FULL-SCALE 5,400 LB. VEHICLE CRASH TEST ON THE IOWA W-BEAM APPROACH GUARDRAIL TO THE CONCRETE SAFETY SHAPE BRIDGE RAIL

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DISCLAIMER STATEMENT

ABSTRACT

One full-scale vehicle crash test was conducted on the Iowa W-Beam Approach Guardrail Transition Section to the Concrete Safety Shape Bridge Rail. Test I6-1 was conducted with a 5,420 lb. vehicle at 20.0 degrees and 61.45 mph.

The overall test length of the installation was 64 ft.- 6 3/4 in. The installation consisted for four major components: (1) concrete safety shape, bridge rail end-section, (2) the w-beam approach guardrail section, (3) the w-beam breakaway end anchorage, and (4) the w-beam terminal connector.

The concrete end-section was 7 ft. long and 2 ft.- 8 in. high. A 6-in. concrete curb was constructed 13 ft. beyond the end of the concrete end-section.

The w-beam approach guardrail section consisted of 62 ft.- 6 in. of 12 gauge standard w-beam. The top of the w-beam was installed at a mounting height of 27-in. The w-beam was supported by 13 timber posts. The design consisted of three 10-in. by 10-in. posts, eight 8-in. by 8-in. posts, and two 6-in. by 8-in. posts. The post spacing between post 1 through 7 and 7 through 13 was 3 ft.- 1 1/2 in. and 6 ft.- 3 in., respectively.

The point of impact was 15 ft. upstream from the end of the concrete end-section between posts 5 and 6.

The test was evaluated according to the safety criteria in NCHRP 230 and also in the AASHTO guide specifications. The safety performance of the Iowa W-Beam Approach Guardrail Transition Section was determined to be satisfactory.

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ACKNOWLEDGEMENTS

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1. INTRODUCTION

1.1. Problem Statement

The Iowa Department of Transportation (IDOT) and the Federal Highway Administration (FHWA) are concerned with the safety and structural adequacy of highway and bridge railing systems installed on Iowa highways. The performance of certain Iowa Railing systems, now in service, cannot be predicted or verified by conventional analysis.

The current *AASHTO Standard Specifications for Highway Bridges* permits the qualification of railing systems by full-scale vehicle crash testing. The Federal Highway Administration has directed that bridge railing systems be successfully crash tested before their use on Federal Aid Projects is approved.

The Iowa W-Beam Approach Guardrail Transition Section is currently installed on the Iowa Primary and Interstate Systems. Thus, full-scale vehicle crash testing was to be performed to evaluate the structural adequacy, occupant risk, and redirectional characteristics.

The results of this study will be used to assist the IDOT in the identification and evaluation of procedures to improve the safety of the roadway environment.

1.2. Objective of Study

The objective of the research study was to evaluate the safety performance of the Iowa W-Beam Approach Guardrail Transition Section by conducting a full-scale vehicle crash test in accordance with the "Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances," NCHRP 230 (1) and also in the "Guide Specifications for Bridge Railings," AASHTO (2).

2. TEST CONDITIONS

2.1. Test Facility

2.2.1. Test Site

The test site facility was located at Lincoln Air-Park on the NW end of the west apron of the Lincoln Municipal Airport. The test facility, shown in Figure 1, is approximately 5 mi. NW of the University of Nebraska-Lincoln.

An 8 ft. high chain-link security fence surrounds the test site facility to ensure that no vandalism occurs to the test articles or test vehicles which could possibly disrupt the results of the tests.

2.1.2. Vehicle Tow System

A reverse cable tow, with a 1:2 mechanical advantage, was used to propel the test vehicle. The distance traveled and the speed of the tow vehicle are one-half that of the test vehicle. A sketch of the cable tow system is shown in Figure 2. The test vehicle was released from the tow cable approximately 18 feet before impact with the W-Beam Approach Guardrail Transition Section. Photographs of the tow vehicle and the attached fifth-wheel are shown in Figure 3. The fifth-wheel, built by the Nucleus Corporation, was used for accurately towing the test vehicle at the required target speed with the aid of a digital speedometer in the tow vehicle.

2.1.3. Vehicle Guidance System

A vehicle guidance system, developed by Hinch (3), was used to steer the test vehicle. A sketch of the guidance system is shown in Figure 2. The Guide flag, attached to the front left wheel and the guide cable, was sheared off 18 feet before impact with the W-Beam

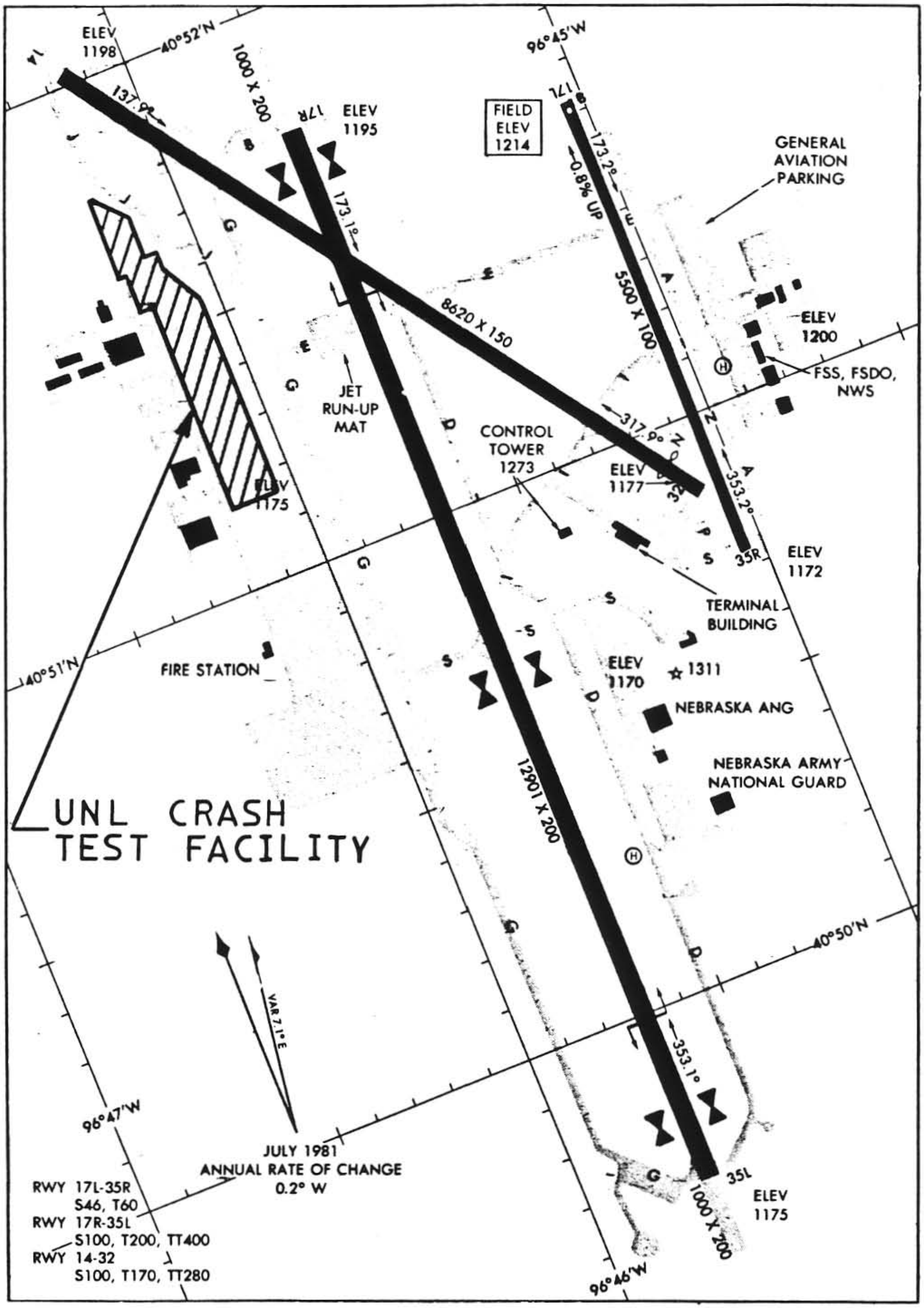


FIGURE 1. FULL-SCALE CRASH TEST FACILITY.

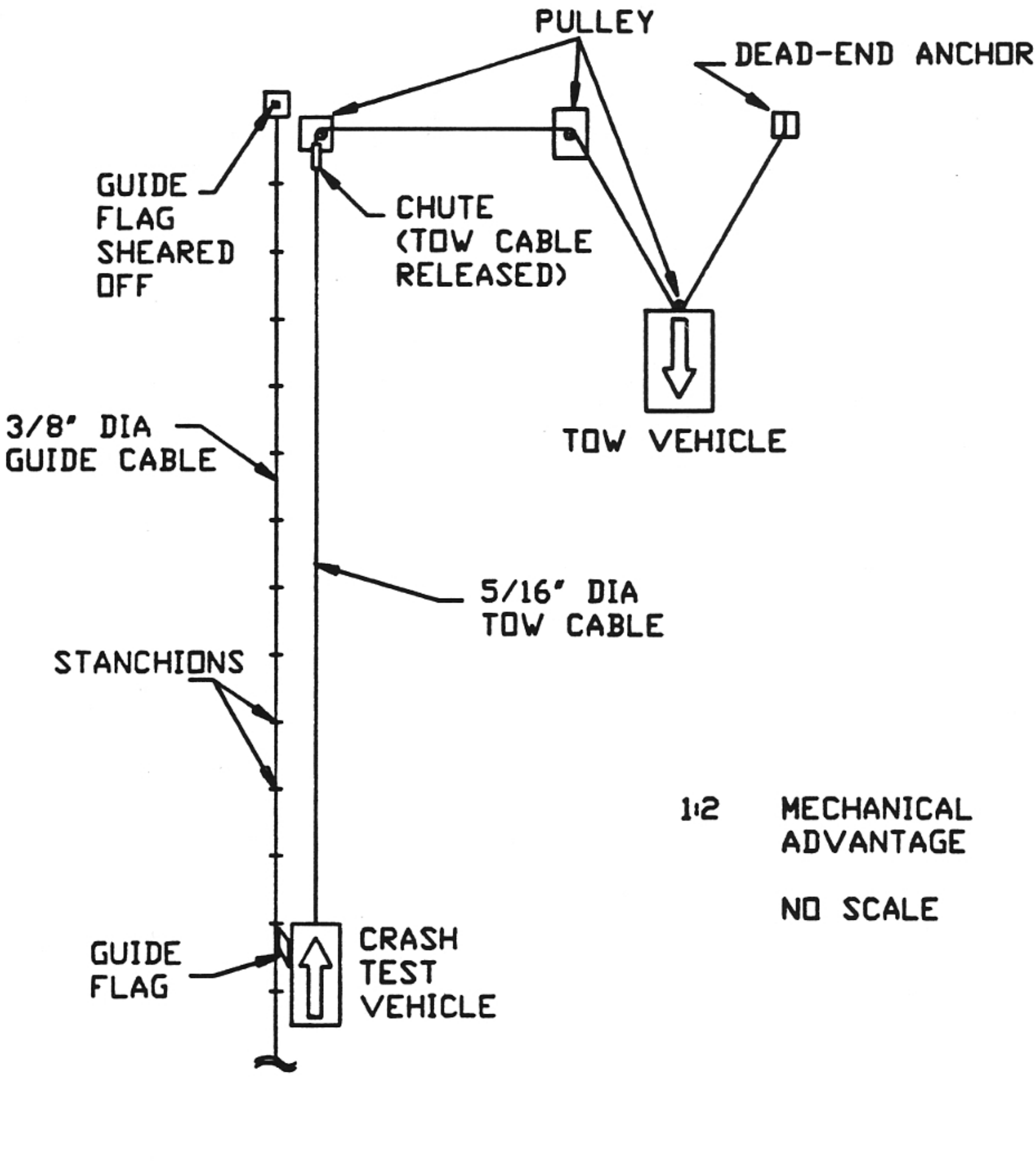


FIGURE 2

SKETCH OF CABLE TOW AND GUIDANCE SYSTEMS

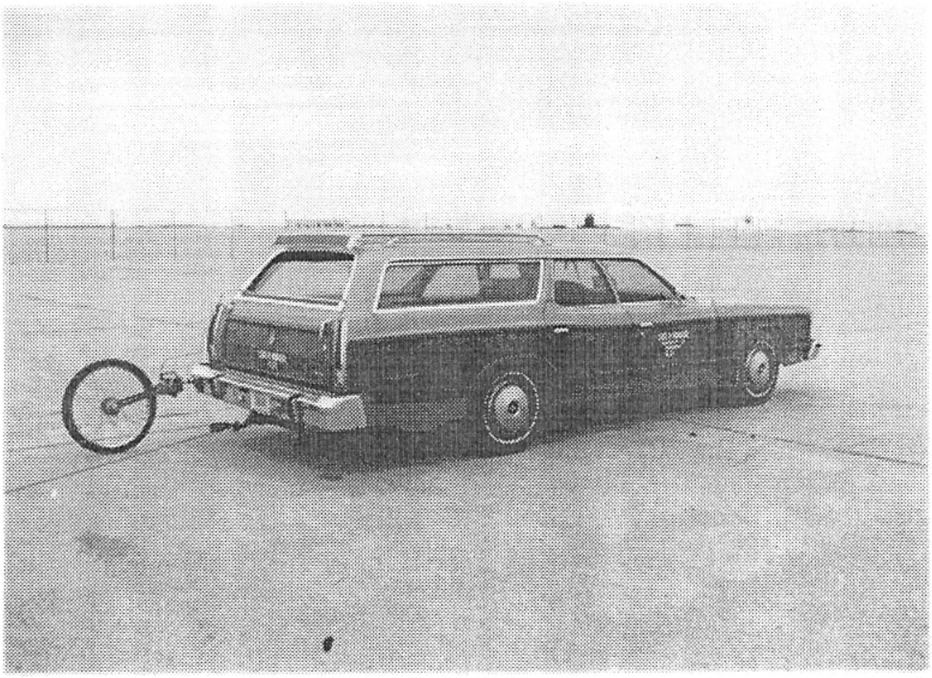


FIGURE 3. PHOTOGRAPH OF TOW VEHICLE AND FIFTH WHEEL

Approach Guardrail Transition Section. The 3/8-in. diameter guide cable was tensioned to 3,000 pounds, and it was supported laterally and vertically every 100 ft. by hinged stanchions. The hinged stanchions stood upright while holding up the guide cable. When the vehicle passed, the guide-flag struck each stanchion and knocked it to the ground. The vehicle guidance system was approximately 1,500 ft. in length.

2.2. W-Beam Approach Guardrail Design Details

The design drawing details of the Iowa W-Beam Approach Guardrail Transition Section are shown in Figures 4 through 12, and photographs of the installation before impact are shown in Figures 13 and 14.

The overall length of the installation was 64 ft.- 6 3/4 in. The installation consisted for four major components: (1) the concrete safety shape, bridge rail end-section, (2) the w-beam approach guardrail section, (3) the w-beam breakaway end anchorage, and (4) the w-beam terminal connector.

The concrete safety shape, bridge rail end-section was constructed with a Nebraska Class 47-B-PHE mix design (see Appendix A). The concrete compressive strength at the time of the crash test averaged about 3,700 psi (see Appendix A). The concrete end-section was 7 ft. long and 2 ft.- 8 in. high. The width of the concrete end-section varied relative to the location of the cross-section, as shown in Figure 4. The concrete end-section was anchored 15-in. into the existing airport concrete apron by 2 No. 5 rebar dowels, spaced at 13-in. on centers over the length of the concrete end-section. An epoxy grout material was used as the bonding agent for the dowels.

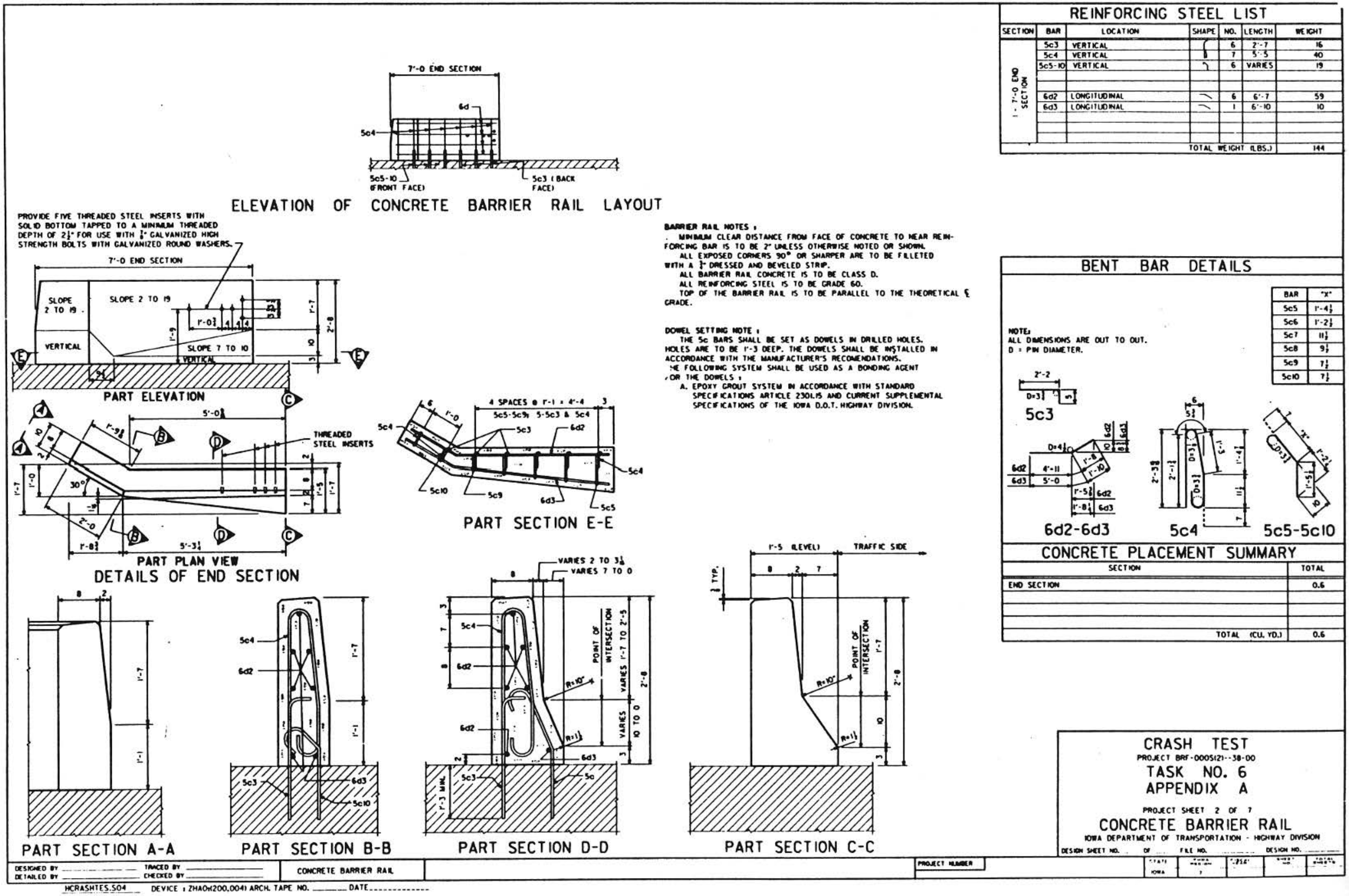
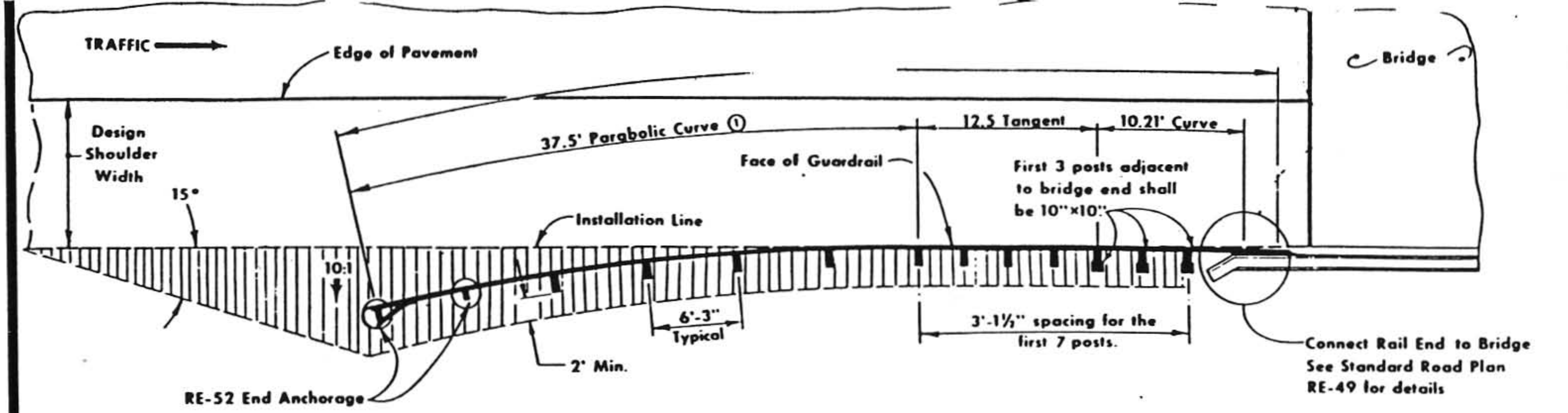
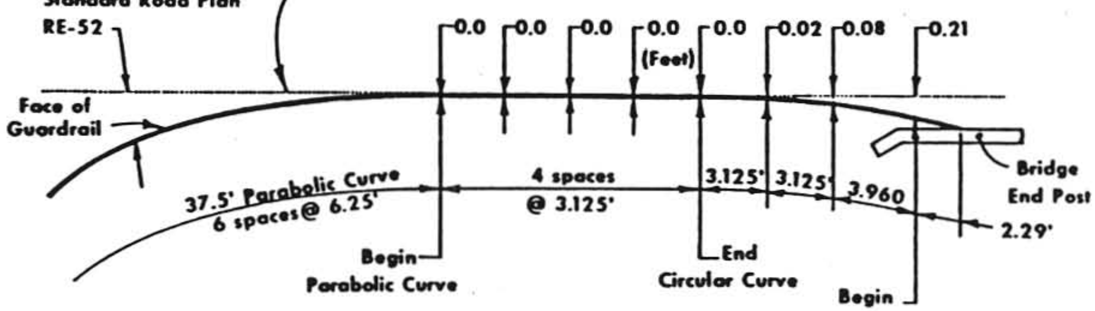


FIGURE 4. SKETCH OF CONCRETE END-SECTION.





OFFSETS FOR CURVED PORTION OF GUARDRAIL

GENERAL NOTES:

Details indicated hereon are for the typical installation of guardrail at approaches to bridges constructed with concrete barrier rail. Refer to project plans, including Tabulation of Beam Guardrail Installations as well as other Standard Road Plans for additional requirements for individual installations.

Horizontal and vertical alignment of the guardrail in the area immediately adjacent to the bridge shall, where necessary, be adjusted to a smoothly curved line with no abrupt changes.

Guardrail shall be lapped towards the structure.

① Refer to standard Road Plan RE-52 for details of Parabolic Curve Section.

CRASH TEST
Project BRF-000S(12)--38-00
TASK No. 6
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GUARDRAIL INSTALLATION
BRIDGE APPROACH
(BRIDGE WITH CONCRETE BARRIER RAIL)

FIGURE 5. SKETCH OF GUARDRAIL INSTALLATION BRIDGE APPROACH.

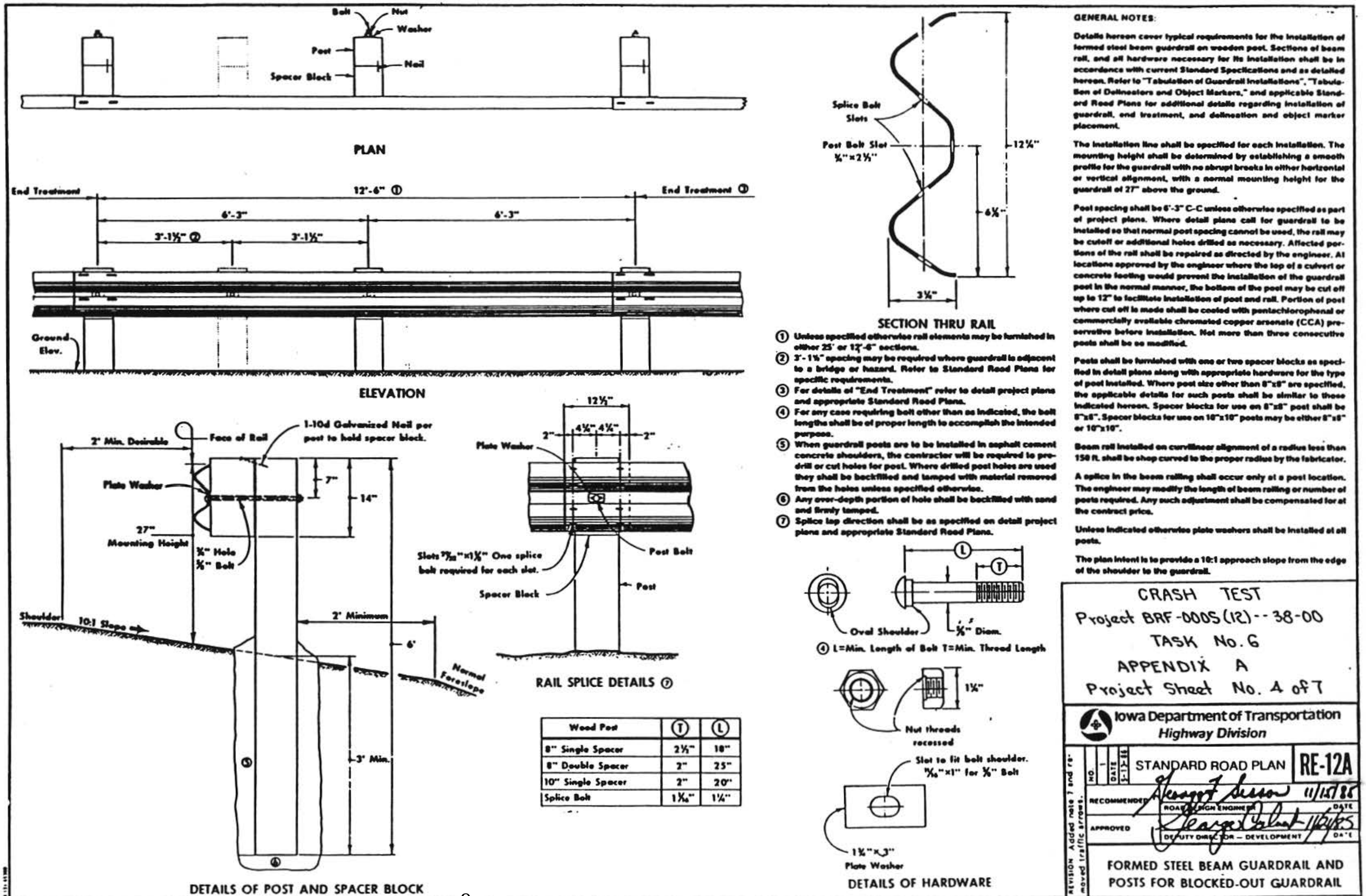
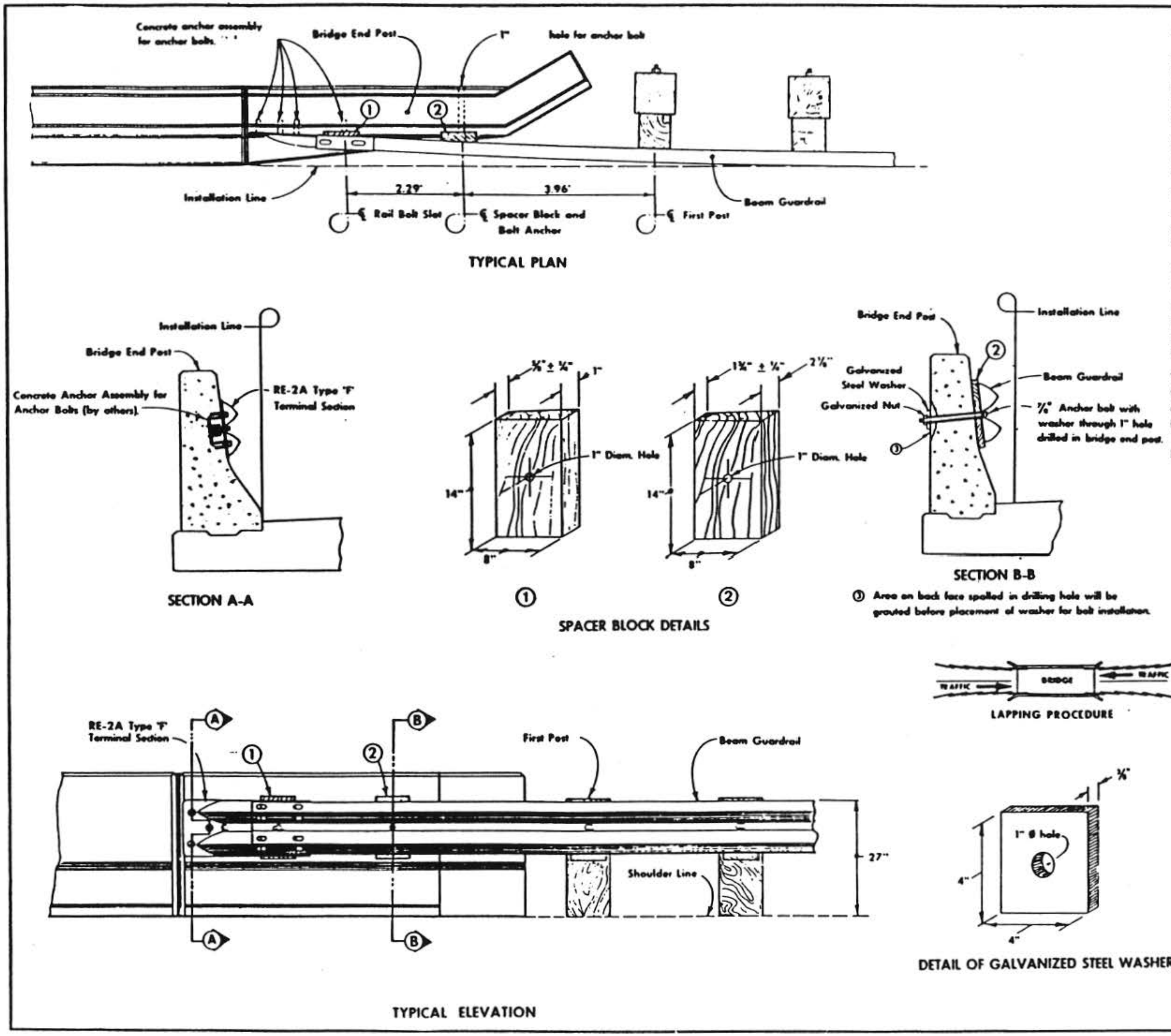


FIGURE 6. SKETCH OF GUARDRAIL TO POST ATTACHMENT.



GENERAL NOTES:

The intent of this plan is to show the attachment of beam guardrail to the bridge end post using all the required connecting devises indicated hereon. Refer to "Tabulation of 'W' Beam Guardrail Installations" and applicable Standard Road Plans for additional details regarding installation of guardrail.

Any materials not specifically detailed hereon shall be in accordance with other appropriate Standard Road Plans as well as current Standard Specifications.

The anchor bolts shall conform to requirements of ASTM A 325 or A449, threaded full length and shall be galvanized in compliance with ASTM A-153. Threads may be chased after galvanizing.

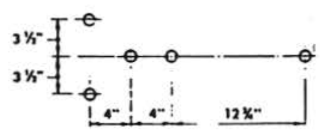
Washers shall be made of steel and shall meet the dimensional requirements of A.N.S.I. B27.2 type A plain washers.

Horizontal and vertical alignment of the guardrail in the area immediately adjacent to the bridge shall be adjusted to a smoothly curved line with no abrupt changes. Exact details of the installation shall be as directed by the engineer.

The RE-49 Guardrail-Bridge Connection shall not be measured for payment. The construction indicated including the furnishing of the RE-2A, Type "F" terminal section, shall be considered incidental to other guardrail work on the project.

LIST OF MATERIALS FOR THE RE-49 BRIDGE CONNECTION

- 5 - Approved 7/8"x2-1/2" H.S. Hex Bolts.
- 5 - Approved 15/16" I.D., 2-¼" O.D., 5/32" Thick Washers.
- 1 - Approved 7/8" x Sufficient length H.S. Hex Bolt.
- 1 - Galvanized Steel Washer (4" x 4" x 3/8").
- 1 - RE-2A Type "F" Terminal Section.
- 2 - Spacer Blocks (as detailed).



BOLT PATTERN
For RE-2A Type 'F' Terminal Section

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Iowa Department of Transportation
Highway Division

STANDARD ROAD PLAN RE-49

RECOMMENDED George F. Sisson 11/10/86 ROAD DESIGN ENGINEER DATE
APPROVED 11/10/86 DEPUTY DIRECTOR - DEVELOPMENT DATE

DETAILS OF GUARDRAIL TO BRIDGE CONNECTION WITH BARRIER CURB

FIGURE 7. SKETCH OF W-BEAM TERMINAL CONNECTOR.

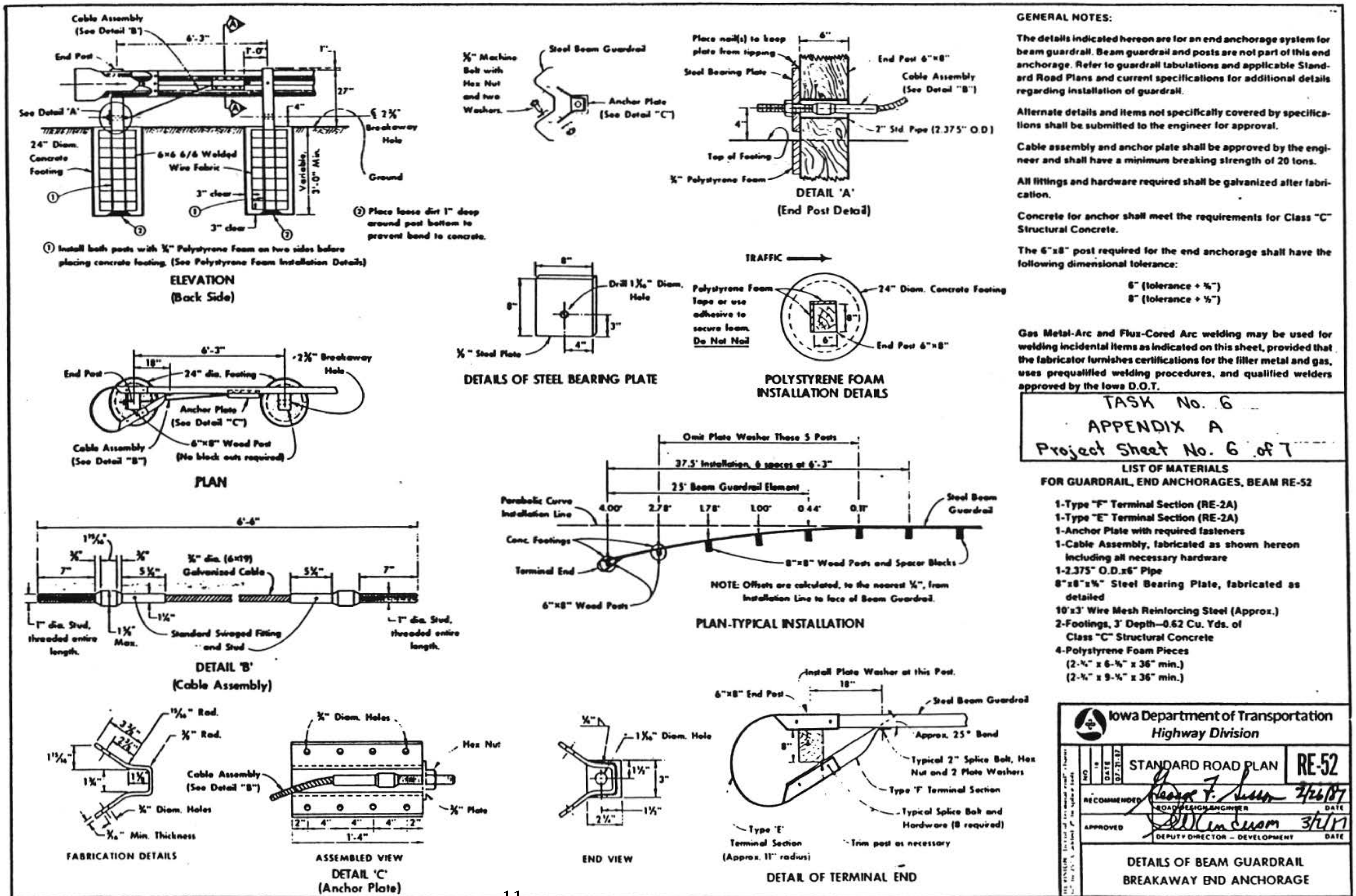
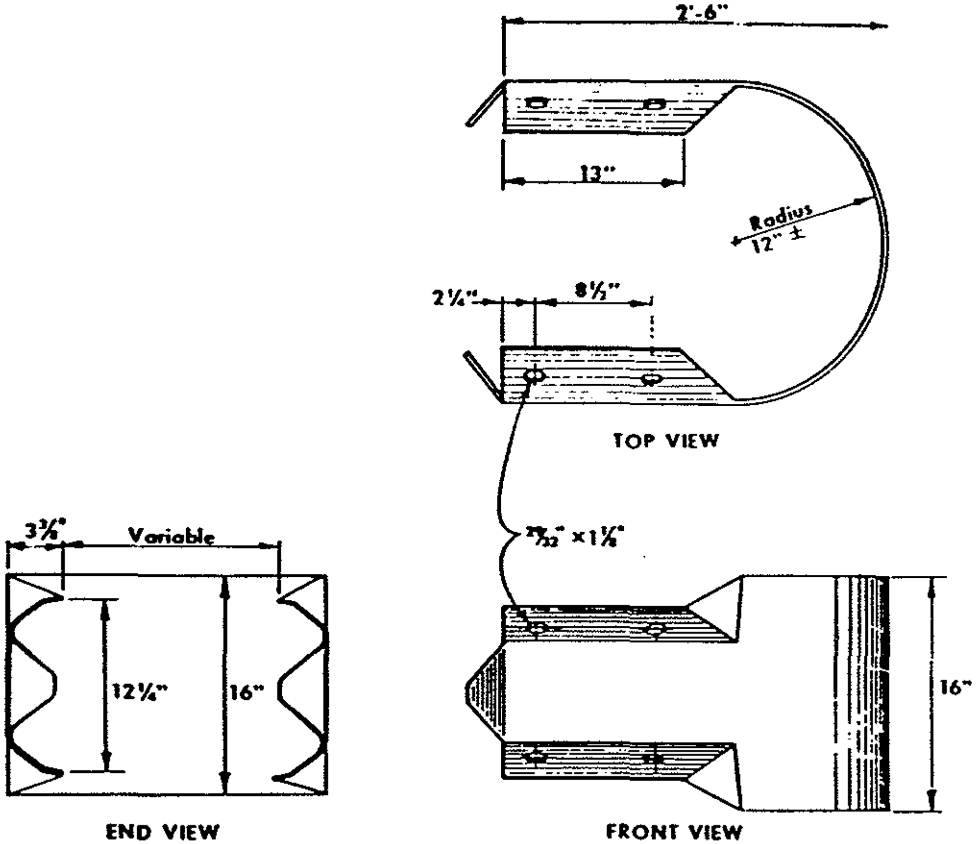
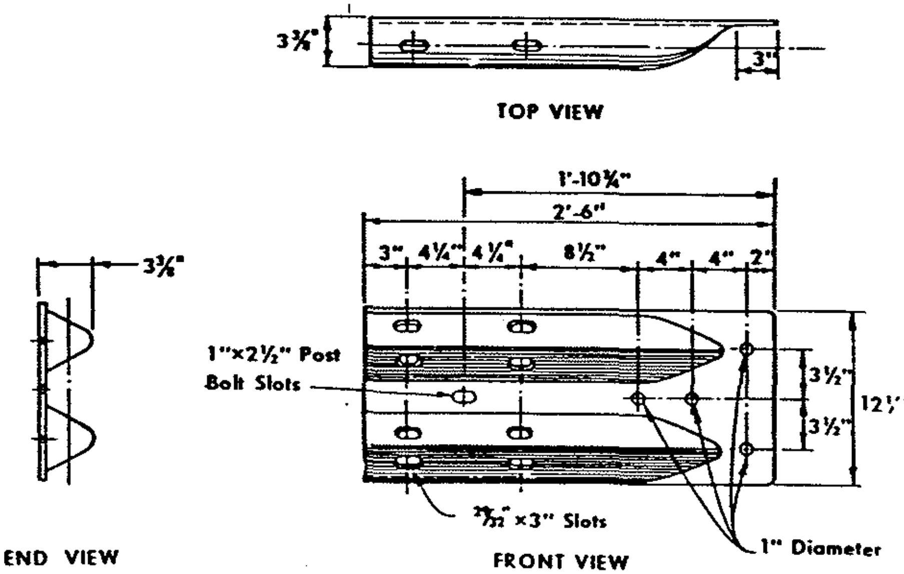


FIGURE 8. SKETCH OF BREAKAWAY END ANCHORAGE.



TYPE "E" TERMINAL SECTION
Buffer End



TYPE "F" TERMINAL SECTION
Terminal Connector

GENERAL NOTES:

Terminal section shall be required as part of the end treatment for all guardrail installations unless specifically indicated otherwise in project plans.

Fabrication and installation of terminal sections shall be in accordance with current Iowa D.O.T. Standard Specifications and appropriate other standard road plans.

Refer to "Tabulation of Guardrail Installations" for additional details of installations.

Tvpe "E" and "F" terminals shall be U.S.S. 10 gage.

FIGURE 9. SKETCH OF FORMED STEEL TERMINAL SECTIONS.

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Project BRF-0005 (12)--38-00
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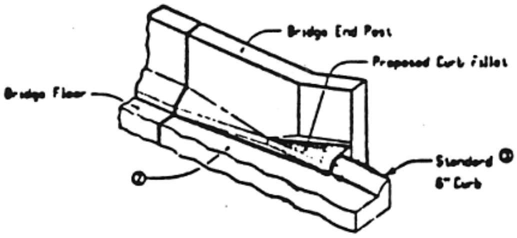
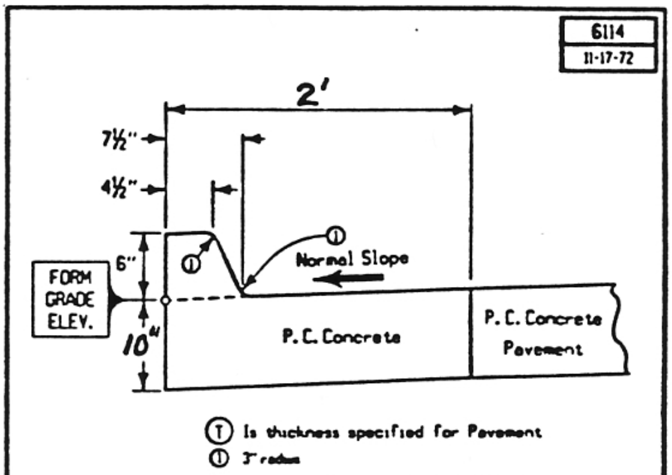
FORMED STEEL BEAM RAILING
TERMINAL SECTIONS

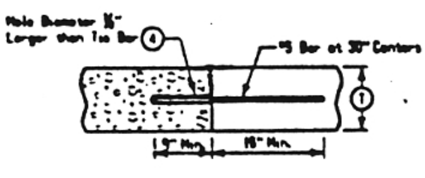


DETAIL "C"
Joint and Curb Fillet
at Bridge End Section

② Reinforced Bridge Approach Section.
③ Build 6" curb to end of Reinforced Bridge Approach Section. The location of the guardrail determines the location of the curb. The back of curb is located 8" back of the face of guardrail.



DETAILS OF 2' P.C. CONC.
CURB AND GUTTER UNIT
Adjacent to PCC Pavement



"BT-3"
ABUTTING PAVEMENT JOINT, RIGID TIE
(FORMERLY "BD" JOINT)

② When tieing into old pavement, Ⓣ represents the depth of sound concrete.

④ Placement of dowels or tie bars shall be in accordance with Standard Specification 2301.15.
The method of anchoring bars into existing pavement shall be as approved by the engineer as set forth in appropriate Materials Instructional Memorandums.

FIGURE 10. SKETCH OF CONCRETE CURB AND ATTACHMENT.

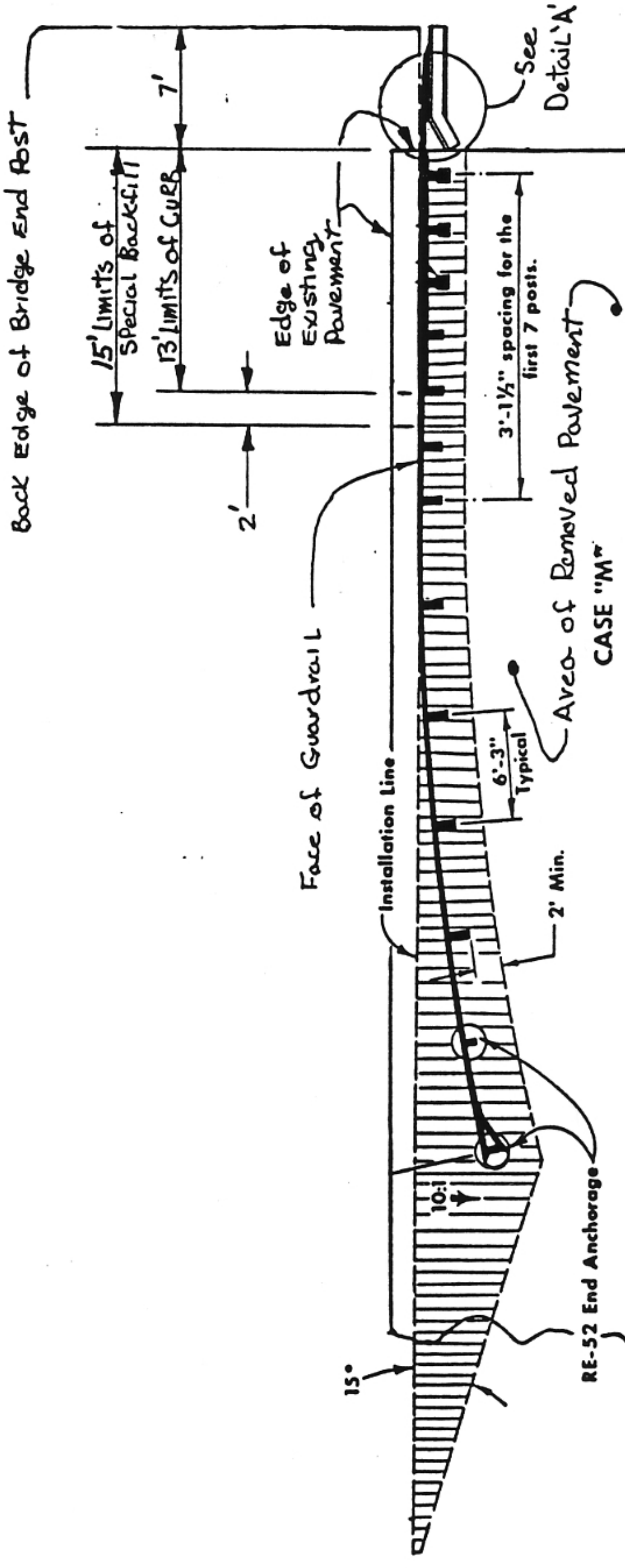
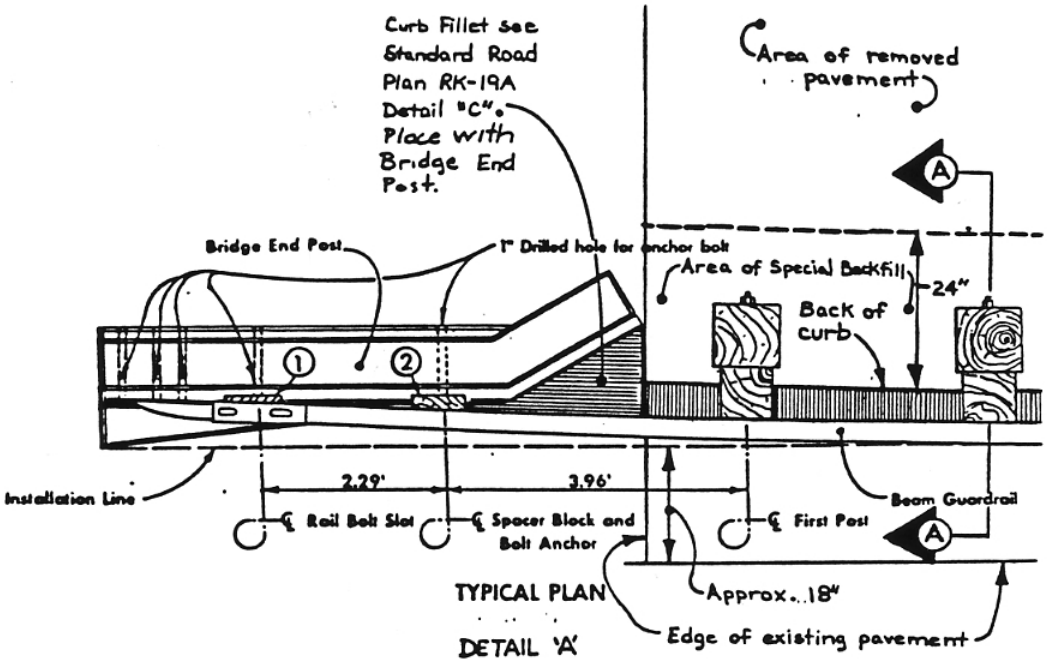


FIGURE 11. SKETCH OF GUARDRAIL INSTALLATION BRIDGE APPROACH.



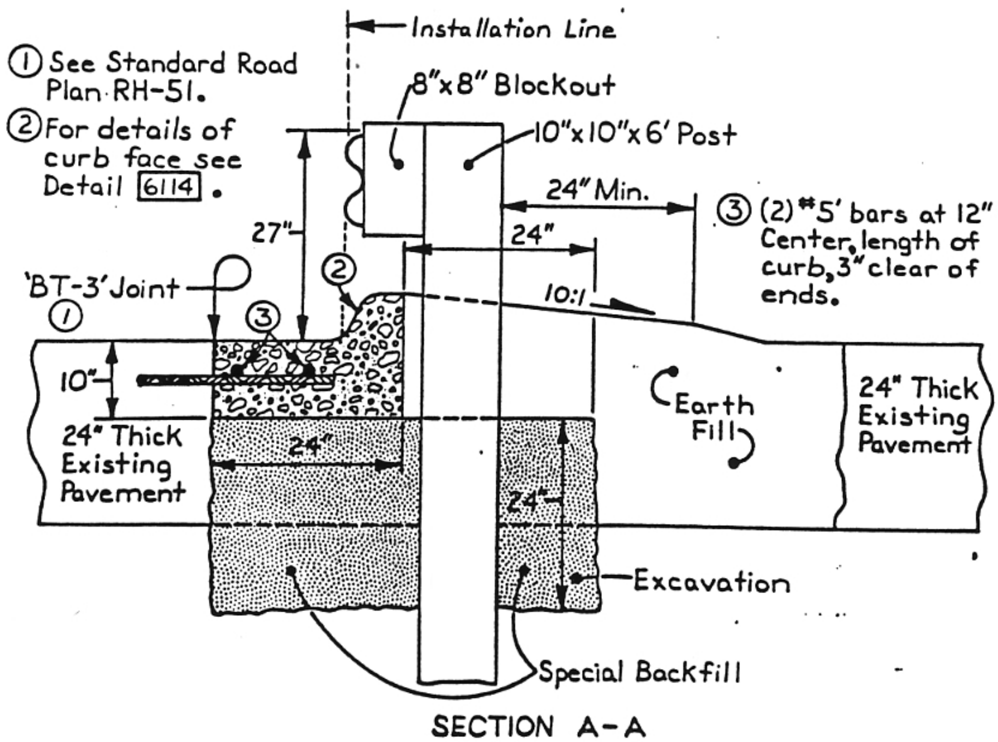
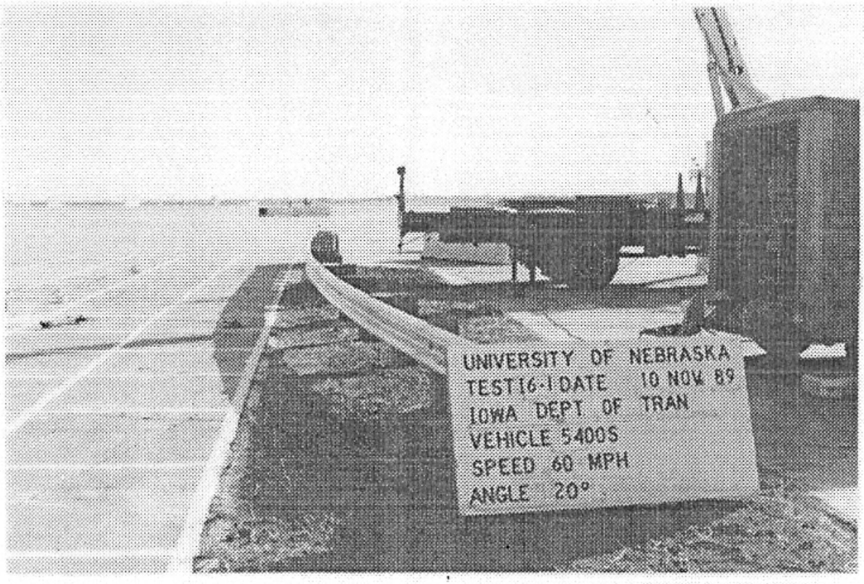
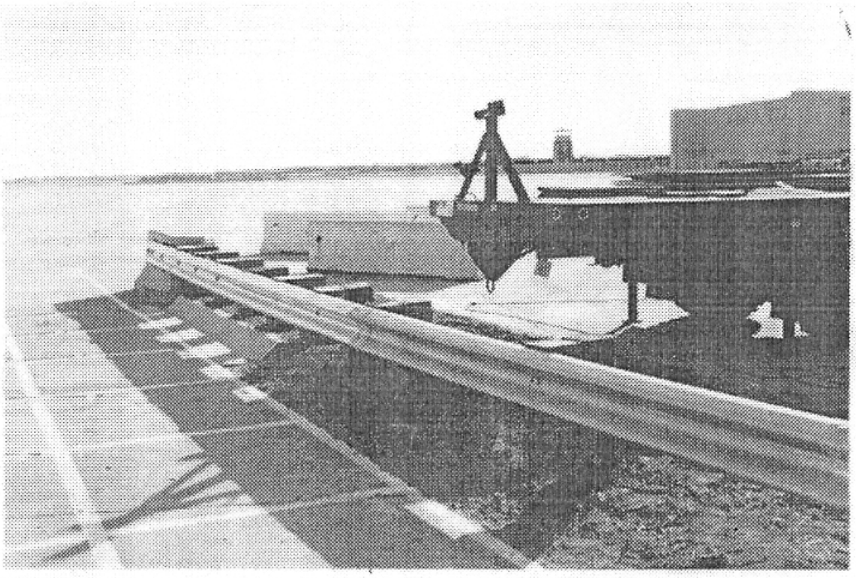


FIGURE 12. DETAIL OF POST EMBEDMENT AND W-BEAM ATTACHMENT.





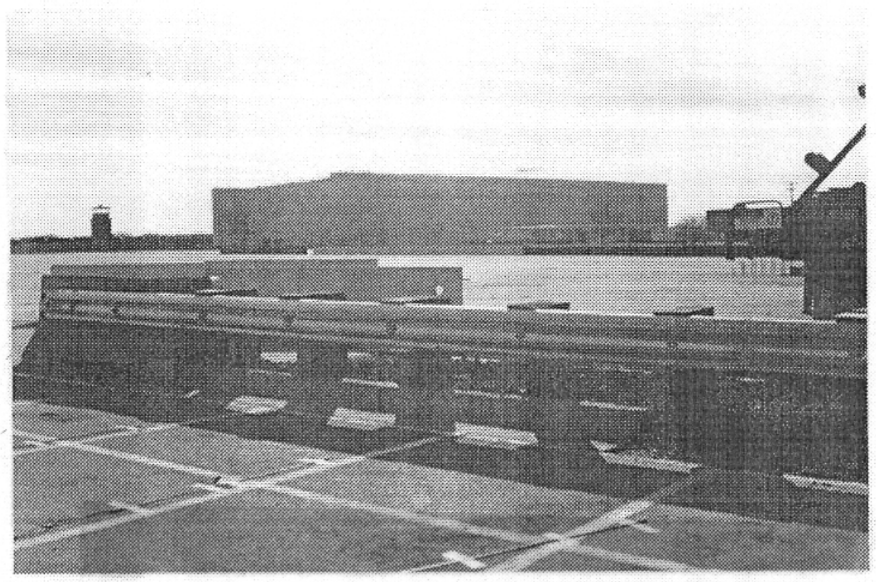


FIGURE 13. PHOTOGRAPHS OF W-BEAM APPROACH GUARDRAIL INSTALLATION.

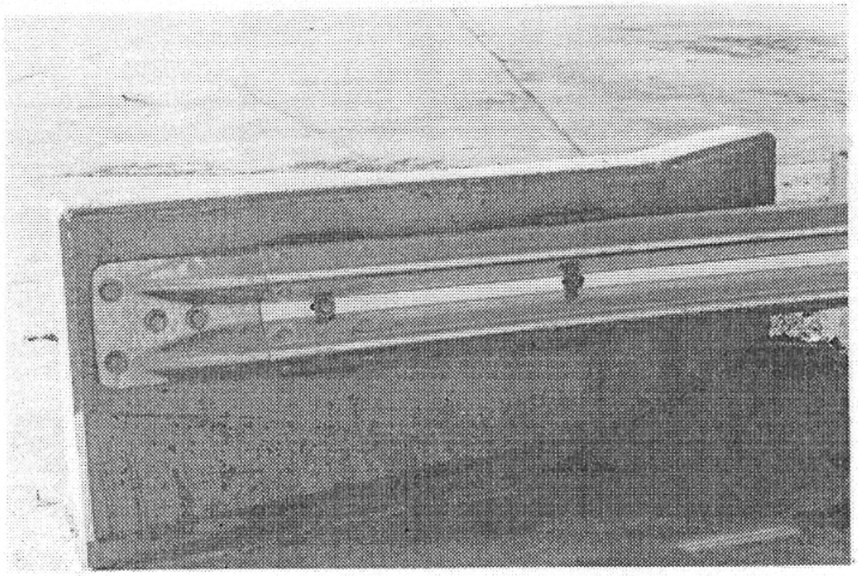


FIGURE 14. PHOTOGRAPHS OF W-BEAM GUARDRAIL APPROACH INSTALLATION.

A concrete curb was constructed 13 ft. beyond the end of the concrete end-section, as shown in Figures 10 through 12. The curb was 6-in. high and had a top width and bottom width of 4 1/2-in. and 7 1/2-in., respectively. The curb was constructed with a concrete slab which was 10-in. deep and 24-in. wide. The concrete slab was anchored 9-in. into the edge of the existing airport concrete apron by No. 5 rebar dowels, spaced at 30-in. on centers over the length of the 13 ft. concrete curb and slab section. An epoxy grout material was used as the bonding agent for the dowels.

The w-beam approach guardrail section consisted of 62 ft.- 6 in. of 12 gauge standard w-beam. The w-beam section was 12 3/4-in. wide and 3 1/4-in. deep, as shown in Figure 6. The w-beam was installed at a mounting height of 27-in., as measured to the top of the w-beam. This is shown in Figures 6 and 12. The back of the concrete curb was located 8-in. back of the face of the w-beam guardrail.

The w-beam guardrail was supported by 13 timber posts, as shown in Figures 5 and 11. The first 3 posts adjacent to the concrete end-section were 10-in. by 10-in. by 72-in. The next 8 posts were 8-in. by 8-in. by 72-in. The last 2 posts, which were part of the breakaway end anchorage system, were 6-in. by 8-in. by 72-in. An 8-in. by 8-in. by 14-in. timber spacer block was used for the first 11 timber posts. The spacer block attachment detail is shown in Figure 6. The post spacing between posts 1 through 7 was 3 ft.- 1 1/2 in., and the post spacing between posts 7 through 13 was 6 ft.- 3 in., as shown in Figures 5 and 11.

The timber posts were embedded into two different materials, as shown in Figure 12. The upper layer consisted of a "native," silty-clay earth fill. The lower layer consisted of a special gravel backfill. The special gravel backfill had the following gradation requirements: 100% passing the no. 1 1/2-in sieve, 45-80% passing the no. 4 sieve, and 4-12% passing the no. 200 sieve.

The w-beam breakaway end anchorage system was located at posts 12 and 13, as shown in Figures 5, 8, and 11. The two posts were embedded in concrete footings, as shown in Figure 8. The breakaway end anchorage system used a steel cable and anchor assembly which increased the load carrying capability of the w-beam. A 10 gauge, Type "E" terminal end section was used at post 13, as shown in Figures 8 and 9.

The w-beam terminal connector was used to attach the w-beam guardrail to the concrete end-section, as shown in Figures 7, 9, and 12. A 10 gauge, Type "F" terminal connector was installed. The section was 12 1/4-in. wide by 30-in. long.

2.3. Test Vehicle

One test vehicle was used to evaluate the Iowa W-Beam Approach Guardrail Transition Section. For Test I6-1, a 1983 Ford F-250 pickup weighing 5,420 lbs. was used as the crash test vehicle. Photographs of the test vehicle are shown in Figure 15. Dimensions of the test vehicle are shown in Figure 16.

Steel plates, bolted to the rear box, were used in order for the test vehicle to conform to the weight and the center-of-mass specifications in AASHTO (2).

The front wheels of the test vehicle were aligned to a toe-in value zero-zero so that the vehicle would track properly along the guide cable.

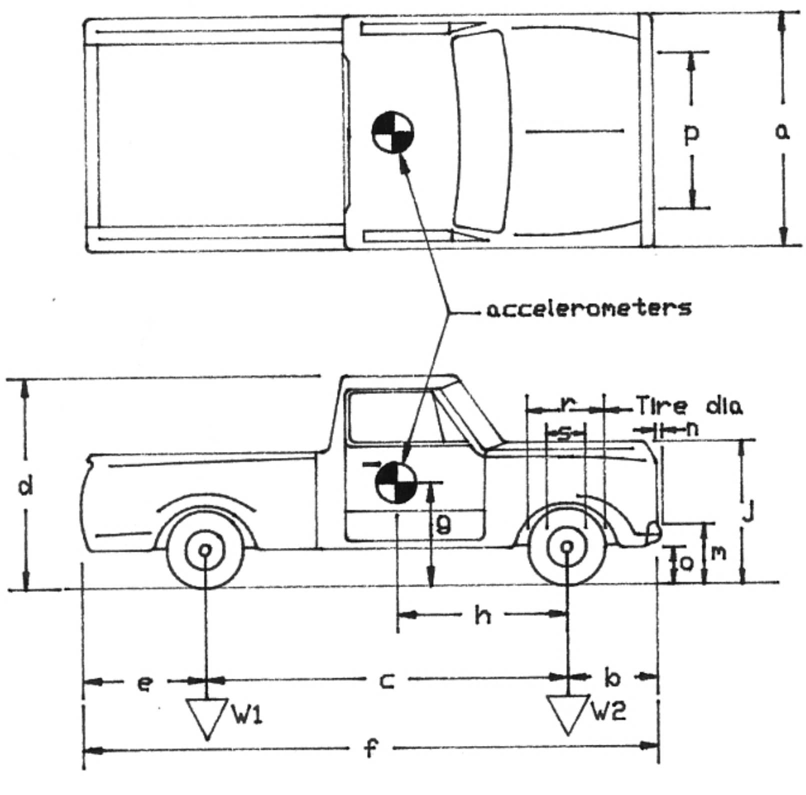
Three 8-in. square, black and white checkered targets were placed on the centerline of the top of the test vehicle. The middle target was placed over the center of mass.

FIGURE 15. PHOTOGRAPHS OF TEST VEHICLE.

Date: 11/10/89 Test No.: I6-1 Vehicle I.D. #: 1PTHF2512DPB1257Ø

Make: Ford Model: F-25Ø Year: 1983 Odometer: Ø9412

Tire Size: 9.5R165LT



Vehicle Geometry - inches

a	77.7	b	29
c	130	d	70
e	49.5	f	208.5
g	26.75	h	54
i	N/A	j	45.75
k	N/A	l	N/A
m	26	n	4
o	19	p	62
r	29	s	16

Engine Type: V8 Diesel

Engine Size: 6.9 Liter

4 - wheel weight: lf____ rf____ lr____ rr____

Transmission Type:

Automatic or Manual

FWD or **RWD** or 4WD

Weight - pounds	Curb	Test Inertial	Gross Static
W1	2,870	3,170	3,170
W2	2,050	2,250	2,250
Wtotal	4,920	5,420	5,420

Note any damage prior to test: None

FIGURE 16. VEHICLE MEASUREMENTS

Additional roof targets were placed ahead and behind the center of mass. The targets were used in the analysis of the high speed film. In addition to the roof targets, side and rear targets were also placed at known positions to aid in the evaluation process.

Two 5B flash-bulbs were mounted on the roof of the test vehicle to record the time of impact with the w-beam approach guardrail on the high-speed film. The flash bulbs were fired by a pressure tape switch mounted on the front face of the bumper.

2.4. Data Acquisition Systems

2.4.1. Accelerometers

Six Endevco triaxial piezoresistive accelerometers (Model 7264) with a range of ± 200 g's were used to measure the accelerations in the longitudinal, lateral, and vertical directions of the test vehicle. Two accelerometers were mounted in each of the three directions so that there would be two readings to compare. The accelerometers were rigidly attached to a metal block mounted at the center-of-mass. The signals from the accelerometers were received and conditioned by an onboard vehicle Metraplex Unit. The multiplexed signal was then radio transmitted to the Honeywell 101 Analog Tape Recorder in the central control van. A flow chart of the accelerometer data acquisition system is shown in Figure 17, and photographs of the system located in the centrally controlled step van are shown in Figure 18. State-of-the-art computer software, "Computerscope and DSP", was used to analyze and plot the accelerometer data on a Cyclone 386/AT, which uses a high-speed data acquisition board.

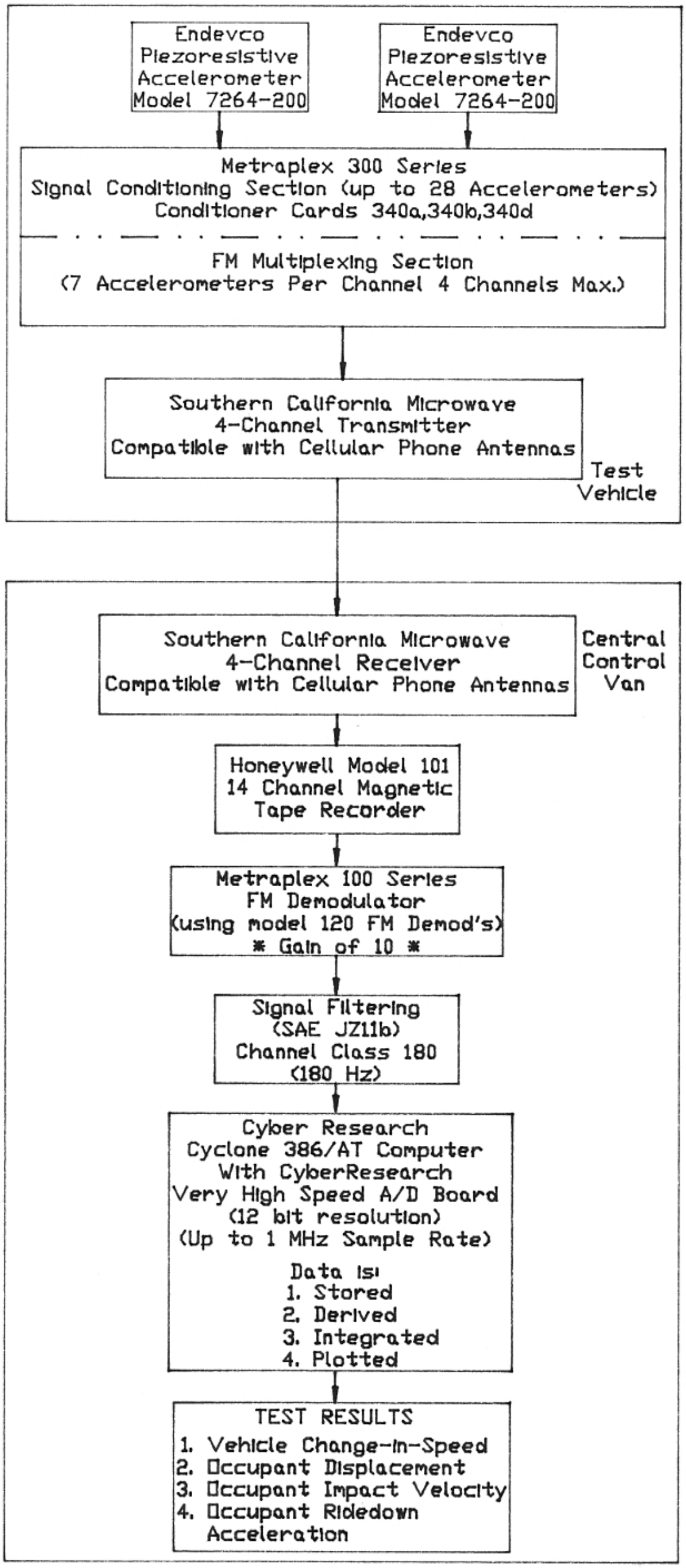


FIGURE 17.

FLOW CHART OF ACCELEROMETER DATA ACQUISITION SYSTEM

Figure 18. Photographs of data recorder and 386/AT computer.

2.4.2. <u>High-Speed Photography</u>

Three high-speed 16 mm cameras were used to film the crash tests. The cameras operated at approximately 500 frames/sec. The overhead camera was a Red Lake Locam with a wide angle 12.5 mm lens. It was placed approximately 65 ft. above the concrete apron. The parallel camera was a Photec IV with an 80 mm lens. It was placed 250 ft. downstream and offset 3.3 ft. from a line parallel to the barrier rail. The perpendicular camera was a Photec IV with a 55 mm lens. It was placed 165 ft. from the vehicle point of impact. A schematic of the camera locations is shown in Figure 19.

A 20 ft. wide by 100 ft. long grid layout, shown in Figure 20, was painted on the concrete slab surface parallel and perpendicular to the barrier. The white-colored grid was incremented with 5 ft. divisions in both directions to give a visible reference system which could be used in the analysis of the overhead high-speed film.

The film was analyzed using the Vanguard Motion Analyzer. The camera divergence correction factors were also taken into consideration in the analysis of the high-speed film.

2.4.3. <u>Speed Trap Switches</u>

Eight tape pressure switches spaced at 5 ft. intervals were used to determine the speed of the vehicle before and after impact. Each tape switch fired a blue 5B flash-bulb located near each switch on the concrete slab as the left front tire of the test vehicle passed over it. The average speed of the test vehicle between the tape switches was determined by knowing the distance between pressure switches, the calibrated camera speed, and the number of frames from the high-speed film between flashes. In addition, the average speed was determined from electronic timing mark data recorded on the oscilloscope software used with the 386/AT computer as the test vehicle passed over each tape switch.

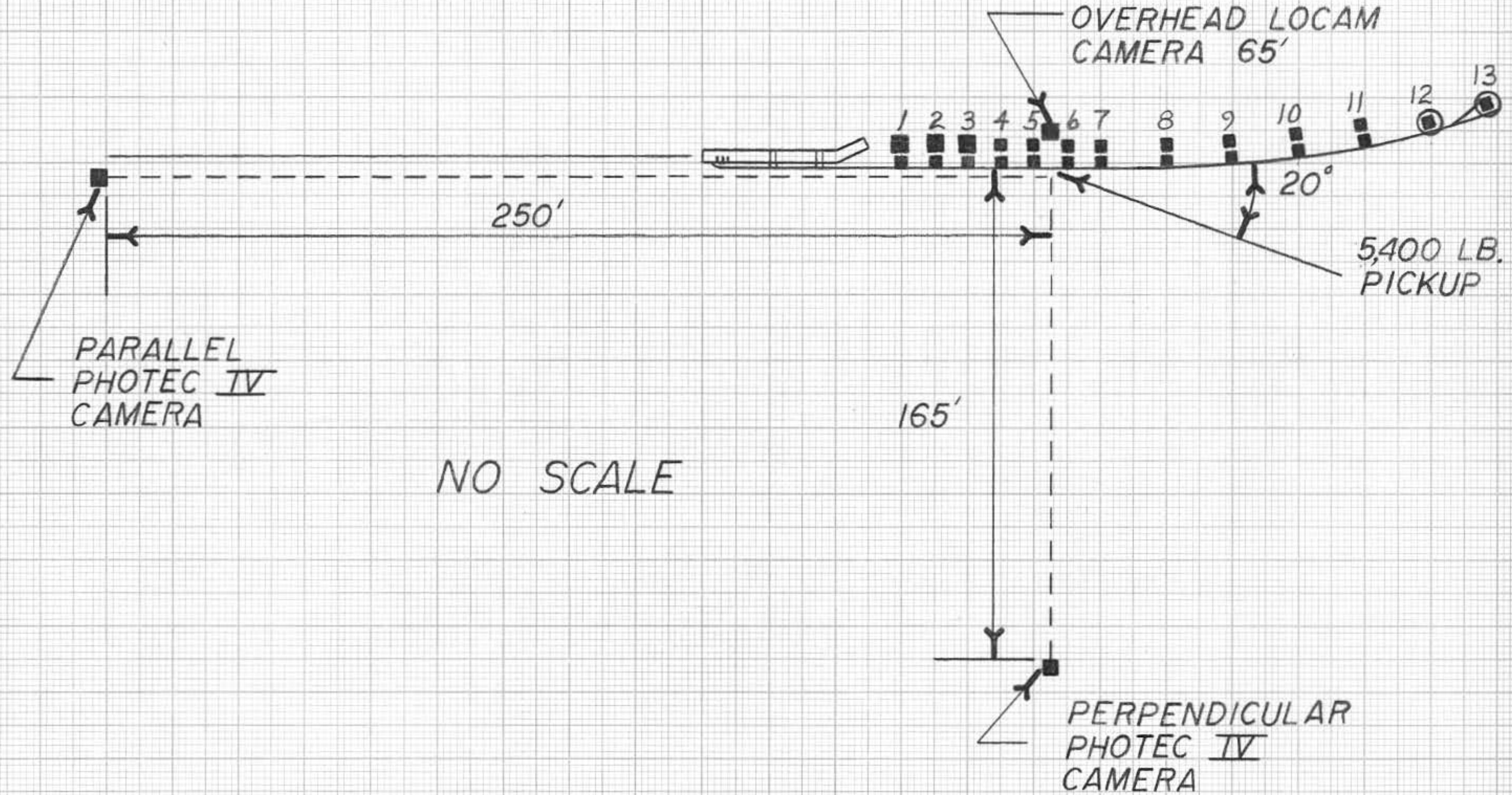


FIGURE 19. LAYOUT OF HIGH-SPEED CAMERAS.

2.5. Test Parameters

One full-scale vehicle crash test was conducted on the Iowa W-Beam Approach Guardrail Transition Section, as shown in Figures 4 through 14.

Test I6-1 was conducted at a target impact speed of 60 mph with an impact angle of 20 degrees. A 1983 Ford F-250 pickup weighing 5,420 lbs. was used as the crash test vehicle. The location of impact was 15 ft. upstream from the end of the concrete end-section between posts 5 and 6.

3. PERFORMANCE EVALUATION CRITERIA

The safety performance objective of a highway appurtenance is to minimize the consequences of a vehicle leaving the roadway to create an off-road incident. The safety goal is met when the appurtenance W-Beam Approach Guardrail Transition Section smoothly redirects the vehicle away from a hazard zone without subjecting the vehicle occupants to major injury producing forces.

Safety performance of a highway appurtenance cannot be measured directly, but it can be evaluated according to three major factors: (1) structural adequacy, (2) occupant risk, and (3) vehicle trajectory after collision. These three factors are defined and explained in NCHRP 230 (1). Similar criteria are presented in the new AASHTO criteria (2).

The test conditions for the matrix are shown in Table 1, and stated in Appendix B. Also, the specific evaluation criteria used to determine the adequacy of the barrier are listed and will be explained later in Tables 2 and 3.

After each test, the vehicle damage was assessed by the traffic accident scale (TAD) (4) and the vehicle damage index (VDI) (5).

TABLE 1. CRASH TEST CONDITIONS AND EVALUATION CRITERIA FOR THE IOWA APPROACH GUARDRAIL TRANSITION SECTION

Test Agency	Test Designation	Performance Level	Appurtenance	Test Vehicle	Impact Conditions			Evaluation Criteria[a]	
					Speed (mph)	Angle (deg)	Location	Required	Desirable
NCHRP 230 (1)	30	-	Transition	4,500 lb. (sedan)	60	25	15 ft. upstream from second system	A,D,E, H,I	-
AASHTO	-	PL-2	Bridge	5,400 lb. (pickup)	60	20	see NCHRP 230 (1)	3. a, b, c, d	3. e, f g, h

Notes:
[a] Criteria described in Tables 2 and 3.

TABLE 2. NCHRP 230 EVALUATION CRITERIA

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

TABLE 3. AASHTO EVALUATION CRITERIA

a.	The test article shall contain the vehicle; neither the vehicle nor its cargo shall penetrate or go over the installation. Controlled lateral deflection of the test article is acceptable.
b.	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.
c.	Integrity of the passenger compartment must be maintained with no intrusion and essentially no deformation.
d.	The vehicle shall remain upright during and after collision.
e.	The test article shall smoothly redirect the vehicle. A redirection is deemed smooth if the rear of the vehicle does not yaw more than 5 degrees away from the railing from time of impact until the vehicle separates from the railing.
f.	The smoothness of the vehicle-railing interaction is further assessed by the effective coefficient of friction μ, where $\mu = (\cos\theta - V_p/V)/\sin\theta$. μ — Assessment 0.0 - 0.25 — Good 0.26 - 0.35 — Fair > 0.35 — Marginal
g.	The impact velocity of a hypothetical front-seat passenger against the vehicle interior, calculated from vehicle accelerations and 2.0 ft. longitudinal and 1.0 ft. lateral displacements, shall be less than: Occupant Impact Velocity - fps Longitudinal: 30 — Lateral: 25 and for the vehicle highest 10-ms average accelerations subsequent to the instant of hypothetical passenger impact should be less than: Occupant Ridedown Accelerations - g's Longitudinal: 15 — Lateral: 15
h.	Vehicle exit angle from the barrier shall not be more than 12 degrees. Within 100 ft. plus the length of the test vehicle from the point of initial impact with the railing, the railing side of the vehicle shall move no more than 20 ft. from the line of the traffic face of the railing.

4. TEST RESULTS

4.1. Test No. I6-1

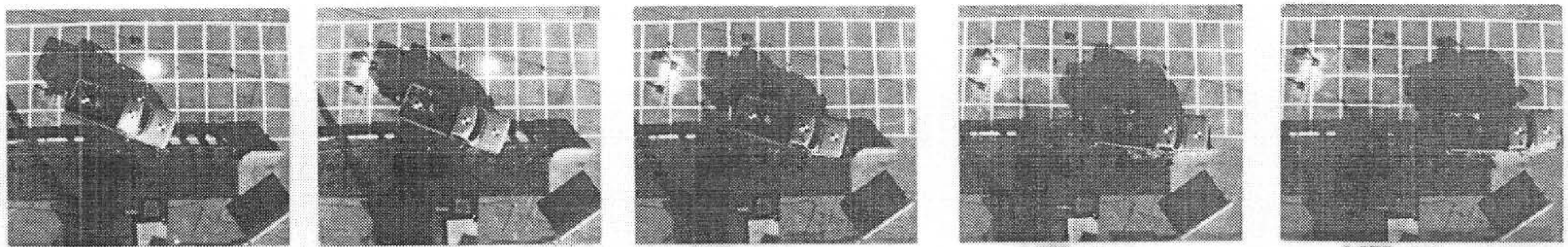
Test I6-1 was conducted with a 5,420 lb. Ford F-250 pickup under the impact conditions of 61.45 mph and 20.0 degrees. The location of impact was 15 ft. upstream from the end of the concrete end-section. A summary of the test results is shown in Figure 20. The sequential photographs are shown in Figures 21 (a), (b), and (c).

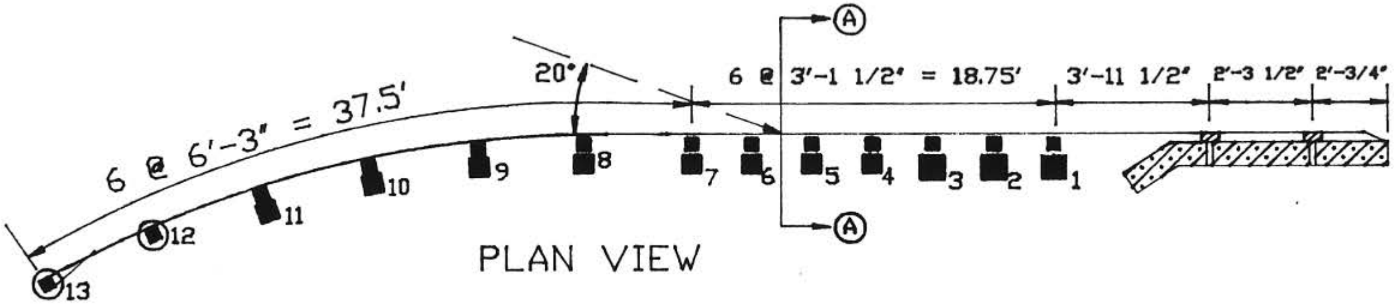
Upon impact with the w-beam approach guardrail, the right front corner of the vehicle began to crush inward. At approximately 0.025 sec., the vehicle was between posts 5 and 4. At 0.040 sec., the right front corner of the vehicle was over post 4. The right front corner of the vehicle was over post 3, 2, and 1 at approximately 0.076, 0.110, and 0.144 sec., respectively. The vehicle began to show an uplifting motion due to the presence of the curb at approximately 0.126 sec.

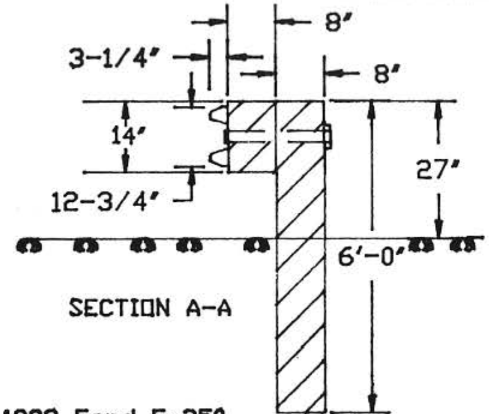
The vehicle came into contact with the concrete end-section at approximately 0.159 sec. At 0.172 sec., the front end of the vehicle began to leave the ground surface. The vehicle was parallel to the installation at approximately 0.273 sec., with a parallel velocity of 42.74 mph. At approximately 0.305 sec., the vehicle began to exit the installation at 41.72 mph and 2.8 degrees.

The vehicle was airborne after being redirected at approximately 0.350 sec. At about 0.521 sec., the vehicle began to fall back toward the ground. At approximately 0.807 sec., the vehicle impacted the concrete apron surface.

Photographs of the vehicle damage are shown in Figure 22. As evident, the vehicle damage was marginal. The TAD and VDI damage classifications are shown in Figure 20.



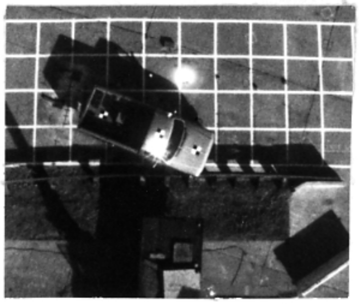




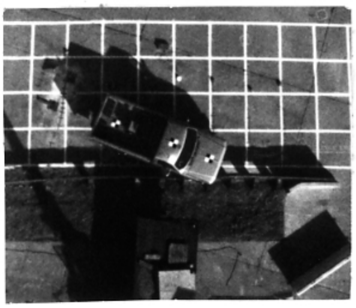
● Test No.	I6-1
● Date	11/10/89
● Installation	Iowa W-Beam Approach Guardrail To The Concrete Safety Shape Bridge Rail
Drawing No.	BRF-000S(12)--38-00
Length	64'-6 3/4"
● Concrete Bridge Rail End	Concrete Safety Shape Barrier Rail
Length	7'-0"
Height	2'-8"
● Guardrail Beam Member	Standard W-Beam
Size	12 Gauge
Length	62'-6"
● Guardrail W-Beam Terminal Connector	10 Gauge (Type F)
Length	2'-6"
● Guardrail Breakaway End Anchorage	10 Gauge (Type E)
● Guardrail Posts	Timber
Size	
Post No. 1 thru 3	10" X 10" X 72"
Post No. 4 thru 11	8" X 8" X 72"
Post No. 12 and 13	6" X 8" X 72"
● Concrete Curb Section	
Width	
Top	4 1/2"
Bottom	7 1/2"
Height	6"
● Soil Conditions	Dry
Type	
Lower Layer	Special Backfill
Upper Layer	Earth Fill

● Vehicle	
Model	1983 Ford F-250 Pickup
Weight	
Test Inertia	5,420 lbs.
Gross Static	5,420 lbs.
● Vehicle Speed	
Impact	61.45 mph
Exit	41.72 mph
● Vehicle Angle	
Impact	20.0 degrees
Exit	2.8 degrees
● Vehicle Snagging	Marginal
● Vehicle Stability	Marginal
● Occupant Impact Velocity	
Longitudinal	21.6 fps
Lateral	17.1 fps
● Occupant Ridedown Deceleration	
Longitudinal	8.5 g's
Lateral	8.9 g's
● Vehicle Damage	Marginal
TAD	1-RFQ-4
VDI	01RFEK2
● Vehicle Rebound Distance	9'-7" @ 118'
● Guardrail Damage	Marginal
● Maximum Guardrail Deflections	
Permanent Set	12.4 in.
Dynamic	20.4 in.

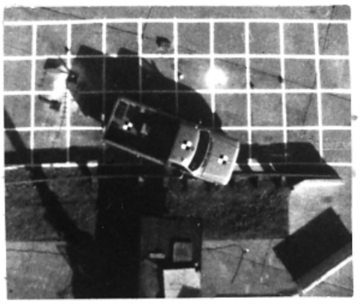
FIGURE 20. TEST I6-1 SUMMARY AND SEQUENTIAL PHOTOGRAPHS



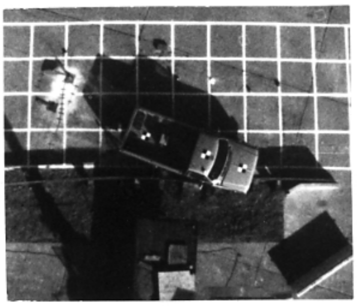
0.000 sec



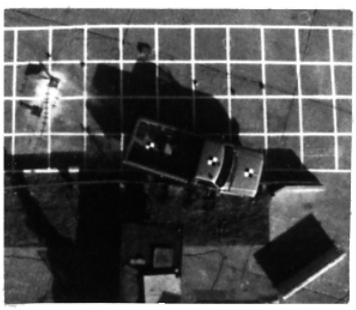
0.025 sec



0.040 sec



0.076 sec



0.110 sec

FIGURE 21(a). TIME-SEQUENTIAL PHOTOGRAPHS.

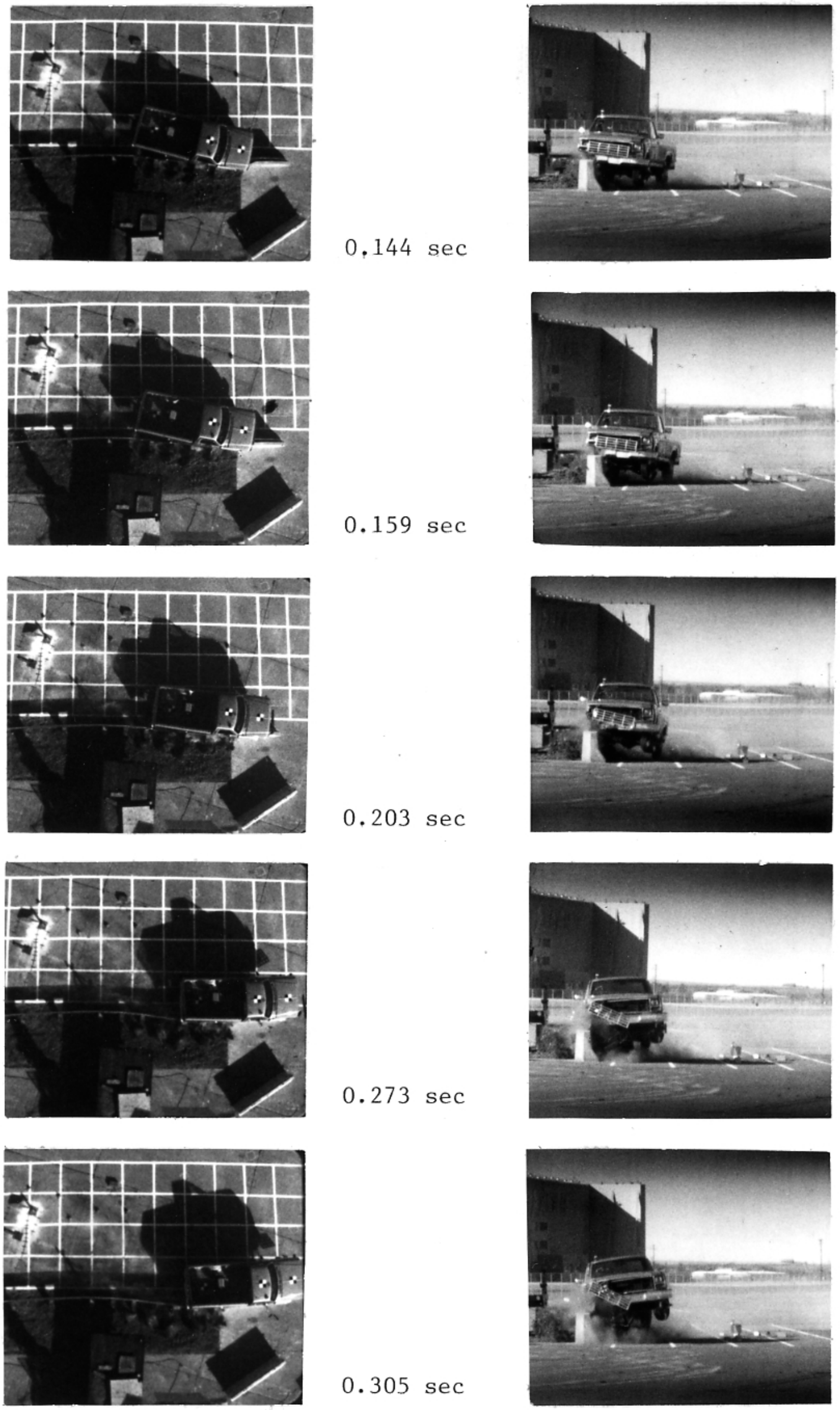


FIGURE 21(b). TIME-SEQUENTIAL PHOTOGRAPHS.

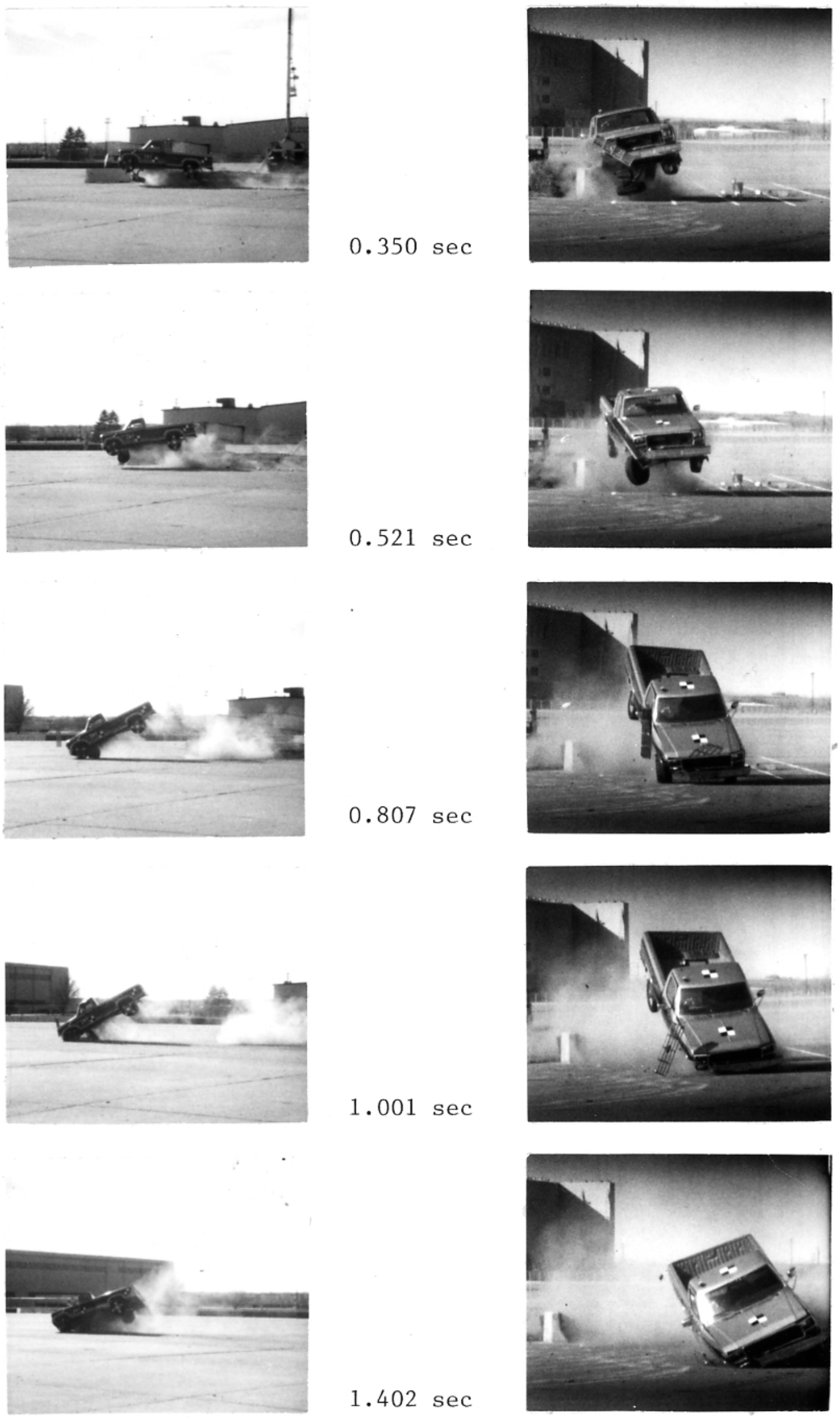


FIGURE 21(c). TIME-SEQUENTIAL PHOTOGRAPHS.

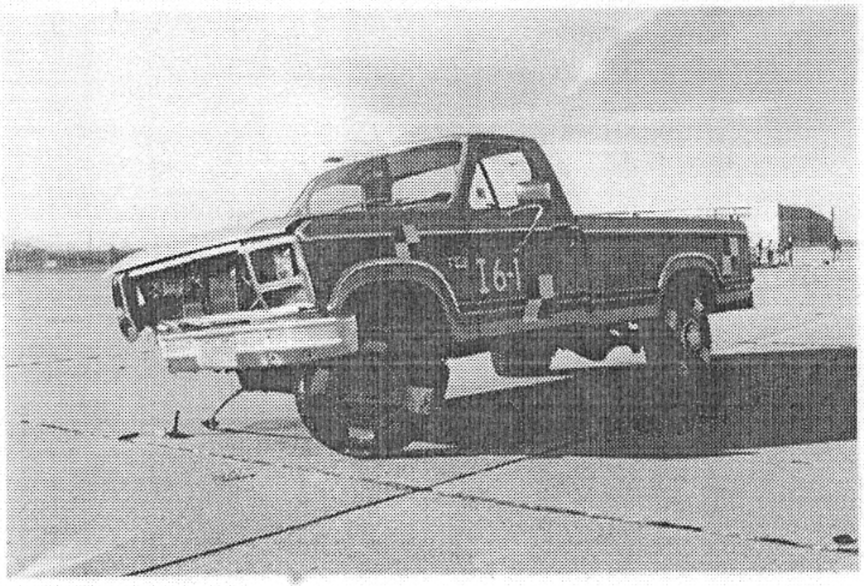


FIGURE 22. PHOTOGRAPHS OF VEHICLE DAMAGE.

Photographs of the marginal damage to the approach guardrail transition section are shown in Figures 23 through 26. After viewing the damaged guardrail, there was evidence that slight snagging occurred at post 1 and minor concrete spalling at the top of the concrete end-section.

After the test, the permanent set was measured and is shown in Figure 27. The maximum permanent set was 12.4-in. which occurred at post 2. The maximum lateral dynamic deflection was 20.4-in., as determined from the overhead high-speed camera.

Graphs of longitudinal and lateral deceleration, vehicle change in speed, lateral occupant impact velocity, and longitudinal and lateral occupant displacement versus time are given in Appendix C.

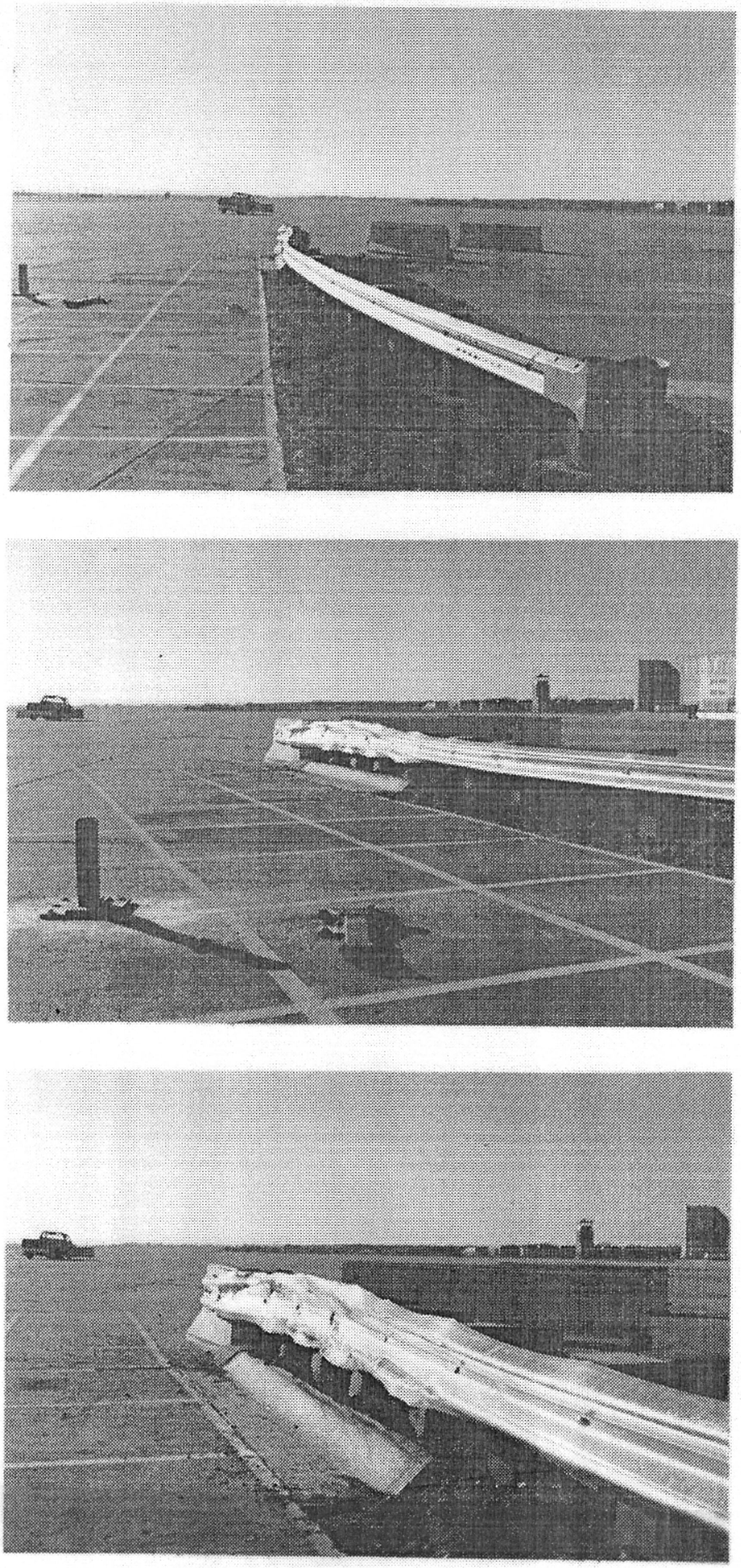
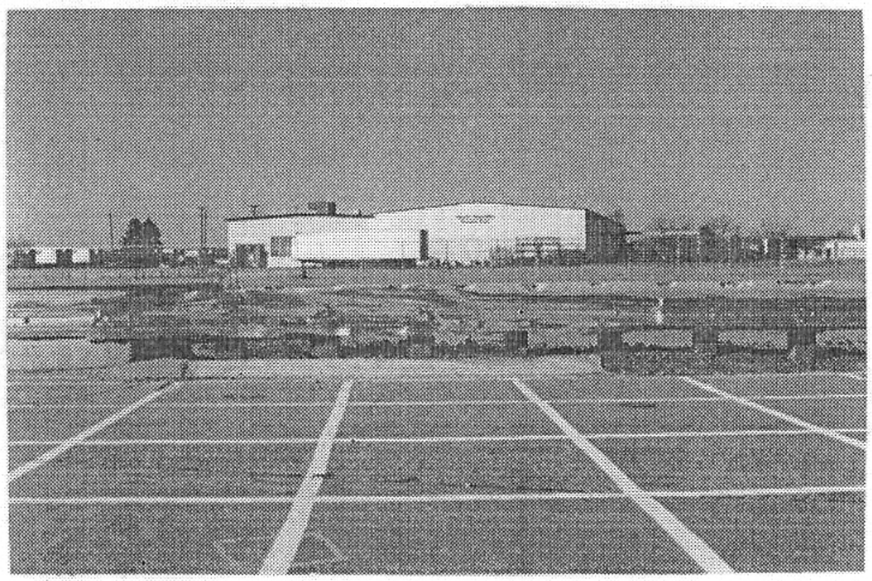


FIGURE 23. PHOTOGRAPHS OF DAMAGE TO APPROACH GUARDRAIL TRANSITION SECTION.



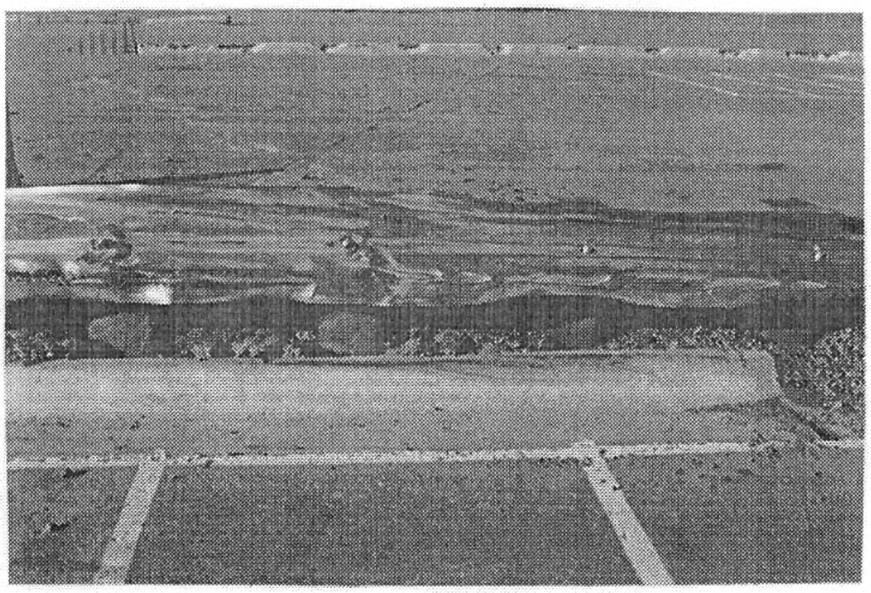
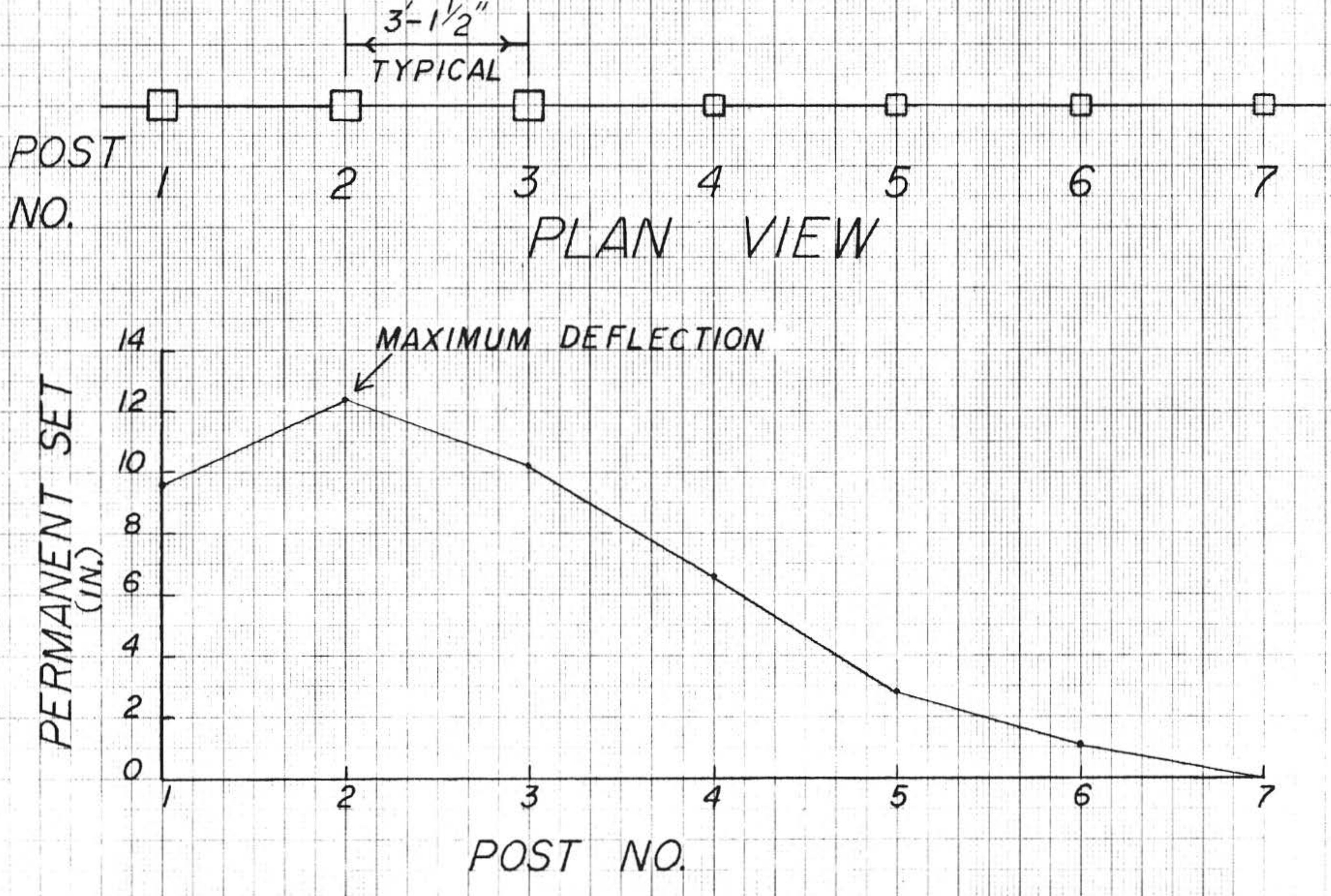


FIGURE 24. PHOTOGRAPHS OF DAMAGE TO APPROACH GUARDRAIL TRANSITION SECTION.

FIGURE 25. PHOTOGRAPHS OF DAMAGE TO APPROACH GUARDRAIL TRANSITION SECTION.

FIGURE 26. PHOTOGRAPHS OF DAMAGE TO APPROACH GUARDRAIL TRANSITION SECTION.

FIGURE 27. GRAPH OF PERMANENT SET DISPLACEMENTS



5. CONCLUSIONS

One full-scale crash test was conducted to evaluate the safety performance of the Iowa W-Beam Approach Guardrail Transition Section.

Test I6-1 was evaluated according to the safety performance criteria given in NCHRP 230 (1) and AASHTO (2). The safety evaluation summaries using both sets of criteria are presented in Tables 4 and 5.

The analysis of the crash test revealed the following:

1. The Iowa W-Beam Approach Guardrail contained the test vehicle.
2. The test vehicle did not penetrate or ride over the installation.
3. The controlled lateral deflection of the test article was acceptable.
4. There were no detached elements or fragments from the test article which showed potential for undue hazard during and after the collision.
5. The integrity of the passenger compartment was maintained.
6. The test vehicle remained upright during and after the collision; although, the test vehicle was vaulted into the air due to the uplifting motion of the curb.
7. The occupant risk values for impact velocity and ridedown decelerations were acceptable during impact.
8. The test vehicle's change in speed was marginal (19.73 mph > 15 mph). The speed change is a trajectory hazard factor only when the redirectional barrier is very near the traffic stream or when the vehicle is redirected abruptly back into the traffic stream.

TABLE 4. NCHRP 230 EVALUATION CRITERIA

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

S - Satisfactory
M - Marginal
U - Unsatisfactory

TABLE 5. AASHTO EVALUATION CRITERIA

AREA	Required	Desirable
a. The test article shall contain the vehicle; neither the vehicle nor its cargo shall penetrate or go over the installation. Controlled lateral deflection of the test article is acceptable.	S	
b. 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	
c. Integrity of the passenger compartment must be maintained with no intrusion and essentially no deformation.	S	
d. The vehicle shall remain upright during and after collision.	M	
e. The test article shall smoothly redirect the vehicle. A redirection is deemed smooth if the rear of the vehicle does not yaw more than 5 degrees away from the railing from time of impact until the vehicle separates from the railing.		S
f. The smoothness of the vehicle-railing interaction is further assessed by the effective coefficient of friction μ, where $\mu = (\cos\Theta - V_p/V)/\sin\Theta$. μ — Assessment 0.0 - 0.25 — Good 0.26 - 0.35 — Fair > 0.35 — Marginal		Marginal (0.71)
g. The impact velocity of a hypothetical front-seat passenger against the vehicle interior, calculated from vehicle accelerations and 2.0 ft. longitudinal and 1.0 ft. lateral displacements, shall be less than: Occupant Impact Velocity - fps Longitudinal: 30 — Lateral: 25		S
and for the vehicle highest 10-ms average accelerations subsequent to the instant of hypothetical passenger impact should be less than: Occupant Ridedown Accelerations - g's Longitudinal: 15 — Lateral: 15		S
h. Vehicle exit angle from the barrier shall not be more than 12 degrees. Within 100 ft. plus the length of the test vehicle from the point of initial impact with the railing, the railing side of the vehicle shall move no more than 20 ft. from the line of the traffic face of the railing.		S

S - Satisfactory
M - Marginal
U - Unsatisfactory

9. The test vehicle's exit angle was satisfactory (2.8 degrees < 12 degrees [60% of 20°]).

Based upon the above listed items, the results of Test I6-1 are acceptable according to the NCHRP 230 (1) and AASHTO (3) guidelines.

6. RECOMMENDATIONS

The Iowa W-Beam Approach Guardrail Transition Section has met the required performance evaluation criteria set forth by NCHRP 230 (1) and AASHTO (2). Thus, it is our recommendation that the Federal Highway Administration accept this installation so that its use on Federal Aid Projects can be approved.

7. REFERENCES

1. "Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances," National Cooperative Highway Research Program Report 230, Transportation Research Board, Washington, D.C., March, 1981.

2. "Guide Specifications for Bridge Railings," American Association of State Highways and Transportation Officials, Washington, D.C., 1989.

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

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

5. "Collision Deformation Classification, Recommended Practice J224 Mar 80, "SAE Handbook Vol. 4, Society of Automotive Engineers, Warrendale, Penn., 1985.

8. APPENDICES

APPENDIX A.

CONCRETE COMPRESSIVE STRENGTHS

AND DESIGN MIX SPECIFICATIONS

MATERIALS TESTING LABORATORY
DEPARTMENT OF ENGINEERING MECHANICS
UNIVERSITY OF NEBRASKA

Course ______

Test: 28 day Strength

Material: $f'_c = ?$

Performed by: Jim Holloway   Date: 10/23/89

Testing Machine: 440 BTE 64305 Calibration good thru 6/90.

Specimen Data: ______

Cyl. #	C_1 (ft) Circumference	C_2 (ft)	C_3 (ft)	$\bar{C}$ (ft)	$r = \frac{C}{2\pi}$ (in)	$A = \pi r^2$ (in)^2	P = load @ yield (#)	STRENGTH = P/A (psi)
1	1.580	1.585	1.590	1.585	3.027	28.786	106,000	3682.3
2	1.570	1.580	1.590	1.580	3.018	28.615	112,500	3931.5
3	1.570	1.580	1.580	1.577	3.012	28.501	99,500	3491.1
								ave: 3701.6

GENERAL TESTING LABORATORIES

TELEPHONE
402-464-6384

P. O. BOX 29208
LINCOLN, NEBRASKA 68529

September 15, 1989

To: Ray Ayars
Ready Mixed Concrete Co
6200 Cornhusker Hwy
Lincoln, Nebraska 68529

RE: State Mix Design, 47B-PHE

MATERIAL	WT/CU YD	SUPPLIER
Portland Cement, Type III, Grey	682 lb	Lone Star Cement Bonner Springs, KS
47B Limestone (SSD)	880 lb	Kerford Limestone Weeping Water, NE
47B Sand & Gravel (SSD)	2040 lb	Western Sand & Gravel Ashland, NE
Air Entraining Admixture, Prokrete AES	3.5 oz	Prokrete Industries Denver, CO
Water Reducing Admixture, Prokrete N	13.5 oz	Prokrete Industries Denver, CO
Total Water	34 gal	Lincoln Water System Lincoln, NE

General Testing Lab,

Bill Fuller

Bill Fuller, Manager

General Testing Laboratories

TELEPHONE
402-464-6384

P. O. BOX 29208
LINCOLN, NEBRASKA 68529

September 15, 1989

AGGREGATE DATA

47B LIMESTONE:

Screen	1"	3/4"	1/2"	3/8"	#4	#8	#16	#20	#200
Spec:	0/8	10/34		55/85		88/100		94/100	
% Retained:	6	19	33	57	87	94	96	97	98

Bulk Specific Gravity (SSD): 2.66

24 Hour Absorption: 1.1%

47B SAND & GRAVEL:

Screen:	3/8"	#4	#8	#10	#16	#30	#50	#100	#200
Spec:		3/23		30/50		60/84			97/100
% Retained:	1	13	29	36	51	76	93	99	99.8

Bulk Specific Gravity (SSD): 2.62

24 Hour Absorption: 0.6%

PROKRETE Industries
ProChemTechnology, Inc.
3990 Havana Street • Denver, Colorado 80239
Telephone: (303) 375-0990
Telefax: (303) 375-9306

January 20, 1989

MANUFACTURER'S
CERTIFICATION

Lincoln Ready Mix
P. O. Box 82114
Lincoln, NE 68501

RE: ProChemTechnology, Inc. Air Entraining Solution (Regular)

Gentlemen:

We hereby certify that ProChemTechnology, Inc. Air Entraining Solution is manufactured to comply with the requirements of the Department of Transportation, Bureau of Reclamation, U.S. Corps of Engineers Specification CRD C-13-79, as well as ASTM Specification C-260-86 and AASHTO Specification M-154-79.

It is further certified that ProChemTechnology, Inc. Air Entraining Solution does not contain any form of Calcium Chloride.

It is also certified that the above stated material has not been changed or altered in any way.

Prokrete Industries
ProChemTechnology, Inc.

Larry J. Kern
Director of Research and Development

PROKRETE Industries
ProChemTechnology, Inc.
3990 Havana Street • Denver, Colorado 80239
Telephone: (303) 375-0990
Telefax: (303) 375-9306

January 20, 1989

MANUFACTURER'S
CERTIFICATION

Lincoln Ready Mix
P. O. Box 82114
Lincoln, NE 68501

RE: ProChemTechnology, Inc. Pro-Krete N

Gentlemen:

This is to certify that ProChemTechnology, Inc. Pro-Krete N conforms to the requirements of ASTM C-494-86, AASHTO M-194-84 and CRD C-87-86, Type A admixture when used at the rate of two fluid ounces per 100 pounds of cement.

ProChemTechnology, Inc. Pro-Krete N is a highly purified and multiple-component admixture which does not contain any form of Calcium Chloride.

Prokrete Industries
ProChemTechnology, Inc.

Larry J. Kern
Director of Research and Development

APPENDIX B.

RELEVANT IDOT CORRESPONDENCE

Iowa Department of Transportation
800 Lincoln Way, Ames, Iowa 50010 515/239-1206

October 26, 1989

Ref. No. State Wide Safety
BRF-000S(2)--38-00

Dr. Edward R. Post
Civil Engineering Department
University of Nebraska
W348 Nebraska Hall
Lincoln, Nebraska 68588-0531

Dear Dr. Post:

This letter is to confirm the phone call on September 25, 1989, relating to the Rail Crash Test Program, Task No. 6. The Iowa DOT wants the test to be carried out as stated in Appendix A of the Supplemental Agreement No. 1, dated July 5, 1989 and as modified by Supplemental Agreement No. 2, dated September 12, 1989.

These agreements require one test with a 5.4 kip pickup traveling 60 MPH and at a 20 degree angle with the guardrail. The impact point will be 15 feet upstream from the end of the concrete rail, which is a point between guardrail posts 5 and 6.

Because of the possibility of additional transition section crash tests we would request that the installation as built be left in place at the conclusion of task No. 6 until we can determine the need for additional testing.

Sincerely,

William A. Lundquist
Bridge Engineer

WAL:rcw
cc: R. Humphrey
G. Anderson
G. Sisson
B. Brakke

APPENDIX C.

ACCELEROMETER DATA ANALYSIS

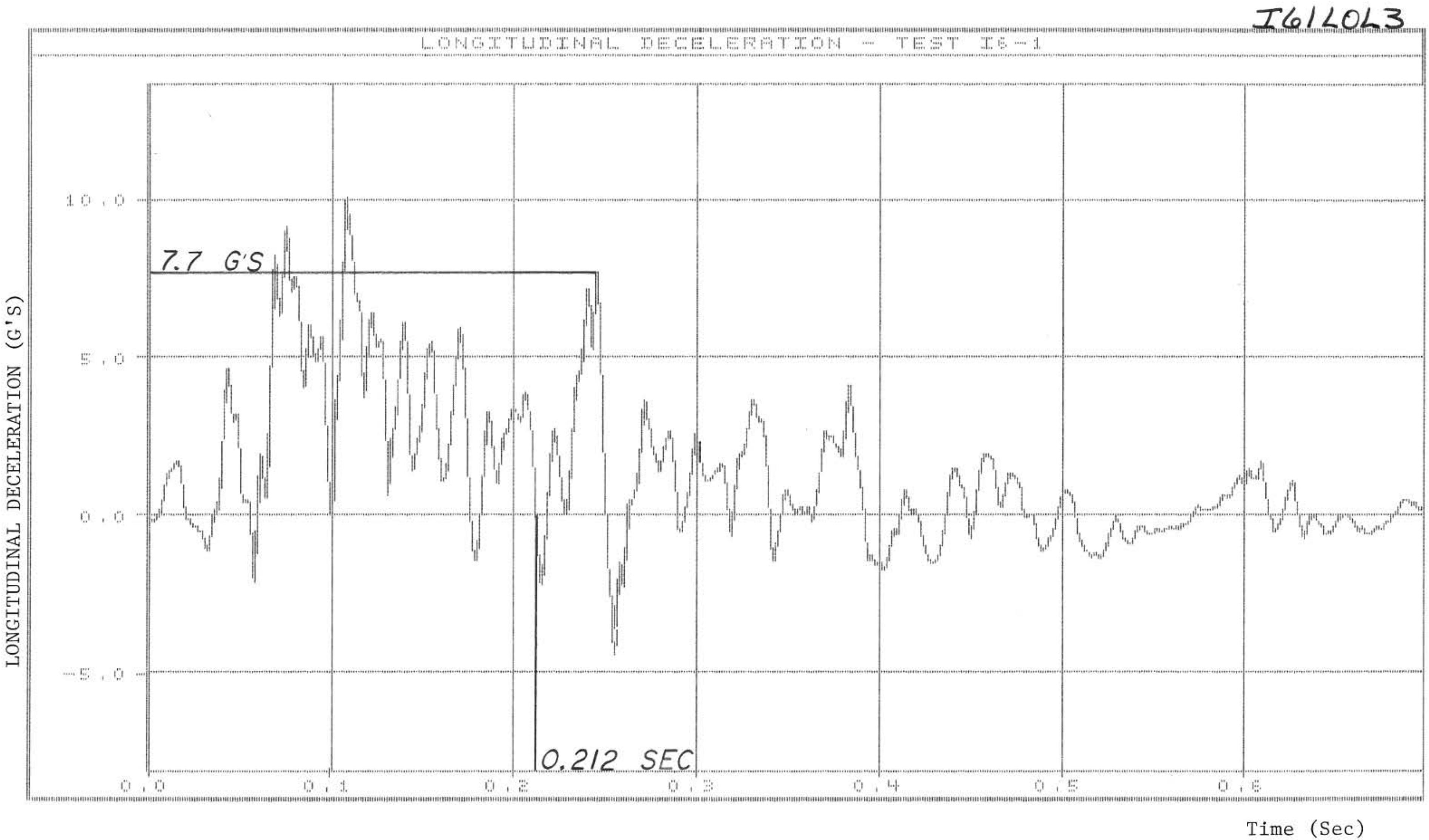


FIGURE C-1. GRAPH OF LONGITUDINAL DECELERATION, TEST I6-1.

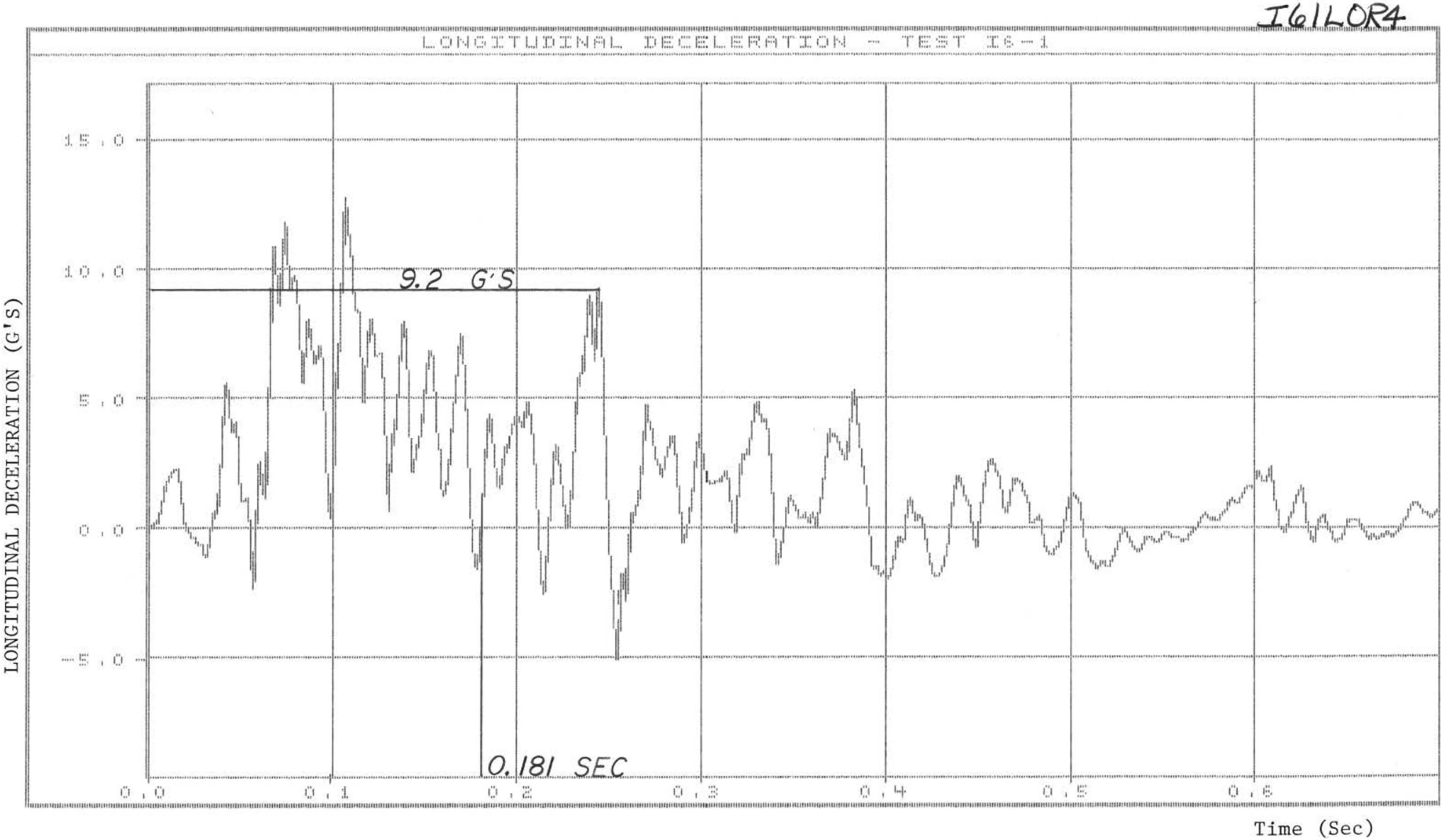
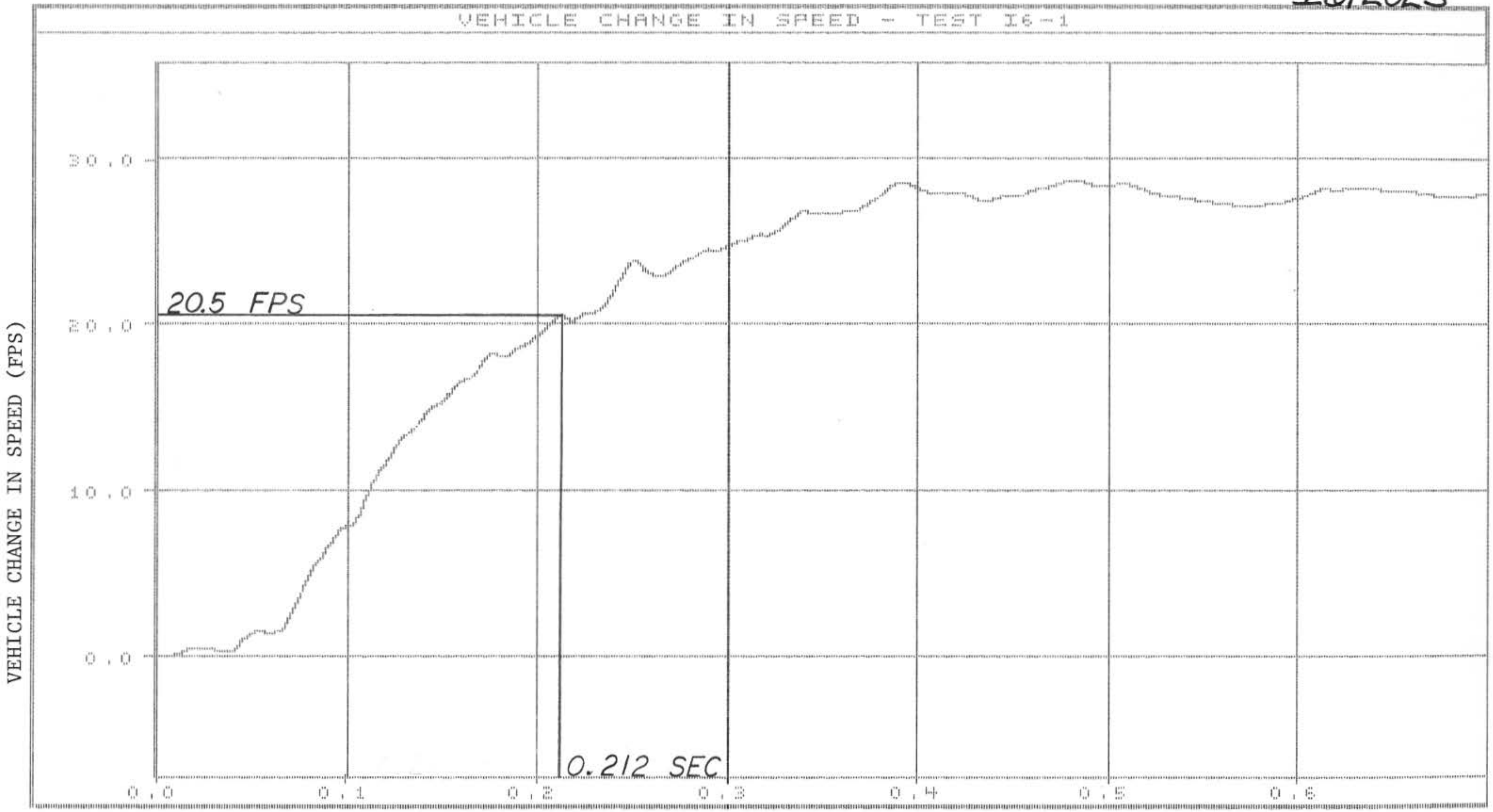


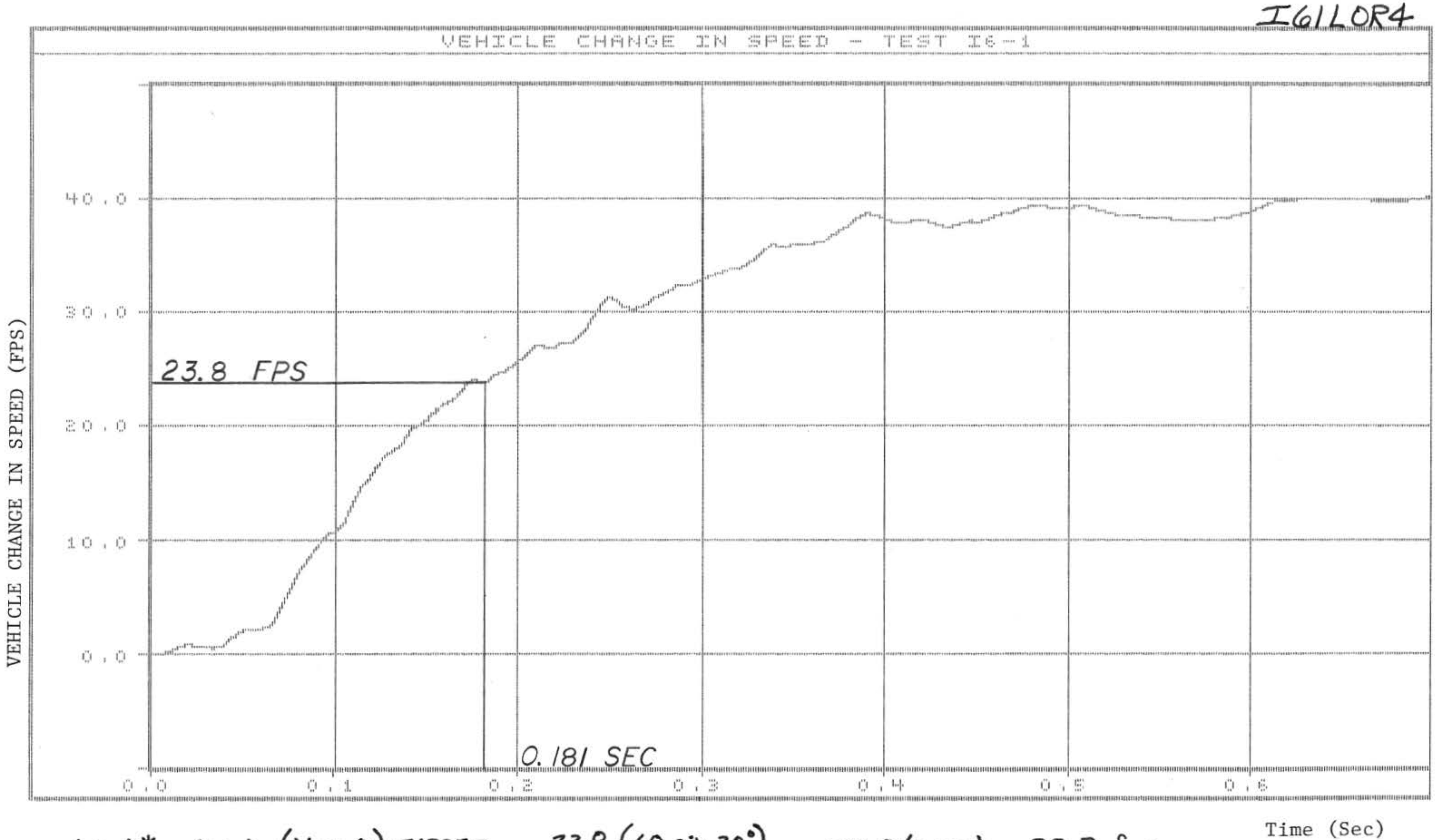
FIGURE C-2. GRAPH OF LONGITUDINAL DECELERATION, TEST I6-1.

I61L0L3



$$(\Delta V)^{*} = (\Delta V)\frac{(V\sin\theta)\ TARGET}{(V\sin\theta)\ ACTUAL} = \frac{20.5\,(60\sin 20^{\circ})}{(61.45\sin 20^{\circ})} = 20.5\,(0.9764) = 20.0\ \text{fps}$$

FIGURE C-3. GRAPH OF VEHICLE CHANGE IN SPEED, TEST I6-1.



$$(\Delta V)^{*} = (\Delta V)\frac{(V\sin\theta)_{TARGET}}{(V\sin\theta)_{ACTUAL}} = \frac{23.8\,(60\sin 20^{\circ})}{(61.45\sin 20^{\circ})} = 23.8(0.9764) = 23.2 \text{ fps}$$

FIGURE C-4. GRAPH OF VEHICLE CHANGE IN SPEED, TEST I6-1.

I61L0L3

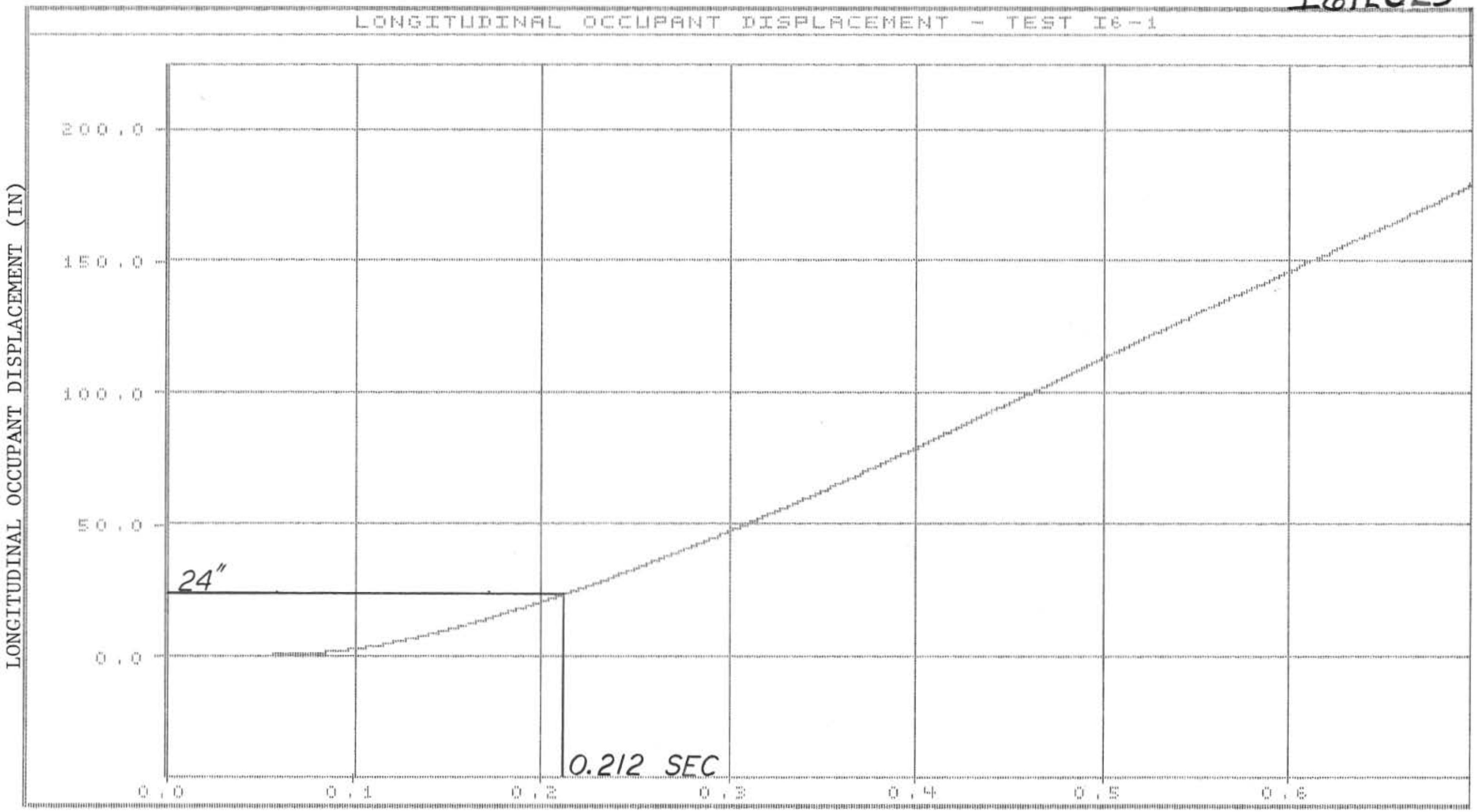


FIGURE C-5. GRAPH OF LONGITUDINAL OCCUPANT DISPLACEMENT, TEST I6-1.

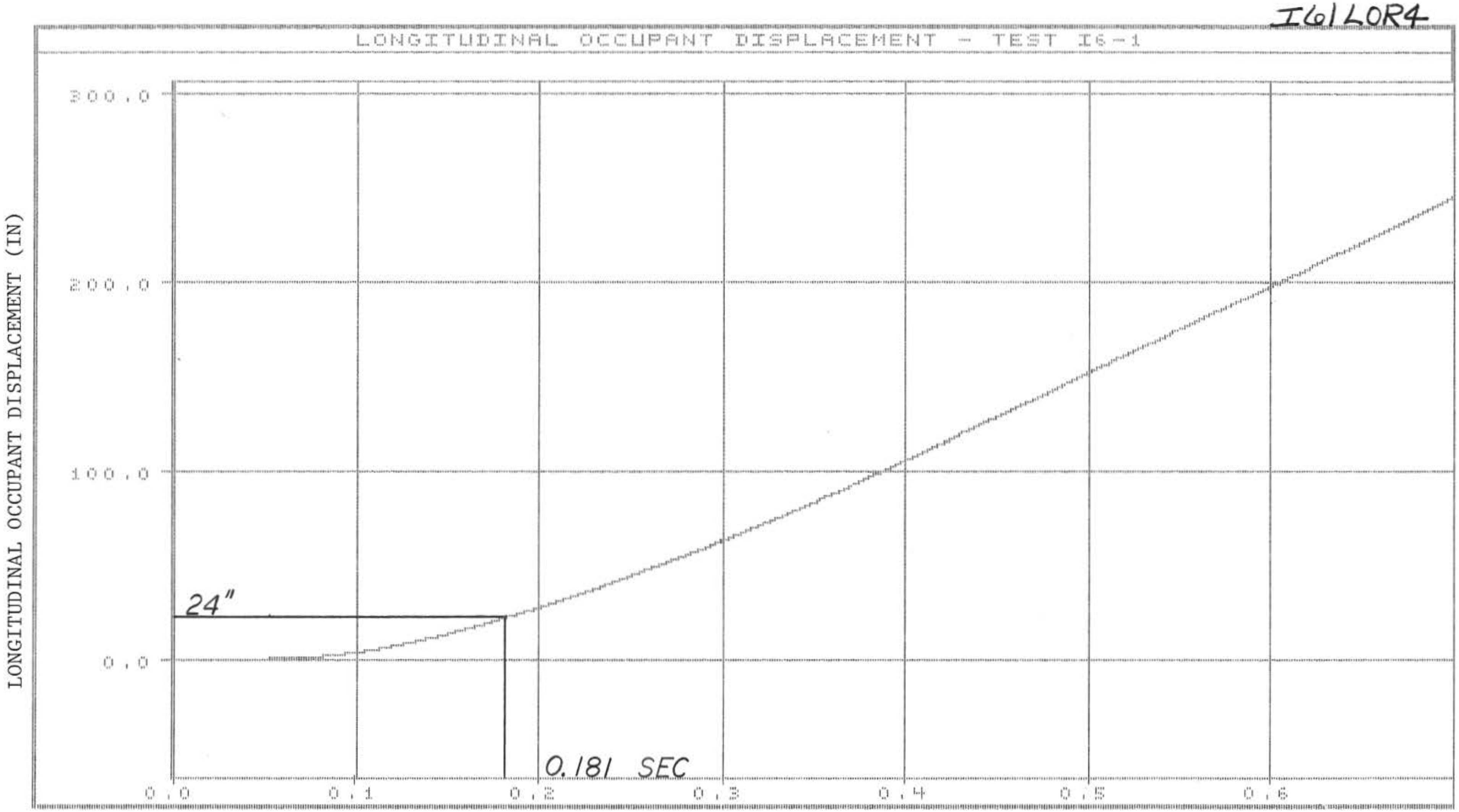


FIGURE C-6. GRAPH OF LONGITUDINAL OCCUPANT DISPLACEMENT, TEST I6-1.

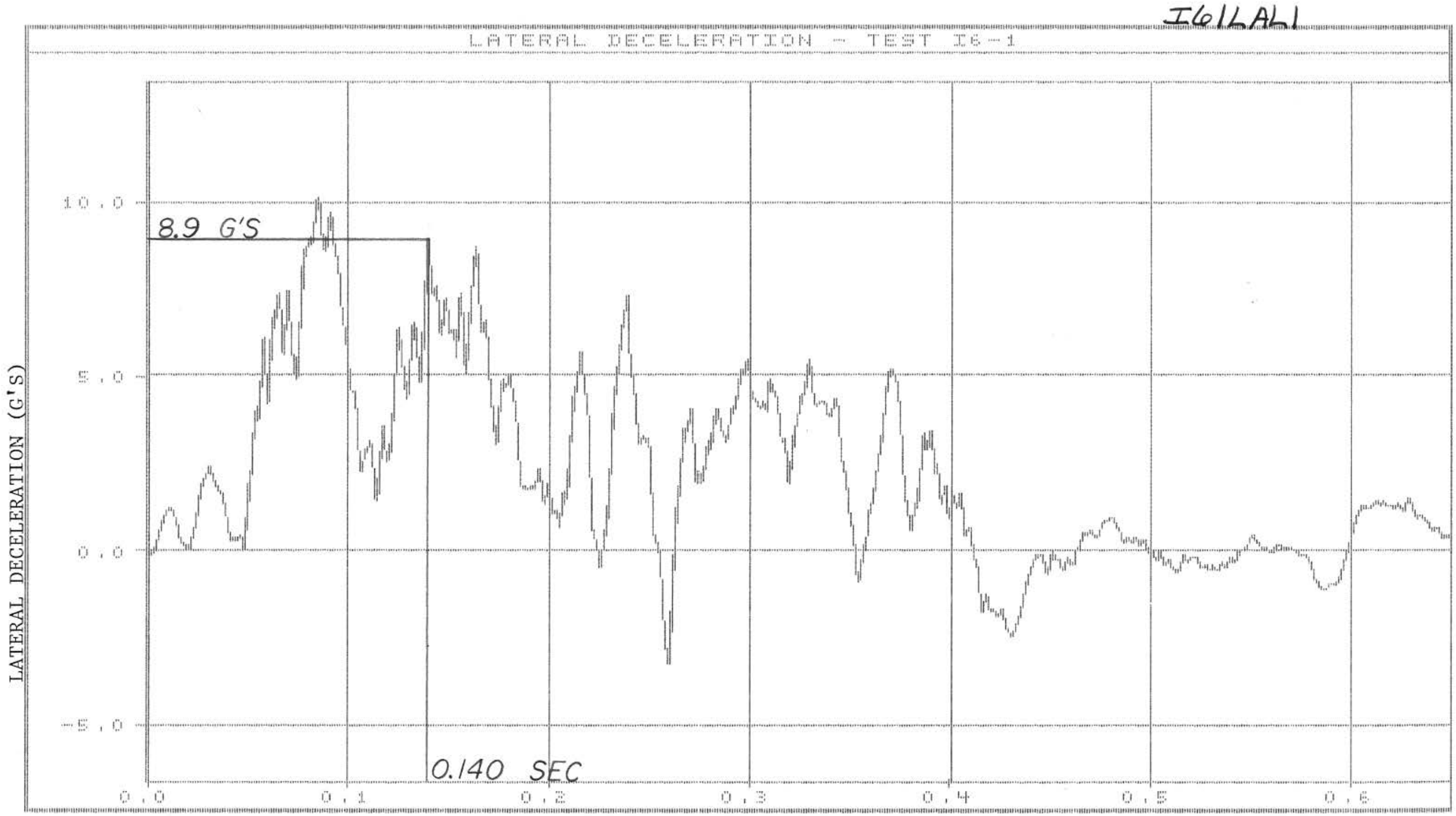
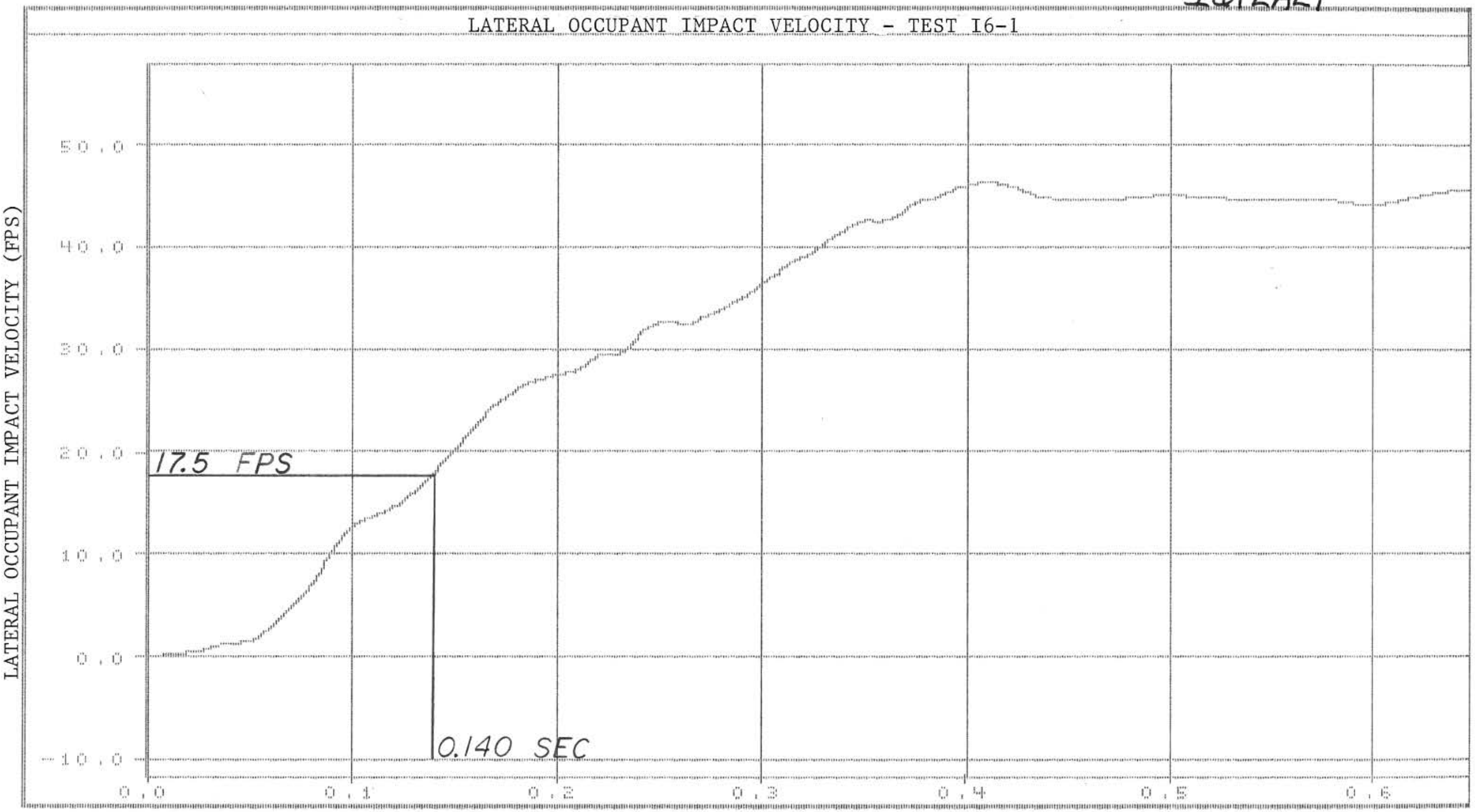


FIGURE C-7. GRAPH OF LATERAL DECELERATION, TEST I6-1.

I61LAL1



$$(\Delta V)^{*} = (\Delta V)\frac{(V\sin\theta)_{TARGET}}{(V\sin\theta)_{ACTUAL}} = \frac{17.5\,(60\sin 20^\circ)}{(61.45\sin 20^\circ)} = 17.5(0.9764) = 17.1\text{ fps}$$

FIGURE C-8. GRAPH OF LATERAL OCCUPANT IMPACT VELOCITY, TEST I6-1.

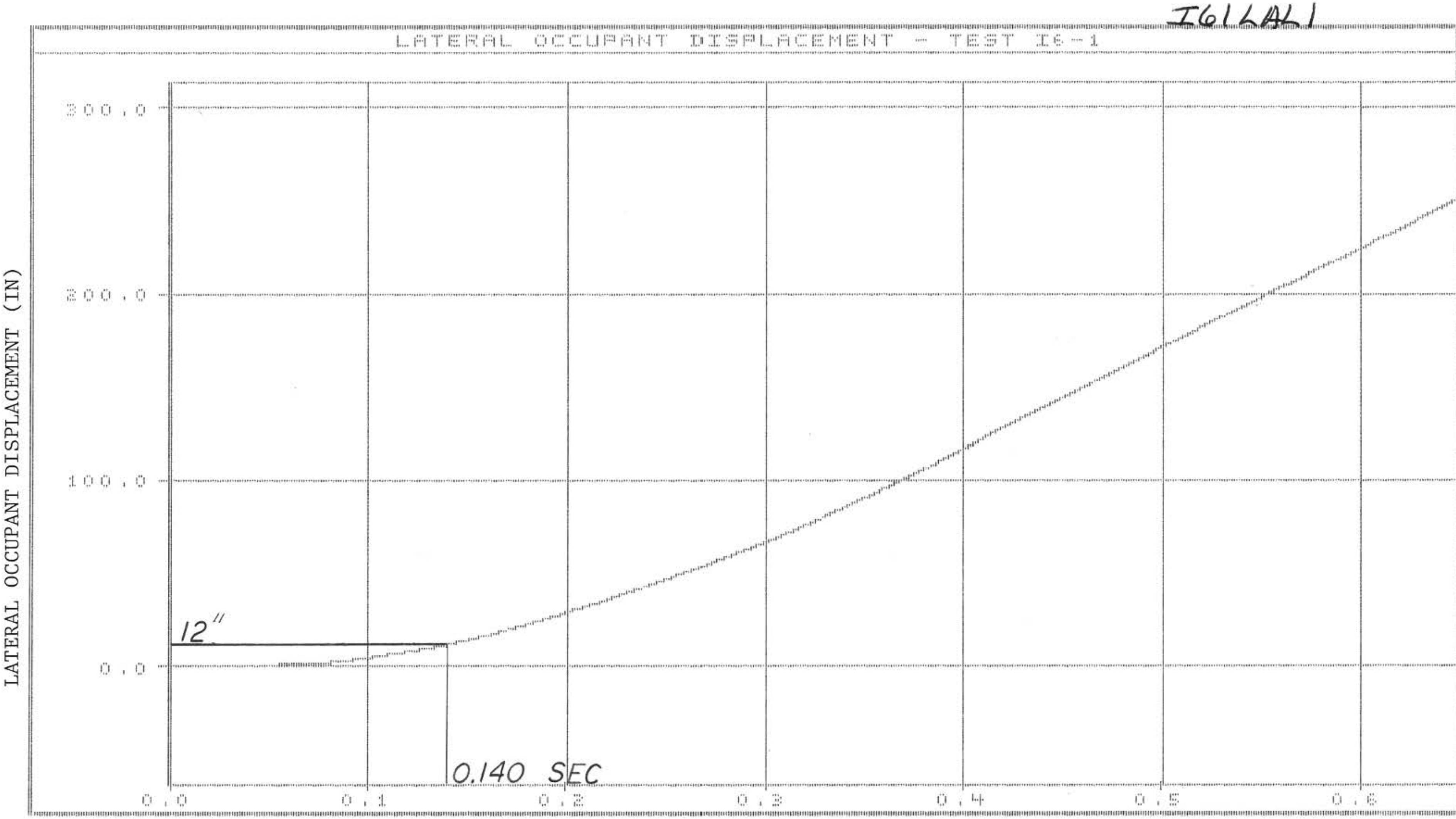


FIGURE C-9. GRAPH OF LATERAL OCCUPANT DISPLACEMENT, TEST I6-1.