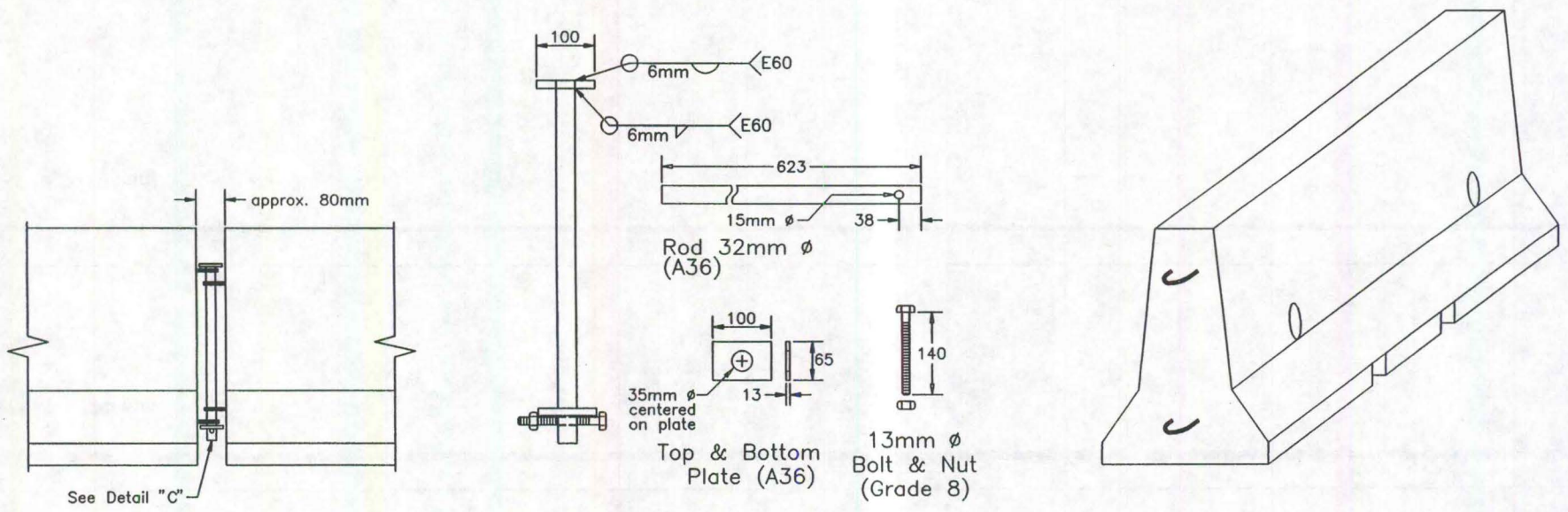
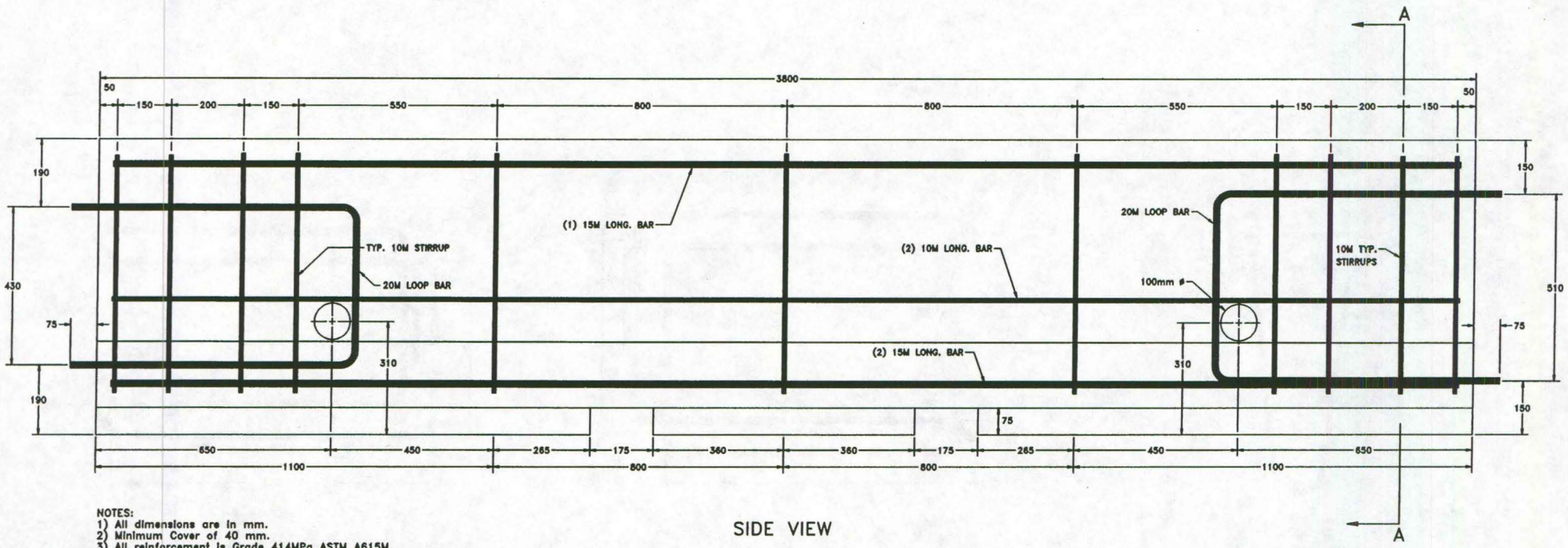
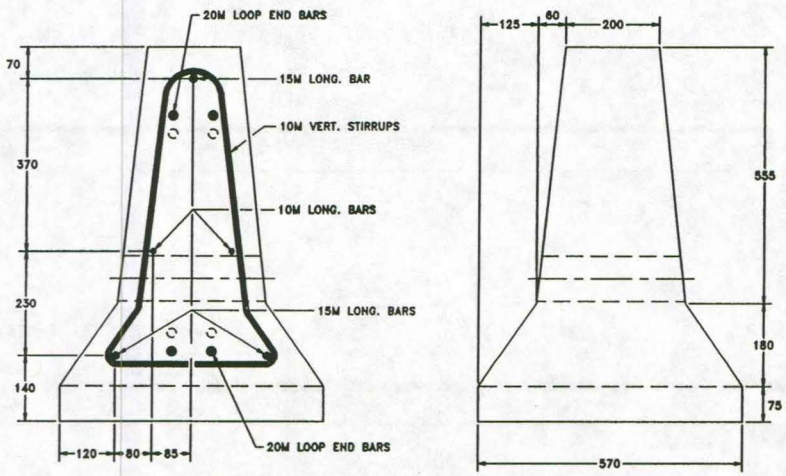


Figure 38. Connection Details, Design No. 3B

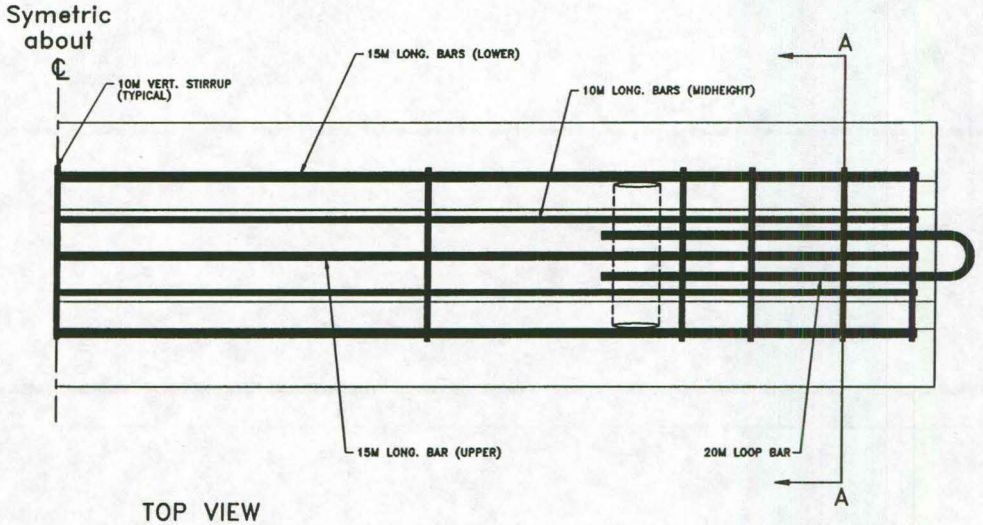


NOTES:
1) All dimensions are in mm.
2) Minimum Cover of 40 mm.
3) All reinforcement is Grade 414MPa ASTM A615M.
4) Minimum lap of all longitudinal bars is 300 mm.



TYPICAL STIRRUP SECTION A–A

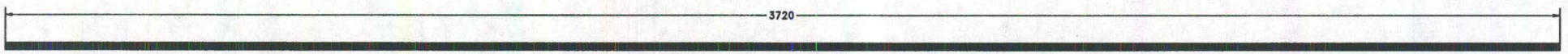
END VIEW



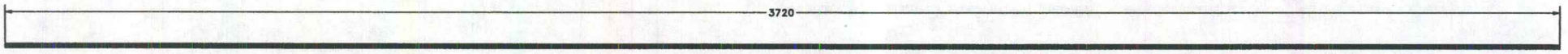
TOP VIEW

Figure 39. Reinforcement Details, Design No. 3B

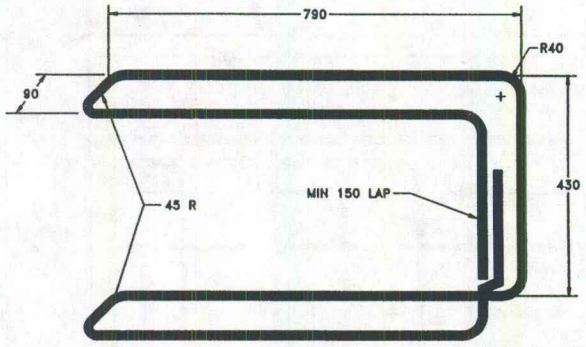
All measurements are in mm.



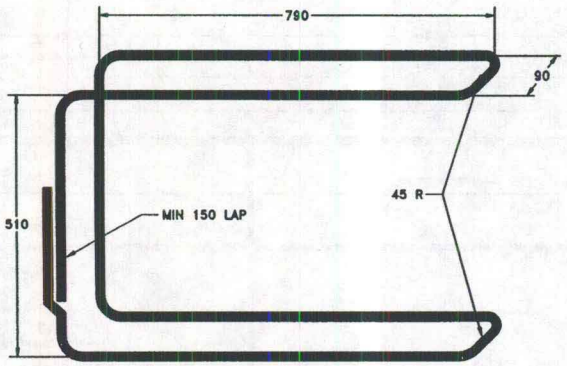
IA 15–1 @ 3720 mm



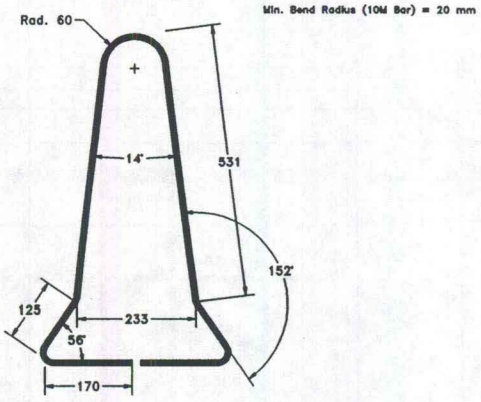
IA 10–2 @ 3720 mm



IA 20–1 @ 4630 mm



IA 20–2 @ 4860 mm



IA 10–1 @ 1720 mm

Figure 40. Reinforcement Bend Diagrams, Design No. 3B

12 REFERENCES

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

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13 APPENDICES

APPENDIX A - ACCELEROMETER DATA ANALYSIS

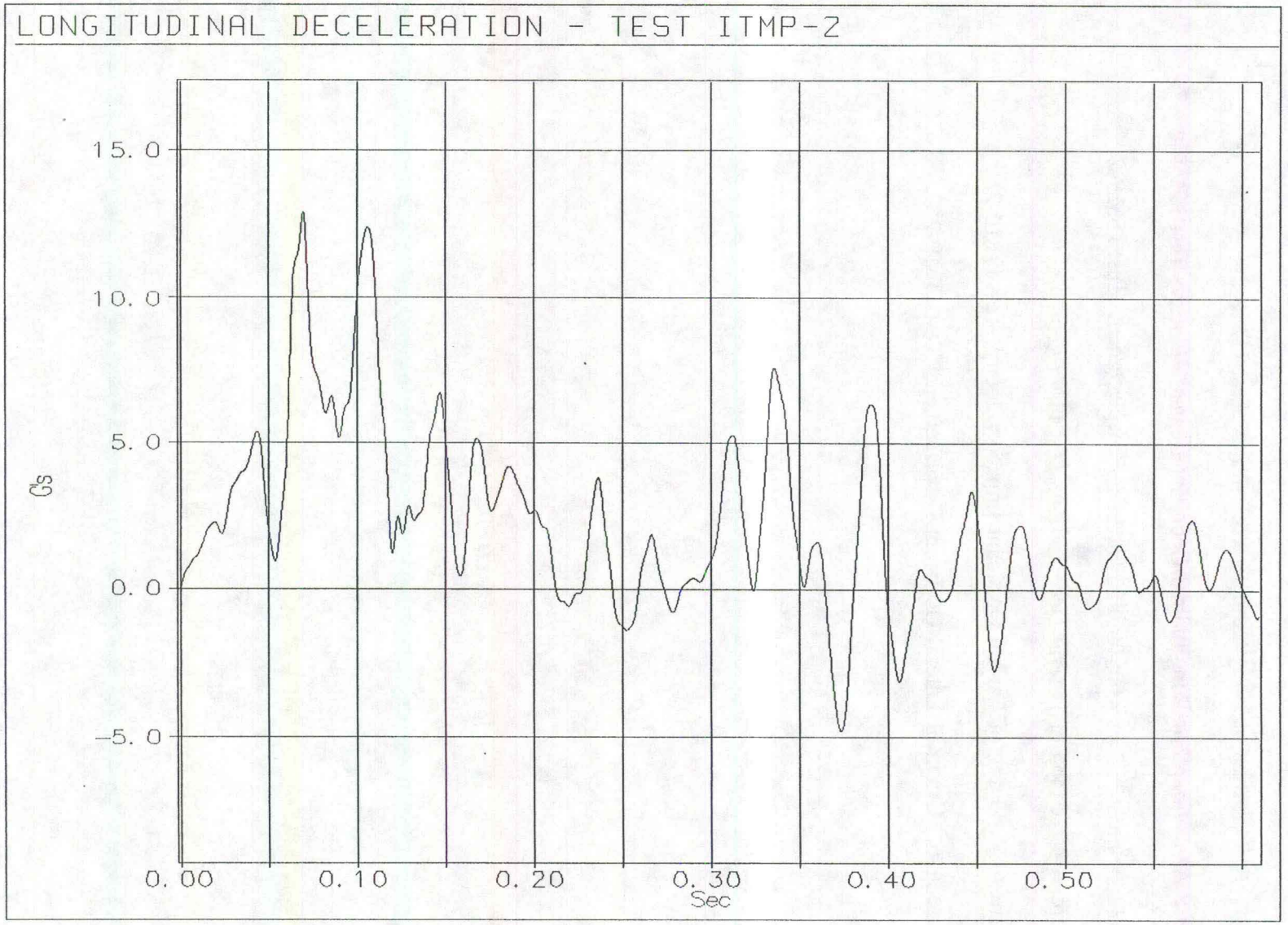

Figure A-1. Graph of Longitudinal Deceleration, Test ITMP-2

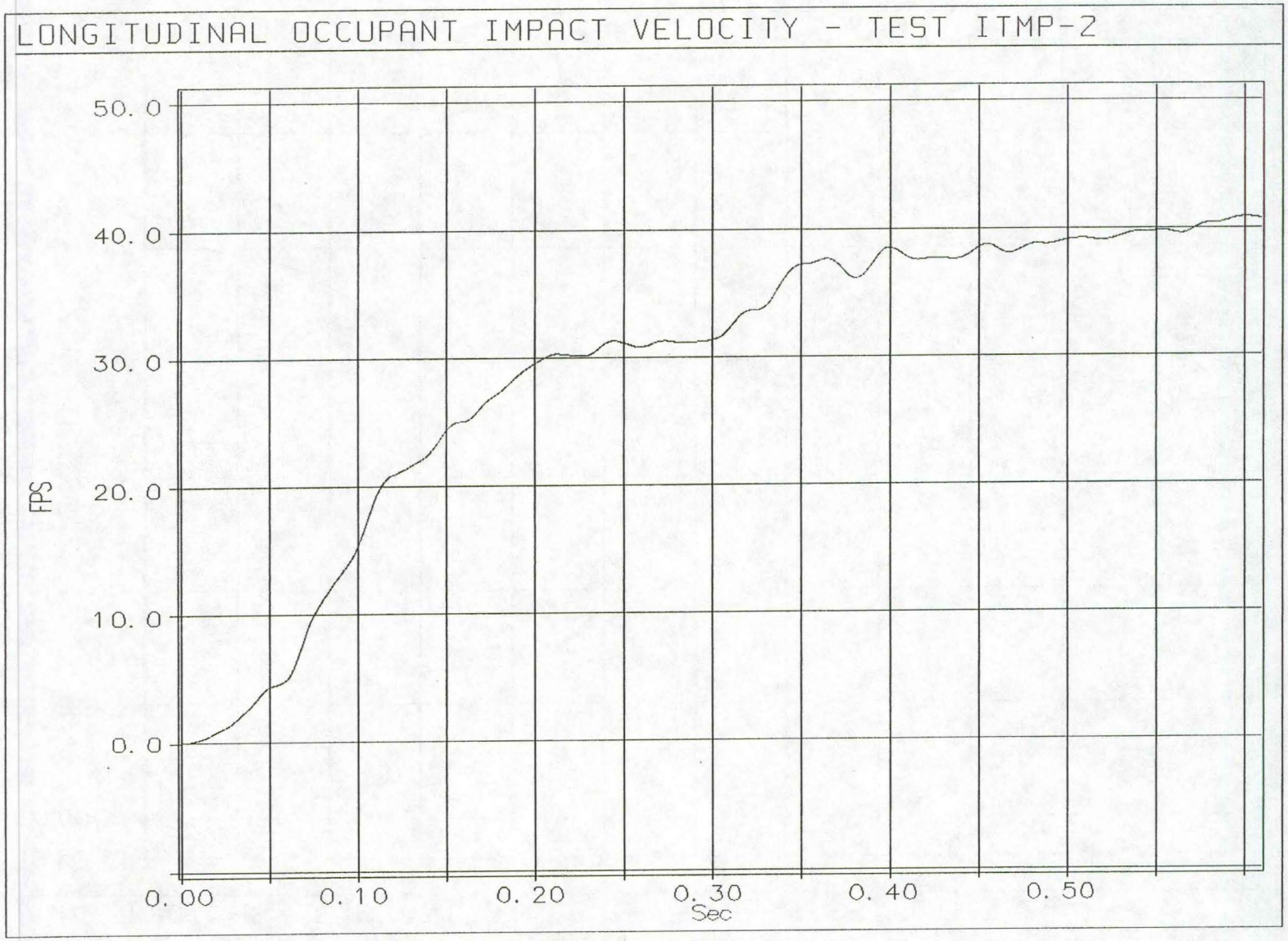

Figure A-2. Graph of Longitudinal Occupant Impact Velocity, Test ITMP-2

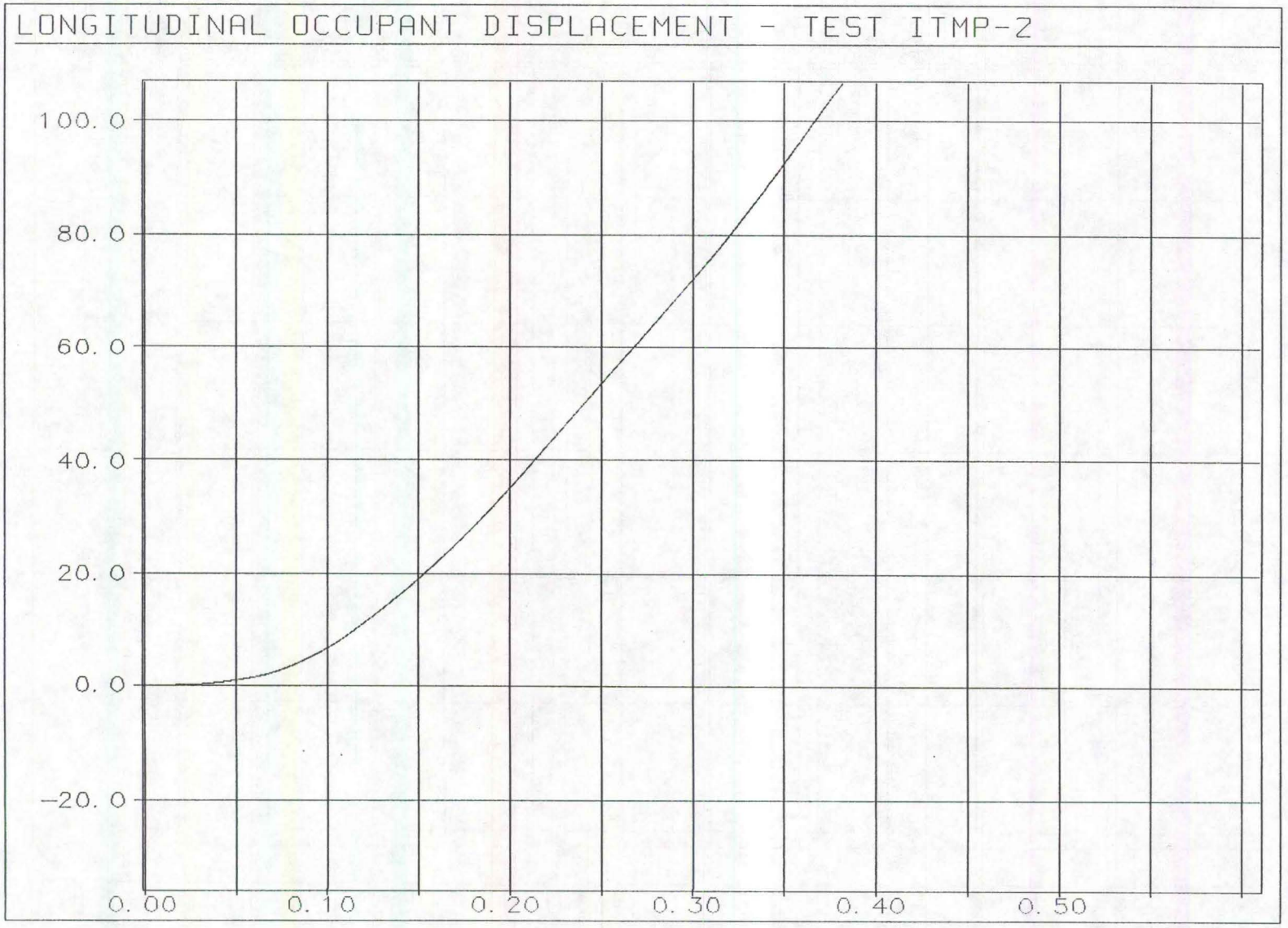

Figure A-3. Graph of Longitudinal Occupant Displacement, Test ITMP-2

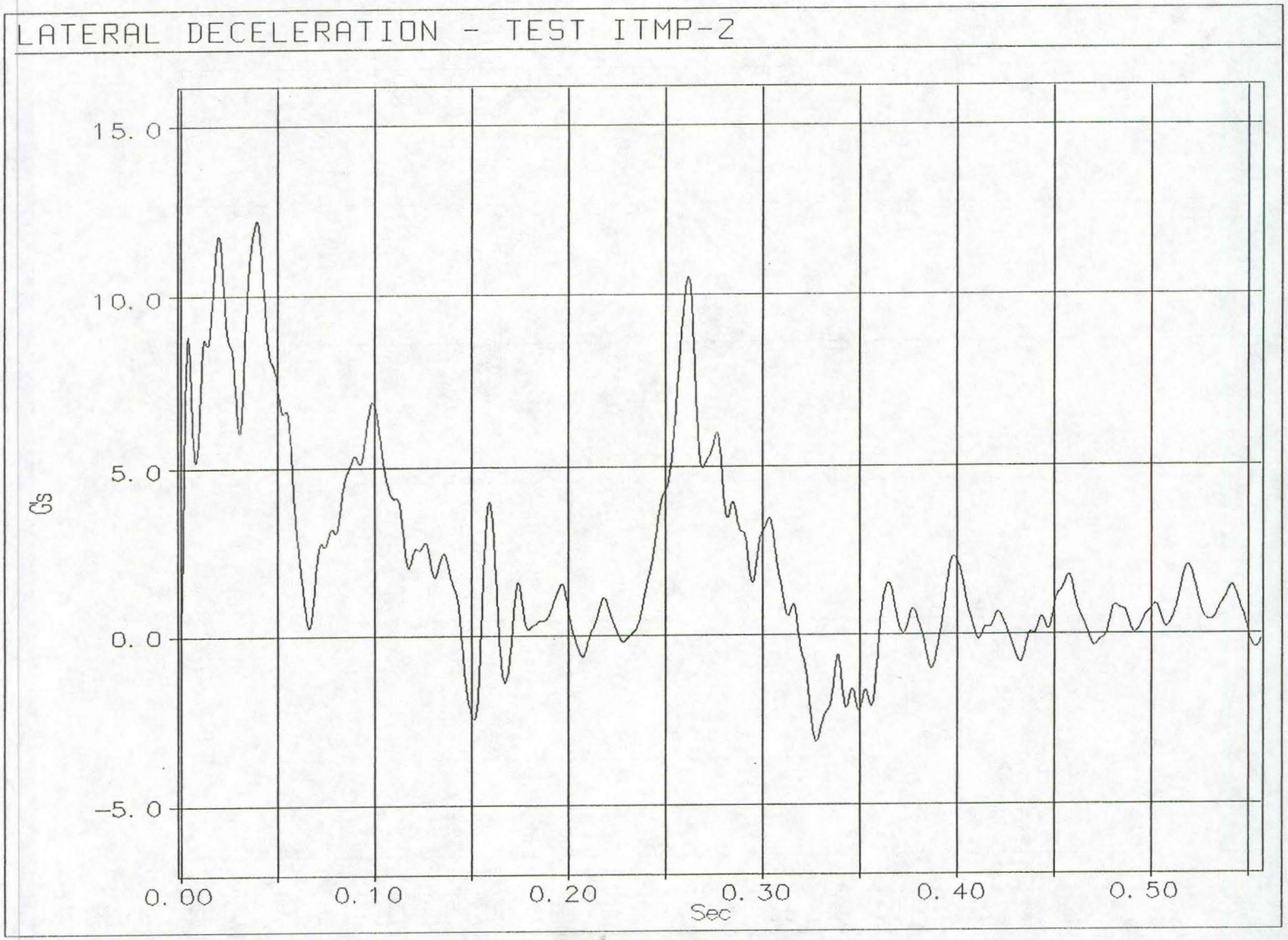

Figure A-4. Graph of Lateral Deceleration, Test ITMP-2

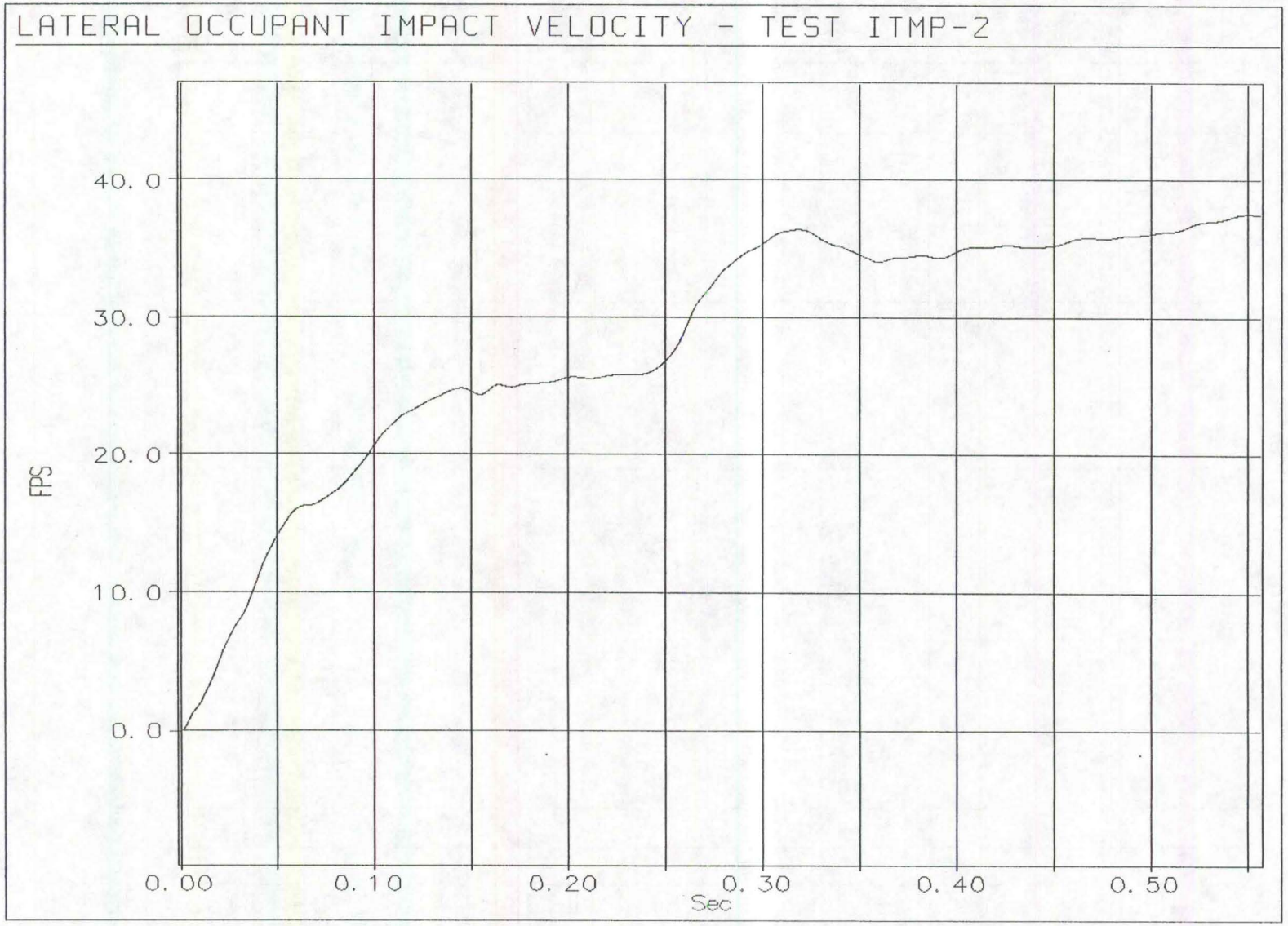

Figure A-5. Graph of Lateral Occupant Impact Velocity, Test ITMP-2

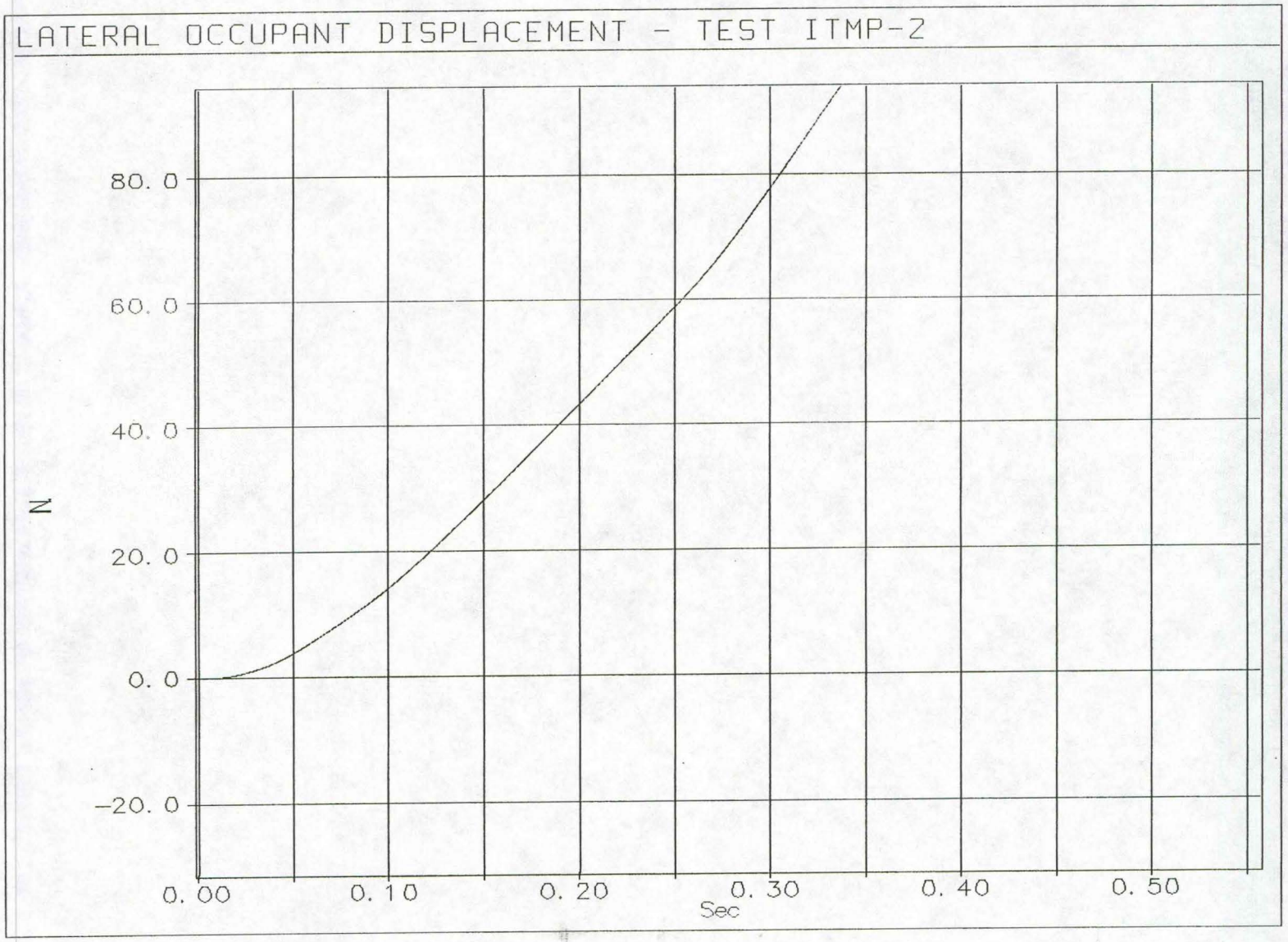

Figure A-6. Graph of Lateral Occupant Displacement, Test ITMP-2

APPENDIX B - RATE TRANSDUCER DATA ANALYSIS

Figure B-1. Graph of Roll, Pitch, and Yaw Angular Displacements, Test ITMP-2

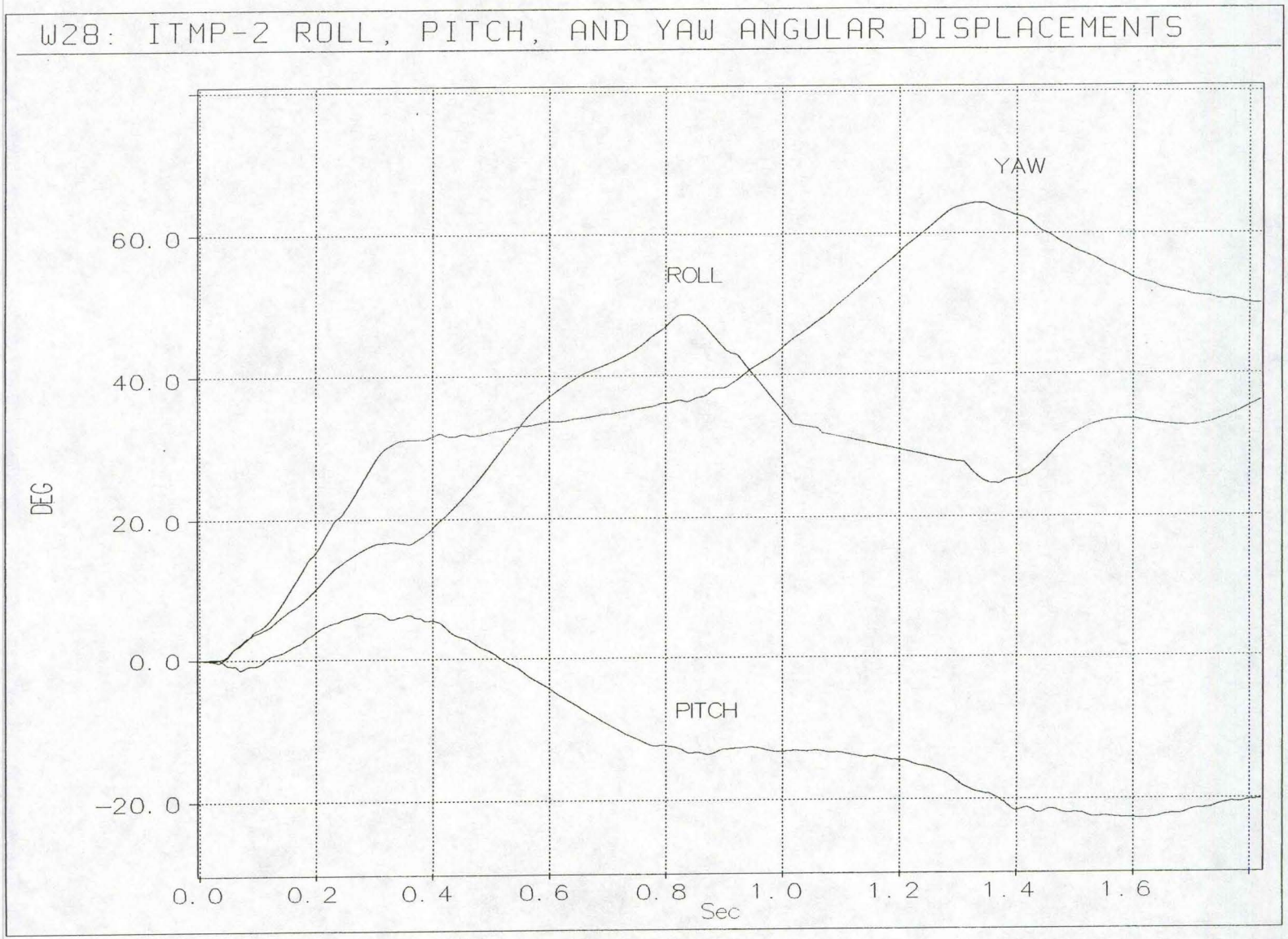

Figure B-1. Graph of Roll, Pitch, and Yaw Angular Displacements, Test ITMP-2