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NATIONAL COOPERATIVE
HIGHWAY RESEARCH PROGRAM REPORT **289**

PERFORMANCE OF LONGITUDINAL TRAFFIC BARRIERS

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL

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PERFORMANCE OF LONGITUDINAL TRAFFIC BARRIERS

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RESEARCH SPONSORED BY THE AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS IN COOPERATION WITH THE FEDERAL HIGHWAY ADMINISTRATION

AREAS OF INTEREST:

FACILITIES DESIGN
TRANSPORTATION SAFETY
VEHICLE CHARACTERISTICS
(HIGHWAY TRANSPORTATION)

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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FOREWORD

By Staff
Transportation
Research Board

Highway designers having responsibility for the selection and testing of roadside hardware will find this report to be of special interest. Guardrail, median barriers, and bridge rail systems were evaluated with full-scale crash tests following the criteria presented in *NCHRP Report 230*. Emphasis was placed on testing barrier systems in current use to determine their effectiveness, and some additional work was accomplished to obtain information on the test criteria, e.g., vehicle type and impact angle. Contained in the report are the test results, barrier designs, and proposed changes to the crash-test criteria.

To date, few longitudinal barriers have been tested under all of the conditions specified in *NCHRP Report 230*. "Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances," which was published in 1981. Actual test results are needed by designers to select barrier systems that will perform satisfactorily. This research was initiated to provide such information on guardrail, median barrier, and bridge railing systems that have been fully tested and found to comply with the requirements of *NCHRP Report 230*. The objective was to develop an array of longitudinal traffic barriers and demonstrate their suitability for immediate application based on successful crash test performance.

In the initial phase of this study five guardrail, two median barrier, and four bridge systems were evaluated with full-scale crash tests for occupant risk with 1,800-lb sedans. The results were evaluated using the recommended values of *NCHRP Report 230* to which all systems were essentially in compliance. Therefore, system modifications were not needed and the project emphasis was shifted to documenting the designs of tested systems, including some designs tested by other research agencies and states, and to conducting additional tests that would provide insights to the test criteria and performance limits of the barrier systems.

The insight tests included five guardrail and one median barrier systems with an 1,800-lb sedan impacting at 60 mph and a 20-deg angle (test S13 of NCHRP Report 230). Six insight tests using vans to determine barrier performance thresholds for this type of vehicle were performed. Seven transition tests were performed as follows: three guardrail/bridge rail transitions, two guardrail/guardrail transitions; and two median barrier/median barrier transitions. Finally, two additional insight tests were performed. The first was a van impacting a G1 cable guardrail system mounted at a 24-in. height. The second test evaluated a blocked-out W-beam system with round wood posts. The insight tests were useful to the FHWA in developing modifications to the Report 230 criteria and in work related to the development of the AASHTO Roadside

Design Guide. States will also find this information of use in revising their test procedures and selection guides.

Design drawings for systems evaluated in this project and other recent projects are shown in a user format in Appendix A. The detailed reports of full-scale crash test evaluations and the high-speed film and transducer data obtained from tests are not published herein, but are available, on a loan basis or for purchase, upon written request to the Cooperative Research Programs, Transportation Research Board, 2101 Constitution Avenue, N.W., Washington, D.C. 20418.

SwRI also provided test films and a script for use in disseminating the research findings. FHWA plans to incorporate this material into a package for general distribution.

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ACKNOWLEDGMENTS

The research reported herein was performed under NCHRP Project 22-4 by Southwest Research Institute. Maurice E. Bronstad, Dynatech Engineering, Ink (previously with Southwest Research Institute) was the principal investigator. The other authors of this report are: Jarvis D. Michie and Joseph D. Mayer, Jr. The authors would like to express their appreciation to the agencies and individuals who provided input to this project.

PERFORMANCE OF LONGITUDINAL TRAFFIC BARRIERS

SUMMARY

This report presents findings and conclusions from the evaluation of an array of longitudinal traffic barriers. The barriers were evaluated according to the *NCHRP Report 230* (*1*) criteria. Special emphasis was given to barrier systems currently in use in large numbers.

Existing crash test performance of longitudinal barrier systems was reviewed for compliance with *NCHRP Report 230.* Based on this review a matrix of five guardrail, two median barrier, and four bridge rail systems was evaluated with full-scale crash tests for occupant risk with 1,800-lb (820-kg) sedans (test 12 in Table 3 of *NCHRP Report 230*). The results were evaluated using the recommended values of *NCHRP Report 230* to which all systems were essentially in compliance.

Further evaluation of five guardrail and one median barrier systems was performed with an 1,800-lb (820-kg) sedan impacting at 60 mph (95 km/h) and a 20-deg angle (test S13 of *NCHRP Report 230*). The purpose of these tests was to provide further insight into the performance of the barrier systems. Six insight tests using vans to determine barrier performance thresholds for this type of vehicle were performed. Seven transition tests were performed as follows; three guardrail/bridge rail transitions, two guardrail/guardrail transitions; and two median barrier/median barrier transitions. Finally, two additional insight tests were performed. The first was a van impacting a G1 cable guardrail system mounted at a 24-in. height. The second test evaluated a blocked-out W-beam system with round wood posts.

The following conclusions are based on the findings of this work. With minor exceptions, all eleven longitudinal barrier systems evaluated according to test 12 of *NCHRP Report 230* performed well and are deemed to have satisfied the assessment criteria.

The six longitudinal barrier systems evaluated according to test S13 of *NCHRP Report 230* satisfied the assessment criteria with the exception of the vehicle trajectory requirements. The six tests conducted with the van-type vehicle resulted in observed stability problems with this type vehicle. The height of the barrier system as well as the strength and geometrical characteristics are important factors for this type of vehicle.

The results of the transition tests showed acceptable behavior with the exception of the G3/BR3 transition. The geometrics of this transition caused severe snagging.

Based on findings of this project it is recommended that the standard test impact angle for the minicar be changed from 15 deg to 20 deg. Most of the current operational longitudinal barriers will perform satisfactorily at this angle and deficiencies in other systems will be more readily identified.

CHAPTER ONE

INTRODUCTION AND RESEARCH APPROACH

PROBLEM STATEMENT AND RESEARCH OBJECTIVES

The number of small cars in use in the United States is growing rapidly, and the changing characteristics of the vehicle fleet should be considered in highway safety design. The latest in a series of documents on evaluation procedures, *NCHRP Report 30,* "Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances," includes 1,800-lb (820-kg) vehicle crash tests to evaluate safety performance (*1*). *Report 230* also included for the first time tests using vehicles larger than the traditional full-size (4,500-lb (2,040-kg)) sedan. The inclusion of these larger vehicles in a supplementary test matrix recognized the potential need for longitudinal traffic barriers with different levels of service. These levels of service are generally specified by a higher energy structural adequacy test, along with the occupant risk test, using the 2,250-lb (1,020-kg) or preferably the 1,800-lb (820-kg) car test, and are based on work in NCHRP Project 22-3 (*4*). Before this project began, most operational longitudinal barrier systems had been evaluated by either or both the 4,500-lb (2,040-kg) car and 2,250-lb (1,020-kg) car tests based on earlier procedures (Refs. *5, 6*), but few systems had been evaluated for the occupant risk criteria using the 1,800-lb (1,020-kg) car test. Thus, designers did not have sufficient information to select barrier systems that had performed satisfactorily according to the evaluation criteria of the latest document.

There was a need to provide small car test information on guardrail, median barrier, and bridge railing systems to assure designers that the systems comply with the requirements of *NCHRP Report 230;* a need also existed to delineate the upper structural limits of effectiveness for each system.

NCHRP Project 22-4 was initiated in response to these needs. The major objectives of the research were twofold. The first was to develop an array of longitudinal traffic barriers, and the second was to demonstrate their suitability for immediate application based on successful crash test performance.

RESEARCH APPROACH

In pursuing these objectives the investigation was divided into two phases. The Phase I effort was comprised of four tasks and these tasks are briefly described as follows:

Task 1. With special emphasis given to barrier systems currently being installed or those already in-place in large numbers, crash test performance of longitudinal barrier systems was reviewed for compliance with *NCHRP Report 230* criteria (*1*).

Task 2. Based on the review of Task 1, a matrix of longitudinal barrier systems was recommended to the NCHRP project panel as candidates for the occupant risk test with 1,800-lb (820-kg) sedans (test 12 in Table 3 of *NCHRP Report 230*). A finalized matrix consisting of five guardrail, two median barrier, and four bridge rail systems was approved, by the project panel, for crash test evaluation.

The tests were conducted according to the procedures of *NCHRP Report 230,* and the results were evaluated using the recommended values of that document.

Task 3. As originally conceived, this task was to be devoted to concept development required to modify those systems which exhibited noncompliance with *NCHRP Report 230* criteria in Task 2.

Results of the Task 2 tests, however, indicated that all systems were essentially in compliance with *NCHRP Report 230,* and thus the modification effort scheduled for this task was not needed.

Task 4. In this task, the findings from the previous tasks were documented in an interim report (*2*) and a Transportation Research Board paper (*3*); a minimum of six barrier systems was recommended for further development. At least two types each of guardrail, median barrier, and bridge railing systems meeting the test requirements of *NCHRP Report 230* were desired. A working plan for the research to be conducted in Task 5 of Phase II was prepared, and submitted as part of the interim report.

The Phase II effort consisted of four tasks including preparation of the final project report:

Task 5. On the basis of a review of the Task 5 Working Plan submitted in the Interim Report, the project panel instructed the researchers to prepare a revised plan to further evaluate barrier systems for impacts corresponding to test S13 in *NCHRP Report 230.* The purpose of this test was to provide further insight into the performance of a barrier system; test conditions called for an 1,800-lb (820-kg) car impacting at 60 mph (95 km/h) and a 20-deg angle. On the basis of a review of the systems evaluated in Phase I, five guardrail systems and one median barrier system were selected for further evaluation using the S13 test condition.

Task 6. The purpose of this task was to develop a working plan for the Task 7 crash test evaluations. Instructions from the project panel were: (1) to perform six insight tests using vans to determine threshold of barrier performance with this type of vehicle; and (2) to perform transition tests—three guardrail/bridge rail tests, two guardrail/guardrail tests, and two median barrier/median barrier tests.

Task 7. The purpose of this task was to conduct insight crash test evaluations on selected systems using vans to determine the system "limit" for this type of vehicle. In addition, a number of transition designs were selected for evaluation. An insight test was also added to examine lower mounting height compatibility of the G1 cable guardrail system with a van impact.

Another evaluated a blocked-out W-beam system utilizing round wood posts.

Task 8. The purpose of this task was to prepare the project final report and a project summary movie. The final report, as submitted by the research agency, is in three volumes: Volume 1—Research Report, Volume 2—Design Drawings, and Volume 3—Full-Scale Crash Test Reports.

REPORT CONTENT

The information presented in this report is derived from Volumes 1, 2, and 3 of the project final report and is organized as follows. The selection of the barrier systems and the crash test conditions are described in Chapter Two; the crash tests are summarized in Chapter Three, and the findings are discussed in Chapter Four. Conclusions and recommendations are provided in Chapter Five. Drawings for systems evaluated in this project and other recent projects are shown in a user format in Appendix A. (*Note:* The drawings shown for these barriers were, in some cases, reproduced from larger drawings containing additional information not needed for basic barrier construction. For questions on dimensions or other barrier details, please contact the NCHRP or Southwest Research Institute.) Cited references are listed in Appendix B.

The detailed reports of the full-scale crash test evaluations and the high-speed film and transducer data obtained from the tests are not published herein, but are available, on a loan basis or for purchase, upon written request to the Cooperative Research Programs, Transportation Research Board, 2101 Constitution Avenue, N.W., Washington, D.C. 20418.

CHAPTER TWO

SELECTION OF LONGITUDINAL TRAFFIC BARRIER SYSTEMS AND TEST CONDITIONS

This chapter provides a summary of the selection process for the longitudinal barrier systems evaluated in this project. In addition, the selection of the impact conditions (i.e., vehicle type, impact speed, and angle) used is also described.

BARRIER AND TEST CONDITION SELECTION (PHASE I)

The chief purpose of this phase was to evaluate selected systems using the most recent crash test procedures. Specifically of interest was the 1,800-lb (820-kg) car test condition specified in *NCHRP Report 230.*

Barrier selection in Phase I began with a review of the operational barrier systems in the AASHTO Barrier Guide (*7*). This guide, published in 1977, included in the operational systems (i.e., systems that had performed successfully in crash tests) many of the most widely used and evaluated systems in the country. As shown in Table 1, only the G4(1S) blocked-out W-beam/steel post guardrail, and the MB5 concrete safety-shaped median barrier had been crash tested for the *NCHRP Report 230* test 12 condition (1,800-lb (820-kg) car, 60 mph (95 km/h), 15 deg) used in the occupant risk assessment. The remaining barriers were assessed further to reduce the number of barriers under consideration. Table 2 provides a summary of further screening and selection process that led to the selection of five guardrail, two median barrier, and four bridge railing designs. The matrix for crash test evaluation was completed by the addition of the Texas Type T4 and the NCHRP Service Level 1 bridge railing designs.

The Texas Type T4 uses a metal railing mounted on an 18-in. (0.46-m) high concrete parapet. This is one of the most common bridge rail systems, and the 18-in. (0.46-m) high parapet meets the current minimum criteria in the AASHTO Bridge Specification (*8*). The NCHRP Service Level 1 bridge railing was developed in NCHRP Project 22-2(3) and is the only bridge railing that had been tested to a lower service level requirement and the *NCHRP Report 230* test 11 condition. Thus, it would be fully evaluated after test 12.

The barriers selected for test are summarized in Table 3 and Figures 1 through 3. As shown in these figures, there are some deviations in the barrier configurations tested and those shown in the AASHTO Barrier Guide. These deviations are briefly discussed as follows:

- *G1 Guardrail.* A recent study by New York has led this State to a barrier height modification based on vehicle geometries. The G1 system height is being lowered from 30 in. (75 cm) to 27 in. (70 cm), as shown in Figure 1.
- *G2 and G3 Guardrail.* The distance from grade to the top of the soil plate was changed according to New York recommendations.
- *G4(2W) Guardrail.* Based on a survey by Task Force 13 of a special AASHTO/ARTBA/AGC subcommittee, the most commonly used 6-in. x 8-in. (15-cm x 20-cm) guardrail post is 6 ft (1.8 m) long. This "standard" post length was used in the evaluations.

Table 1. Operational longitudinal barrier systems, AASHTO Barrier Guide 1977.

Barrier System	NCHRP Report 230 Test Experience											Demonstrated⁺ Service Level
	10	11	12	S13	S14	S15	S16	S18	S19	S20	Other	
G1	P											2
G2	P											2
G3	P											2
G4(1W)	P											2
G4(2W)	P											2
G4(1S)	P		P	P				F			(A)	2
G4(2S)	P											2
G9	P							F			(D)	2
MB1	P											2
MB2	P											2
MB3	P											2
MB4W	P											2
MB4S					P							2
MB5	P	X	X	X		(B)		F			(C)	2
MB7	P											2
MB8	P											2
MB9	P	X			P							2
MB10	P	X			P							2
BR1	P											2
BR2	P	X										2
BR3	P	X										2
BR4												2
BR5	P											2

⁺NCHRP Report 230

Legend: P - passed Report 230 criteria
X - tested, not judged
O - different version or different notation shown
F - failed
(A) - 2 pickup sizes successfully redirected; van rolled over at 60 mph & 25°
(B) - bus redirected on lightly reinforced CMB and rigid CMB
(C) - 40,000-lb tractor trailer overrode barrier @ 53 mph & 15° angle
(D) - pickup, 62 mph, 29° angle, rollover

Table 2. Summary of barrier selection criteria, operational systems of 1977 ASSHTO Barrier Guide.

System	Comments	Selected for Test
G1	Cable system; widely used cables are popular in snow country; demonstrated advantage on sloping terrain	Yes
G2	W-beam/weak post system; low initial cost; good impact performance	Yes
G3	Box beam system used in 6 states. Has been extensively tested for cars, but not for 1800-lb car	Yes
G4(1W)	Blocked-out W-beam on 8x8 posts. Usage has declined since California and others have switched to 6x8 posts (G42W)	No
G4(2W)	Blocked-out W-beam on 6x8 posts; one of the most widely used guardrail systems	Yes
G4(1S)	Test 12 and S13 have both been conducted	No
G4(2S)	Test 12 has been conducted on a very similar system	No
G9	Blocked-out thrie beam on steel posts; usage is accelerating on this design	Yes
MB1	Obsolete system no longer being specified	No
MB2	Due to similarity with G2, Test 12 is not considered necessary if conducted on G2	No
MB3	Box beam median barrier; used in 14 states	Yes
MB4W	Blocked-out W-beam on timber posts with rub rail; higher service level barrier than other W-beam barriers without rub rail	Yes
MB4S	Due to expected similarity with G4(1S), Test 12 is considered unnecessary	No
MB5	Test 12 and S13 have been conducted on concrete safety shape	No
MB7	This aluminum strong beam median barrier has been systematically replaced and is not currently being specified	No
MB8	The aluminum balanced beam system has limited usage	No
MB9	Blocked-out thrie beam on steel posts; due to similarity with G9 guardrail, Test 12 is considered unnecessary	No
MB10	W-beam on breakaway posts; due to decline of the more flexible median barrier usage, this system is not selected	No
BR1	Concrete safety shape, Tests 12 and S13 already conducted	No
BR2	Steel rail on 15-in high parapet. Representative of many low parapet/metal rail systems	Yes
BR3	Two-rail system shown on curb in Barrier Guide. Recent application on flush decks	Yes
BR4	Dual steel box beam railing no longer being specified	No
BR5	Design shown in Barrier Guide has never been constructed as shown	No

• *G9 Guardrail.* Post/block-out dimensions were changed slightly to agree with the standard drawing in the AASHTO/ARTBA/AGC standard barrier hardware guide (*9*).

• *MB3 Median Barrier.* The post dimension was changed slightly to agree with the standardized hardware guide.

• *BR3 Bridge Rail.* The system was tested on a flush deck; the Barrier Guide shows this system mounted on a 10-in. (25-cm) high safety walk. The flush deck version is currently being specified in New York.

BARRIER AND TEST CONDITION SELECTION (PHASE II)

The working plan submitted at the end of Phase I was revised at the request of the project panel, in Phase II, Task 5. It is worth a digression at this point to briefly discuss the background that led to the revised plan.

In developing the working plan, several factors were important. Phase I of this project provided considerable insight into the performance of traffic barrier systems with the test 12 (1,800-lb car, 60 mph, 15-deg impact angle) conditions of *NCHRP Report 230.* Although there was considerable variation in the dynamic deflections of the barriers ranging from undeformed to over 40 in. (100 cm), and despite the fact that moderate-to-severe front-wheel snagging occurred in some of the tests, all of the systems met the *NCHRP Report 230* occupant risk criteria. To be noted also are the findings from recent accident data, as analyzed by Viner (*10*), that have indicated that a considerable percentage of the reported traffic barrier accidents have occurred with impact angles exceeding 15 deg and that in approximately 50 percent of these accidents, the vehicle was yawing prior to impact. On the basis of these observations, the 15-deg angle of test 12 might not be adequate for fully evaluating barrier performance. Test S13 of *NCHRP Report 230,* suggested as a supplementary test, would provide a more critical evaluation of significant wheel snagging potential of beam and post systems. Test S13 has been used in some previous testing. Two of the more common longitudinal barrier systems, the G4(1S) guardrail and the MB5 median barrier (concrete safety shape), have been evaluated for the test S13 conditions (*11,12*). In both instances, the test results indicated compliance with *NCHRP Report 230,* although there was severe wheel snagging in the G4(1S) test as shown in Figure 4. In the MB5 test, the vehicle remained upright with a maximum roll angle of 23 deg; vehicle damage for the test is shown in Figure 4.

To perform Task 5 insight testing, it was decided to select six systems. Bridge railings were eliminated from consideration based on the following rationale. The emphasis of this project has been on barrier systems with significant usage. A recent FHWA study at Southwest Research Institute (*13*) revealed that there are over 160 bridge rail designs currently being specified by the states. The actual number of designs in-place is many times that number; thus with the exception of the concrete safety "shape," there appears to be no bridge rail design that is widely used in more than one state.

One change in barrier installation details in Task 5 involved the elimination of a rectangular washer. A recent FHWA Technical Advisory T5040.23, dated March 13, 1984, recommended elimination of the rectangular washer used between the bolt head and the beam W-beam guardrail systems.

Table 3. Summary of longitudinal barriers selected for test.

	AASHTO Barrier Guide Designation	Description
1. Guardrails	G1	3-cable on weak posts (steel)
	G2	W-beam on weak posts (steel)
	G3	Box beam on weak posts (steel)
	G4(2W)	Blocked-out W-beam (wood post)
	G9	Blocked-out thrie beam (steel post)
2. Median Barriers	MB3	Box beam on weak posts (steel)
	MB4W	Blocked-out W-beam (wood posts) w/rub rail
3. Bridge Railings	BR2	Steel tube rail on 15-in. high concrete parapet
	BR3	Double rail-flush deck mounted
	not shown	Texas Type T4 - aluminum rail on 18-in. high concrete parapet
	not shown	NCHRP Service Level 1, thrie beam on breakaway steel posts

6. *Elimination of Rectangular Plate Washers*

a. The 3 x 1 ¾-inch rectangular washers typically installed under the head of the ⅝-inch diameter, button head post mounting bolts were originally specified in an effort to prevent the bolt heads at the posts near the end of a run of guardrail from pulling through the rail. This practice effected rail anchorage through the posts. The much better practice of anchoring guardrail ends by attaching them to buried anchors has eliminated the need for these washers. Nevertheless, these washers are still being installed. Actually, retention of the washers may be reducing guardrail effectiveness by not allowing the rail to separate from the posts upon impact, thus causing the rail to be pulled toward the ground by deflecting posts. Because the installation of these washers entails some cost with no apparent operational advantage and could even bring detrimental results, it would seem prudent to eliminate them on all new construction.

In the Phase I testing, these washers were installed; however, the presence of this washer was believed to be of no consequence in the tests because of the small barrier displacements.

Thus, building on the evaluated systems of the Phase I effort, it was proposed to evaluate certain of the more widely used systems using the S13 (20-deg angle) test condition.

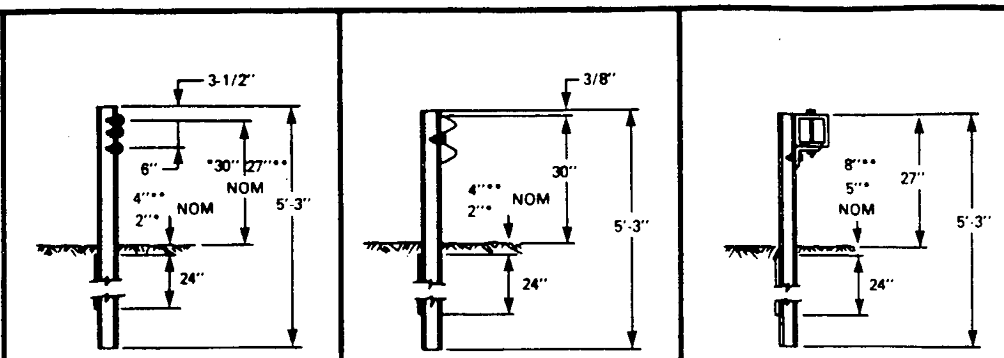
By eliminating the bridge rail systems of Phase I and the MB4W system because of limited future use, six systems remained. Accordingly, the proposed Task 5 insight series included the most widely used longitudinal traffic barrier systems in the country. Also, because barrier deflections would be more for the S13 condition than for the 12, the elimination of the rectangular washers in the G4(2W) and G9 test installations should provide improved performance by easing the separation of the beam from the posts.

Moreover, although it could be inferred that the G4(1S) system test provides sufficient documentation for the G4(2W) and G9 systems, the performance of these tests would provide additional documentation that these widely used strong post systems perform adequately for the 20-deg angle test. It was also considered possible that the wheel snagging which occurred in the G4(1S) system would not occur with the G4(2W) and G9 systems.

It was anticipated that the proposed work of Task 5 would provide the basis for performance comparison of eight (including G4(1S) and MB5) widely used traffic barrier systems using the S13 impact condition. It was also expected that these tests would show that many, if not all, of these barriers would meet the design requirements for this severe test, although vehicle and barrier damage would be dramatically different from that for the previous test series of Phase I. Advantages of certain systems

*BARRIER GUIDE
**AS TESTED

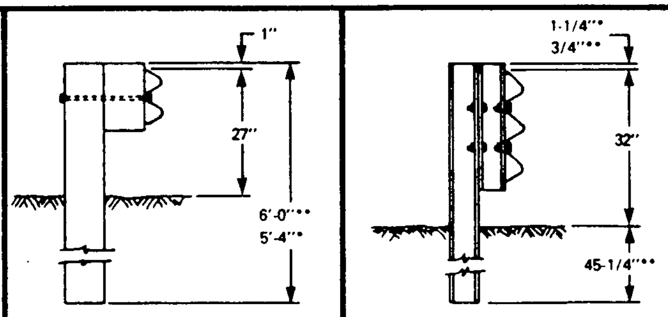
METRIC CONVERSIONS
1 ft. = 0.305 m 1 in. = 25.4 mm 1 mph = 1.61 km/hr 1 lb = 0.454 kg



SYSTEM	G1 CABLE GUARDRAIL	G2 "W" BEAM (STEEL WEAK POST)	G3 BOX BEAM
BARRIER DESCRIPTION			
POST SPACING	16'0"	12'6" NOMINAL	6'-0"
POST TYPE	S3 x 5.7 STEEL	S3 x 5.7 STEEL	S3 x 5.7 STEEL
BEAM TYPE	THREE 3/4" DIAMETER STEEL CABLES	STEEL "W" SECTION, 12 GA.	6" x 6" x 0.180" STEEL TUBE
OFFSET BRACKETS	-------	---	L5" x 3-1/2" x 1/4" STEEL ANGLE, 4-1/2" L
MOUNTINGS	5/16" DIAMETER STEEL HOOK BOLTS	5/16" DIAMETER STEEL BOLT	3/8" DIA. STEEL BOLT (BEAM TO ANGLE)
FOOTINGS	1/4" x 8" x 24" STEEL PLATE WELDED TO POST	1/4" x 8" x 24" STEEL PLATE WELDED TO POST	1/4" x 8" x 24" STEEL PLATE WELDED TO POST

*BARRIER GUIDE
**AS TESTED

METRIC CONVERSIONS
1ft. = 0.305 m 1 in. = 24.4 mm 1 mph = 161 km/hr 1 lb = 0.454 kg



SYSTEM	G4(2W) BLOCKED-OUT "W" BEAM (WOOD POST)	G9 BLOCKED-OUT "THRIE BEAM" (STEEL POST)
BARRIER DESCRIPTION		
POST SPACING	6' 3"	6'3"
POST TYPE	6" x 8" DOUGLAS FIR³	W6 x 8.5 STEEL
BEAM TYPE	STEEL "W" SECTION, 12 GA	THRIE BEAM, STEEL, 12 GA
OFFSET BRACKETS	6" x 8" x 14" DOUGLAS FIR BLOCK ³	W6 x 8.5 AND M14 x 17.2, STEEL
MOUNTINGS	5/8" DIAMETER CARRIAGE BOLTS	2 5/8" DIAMETER STEEL BOLTS
FOOTINGS	NONE	NONE
	³SOUTHERN PINE (TESTED)	

Figure 1. NCHRP Project 22-4 guardrail systems, Phase I

over others regarding problems associated with wheel snagging would be more clearly defined in this test series.

In the conduct of Task 6, the project panel gave instructions, as summarized in Table 4, to the Southwest Research team regarding insight tests to be conducted in Task 7. As shown in this table, transition designs and high center of gravity (c.g.) vehicle impacts with barrier systems were emphasized.

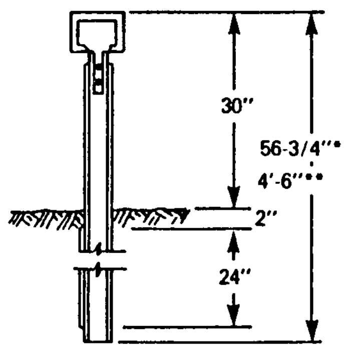
Transition Considerations

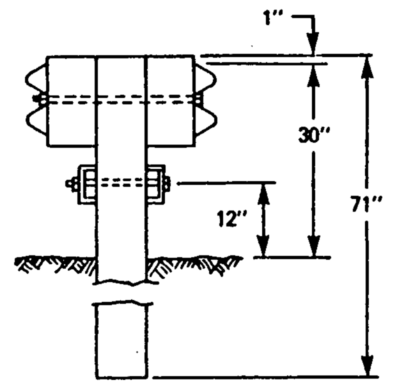
The minimum matrix (Table 3) of *Report 230* requires only one test for barrier transitions. This test (test 30) has the same impact conditions as test 10 (4,500-lb car, 60 mph, 25-deg angle). There are two supplementary tests for transitions (tests S31 and S32), as shown in Table 5. Tests S31 (SL1) and S32 (SL3) are multiple service level tests. Thus, there is no requirement in *Report 230* for a small car test of transition designs. Two problems associated with barrier transitions are: (1) deflection incompatibility—this can lead to pocketing or snagging; and (2) barrier interface incompatibility—this can lead to snagging of the vehicle.

For SL2 designs, the performance of test 30 is considered by the Southwest Research staff to provide an adequate evaluation of a transition design where deflection compatibility is of concern. For barrier interface compatibility, test 12 or S13 might also be required to evaluate the transition.

*BARRIER GUIDE
**AS TESTED

METRIC CONVERSIONS
1 ft. = 0.305 m
1 in. = 25.4 mm
1 mph = 1.61 km/hr
1 lb. = 0.454 kg





SYSTEM	MB3 BOX BEAM	MB4W BLOCKED-OUT "W" BEAM (WOOD POSTS)
BARRIER DESCRIPTION		
POST SPACING	6' 0"	6' 3"
POST TYPE	S3 x 5.7	8" x 8" DOUGLAS FIR³
BEAM TYPE	8" x 6" x 1/4" STEEL TUBE	TWO "W" SECTION, TWO C6 x 8.2 RUBRAILS
OFFSET BRACKETS	NONE	TWO 8" x 8" x 14" DOUGLAS FIR BLOCKS
MOUNTINGS	STEEL PADDLES	5/8" DIAMETER BOLTS
FOOTINGS	8" x 1/4" x 24" STEEL PLATE WELDED TO POST	NONE
		³SOUTHERN PINE (TESTED)

Figure 2. NCHRP Project 22-4 median barrier systems, Phase I

A current FHWA contract at SwRI (DTFH61-3-C-00028) includes in-depth review of current GR/BR transition designs, crash test evaluation of selected designs, upgrading/retrofit designs, and preparation of guidelines for these transitions. Findings from that contract are directly applicable to the objectives of this project and are included in Appendix A of this report.

High c.g. Vehicle Considerations

In recent years, a number of barrier systems have been evaluated for impact conditions more severe than the "standard" strength test conditions of test 10 (*Report 230*). It has been demonstrated that many of the current barrier systems do not have adequate strength or geometry to redirect school buses, intercity buses, and tractor trailers. High performance barrier systems have been designed and developed to contain and redirect these heavy vehicles under 60 mph (95 km/h), 15-deg angle impacts.

A limited number of tests have been conducted with vans in the 4,500-lb (2,000-kg) range. It was demonstrated that the G4(1S) guardrail system was inadequate in keeping a 4,324-lb (1,954-kg) van upright during a 60-mph (95-km/h), 25-deg angle test, even though the system had adequate containment strength (*14*). Thus, the strength of current guardrail systems is adequate for many van vehicles, but the system height is insufficient for the higher center-of-gravity vehicles.

Guardrail Terminals

Accident data have shown that guardrail terminals continue to be a problem based on reported accidents. Research and development of new and upgraded terminal designs have been completed at SwRI and other agencies. Among the recently developed terminals designed for compatibility with the 1,800-lb (820-kg) car are:

Terminal	Developer	Sponsor
SENTRE	Energy Absorption Systems	Same
Eccentric Loader	SwRI	FHWA
Controlled Releasing Terminal	ENSCO	FHWA
Vehicle Attenuating Terminal	SwRI	FHWA/ Syro Steel

Development of barrier terminals was considered to be beyond the scope of this contract because of the large number of tests required.

Test Matrix

Impact conditions and barrier selection are discussed for transition and high c.g. vehicle tests. With respect to the latter (high c.g. vehicles), because most of the operational systems were not

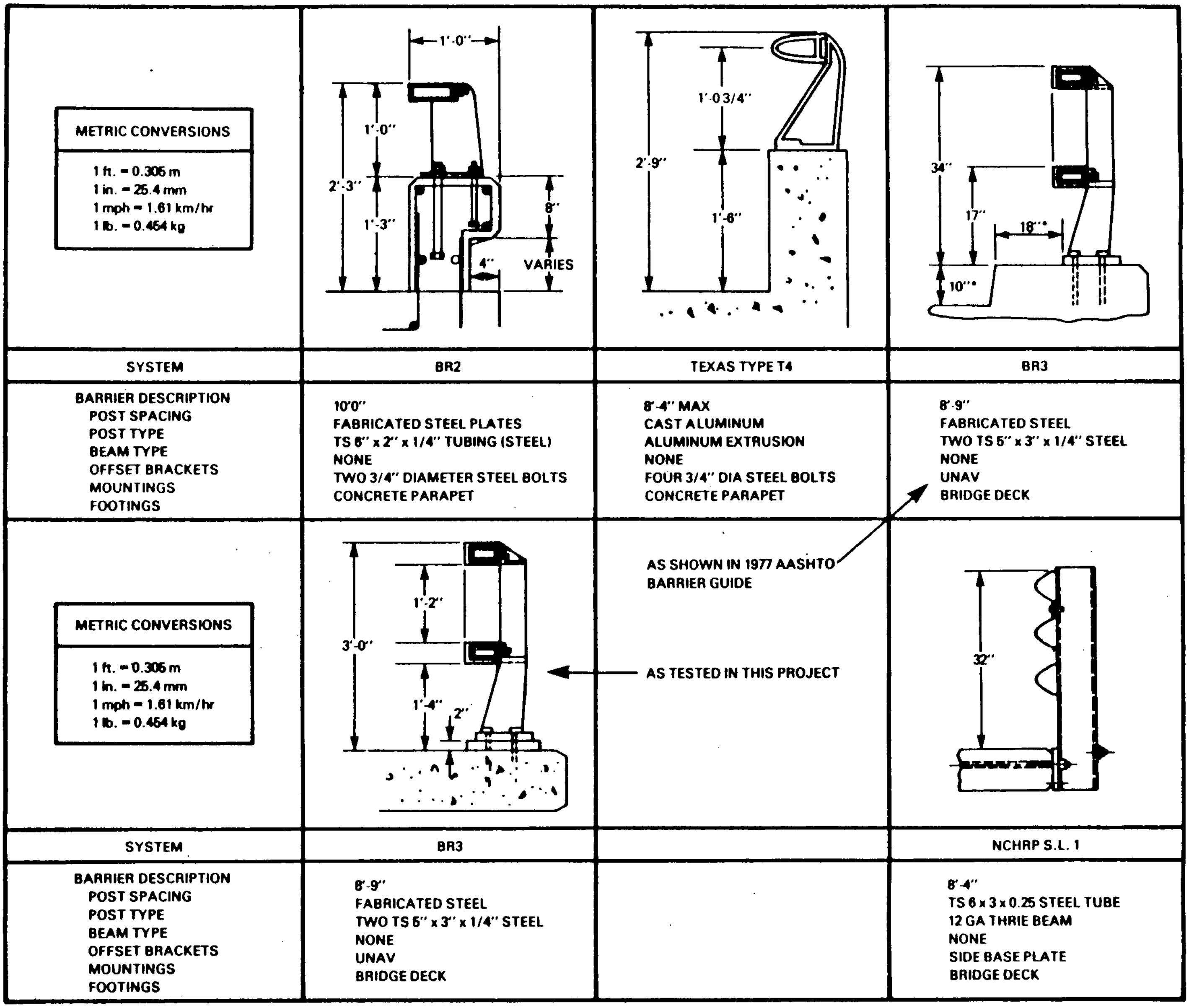


Figure 3. NCHRP Project 22-4 bridge rail systems, Phase I

Table 4. Task 7 workplan guidelines.

Test Description*	Approximate Number of Tests
Transition 3BR x 1GR x Tests (10, 12)	6
Transition MB-MB x Tests (10, 12)	2
Transition GR-GR x Tests (10, 12)	2
Barrier System- High c.g. Vehicle	6
Total	16

Terminals - some consideration of terminals

*Legend:
BR - bridge rail
GR - guardrail
MB - median barrier
(10,12) - correspond to NCHRP Report 230 test conditions

Table 5. Transition tests, *NCHRP REPORT 230*.

		Impact Conditions		
		Vehicle (lb)	Speed (mph)	Angle (deg)
1.	Minimum Matrix Test			
	Test 30	4500	60	25
2.	Supplementary Tests			
	Test S31 (Service Level 1)	4500	60	15
	Test S32 (Service Level 3)	40,000	60	15

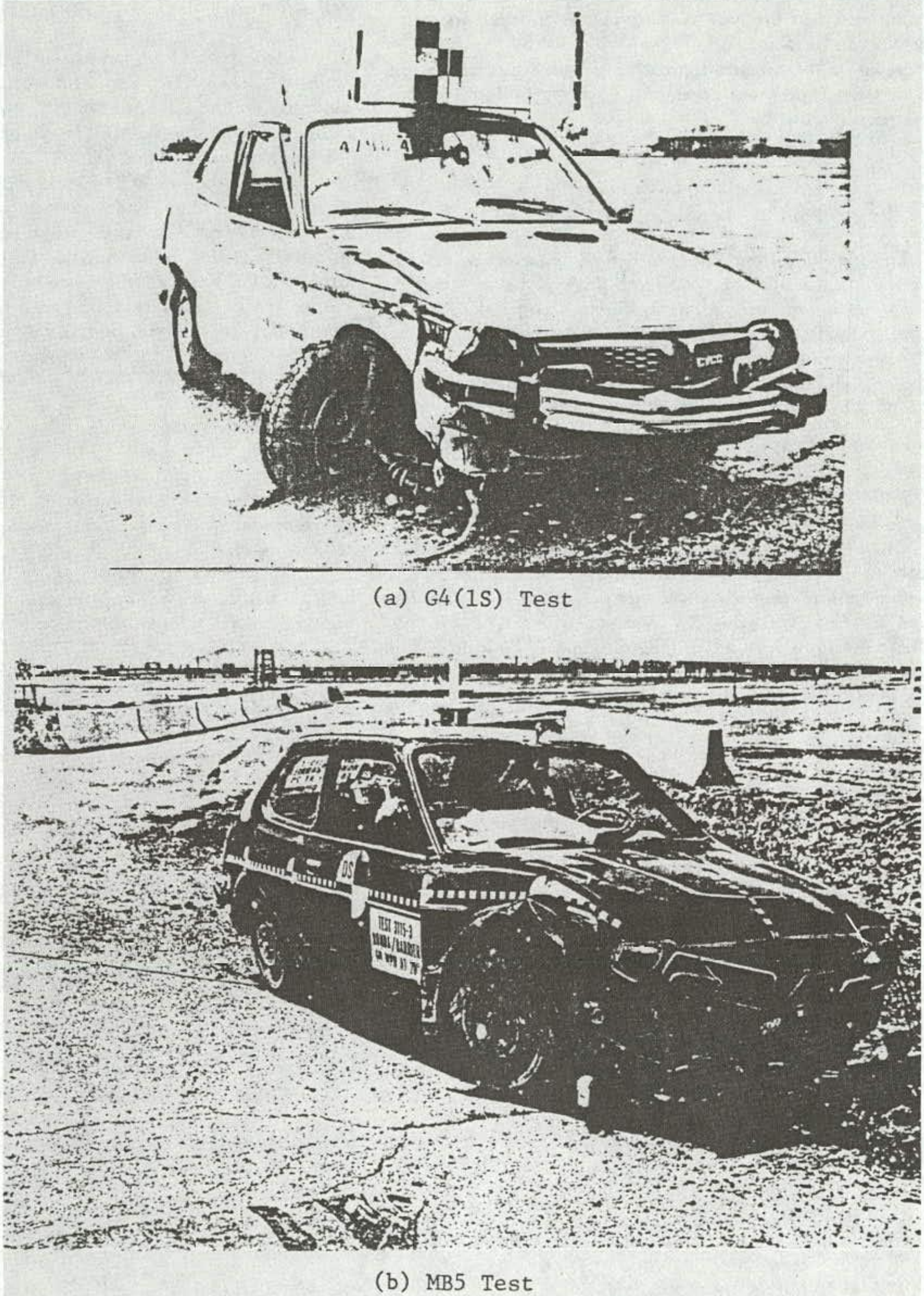


Figure 4. Vehicles after test S13.

expected to meet higher service level requirements, it was recommended that the limit of performance of selected systems with a van be examined.

Based on the research approach previously discussed, a test matrix for Task 7 was developed, as shown in Table 6. This matrix is discussed.

GR-GR Transitions

The transition from W-beam to thrie beam detail had not been evaluated although widespread usage had been reported. Since this is considered primarily an interface problem, it was proposed to test the transition element and details by impacting the W-beam rail upstream of the transition element with both the 1,800-lb (820-kg) and 4,500-lb (2,040-kg) cars. A California design shown in Figure 5 was selected for evaluation.

GR-BR Transitions

Due to the extensive work in this area in progress in SwRI, only two of these systems were recommended for test in this task. The thrie beam weak post approach to the SL1 bridge rail and the New York G3-BR3 transition design were selected. These designs are shown in Figures 6 and 7. Both deflection and interface compatibility are considered worthy of evaluation for the G3-BR3 tests.

MB-MB Transitions

A widely specified median barrier is the CMB or MB5 concrete safety shape. Two semi-rigid median systems in common use today are the MB4 and the MB9 (wood or steel posts). A California design for the MB9 (wood post) was recommended for test, as shown in Figure 8.

A project in progress at SwRI was to develop W-beam guardrail approaches to safety shape bridge parapets. The findings from this research were considered to be appropriate, and thus no tests on MB4 W-beam transition to the safety shape median barrier (MB5) were considered necessary. The W-beam median barrier (MB4) could be transitioned to a minimum length (MB9) thrie beam system, and, therefore, the MB4/MB5 transition test in this project was considered unnecessary.

Miscellaneous Tests

Although not a part of the test matrix shown in Table 6, three other tests were conducted on barrier systems based on recommendations by panel members and the SwRI staff. These tests included:

- An 8,000-lb (3,600-kg) van test of the G9 (wood post) guardrail system to examine performance limits of this system.
- A 4,500-lb (2,000-kg) car, 60 mph (95 km/h) impact of a blocked out W-beam guardrail system using round wood posts (see Fig. 9).

Table 6. Task 7 crash test matrix.

		Vehicle Wt (lb)	Speed (mph)	Angle (deg)	Remarks
1. Transitions, GR-BR					
Guardrail	Bridge Rail				
Thrie beam/ weak post	SL1	4500	60	15	Service Level 1 transition
G3	BR3	1800	60	15	Interface compatibility
G3	BR3	4500	60	25	Deflection/interface compatibility
2. Transition GR-GR					
GR Upstream	GR Downstream				
G4(2W)	G9 (wood post)	1800	60	15	Interface compatibility
		4500	60	25	Deflection/interface compatibility
3. Transition, MB-MB					
MB Upstream	MB Downstream				
MB4 (S)	MB5	4500	60	25	Deflection compatibility
MB9 (wood post)	MB5	4500	60	25	Deflection compatibility
4. Van Tests					
Barrier					
G1		4300	60	to be determined	Stability test
G2		4300	60		Stability test
G3		4300	60		Stability test
G4(2W)		4300	60		Stability test
G9 (wood post)		4300	60		Stability test
MB3		4300	60		Stability test

*Legend: GR - Guardrail; MB - Median Barrier; BR - Bridge Rail

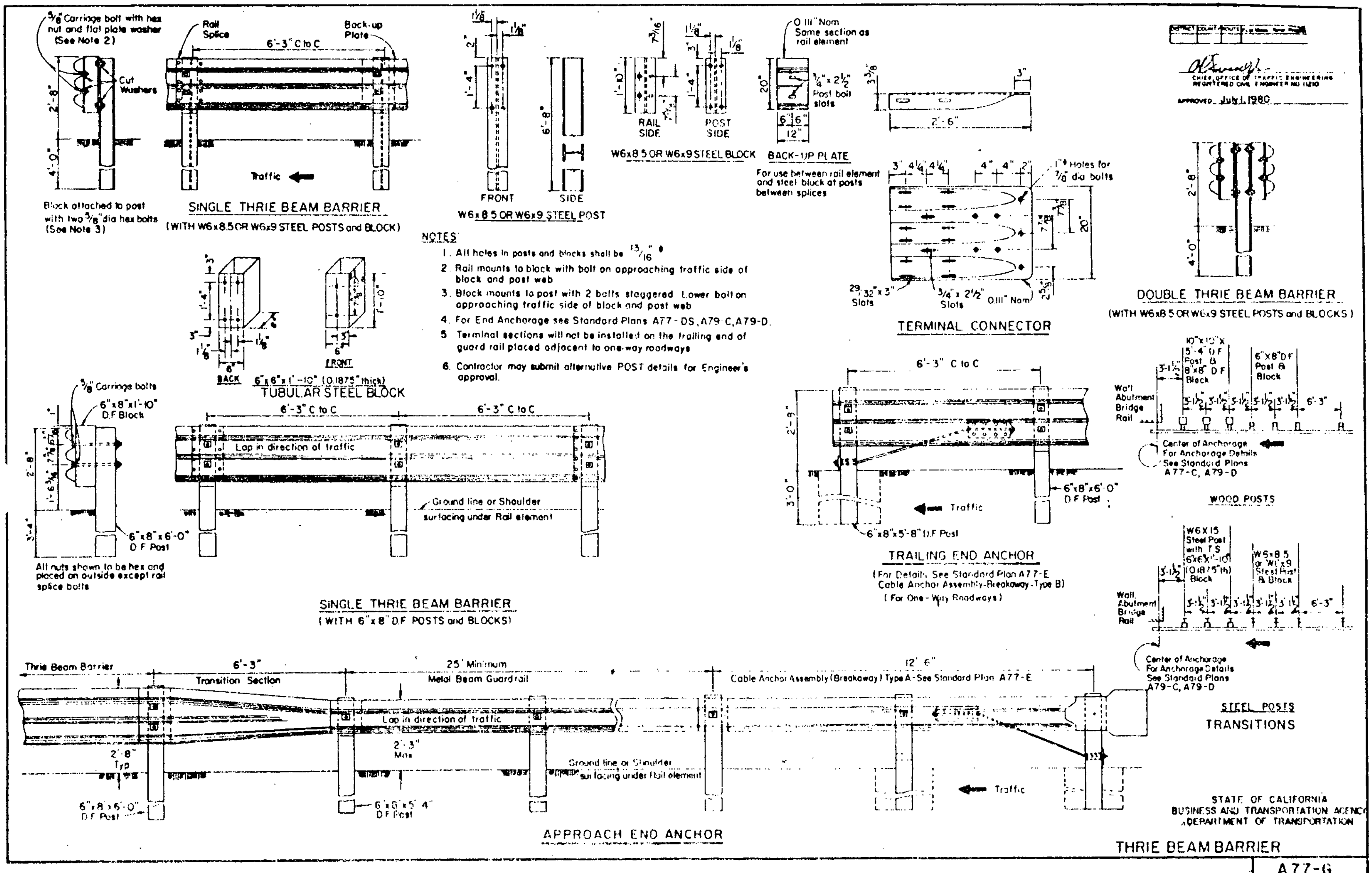


Figure 5. California design, G4(2W)-G9 (wood post).

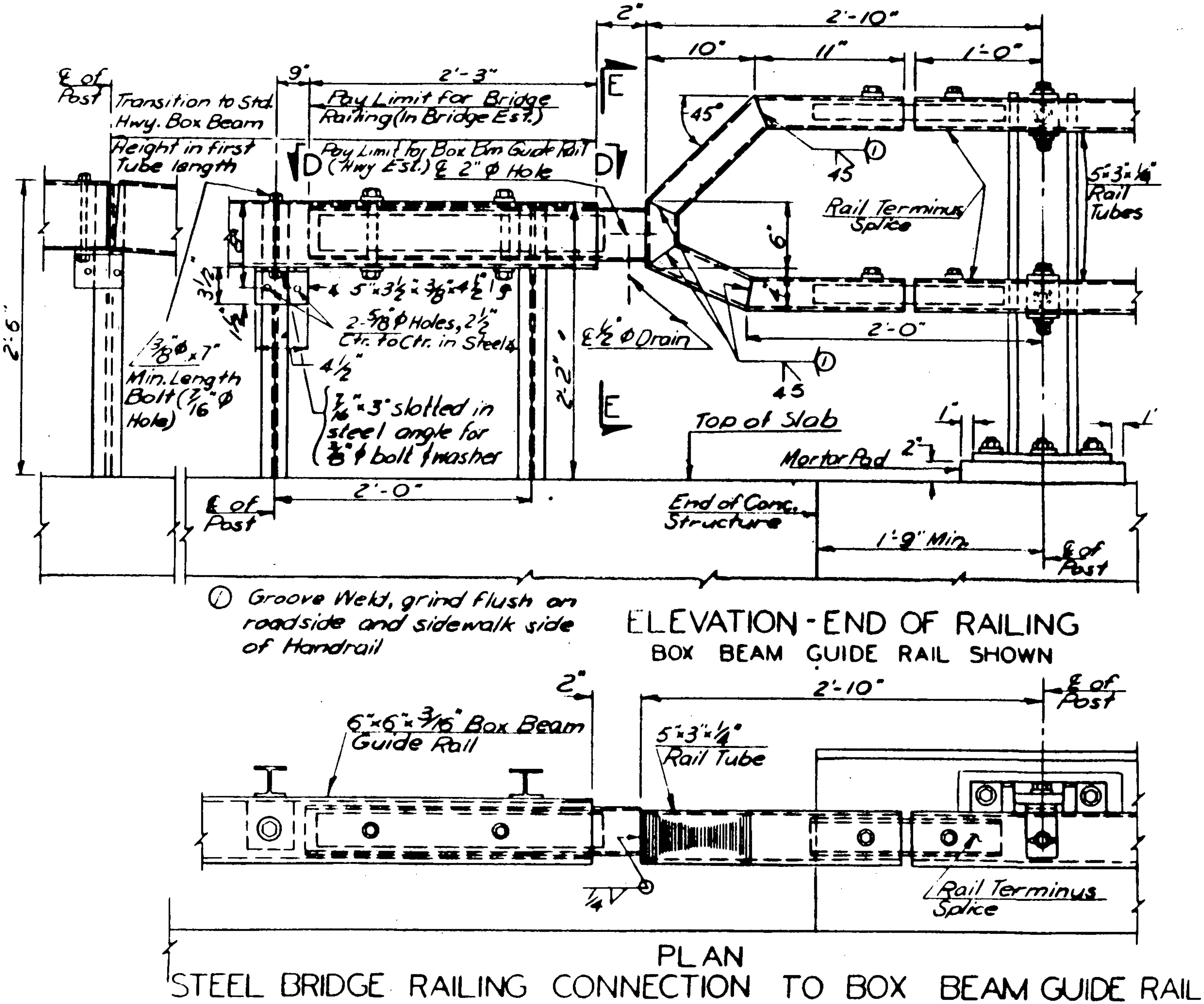
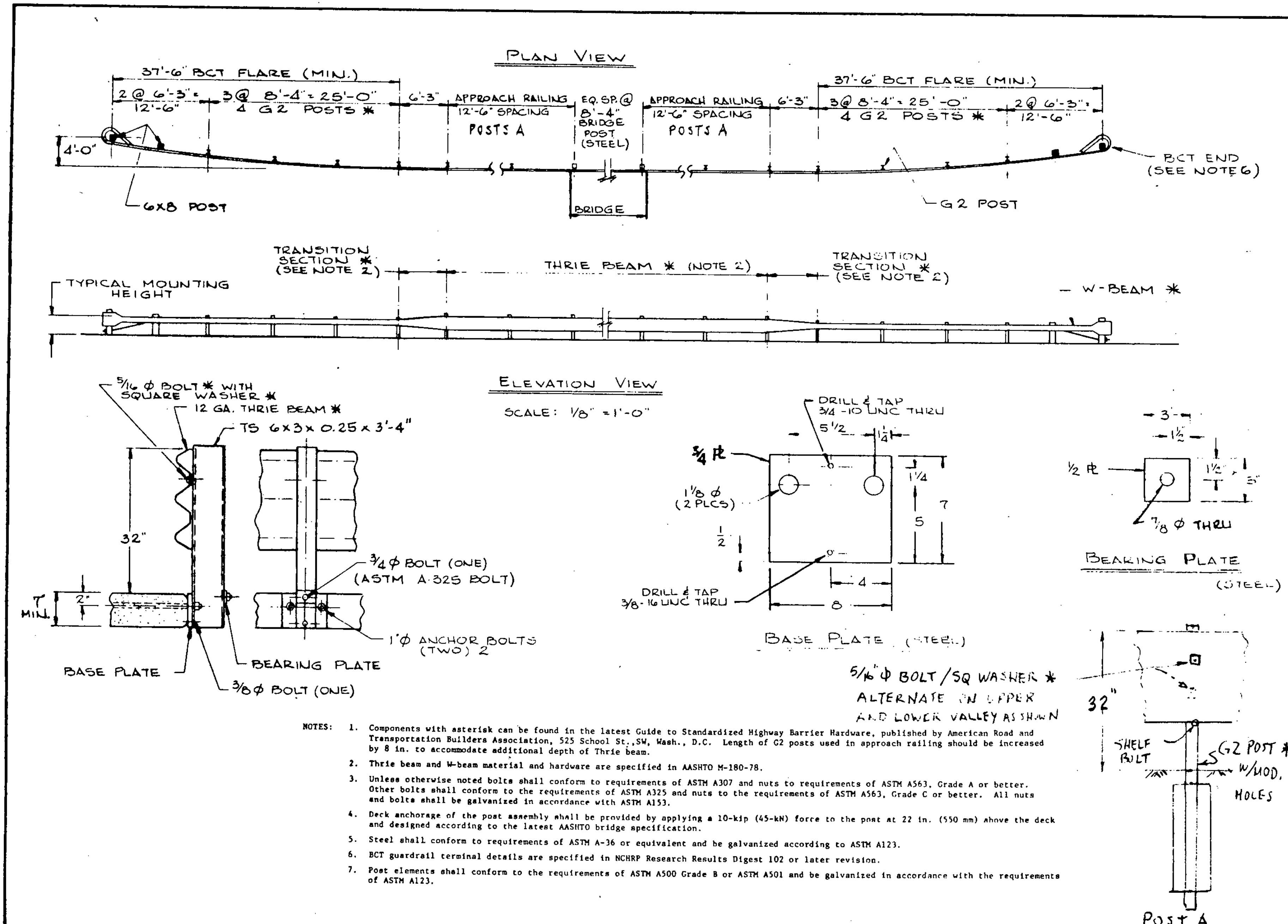


Figure 6. New York design, GR3-BR3 transition.



NOTES:

1. Components with asterisk can be found in the latest Guide to Standardized Highway Barrier Hardware, published by American Road and Transportation Builders Association, 525 School St.,SW, Wash., D.C. Length of G2 posts used in approach railing should be increased by 8 in. to accommodate additional depth of Thrie beam.
2. Thrie beam and W-beam material and hardware are specified in AASHTO M-180-78.
3. Unless otherwise noted bolts shall conform to requirements of ASTM A307 and nuts to requirements of ASTM A563, Grade A or better. Other bolts shall conform to the requirements of ASTM A325 and nuts to the requirements of ASTM A563, Grade C or better. All nuts and bolts shall be galvanized in accordance with ASTM A153.
4. Deck anchorage of the post assembly shall be provided by applying a 10-kip (45-kN) force to the post at 22 in. (550 mm) above the deck and designed according to the latest AASHTO bridge specification.
5. Steel shall conform to requirements of ASTM A-36 or equivalent and be galvanized according to ASTM A123.
6. BCT guardrail terminal details are specified in NCHRP Research Results Digest 102 or later revision.
7. Post elements shall conform to the requirements of ASTM A500 Grade B or ASTM A501 and be galvanized in accordance with the requirements of ASTM A123.

Figure 7. Thrie beam/weak post guardrail—SL1 bridge rail transition.

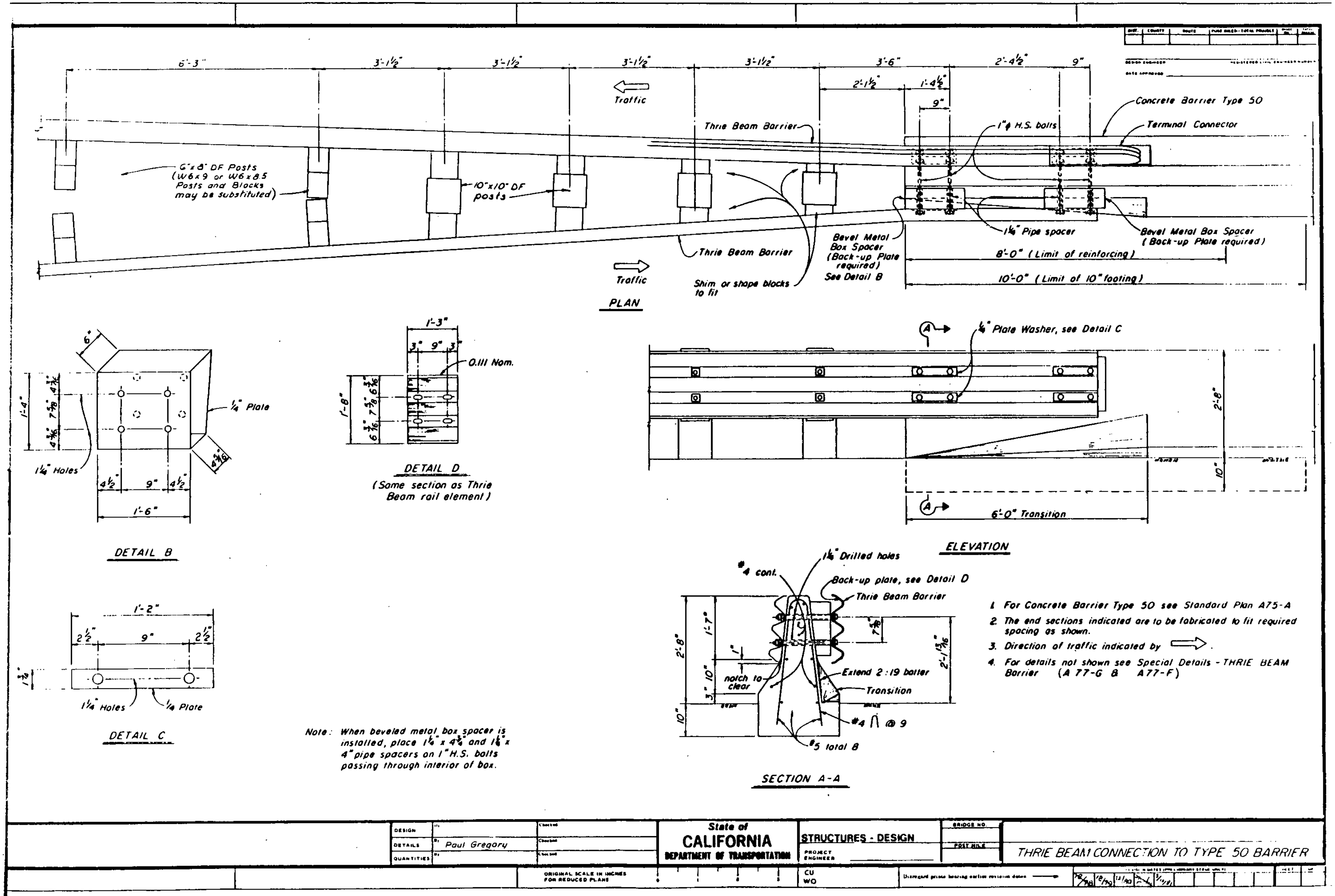


Figure 8. California design, MB9 (wood post)-MB5.

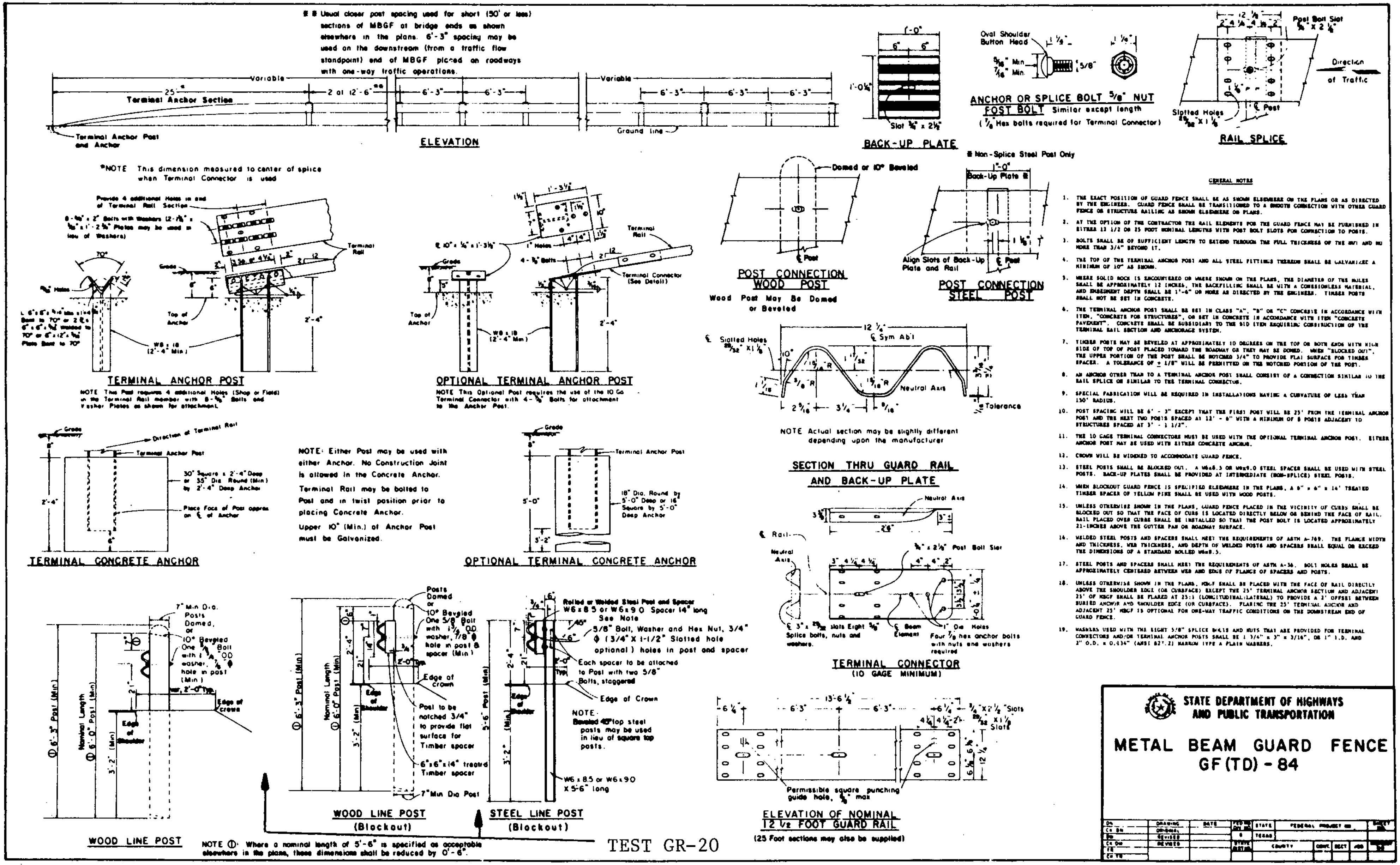


Figure 9. Texas design, blocked-out W-beam on round wood posts.

• A 4,300-lb (1,900-kg) van test on the G1 cable guardrail system mounted at 24 in. (60 cm) high. The purpose of this test was to evaluate a cable system mounted lower with a high c.g. vehicle. This lower height consideration was triggered by the concern for barrier interaction with some of the new aerodynamically styled vehicles with sloping front ends. Evaluation of the system with such a car was programmed in an FHWA project at SwRI.

CHAPTER THREE

CRASH TEST EVALUATIONS

GENERAL

The selected barrier systems were installed and evaluated by full-scale crash test according to the procedures of *NCHRP Report 230.* An unrestrained side impact dummy (SD) provided by NHTSA was used in all tests. Data were recorded by high-speed cameras and electronic transducers. Drawings of the barriers evaluated in this project are contained in Appendix A, in a user format. (*Note:* The drawings shown for these barriers were, in some cases, reproduced from larger drawings containing additional information not needed for basic barrier construction. For questions on dimensions or other barrier details, please contact the NCHRP or Southwest Research Institute.) Detailed descriptions of the tests are given in Volume 3 of the agency final report along with the test procedures (see Foreword for availability).

The test data were obtained from two sources: film data and transducer data. The film data record the motion of two targets on the vehicle roof. These basic data correspond to coordinates of the vehicle center of gravity (c.g.) and the vehicle heading angle as a function of time. Subsequent calculations convert these data to velocities and accelerations as a function of time.

To obtain transducer data, accelerometers were placed near the vehicle center of gravity and in the side impact dummy. In addition, a yaw angular rate transducer was placed at the vehicle horizonal c.g. location near the vertical c.g. of the car. The basic data obtained are vehicle and dummy accelerations, and vehicle heading angle change as a function of time. These data are subsequently used to obtain vehicle velocities and displacements as a function of time. In addition, the head injury criterion (HIC) value as well as other values were computed from the dummy data.

As can be seen in the review of the tests, the correlation between film and accelerometer data varies. One of the variances is inherent with differences in motion at the roof and at the vehicle c.g. which is approximately 20 in. (50 cm) above the ground. Another is the difference in the first order values measured, i.e., the film measures displacements whereas the accelerometers measure accelerations. For rigid body motions of the vehicle c.g., the transducer data are considered superior, particularly if there is considerable roll or pitch of the vehicle. For values, such as the exit speed of the vehicle, which occur late in the event, the film data are usually considered to be more accurate. SwRI uses both techniques as a backup in case one mode fails and as a check. The actual impact conditions are obtained from the high-speed film analysis.

The crash tests are briefly described in following sections; the tests are summarized in Tables 7 through 13. In these tables, an assessment is made regarding compliance with the recommended evaluation criteria of *NCHRP Report 230,* Table 8. In judging these tests, the researchers did not consider the values as being absolute, and some small exceedance of *one* value was allowed if all other values were within the recommended limits. Thus, some of the systems that had one test value slightly in excess of the recommended value were given marginal pass ratings. One test resulted in failure because of a secondary end treatment impact that caused rollover; however, this was not considered a system failure, but an end treatment failure.

PHASE I CRASH TESTS

All of the crash tests evaluated operational barrier systems from the AASHTO Barrier Guide (SL1 bridge rail lone exception) for *Report 230* test 12 conditions (i.e., 1,800-lb (800-kg) car, 60 mph (95 km/h), 15-deg angle).

Test GR-1

This test evaluated the G4(2W) blocked-out W-beam on 6-in. x 8-in. (15 x 20-cm) timber posts. The vehicle was smoothly redirected with a maximum dynamic barrier deflection of 7.7 in. (20 cm) as shown in Figure 10. Damage to the barrier and vehicle was moderate. The vehicle was operable after coming off of the rail, and the barrier was fully serviceable with small permanent deformations as shown in Figure 11. Measured data indicated compliance with the recommended values of *NCHRP Report 230.*

Table 7. Summary of Guardrail crash tests, Phase I.

Test No.	GR-1	GR-2	GR-3	GR-4	GR-5
Barrier*	G4(2W)	G9	G2	G3	G1
Test Vehicle	1977 Honda Civic	1978 Honda Civic	1976 Honda Civic	1978 Honda Civic	1976 Honda Civic
Gross Vehicle Weight, lb	1989	1948	1857	1916	1973
Impact Speed (film), mph	60.1	59.3	59.7	60.4	60.5
Impact Angle, deg	15.5	14.4	15.4	15.3	15.8
Impact Duration, sec	.25	.22	.38	.27	.84
Maximum Deflection, in.					
Dynamic	7.7	6.0	16.0	6.4	43.4
Permanent	3.2	1.5	11.9	0	slack cables
Exit Angle, deg					
Film	-2.1	-3.5	-1.7	4.1	not available
Yaw Rate Transducer	-1.6	-4.0	-6.0	2.4	1.7
Exit Speed, mph					
Film	54.7	52.3	50.4	49.3	not available
Accelerometer	55.9	52.1	59.0	46.8	43.8
Maximum 50 msec Avg Accel (film/accelerometer)					
Longitudinal	1.8/2.1	3.5/3.1	2.1/2.3	3.2/4.1	2.9/2.1
Lateral	5.9/7.3	6.7/8.1	4.3/6.9	6.7/5.9	2.7/2.2
Occupant Risk, NCHRP Report 230† (film/accelerometer)					
ΔV long., fps (30)	††/††	††/††	15.7/††	††/18.3	12.7/9.8
ΔV lat, fps (20)	19.8/18.6	21.5/20.4	17.0/17.3	18.9/17.8	11.9/10.6
Ridedown Acceleration, g's (accelerometer)					
Longitudinal (15)	††	††	††	6.2	1.7
Lateral (15)	5.4/13.8	5.6/10.6	4.0/14.7	3.9/10.0	2.7/8.7
NCHRP Report 230 Evaluation					
Structural Adequacy (A,D)	pass	pass	pass	pass	pass
Occupant Risk (E,F,G)	pass	pass (marginal F)	pass	pass	pass***
Vehicle Trajectory (H,I)	pass	pass	pass	pass	pass (marginal I)
Barrier Damage Rating**	2	2	3	3	4
Posts Not Serviceable	none	none	1	2	3

†Numbers in parentheses are recommended values for NCHRP Report 230.

††Occupant did not travel the flail distance.

*1977 AASHTO Barrier Guide designation.

**Barrier damage code: 1) Undamaged 2) Fully serviceable, but moderately damaged
3) Reduced service due to damage in impact area
4) Not serviceable in impact area. Damage repair indicated for 3, immediate damage repair for 4.

***The vehicle rolled over due to secondary impact with end treatment.

Table 8. Summary of median barrier tests, Phase I.

Test No.	MB-1	MB-2
Barrier*	MB4W	MB3
Test Vehicle	1977 Honda Civic	1978 Honda Civic
Gross Vehicle Weight, lb	1947	1979
Impact Speed (film), mph	58.5	61.6
Impact Angle, deg	17.2	14.5
Impact Duration, sec	.24	.38
Maximum Deflection, in.		
Dynamic	2.5	7.0
Permanent	0	0
Exit Angle, deg		
Film	-5.3	2.5
Yaw Rate Transducer	not avail	2.6
Exit Speed, mph		
Film	54.7	46.7
Accelerometer	not avail	49.2
Maximum 50 msec Avg Accel (film/accelerometer)		
Longitudinal	2.2/not avail	3.8/3.8
Lateral	7.4/not avail	5.1/5.1
Occupant Risk, NCHRP Report 230†		
(film/accelerometer)	††/not avail	16.6/13.8
ΔV long., fps (30)	21.4/not avail	16.1/16.9
ΔV lat, fps (20)		
Ridedown Acceleration, g's (accelerometer)		
Longitudinal (15)	not avail	3.6
Lateral (15)	not avail	5.9
NCHRP Report 230 Evaluation		
Structural Adequacy (A,D)	pass	pass
Occupant Risk (E,F,G)	pass (marginal F)	pass
Vehicle Trajectory (H,I)	pass	pass
Barrier Damage Rating**	2	3
Posts not serviceable	0	3

†Numbers in parentheses are recommended values for NCHRP Report 230.

††Occupant did not travel the flail distance.

*1977 AASHTO Barrier Guide designation.

**Barrier damage code: 1) Undamaged 2) Fully serviceable, but moderately damaged
3) Reduced service due to damage in impact area
4) Not serviceable in impact area. Damage repair indicated for 3, immediate damage repair for 4.

Table 9. Summary of bridge rail tests, Phase I.

Test No.	BR-1	BR-2	BR-3	BR-4
Barrier*	BR2	Texas Type T4	BR3	NCHRP S.L. 1
Test Vehicle	1978 Honda Civic	1978 Honda Civic	1979 Honda Civic	1978 Honda Civic
Gross Vehicle Weight, lb	1929	1980	1990	1987
Impact Speed (film), mph	60.9	61.0	61.0	61.4
Impact Angle, deg	13.1	15.0	14.2	14.1
Impact Duration, sec	.24	.25	.28	.32
Maximum Deflection, in.				
Dynamic	0	0	0	17.2
Permanent	0	0	0	6.8
Exit Angle, deg				
Film	-4.1	-5.6	0.5	-5.5
Yaw Rate Transducer	0.2	0.3	0.3	-1.6
Exit Speed, mph				
Film	57.9	54.5	51.0	55.9
Accelerometer	55.0	50.0	48.2	58.1
Maximum 50 msec Avg Accel (film/accelerometer)				
Longitudinal	2.7/3.7	1.9/6.1	3.1/6.9	1.8/2.0
Lateral	4.6/10.2	4.8/10.3	6.1/8.0	3.5/6.4
Occupant Risk, NCHRP Report 230† (film/accelerometer)				
ΔV long., fps (30)	++/5.9	++/13.1	12.0/15.8	11.7/8.4
ΔV lat, fps (20)	17.2/16.2	17.5/18.5	19.5/18.0	15.1/17.0
Ridedown Acceleration, g's (accelerometer)				
Longitudinal (15)	++	2.90	3.5	0.8
Lateral (15)	9.6	14.1	13.2	8.5
NCHRP Report 230 Evaluation				
Structural Adequacy (A,D)	pass	pass	pass	pass
Occupant Risk (E,F,G)	pass	pass	pass	pass
Vehicle Trajectory (H,I)	pass	pass	pass	pass
Barrier Damage Rating**	1	1	1	3
Posts Not Serviceable	0	0	0	2

†Numbers in parentheses are recommended values for NCHRP Report 230.

††Occupant did not travel the flail distance.

*1977 AASHTO Barrier Guide designation.

**Barrier damage code: 1) Undamaged 2) Fully serviceable, but moderately damaged
3) Reduced service due to damage in impact area
4) Not serviceable in impact area. Damage repair indicated for 3, immediate damage repair for 4.

Table 10. Summary of 1,800-lb car, 20-deg angle tests.

Test No.	GR-6	GR-8	GR-10	GR-12	GR-13	GR-16
Barrier*	G4(2W)	G2	G3	MB3	G9	G1
Test Vehicle	1978 Honda	1979 Honda	1979 Honda	1979 Honda	1979 Honda	1980 Honda
Gross Vehicle Weight, lb	1928	1960	1960	1995	2000	1995
Impact Speed (film), mph	61.9	58.5	59.3	58.5	59.5	59.2
Impact Angle, deg	21.7	19.3	18.4	19.4	22.6	19.5
Impact Duration, sec	0.24	0.52	0.26	0.45	0.29	n/a
Maximum deflection, in.						
Dynamic	10.4	31.7	15.6	12.1	15.2	5.8 (ft)
Permanent	5.3	16.0	2.1	none	6.0	n/a
Exit Angle, deg						
Film	-5.2	1.0	0.94	10.7	-0.6	did not exit
Yaw Rate Transducer	-5.2	-0.75	1.9	6.2	2.2	did not exit
Exit Speed, mph						
Film	50.0	43.1	48.0	40.6	52.4	did not exit
Accelerometer	52.6	55.4	49.5	37.3	46.5	did not exit
Maximum 50 msec Avg Accel (film/accel)						
Longitudinal	4.7/3.9	2.3/3.4	3.3/3.3	2.9/4.9	3.6/4.3	1.9/3.6
Lateral	8.6/11.2	4.1/7.4	6.3/7.7	5.4/6.1	7.4/9.2	3.1/3.5
Occupant Risk, NCHRP Report 230 (film/accel)						
ΔV long., fps (30)	12.8/***	13.6/5.4	15.6/13.7	17.0/17.9	14.9/14.2	11.8/9.0
ΔV lat., fps (20)	23.0/23.1	13.4/14.7	19.7/19.5	17.6/16.9	21.4/18.8	12.3/11.2
Ridedown Acceleratons, g's (accel)						
Longitudinal (15)	***	***	1.3	9.0	1.0	4.5
Lateral (15)	12.9	9.4	8.7	8.5	11.4	5.6
NCHRP Report 230 Evaluation						
Structural Adequacy (A,D)	Passed	Passed	Passed	Passed	Passed	Passed
Occupant Risk (E,F,G)	Lat ΔV>20	Passed	Passed	Passed	Passed	Passed
Vehicle Trajectory (H,I)	Passed	Passed	Passed	Passed	Passed	did not exit
Barrier Damage Rating**	2	4	3	3	2	4
Posts not serviceable	0	5	6	5	0	8

*1977 AASHTO Barrier Guide designation.
**Barrier damage code: 1) Undamaged 2) Fully serviceable, but moderately damaged 3) Reduced service due to damage in impact area 4) Not serviceable in impact area Damage repair indicated for 3, immediate damage repair for 4.
***Occupant did not travel flail distance.

Table 11. Summary of van insight tests.

Test No.	GR-7	GR-9	GR-11	GR-14	GR-15	GR-17
Barrier*	G4(2W)	G2	G3	MB3	G9	G1
Test Vehicle	1979 Dodge Van	1980 Dodge Van	1979 Dodge Van	1980 Dodge Van	1980 Dodge Van	1979 Dodge Van
Gross Vehicle Weight, lb	4650	4640	4380	4050	4380	4160
Impact Speed (film), mph	58.7	59.4	61.0	58.4	60	58.1
Impact Angle, deg	20.9	23.9	18.8	18.7	25	24.2
Impact Duration, sec	0.48	2.8	2.1	1.3	0.73	1.5
Maximum deflection, in.						
Dynamic	25.2	45	25.9	26.1	40.2	8.9 (ft)
Permanent	14.5	n/a	18.8	n/a	31.5	n/a
Exit Angle, deg						
Film	-11.7	did not exit	spin-out	spin-out	n/a	+
Yaw Rate Transducer	- 8.8	did not exit	spin-out	spin-out	8.0	+
Exit Speed, mph						
Film	44.6	did not exit	spin-out	spin-out	n/a	+
Accelerometer	45.8	did not exit	spin-out	spin-out	26.0	+
Max. Roll Angle, deg.	14.5	rollover	11.5	11.0	15.0	10.5
Maximum 50 msec Avg Accel (film/accel)						
Longitudinal	3.2/3.1	-4.4/-2.0	3.3/4.5	2.3/3.4	6.6 (accel)	1.8/6.9
Lateral	3.8/4.6	-2.3/-2.6	3.7/4.0	4.3/5.4	5.4 (accel)	2.4/3.1
NCHRP Report 230 Evaluation	(not a Report 230 test, use Test 10 criteria)					
Structural Adequacy (A,D)	Passed	Failed	Failed	Passed	Passed	Passed
Occupant Risk (E,F,G)	n/a	Failed	Passed	Passed	Passed	Passed
Vehicle Trajectory (H,I)	Passed	Failed	Failed exit angle	Failed exit angle	Passed	Passed
Barrier Damage Rating**	3	4	4	4	3	4
Posts not serviceable	0	9	10	11	2	7

* 1977 AASHTO Barrier Guide designation.
** Barrier damage code: 1) Undamaged 2) Fully serviceable, but moderately damaged 3) Reduced service due to damage in impact area 4) Not serviceable in impact area. Damage repair indicated for 3, immediate damage repair for 4.
+ Excessive contact length (80ft) and time (1.4 sec) prevented complete data analysis exit angle was nearly parallel to barrier.

Table 12. Summary of transition tests.

Test No.	TR-1	TR-2	TR-3	TR-4
Barrier*	W-beam to thrie beam	W-beam to thrie beam	W-beam to thrie beam	MB9/MB5
Test Vehicle	1979 Honda	1978 Dodge	1978 Plymouth	1978 Plymouth
Gross Vehicle Weight, lb	1920	4780	4560	4490
Impact Speed (film), mph	61.5	63.2	62.1	60.2
Impact Angle, deg	14.1	23.4	24.4	24.8
Impact Duration, sec	0.25	>0.73	>1.0	0.40
Maximum deflection, in.				
Dynamic	5.2	33.5	29.6	10.0
Permanent	none	29.5	25.3	2.3
Exit Angle, deg				
Film	-2.9	n/a	did not exit	-10.4
Yaw Rate Transducer	-1.3	n/a	did not exit	-7.8
Exit Speed, mph				
Film	52.6	n/a	did not exit	42.6
Accelerometer	48.4	n/a	did not exit	44.9
Maximum 50 msec Avg Accel (film/accel)				
Longitudinal	-2.7/-3.8	6.2 (film)	6.3 (film)	4.7/7.5
Lateral	-5.3/-6.7	4.0 (film)	5.0 (film)	7.4/12.0
Occupant Risk, NCHRP Report 230 (film/accel)				
ΔV long., fps (30)	11.7/16.6	26.6 (film)	25.7 (film)	7.4/ 8.9
ΔV lat., fps (20)	18.7/19.3	15.5 (film)	17.1 (film)	19.7/ 24.4
Ridedown Acceleratons, g's (accel)				
Longitudinal (15)	-1.3	n/a	n/a	***
Lateral (15)	-6.4	n/a	n/a	16.1
NCHRP Report 230 Evaluation				
Structural Adequacy (A,D)	Passed	Failed	Failed	Passed
Occupant Risk (E,F,G)	Passed	Passed	Passed	Passed
Vehicle Trajectory (H,I)	Passed	Passed	Passed	Passed
Barrier Damage Rating**	1	4	4	2
Posts not serviceable	0	5	5	0

*1977 AASHTO Barrier Guide designation.
**Barrier damage code: 1) Undamaged 2) Fully serviceable, but moderately damaged 3) Reduced service due to damage in impact area 4) Not serviceable in impact area Damage repair indicated for 3, immediate damage repair for 4.
***Occupant did not travel flail distance.

Table 12. Continued

Test No.	TR-5	TR-6	TR-7
Barrier*	SL1 thrie-beam bridge rail transition	G3 box beam to two rail steel bridge rail	W-beam to thrie beam transition
Test Vehicle	1978 Plymouth	1980 Honda	1978 Plymouth
Gross Vehicle Weight, lb	4680	2000	4660
Impact Speed (film), mph	59.9	59.6	59.1
Impact Angle, deg	14.1	13.7	24.0
Impact Duration, sec	0.79	0.45	0.56
Maximum deflection, in.			
Dynamic	4.8	2.9	33.5
Permanent	3.1	0.5	25.2
Exit Angle, deg			
Film	n/a	24.8	-11.8
Yaw Rate Transducer	n/a	n/a	n/a
Exit Speed, mph			
Film	n/a	30.9	38.7
Accelerometer	n/a	n/a	n/a
Maximum 50 msec Avg Accel (film/accel)			
Longitudinal	1.2/1.8	6.9/16.3	3.3/5.7
Lateral	1.9/5.5	4.1/8.5	5.0/7.8
Occupant Risk, NCHRP Report 230 (film/accel)			
ΔV long., fps (30)	1.4/6.4	24.9/39.5	13.6/9.4
ΔV lat., fps (20)	10.0/11.8	14.8/19.2	15.2/17.4
Ridedown Acceleratons, g's (accel)			
Longitudinal (15)	***	8.8	***
Lateral (15)	7.4	10.2	12.3
NCHRP Report 230 Evaluation			
Structural Adequacy (A,D)	Passed	Failed	Passed
Occupant Risk (E,F,G)	Passed	Failed	Passed
Vehicle Trajectory (H,I)	Passed	Passed	Passed
Barrier Damage Rating**	3	1	3
Posts not serviceable	4	0	0

*1977 AASHTO Barrier Guide designation.
**Barrier damage code: 1) Undamaged 2) Fully serviceable, but moderately damaged 3) Reduced service due to damage in impact area 4) Not serviceable in impact area Damage repair indicated for 3, immediate damage repair for 4.
***Occupant did not travel flail distance.

Table 13. Summary of miscellaneous tests.

Test No.	GR-18	GR-19	GR-20
Barrier*	G 9(W)	Texas round post wood blocked out W-beam	G1
Test Vehicle	1980 Ford Van	1978 Plymouth	1979 Dodge van
Gross Vehicle Weight, lb	7985	4695	4160
Impact Speed (film), mph	58.7	59.3	56.0
Impact Angle, deg	23.9	24.3	23.3
Impact Duration, sec	0.73	>0.65	n/a
Maximum deflection, in.			
Dynamic	39.2	28.9	n/a
Permanent	29.5	22.5	n/a
Exit Angle, deg			
Film	n/a	n/a	n/a
Yaw Rate Transducer	n/a	n/a	n/a
Exit Speed, mph			
Film	n/a	n/a	n/a
Accelerometer	n/a	n/a	n/a
Maximum 50 msec Avg Accel (film/accel)			
Longitudinal	4.4/6.1	2.2/n/a	-2.3 (accel)
Lateral	3.2/4.0	4.0/n/a	-2.1 (accel)
Max. Roll Angle, deg.	rolled over	neglible	7.3
Occupant Risk, NCHRP <u>Report 230</u> (film/accel)			
ΔV long., fps (30)	14.6/n/a	13.1/n/a	14.1 (accel)
ΔV lat., fps (20)	11.8/n/a	14.3/n/a	9.2 (accel)
Ridedown Acceleratons, g's (accel)			
Longitudinal (15)	***	n/a	-2.4
Lateral (15)	5.1	n/a	-2.5
NCHRP <u>Report 230</u> Evaluation			
Structural Adequacy (A,D)	Passed	Passed	Failed
Occupant Risk (E,F,G)	Failed	Passed	Failed
Vehicle Trajectory (H,I)	Failed	Passed	Failed
Barrier Damage Rating**	3	3	3
Posts not serviceable	5	4	6

*1977 AASHTO Barrier Guide designation.
**Barrier damage code: 1) Undamaged 2) Fully serviceable, but moderately damaged 3) Reduced service due to damage in impact area 4) Not serviceable in impact area Damage repair indicated for 3, immediate damage repair for 4.
***Occupant did not travel flail distance.

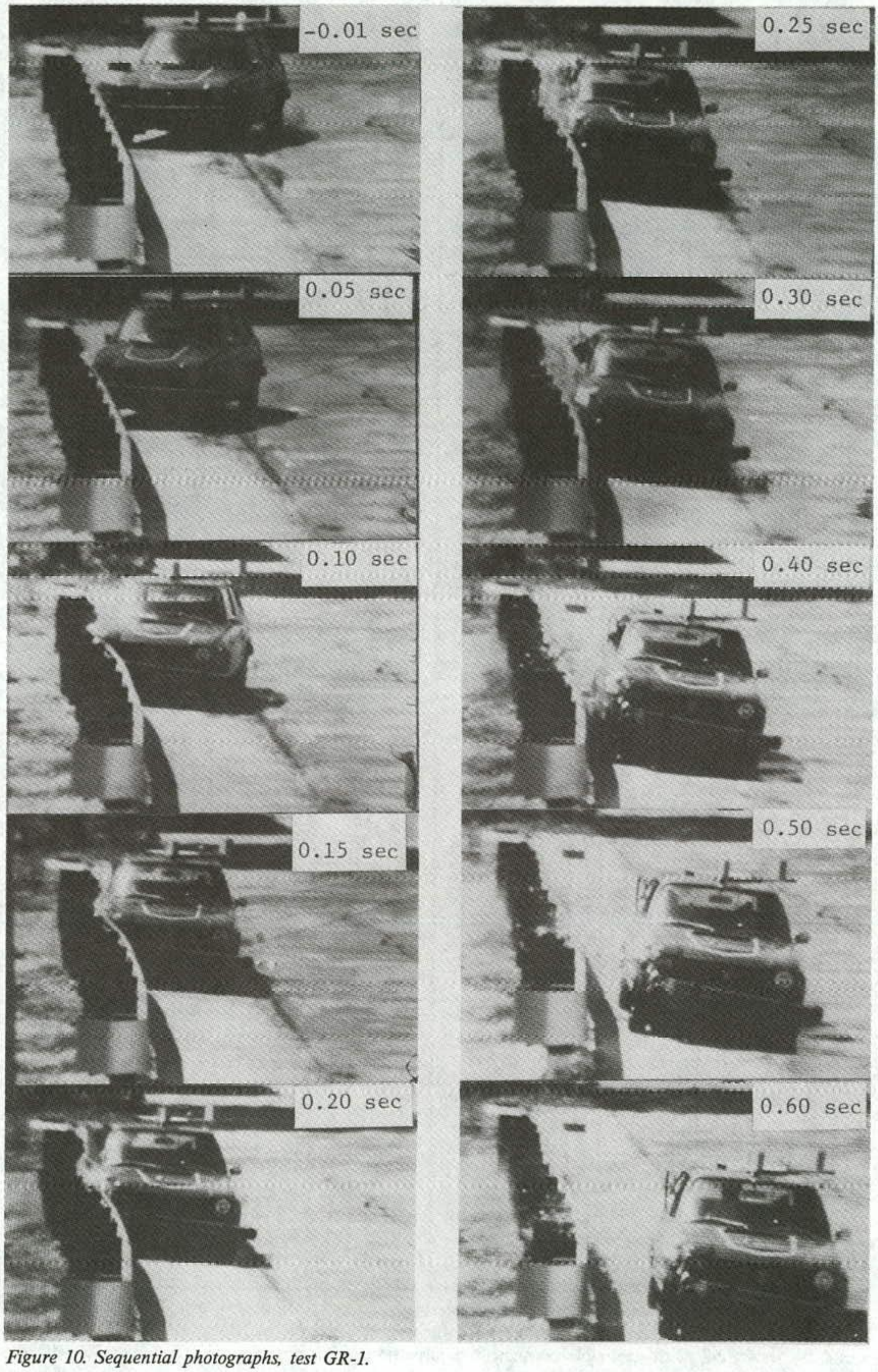
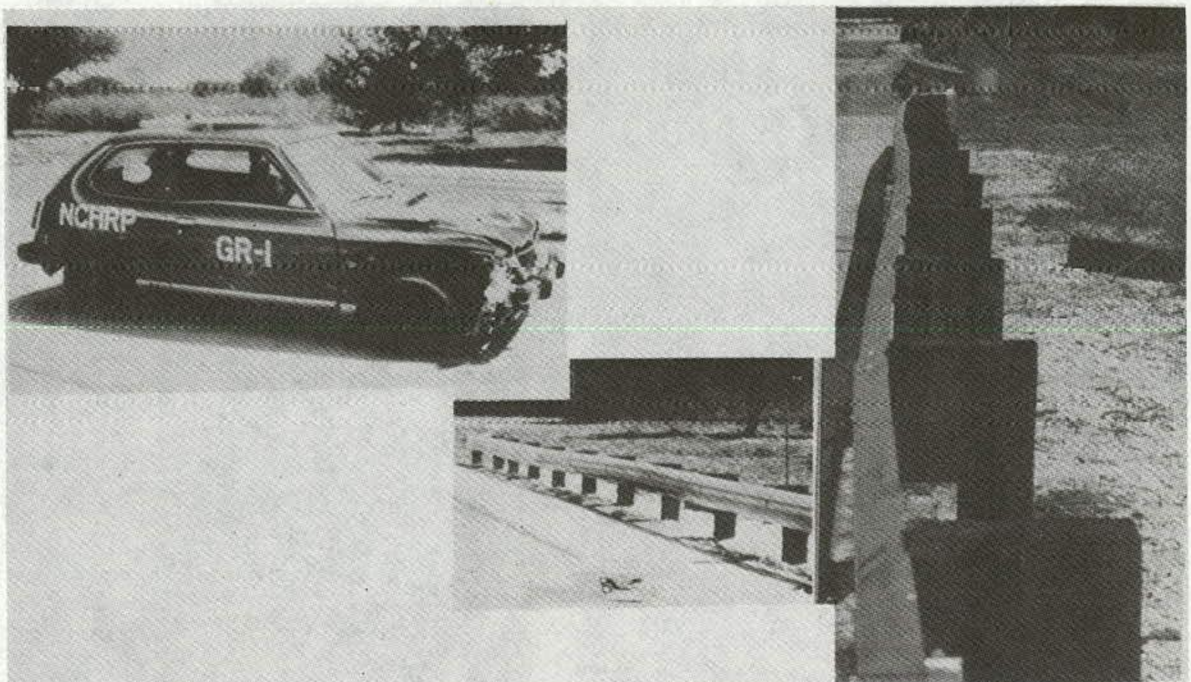
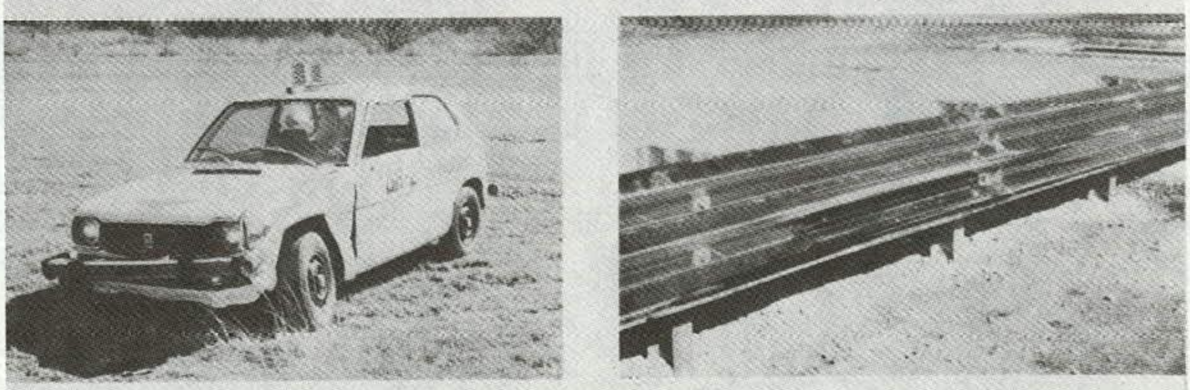


Figure 10. Sequential photographs, test GR-1.



(a) Test GR-1, System G4(2W)



(b) Test GR-2, System G9

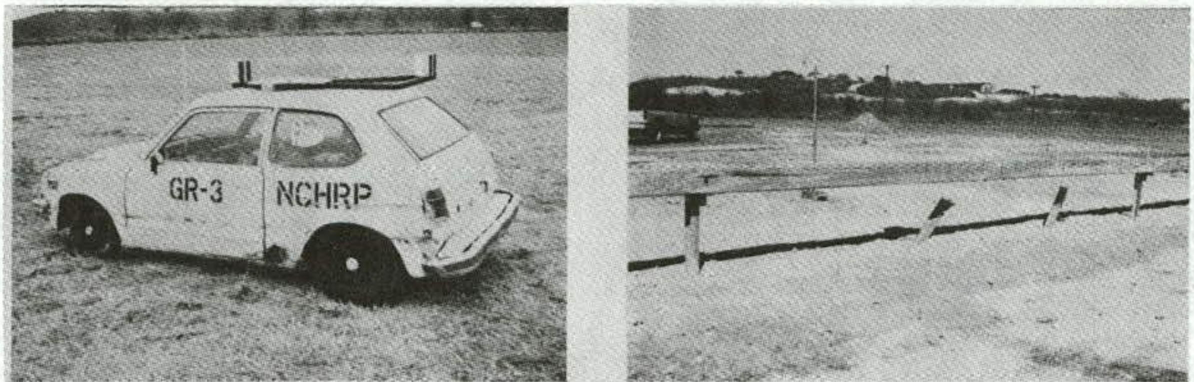
Figure 11. Barrier and vehicle damage after guardrail tests.

Test GR-2

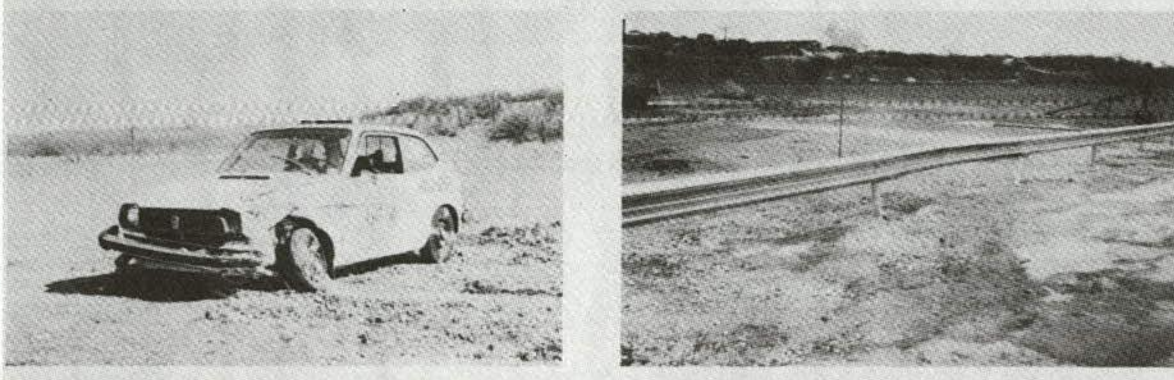
This test evaluated the G9 blocked-out thrie beam on steel post guardrail system. The test vehicle was smoothly redirected with a maximum dynamic barrier deflection of 6.0 in. (15 cm), as shown in Figure 12. Damage to the barrier and the vehicle was moderate (as shown in Figure 11). The vehicle was operable after the test with mostly sheet metal damage, and the barrier was fully serviceable with negligible permanent deformation. Test values indicated marginal compliance with the recommended lateral ΔV occupant risk values of *NCHRP Report 230.* The test was judged to be successful.

Test GR-3

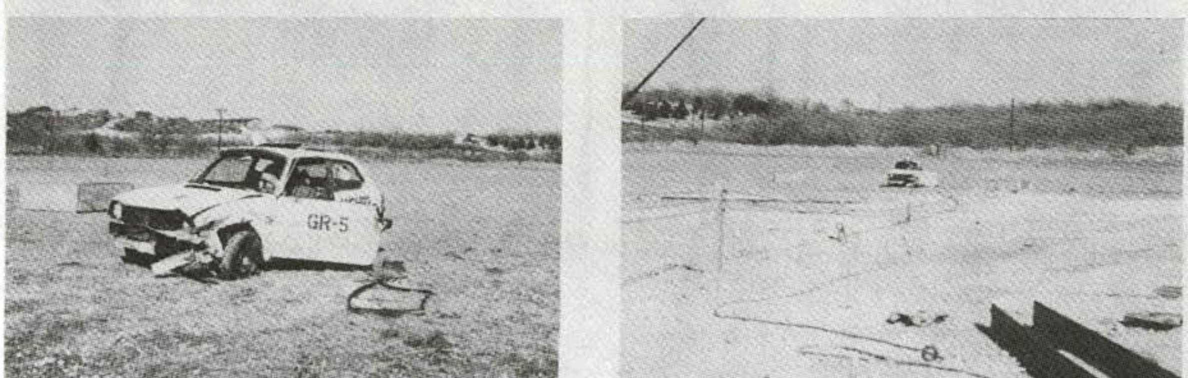
This test evaluated the G2 W-beam on weak steel post guardrail system. The vehicle was smoothly redirected with a maximum dynamic barrier deflection of 16.0 in. (41.0 cm) as shown in Figure 13. Contact with the posts caused the rear of the vehicle to yaw away from the barrier as it left the rail. Damage to the vehicle consisted of sheet metal and left front wheel/tire damage resulting from contact with the posts. Damage to the barrier was sufficient to reduce the serviceability (as shown in Figure 11). One post was completely out of service. Measured test values indicated compliance with *NCHRP Report 230.*



(c) Test GR-3, System G2



(d) Test GR-4, System G3



(e) Test GR-5, System G1

Figure 11. Continued

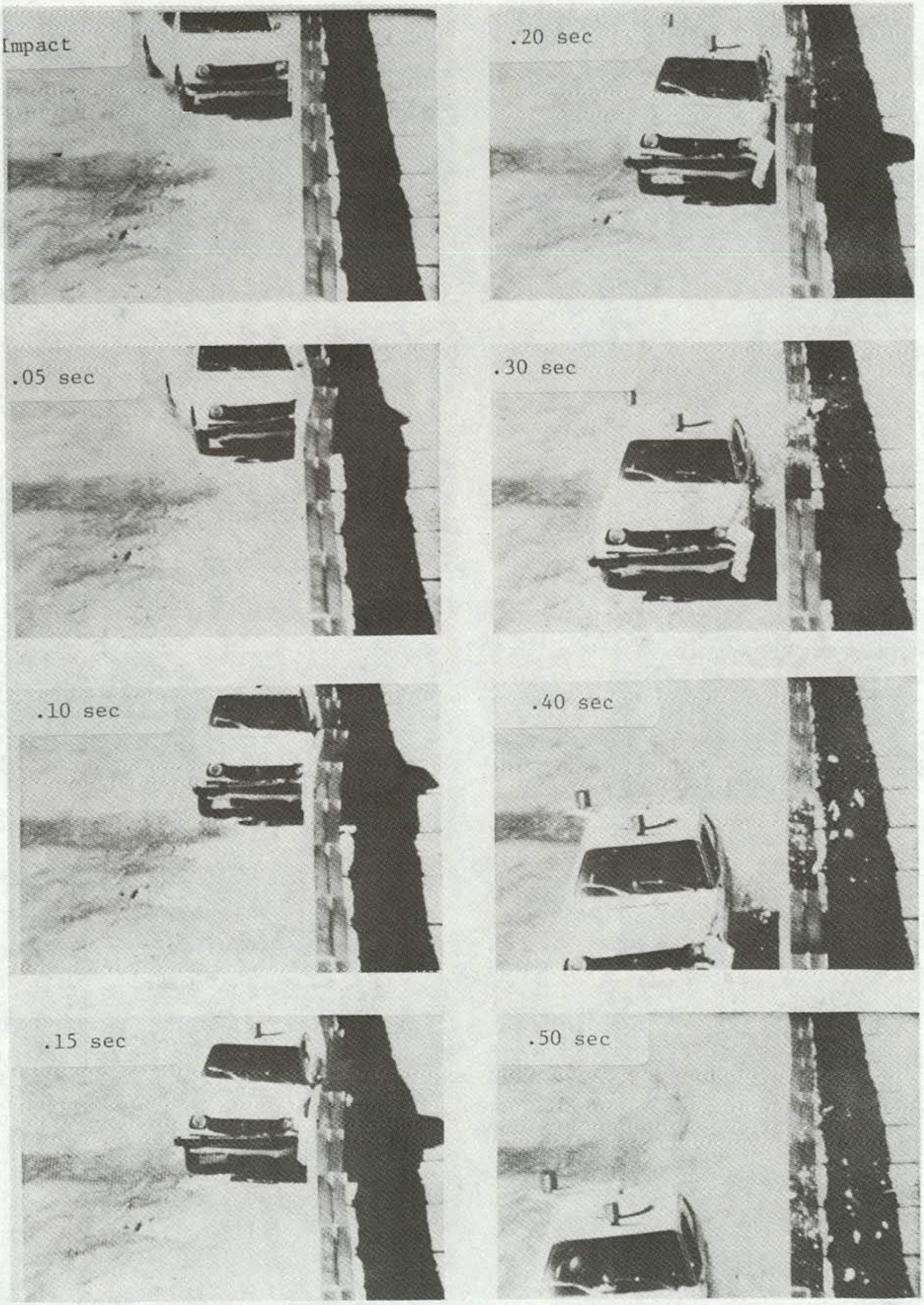


Figure 12. Sequential photographs, test GR-2.

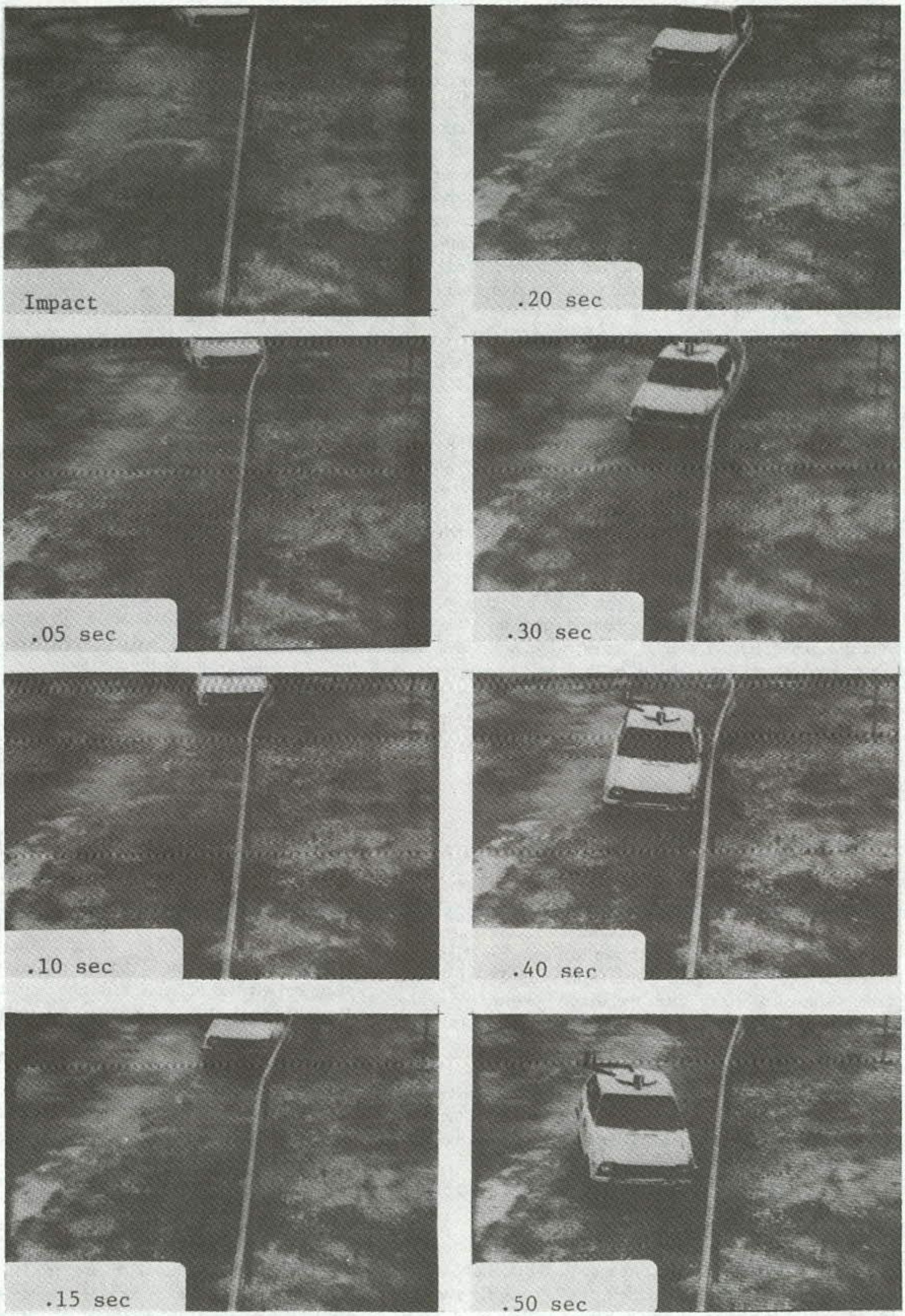


Figure 13. Sequential photographs, test GR-3.

Test GR-4

This test evaluated the G3 box-beam system on weak steel posts. The vehicle was smoothly redirected with a maximum dynamic barrier deflection of 6.4 in. (16.3 cm) as shown in Figure 14. Contact with the posts caused the rear of the vehicle to yaw away from the barrier as it left the rail and the vehicle recontacted the barrier downstream. There was considerable front wheel damage due to contact with the posts; sheet metal damage was extensive in the front quadrant. There was no permanent set in the rail, although two posts were completely out of service and another was detached from the rail, as shown in Figure 11. Test values measured indicated compliance with *NCHRP Report 230.*

Test GR-5

This test evaluated the G1 cable on steel weak post guardrail system; mounting height was 27 in. (76 cm). The vehicle was smoothly redirected with a maximum dynamic barrier deflection of 43.4 in. (1.1 m) as shown in Figure 15. The rear of the vehicle yawed away from the barrier as the vehicle left the barrier; the vehicle then recontacted the barrier terminal, snagged, and rolled over. The breakaway feature of the terminal failed to release the cables from the anchorage. Vehicle damage prior to rollover was confined to sheet metal and the front wheel (due to post contact). Barrier damage was extensive, with three posts out of service and cables lying on the ground (as shown in Figure 11). Before the rollover the test would have been judged successful, except for the 15-mph (24-km/h) velocity change Criterion I of *NCHRP Report 230.* This value was slightly exceeded and a marginal pass is indicated.

Test MB-1

This test evaluated the MB4W blocked-out W-beam on 8 x 8-in. (20 x 20-cm) timber posts with channel rub rail. The test vehicle was redirected with a maximum dynamic barrier deflection of 2.5 in. (6.3 cm) as shown in Figure 16. There was no evidence of vehicle contact with the rub rail. Damage to the vehicle consisted of side sheet metal and bumper; the vehicle was operable after the test. Damage to the barrier consisted of local beam deformation at two block-outs as shown in Figure 17. The barrier was fully serviceable with no measurable permanent deformation. Based on measured values, the test was judged to be successful, although the occupant risk lateral ΔV velocity slightly exceeded the *NCHRP Report 230* value.

Test MB-2

This test evaluated the performance of the MB3 box beam on weak steel posts median barrier. The test vehicle was redirected with a maximum dynamic barrier deflection of 7.0 in. (17.8 cm) as shown in Figure 18. Because of contact with the posts, the rear of the vehicle yawed away from the barrier as contact with the barrier was lost. Vehicle damage was limited to sheet metal and bumper; all tires remained inflated and the vehicle was operable after the test. Damage to the barrier consisted of three failed posts, as shown in Figure 17; there was no permanent set in the rail. Measured values indicated full compliance with the recommendations of *NCHRP Report 230.*

Test BR-1

This test evaluated the BR2 California Type 9 bridge rail system featuring a steel rail mounted on 15-in. (38-cm) high parapet (this is 3 in. (8 cm) below the current AASHTO specification requirement). The vehicle was smoothly redirected with no barrier deflection as shown in Figure 19; no snagging or wedging of the vehicle under the rail was noted. There was sheet metal deformation of the right front and side of the vehicle; the vehicle was operable after the test. Damage to the barrier was not evident as shown in Figure 20. Measured values indicated compliance with *NCHRP Report 230.*

Test BR-2

This test evaluated the Texas Type T4 (aluminum) bridge rail mounted on an 18-in. (46-cm) high parapet. The vehicle was smoothly redirected, with no barrier deflection and no evidence of snagging as shown in Figure 21. Damage to the vehicle consisted of front and side sheet metal damage. All tires remained inflated and the vehicle was considered operable after the test. No damage to the barrier was evident, as shown in Figure 19. Measured values indicated compliance with *NCHRP Report 230.*

Test BR-3

This test evaluated the BR3 New York box beam bridge rail mounted on a flush deck. The test vehicle was redirected after *significant* wheel snagging on the first downstream post occurred as shown in Figure 22. The redirected vehicle remained essentially parallel to rail for a considerable distance. No barrier deflection was evident. The damage to the vehicle was severe, with extensive sheet metal damage as shown in Figure 20. A-pillar and windshield frame distortion contributed to windshield damage. The right A-frame was significantly damaged. No significant damage to the barrier system was evident. Measured values indicated compliance with *NCHRP Report 230.*

Test BR-4

This test evaluated the NCHRP Service Level 1 bridge rail system which uses a thrie beam mounted on breakaway steel posts. The test vehicle was smoothly redirected after 17.2 in. (43.7 cm) maximum dynamic deflection as shown in Figure 23. The right wheels of the vehicle dropped off, below the deck, as the redirection continued. Vehicle damage was slight and confined to sheet metal. The vehicle was operable after the test. Barrier damage included one slightly deformed thrie beam section and two posts that were detached from the base plate, as shown in Figure 20. Measured values indicated compliance with *NCHRP Report 230.*

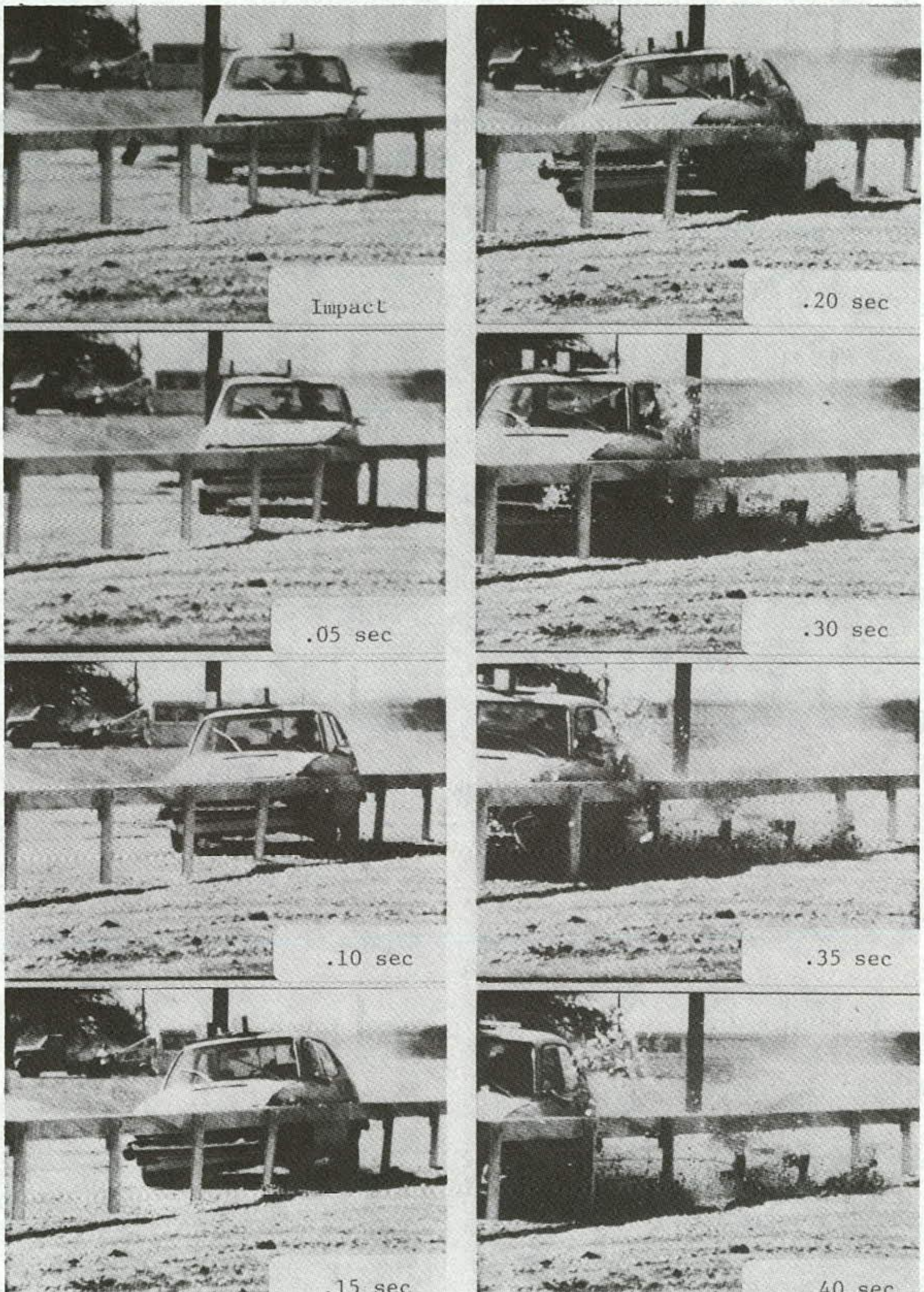


Figure 14. Sequential photographs, test GR-4.

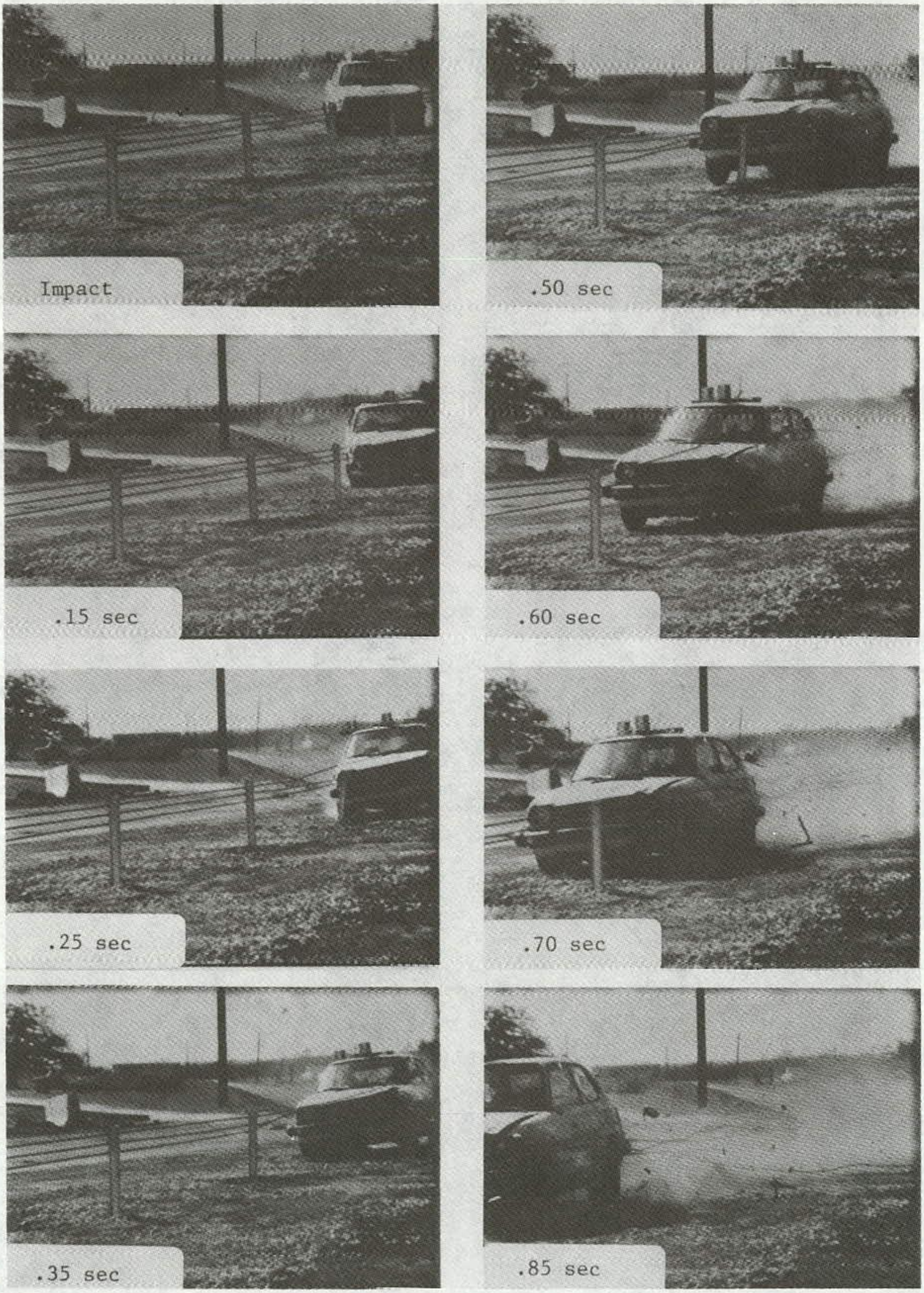


Figure 15. Sequential photographs, test GR-5.

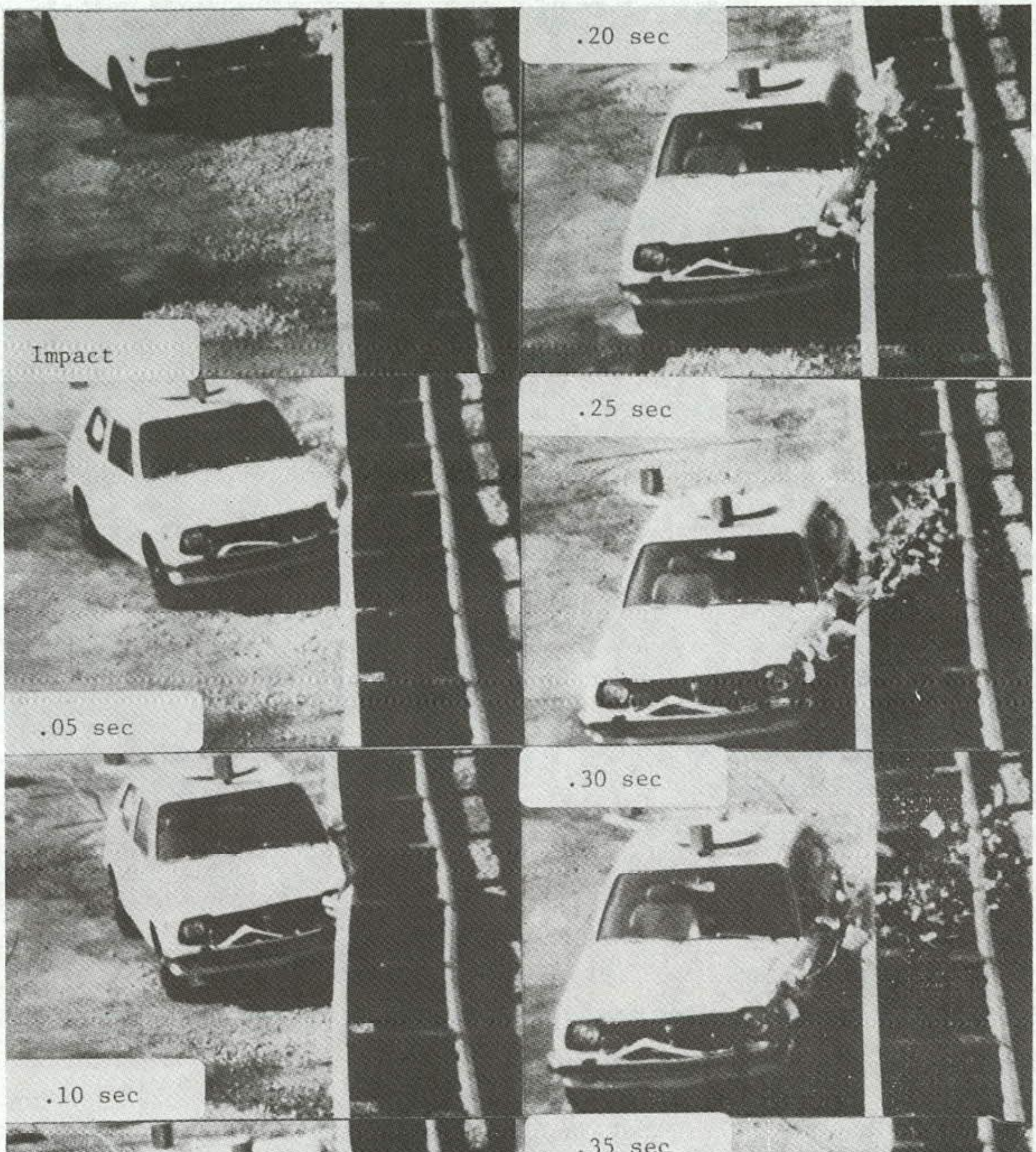
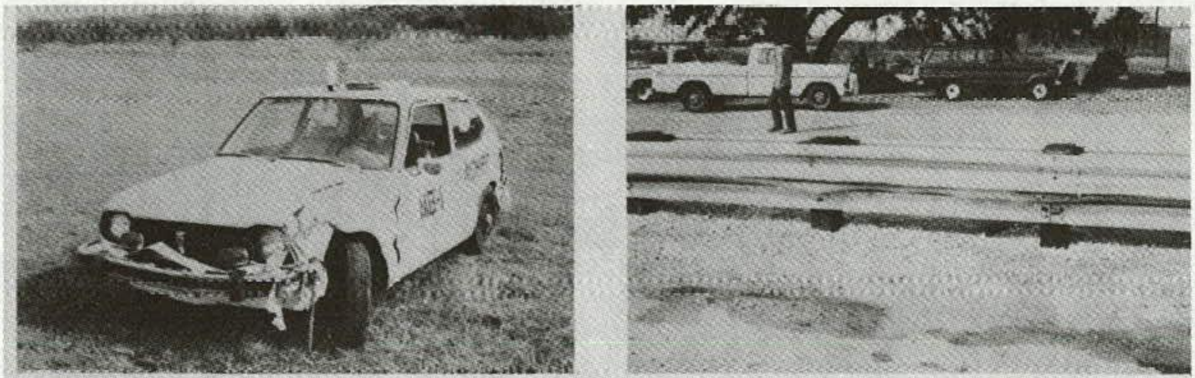
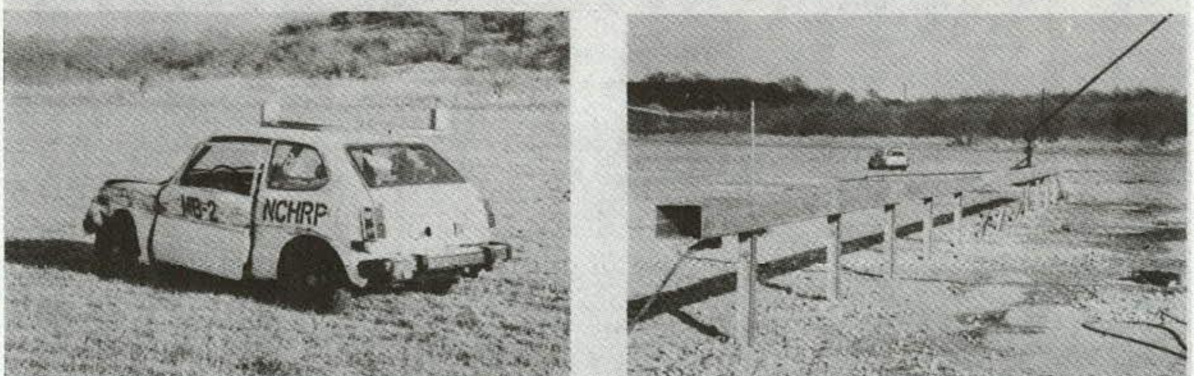


Figure 16. Sequential photographs, test MB-1.



(a) Test MB-1, System MB4W



(b) Test MB-2, System MB3

Figure 17. Barrier and vehicle damage after median barrier tests.

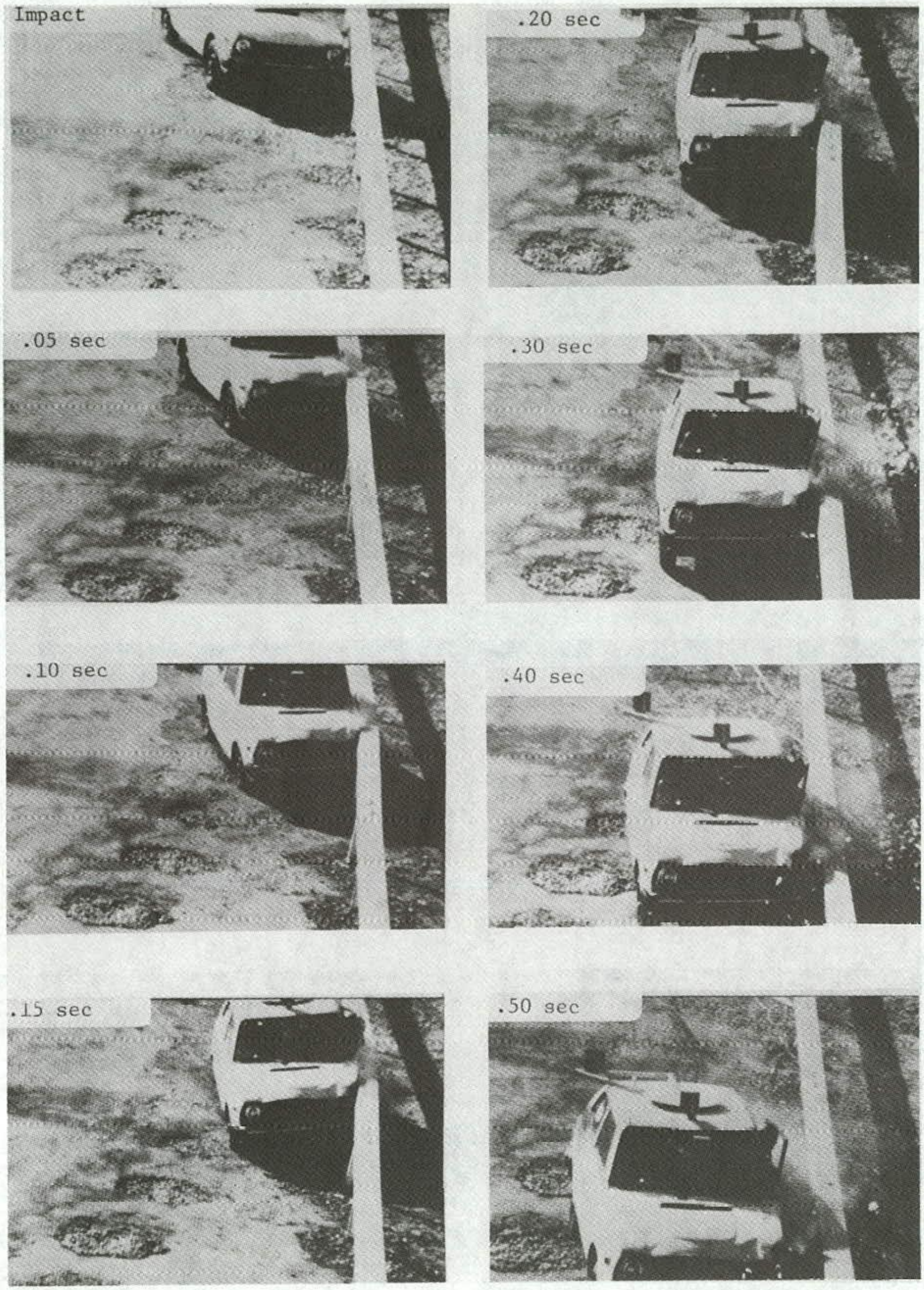


Figure 18. Sequential photographs, test MB-2.

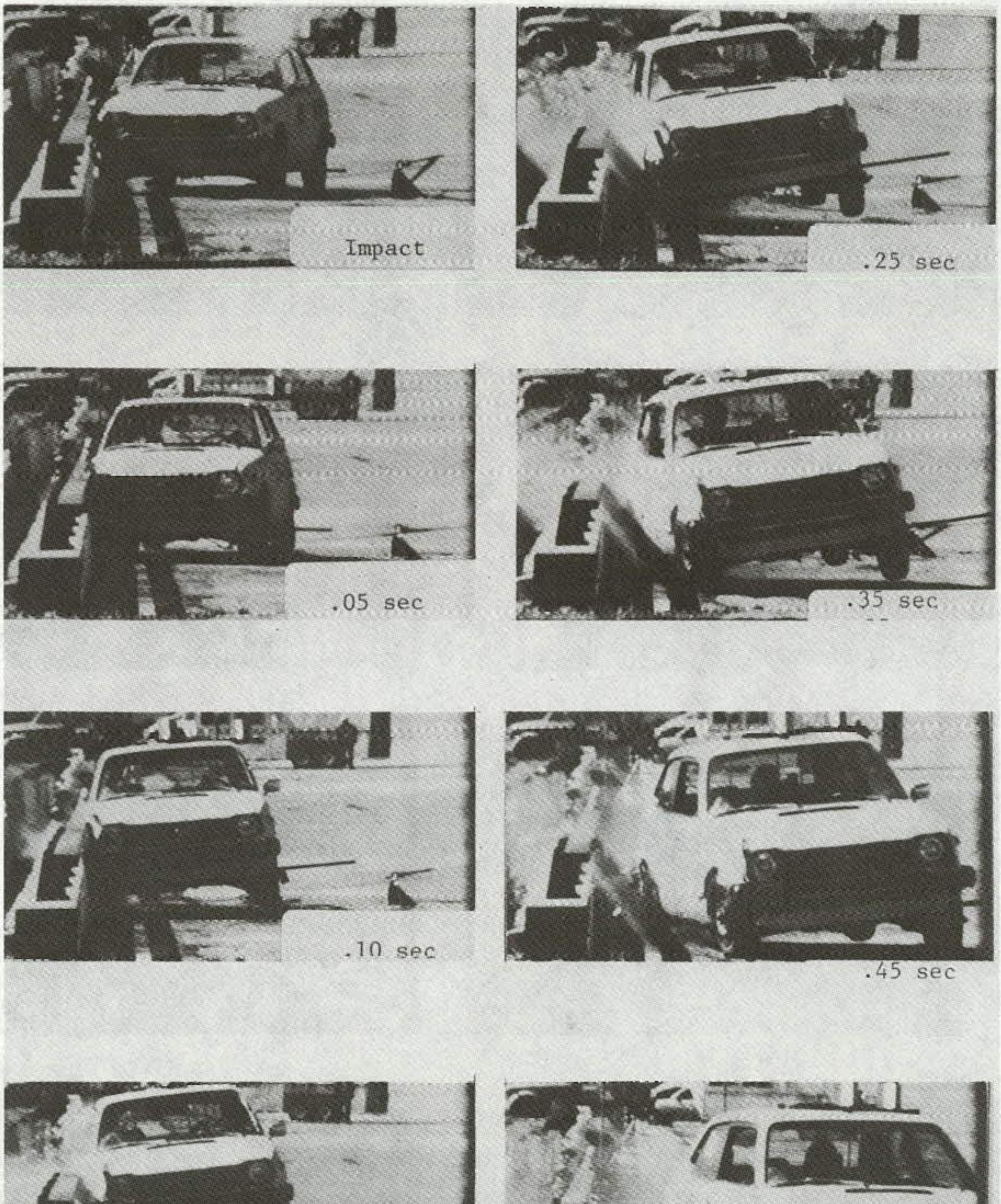
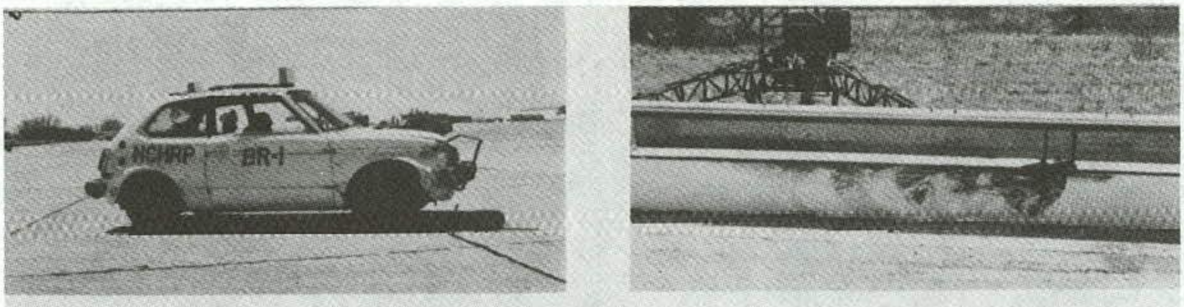
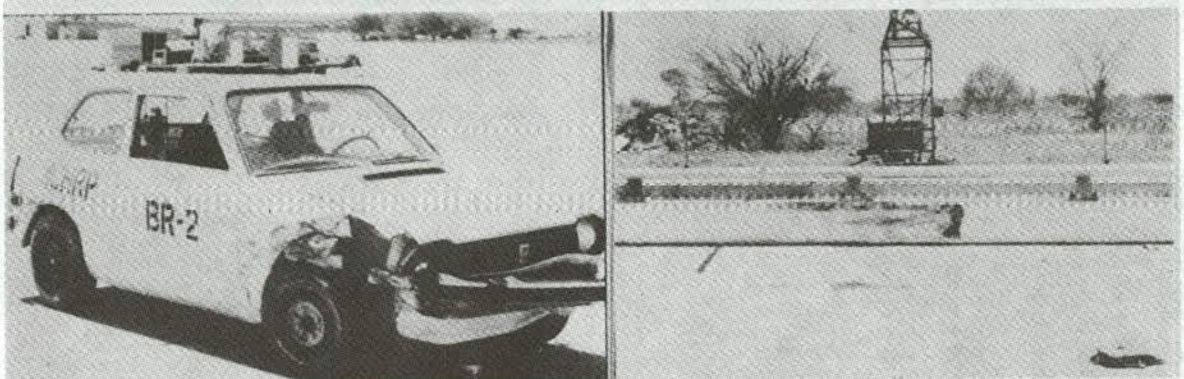


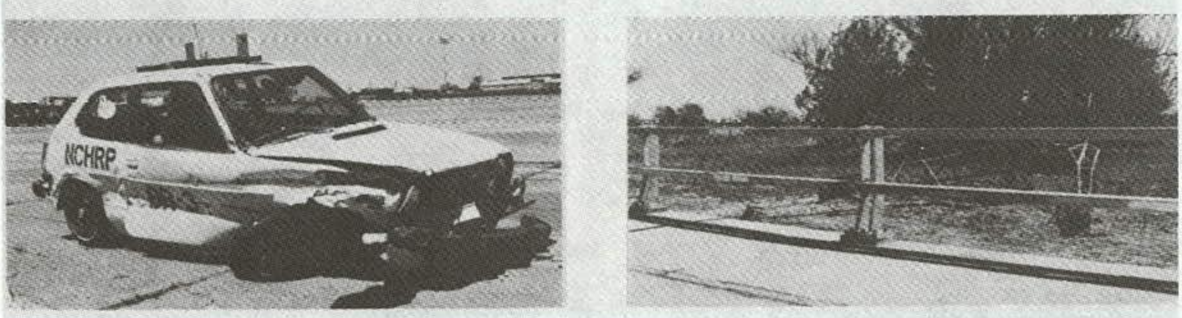
Figure 19. Sequential photographs, test BR-1.



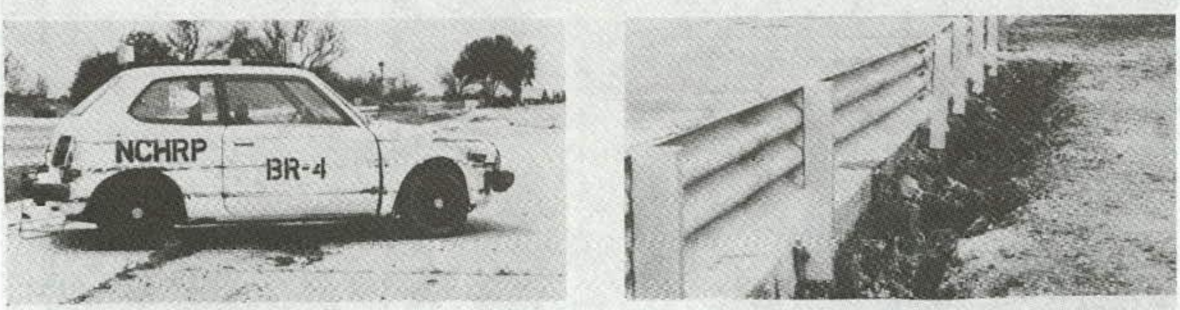
(a) Test BR-1, System BR2



(b) Test BR-2, Texas Type T4



(c) Test BR-3, System BR3



(d) Test BR-4, Service Level 1 Bridge Rail

Figure 20. Barrier and vehicle damage after bridge rail tests.

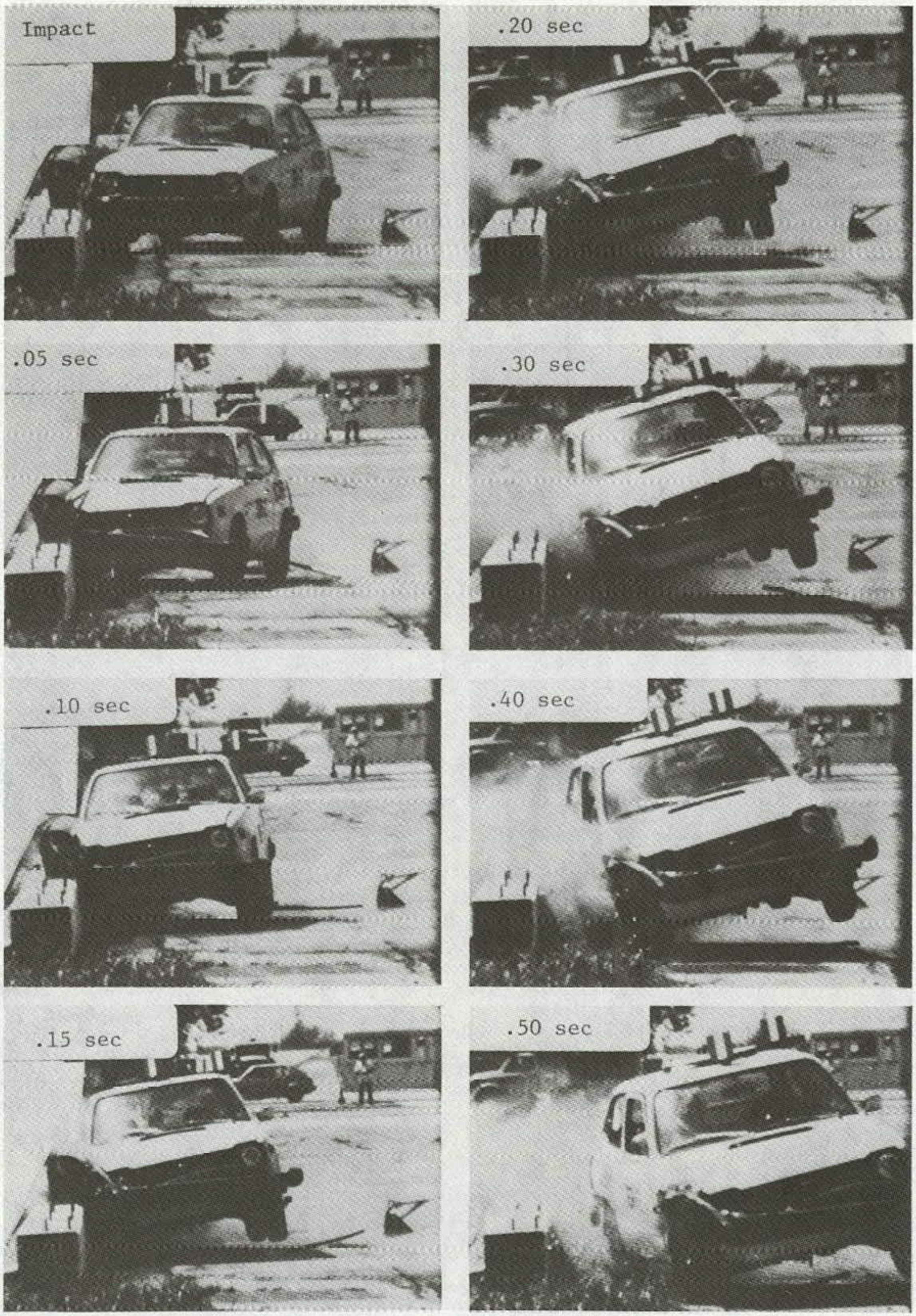


Figure 21. Sequential photographs, test BR-2.

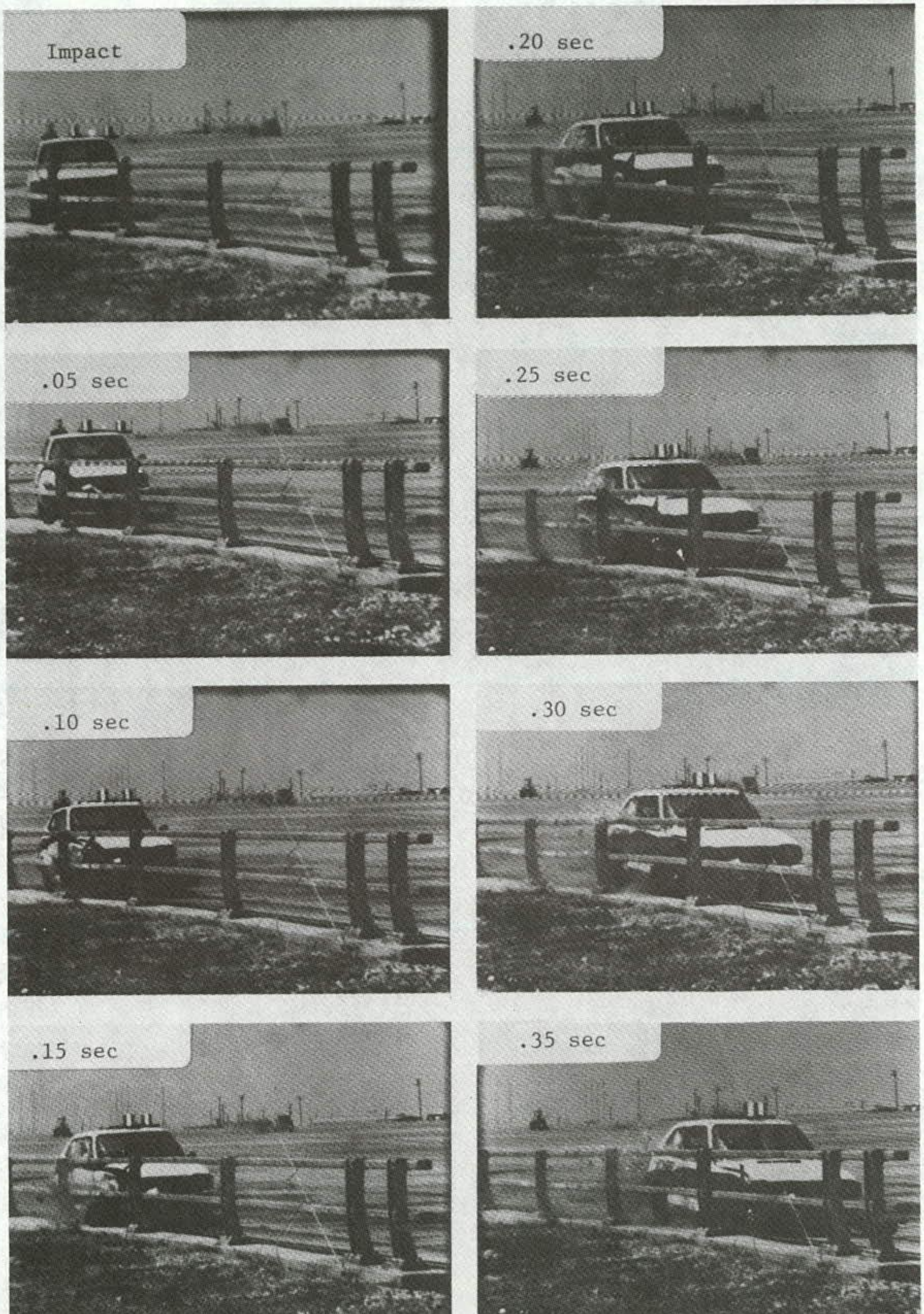


Figure 22. Sequential photographs, test BR-3.

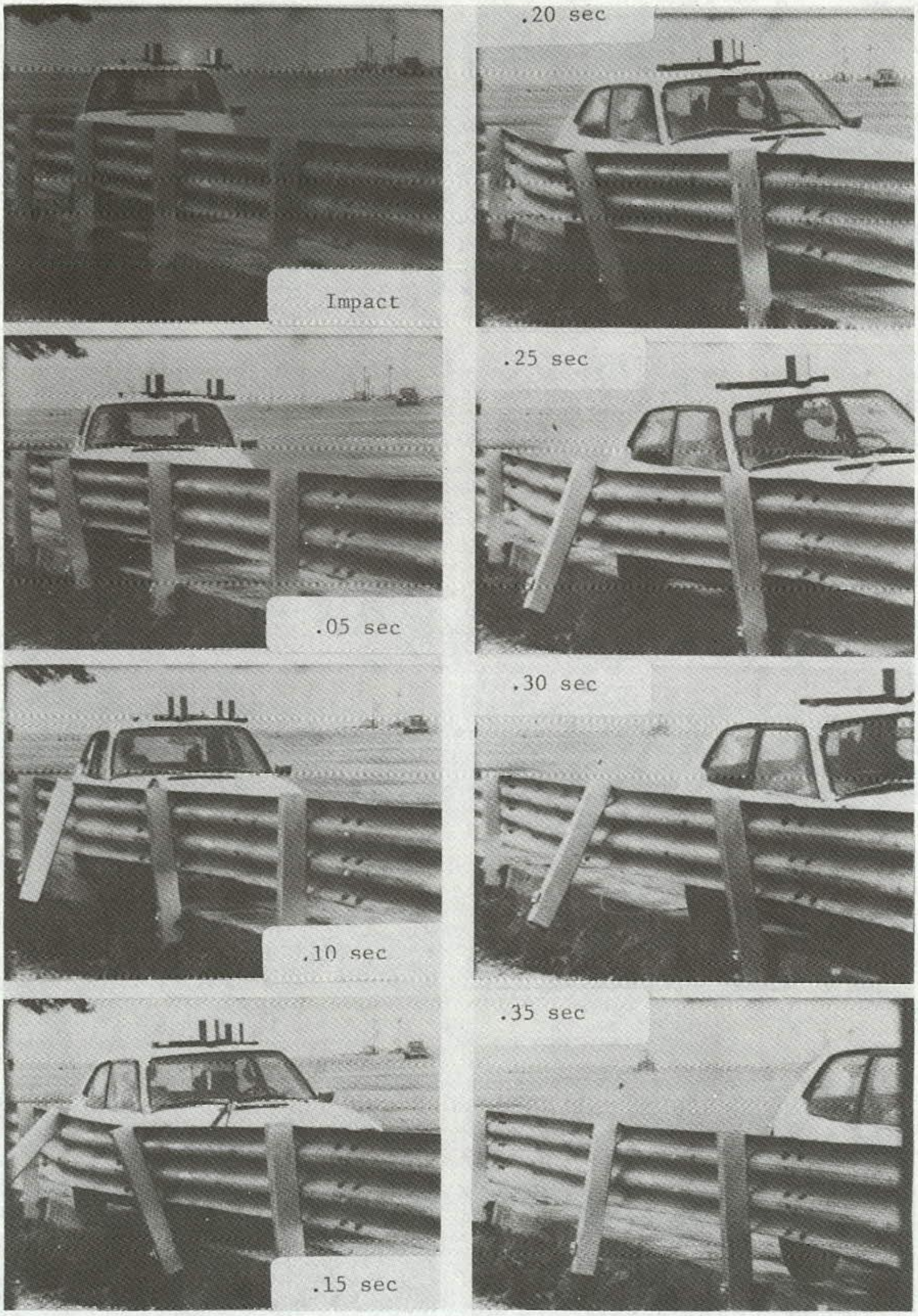


Figure 23. Sequential photographs, test BR-4.

PHASE II CRASH TESTS

Crash test evaluations in this phase can be grouped into three categories: (1) insight tests of operational barriers using two test conditions: a. 1,800-lb (800-kg) cars, 60 mph (95 km/h), 20-deg angle, and b. 4,300-lb (1900-kg) vans, 60 mph (95 km/h), 20–25-deg angle; (2) transition tests using both 4,500-lb (2,000-kg) and 1,800-lb (800-kg) cars: a. guardrail/guardrail transition, b. guardrail/bridge rail transition, and c. semirigid median barrier/rigid median barrier transition; (3) miscellaneous tests: a. limit test of G9 (wood post) using 8,000-lb (3,600-kg) van, b. blocked-out W-beam guardrail system with round wood posts, and c. cable guardrail height question with van.

Insight Tests

Guardrail systems G1, G2, G3, G4(2W), and G9 (wood post) and median barrier system MB3 were evaluated for *Report 230* test S13 conditions (1,800 lb (800 kg), 60 mph (95 km/h), 20-deg angle) and for impacts with a 4,300-lb (1,900-kg) van at 60 mph (95 km/h) and angles from 20 to 25 deg based on predicted threshold of performance.

Test GR-6

This test evaluated the G4(2W) guardrail system for *Report 230* test S13 conditions (actual 61.9 mph (100 km/h), 21.7 deg). The vehicle was smoothly redirected after a maximum dynamic deflection of 10.4 in. (26.4 cm) as shown in Figure 24. Damage to the barrier was not significant; the vehicle damage was limited to the front quarter as shown in Figure 25.

Test GR-8

This S13 test evaluated the G2 guardrail system when impacted at 58.5 mph (94.2 km/h) and 19.3 deg. The test vehicle was smoothly redirected as shown in Figure 26, with all values meeting the requirements of *NCHRP Report 230.* The test vehicle crossed the barrier line downstream at an angle less than 15 deg before contacting another barrier. Thus, the second impact with a longer G2 barrier would have been less severe because of the reduced speed and angle. The maximum dynamic deflection was 31.7 in. (80.5 cm). Photographs after test are as shown in Figure 25.

Test GR-10

This S13 test evaluated the G3 box beam guardrail system for an 18.4 deg, 59.3 mph (95.5 km/h) impact. Severe snagging caused the vehicle to yaw significantly away from the barrier, as shown in Figure 27, before recontacting the barrier and eventually exiting at a very flat angle. Occupant risk values were within the *NCHRP Report 230* recommended values. The maximum dynamic deflection was 15.6 in. (39.6 cm). Photographs after test (see Fig. 25) show significant vehicle front end and side damage. The left front wheel/A-frame assembly was displaced rearward.

Test GR-12

The purpose of this test was to evaluate the MB3 box beam median barrier for the 58.5-mph (94.2-km/h), 19.4-deg angle impact. The vehicle impacted at 58.5 mph (94.2 km/h) and a 19.4-deg angle. The vehicle had been redirected before snagging and spinout occurred as shown in Figure 28. The vehicle rotated through a 90-deg angle before recontacting the barrier and eventually traveled in a "reverse" direction before coming to rest. The occupant risk values complied with the recommended values of *NCHRP Report 230.* The maximum dynamic deflection was 12.1 in. (30.7 cm). Photographs after test (see Fig. 25) show significant vehicle front end and side damage. The left front wheel/A-frame assembly was displaced rearward.

Test GR-13

This S13 test evaluated the G9 (wood post) guardrail system for 59.5-mph (95.8-km/h), 22.6-deg angle impact. The vehicle was smoothly redirected, as shown in Figure 29, with measured values in conformance with *NCHRP Report 230.* The maximum dynamic deflection was 15.2 in. (3.6 cm); the vehicle recrossed the barrier plane at a 5.4-deg angle. Photographs after test (Fig. 25) show vehicle sheet metal and bumper damage. The front right tire was blown, but suspension damage was minimal.

Test GR-16

The G1 cable system was evaluated at a 30-in. (75-cm) mounting height for 59.2 mph (95.3 km/h), 19.5-deg angle impact conditions with the 1,800-lb (800-kg) car. The vehicle was redirected with a maximum dynamic deflection of 5.8 ft (1.8 m), as shown in Figure 30, before yawing away from the barrier began. The vehicle came to rest in contact with the barrier (see Fig. 25). *NCHRP Report 230* criteria were met with the exception of the velocity change section. This part of *Report 230* does not recognize the long contact periods characteristic of the cable systems and is not considered to be an appropriate evaluation criterion.

Test GR-7

This test evaluated the performance of the G4(2W) guardrail when impacted by a 4,650-lb (2,102-kg) van at 58.7 mph (94.5 km/h) and 20.9 deg. An almost identical van had rolled over after impacting a G4(1S) guardrail at 60 mph (95 km/h) and a higher 25-deg angle (*14*). The weight, c.g. location, and yaw mass moment of inertia were measured and these are compared to the van used in the G4(1S) test (see Table 14).

The van impacted the guardrail, as shown in Figure 31, and was smoothly redirected with a maximum vehicle roll angle of 14.3 deg. The vehicle remained in contact with the barrier for 22.7 ft (6.9 m) before redirection at an 11.7-deg angle. The maximum dynamic deflection was 25.2 in. (64.0 cm). Photographs after test are shown in Figure 32.

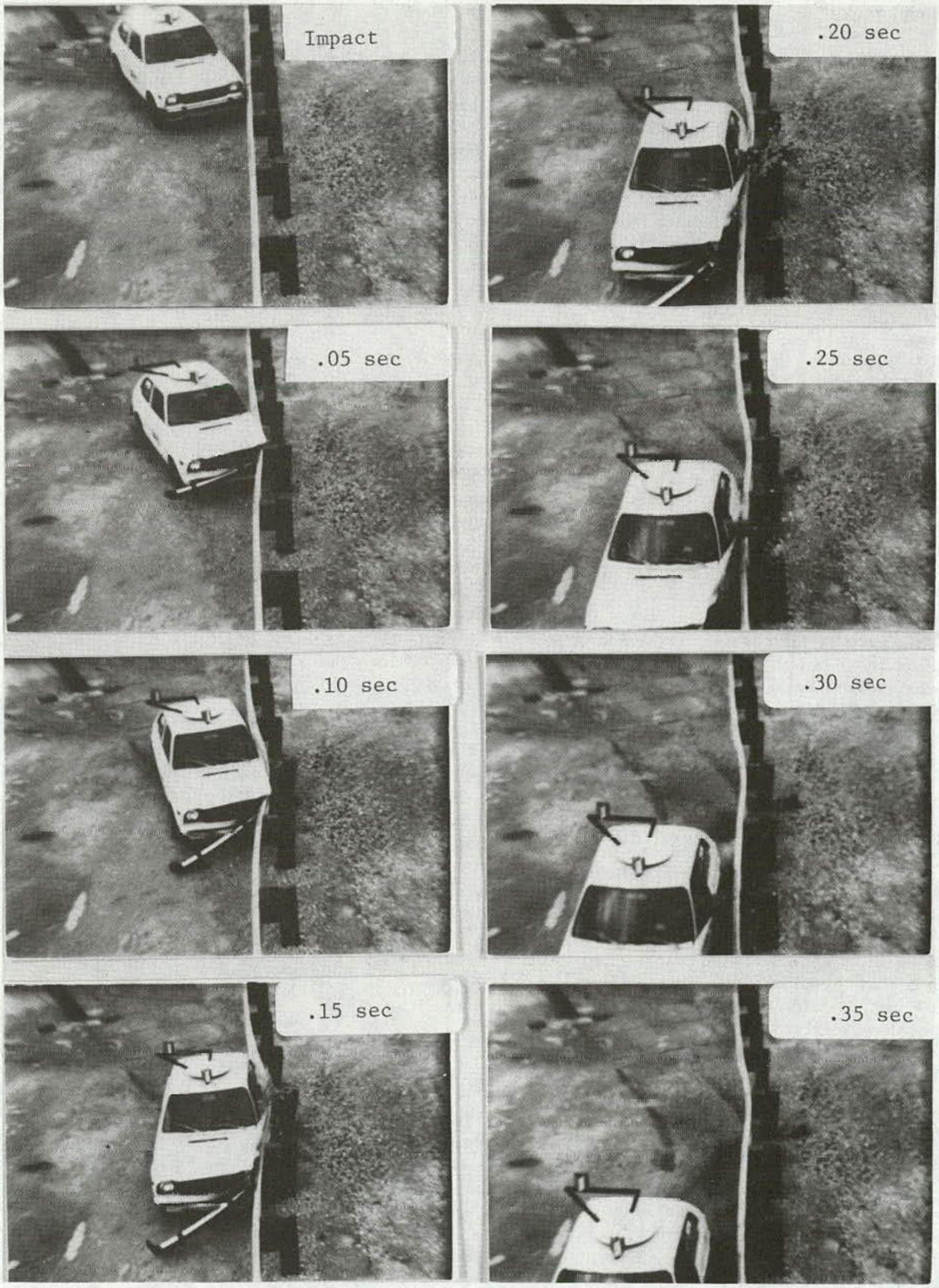
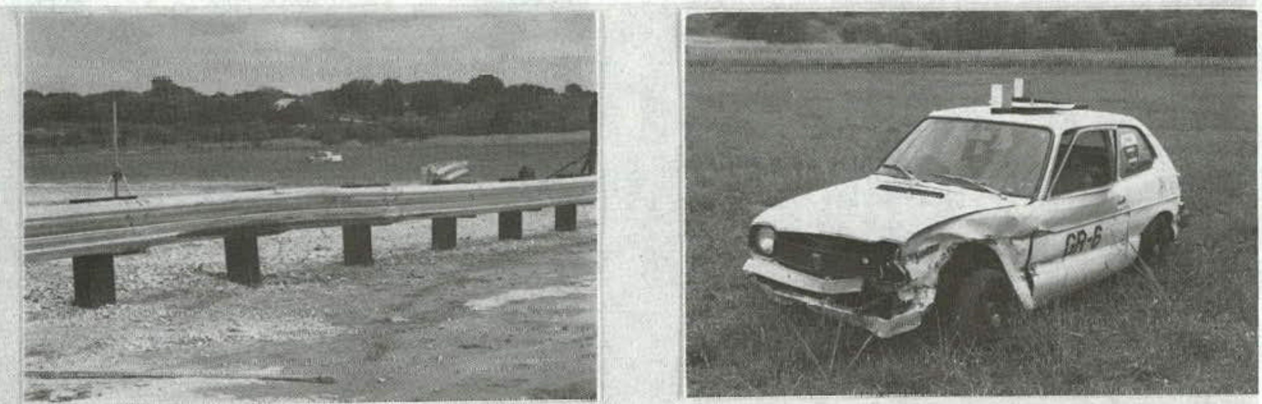
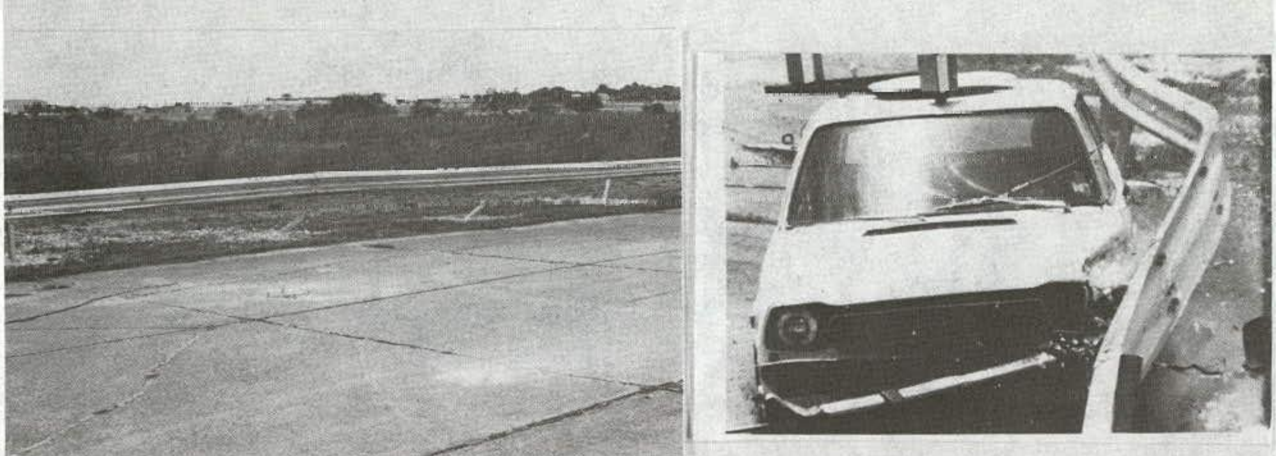


Figure 24. Sequential photographs, test GR-6.

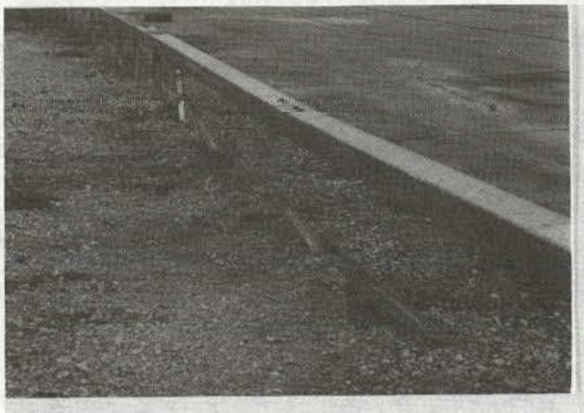


Test GR-6



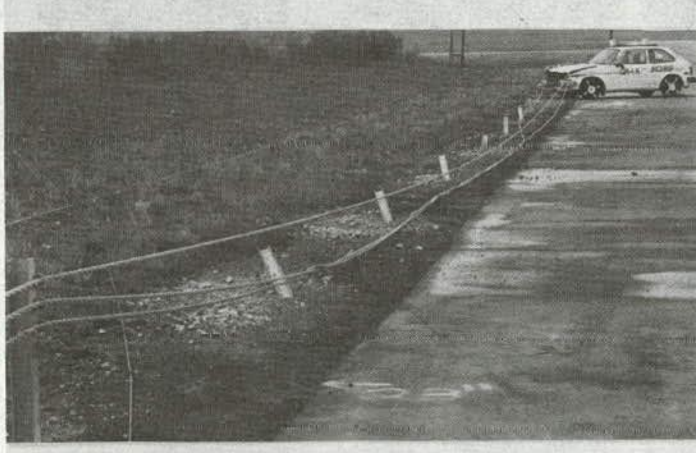
Test GR-8

Figure 25. Photographs after S13 tests.



Test GR-12

Test GR-13



Test GR-16

Figure 25. Continued

Figure 26. Sequential photographs, test GR-8.

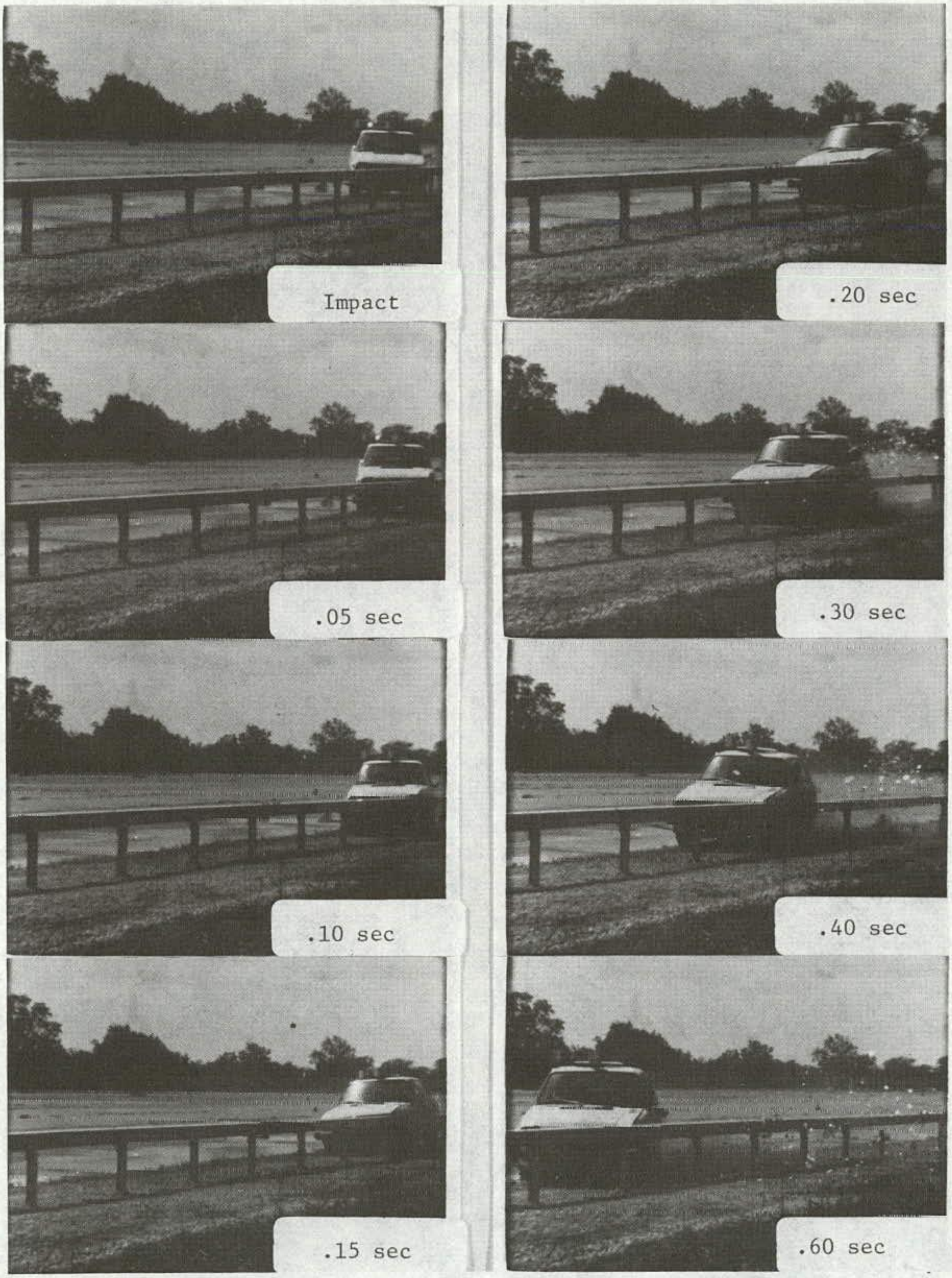


Figure 27. Sequential photographs, test GR-10.

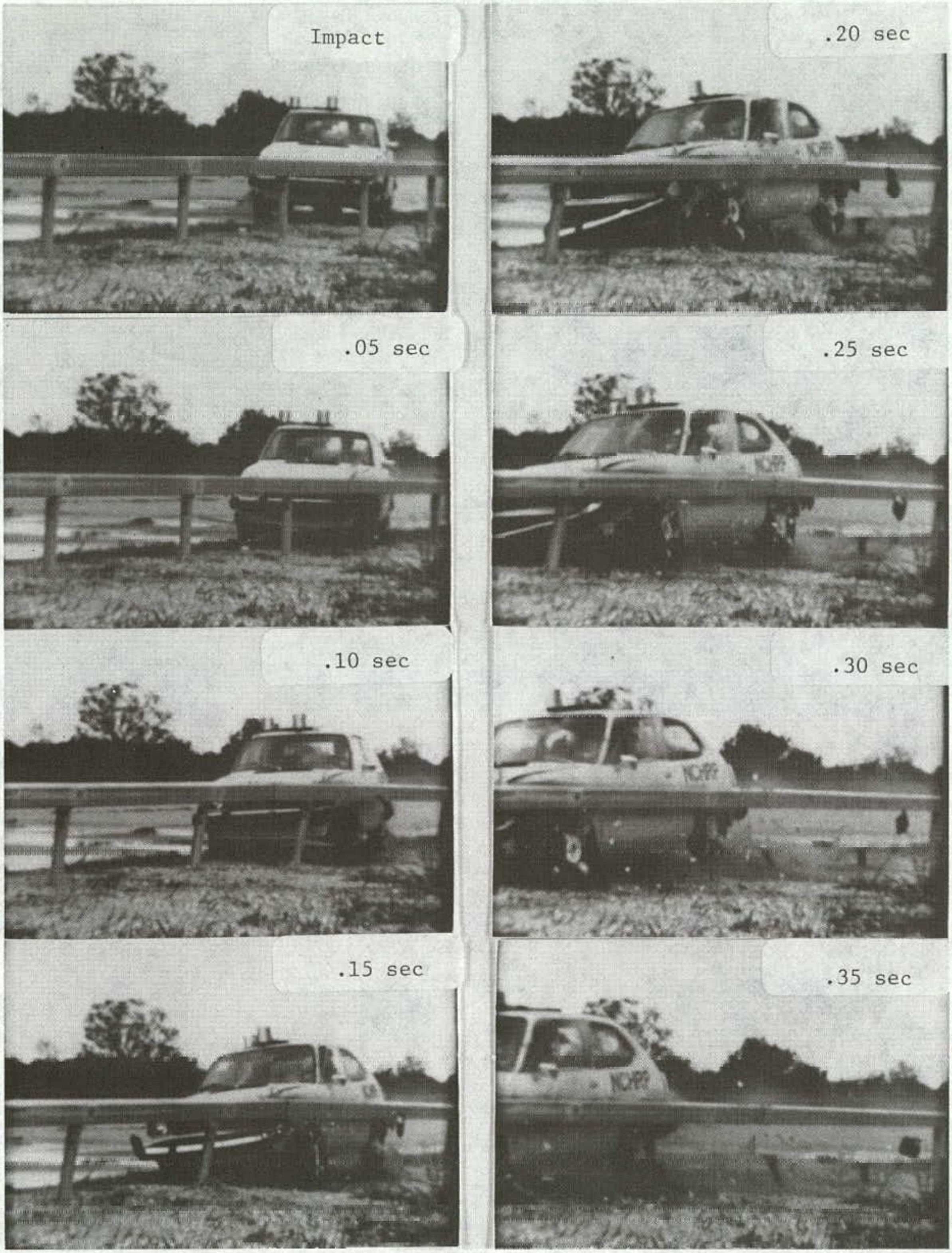


Figure 28. Sequential photographs, test GR-12.

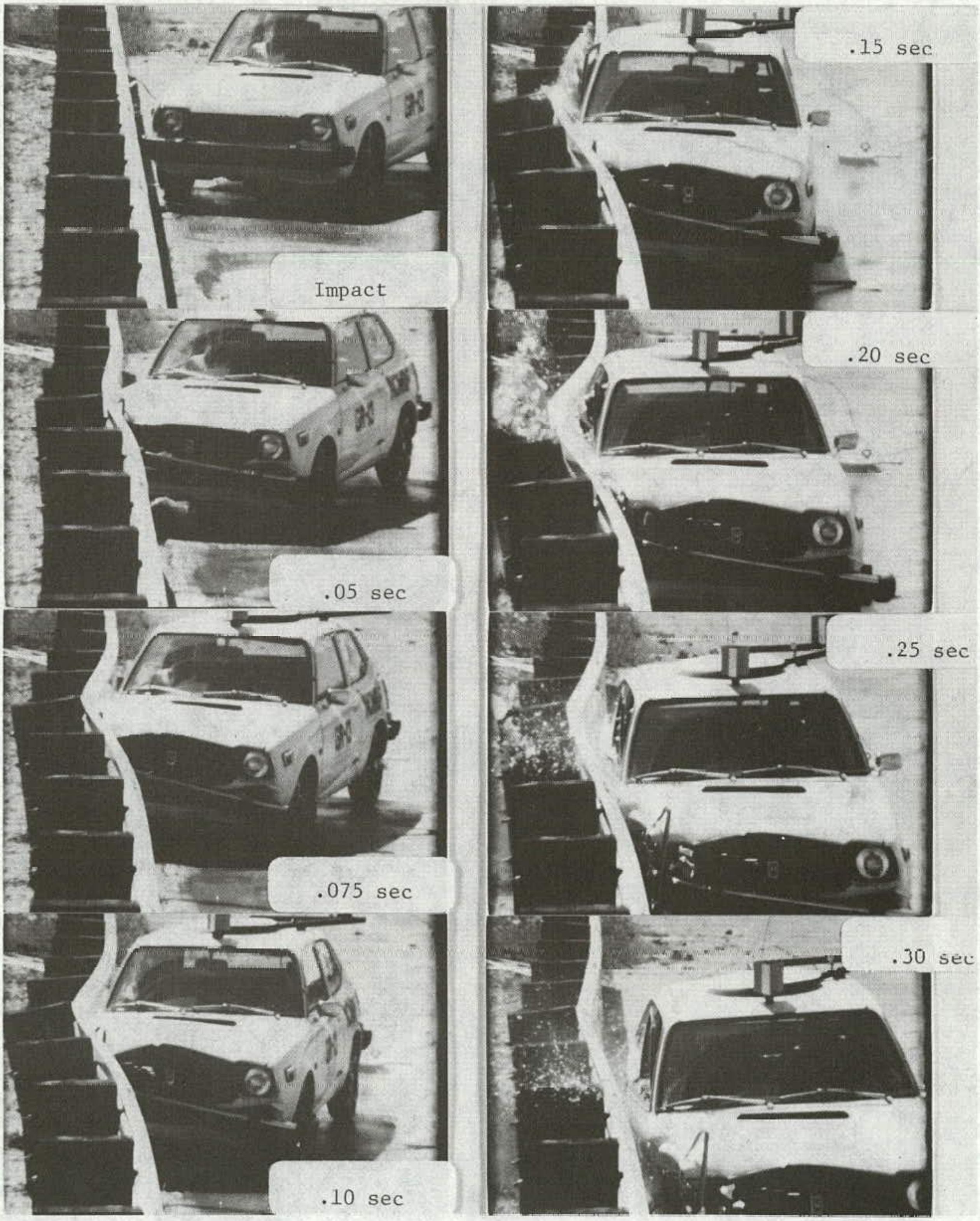


Figure 29. Sequential photographs, test GR-13.

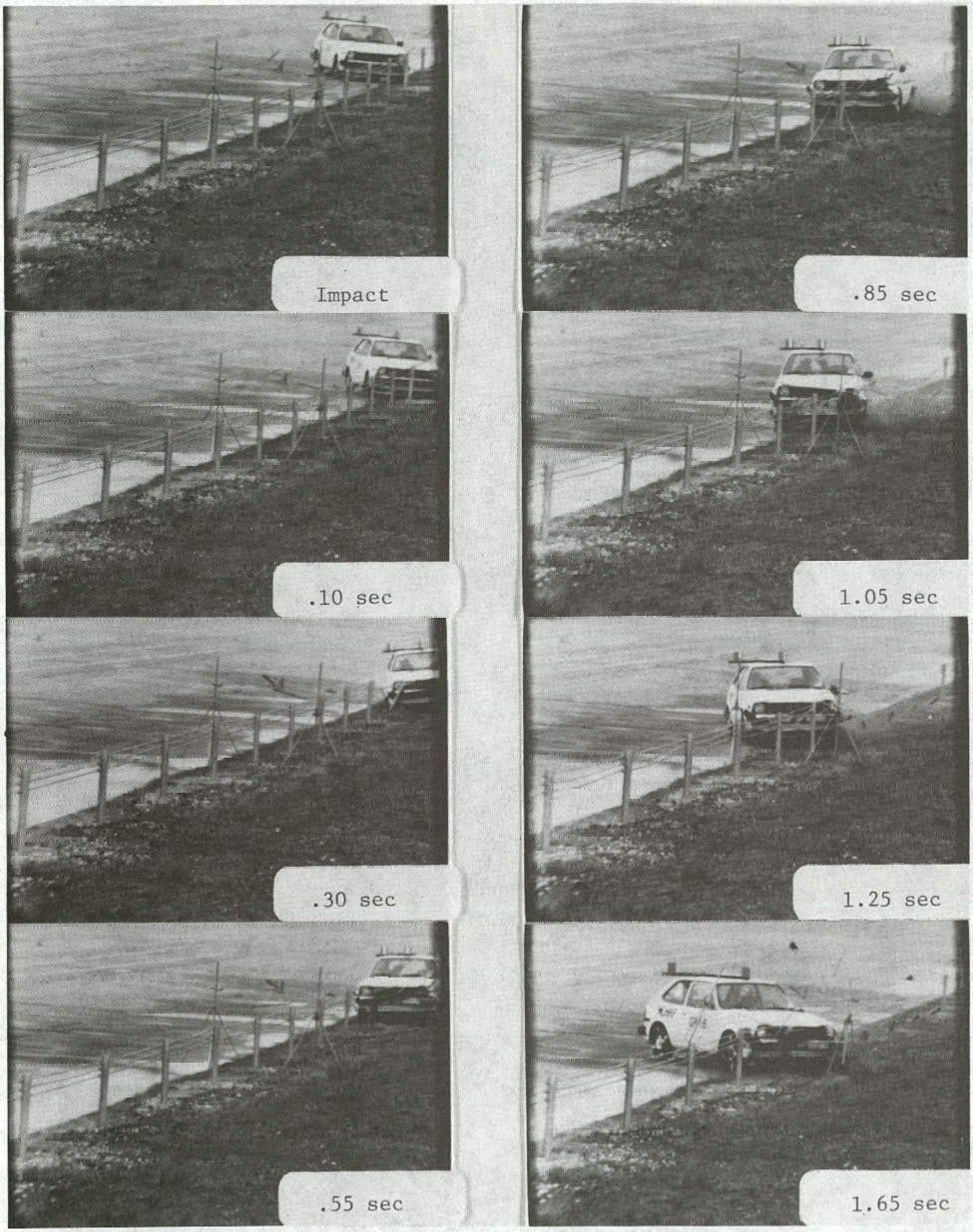


Figure 30. Sequential photographs, test GR-16.

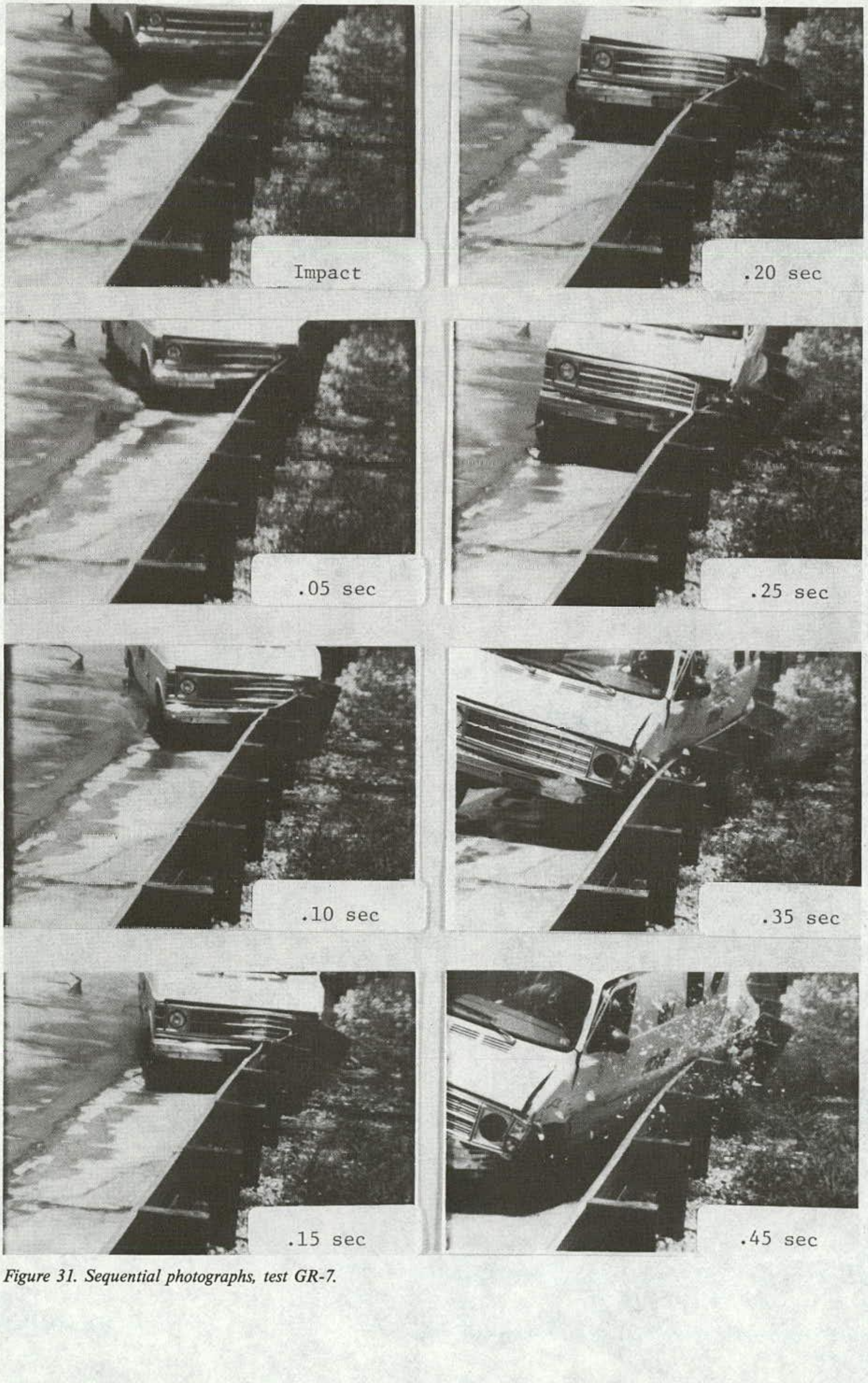
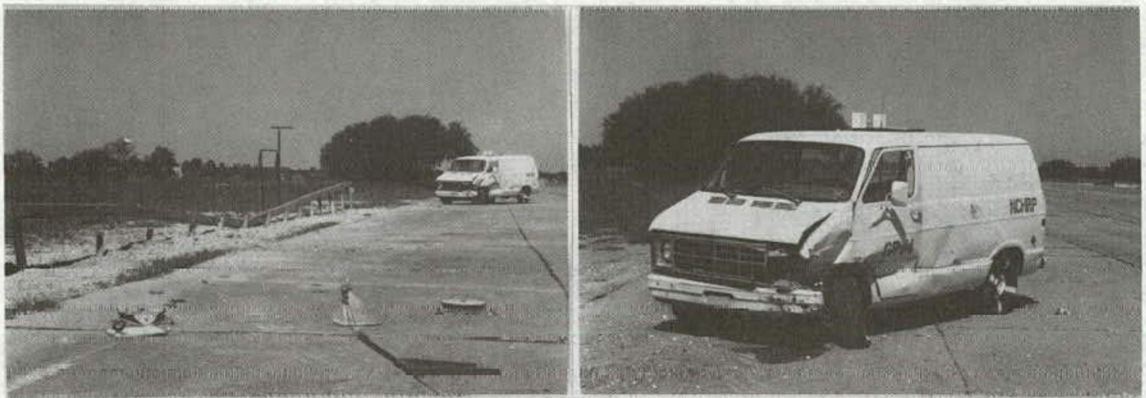


Figure 31. Sequential photographs, test GR-7.

Test GR-7

Test GR-9

Figure 32. Photographs after van tests.



Test GR-14

Test GR-15

Figure 32. Continued

Table 14. Properties of 1979 Dodge B200 vans.

		Test 4798-7 Vehicle	Test GR-7 Vehicle
1.	Inertia weight, lb	3983	4320
2.	Gross static weight, lb	4324	4650
3.	Horizontal c.g. location, in. (as measured from front wheel)	48.96	48.2
4.	Vertical c.g. location, in.	29.48	n/m
5.	Yaw mass moment of inertia, in-lb-sec^2 (does not include dummies)	39,633	40,674

Test GR-9

This test evaluated the G2 (W-beam/steel weak post) guardrail system with a 4,640-lb (2,097-kg) (nominal) van impacting at 59.4 mph (95.6 km/h) and a 23.9-deg angle. This van test was conducted at 25 deg (nominal) recognizing the possibility that the more flexible system and 30-in. (75-cm) mounting height might accommodate this impact condition. This did not prove to be the case as the van rolled on its side, as shown in Figure 33, and eventually contacted a downstream anchor post, which is not considered to be typical for this system. Nevertheless, it was demonstrated that the G2 system will not keep this model van upright under these impact conditions. Photographs after test are shown in Figure 32.

Test GR-11

This test evaluated the G3 box beam guardrail system for a 61.0-mph (98.2-km/h), 18.8-deg angle impact with a 4,380-lb (1,980-kg) van. As shown in Figure 34, the van impacted the barrier, the bumper rode under the beam, and after crushing of the fender sheet metal, the wheel also went under the beam. The wheel remained under the beam for five posts, before contact with the sixth post caused the rear end to yaw away from the barrier. The vehicle remained in contact with the barrier for 60.6 ft (28.5 m) after impact; the maximum dynamic barrier deflection was 2.2 ft (0.7 m). Photographs after the test are shown in Figure 32.

Test GR-14

This test evaluated the performance of the MB3 box beam median barrier system when impacted by a 4,050-lb (1,831-kg) van at 58.4 mph (94.0 km/h) and 18.7 deg. The vehicle was redirected before subsequent wheel snagging on the posts caused the vehicle to spin out as shown in Figure 35. This is not considered a smooth redirection, although the vehicle was contained and remained upright. Maximum dynamic deflection was 26.1 in (66.3 cm). Photographs after test are shown in Figure 32.

Test GR-15

This test evaluated the G9 thrie beam (wood post) system for a 60-mph (95-km/h), 25-deg angle impact with the 4,380-lb (1,979-kg) van. The vehicle was smoothly redirected with a maximum roll angle of 15 deg as shown in Figure 36 (*14*). The maximum dynamic deflection was 40.2 in (102.1 cm).

Test GR-17

This test evaluated the G1 cable system mounted at 27 in. (70 cm) for a 58.1-mph (93.5-km/h), 24.2-deg angle impact with a 4,160-lb (1,880-kg) van. The vehicle remained in contact with the barrier system for only 80 ft (24 m) (as compared to the 1,800-lb (800-kg) car test—138 ft (42m)) before being redirected. No serious rolling of the vehicle occurred as shown in Figure 37. The maximum dynamic deflection was 8.9 ft (2.7 m). Photographs after the test are shown in Figure 32.

Transition Tests

Seven crash tests were conducted in this series as summarized in Table 12.

Test TR-1

This test evaluated the transition from the G4(2W) W-beam system to a blocked-out G9 wood post thrie beam system using a 1,920-lb (871-kg) car impacting the W-beam system just upstream of the special transition element at 61.5 mph (99.0 km/h) and 14.1 deg. Redirection was smooth, as shown in Figure 38, with measured values indicating compliance with *NCHRP Report 230.* Photographs after test are shown in Figure 39.

Test TR-2

This test evaluated the same transition as the previous test using a 4,780-lb (2,161-kg) car impacting at 63.2 mph (101.8 km/h) and a 23.4-deg angle. The surprising result of this test was the almost immediate underride of the vehicle bumper under the W-beam, which caused the vehicle to wedge under the beam, break several posts in the transition zone, and eventually spin out as shown in Figure 40. These results were considered to be unsatisfactory; photographs after test are shown in Figure 39.

Test TR-3

The previous test was repeated because it was conjectured that test was an anomaly; however, the results were very much the same as shown in Figures 39 and 41.

In-depth investigations of the two tests revealed that the bumper was lower at impact than its pretest position. Film analysis of the vehicle trajectory prior to impact revealed that the vehicle was remaining level, whereas the suspension was reacting to the unevenness of the approach pavement. Measurements of the vehicle approach for the two tests are summarized in Table 15. The deviations from level or constant slope grade did not appear to be significant enough to have caused the problem; however an HVOSM (*14*) case was conducted using the terrain values given in Table 15.

Results of this HVOSM simulation, as presented in Table 16, indicate that the bumper height (18 in. (46 cm) nom) was at 14.8 in. (37.6 cm) at impact or 3.2 in. (8.1 cm) lower than level terrain.

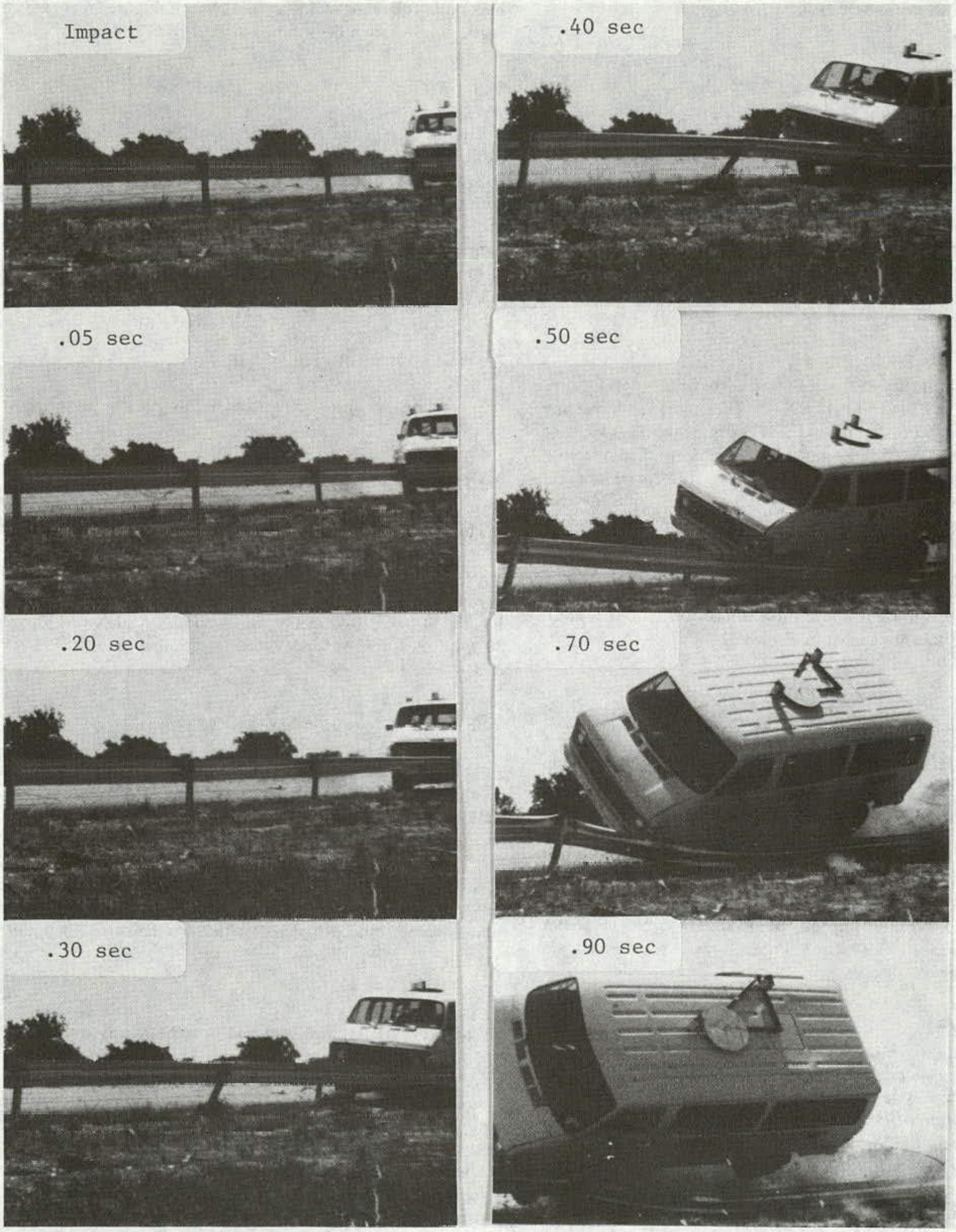


Figure 33. Sequential photographs, test GR-9.

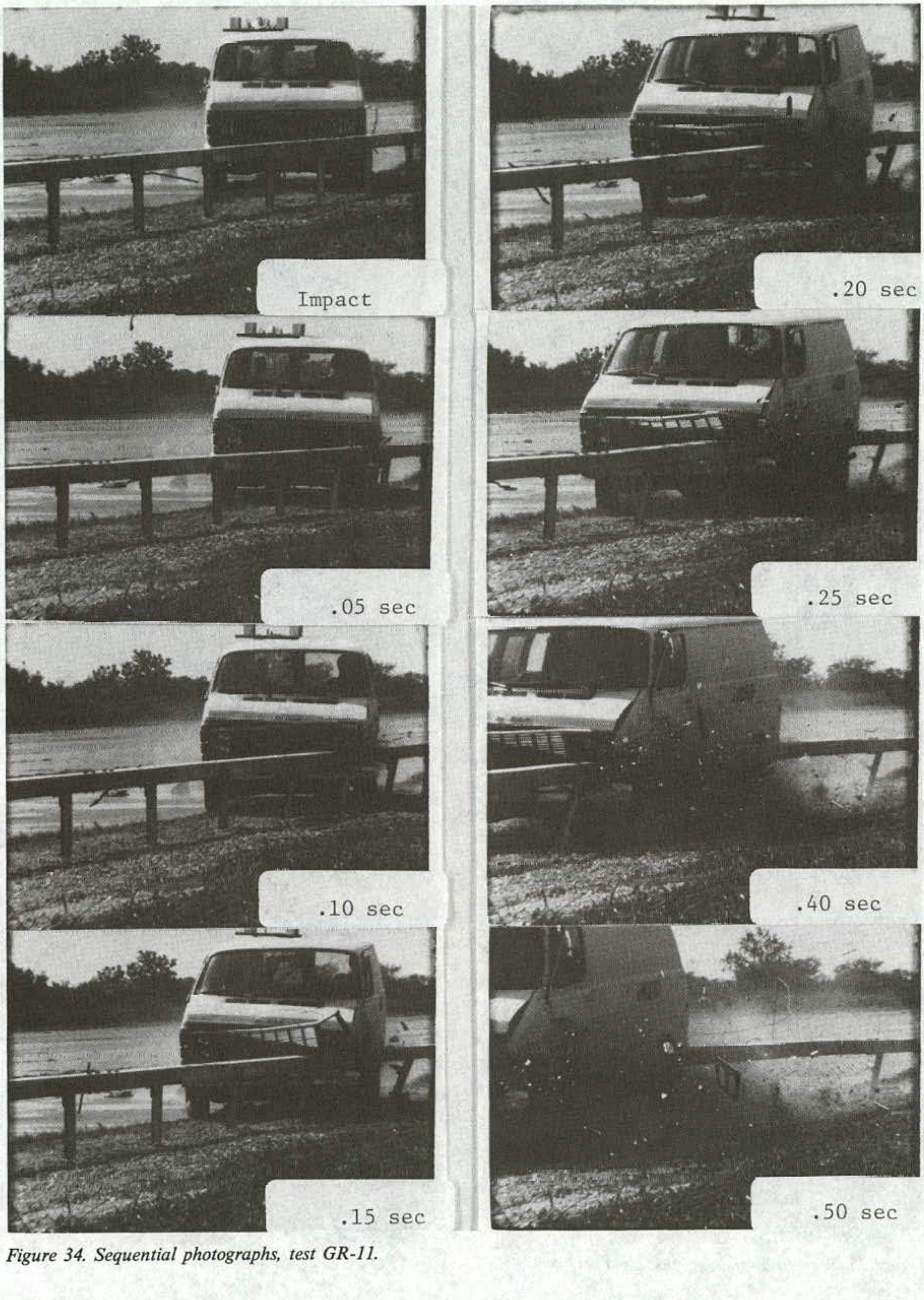


Figure 34. Sequential photographs, test GR-11.

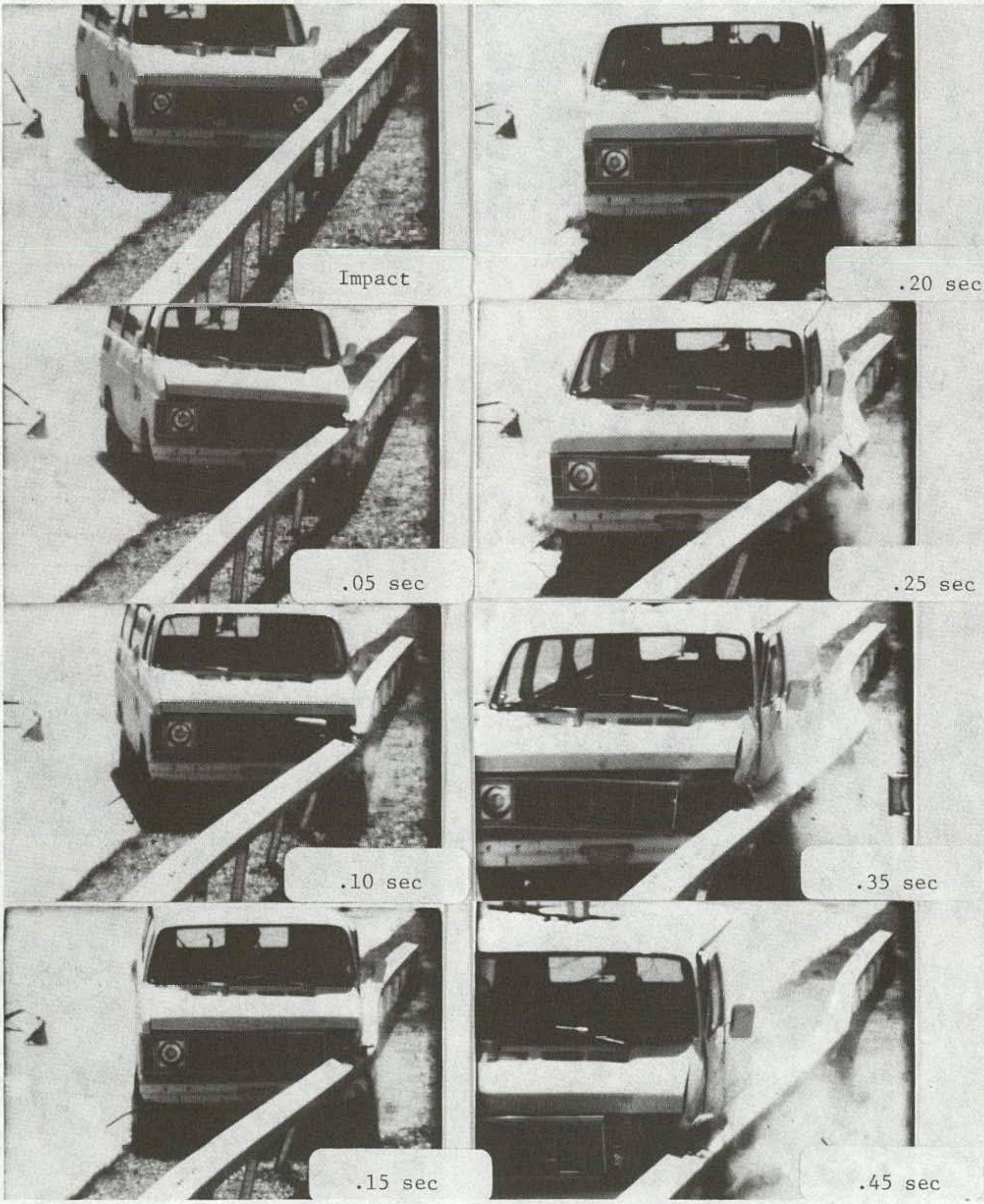


Figure 35. Sequential photographs, test GR-14.

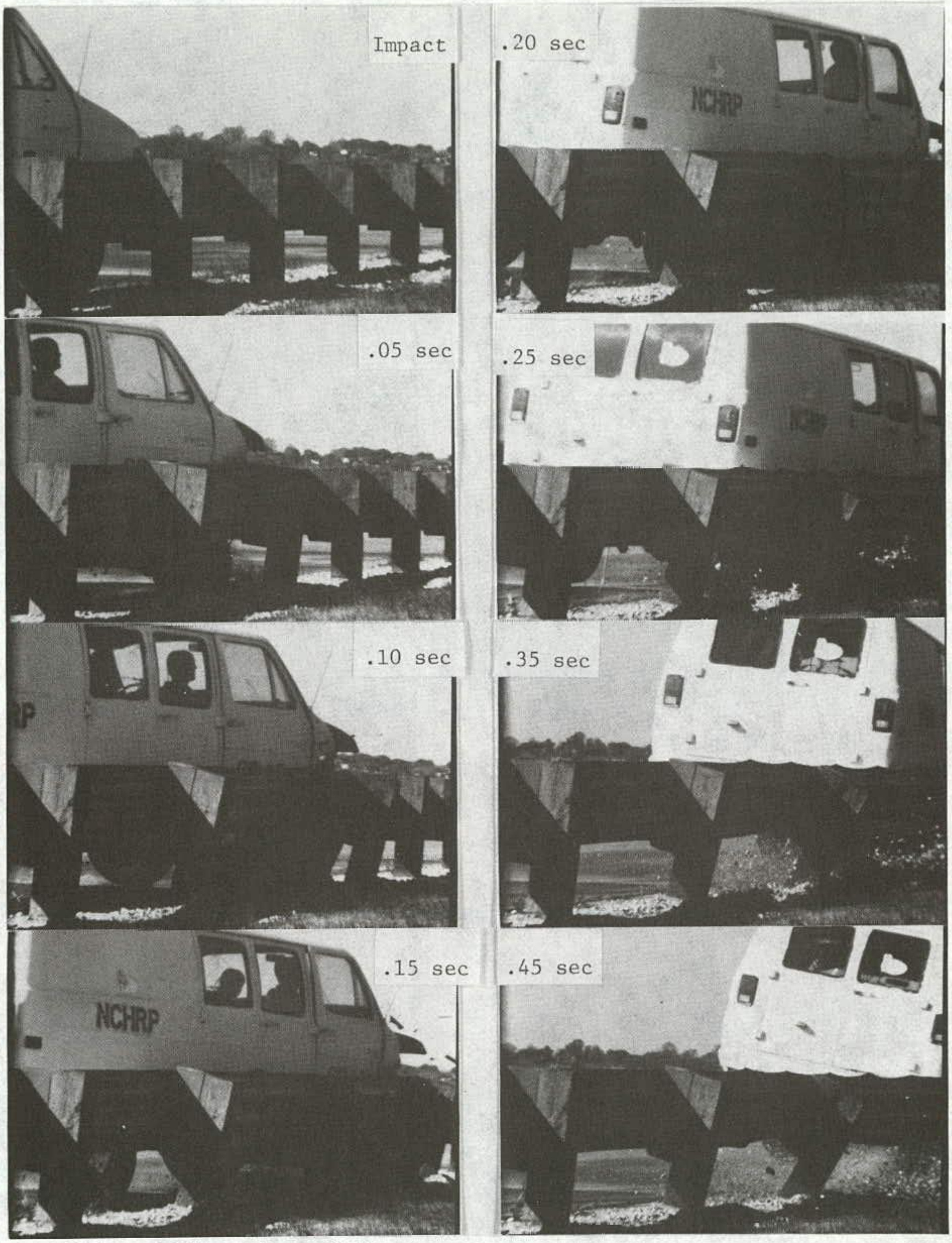


Figure 36. Sequential photographs, test GR-15.

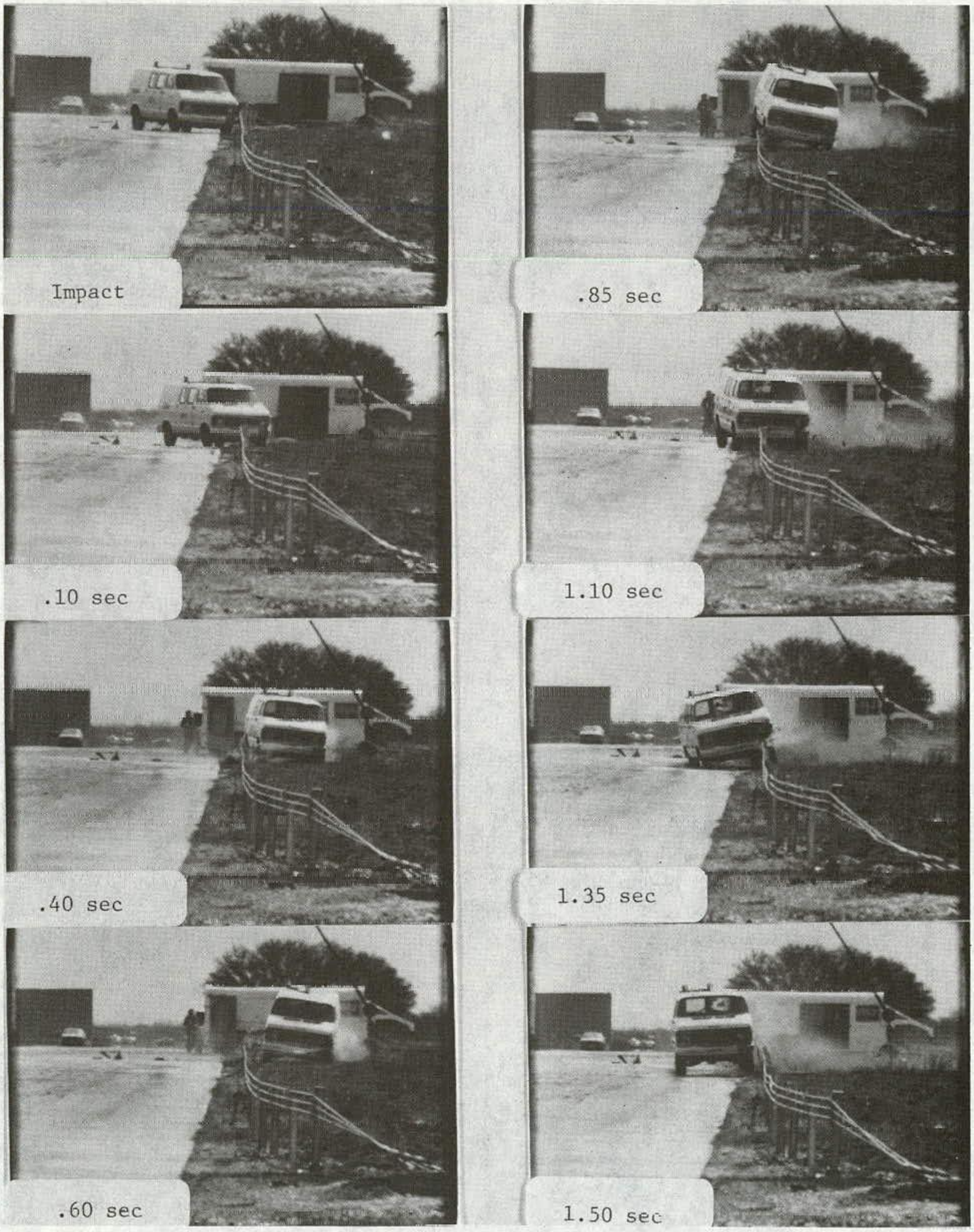


Figure 37. Sequential photographs as viewed from downstream of the barrier, test GR-17.

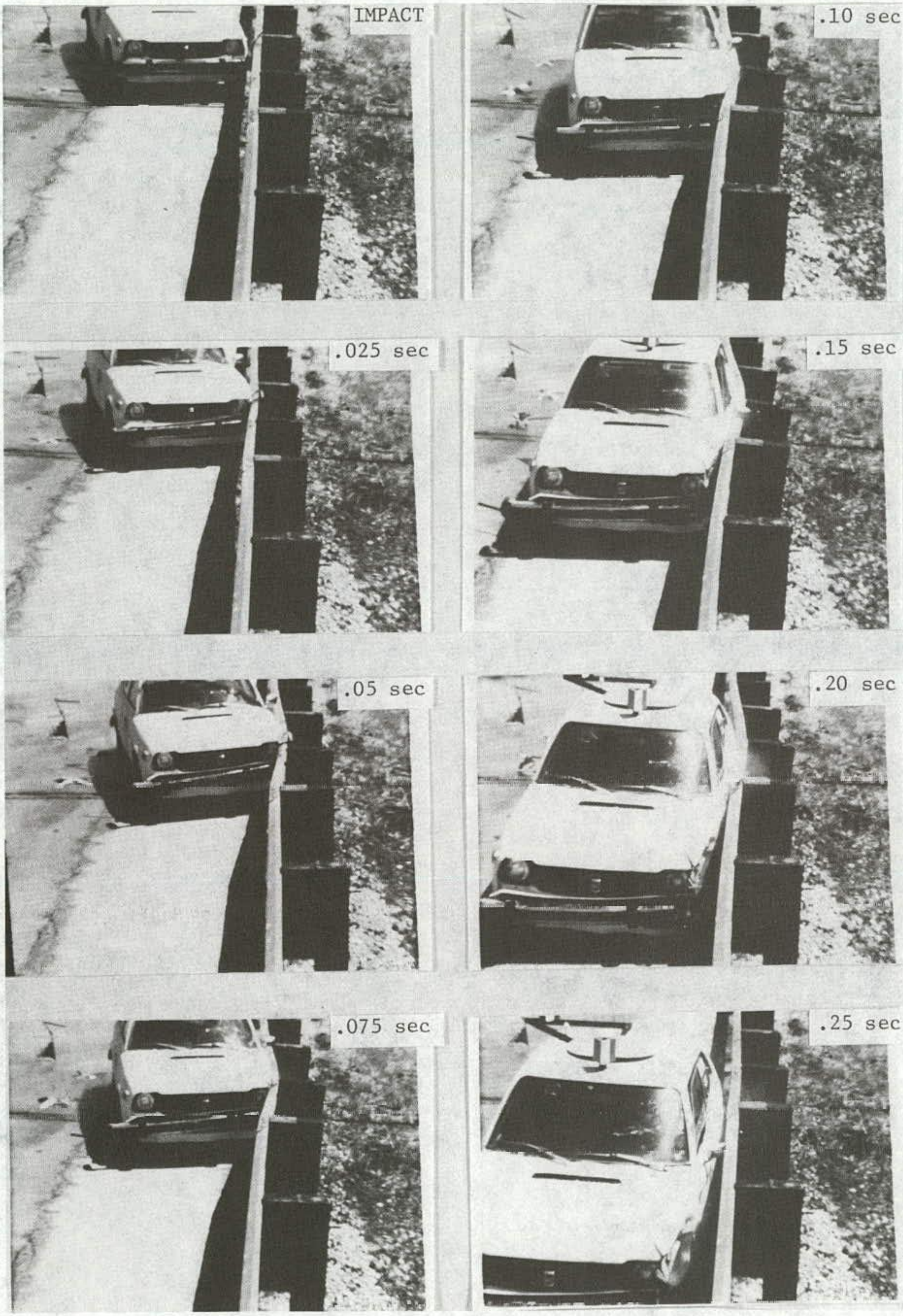
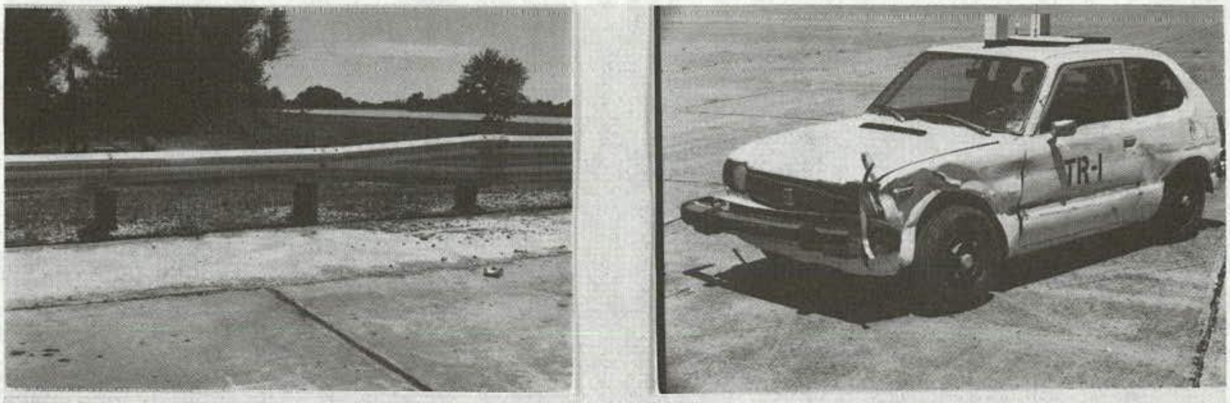


Figure 38. Sequential photographs, test TR-1.



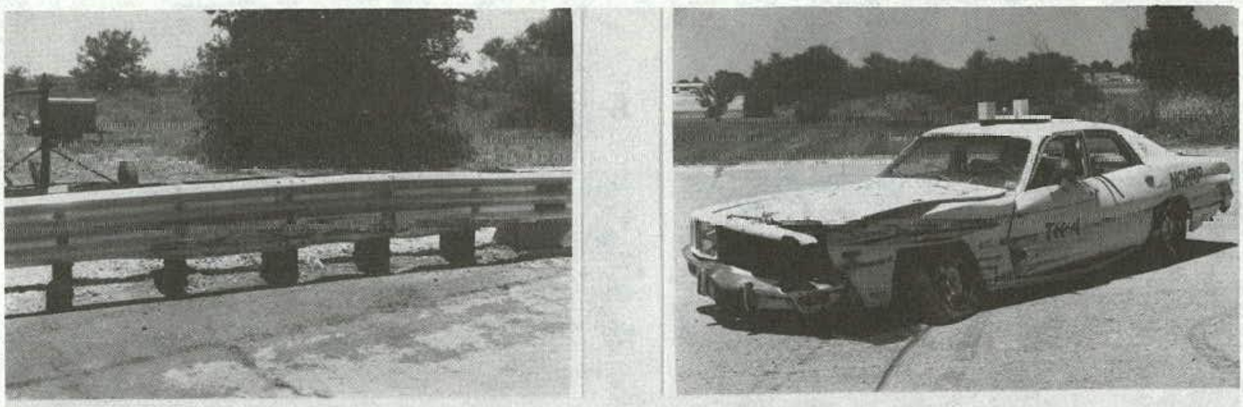
Test TR-1

Test TR-2

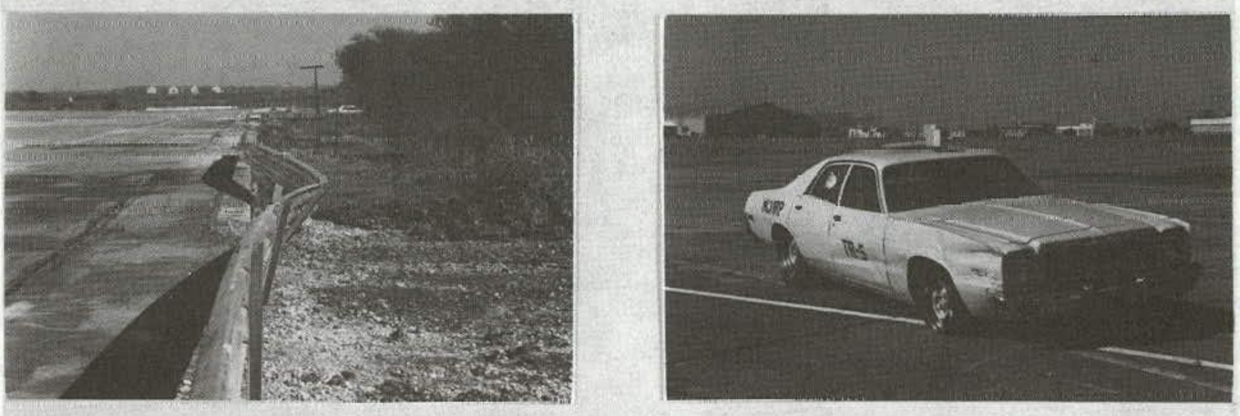
Test TR-3

Test TR-7

Figure 39. Photographs after transition tests.



Test TR-4



Test TR-5

Test TR-6

Figure 39. Continued

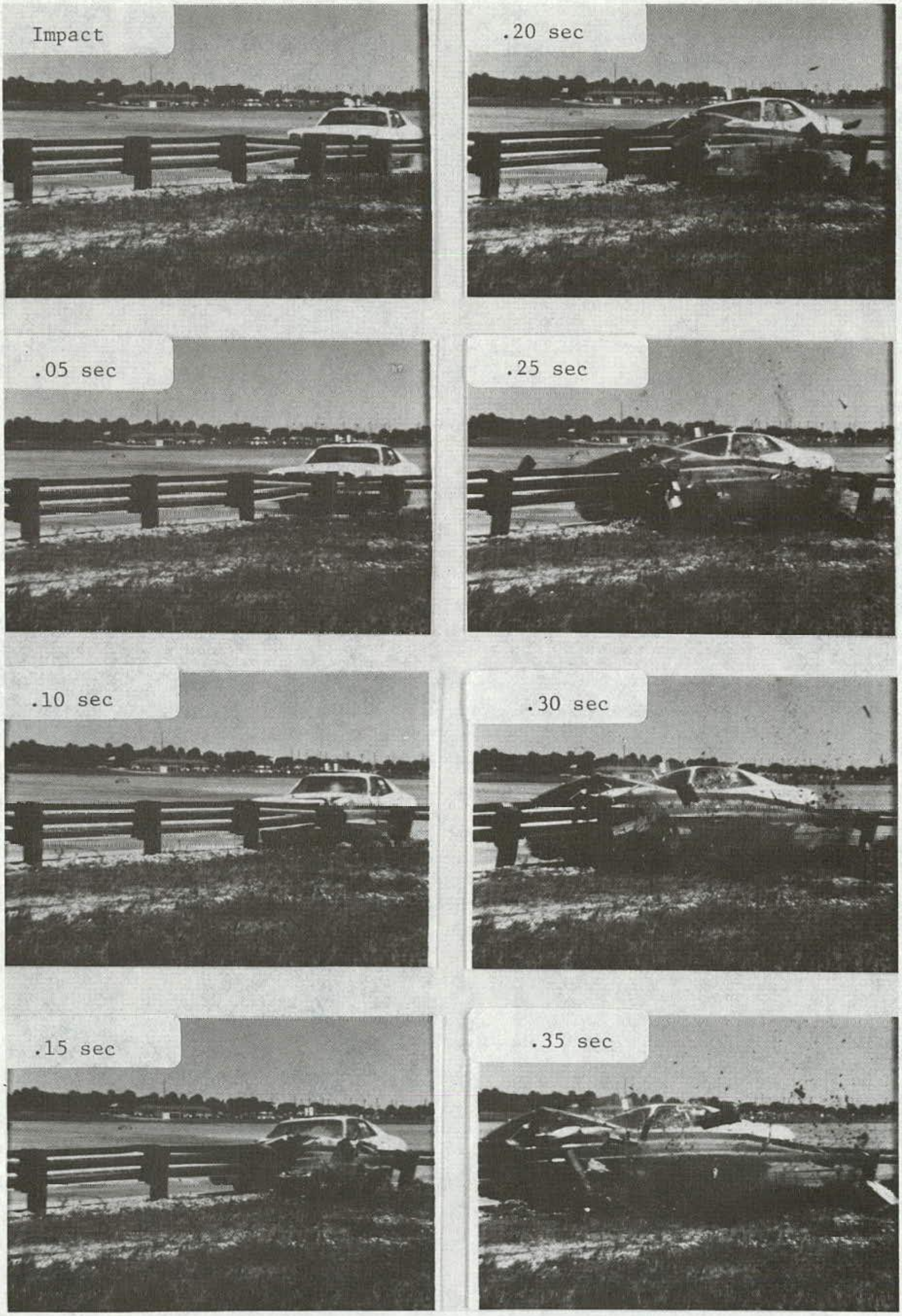


Figure 40. Sequential photographs, test TR-2.

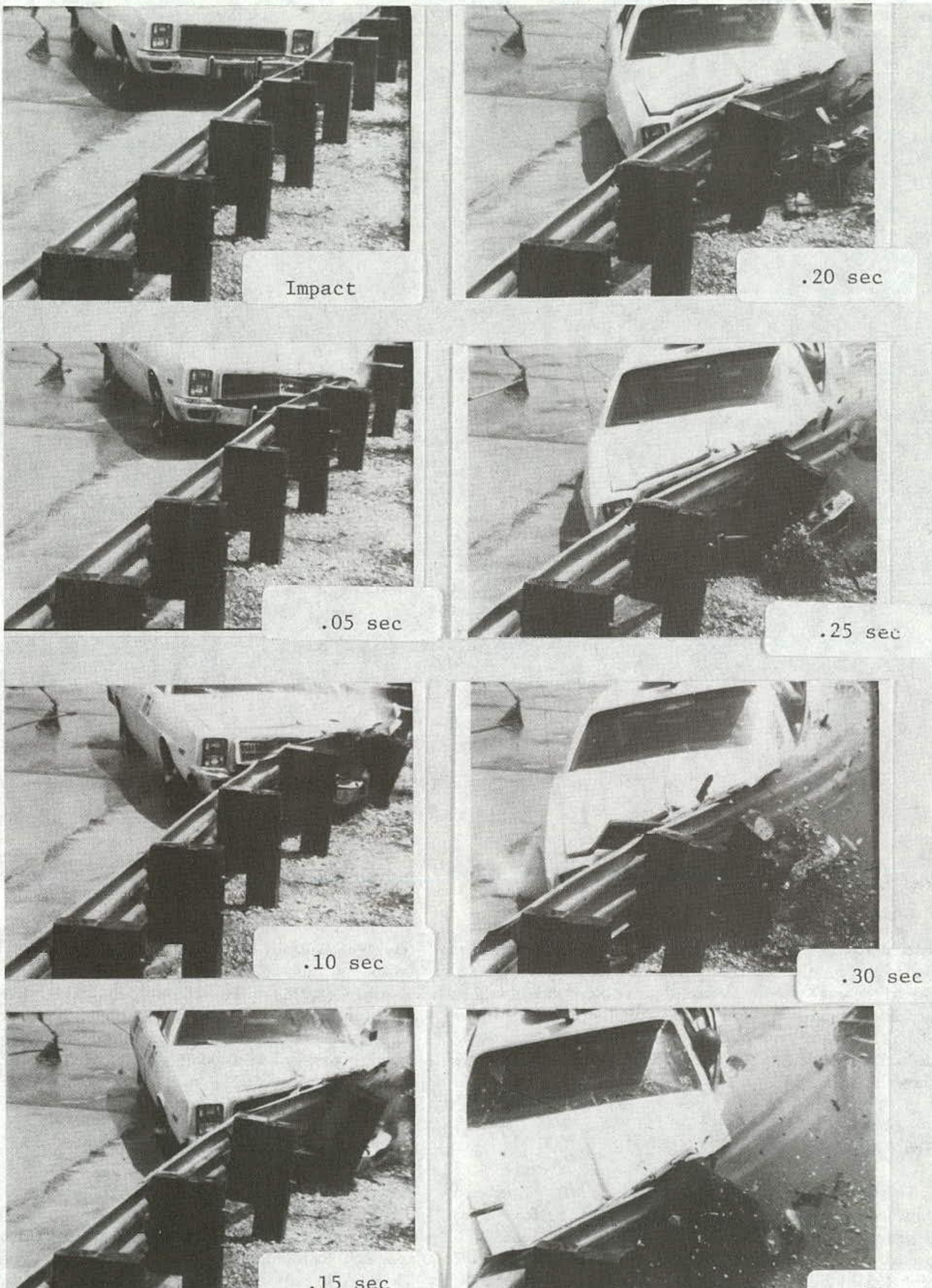


Figure 41. Sequential photographs, test TR-3.

Table 15. TR-2 and TR-3 approach elevations.

Distance From Impact L, ft	Elevation, in.*
0	0
1	-3/4
3	0
6	-3/4
9	-1
12	-2-1/2
13.2	-2-7/8
15	-2-3/4
20	-3
25	-3-7/8
30	-2-13/16
35	-2-13/16
40	-2-5/8
45	-2-1/2
50	-2-1/8
60	-1
65	-3/8

*Measurements of elevation z = + up
HVOSM computer simulation z = - up

Table 16. HVOSM simulation, approach terrain tests TR-2 and TR-3.

BUMPER MONITOR LOCATION(SPACE REF.)

X(INS.) !	Y(INS.) !	Z(INS.)*	
143.74	153.38	-17.63	Grade @ z = +0.38
167.67	164.53	-17.62	
191.60	175.69	-17.60	
215.53	186.84	-17.53	
239.46	197.99	-17.43	
263.39	209.14	-17.26	
287.32	220.29	-17.08	
311.25	231.45	-16.83	
335.18	242.60	-16.54	
359.12	253.76	-16.25	
383.05	264.93	-15.91	
406.97	275.11	-15.59	
430.90	287.25	-15.29	
454.83	298.45	-15.02	
478.75	309.58	-14.78	
502.67	320.69	-14.58	
526.60	332.09	-14.41	
550.52	343.29	-14.29	
574.45	354.49	-14.20	
598.39	365.63	-14.14	
622.32	375.87	-14.12	
646.25	388.05	-14.12	
670.21	399.23	-14.12	
694.15	410.39	-14.16	
718.11	421.56	-14.21	
742.06	432.71	-14.27	
766.02	443.35	-14.43	
789.96	454.99	-14.74	← Impact { Y = 456.4, Z = -14.8, Grade @ z = 0
813.94	466.13	-15.14	
837.90	477.25	-15.61	
861.85	488.37	-16.16	
885.81	499.48	-16.79	
909.76	510.58	-17.39	
933.72	521.66	-17.95	
957.66	532.73	-18.55	
981.64	543.80	-19.07	
1005.60	554.86	-19.49	
1029.56	565.92	-19.82	
1053.51	575.97	-20.05	
1077.46	588.04	-20.25	
1101.41	599.13	-20.42	
1103.60	600.24	-20.43	

*Note: in HVOSM -z is up. No impact is simulated; the vehicle is running over a terrain simulated by the coordinates from Table 2. Beyond impact the terrain is at constant z = 0.0.

Test TR-7

The approach terrain for the previous two tests was not considered typical of highway construction; the same transition design was installed on level terrain. As shown in Figure 42, the vehicle was smoothly redirected with no evidence of vehicle underride noted in the previous tests after striking the barrier at 59.1 mph (95.2) and 24.0-deg angle. The maximum dynamic deflection was 33.5 in. (85.1 cm). Photographs after test are shown in Figure 39.

Test TR-4

This test evaluated the transition from the MB9 (thrie beam on wood post) median barrier to MB5 (concrete safety shape) design used by California. The 4,490-lb (2,029-kg) vehicle impacted 15 ft (4.6 m) upstream of the concrete barrier at 60.2 mph (96.9 km/h) with an angle of impact of 24.8 deg. The vehicle was smoothly redirected with no evidence of snagging, as shown in Figure 43. Photographs after test are shown in Figure 39.

Test TR-5

This test evaluated the Service Level 1 (SL1) bridge rail transition. Basically, the transition involves the thrie beam approach rail attached to soil mounted weak steel posts spaced at 12-ft 6-in. (3.8-m) centers. The 4,680-lb (2,115-kg) vehicle impacted the railing for SL1 strength test conditions (actual 59.9 mph (96.4 km/h), 14.1-deg angle) upstream of the last soil mounted post and was smoothly redirected after 48.6 ft (14.8 m) of approach rail/bridge rail contact, as shown in Figure 44. The maximum dynamic deflection was 4.8 ft. (1.5 m). Photographs after test are shown in Figure 39.

Test TR-6

This test evaluated the transition from the G3 box beam approach guardrail to the BR3 (dual box beam) bridge rail. The 2,000-lb (904-kg), 59.6 mph (96.0 km/h), 13.7-deg angle impact resulted in severe snagging of the vehicle front wheel and passenger compartment intrusion, as shown in Figures 39 and 45.

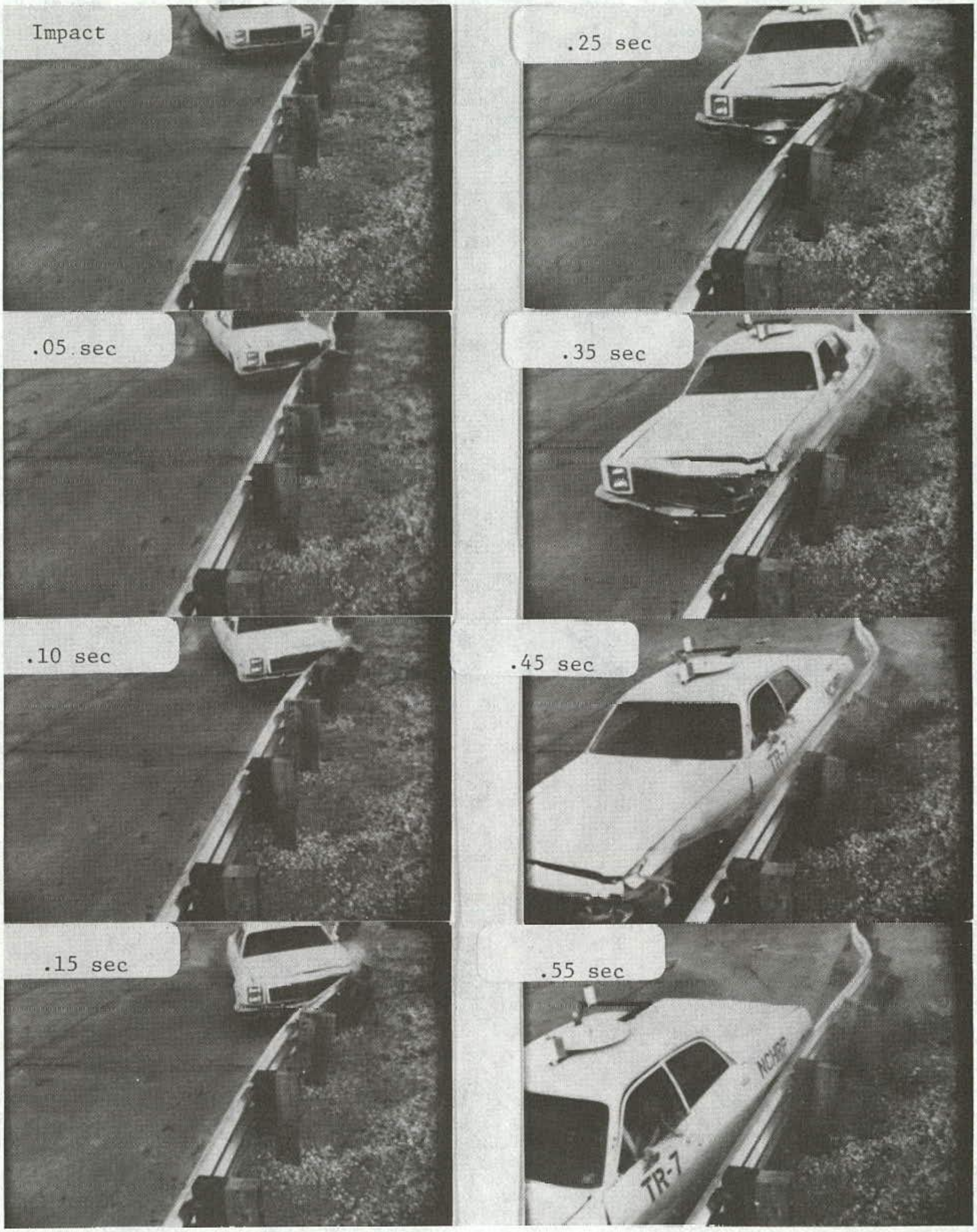


Figure 42. Sequential photographs, test TR-7.

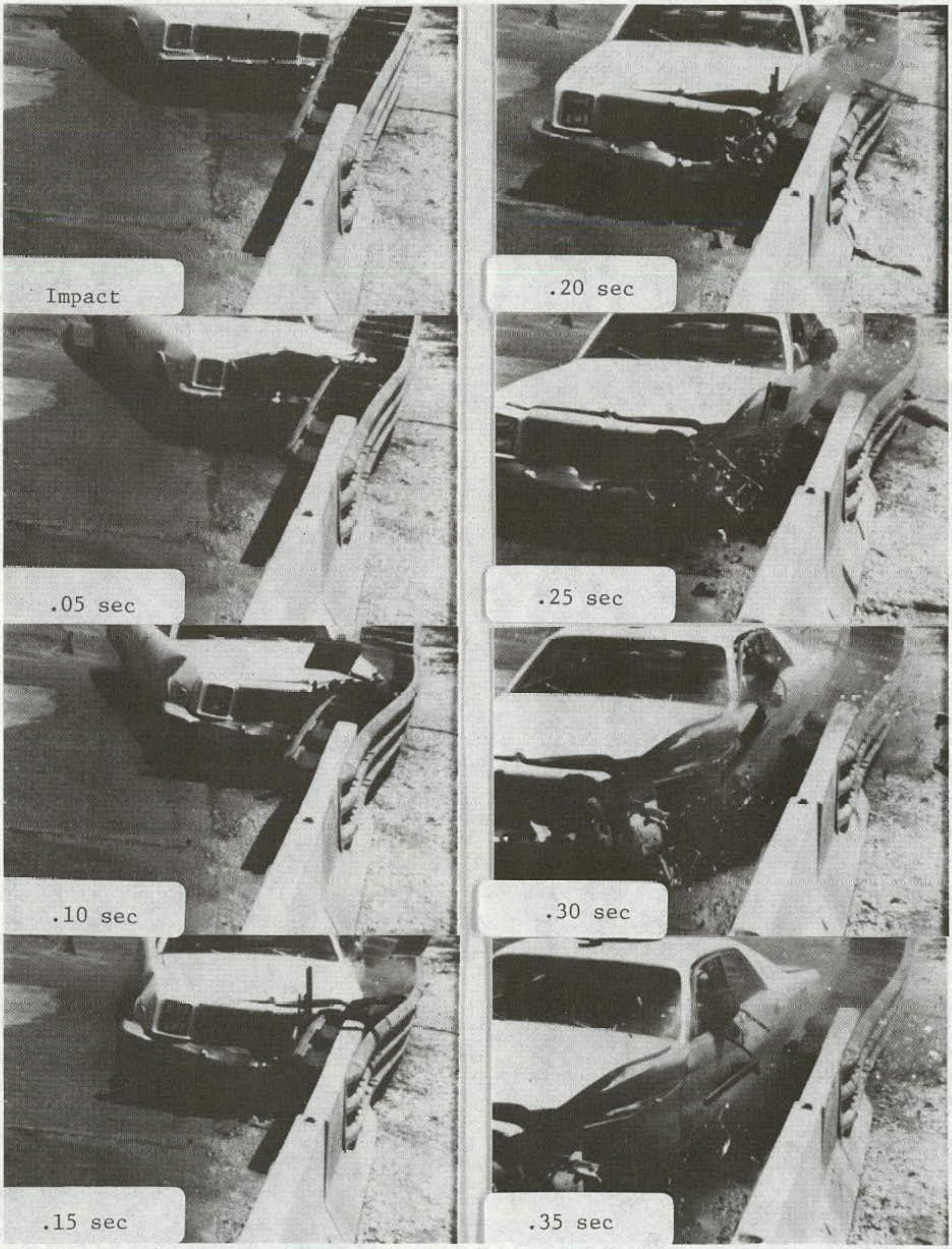


Figure 43. Sequential photographs, test TR-4.

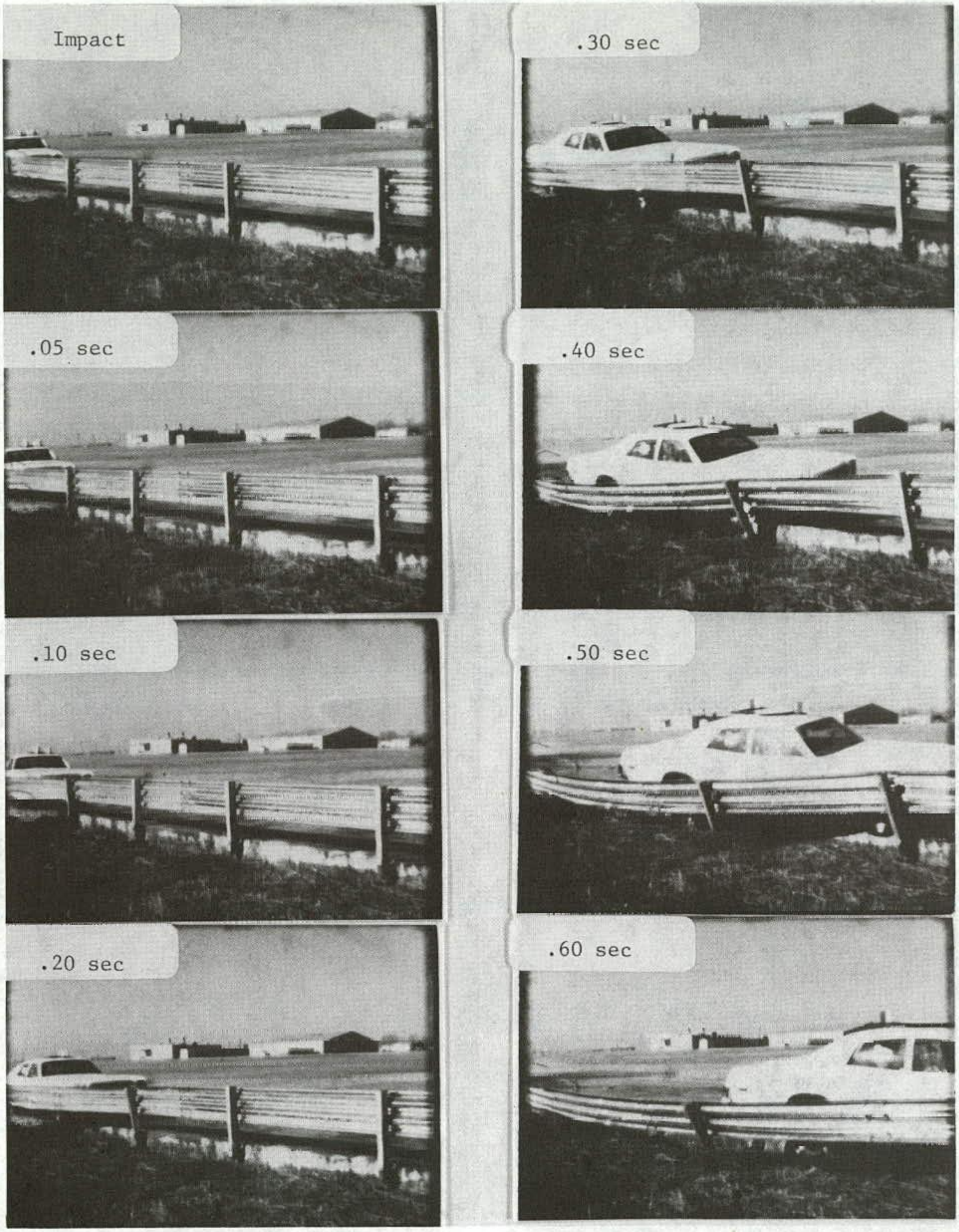


Figure 44. Sequential photographs, test TR-5.

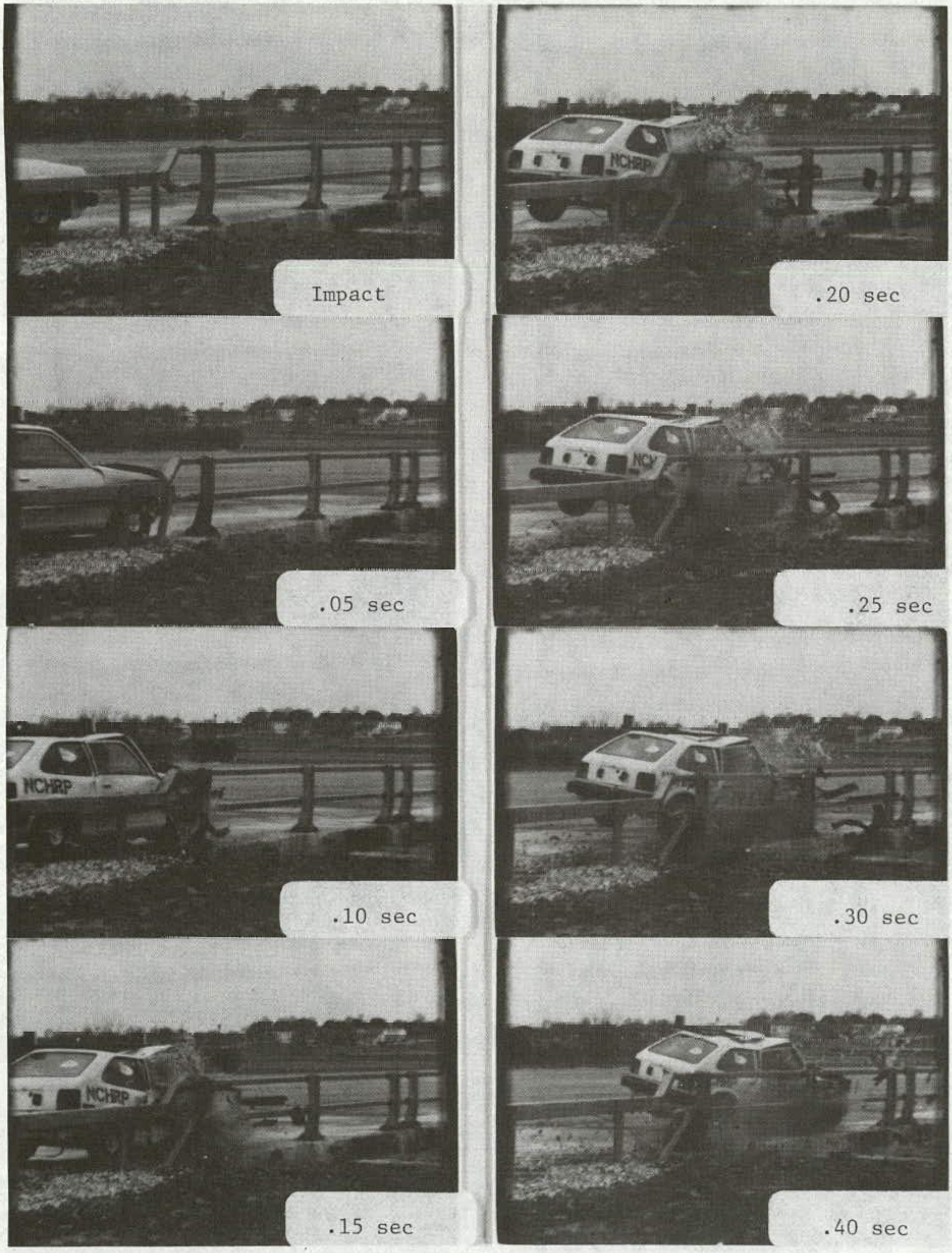


Figure 45. Sequential photographs, test TR-6.

Miscellaneous Tests

These three tests examined three different guardrail systems for performance with vans and a full size sedan.

Test GR-18

This test evaluated the G9 (wood post) thrie beam guardrail for a 7,985-lb (3,610-kg) van, 58.7-mph (94.5-km/h), 23.9-deg angle impact. The vehicle completed a roll onto its side after severe rolling was initiated during barrier contact, as shown in Figure 46. The vehicle was contained and redirected. The maximum dynamic deflection was 39.2 in. (100 cm) and length of barrier contact was 32 ft (10 m). Photographs after test are shown in Figure 47.

Test GR-19

This test evaluated the Texas round wood post/blocked-out W-beam guardrail system for 4,695-lb (2,122-kg) car, 59.3-mph (95.5-km/h), 24.3-deg angle impact conditions. Although severe wheel snagging occurred, the vehicle was redirected after 31 ft (9.4 m) of barrier contact, as shown in Figure 48. Wheel snagging is common for strong post guardrail systems under these impact conditions; thus, although this snagging resulted in severe front end damage, the smooth redirection criteria of *Report 230* was met. Photographs after test are shown in Figure 47.

Test GR-20

This test evaluated the G1 cable system mounted at 24 in. (61 cm) high for a 4,160-lb (1,887-kg) van impact at 56.0 mph (90.1 km/h) and 23.3 deg. The purpose of this test was to evaluate the performance of this "lowered" system with a higher c.g. vehicle. Unfortunately, as shown in Figures 47 and 49, the downstream anchor block pulled out of the ground during the impact and the vehicle overrode the system. Although there appeared to be no connection between the lowered mounting height and the anchorage failure, the results were inconclusive.

CHAPTER FOUR

DISCUSSION OF FINDINGS

GENERAL

The findings of this project are considered to be significant. For the first time, comprehensive series of tests were conducted on the most commonly specified U.S. longitudinal traffic barriers, using the most recent crash test evaluation criteria, *NCHRP Report 230,* and the 1,800-lb (800-kg) car specified in this document. At the time of publication, no one knew if the popular systems could pass the new criteria with the minicar. Findings from the first series of tests confirmed that the new criteria could be met by the popular systems, and recommendations for increasing the impact angle for the minicar tests, as discussed in *Report 230,* were made.

Further insight into the performance of the popular systems was gained by conducting the 1,800-lb (800-kg) car tests at 60 mph (95 km/h) and 20 deg. Again, the systems performed well for this more severe impact condition. Additional insight was gained in the performance of the popular systems with higher c.g. van vehicles. Redirection was generally not as smooth, and vehicle instability was a problem with some systems. The G9 (wood post) thrie beam system and G1 cable system performed comparably to the standard sedans at 60 mph (95 km/h) and a 25-deg angle.

Tests on barrier transition systems also provided significant insight into these unique discontinuities. Problems were demonstrated in effecting transitions from one barrier system to another.

Miscellaneous tests were conducted to provide additional insight into barrier performance. One existing system, evaluated for an 8,000-lb (3,600-kg) van, 60 mph (95 km/h), 25-deg angle impact, proved to be too low to keep the vehicle upright, although containment and redirection were achieved. A blocked-out wood post system on round wood posts was tested for the first time for standard full-size car test conditions; results were favorable. An unfortunate anchorage failure prevented additional insight into high c.g. vehicle performance with a low (24 in. (61 cm)) G1 cable system mounting height.

PHASE I

The barriers evaluated by crash test in Phase I of the project essentially met all requirements of *NCHRP Report 230,* test 12. One vehicle rollover (a barrier failure mode) did occur with the G1 cable system, but the rollover occurred after a successful redirection and during a secondary collision with the G1 ter-

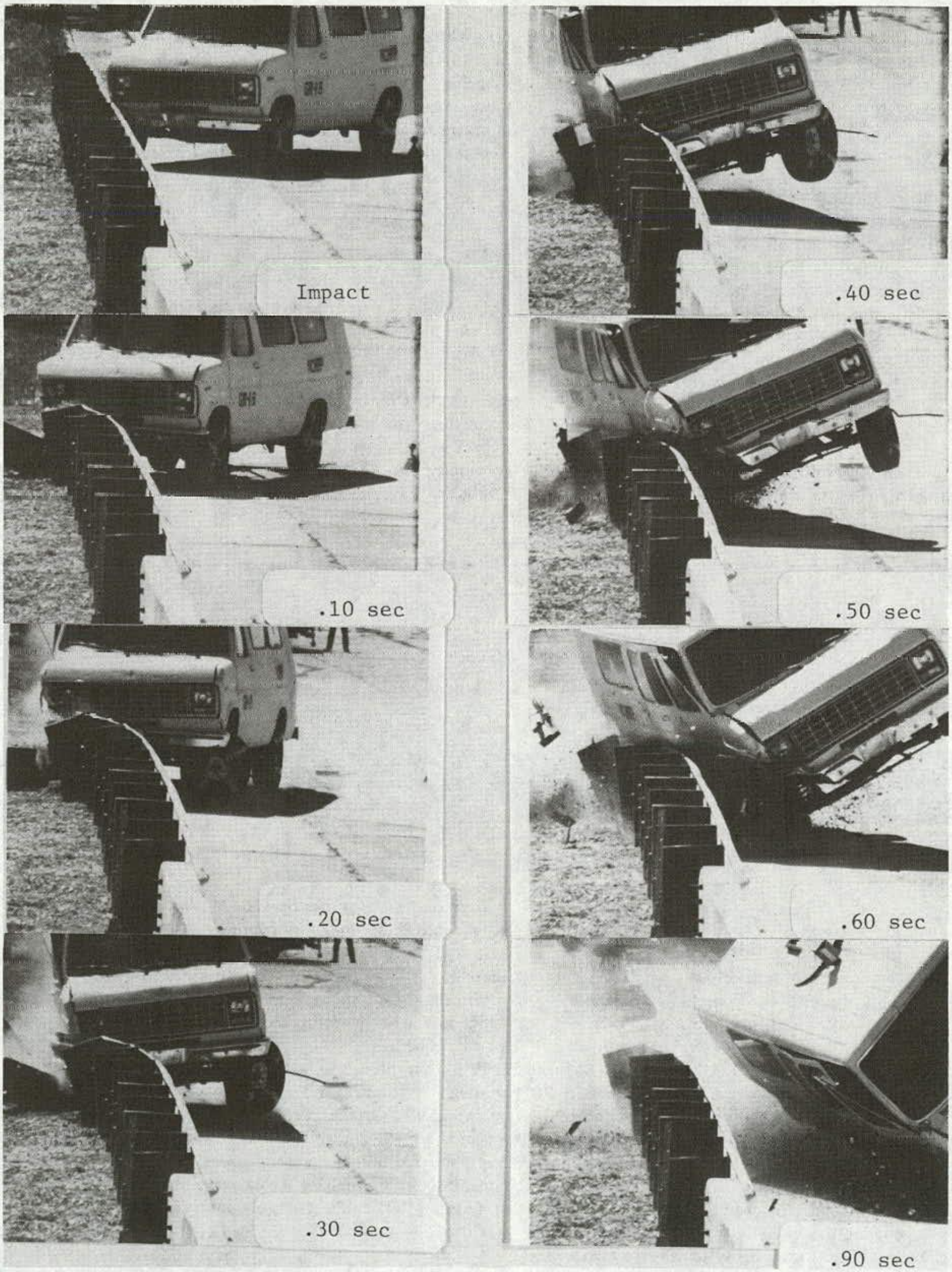
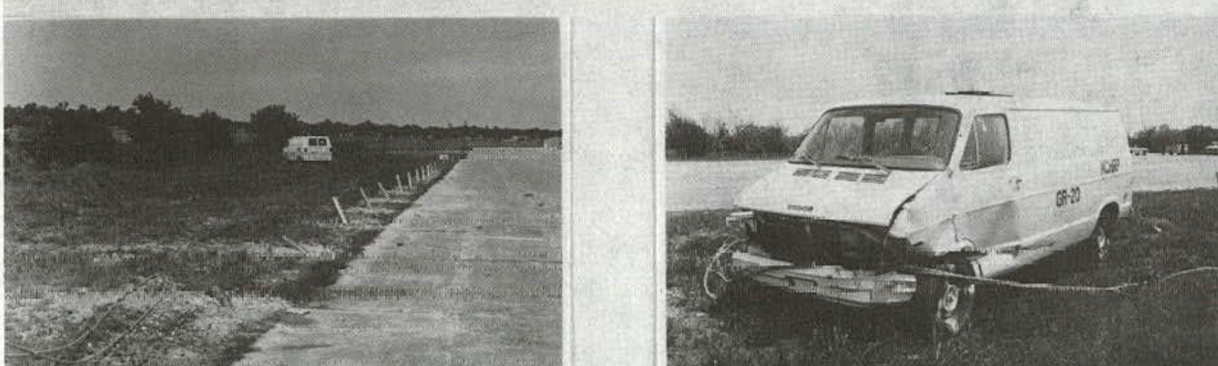


Figure 46. Sequential photographs, test GR-18.

Test GR-18

Test GR-19



Test GR-20

Figure 47. Photographs after miscellaneous tests.

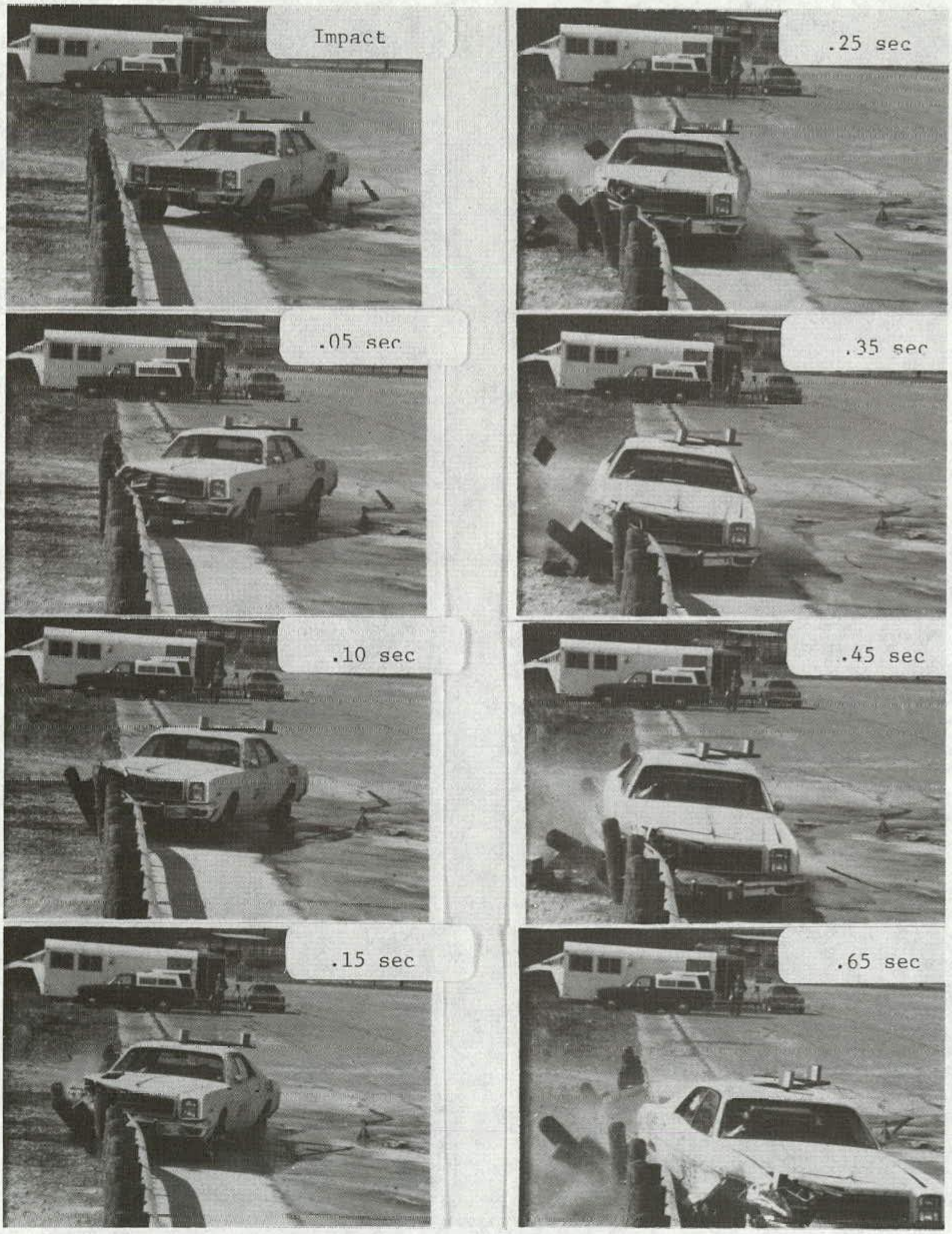


Figure 48. Sequential photographs as viewed from downstream, test GR-19.

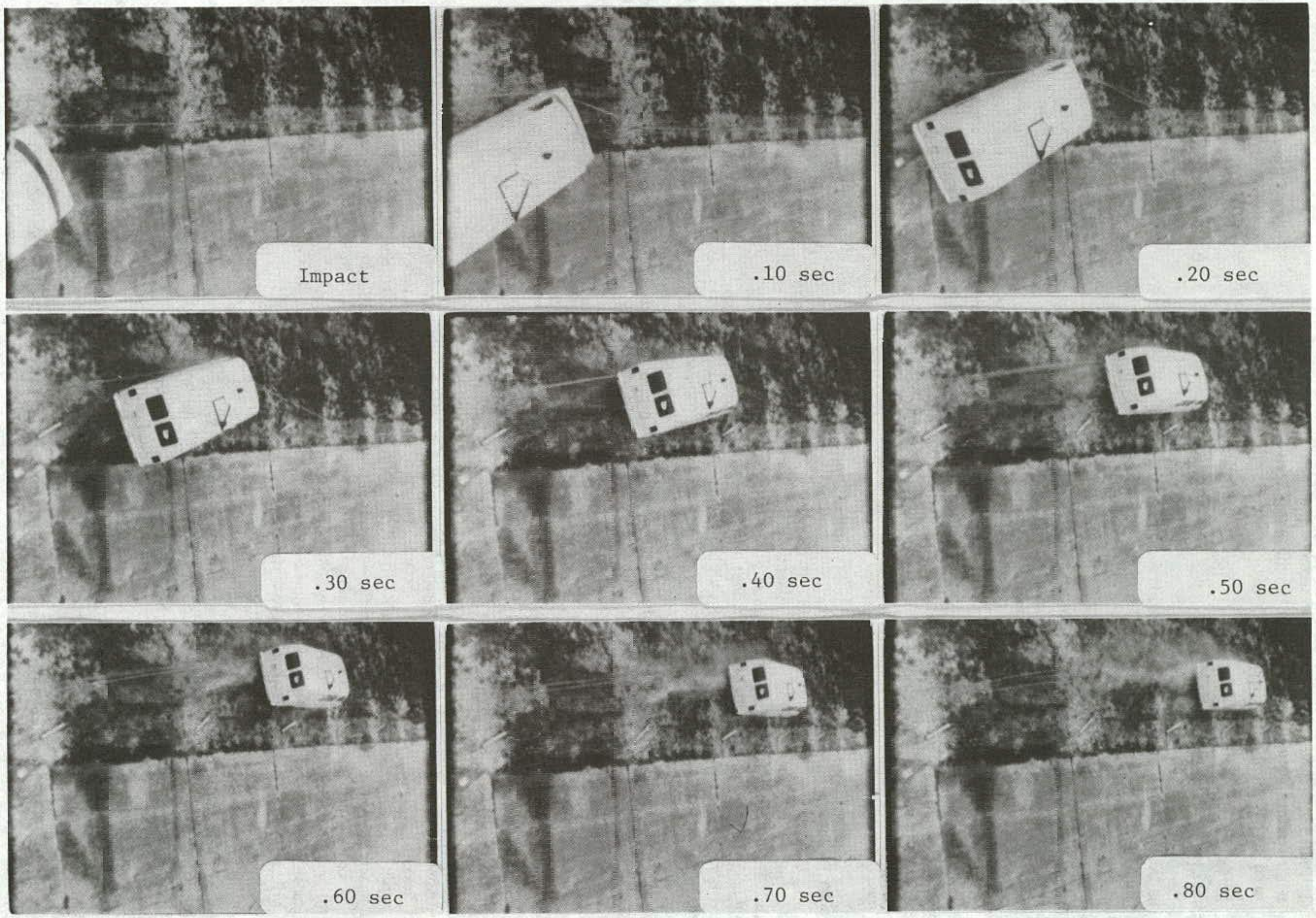


Figure 49. Sequential photographs, test GR-20.

minal detail. The rollover was considered a terminal problem, and not a reason to reject the G1 system. Findings from the test series are discussed in the following sections.

Significance of Barrier Deflection

The range of maximum dynamic deflection was from 0 to 43.4 in. (1.1 m). There was no clear trend in the occupant risk values that indicated advantages of barrier deflection, although the cable system with deflection of 43.4 in. (1.1 m) definitely showed lower values for all vehicle acceleration-related factors. Notably, two systems, the G2 guardrail and Service Level 1 bridge rail which had maximum deflections of 16.0 in. (40.5 cm) and 17.2 in. (43.7 cm), respectively, had some acceleration-related values that exceeded some of the more rigid systems. Thus, it appears that considerable lateral barrier deflection is required in order to reduce the impact severity based on current evaluation criteria and the previously used 50-msec acceleration averages.

Vehicle Trajectory

The vehicle trajectory for most of the systems was similar with the vehicle leaving the barrier at a small angle with the front of the vehicle away from the barrier as the rear lost contact. Exceptions to this behavior were observed with the weak post systems. Wheel contact with the posts in all cases caused the rear end of the vehicle to begin yawing away from the barrier that redirected the vehicle back into the barrier or across the barrier line (where there was no barrier). In two instances, the barrier was recontacted a second time (System G1 and G3).

Vehicle Damage

Damage to the vehicles was quite different. With the strong post guardrail and median barrier tests (Systems G4(2W), G9, and MB4W), the vehicles were in operable condition after the test. After the parapet mounted bridge rail tests (Systems BR2 and Texas Type T4), the vehicles were in operable condition. After the weak post guardrail tests (Systems G1, G2 and G3), significant wheel damage and front tire deflation were noted. The weak post median barrier (MB3) test did not exhibit this performance. This could be because of the higher mounting height of the MB3 system and the post/paddle detail. Only in the MB3 system test among the weak post tests was the vehicle considered operable. The vehicle was considered to be operable after the NCHRP Service Level 1 bridge railing test.

By far the most extensive vehicle damage resulted in the test of the BR3 bridge railing system. The vehicle wheel rode under the lower rail and snagged on a post. The snagging pushed the wheel into the floor pan causing deformation, but not penetration. A-pillar and windshield damage also occurred in this test, which was not observed in any of the other tests.

Damage caused by the side impact dummy (SID) was generally uniform, although the degree of damage varied somewhat. In all tests but those on Systems G1, G2, and SL1, the dummy contact resulted in significant bending of the door and shattering of the door window during the primary barrier contact (in G1 test the rollover broke this window). The three systems (G1, G2, and SL1) had by far the largest dynamic barrier deflection. Thus, based on this observation, there would appear to be some reduction in forces on the occupant with the more flexible barrier systems, although the current evaluation data values did not indicate this convincingly.

Barrier Damage

Barrier damage ranged from none to significant (requiring immediate damage repair to restore service). Three of the bridge rail designs (BR2, BR3, and Texas Type 4) sustained no damage; the Service Level (SL) 1 bridge railing would require repair to restore the system to its previous capacity. The G1 cable guardrail system was the only system that would not offer any resistance to impacts in the damaged area as the cables were on the ground. Weak post barrier systems G2, G3, and MB3 would require repair to restore the systems to their full pre-impact capacity; however, they are judged to have retained partial capacity for resisting a subsequent impact in the damaged area. Barrier systems G4(2W), G9, and MB4W were essentially undamaged and were considered fully serviceable.

Occupant Risk

Three indicators of occupant risk were measured in 10 of the 11 crash tests: vehicle 50-ms peak accelerations, side impact dummy responses, and flail space indices. Electronic data systems malfunctioned during test MB-1, and System MB4W is not included in this discussion (MB4W assessment was based on data from the cine backup data system).

Vehicle Accelerations

Prior to publication of *Report 230*, the principal indicators of impact severity with regard to occupant risk were vehicle peak lateral and longitudinal accelerations averaged over 50-ms duration. In *TRB Circular 191* (*6*), the recommended maximum vehicle accelerations measured near the center of mass were the following:

Lateral	Longitudinal	Total	Remarks
3	5	6	Preferred
5	10	12	Acceptable

The rigid body accelerations were applied to impact tests at 15 deg or less, and could occur at any time within the collision pulse. Only the most flexible longitudinal barrier systems have redirected vehicles with lateral acceleration less than the preferred or even the acceptable values. Highway engineers have essentially ignored these criteria because they were nearly impossible to meet, and rigid barriers that failed these limits by large margin appeared to be adequately performing in service. As shown in Table 7, all but the G1 cable guardrail system failed the 5-g lateral criterion. (The vehicle peak acceleration averages are shown here only for reference and were not used in assessing the barrier systems.)

Table 17. Occupant risk summary.

Test	System	Vehicle Wt (lb)	Vehicle Speed (mph)	Vehicle Angle (deg)	Vehicle 50 ms Acceleration Peaks Long.	Vehicle 50 ms Acceleration Peaks Lat	Flail Space Indices (fps) Long. ΔV	Flail Space Indices (fps) Lat $\Delta V^{(1)}$	Flail Space Indices (fps) Lat $\Delta V^{(2)}$	Side Impact Dummy HIC	Side Impact Dummy HIC Time(s)	Side Impact Dummy $d^{(3)}$ (ft)
GR1	G4 (2W)	1989	60.1	15.5	2.1	7.3*	--	18.8	10	50	0.120-0.197	0.44
GR2	G9	1948	59.3	14.4	3.1	8.1*	--	20.4	11	22	0.044-0.402	0.30
GR3	G2	1857	59.7	15.4	2.3	6.9*	--	17.3	10	82	0.127-0.136	0.50
GR4	G3	1916	60.4	15.3	4.1	5.9*	18.3	17.8	12	208	0.124-0.130	0.47
GR5	G1	1973	60.5	15.8	2.1	2.2	9.8	10.6	5.7	42	0.193-0.198	0.32
MB1	MB4W	1947	58.5	17.2	NO ELECTRONIC DATA							
MB2	MB3	1979	61.6	14.5	3.8	5.1*	13.8	16.9	11	31	0.071-0.257	0.13
BR1	BR2	1929	60.9	13.1	3.8	10.2*	5.9	16.2	14	276	0.083-0.089	0.82
BR2	TEX T4	1980	61.0	15.0	6.1	10.3*	13.1	18.5	17	90	0.075-0.082	0.45
BR3	BR3	1990	61.0	14.2	6.9	8.0*	15.8	18.0	14	242	0.090-0.158	0.55
BR4	NCHRP SL1	1987	61.4	14.1	2.0	6.4*	8.4	17.0	11	35	0.077-0.265	0.43

Notes: (1) Based on 1.0 ft lateral flail space.
(2) Based on 0.5 ft lateral flail space.
(3) Calculated lateral flail distance at HIC onset.

* Exceeds TRC 191 5-g level.

Anthropometric Dummy

A relatively new dummy developed for NHTSA was used in the 11 tests. The SID, or side impact dummy, was specifically designed to respond to side impact forces, and is contrasted to the Part 572 dummy which is designed for frontal or near frontal impacts. Although the chest cavity design and instrumentation systems for the SID are new, the head and stiff neck are similar to the Part 572 components and may not be good anthropomorphic models. Nevertheless, the SID is considered the current state-of-the-art device.

Head Injury Criteria (HIC), an index derived from resultant dummy head accelerations, are presented in Table 17 for each crash test. Maximum limit for HIC, as established by FMVSS 208, is 1000 which is usually taken as the threshold of serious head injury. All values are less than 300, considerably less than the 1000 criterion. NHTSA technical staff recognize the limits of the SID head and neck design but deemed that the modest HIC numbers generated in the 11 test matrix are subcritical with respect to serious injury to the occupant.

In addition to the HIC values, the time durations for the HIC calculations are given in Table 17. The first time is the onset of significant head accelerations and is assumed to be the time of head impact. Using the time between vehicle impact ($t = 0$) and head impact (t_{imp}), the "effective" distance (or lateral flail space) the SID head moved was calculated from vehicle accelerations and yaw rates; the value "d" is presented in Table 17 and is contrasted with the assumed 1.0-ft (0.3-m) lateral flail distance of *Report 230.*

Flail Space Indices

Recently completed research in an FHWA project at SwRI (*15*) provided additional insight into actual flail space distance. Based on a survey using NHTSA New Car Assessment Program (NCAP) data, Table 18 summarizes these values for 1978–1984 passenger sedans. Longitudinal and lateral impact velocities of the hypothetical "free missile" occupant are also presented in Table 17. Generally, the longitudinal values are considerably less than the threshold of 40 fps, (12.2 m/s) and, in the first three tests, hypothetical occupant contact with the windshield did not occur during the crash pulse.

Lateral Delta V's are presented for both the standard 1.0-ft flail space (*Report 230*) and for a 0.5-ft flail space. The smaller lateral flail space is more in line with the "d" determined from the SID head impact and from recent anthropometric measurements of small car components, seat positions, and dummy sizes. Based on the previously mentioned survey, it is believed that the 1.0-ft (0.3-m) distance is a conservative lateral flail distance and the actual measured value could be used to provide some measure of relief in meeting the criteria.

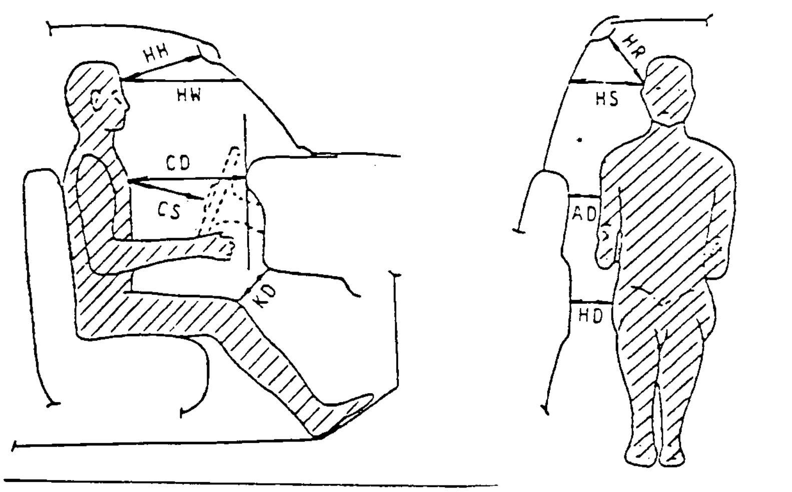
Regardless of choice of 1.0 ft (0.3 m) or actual flail distances, the lateral impacts of the hypothetical occupant against the car side are deemed noncritical for all 10 tests in which electronic data were acquired.

Test 12 (1,800-lb Car, 60 mph, 15 Deg) Conditions

During development of *Report 230,* little test experience has been acquired with test 12, and it was unknown whether existing and operational appurtenances would perform with this new vehicle. Consequently, test 12 was inserted provisionally awaiting this test experience and assessment of test 12. In addition to evaluating a number of important longitudinal barrier sys-

Table 18. Typical passenger compartment clearance dimensions.

Dimension+	Range*	Median* Distance	75th Percentile* Distance
HW	15-24	20	22
CD	19-24	21	22.5
CS	10-17	13	15
HS	7-13	9	10
AD	1-7	4.5	5.5
HD	5.5-9.5	6	8
HH	11-20	14	15
HR	4-10	6	7.5
KD	3-10.5	7	8



+Dimensions are for a 5th percentile female seated in the driver position with the seat in its rearmost position.
*The dimensions are, to a small degree, functions of the vehicle weight. The values reported are for 1978 to 1984 passenger cars with core weights greater than 3680.

tems, an unstated secondary objective of the program was to assess the effectiveness and benefit of test 12. Based on findings from the crash tests in Phase I, it is evident that these systems performed well with these test conditions (i.e., 1,800-lb (800-kg) vehicle, 60 mph (95 km/h) and 15-deg angle). Moreover, it has become evident from the program that test 12 was not a critical or discerning test for most state-of-the-practice longitudinal barrier systems. It failed to subject the candidate barrier to conditions at which superior barrier performance could be distinguished from acceptable or possibly inadequate dynamic behavior.

It was noted that the impact severity test of *TRB Circular 191* (*6*) (2,250-lb (1,000-kg) car, 60 mph (95 km/h)) and the occupant risk tests of *Report 230* involved impact angles of 15 deg. Coupled with a 60-mph (95-km/h) speed, it was believed that 15 deg was the largest angle redirection collision which vehicle occupants could sustain without major injuries. However, as discussed in Section 5, the *TRB Circular 191* occupant severity indices are considered to be excessively conservative.

Recently, improved accident files have permitted the more in-depth analyses of vehicle impact conditions. Although these files are mostly limited to *reported* accidents and, therefore, do not reflect the driveaways (obvious barrier successes), they do provide conditions under which barrier failures occur. An ongoing study by Viner (*10*) presents evidence that the current 15-deg angle impact is not addressing collision conditions of these reported accidents; he suggests that a 20-deg impact angle is a more appropriate level for testing to reflect a greater percentage of reported accidents and to partially address the large number (about 50 percent) of vehicles that are yawing or nontracking at impact. From an occupant risk viewpoint, the 20-deg test (see test S13 in *Report 230*) appears to be a more discerning experiment to evaluate safety performance of longitudinal barriers.

Snagging Potential

Vehicle snagging during redirection is generally caused by parts of the vehicle becoming mechanically interlocked with elements of barrier. Examples of snagging include bumpers or fender panels protruding under or over a rail member and catching on a vertical barrier member, such as a post. In extreme cases, the snagging can cause the vehicle to "spin out" or to be abruptly stopped, or snagging may only result in minor vehicle/barrier damage and not affect vehicle dynamics or trajectory. With the downsized car, there was concern that snagging may be a more important problem; this may be attributed to either or both poor interaction between vehicle and barrier or the adverse consequences of snagging on small cars due to a decrease in dynamic stability.

In the Phase I effort, snagging was not revealed to be a problem with the 15-deg test 12 impact condition. Research by others also suggests that 15 deg is a subcritical angle to reveal snagging inadequacies of a longitudinal barrier and that a 20-deg test is a more appropriate evaluation level. This test, test S13, is suggested in *Report 230.* From the *Report 230* Commentary, the need and objective of test S13 are presented:

> Test S13 (1800S/60 mph/20 deg)
>
> The objective of this test is to investigate the dynamic interactions of the small car with redirective barriers. Because the 1800s vehicle has small diameter wheels, generally with the forward wheels being driven, there is concern that a forward wheel will wedge under the lower beam of a beam and post system and snag on a post. Further, there is concern for vehicle rollover during or after collisions with typical shaped barriers due to critical inertial properties of this vehicle. Goals for this test are (1) that the vehicle should be smoothly redirected without exhibiting any tendency to snag on post or other elements or to pocket, (2) that the vehicle should remain upright throughout the collision, and (3) its after-collision trajectory should not present undue hazard to other traffic.

In view of the national importance of barrier under consideration in this program, it is deemed important that the systems be thoroughly evaluated to the most rigorous standards.

PHASE II, TEST S13

Five tests were conducted on four guardrails and one median barrier for *NCHRP Report 230* S13 test conditions (i.e., 1,800-lb (800-kg) car, 60 mph (95 km/h), 20-deg angle). Findings from this test series are discussed in following sections.

Significance of Barrier Deflection

The range of maximum dynamic deflection was from 1.3 ft (0.4 m) to 5.8 ft (1.8 m). Similar to the results for test 12 in Phase I, there is a clear trend that indicated the advantages of barrier deflection begin to show with considerable barrier deflection. For deflection in the 0–1 ft (0.3 in.) range, there is no clear advantage for deformable barriers.

Vehicle Trajectory

Post impact trajectory trends were basically the same, but more pronounced than for the 15-deg angle tests (test 12). The G1 cable system brought the vehicle to a stop in contact with the barrier. Yawing of the vehicle rear end away from the barrier occurred in all weak post tests with the exception of the G2 W-beam system.

Vehicle Damage

Damage to the vehicles was considerably more than in the 15-deg angle tests. The more flexible systems generally produced less vehicle damage. The upper cable in the G1 system left severe marks on the A-pillar, but the passenger compartment was not violated.

Barrier Damage

The weak post systems all sustained significant damage, whereas the strong post W and thrie beam systems were permanently deformed, but still serviceable at near pre-impact condition.

Occupant Risk

Three indicators of occupant risk were measured in the tests: vehicle 50-ms peak average accelerations, side impact dummy responses, and flail space values. Electronic data were used to determine these values as summarized in Table 19.

Vehicle Accelerations

As in the test 12 evaluations, all but the G1 cable system test resulted in lateral 50-ms average g values exceeding the 5-g criteria of *TRB Circular 191* (*6*).

SID Dummy

As in the test 12 evaluations, all HIC values were below 300, considerably lower than the 1000 criterion.

Flail Space Values

All values were below the *NCHRP Report 230* criteria. The influence of barrier deflection in reducing the lateral ΔV was more evident in this test series than in the S12 test series; but the ΔV values were still close for low deflections.

Vehicle and Barrier Damage

Damage to both vehicles and barriers was significantly more due to the impact angle increase.

Table 19. Occupant risk summary, test S13 series.

Test	System	Vehicle Weight (lb)	Vehicle Speed (mph)	Vehicle Angle (deg)	Barrier Defl (ft)	Vehicle 50 ms Accel Peaks Long.	Vehicle 50 ms Accel Peaks Lat	Flail Space Indices (fps) Long. ΔV	Flail Space Indices (fps) Lat* $\Delta V^{(1)}$	Flail Space Indices (fps) Lat* $\Delta V^{(2)}$	Side Impact Dummy HIC	Side Impact Dummy HIC Time(s)
GR-6	G4(2W)	1928	61.9	21.7	0.8	3.9	11.2	5.5	23.1	13.1	210.2	.054-.249
GR-8	G2	1960	58.5	19.3	2.6	3.4	7.4	5.4	14.7	9.8	57.6	.088-.094
GR-10	G3	1960	59.3	18.4	1.3	3.3	7.7	13.7	19.5	12.4	236.4	.082-.359
GR-12	MB3	1995	58.5	19.4	1.0	4.9	6.1	17.9	16.9	12.0	187.0	.079-.096
GR-13	G9 (wood post)	2000	59.5	22.6	1.3	4.3	9.2	14.2	18.8	13.3	67.1	.064-.185
GR-16	G1	1995	59.2	19.5	5.8	3.6	3.5	9.0	11.2	7.5	57.4	.070-.485

*(1) Based on 1.0 ft lateral flail space
(2) Based on 0.5 ft lateral flail space

Snagging Potential

The potential for snagging was much more evident in comparing system performance in this test series than for test 12 Phase I tests. The weak post systems displayed a much more pronounced snagging behavior with the exception of the G2 W-beam system.

PHASE II, VAN TESTS

Six tests were conducted on the five guardrail and one median barrier system previously discussed in the test S13 series. Findings from this test series are discussed in following sections.

Significance of Van Properties

The vans used in this series were on the low end of the gross weight for the full-size van fleet. The c.g. height was approximately 10 in. (25 cm) above that of the full-size sedan. The front end (bumper and sheet metal) of the vans appeared to be less crashworthy than the full-size sedans. These two factors contribute to a less stable vehicle in a crash environment.

Significance of Impact Condition

The van tests were conducted at nominal 20- and 25-deg angles based on predicted performance. Table 20 summarizes the performance of the six tests.

GR-7

Because of the rollover experienced by a similar van with the G4(1S) system at 25 deg, the G4(2W) test (GR-7) was conducted at 20 deg. Based on the relatively small roll angle observed in this test, the threshold for the G4(2W) system is probably closer to 25 deg than it is to 20 deg. The vehicle was smoothly redirected.

GR-9

An impact angle of 25 deg was selected for the G2 guardrail van test because of two factors: (1) the beam mounting height of 30 in. (76 m) is 3 in. (8 cm) higher than the G4 systems, and (2) the G2 is a more flexible barrier that results in lower g forces and reduces rollover probabilities.

Roll of the vehicle onto the top of the rail occurred, and the long span produced by the failed posts caused the rail to drop even lower. Thus, the rollover limit of this barrier system was reached, although the vehicle was contained and redirected.

GR-11

Because of the rollover of the G2 W-beam weak post system, an impact angle of 20 deg was selected for the G3 box beam guardrail van test. Performance of the system was not at all similar to the G2 system as the vehicle wheel wedged under the beam after impact. Redirection occurred with little vehicle roll until the rear of the vehicle began to yaw away from the barrier. This yawing continued until the vehicle was actually backing away from the barrier.

GR-14

Because of the unusual performance of the G3 system with the van in test GR-11, the impact angle for the MB3 box beam system was also selected at 20 deg. Performance with this system was quite similar to the G3 test.

GR-15

Rollover of the van with the G9 (steel post) system had occurred in an FHWA test conducted by TTI with a similar van at 25 deg. On the basis of the van test results with the G4(2W) system, the G9 (wood post) system was believed to

Table 20. Summary of selected data, van tests.

Test No.	Barrier	Impact Angle (deg)	Max Defl (ft)	Length of Barrier Impact to θ = 0	Contact, ft Total	Max Roll Angle, deg	Exit Angle (deg)
1. Nominal 20-deg angle tests							
GR-7	G4(2W)	20.9	2.1	18	22.7	14.3	-11.7
GR-11	G3	18.8	2.2	42	60.6		>+90 spin-out
GR-14	MB3	18.7	2.2	29	75.5	-11**	>+90 spin-out
2. Nominal 25-degree angle tests							
GR-9	G2	23.9	3.7	27	>102*	*	*
GR-15	G9 (wood post)	25.0	3.4	21	29.0	15.0	-8.0
GR-17	G1	24.2	8.9	41	80.0	10.5	0

*Vehicle rolled onto barrier and remained in contact for full length of barrier.
**Rolled away from the barrier near the time of barrier loss of contact.

have a greater capacity for keeping the impacting van upright; thus, the G9 (wood post) guardrail van test angle was 25 deg. The vehicle was smoothly redirected with only a 15-deg maximum roll angle.

GR-17

Because of the great flexibility of the cable guardrail and the tendency for the cables to "lock" onto the vehicle, this system was judged to be capable of a 25-deg angle impact. Results of the test were excellent as the vehicle rolled only 10.5 deg and was smoothly redirected at a very flat exit angle.

Snagging Potential

The box beam systems exhibited significant snagging, resulting in spinout of the vans away from the barrier. The other systems redirected the vans in a manner similar to passenger car performance. Rolling of the van onto the G2 system was due not to snagging, but to loss of rail height.

PHASE II, TRANSITION TESTS

Transition tests were conducted on a variety of designs using both 1,800-lb and 4,500-lb (800- and 2,000-kg) sedans. Each design is discussed regarding test findings.

W-Beam/Thrie Beam Transition

Early tests on nontypical terrain resulted in full-size vehicle underride, snagging, and spinout; no problems had occurred with the 1,800-lb (800-kg) car test on same terrain. When tested on level terrain, the transition performed well, and smooth redirection was achieved with the 4,500-lb (2,000-kg) car impacting at 60 mph (95 km/h) and 25 deg.

Thrie Beam/Weak Post Guardrail/SL1 Bridge Rail Transition

Smooth redirection was achieved for the SL1 conditions (4,500-lb (200-kg) car, 60 mph (95 km/h), 15 deg), although the maximum deflection value was larger than expected.

G3 Guardrail/BR3 Bridge Rail

Severe snagging resulting in passenger compartment intrusion was observed in the 1,800-lb (800-kg) car, 60-mph (95-km/h), 15-deg angle impact. This poor performance was attributed to a detail bringing a two-rail bridge rail system into a single rail guardrail system. The vehicle wheel wedged under the guardrail and snagged on the lower bridge rail that was below the guardrail.

Thrie Beam Median Barrier/Concrete Median Barrier Transition

A detail provided by California was successfully tested.

MISCELLANEOUS TESTS

Three tests were conducted on three different barrier systems, described as follows.

8,000-lb (3,600-kg) Van Test

Because of the successful results of the 25-deg van test on the G9 (wood post) thrie beam system, it was decided to further evaluate the barrier strength/vehicle stability of this higher performance system. Although the van was contained and redirected without any indication of structural failure, the vehicle rolled on its side after leaving the barrier. Thus, the G9 system mounted at 32 in. (80 cm) was more than adequate to contain an 8,000-lb (3,600-kg) van impacting at 60 mph (95 km/h) and 25 deg, but was not adequate to keep the vehicle upright.

Blocked-Out W-beam on Round Wood Posts

A version of the Texas system tested is specified by 11 states; no crash test experience was known. The system was tested for the *Report 230* test 10 conditions (4,500-lb (200-kg) car, 60 mph (95 km/h), 25-deg angle). Although smooth redirection occurred, there was considerable front wheel damage and barrier damage when compared to the G4(1S) or G4(2W) systems under similar impact conditions. The maximum dynamic deflection value of 2.4 ft (0.7 m) is comparable to values shown for the G4(2W) and G4(1S) systems in the AASHTO Barrier Guide.

Van Test With Lowered G1 Guardrail

Results of this test were disappointing because of inconclusive findings. Performance information on the G1 system mounted at 24 in. (61 m) with a higher c.g. van was desired in order to explore this possible mounting height. With the low front profile cars becoming more popular, the feasibility for lower cable mounting height for this class of vehicle was worth considering.

The downstream anchorage failure which occurred in this test (GR-20) resulted in penetration of the barrier. This anchorage failure cannot be explained as a function of the lower mounting height, and resulted in inconclusive test results.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

Phase I

The following conclusions have been derived from the findings obtained during the Phase I program:

1. With minor exceptions, all 11 longitudinal barrier systems evaluated according to *NCHRP Report 230* test 12 (1,800-lb car, 60 mph, and 15-deg angle) conditions performed well and are deemed to have satisfied the assessment criteria. The vehicles remained upright (rollover in G1 cable guardrail test is considered an end treatment problem), they were smoothly redirected, and they sustained only moderate damage. Potential modifications to enhance the barrier systems performance with the test 12 conditions are considered unwarranted.

2. With regard to barrier deflection, there was evidence that the two more flexible systems (G1 and G2 guardrail) did reduce vehicle acceleration-related values; however, the more rigid, but deformable, systems did not show clear superiority over the rigid systems for the same consideration. Thus, significant barrier deflection is required to effect significant reductions in vehicle acceleration values.

3. With regard to vehicle snagging or occupant risk determination, test 12 (1,800-lb car, 60 mph, 15-deg angle) was not a discerning experiment because all 11 longitudinal barrier systems passed the evaluation criteria. A more discerning test, test S13—1,800-lb car, 60 mph, 20-deg angle—was considered necessary to thoroughly evaluate the snagging and possible occupant risk limits of the 11 barrier systems.

4. Although the 11 barrier systems have been demonstrated to satisfactorily perform with *Report 230* minimum matrix tests 10 and 12, two supplementary, but important, performance properties were not evaluated, namely, capability to perform with vehicles with high center of gravity, such as vans and school buses, and the structural limit to contain higher service level loadings.

Phase II

The following conclusions have been derived based on the findings obtained in Phase II:

1. *The 1,800-lb (800-kg) car tests.* The six longitudinal barrier systems evaluated according to *Report 230* test S13 conditions (1,800-lb car, 60 mph and 20-deg angle) satisfied all of the criteria of *Report 230* with the exception of the vehicle trajectory requirements as applied to the G1 cable guardrail system, G3 box beam guardrail system, and MB3 box beam system. Tests of these three weak post systems resulted in unusual postimpact trajectories.

G1 cable system (test GR-16)—The vehicle came to rest in contact with the barrier after 138 ft (42 m) of contact. Although the 60-mph (95-km/h) velocity change exceeded the 15-mph (24-km/h) criteria in *Report 230* Table 6, I, calculated values based on vehicle accelerations indicate that the 15-mph (24-km/h) criteria should not be considered to be appropriate. The 138 ft (42 m) of barrier contact did represent considerable barrier damage for this test condition, even though the cables were reusable and only the posts required replacement.

Box beam systems (tests GR-10 and GR-12)—In both tests the vehicle wheel wedged under the beam and the rear of the vehicle yawed away from the barrier. A secondary impact occurred in both tests as the vehicle was yawing through a large angle. Because of the yaw attitude of the vehicle when this secondary impact occurred, the final trajectory varied from redirection parallel to the barrier to the vehicle traveling in a reverse direction across the roadway side of the barrier.

It is not clear how this erratic redirection should be treated in the evaluation process. For roadways with low traffic volumes, the postimpact trajectory is probably not a problem. For higher traffic densities, it may be a significant problem.

2. *Van tests.* The six tests conducted with the van-type vehicle resulted in a different performance similar to that observed in the 1,800-lb (800-kg) car tests. It is clear that not only the height of the barrier system, but also the structural and geometrical characteristics, are important for this type of vehicle. The tests illustrated that a van is not a replacement vehicle for the 4,500-lb (2,000-kg) car because of the observed stability problems.

G1 cable guardrail—This system adequately contained and redirected the van for 60-mph (95-km/h) and 25-deg angle impacts. Performance was much better than the 1,800-lb (800-kg) car, 20-deg test when considering redirection and length of barrier contact.

G2 W-beam weak post guardrail—Although this barrier was mounted slightly higher than the G1 system, the beam lost height because the vehicle rolled over onto it and, subsequently, rolled on its side. Thus, the capacity for keeping the vehicle upright was much greater with the cable system than with the G2 system.

G3 beam box guardrail—Snagging and spin-out resulted in this test, although vehicle rollover was not an issue for the 60-mph (95-km/h), 20-deg angle test. Adequate strength was evident for more severe impacts.

G4(2W) guardrail—Although rollover had occurred with the G4(1S) guardrail system at 60 mph (95 km/h) and 25 deg with the van, the G4(2W) threshold for preventing the van rollover is much closer to a 25-deg impact angle than the 20 deg tested based on the low maximum roll angle observed. Thus, the wood post W-beam systems probably have a greater capacity for van impacts than the steel post systems based on comparable performance with the G9 thrie beam (wood and steel post) systems.

G9 (wood post) guardrail—The van remained upright with a relatively low roll angle value during the 60-mph (95-km/h), 25-deg angle test.

MB3 box beam median barrier—Snagging and spin-out occurred in this test similar to the G3 system. Rollover stability was not an issue in this 60-mph (95-km/h), 20-deg angle test. Adequate strength was evident for more severe impacts.

3. *Transition tests.* Conclusions from these tests follow.

W-beam/thrie beam transition—The W-beam/thrie beam transition element proved to be a satisfactory component for effecting the transition from a standard G4 W-beam system to a standard G9 thrie beam system. Both 1,800-lb (800-kg) and 4,500-lb (2,000-kg) car tests were used in these evaluations.

SL1 bridge rail transition test—Smooth redirection was achieved for the 4,500-lb (2,000-kg), 60-mph (95-km/h), 15-deg angle test. This test illustrates the advantages of having bridge rail and approach guardrail with similar structural characteristics.

G3/BR3 transition—Unsatisfactory performance with this transition design illustrates the need for interface compatibility between vehicle and barrier. Although small barrier deflections occurred, the lower taper of the transition rail caused severe wheel snagging and passenger compartment intrusion.

MB9/MB5 transition—Smooth redirection was achieved with the selected design. The thrie beam 20-in. (50-cm) width makes a very compatible beam interface for the safety shape.

4. *Miscellaneous tests.* Conclusions from these tests include the following:

8,000-lb (3,600-kg) van test—This test illustrated that most of the operational barrier systems will fail by vehicle stability considerations with heavier vehicles before the strength of the system is exceeded.

Blocked-out W-beam on round wood posts—Although this system resulted in more extensive vehicle and barrier damage than associated with the G4 guardrail systems, the test criteria were met. The advantages of the round posts are associated with cost.

RECOMMENDATIONS

1. *1,800-lb (800-kg) car tests.* On the basis of the findings of this project and previously cited evidence from reported accidents, it is recommended that the standard test impact for the minicar be changed from 15 deg to 20 deg. Most of the current operational longitudinal barriers will perform satisfactorily at this angle, and deficiencies in other systems will be more readily identified.

2. *Longitudinal barrier systems.* A large number of longitudinal barrier systems were evaluated in this project. The User's Manual (Appen. A) contains drawings of recommended systems from this project. The insight tests with the 1,800-lb (800-kg) car and vans produced different results among the different system types. Users are encouraged to evaluate these differences.

3. *Other longitudinal barriers.* A large number of transition and bridge rail designs recently evaluated at SwRI for FHWA are also shown in the User's Manual. These systems are also recommended for use based on demonstrated crash test performance.

4. *Barrier height considerations.* The User's Manual also contains mounting height guidelines for W-beam and thrie beam barriers based on findings from a recently completed FHWA project at SwRI.

APPENDIX A

USER'S MANUAL—DESIGN DRAWINGS

INTRODUCTION

Many longitudinal barriers were evaluated in the crash test portion of this project. Drawings of barrier systems which behaved satisfactorily are shown in this appendix. Following these are drawings of barrier systems with satisfactory crash test performances from recent Federal Highway Administration (FHWA) contracts at Southwest Research Institute (SwRI). Finally, other crash test experience with longitudinal barriers using the procedures of *NCHRP Report 230* (*1*) is given.

The purpose of these drawings and guidelines is to furnish designers with an array of barrier systems that have been evaluated according to the latest test criteria, *NCHRP Report 230.* Most of the components of these systems can be found in the latest edition of "A Guide to Standardized Highway Barrier Rail Hardware." (*9*)

The full-scale test results from this project are summarized in Chapter Three of the main report and described in detail in Volume 3 (see Foreword for availability). It should also be pointed out that the barrier drawings shown on the following pages were, in some cases, reproduced from larger drawings containing additional information not needed for basic barrier construction. For questions on dimensions or other barrier details, please contact the NCHRP or Southwest Research Institute.

GUARDRAILS (ROADSIDE BARRIER)

The AASHTO Barrier Guide (*7*) shows eight operational roadside barrier systems. Six of the eight systems now have test experience with the 1,800-lb (800-kg) car; six were evaluated in this project and the G4(1S) system was evaluated at TTI (*14*). The G4(1W) guardrail system has been essentially replaced by the G4(2W) system and was not considered for evaluation in this project; the G4(2S) system was also not evaluated in the project. In addition, tests of the wood post G9 and MB9 system shown in the AASHTO Barrier Guide are considered completed based on tests with the 1,800-lb (800-kg) car conducted in this project. Insight tests were conducted on five of the guardrail systems with full-size vans.

Design drawings for the following roadside barrier or guardrail systems are provided in this section.

		Tests GR
G1	3-Cable System	5,16,17
G2	W-Beam/Weak Post System	3,8,9
G3	Box Beam System	4,10,11
G4(1S)	Blocked Out steel Post W-Beam System	Ref. 4
G4(2W)	Blocked Out Wood Post W-Beam System	1,6,7
G9 (Steel Post)	Blocked Out Steel Post Thrie Beam System	2, Ref. 14
G9 (Wood Post)	Blocked Out Wood Post Thrie Beam System	13,15,18,20
	Blocked Out Round Wood Post W-Beam	19

MEDIAN BARRIERS

Both the MB3 box beam and MB5 concrete median barriers now have 1,800-lb (800-kg) car test experience. Insight tests were conducted in the MB3 system with a van. Only the MB3 box beam drawing is shown here (test MB-2 and GR-12); the MB5 safety shape is a standard geometry which has a number of reinforcement schemes. MB5 test results are covered in Refs. 14 and *12*.

Performance of the MB2 W-beam with steel weak posts is expected to be comparable to the G2 results. Similarly, blocked out W and thrie beam median barrier systems using wood or steel posts are expected to perform in a similar manner to the guardrail systems using the same components. Thus MB2, MB3, and MB9W thrie beam system performance is considered to be covered by this project. Insight tests with vans were also conducted on most of these systems.

BRIDGE RAILS

Four bridge rail systems were evaluated in this project. In addition, recent test experience with the concrete safety shape median barrier and bridge rail have been accomplished with the 1,800-lb (800-kg) van (*14,12*). An extensive FHWA contract at SwRI evaluated other bridge railings for the S13 (1,800-lb (800-kg)) car test and drawings of systems with satisfactory performances are given (*13*). These systems included:

Project	Bridge Rail System	Test No.
NCHRP 22-4	BR2 (AASHTO Barrier Guide)	BR-1
NCHRP 22-4	BR3 (AASHTO Barrier Guide)	BR-2
NCHRP 22-4	Texas T4	BR-3
NCHRP 22-4	NCHRP SL1	BR-4
FHWA (Ref. *13*)	Nevada Safety Shape w/Rail	
FHWA (Ref. *13*)	North Carolina Parapet/Rail	
FHWA (Ref. *13*)	Ohio Box Beam	
FHWA (Ref. *13*)	Oregon Two-Rail	
FHWA (Ref. *13*)	Nebraska Tubular Thrie Beam	
FHWA (Ref. *13*)	Modified Kansas Open Parapet	
FHWA (Ref. *13*)	Oklahoma Open Parapet	

Drawings of these systems follow.

TRANSITIONS

A number of different types of barrier transitions were evaluated in this project including: (1) W-beam/thrie beam guardrail transition, (2) SL1 guardrail/bridge rail transition (see bridge rail drawing), and (3) thrie beam/concrete safety shape median barrier transition.

In addition, a comprehensive FHWA project has recently been completed at SwRI. Included in the design/development effort of this project (*17*) are: (1) straight parapet bridge rails (W-beam steel post, G4(1S); W-beam wood post, G4(2W); thrie beam steel post, G9; thrie beam wood post, G9; and modified thrie beam); (2) tapered parapet bridge rail (W-beam steel post, G4(1S); W-beam wood post, G4(2W); thrie beam steel post, G9; thrie beam wood post, G9; and W-beam steel post, G4(1S) North Carolina Design); (3) independent end block; and (4) intersecting roadways transition. Drawings of these systems follow.

TERMINALS

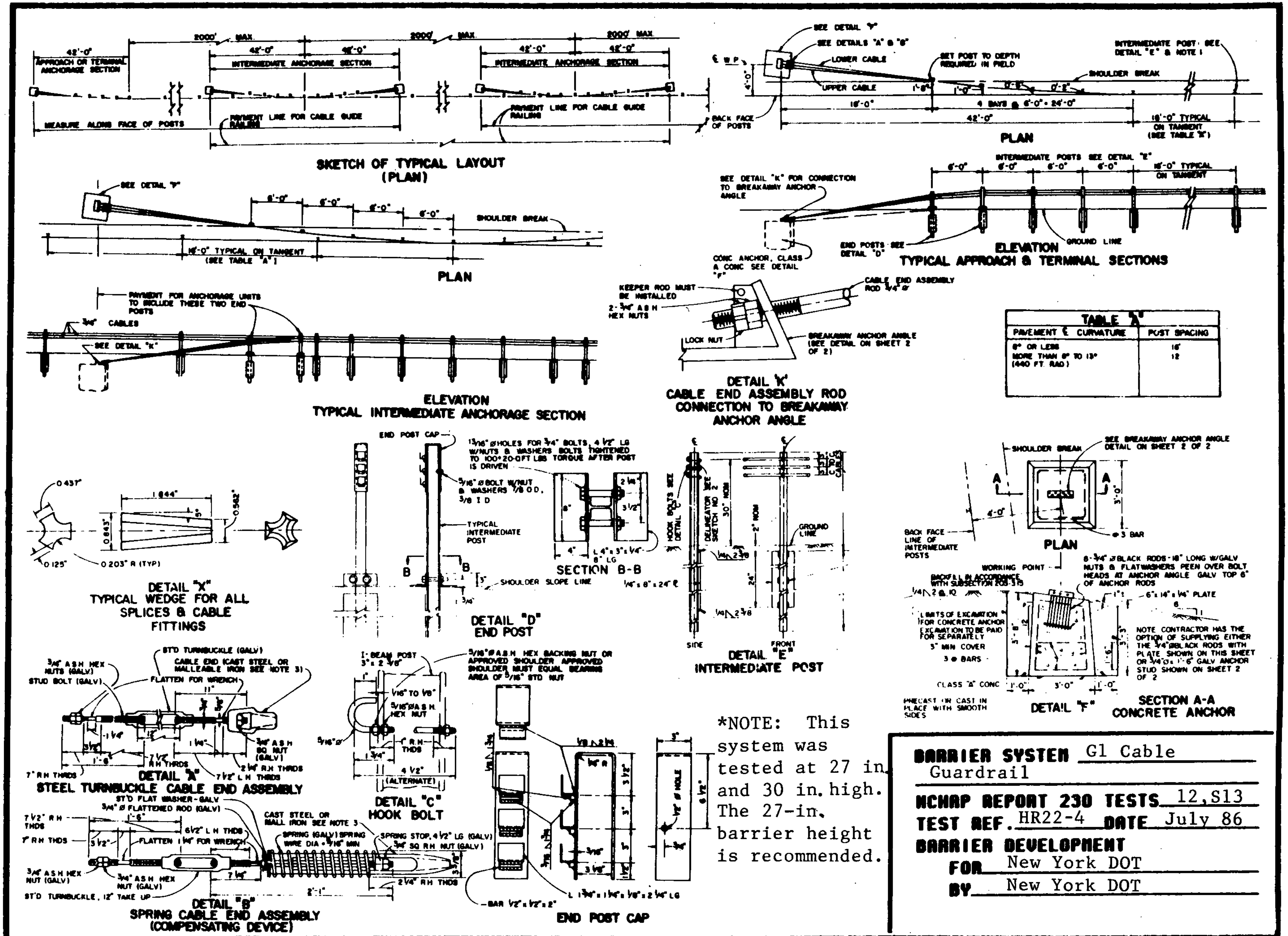
Two terminals have recently been developed at SwRI for the FHWA and Syro Steel Company. The eccentric loader guardrail terminal, which has been approved as an experimental device by the FHWA Office of Engineering, features both 4-ft (1.2-m) and 1.5-ft (0.5-m) flare offset geometries (*18*). The 4-ft (1.2-m) flail design is preferred if space is available. The vehicle attenuating terminal (V-A-T) was designed under an FHWA contract (*19*), but development was completed under contract to Syro Steel Company (*20*). Initial approval of the V-A-T system as a guardrail end treatment has been given. Drawings for the eccentric loader terminal and V-A-T follow.

ADDITIONAL BARRIER CRASH TESTS

A number of research agencies were contacted with respect to the crash test experiences of longitudinal barriers using the procedures of *NCHRP Report 230.* Summaries of their response are included in this section. Also included in this section are crash test evaluations performed by SwRI that are not a part of this NCHRP project.

The summary tables of all responses follow.

Table	
1	Bridge rail tests, SwRI
2	Summary of thrie beam/wingwall transition tests, SwRI
3	Summary of W-beam/wingwall transition tests, SwRI
4	Summary of V-A-T crash tests, SwRI
5	New York State DOT tests
6	Texas Transportation Institute
7	FHWA bridge rail data



*NOTE: This system was tested at 27 in. and 30 in. high. The 27-in. barrier height is recommended.

BARRIER SYSTEM G1 Cable Guardrail

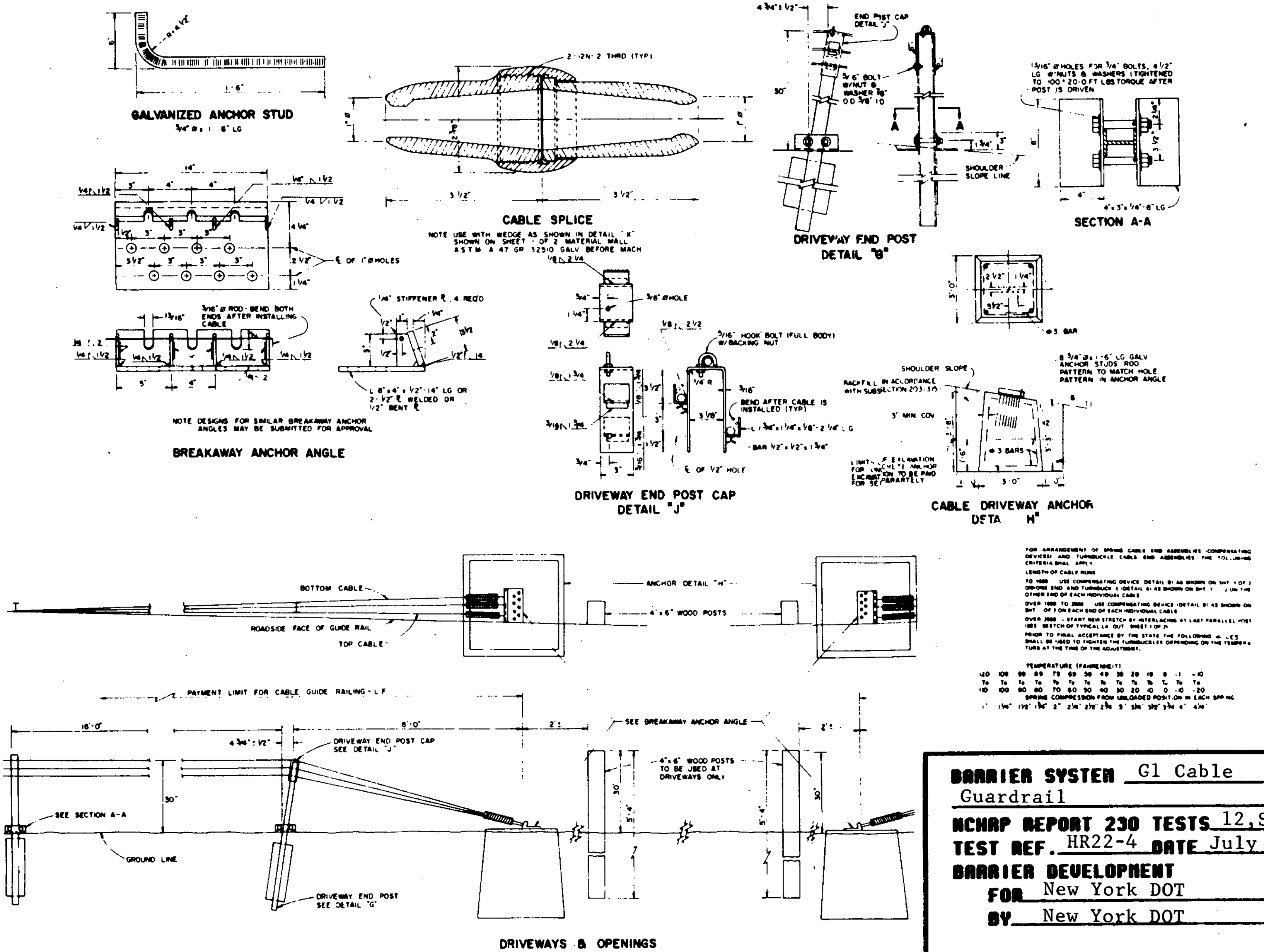
NCHRP REPORT 230 TESTS 12,S13

TEST REF. HR22-4 **DATE** July 86

BARRIER DEVELOPMENT

FOR New York DOT

BY New York DOT



BARRIER SYSTEM G1 Cable Guardrail

NCHRP REPORT 230 TESTS 12,S13

TEST REF. HR22-4 **DATE** July 86

BARRIER DEVELOPMENT

FOR New York DOT

BY New York DOT

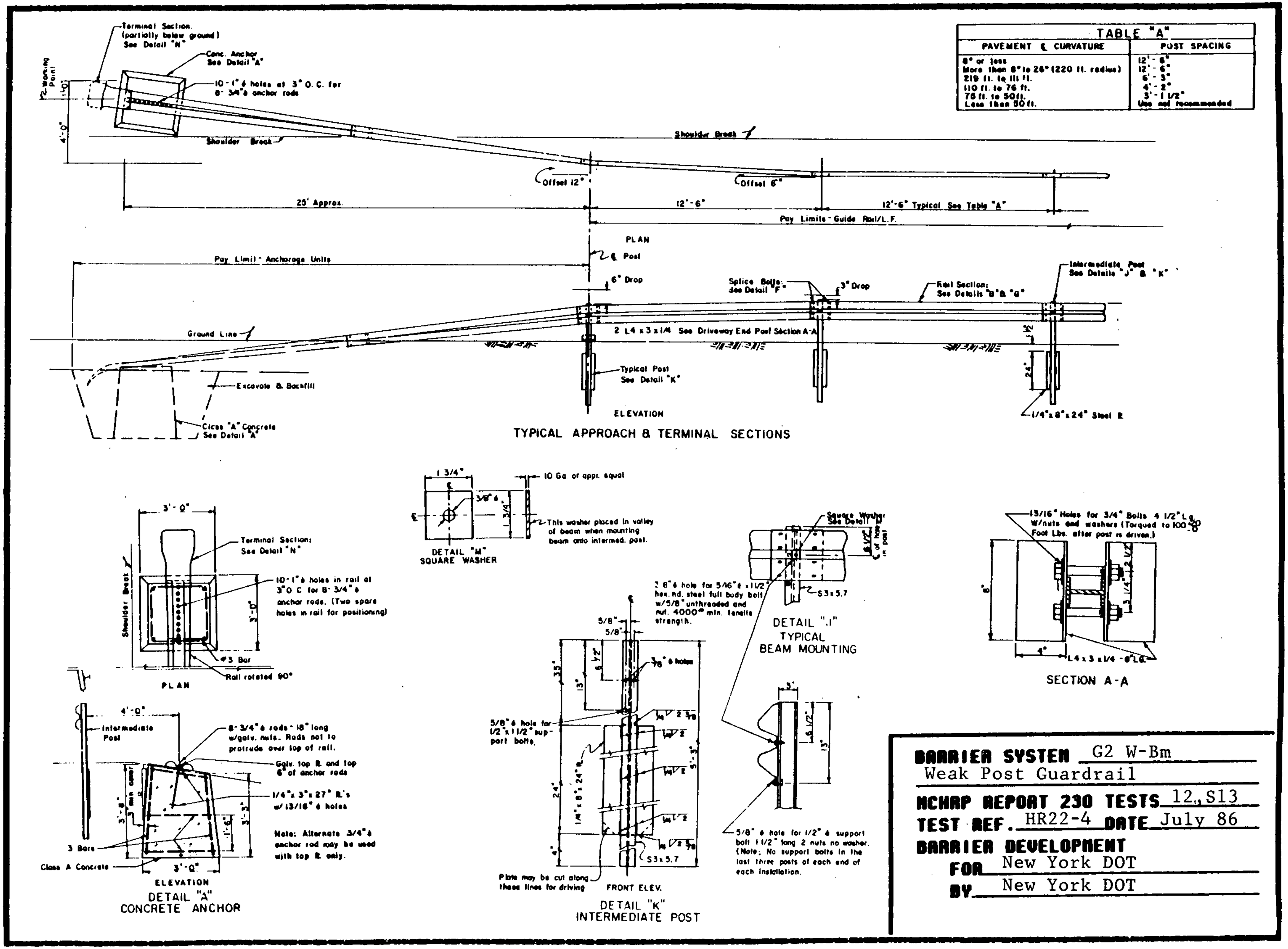
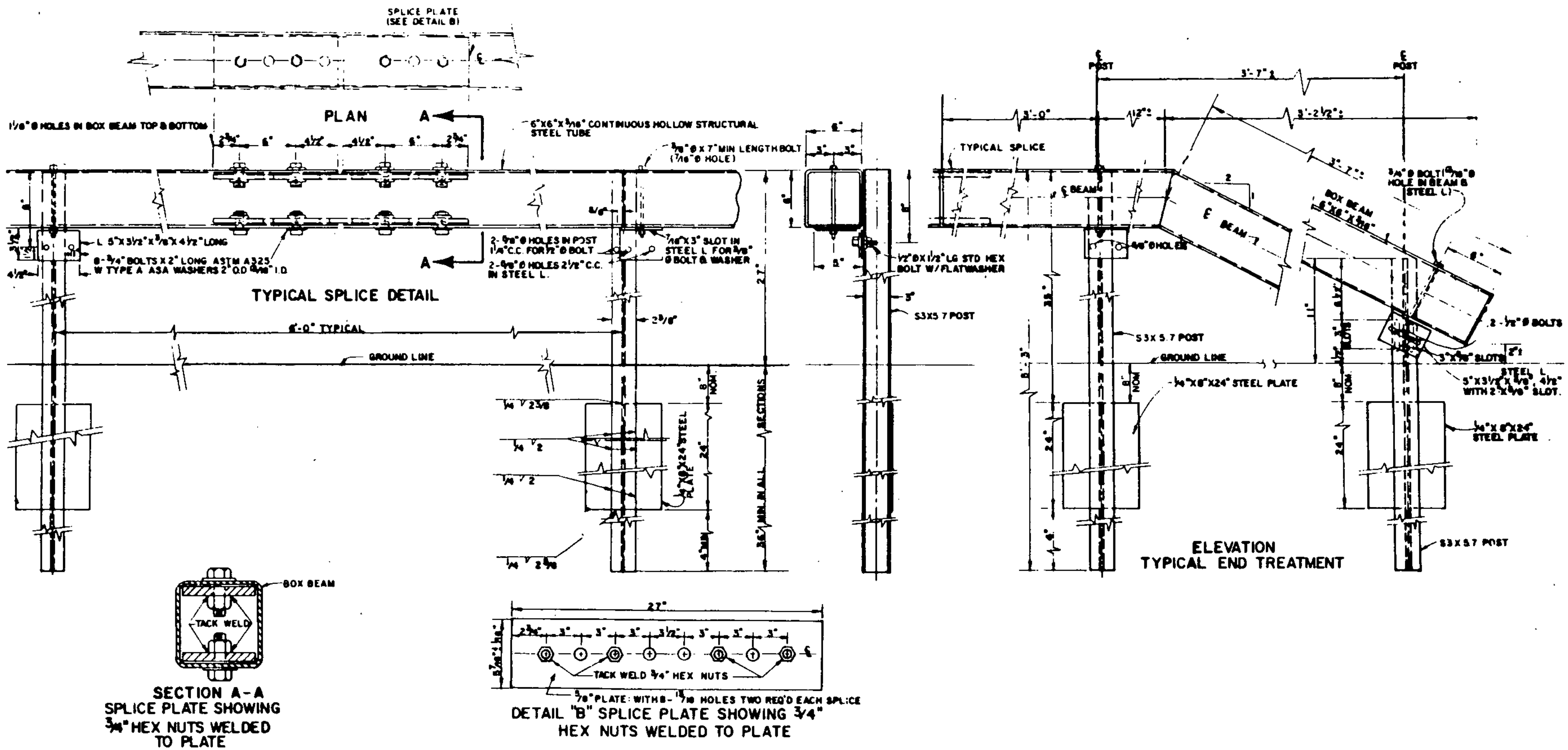


TABLE "A"

PAVEMENT ℄ CURVATURE	POST SPACING
8° or less	12' - 6"
More than 8° to 26° (220 ft. radius)	12' - 6"
219 ft. to 111 ft.	6' - 3"
110 ft. to 76 ft.	4' - 2"
75 ft. to 50 ft.	3' - 1 1/2"
Less than 50 ft.	Use not recommended

BARRIER SYSTEM G2 W-Bm
Weak Post Guardrail
NCHRP REPORT 230 TESTS 12, S13
TEST REF. HR22-4 **DATE** July 86
BARRIER DEVELOPMENT
FOR New York DOT
BY New York DOT



BARRIER SYSTEM G3 Box Beam Guardrail

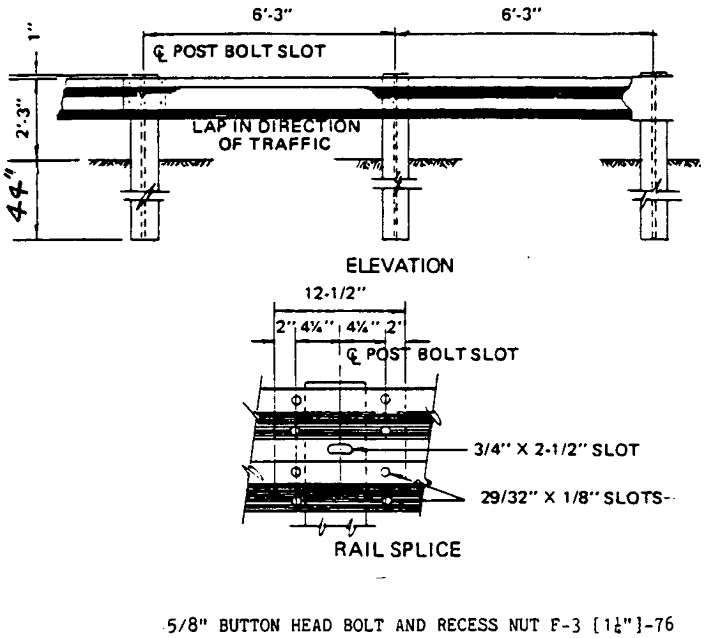
NCHRP REPORT 230 TESTS 12,S13

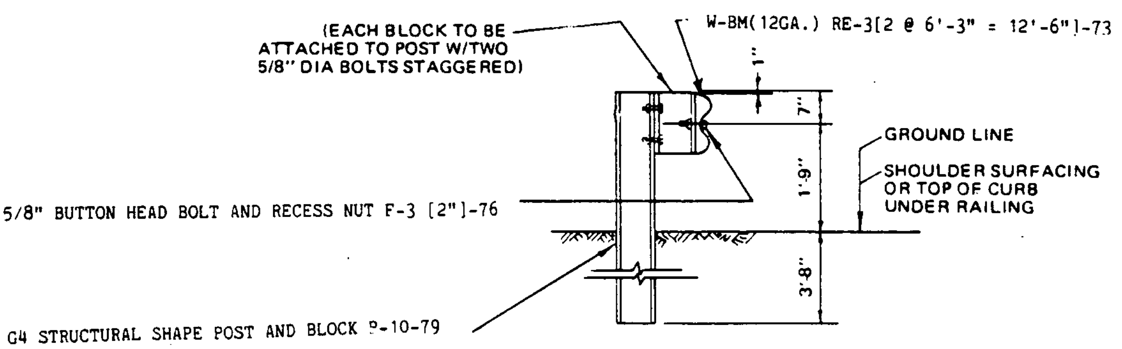
TEST REF. HR22-4 **DATE** July 86

BARRIER DEVELOPMENT

FOR New York DOT

BY New York DOT





Barrier components with F, P, and RE prefixes are found in the latest edition of "A Guide to Standardized Highway Rail Hardware," a report prepared and approved by the AASHTO-AGC-ARTBA Joint Cooperative Committee.

BARRIER SYSTEM G4(1S) Guard-rail

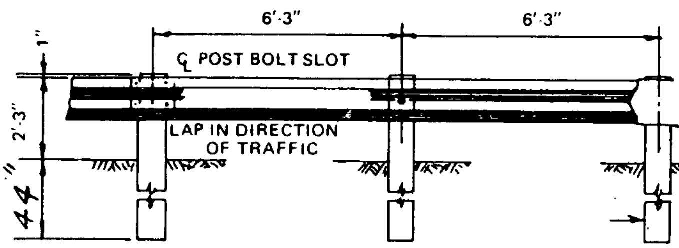
NCHRP REPORT 230 TESTS 12,S13

TEST REF. HR22-4,4 **DATE** 7/86, 1/85

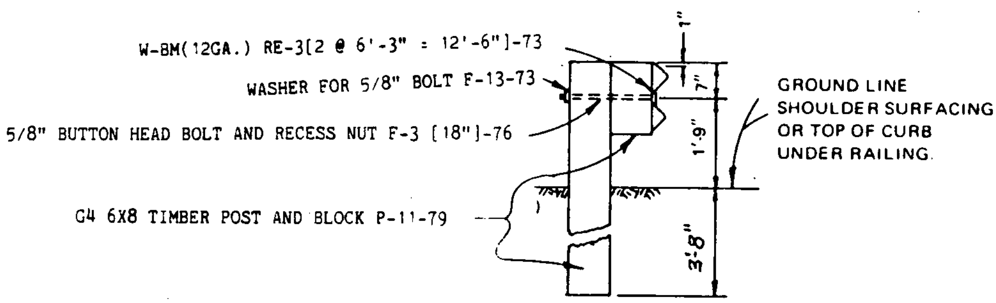
BARRIER DEVELOPMENT

FOR NCHRP

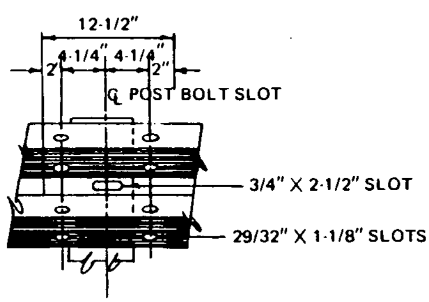
BY SwRI, TTI



METAL BEAM GUARD RAIL.



TYPICAL POST SPACING 6'-3" C. TO C.



RAIL SPLICE

EIGHT 5/8" BUTTON HEAD BOLT AND RECESS NUT F-3 [1¼"]-76

Barrier components with F, P, and RE prefixes are found in the latest edition of "A Guide to Standardized Highway Rail Hardware," a report prepared and approved by the AASHTO-AGC-ARTBA Joint Cooperative Committee.

BARRIER SYSTEM G4(2W) Guardrail

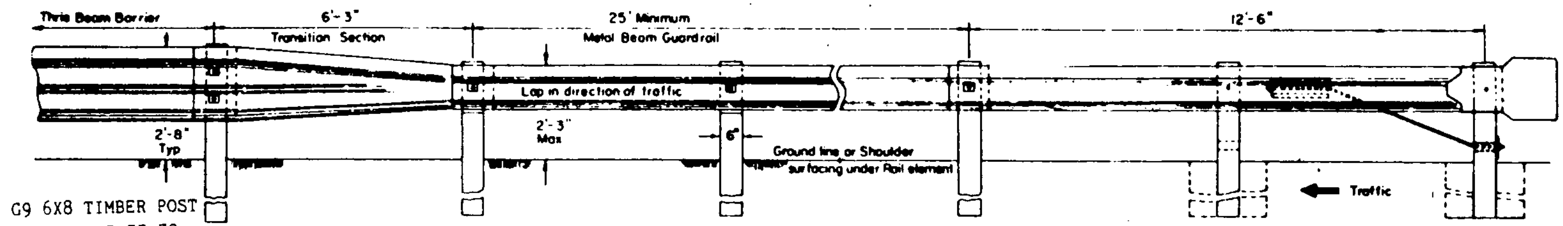
NCHRP REPORT 230 TESTS 12, S13

TEST REF. HR 22-4 **DATE** 7/86

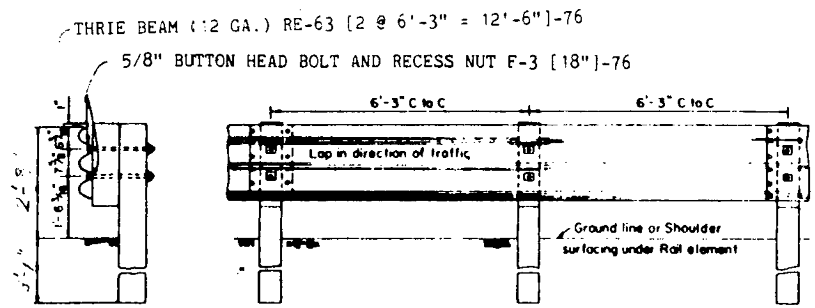
BARRIER DEVELOPMENT

FOR NCHRP

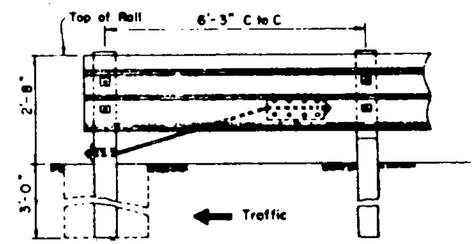
BY SwRI



APPROACH END ANCHOR



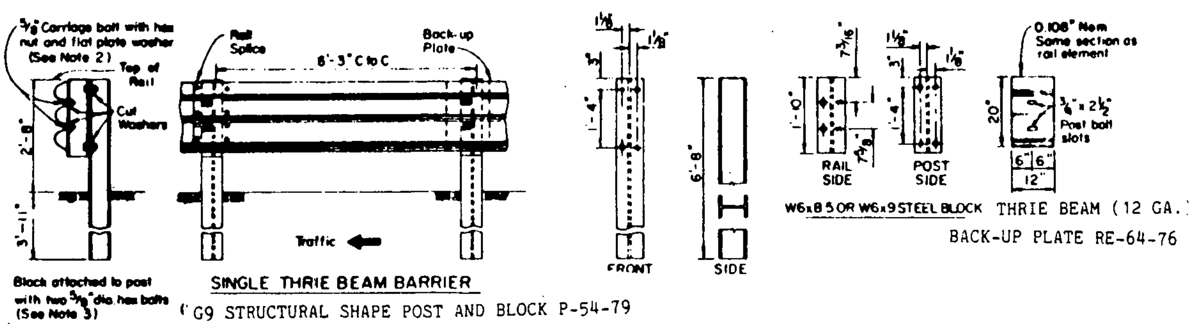
SINGLE THRIE BEAM BARRIER



TRAILING END ANCHOR

NOTES

1. All holes in steel posts and blocks shall be 13/16" Ø
2. Rail mounts to block with bolt on approaching traffic side of block and post web
3. Block mounts to post with 2 bolts staggered. Lower bolt on approaching traffic side of block and post web



SINGLE THRIE BEAM BARRIER

G9 STRUCTURAL SHAPE POST AND BLOCK P-54-79

BARRIER SYSTEM G9 Thrie Bm Guardrail

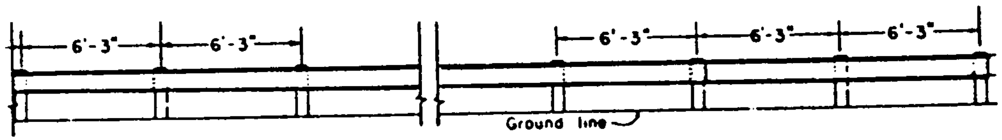
NCHRP REPORT 230 TESTS 12,S13

TEST REF. HR22-4 **DATE** July 86

BARRIER DEVELOPMENT

FOR Anderson Safeway

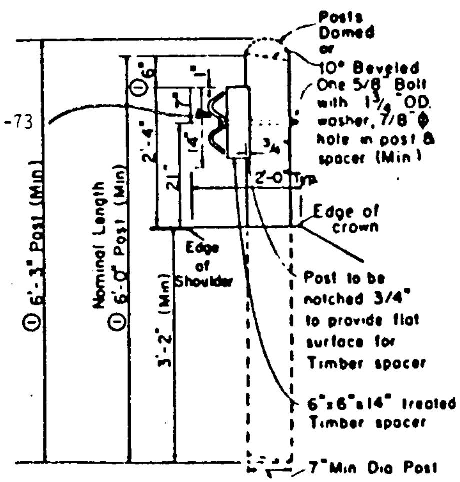
BY SwRI



ELEVATION

W-BM(12GA.) RE-3[2 @ 6'-3" = 12'-6"]-73

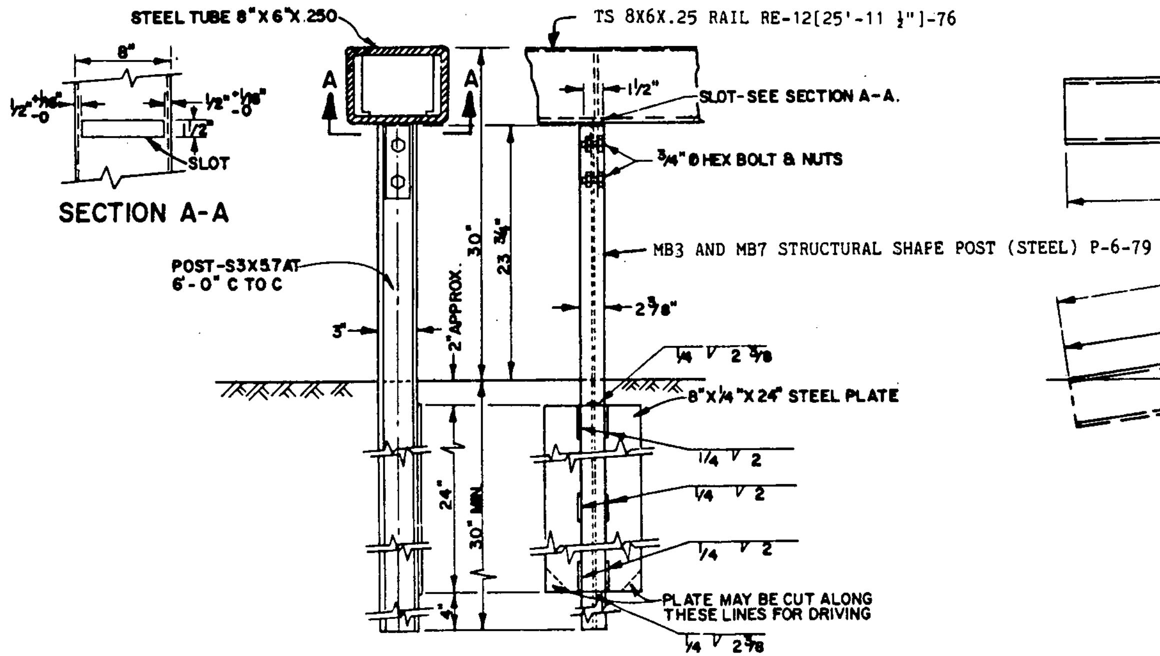
5/8" BUTTON HEAD BOLT AND RECESS NUT F-3 [1¼"]-76



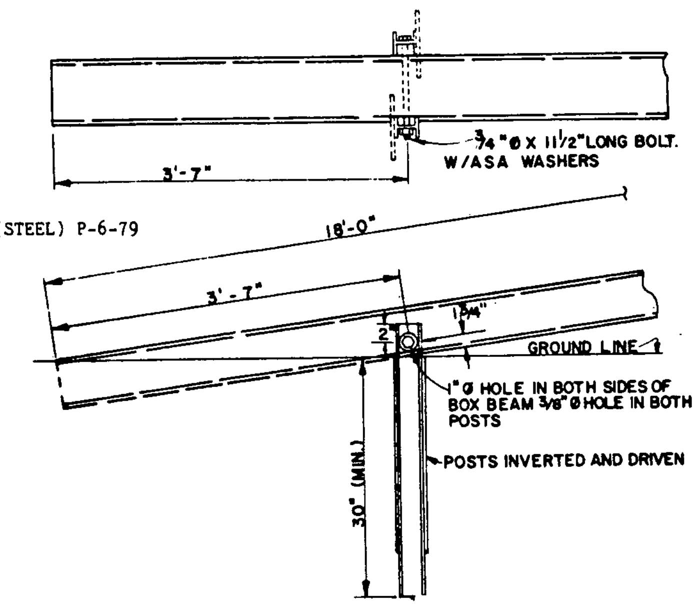
WOOD LINE POST
(Blockout)

Barrier components with F, P, and RE prefixes are found in the latest edition of "A Guide to Standardized Highway Rail Hardware," a report prepared and approved by the AASHTO-AGC-ARTBA Joint Cooperative Committee.

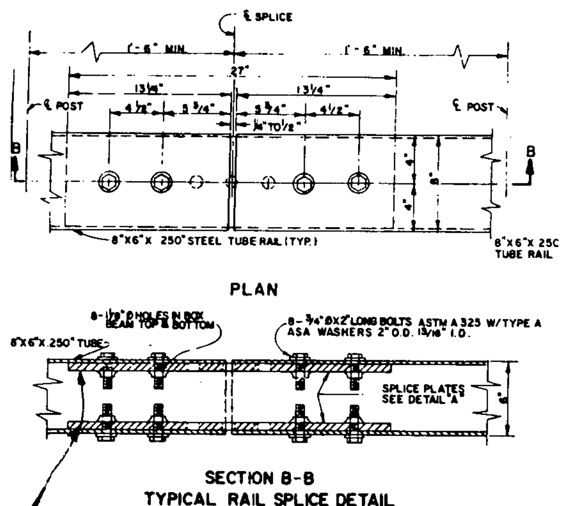
BARRIER SYSTEM Texas Blocked-out W-Bm on Round Wood Posts G.R.
NCHRP REPORT 230 TESTS 10
TEST REF. HR22-4 **DATE** July 86
BARRIER DEVELOPMENT
FOR Texas DH&PT
BY Texas DH&PT



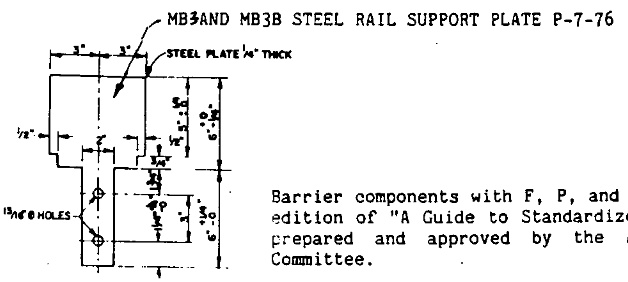
TYPICAL SECTION FOR FLUSH MEDIAN



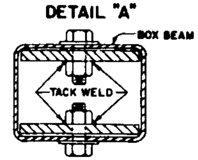
TYPICAL END TREATMENT



TS 8X6X.25 RAIL SPLICE PLATES RE-13-73



RAIL SUPPORT PLATE



DETAIL "A"

Barrier components with F, P, and RE prefixes are found in the latest edition of "A Guide to Standardized Highway Rail Hardware," a report prepared and approved by the AASHTO-AGC-ARTBA Joint Cooperative Committee.

BARRIER SYSTEM MB3 Box Beam Median Barrier

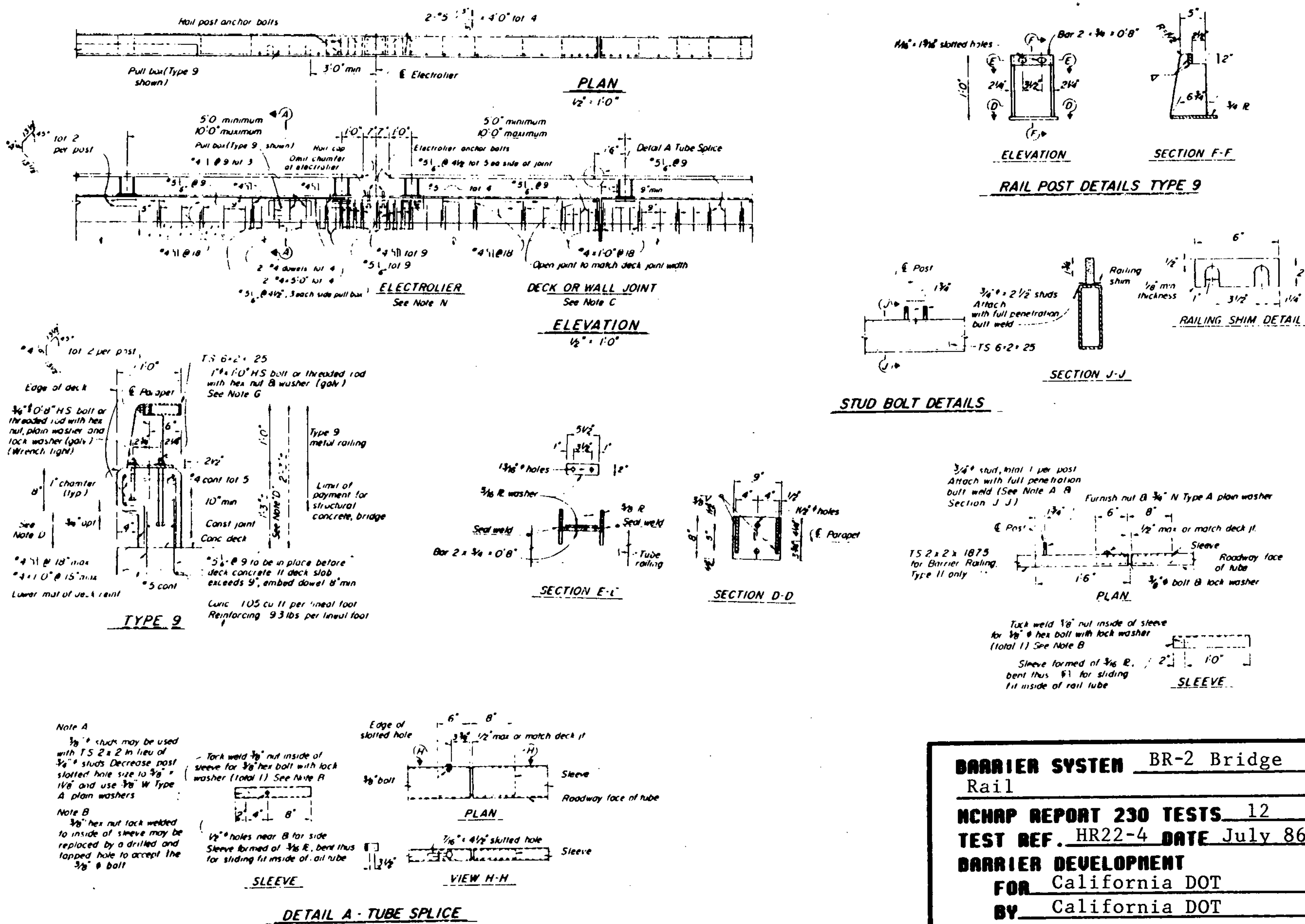
NCHRP REPORT 230 TESTS 12,S13

TEST REF. HR22-4 **DATE** 7/86

BARRIER DEVELOPMENT

FOR New York DOT

BY New York DOT



BARRIER SYSTEM BR-2 Bridge Rail

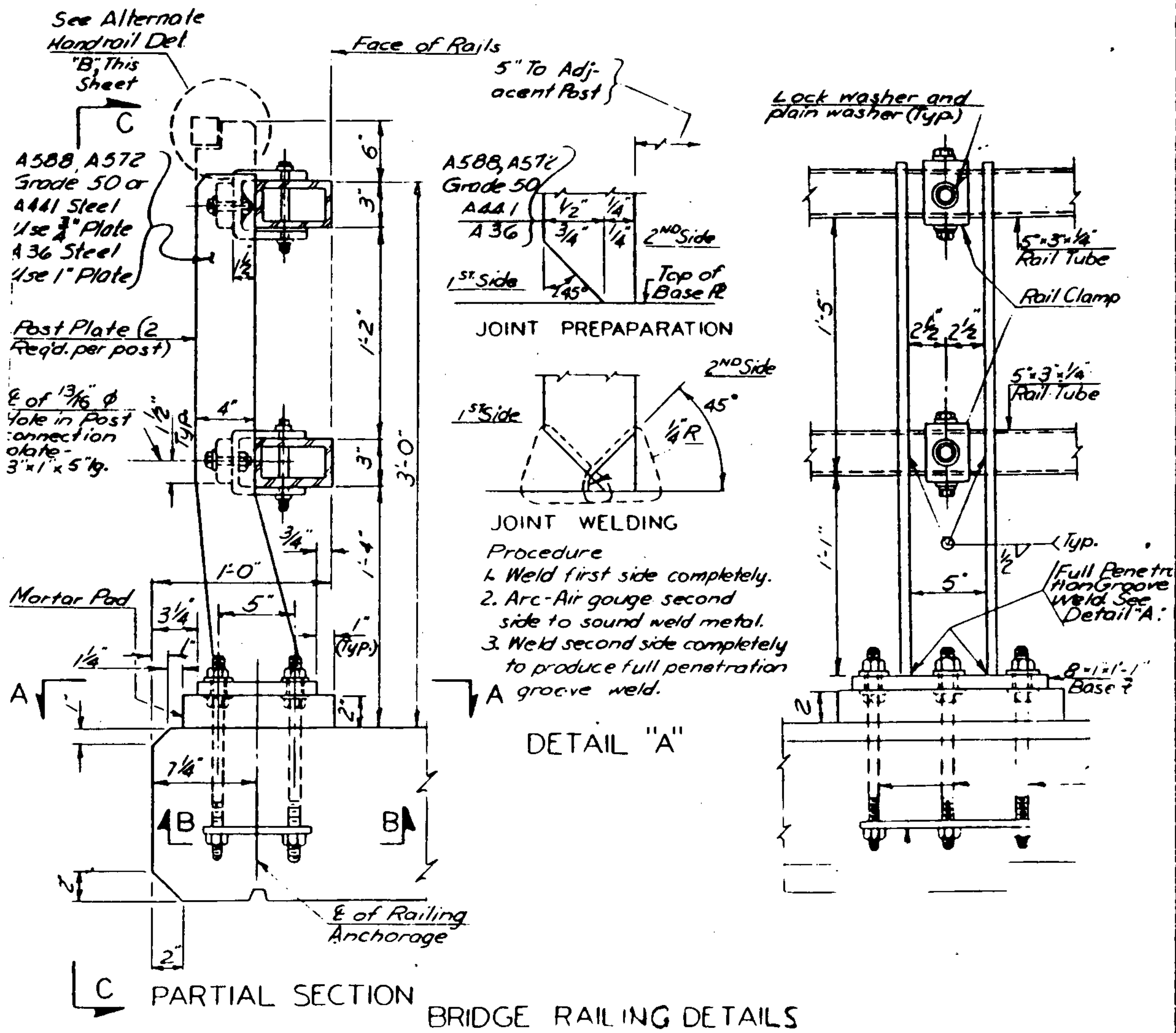
NCHRP REPORT 230 TESTS 12

TEST REF. HR22-4 **DATE** July 86

BARRIER DEVELOPMENT

FOR California DOT

BY California DOT



BARRIER SYSTEM BR-3 Bridge Rail

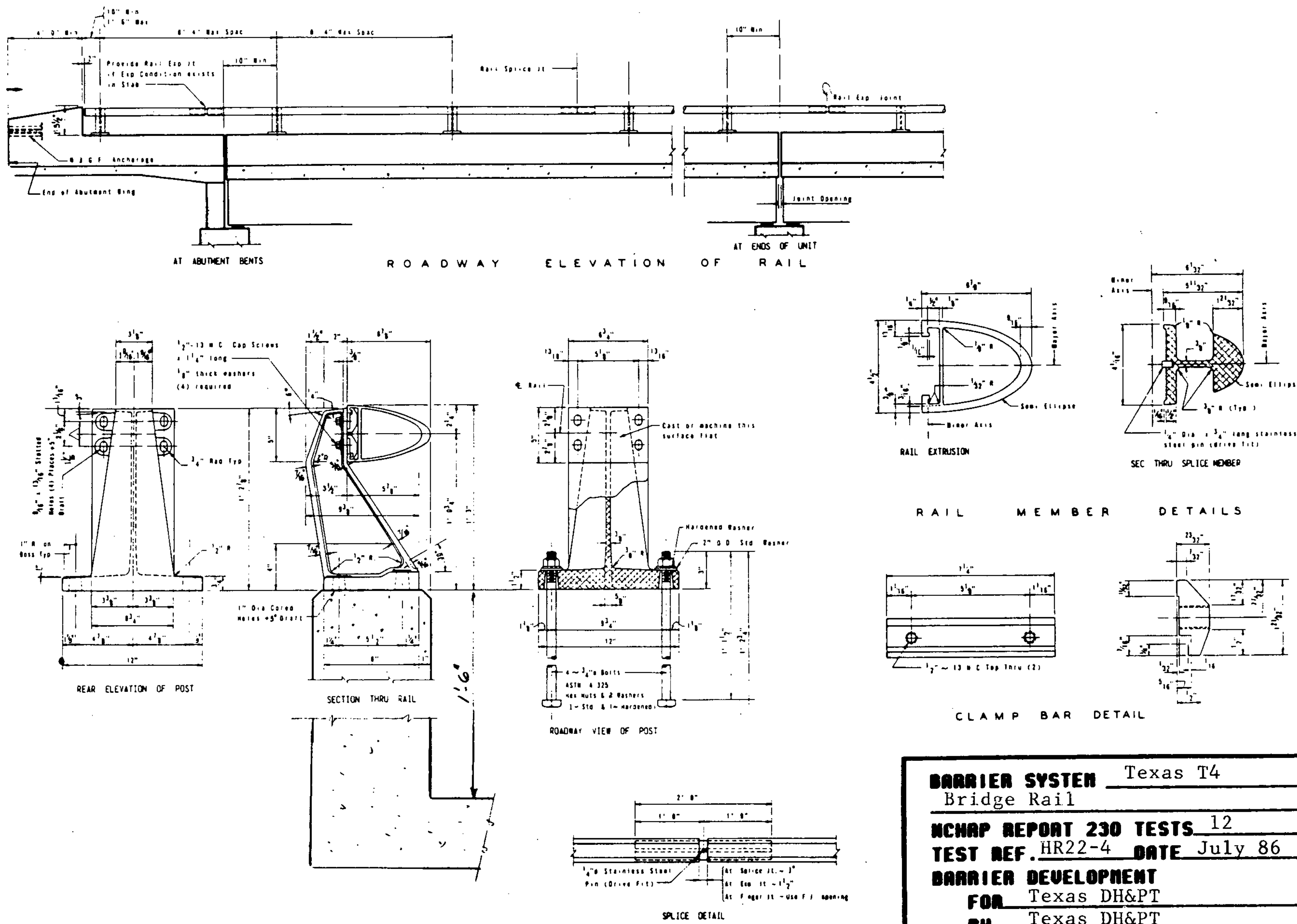
NCHRP REPORT 230 TESTS 12

TEST REF. HR 22-4 **DATE** 7/86

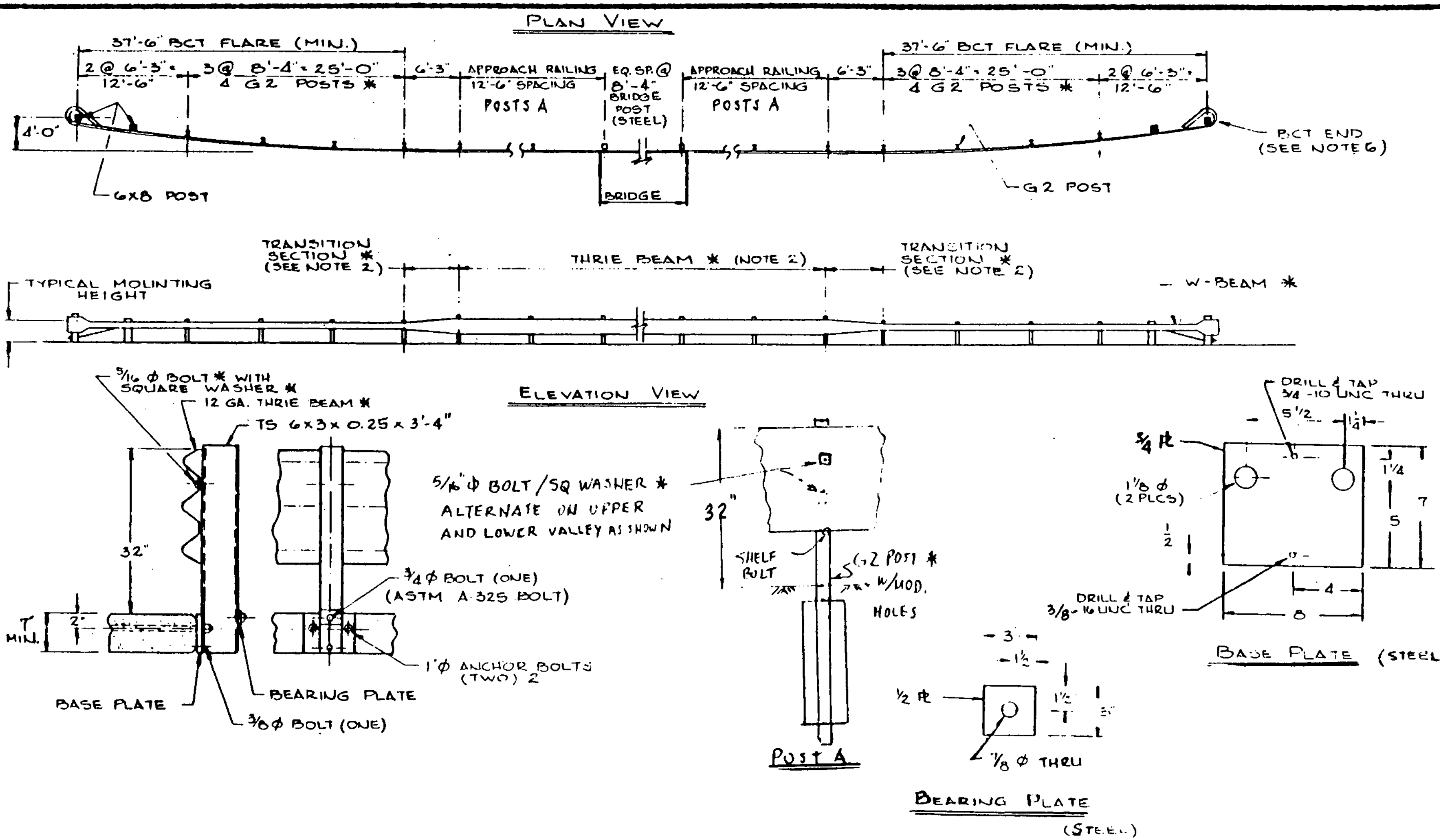
BARRIER DEVELOPMENT

FOR New York DOT

BY New York DOT



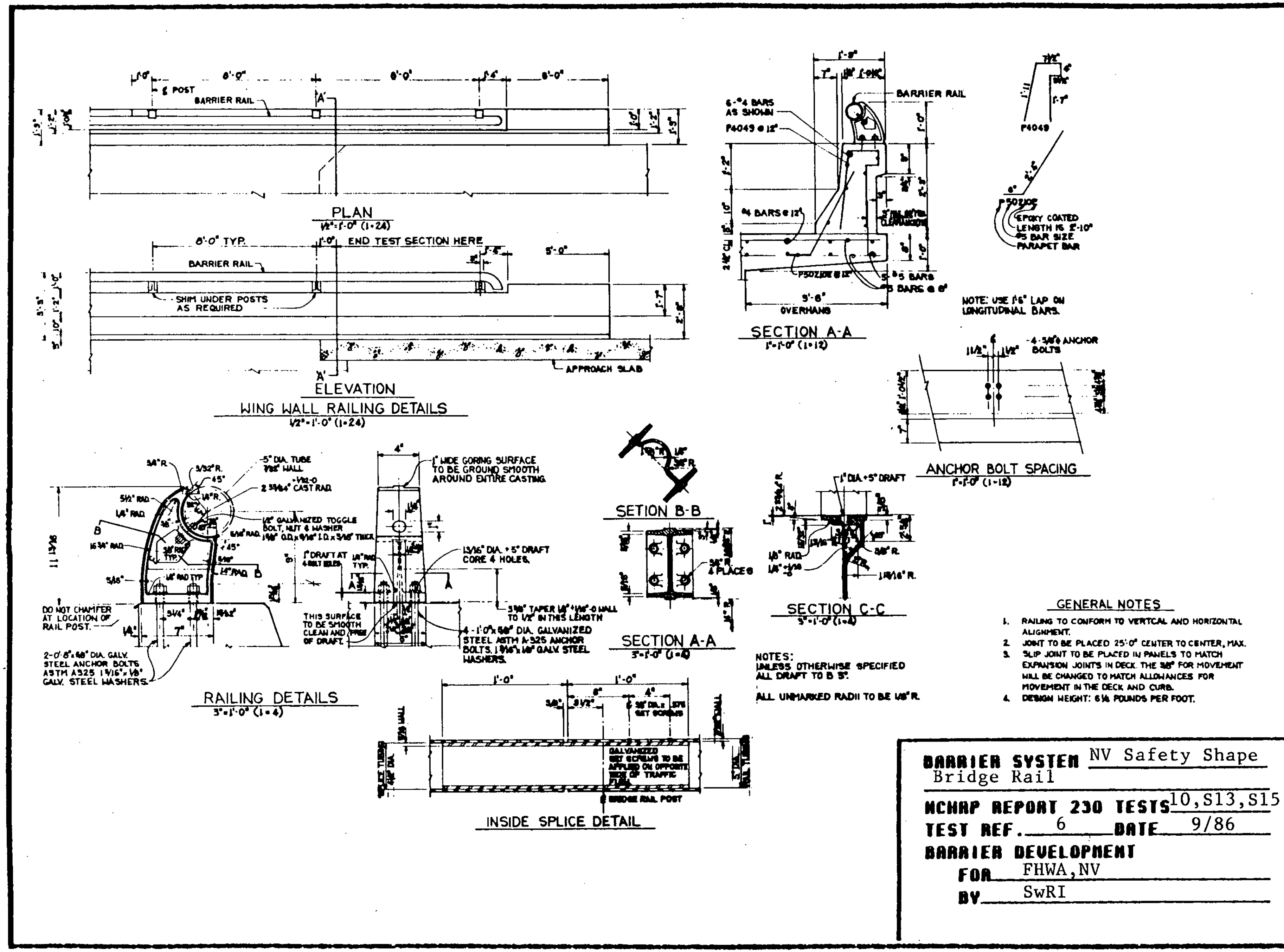
BARRIER SYSTEM Texas T4
Bridge Rail
NCHRP REPORT 230 TESTS 12
TEST REF. HR22-4 **DATE** July 86
BARRIER DEVELOPMENT
FOR Texas DH&PT
BY Texas DH&PT

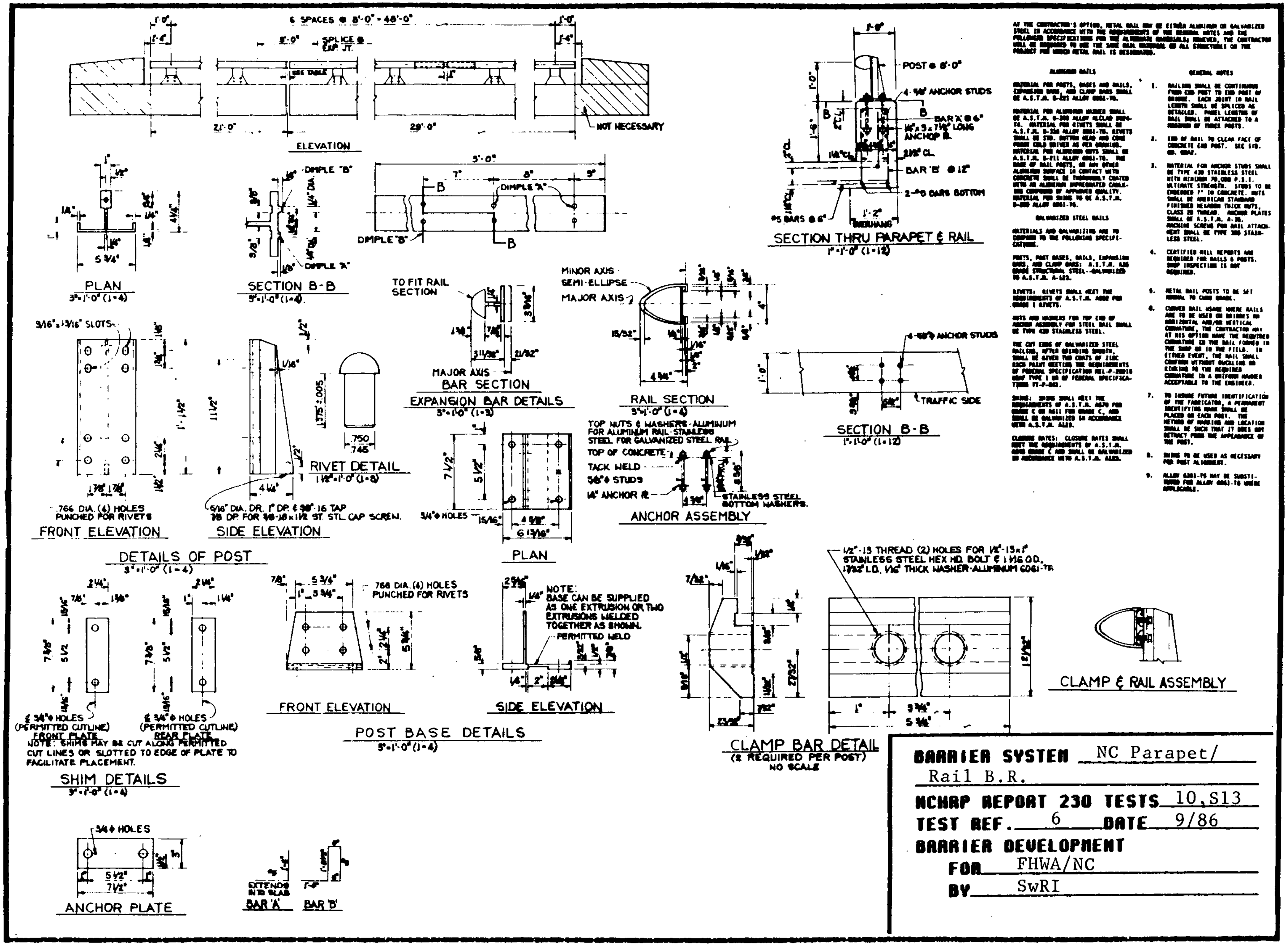


NOTES:

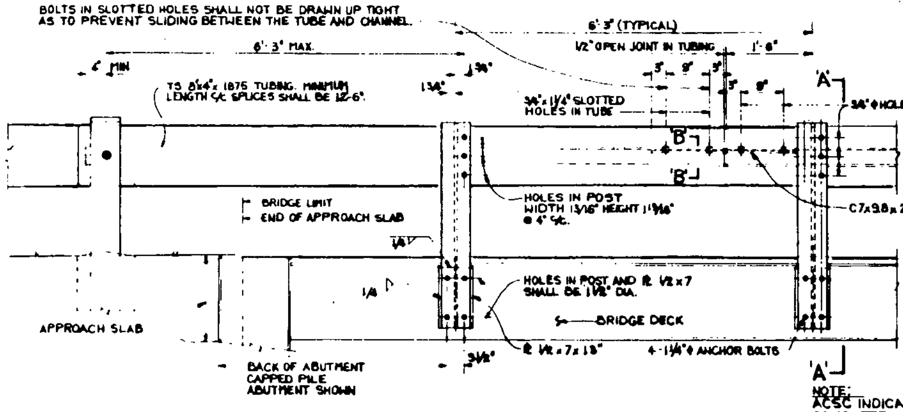
1. Components with asterisk can be found in the latest Guide to Standardized Highway Barrier Hardware, published by American Road and Transportation Builders Association, 525 School St.,SW, Wash., D.C. Length of G2 posts used in approach railing should be increased by 8 in. to accommodate additional depth of Thrie beam.
2. Thrie beam and W-beam material and hardware are specified in AASHTO M-180-78.
3. Unless otherwise noted bolts shall conform to requirements of ASTM A307 and nuts to requirements of ASTM A563, Grade A or better. Other bolts shall conform to the requirements of ASTM A325 and nuts to the requirements of ASTM A563, Grade C or better. All nuts and bolts shall be galvanized in accordance with ASTM A153.
4. Deck anchorage of the post assembly shall be provided by applying a 10-kip (45-kN) force to the post at 22 in. (550 mm) above the deck and designed according to the latest AASHTO bridge specification.
5. Steel shall conform to requirements of ASTM A-36 or equivalent and be galvanized according to ASTM A123.
6. BCT guardrail terminal details are specified in NCHRP Research Results Digest 102 or later revision.
7. Post elements shall conform to the requirements of ASTM A500 Grade B or ASTM A501 and be galvanized in accordance with the requirements of ASTM A123.

BARRIER SYSTEM Service Level 1 Bridge Rail/Transition
NCHRP REPORT 230 TESTS 12,S13,S14
TEST REF. HR22-4, 12 **DATE** 1981,1986
BARRIER DEVELOPMENT
FOR NCHRP
BY SwRI


PLAN
1/2"=1'-0" (1:24)
ELEVATION
WING WALL RAILING DETAILS
1/2"=1'-0" (1:24)
BARRIER RAIL
SHIM UNDER POSTS AS REQUIRED
END TEST SECTION HERE
APPROACH SLAB
SECTION A-A
1"=1'-0" (1:12)
OVERHANG
NOTE: USE 1'6" LAP ON LONGITUDINAL BARS.
ANCHOR BOLT SPACING
1"=1'-0" (1:12)
SECTION B-B
SECTION A-A
3"=1'-0" (1:4)
SECTION C-C
3"=1'-0" (1:4)
RAILING DETAILS
3"=1'-0" (1:4)
INSIDE SPLICE DETAIL
NOTES:
UNLESS OTHERWISE SPECIFIED ALL DRAFT TO BE 3°.
ALL UNMARKED RADII TO BE 1/8" R.
GENERAL NOTES
1. RAILING TO CONFORM TO VERTICAL AND HORIZONTAL ALIGNMENT.
2. JOINT TO BE PLACED 25'-0" CENTER TO CENTER, MAX.
3. SLIP JOINT TO BE PLACED IN PANELS TO MATCH EXPANSION JOINTS IN DECK. THE 3/8" FOR MOVEMENT WILL BE CHANGED TO MATCH ALLOWANCES FOR MOVEMENT IN THE DECK AND CURB.
4. DESIGN WEIGHT: 6 1/4 POUNDS PER FOOT.
BARRIER SYSTEM NV Safety Shape Bridge Rail
NCHRP REPORT 230 TESTS 10,S13,S15
TEST REF. 6 DATE 9/86
BARRIER DEVELOPMENT
FOR FHWA,NV
BY SwRI

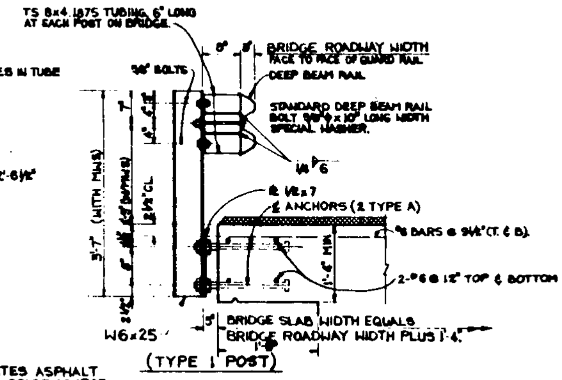


6 SPACES @ 8'-0" = 48'-0"
SPLICE @ EXP. JT.
NOT NECESSARY
ELEVATION
PLAN
3" = 1'-0" (1 = 4)
SECTION B-B
3" = 1'-0" (1 = 4)
DIMPLE "B"
DIMPLE "A"
TO FIT RAIL SECTION
MAJOR AXIS
BAR SECTION
EXPANSION BAR DETAILS
3" = 1'-0" (1 = 3)
MINOR AXIS
SEMI-ELLIPSE
RAIL SECTION
3" = 1'-0" (1 = 4)
POST @ 8'-0"
4-5/8" ANCHOR STUDS
BAR 'A' @ 6"
2-#5 BARS BOTTOM
#5 BARS @ 6"
OVERHANG
SECTION THRU PARAPET & RAIL
1" = 1'-0" (1 = 12)
TRAFFIC SIDE
SECTION B-B
1" = 1'-0" (1 = 12)
9/16" x 13/16" SLOTS
.766 DIA. (4) HOLES PUNCHED FOR RIVETS
FRONT ELEVATION
SIDE ELEVATION
RIVET DETAIL
1 1/2" = 1'-0" (1 = 8)
DETAILS OF POST
3" = 1'-0" (1 = 4)
PLAN
TOP NUTS & WASHERS-ALUMINUM FOR ALUMINUM RAIL-STAINLESS STEEL FOR GALVANIZED STEEL RAIL
TOP OF CONCRETE
TACK WELD
5/8"Φ STUDS
1/4" ANCHOR PL.
STAINLESS STEEL BOTTOM WASHERS
ANCHOR ASSEMBLY
1/2"-13 THREAD (2) HOLES FOR 1/2"-13x1" STAINLESS STEEL HEX HD. BOLT & 1 1/16 O.D., 17/32 I.D., 1/16" THICK WASHER-ALUMINUM 6061-T6
SHIM DETAILS
3" = 1'-0" (1 = 4)
FRONT PLATE
REAR PLATE
NOTE: SHIMS MAY BE CUT ALONG PERMITTED CUT LINES OR SLOTTED TO EDGE OF PLATE TO FACILITATE PLACEMENT.
.766 DIA. (4) HOLES PUNCHED FOR RIVETS
FRONT ELEVATION
NOTE: BASE CAN BE SUPPLIED AS ONE EXTRUSION OR TWO EXTRUSIONS WELDED TOGETHER AS SHOWN.
PERMITTED WELD
SIDE ELEVATION
POST BASE DETAILS
3" = 1'-0" (1 = 4)
CLAMP BAR DETAIL
(2 REQUIRED PER POST)
NO SCALE
CLAMP & RAIL ASSEMBLY
3/4Φ HOLES
ANCHOR PLATE
EXTENDS INTO SLAB
BAR 'A'
BAR 'B'
BARRIER SYSTEM NC Parapet/ Rail B.R.
NCHRP REPORT 230 TESTS 10,S13
TEST REF. 6 DATE 9/86
BARRIER DEVELOPMENT
FOR FHWA/NC
BY SwRI

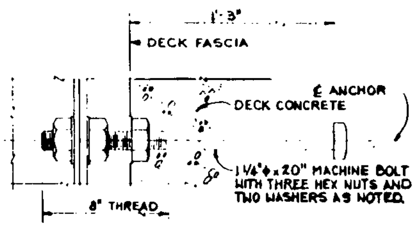


RAILING ELEVATION
(TYPE 1 POSTS SHOWN)
1"=1'-0" (1=12)

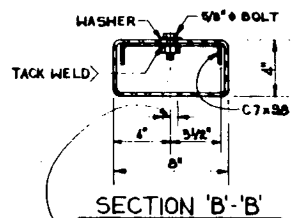
NOTE:
ACSC INDICATES ASPHALT CONCRETE SURFACE COURSE
MWS INDICATES MONOLITHIC WEARING SURFACE.



SECTION 'A'-'A'
(TYPE 1 POST)
1"=1'-0" (1=12)

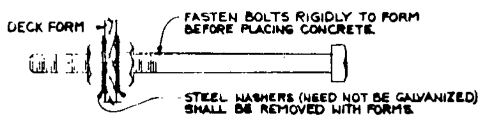


TYPE A ANCHOR DETAIL
NO SCALE



SECTION 'B'-'B'
NO SCALE

1"ϕ DRAIN HOLE (ONLY IN TUBE AT LOWEST POINT WHEN SAG VERTICAL CURVES ARE ENCOUNTERED). LOCATION TO BE SHOWN ON PROJECT PLANS.



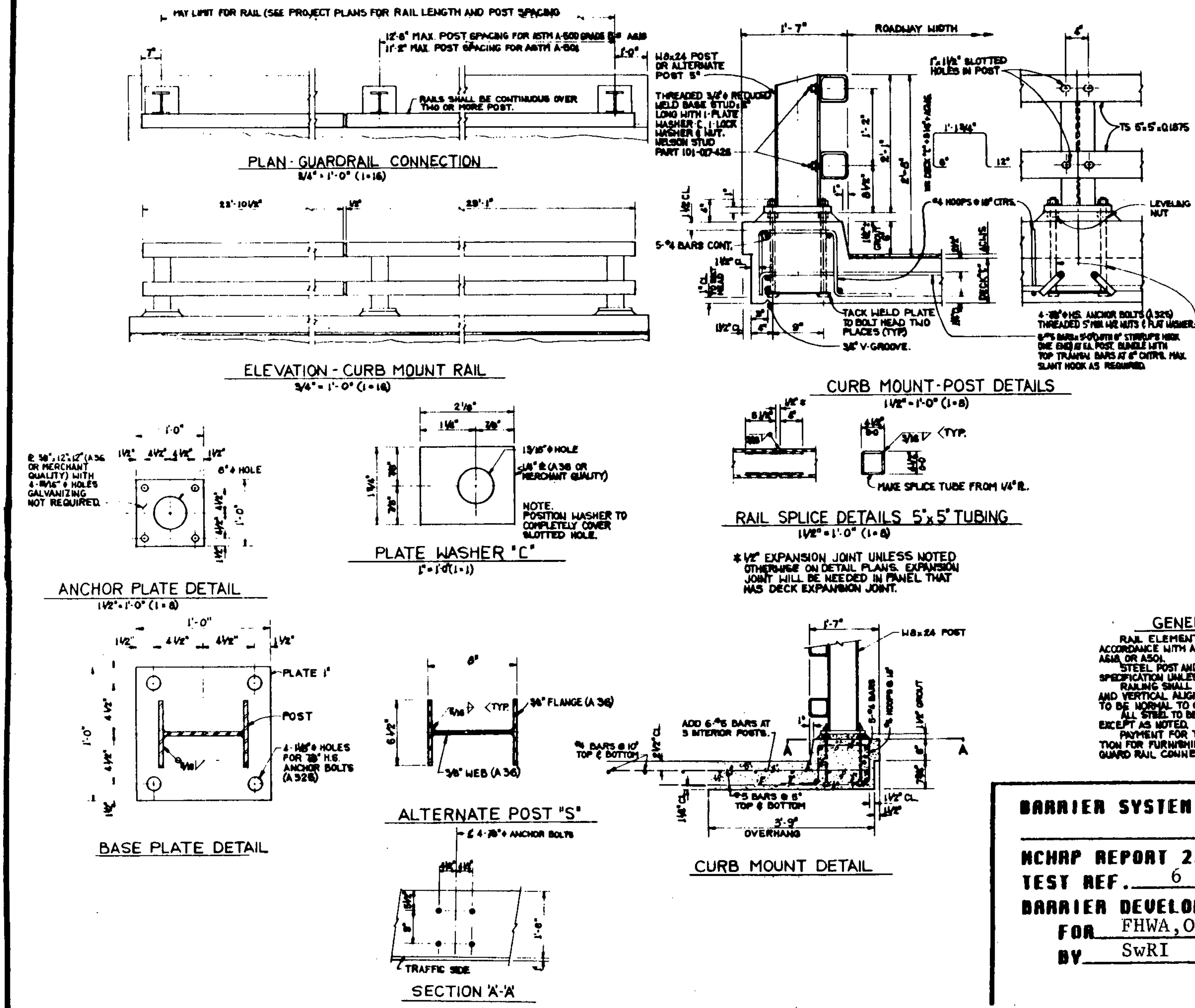
TYPE A ANCHORS SUPPORTED BY FORMS
NO SCALE

MATERIAL: ALL ANCHOR BOLTS, NUTS AND STUDS SHALL CONFORM THE PHYSICAL PROPERTIES OF ASTM A325 EXCEPT THAT THE MINIMUM ELONGATION SHALL BE 10%. THE CHEMICAL PROPERTIES ARE WAIVED.

GALVANIZING: ALL GUARD RAIL POSTS, TUBES, HARDWARE AND ACCESSORIES SHALL BE GALVANIZED IN ACCORDANCE WITH ASTM A123 OR ASTM A153, EXCEPT AS OTHERWISE NOTED.

BARRIER SYSTEM OH Bridge Rail

NCHRP REPORT 230 TESTS 10,S13
TEST REF. 6 **DATE** 9/86
BARRIER DEVELOPMENT
FOR FHWA,OH
BY SwRI



GENERAL NOTES

RAIL ELEMENTS SHALL BE STRUCTURAL TUBING IN ACCORDANCE WITH ASTM SPECIFICATION A500 GRADE B, A618, OR A501.
STEEL POST AND PLATES SHALL CONFORM TO ASTM SPECIFICATION UNLESS OTHERWISE NOTED.
RAILING SHALL BE FABRICATED TO THE HORIZONTAL AND VERTICAL ALIGNMENT OF THE STRUCTURE. POST TO BE NORMAL TO GRADE.
ALL STEEL TO BE HOT-DIP GALVANIZED AFTER FABRICATION, EXCEPT AS NOTED.
PAYMENT FOR THE RAILING SHALL INCLUDE COMPENSATION FOR FURNISHING AND INSTALLING THE NECESSARY GUARD RAIL CONNECTION PLATES.

BARRIER SYSTEM OR Bridge Rail

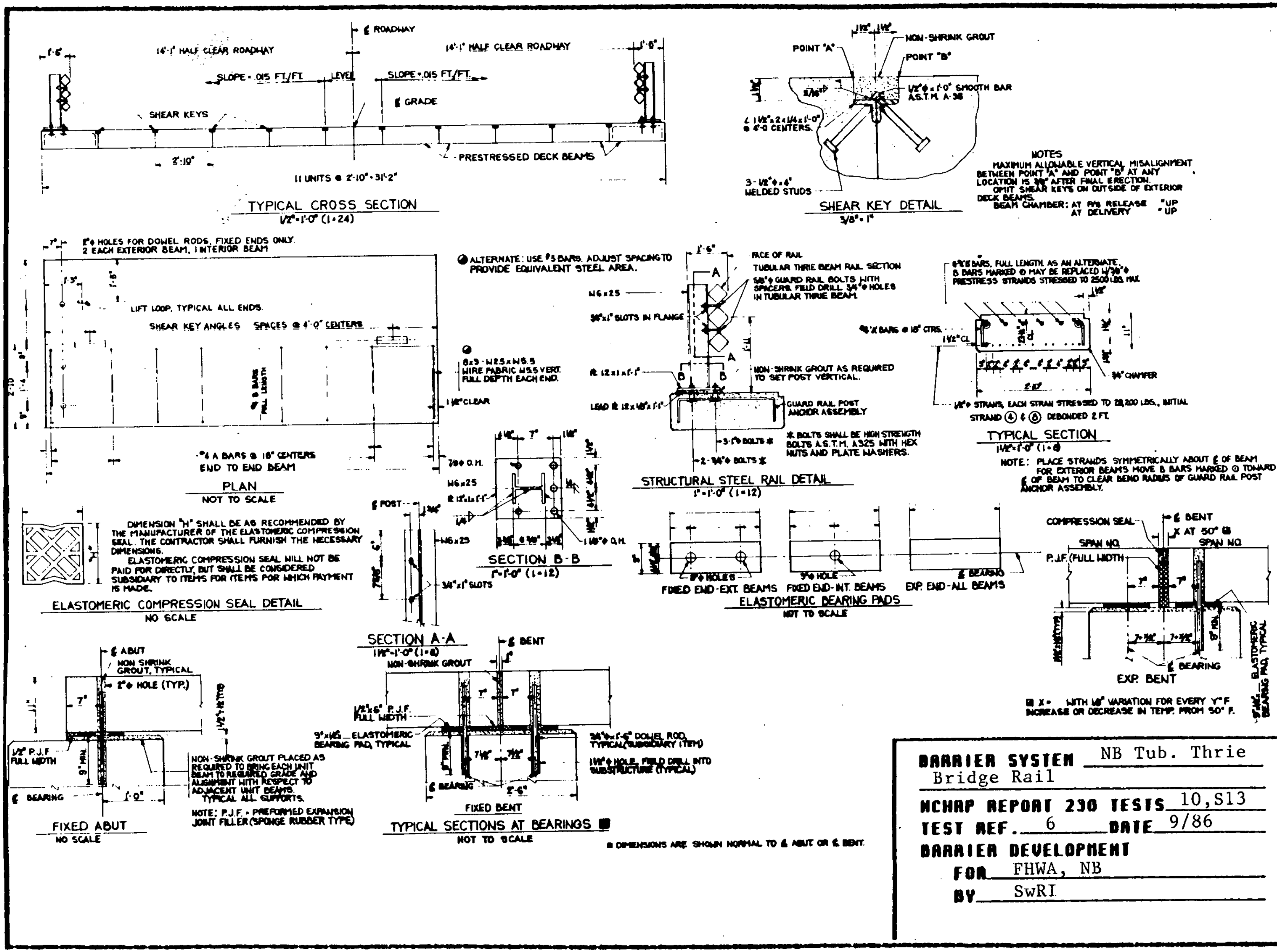
NCHRP REPORT 230 TESTS 10, S13

TEST REF. 6 **DATE** 9/86

BARRIER DEVELOPMENT

FOR FHWA, OR

BY SwRI



BARRIER SYSTEM NB Tub. Thrie Bridge Rail

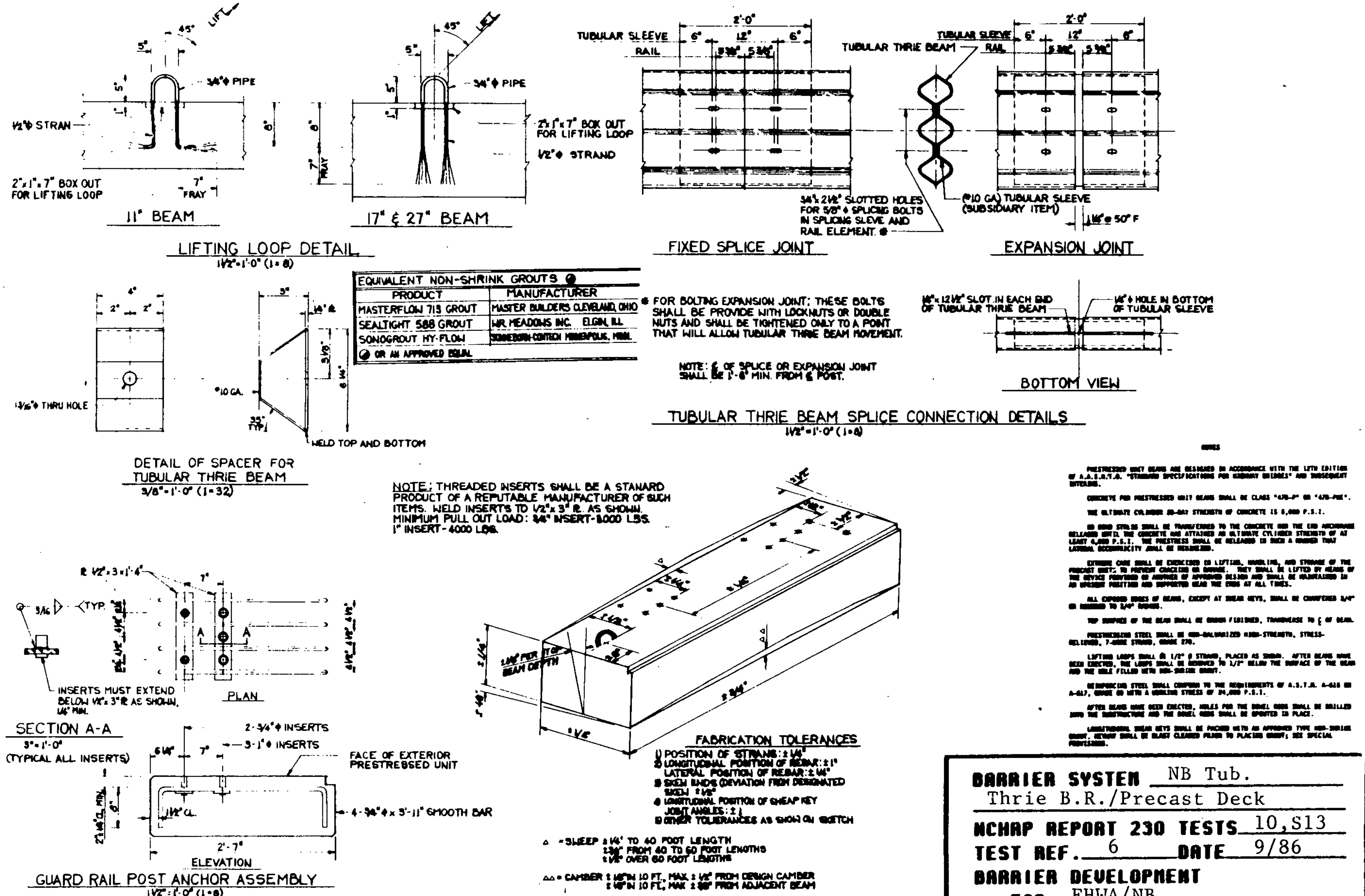
NCHRP REPORT 230 TESTS 10,S13

TEST REF. 6 **DATE** 9/86

BARRIER DEVELOPMENT

FOR FHWA, NB

BY SwRI



EQUIVALENT NON-SHRINK GROUTS ⊘	
PRODUCT	MANUFACTURER
MASTERFLOW 713 GROUT	MASTER BUILDERS CLEVELAND, OHIO
SEALTIGHT 588 GROUT	W.R. MEADOWS INC. ELGIN, ILL.
SONOGROUT HY-FLOW	SONNEBORN-CONTECH MINNEAPOLIS, MINN.
⊘ OR AN APPROVED EQUAL	

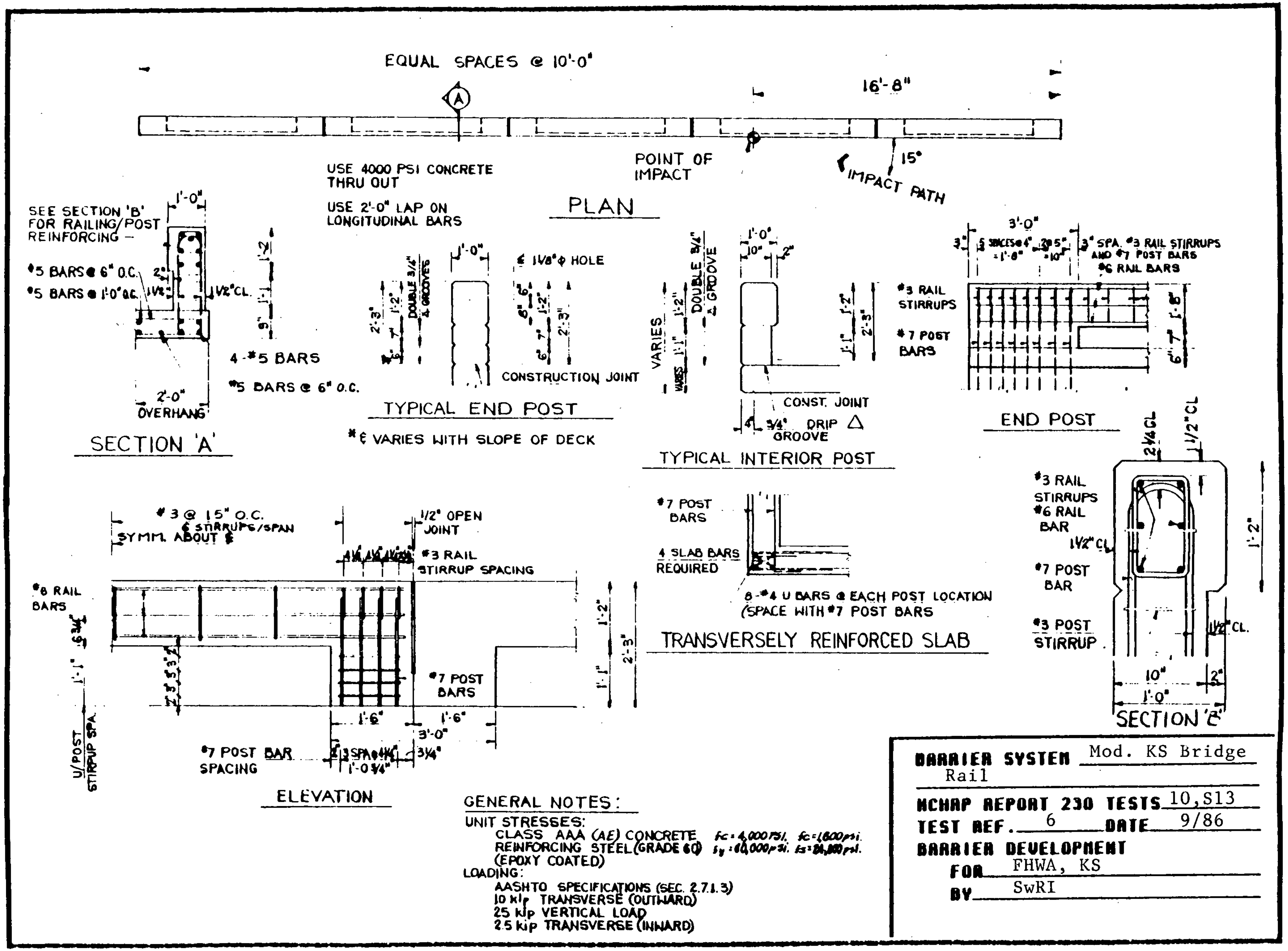
BARRIER SYSTEM NB Tub. Thrie B.R./Precast Deck

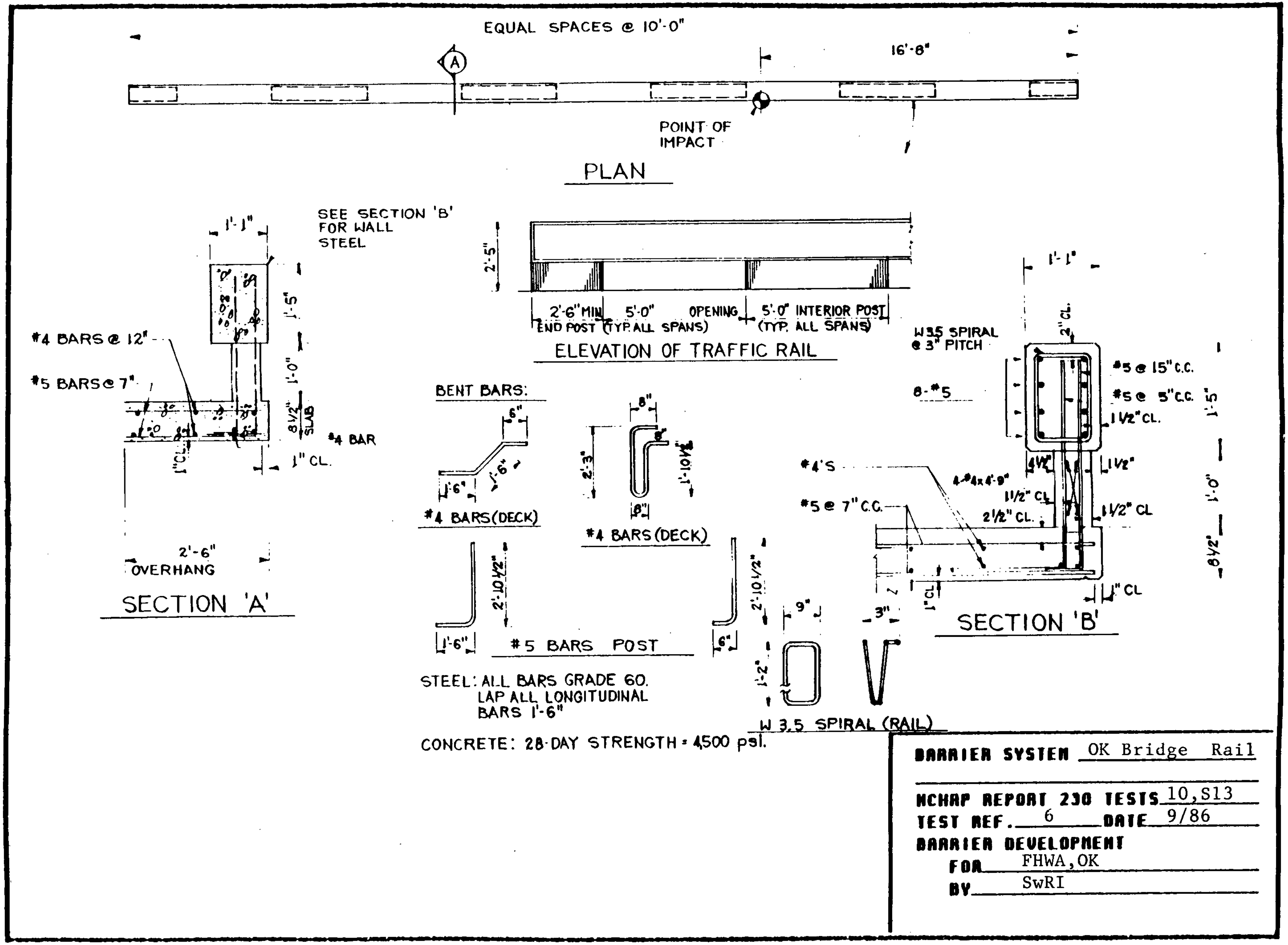
NCHRP REPORT 230 TESTS 10,S13

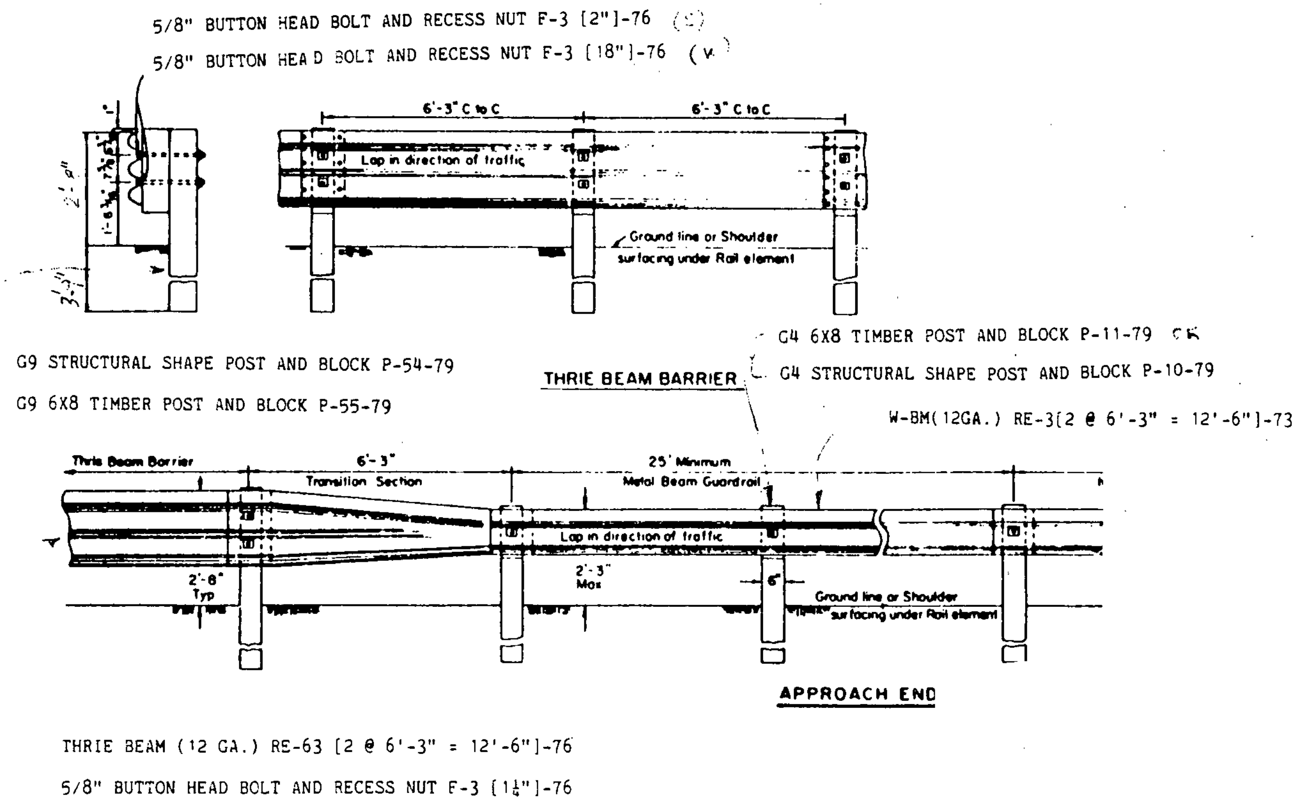
TEST REF. 6 **DATE** 9/86

BARRIER DEVELOPMENT FOR FHWA/NB

BY SwRI


EQUAL SPACES @ 10'-0"
16'-8"
PLAN
USE 4000 PSI CONCRETE THRU OUT
USE 2'-0" LAP ON LONGITUDINAL BARS
POINT OF IMPACT
15°
IMPACT PATH
SEE SECTION 'B' FOR RAILING/POST REINFORCING
#5 BARS @ 6" O.C.
#5 BARS @ 1'-0" O.C.
4-#5 BARS
#5 BARS @ 6" O.C.
2'-0" OVERHANG
SECTION 'A'
TYPICAL END POST
℄ 1 1/8" ⌀ HOLE
CONSTRUCTION JOINT
*℄ VARIES WITH SLOPE OF DECK
DOUBLE 3/4" ∆ GROOVE
VARIES
TYPICAL INTERIOR POST
CONST. JOINT
3/4" DRIP GROOVE
#3 RAIL STIRRUPS
#7 POST BARS
3" SPA. #3 RAIL STIRRUPS AND #7 POST BARS
#6 RAIL BARS
END POST
#3 @ 15" O.C. ℄ STIRRUPS/SPAN
SYMM. ABOUT ℄
1/2" OPEN JOINT
#3 RAIL STIRRUP SPACING
#6 RAIL BARS
#7 POST BARS
#7 POST BAR SPACING
U/POST STIRRUP SPA.
ELEVATION
#7 POST BARS
4 SLAB BARS REQUIRED
8-#4 U BARS @ EACH POST LOCATION (SPACE WITH #7 POST BARS
TRANSVERSELY REINFORCED SLAB
#3 RAIL STIRRUPS
#6 RAIL BAR
#7 POST BAR
#3 POST STIRRUP
SECTION 'C'
GENERAL NOTES:
UNIT STRESSES:
CLASS AAA (AE) CONCRETE f'c = 4,000 psi. fc = 1,600 psi.
REINFORCING STEEL (GRADE 60) fy = 60,000 psi. fs = 24,000 psi.
(EPOXY COATED)
LOADING:
AASHTO SPECIFICATIONS (SEC. 2.7.1.3)
10 kip TRANSVERSE (OUTWARD)
25 kip VERTICAL LOAD
2.5 kip TRANSVERSE (INWARD)
BARRIER SYSTEM Mod. KS Bridge Rail
NCHRP REPORT 230 TESTS 10, S13
TEST REF. 6 DATE 9/86
BARRIER DEVELOPMENT
FOR FHWA, KS
BY SwRI


EQUAL SPACES @ 10'-0"
16'-8"
POINT OF IMPACT
PLAN
SEE SECTION 'B' FOR WALL STEEL
1'-1"
1'-5"
1'-0"
8 1/2" SLAB
#4 BARS @ 12"
#5 BARS @ 7"
#4 BAR
1" CL.
2'-6" OVERHANG
SECTION 'A'
2'-5"
2'-6" MIN END POST
5'-0" (TYP. ALL SPANS)
OPENING
5'-0" INTERIOR POST (TYP. ALL SPANS)
ELEVATION OF TRAFFIC RAIL
BENT BARS:
#4 BARS (DECK)
#4 BARS (DECK)
#5 BARS POST
STEEL: ALL BARS GRADE 60. LAP ALL LONGITUDINAL BARS 1'-6"
CONCRETE: 28-DAY STRENGTH = 4500 psi.
W 3.5 SPIRAL @ 3" PITCH
8-#5
#5 @ 15" C.C.
#5 @ 5" C.C.
1 1/2" CL.
#4'S
#5 @ 7" C.C.
1 1/2" CL
2 1/2" CL.
W 3.5 SPIRAL (RAIL)
SECTION 'B'
BARRIER SYSTEM OK Bridge Rail
NCHRP REPORT 230 TESTS 10, S13
TEST REF. 6 DATE 9/86
BARRIER DEVELOPMENT
FOR FHWA, OK
BY SwRI



BARRIER SYSTEM G4/G9
Guardrail Transition

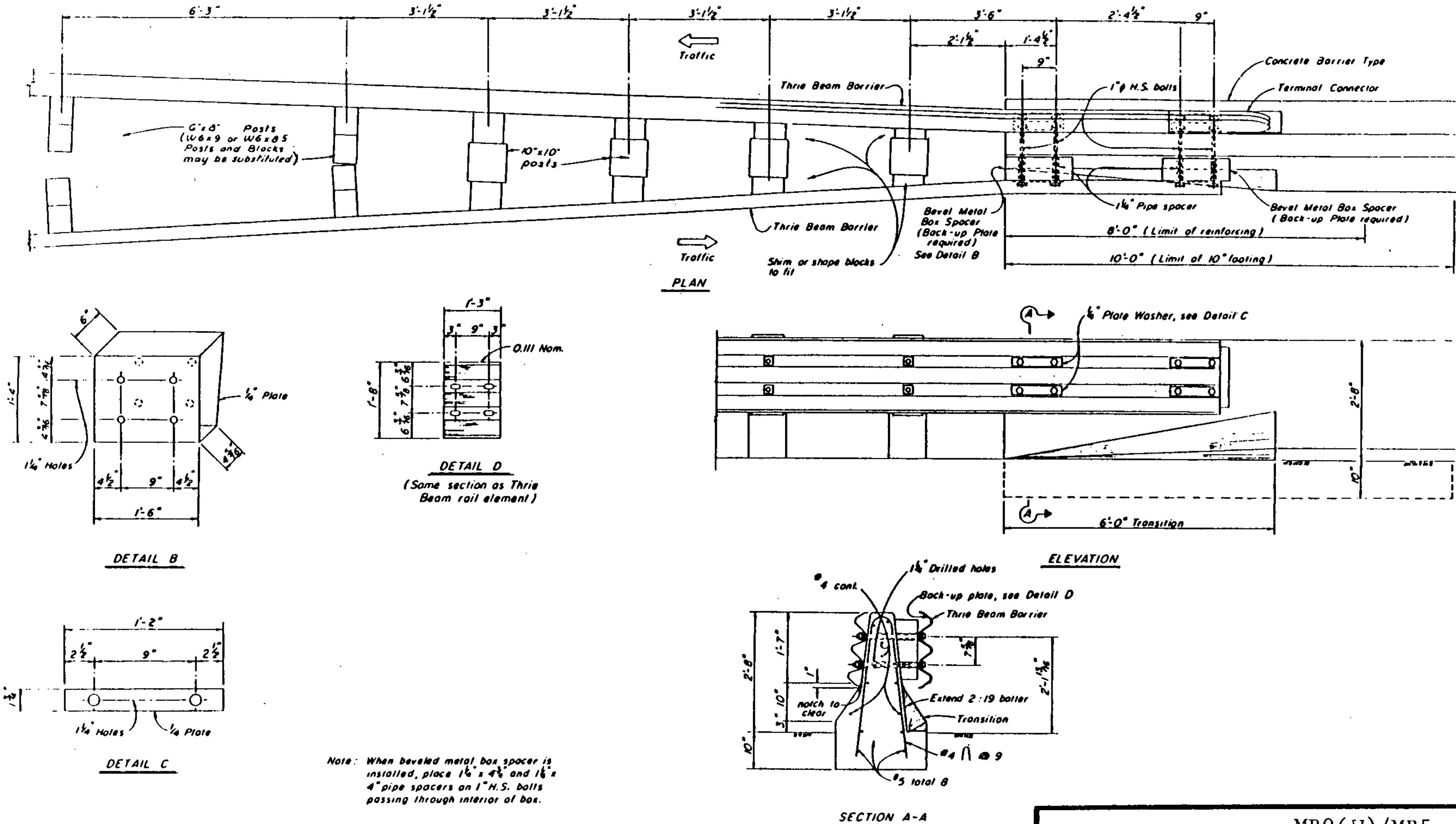
NCHRP REPORT 230 TESTS 12,30

TEST REF. HR22-4 **DATE** July 86

BARRIER DEVELOPMENT

FOR NCHRP

BY SwRI



BARRIER SYSTEM MB9(W)/MB5 Transition

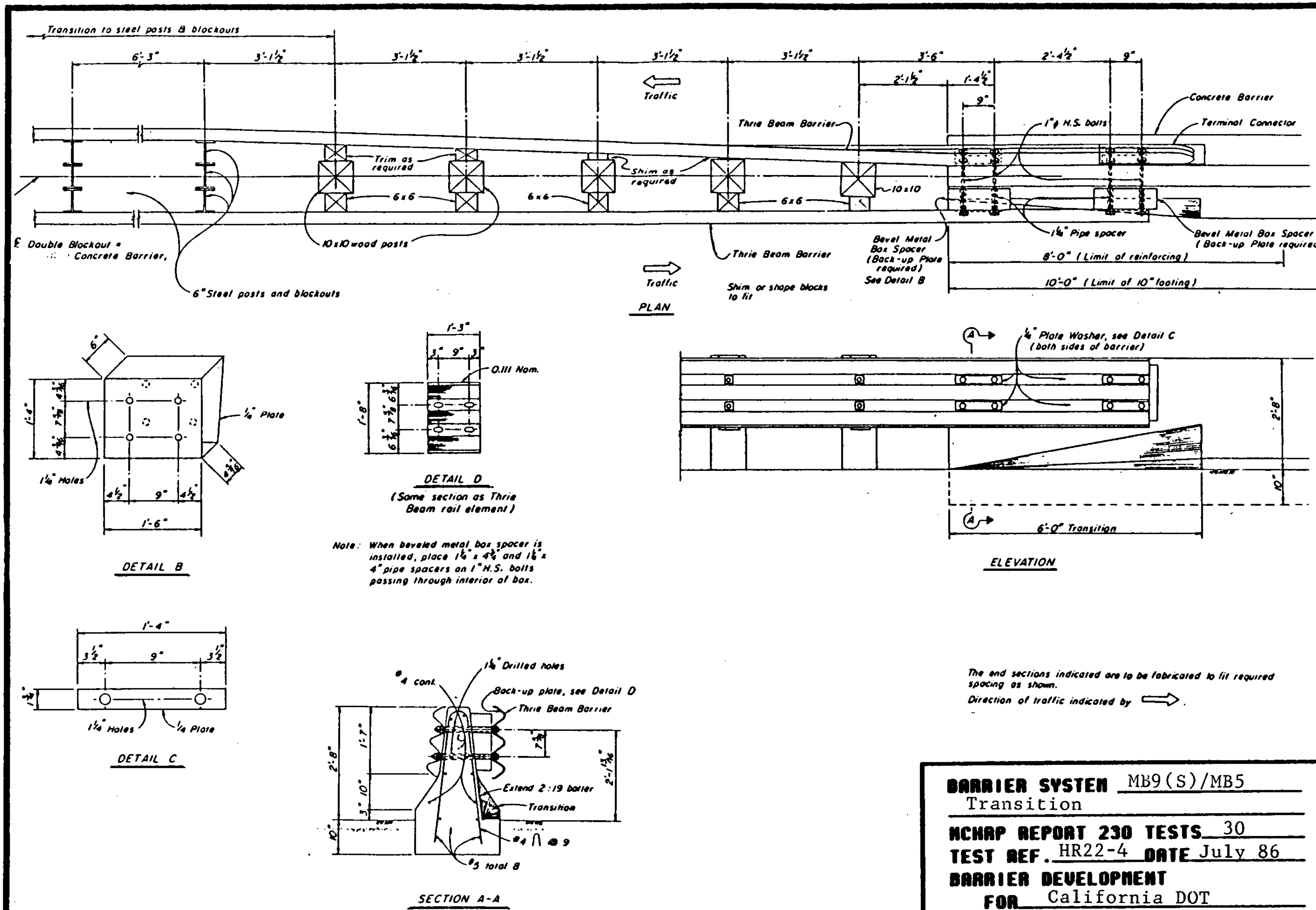
NCHRP REPORT 230 TESTS 30

TEST REF. HR22-4 **DATE** July 86

BARRIER DEVELOPMENT

FOR California DOT

BY California DOT



BARRIER SYSTEM MB9(S)/MB5
Transition

NCHRP REPORT 230 TESTS 30

TEST REF. HR22-4 **DATE** July 86

BARRIER DEVELOPMENT

FOR California DOT

BY California DOT

Barrier components with F, P, and RE prefixes are found in latest edition of "A Guide to Standardized Highway Barrier Rail Hardware," a report prepared and approved by the AASHTO-AGC-ARTBA Joint Cooperative Committee.

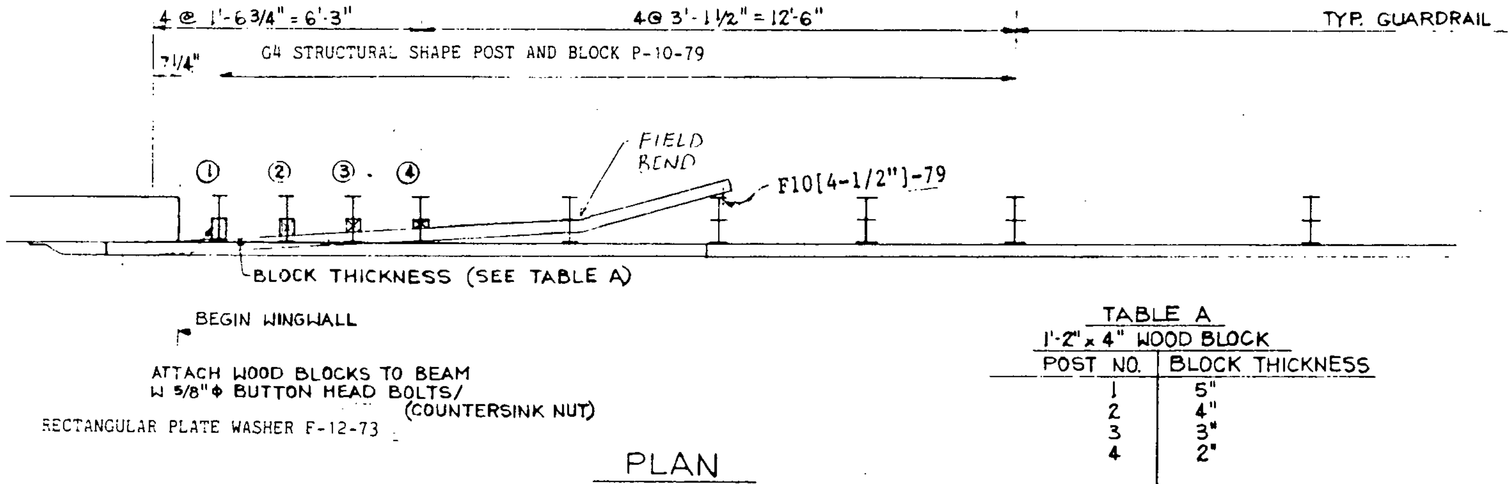
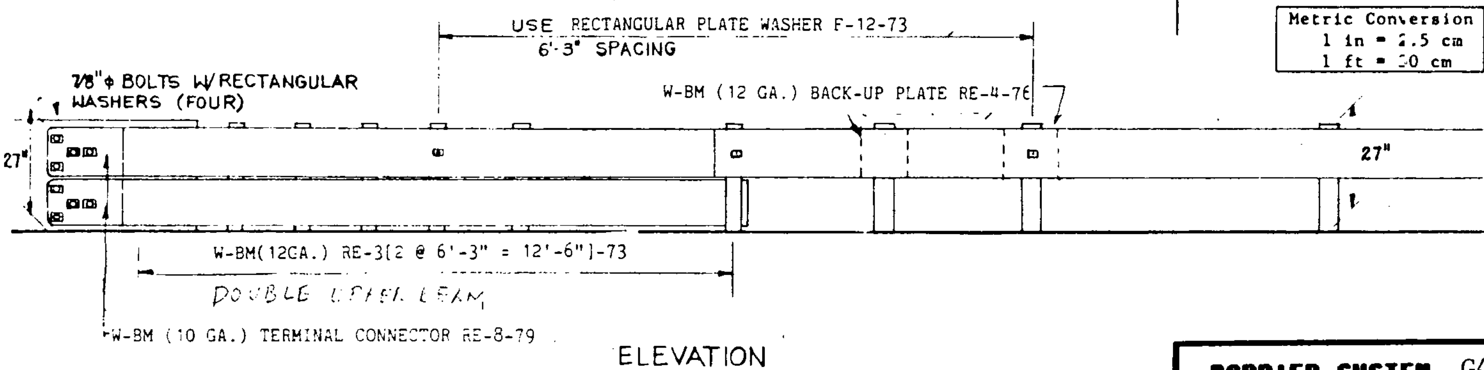


TABLE A
1'-2" x 4" WOOD BLOCK

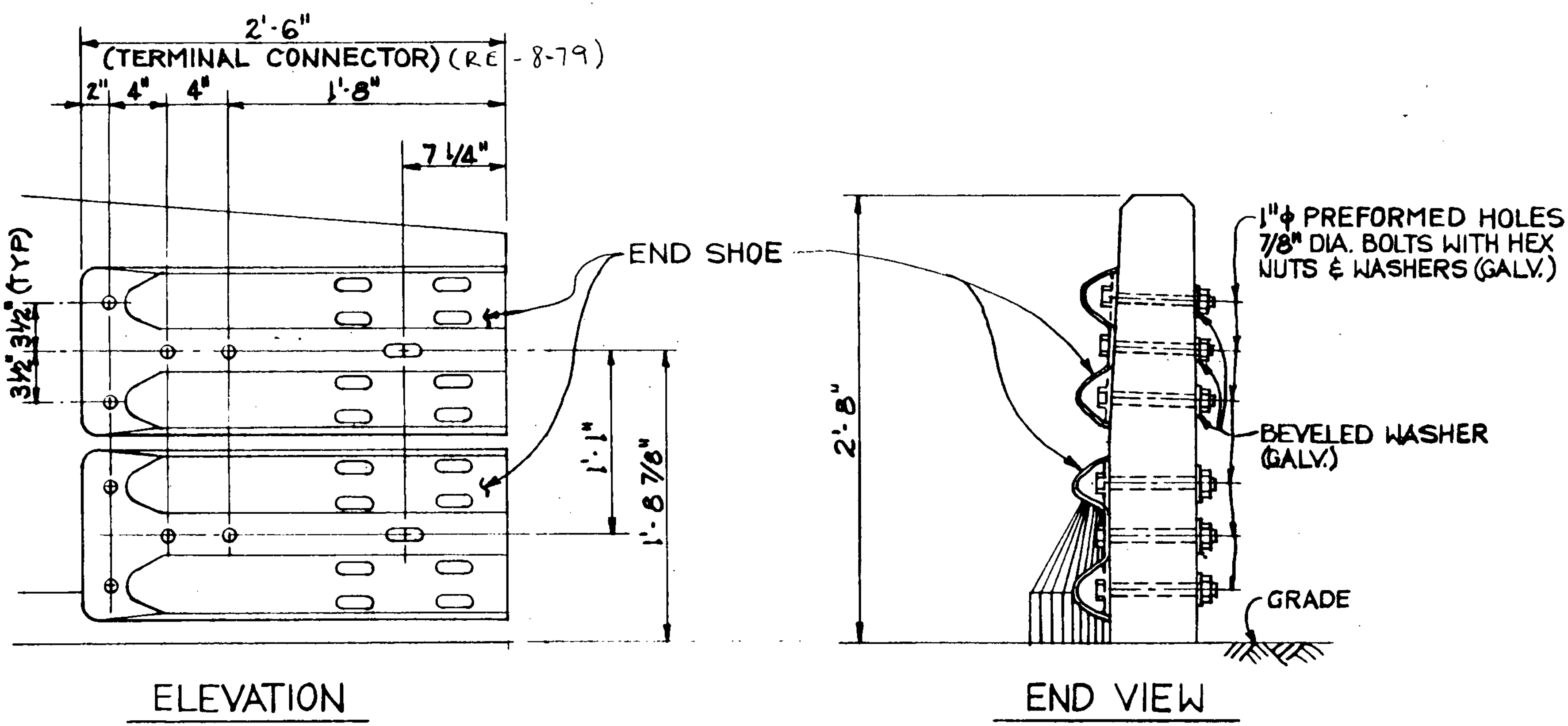
POST NO.	BLOCK THICKNESS
1	5"
2	4"
3	3"
4	2"

Metric Conversion
1 in = 2.5 cm
1 ft = 30 cm



BARRIER SYSTEM G4(1S) Transition - Straight Wingwall
NCHRP REPORT 230 TESTS 30
TEST REF. 7 **DATE** 6/86
BARRIER DEVELOPMENT
FOR FHWA
BY SwRI

Barrier components with F, P, and RE prefixes are found in latest edition of "A Guide to Standardized Highway Barrier Rail Hardware," a report prepared and approved by the AASHTO-AGC-ARTBA Joint Cooperative Committee.



GUARDRAIL CONNECTION

Barrier components with F, P, and RE prefixes are found in latest edition of "A Guide to Standardized Highway Barrier Rail Hardware," a report prepared and approved by the AASHTO-AGC-ARTBA Joint Cooperative Committee.

BARRIER SYSTEM Connection Dtls.- G4/Straight Wingwall
NCHRP REPORT 230 TESTS 30
TEST REF. 7 **DATE** 6/86
BARRIER DEVELOPMENT
FOR FHWA
BY SwRI

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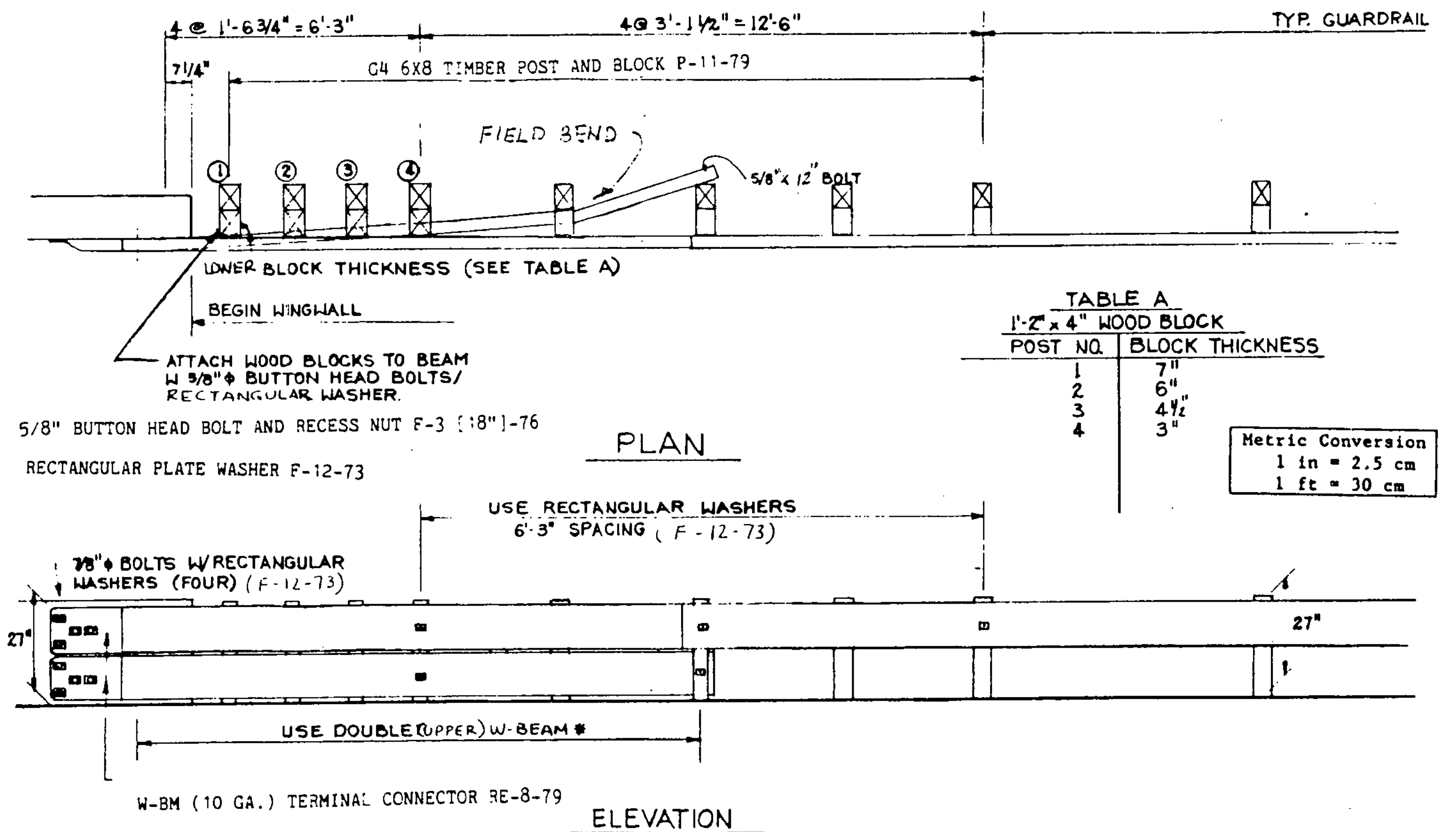


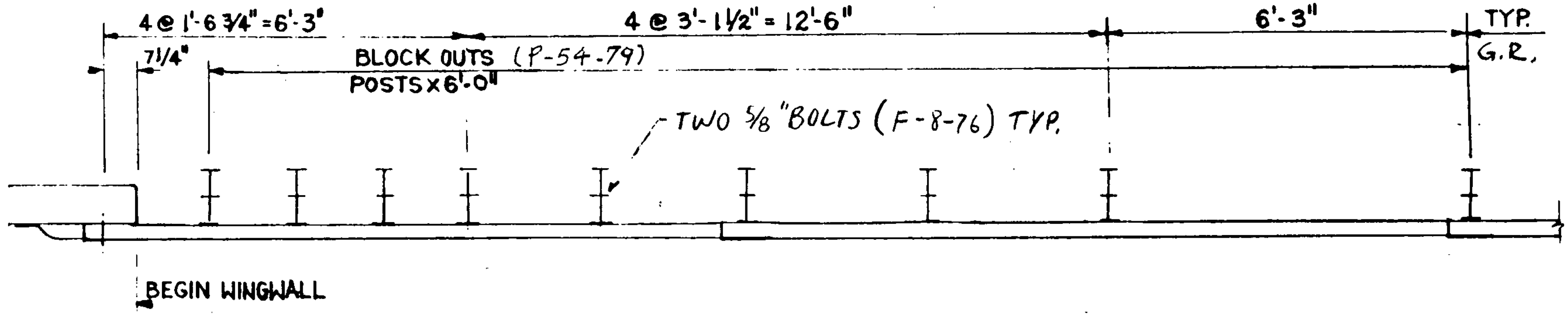
TABLE A
1'-2" x 4" WOOD BLOCK

POST NO.	BLOCK THICKNESS
1	7"
2	6"
3	4 1/2"
4	3"

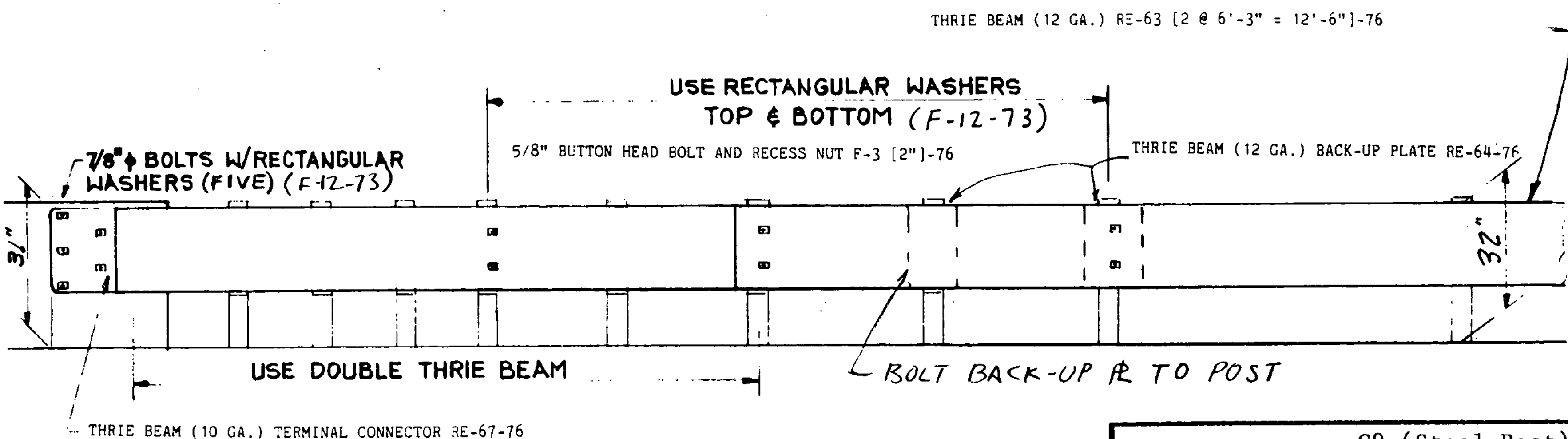
Metric Conversion
1 in = 2.5 cm
1 ft = 30 cm

* TESTED WITH SINGLE UPPER BEAM.

BARRIER SYSTEM G4(2W) Transition - Straight Wingwall
NCHRP REPORT 230 TESTS 30
TEST REF. 7 **DATE** 6/86
BARRIER DEVELOPMENT
FOR FHWA
BY SwRI



PLAN



ELEVATION

Barrier components with F, P, and RE prefixes are found in the latest edition of "A Guide to Standardized Highway Rail Hardware," a report prepared and approved by the AASHTO-AGC-ARTBA Joint Cooperative Committee.

BARRIER SYSTEM G9 (Steel Post)
Transition - Straight Wingwall

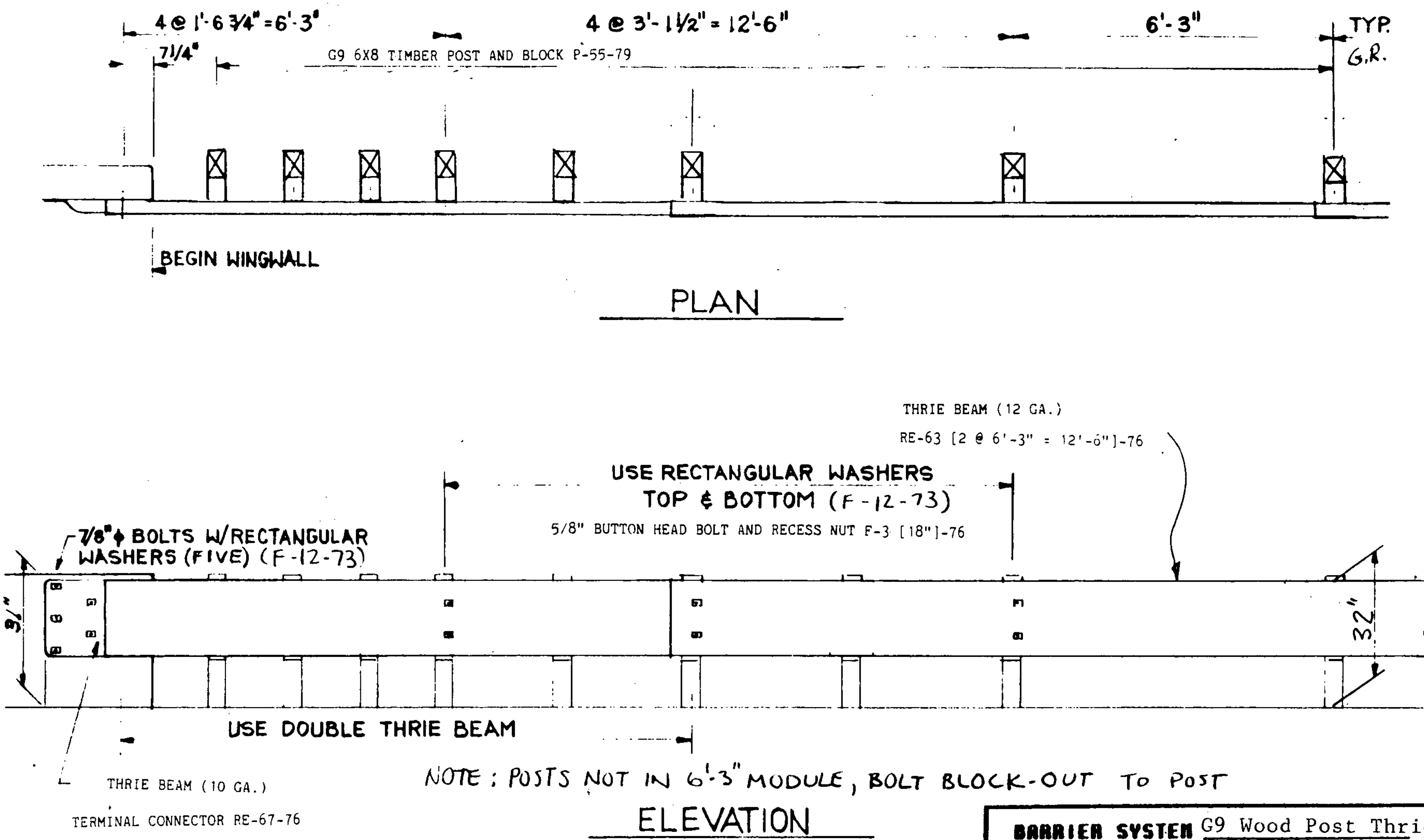
NCHRP REPORT 230 TESTS 30

TEST REF. 7 **DATE** 6/86

BARRIER DEVELOPMENT

FOR FHWA

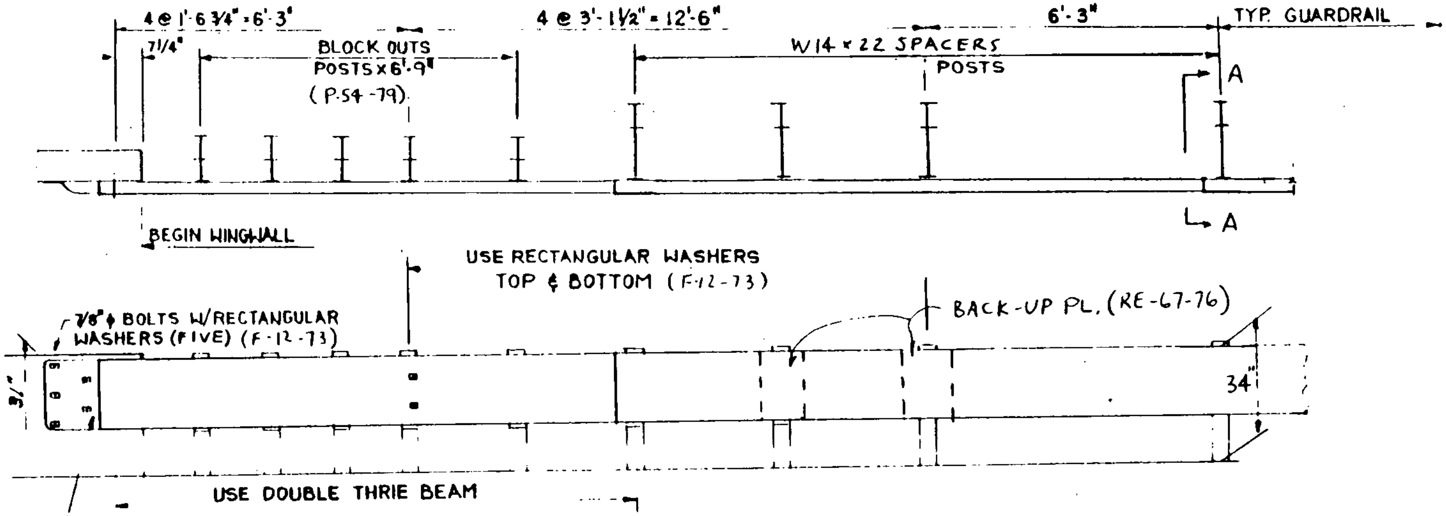
BY SwRI



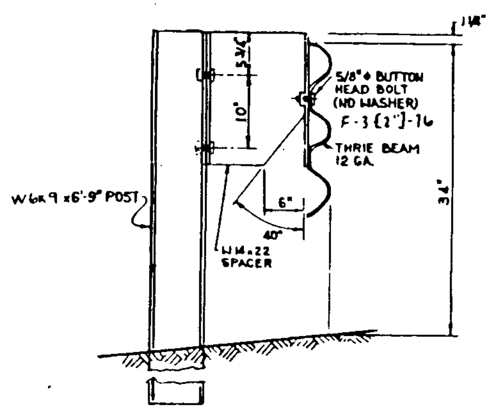
Barrier components with F, P, and RE prefixes are found in the latest edition of "A Guide to Standardized Highway Rail Hardware," a report prepared and approved by the AASHTO-AGC-ARTBA Joint Cooperative Committee.

BARRIER SYSTEM G9 Wood Post Thrie Bm Transition-Straight Wingwall
NCHRP REPORT 230 TESTS 30
TEST REF. 7 **DATE** 6/86
BARRIER DEVELOPMENT
FOR FHWA
BY SwRI

Barrier components with F, P, and RE prefixes are found in latest edition of "A Guide to Standardized Highway Barrier Rail Hardware," a report prepared and approved by the AASHTO-AGC-ARTBA Joint Cooperative Committee.



ELEVATION



SEC A - A

BARRIER SYSTEM Modified Thrie Transition - Straight Wingwall

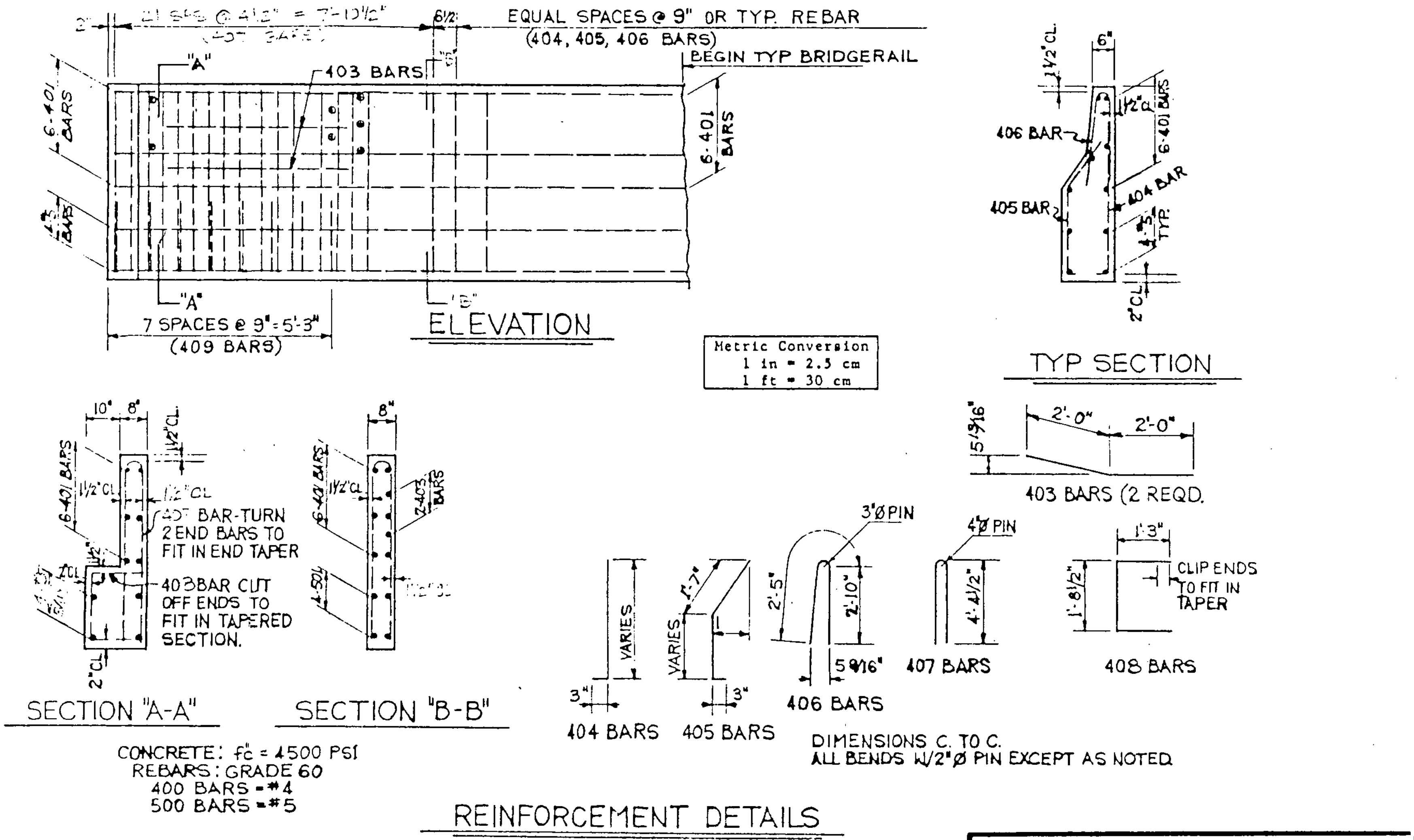
NCHRP REPORT 230 TESTS 30

TEST REF. 7 **DATE** 6/86

BARRIER DEVELOPMENT

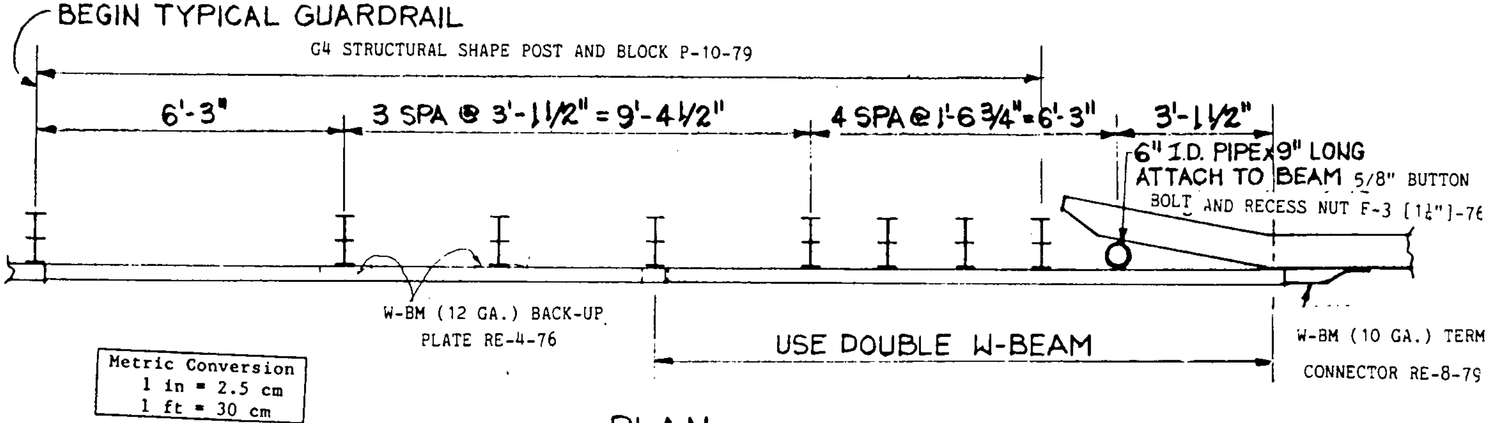
FOR FHWA

BY SwRI

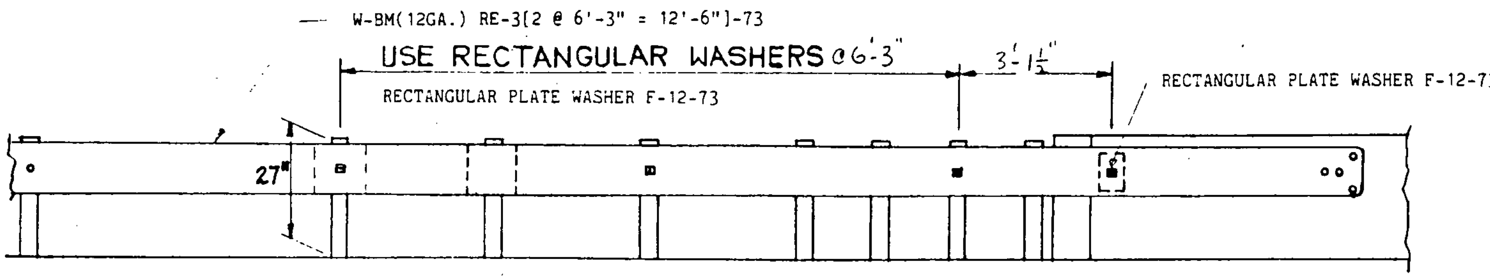


BARRIER SYSTEM Wingwall Reinforcement Details - Transitions
NCHRP REPORT 230 TESTS 30
TEST REF. 7 **DATE** 6/86
BARRIER DEVELOPMENT
FOR FHWA
BY SwRI

Barrier components with F, P, and RE prefixes are found in latest edition of "A Guide to Standardized Highway Barrier Rail Hardware," a report prepared and approved by the AASHTO-AGC-ARTBA Joint Cooperative Committee.



PLAN



ELEVATION

BARRIER SYSTEM G4(1S) Transition - Tapered Wingwall

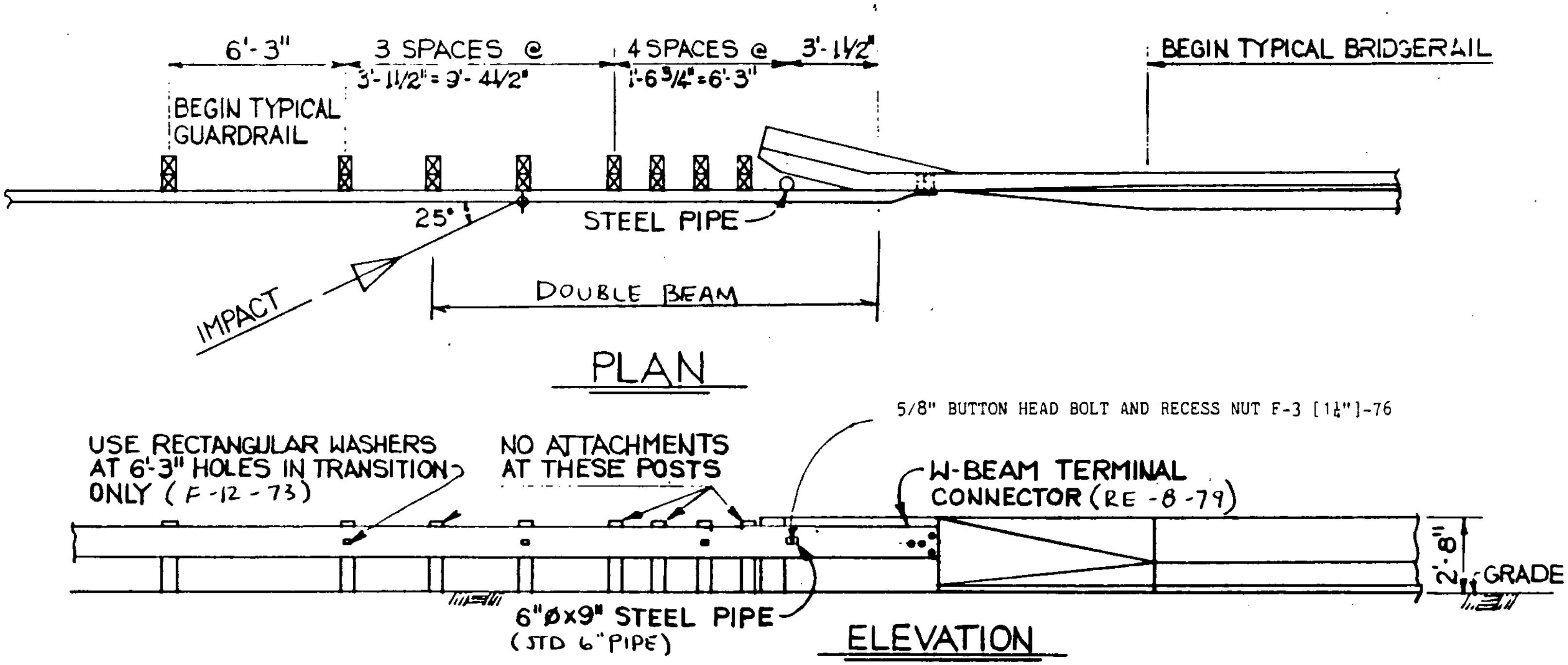
NCHRP REPORT 230 TESTS 30

TEST REF. 7 **DATE** 6/86

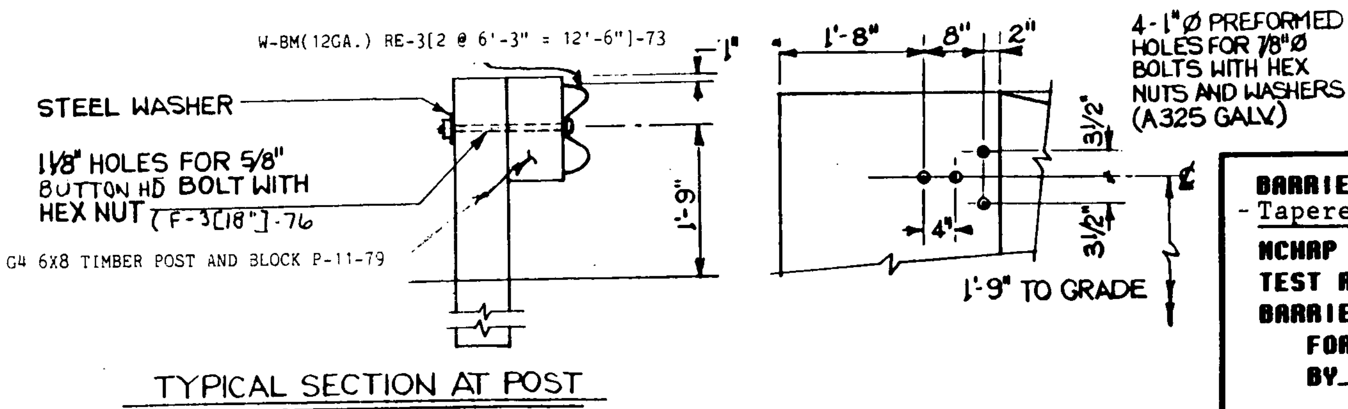
BARRIER DEVELOPMENT

FOR FHWA

BY SwRI



Barrier components with F, P, and RE prefixes are found in latest edition of "A Guide to Standardized Highway Barrier Rail Hardware," a report prepared and approved by the AASHTO-AGC-ARTBA Joint Cooperative Committee.



BARRIER SYSTEM G4(2W) Transition - Tapered Wingwall

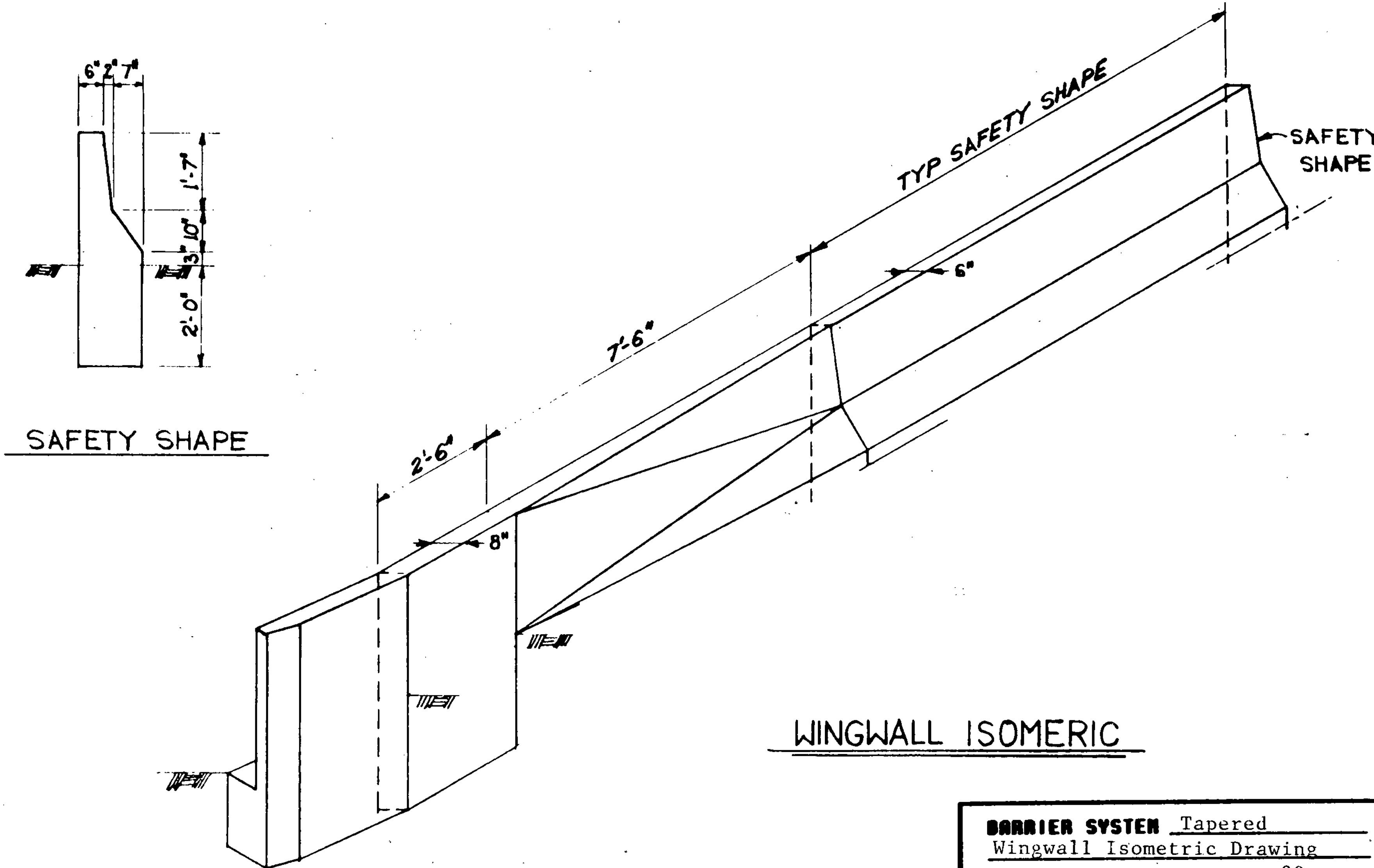
NCHRP REPORT 230 TESTS 30

TEST REF. 7 **DATE** 6/86

BARRIER DEVELOPMENT

FOR FHWA

BY SwRI



BARRIER SYSTEM Tapered Wingwall Isometric Drawing

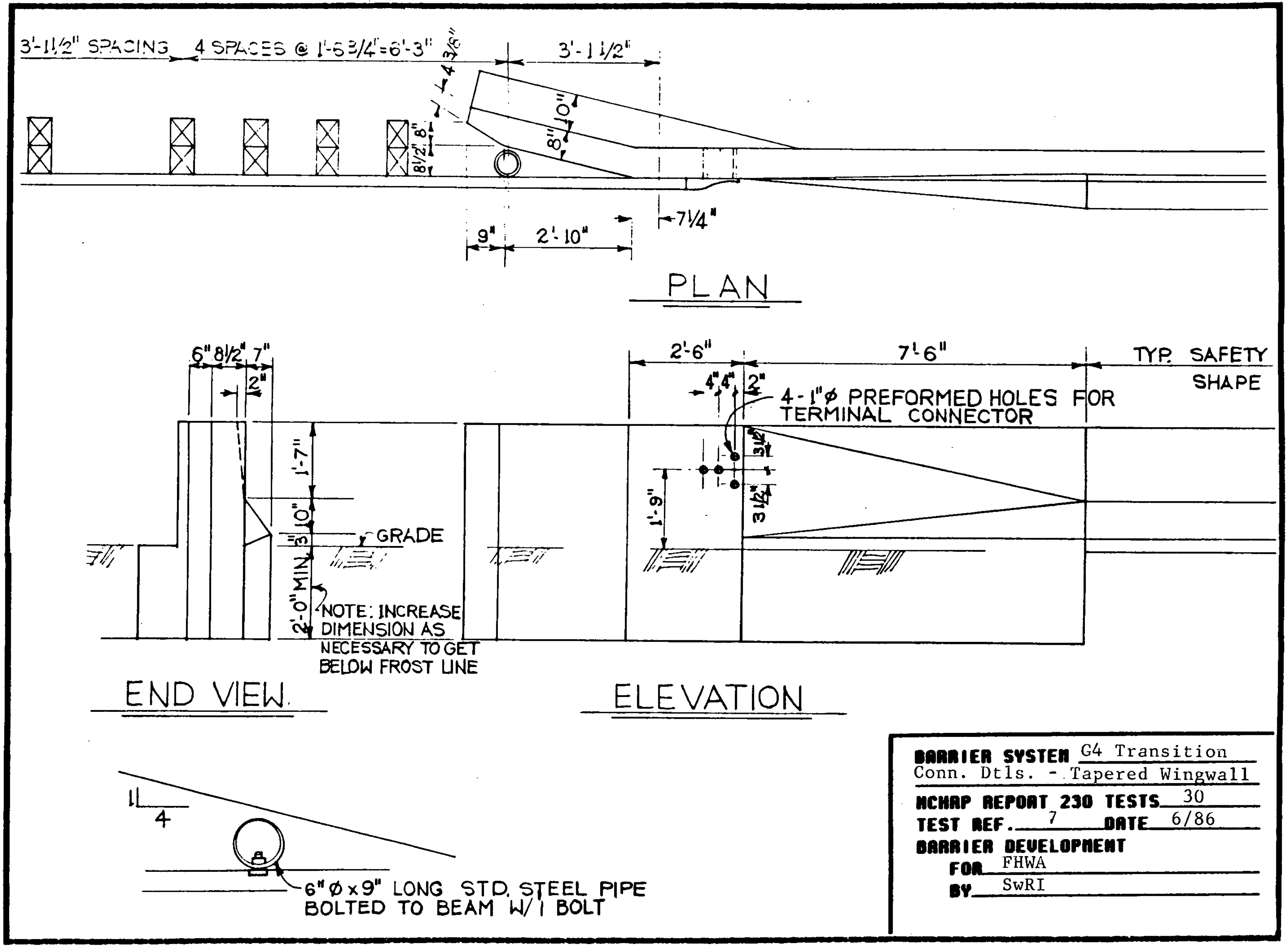
NCHRP REPORT 230 TESTS 30

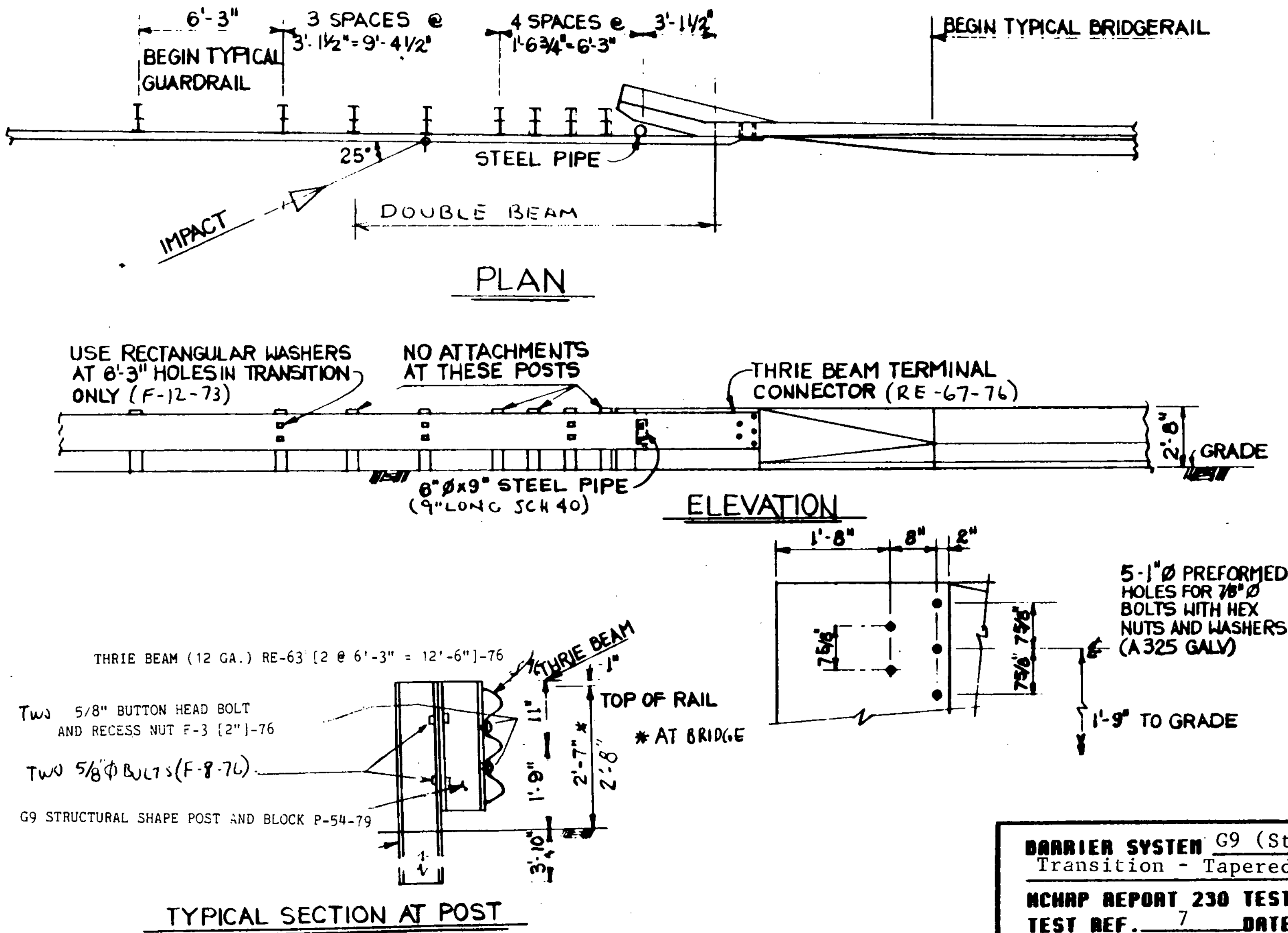
TEST REF. 7 **DATE** 6/86

BARRIER DEVELOPMENT

FOR FHWA

BY SwRI


3'-1½" SPACING
4 SPACES @ 1'-6¾"=6'-3"
3'-1½"
4⅜"
10"
8"
8½" 8"
9"
2'-10"
7¼"
PLAN
6" 8½" 7"
2"
1'-7"
10"
3"
GRADE
2'-0" MIN.
NOTE: INCREASE DIMENSION AS NECESSARY TO GET BELOW FROST LINE
END VIEW
2'-6"
7'-6"
TYP. SAFETY SHAPE
4" 4" 2"
4 - 1"ϕ PREFORMED HOLES FOR TERMINAL CONNECTOR
3½"
3½"
1'-9"
ELEVATION
1
4
6"ϕ x 9" LONG STD. STEEL PIPE BOLTED TO BEAM W/ 1 BOLT
BARRIER SYSTEM G4 Transition
Conn. Dtls. - Tapered Wingwall
NCHRP REPORT 230 TESTS 30
TEST REF. 7 DATE 6/86
BARRIER DEVELOPMENT
FOR FHWA
BY SwRI



Barrier components with F, P, and RE prefixes are found in the latest edition of "A Guide to Standardized Highway Rail Hardware," a report prepared and approved by the AASHTO-AGC-ARTBA Joint Cooperative Committee.

BARRIER SYSTEM G9 (Steel Post) Transition - Tapered Wingwall

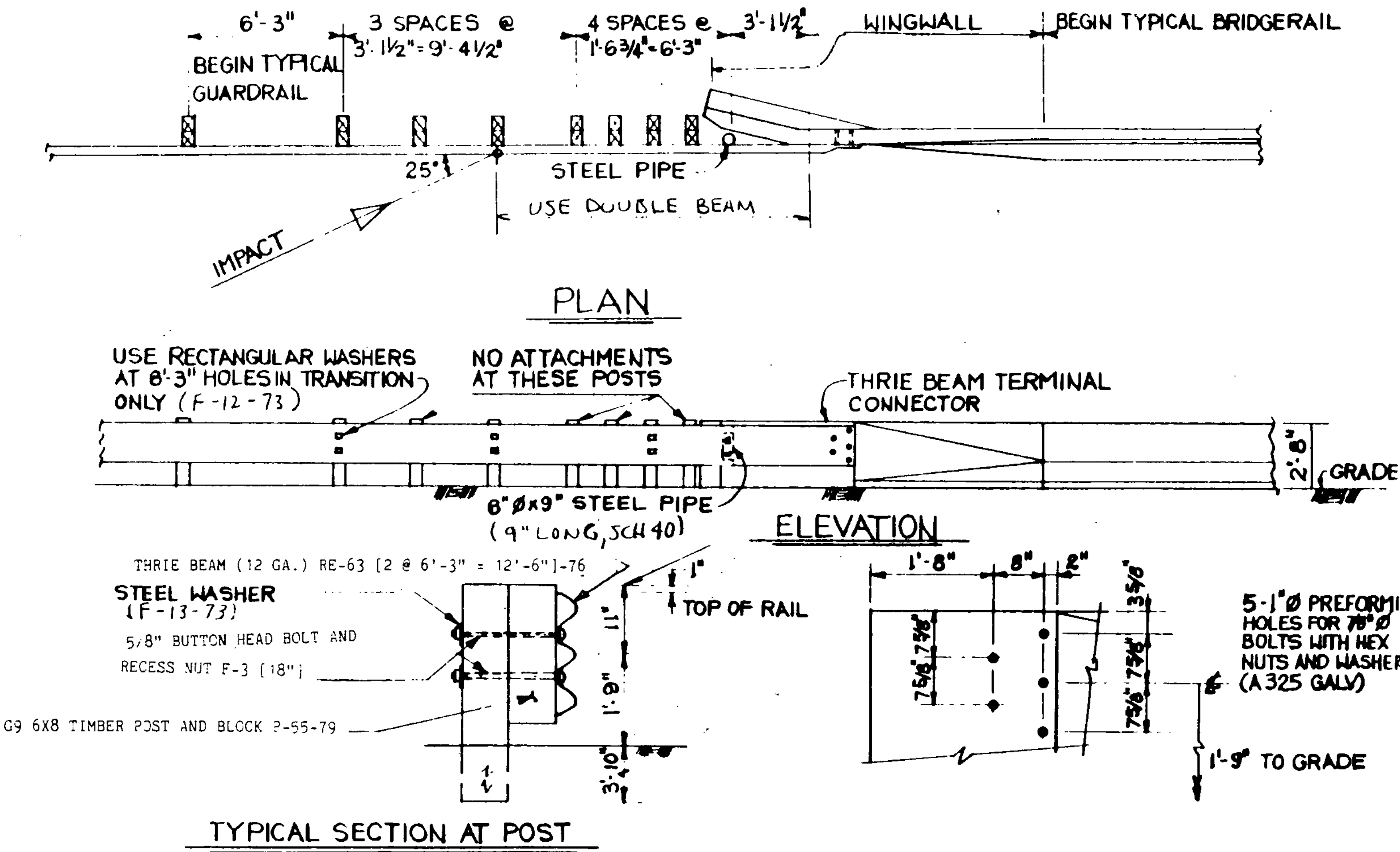
NCHRP REPORT 230 TESTS 30

TEST REF. 7 **DATE** 6/86

BARRIER DEVELOPMENT

FOR FHWA

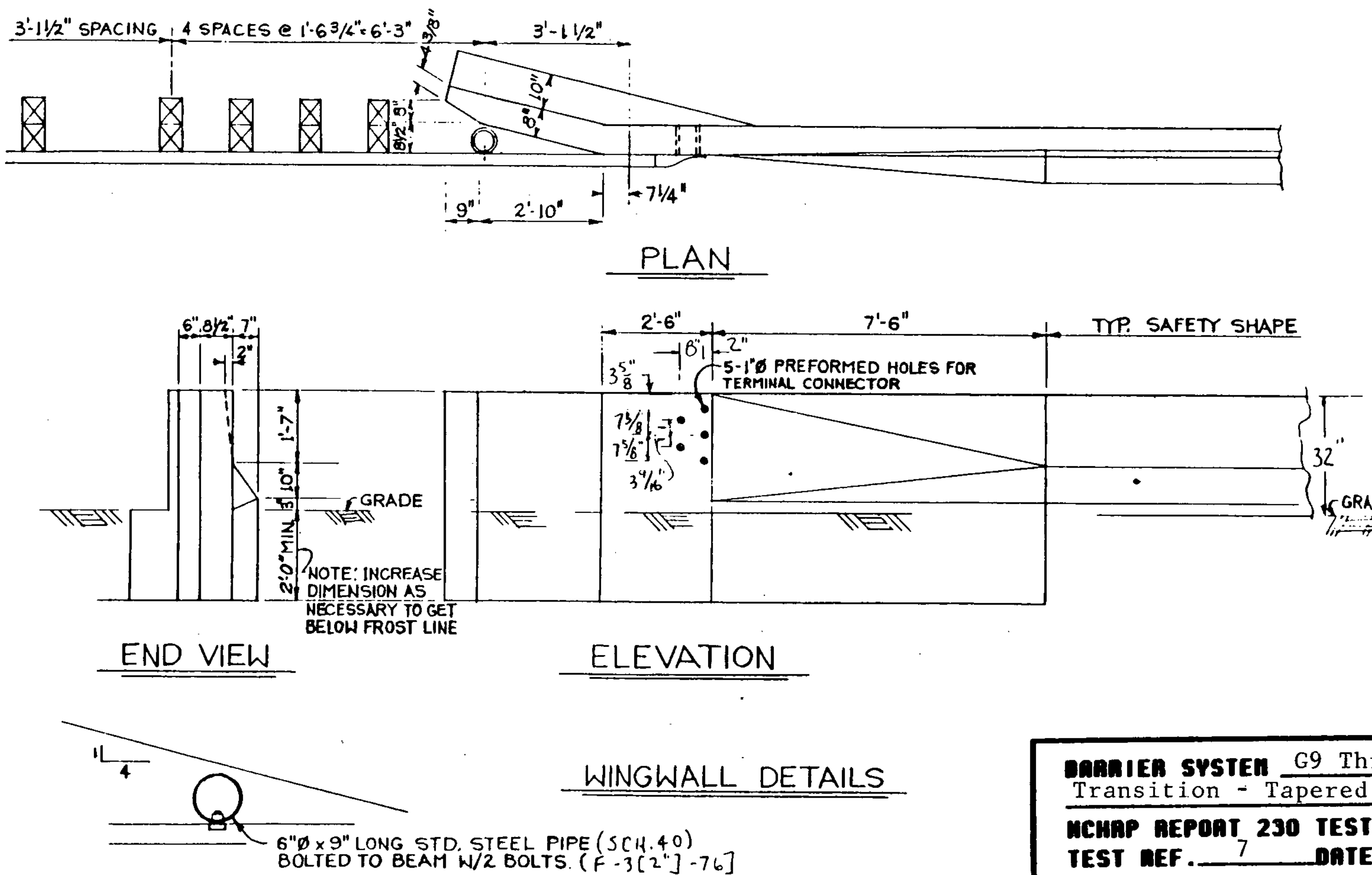
BY SwRI



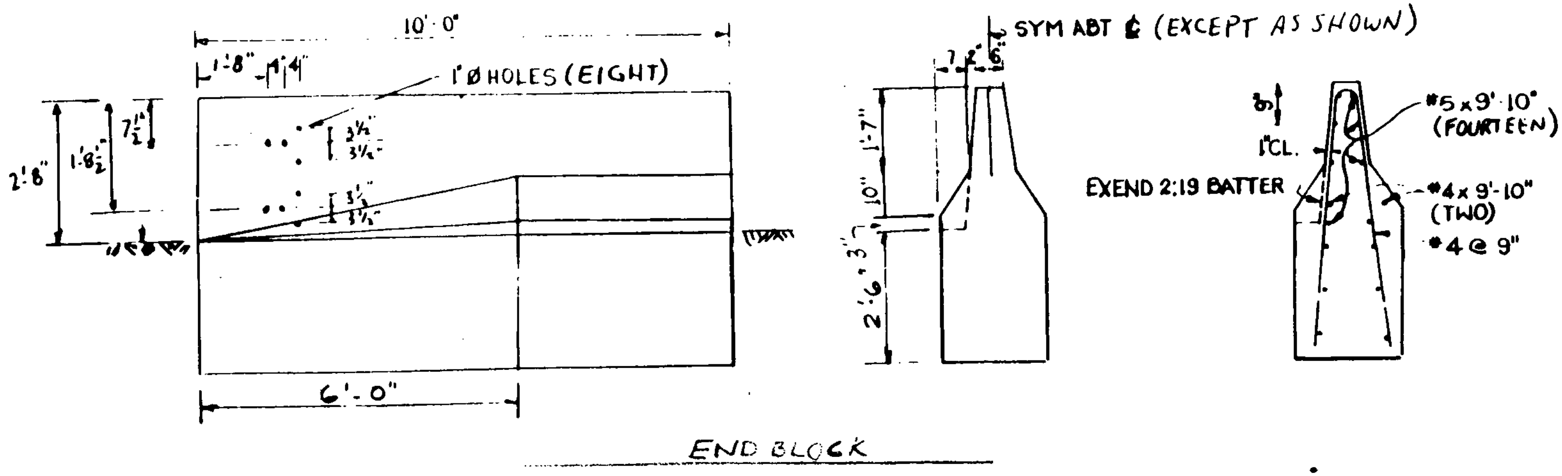
Barrier components with F, P, and RE prefixes are found in the latest edition of "A Guide to Standardized Highway Rail Hardware," a report prepared and approved by the AASHTO-AGC-ARTBA Joint Cooperative Committee.

BARRIER SYSTEM G9 (Wood Post)
Transition - Tapered Wingwall
NCHRP REPORT 230 TESTS 30
TEST REF. 7 **DATE** 6/86
BARRIER DEVELOPMENT
FOR FHWA
BY SwRI

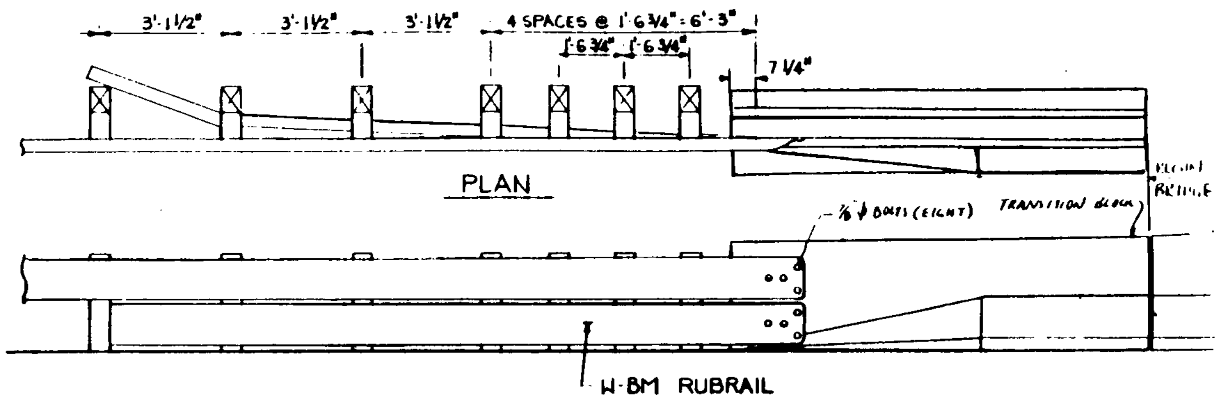
Barrier components with F, P, and RE prefixes are found in latest edition of "A Guide to Standardized Highway Barrier Rail Hardware," a report prepared and approved by the AASHTO-AGC-ARTBA Joint Cooperative Committee.



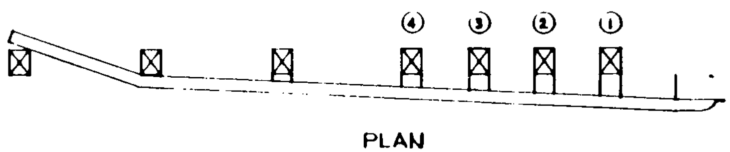
BARRIER SYSTEM	G9 Thrie Bm Transition - Tapered Wingwall
NCHRP REPORT 230 TESTS	30
TEST REF.	7
DATE	6/86
BARRIER DEVELOPMENT FOR	FHWA
BY	SwRI



END BLOCK



ELEVATION



LOWER BEAM BLOCKOUTS

LOWER BLOCK SIZE

POST NO.	6x8 BLOCK THICKNESS
4	3"
3	4"
2	5"
1	6"

BARRIER SYSTEM Independent End Block Transition

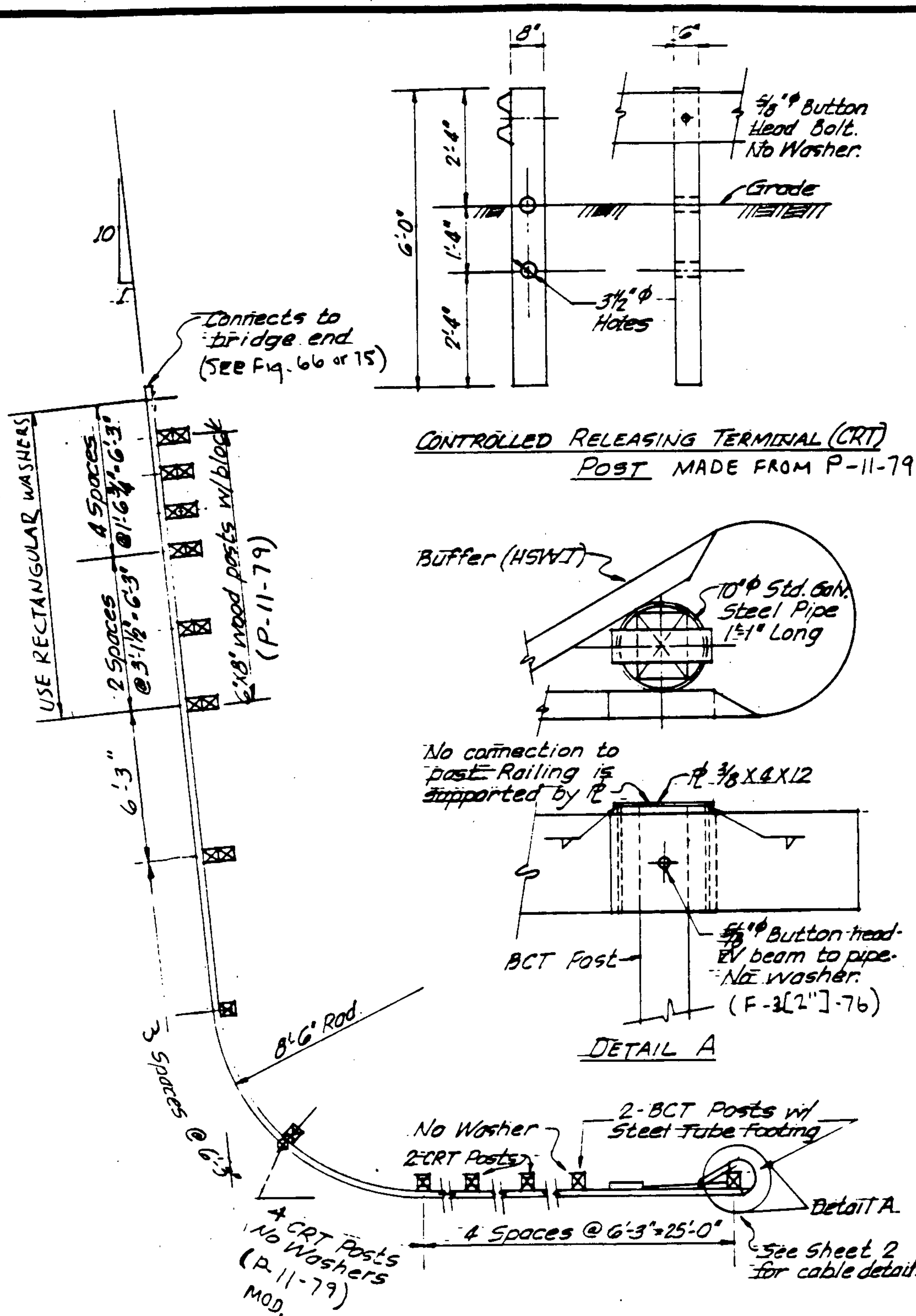
NCHRP REPORT 230 TESTS 30

TEST REF. 7 **DATE** 6/86

BARRIER DEVELOPMENT

FOR FHWA

BY SwRI



BARRIER SYSTEM Intersecting Roadway Transition

NCHRP REPORT 230 TESTS 30

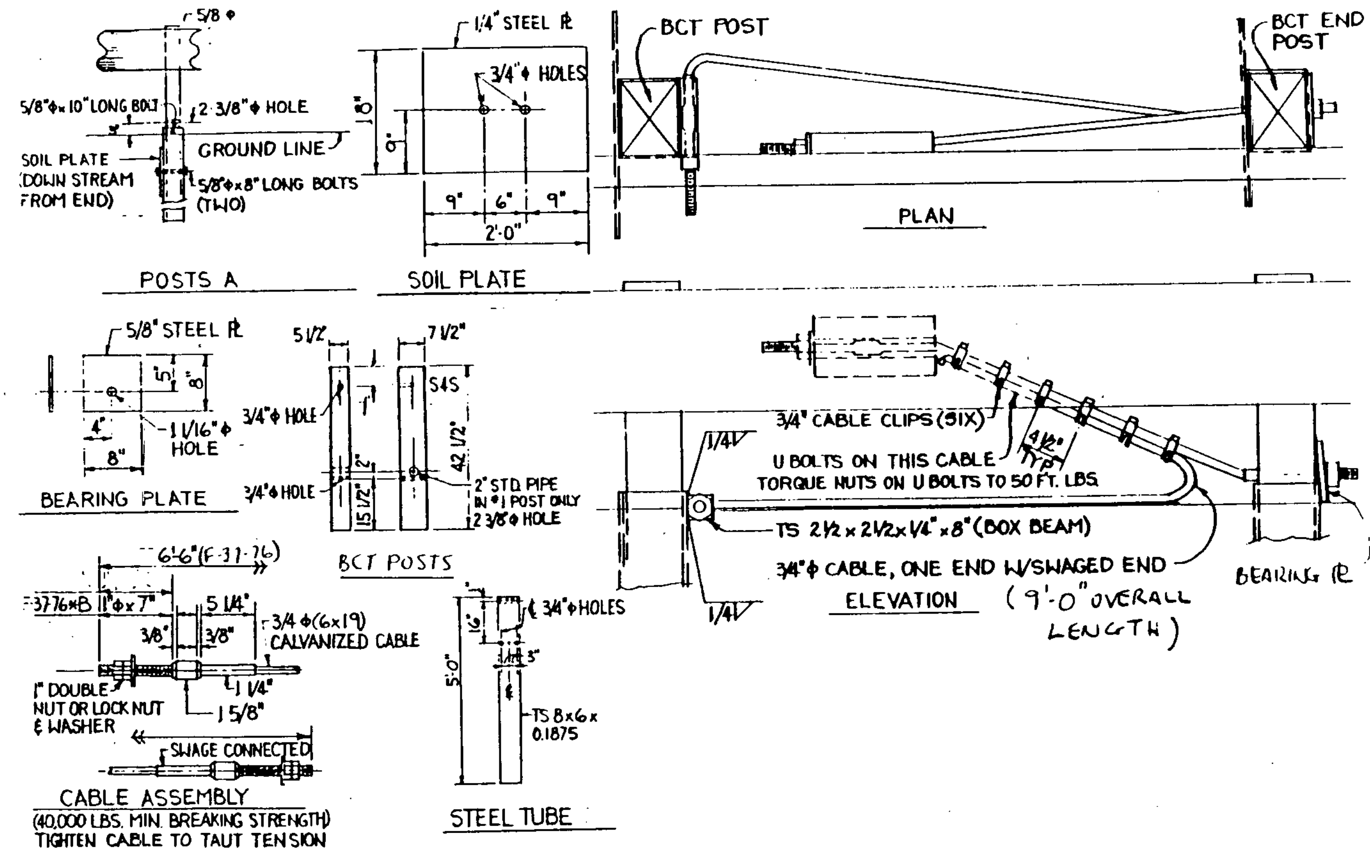
TEST REF. 7 **DATE** 6/86

BARRIER DEVELOPMENT

FOR FHWA

BY SwRI

Barrier components with F, P, and RE prefixes are found in latest edition of "A Guide to Standardized Highway Barrier Rail Hardware," a report prepared and approved by the AASHTO-AGC-ARTBA Joint Cooperative Committee.



BARRIER SYSTEM Intersecting Roadway Guardrail

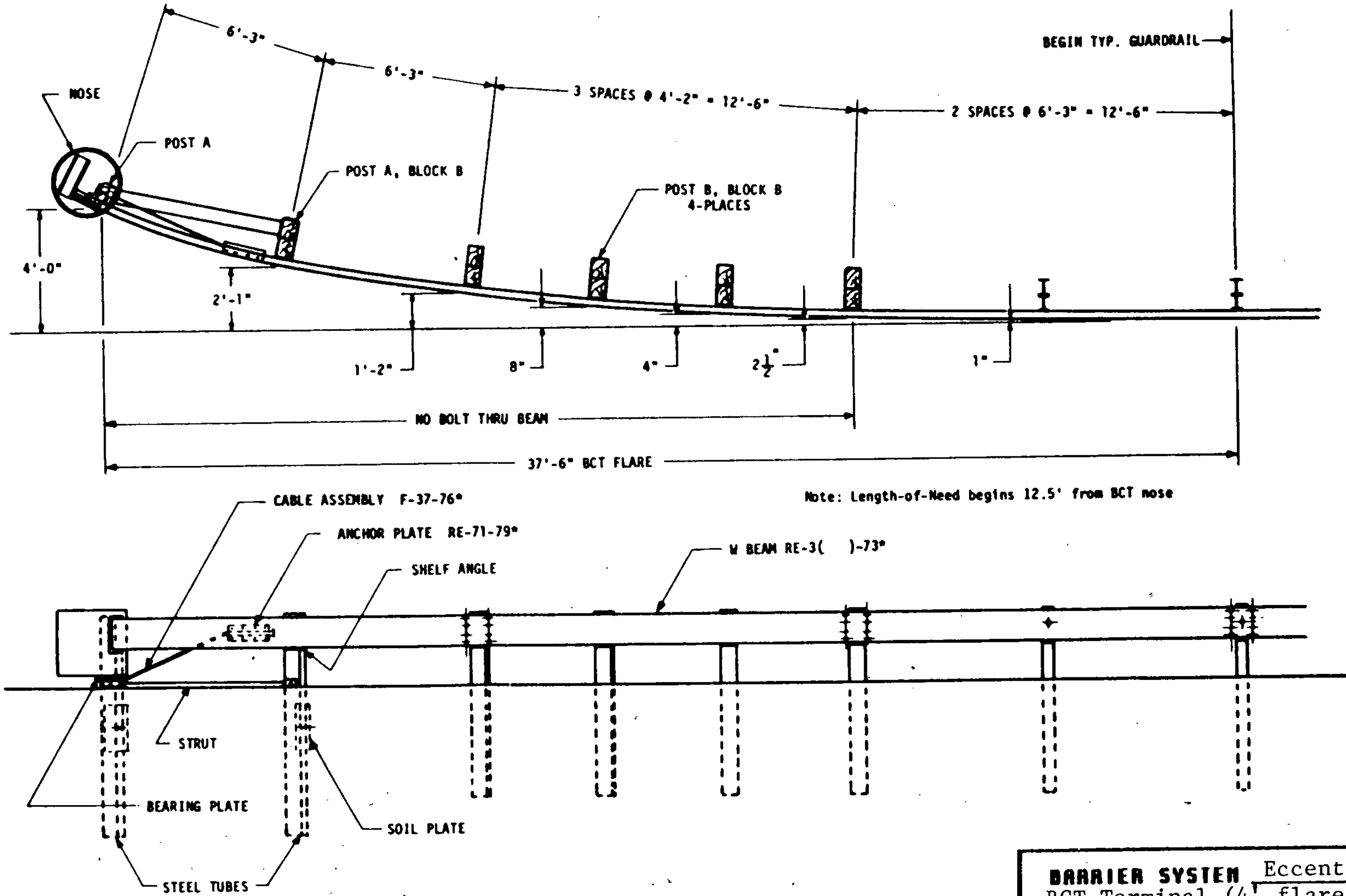
NCHRP REPORT 230 TESTS 30

TEST REF. 7 **DATE** 6/86

BARRIER DEVELOPMENT

FOR FHWA/Wash. State

BY SwRI



BARRIER SYSTEM Eccentric Loader BCT Terminal (4' flare)

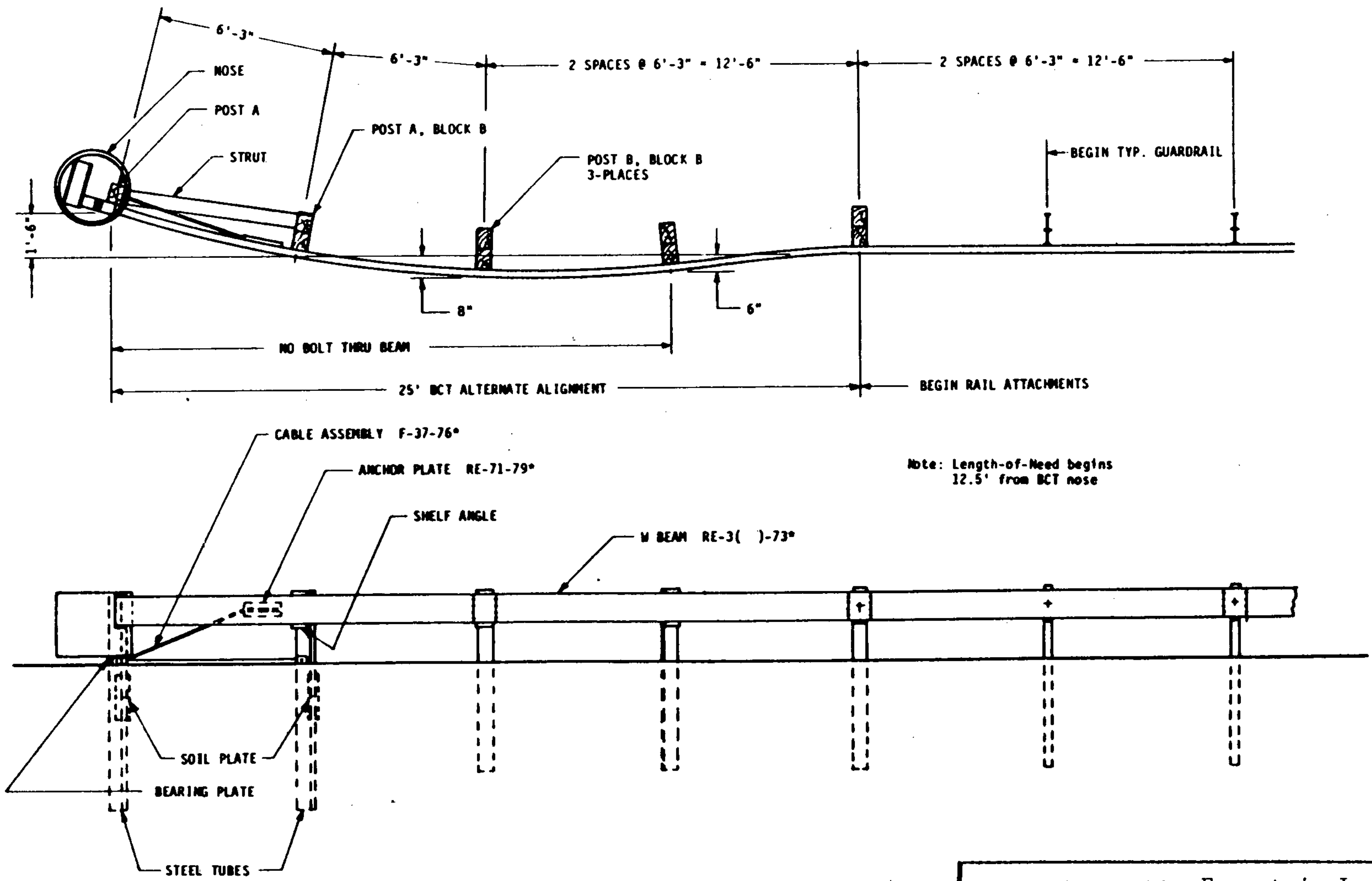
NCHRP REPORT 230 TESTS 40,41,44,45

TEST REF. 8 **DATE** 1985

BARRIER DEVELOPMENT

FOR FHWA

BY SwRI



BARRIER SYSTEM Eccentric Loader BCT Terminal (1.5' flare)

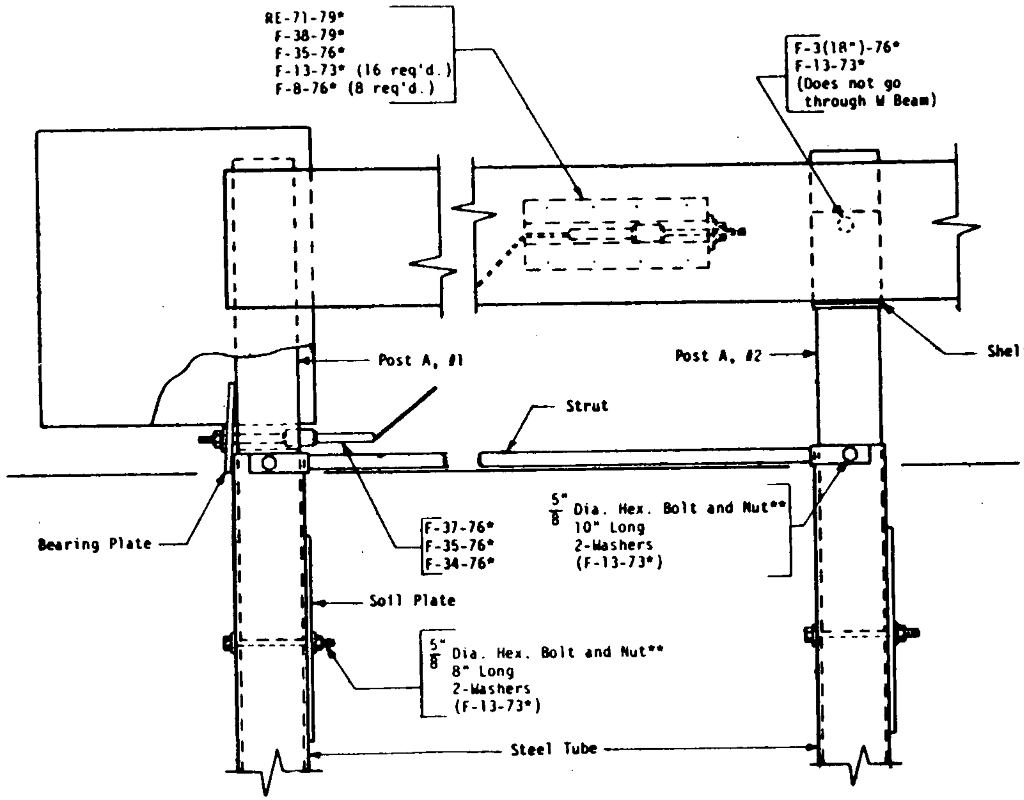
NCHRP REPORT 230 TESTS 40,41,44,4[illegible]

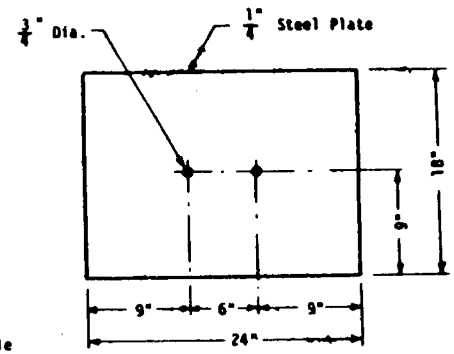
TEST REF. 8 DATE 1985

BARRIER DEVELOPMENT

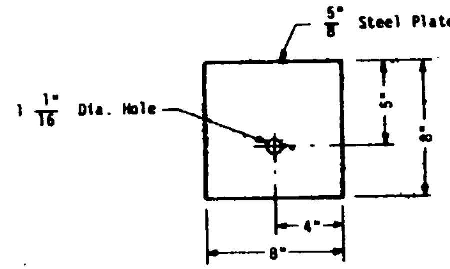
FOR FHWA

BY SwRI

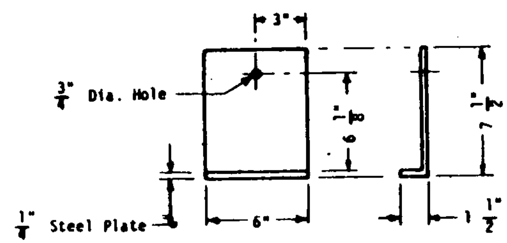




SOIL PLATE (Post A) ***



BEARING PLATE ***



SHELF ANGLE ***

* See report prepared and approved by the AASHTO-AGC-ARTBA Joint Cooperative Committee, "A GUIDE TO STANDARDIZED HIGHWAY BARRIER RAIL HARDWARE".

** Bolts shall conform to the requirements of A.S.T.M. A307 and nuts to the requirements of A.S.T.M. A563, Grade A or better, and be galvanized in accordance with A.S.T.M. A153.

*** All angles, channels and plates shall conform to the requirements of A.S.T.M. A36 and structural tubing to A.S.T.M. A500. Welding shall meet the current requirements of the American Welding Society Structural Welding Code ANSI/AWS D1.1. All structural steel shall be galvanized in accordance with A.S.T.M. A123. No punching, drilling, cutting or welding will be permitted after galvanizing.

**** Wood Post A shall be made of S4S timber with a stress grade of 1200 psi and shall be grademarked or certified by a recognized association or agency which is certified by the Board of Review, American Lumber Standards Committee, to grade the species. It shall receive a preservative treatment in accordance with AASHTO designation M-133.

BARRIER SYSTEM Eccentric Loader BCT Terminal

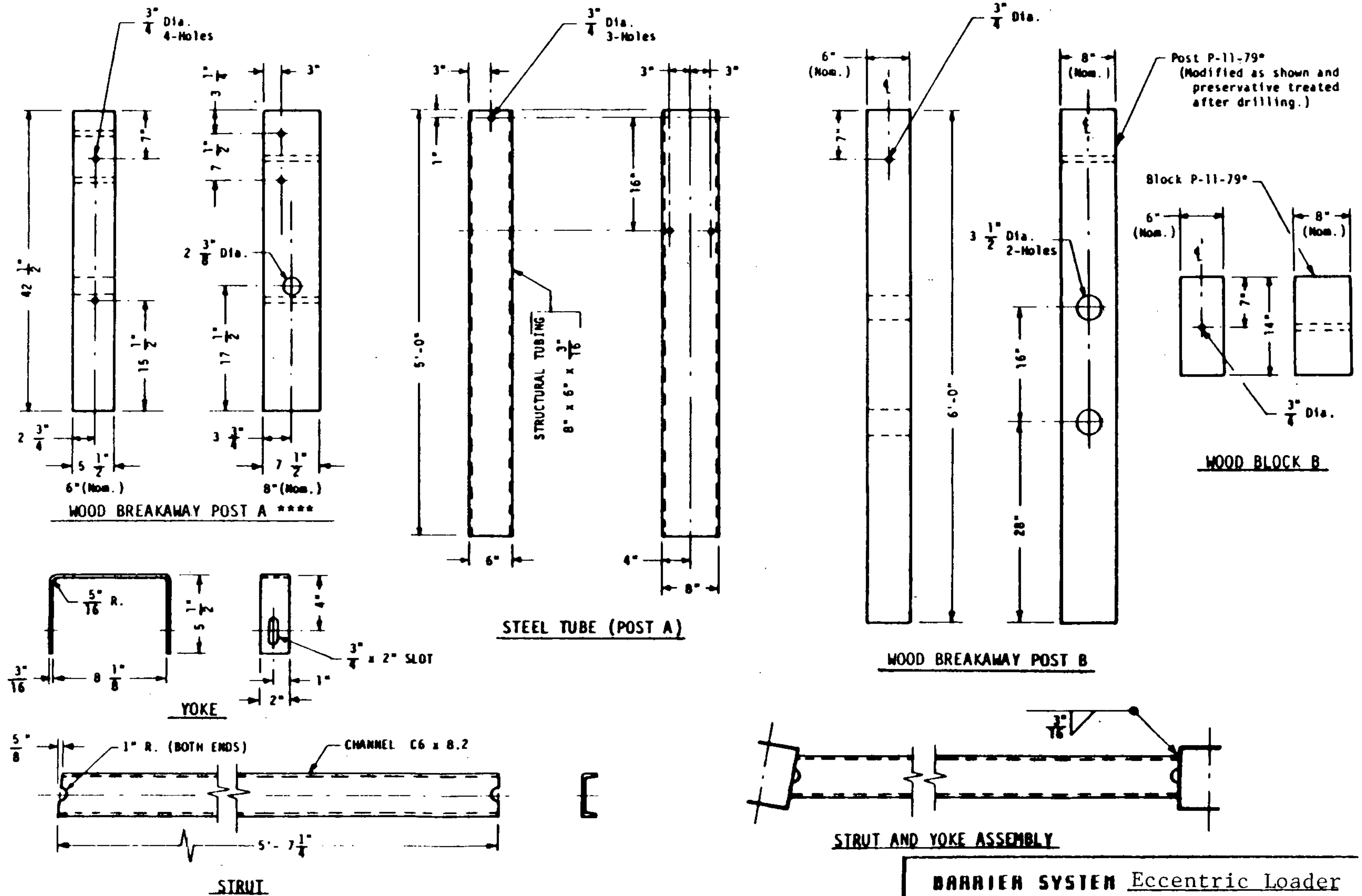
NCHRP REPORT 230 TESTS 40,41,44,45

TEST REF. 8 **DATE** 1985

BARRIER DEVELOPMENT

FOR FHWA

BY SwRI



BARRIER SYSTEM Eccentric Loader BCT Terminal

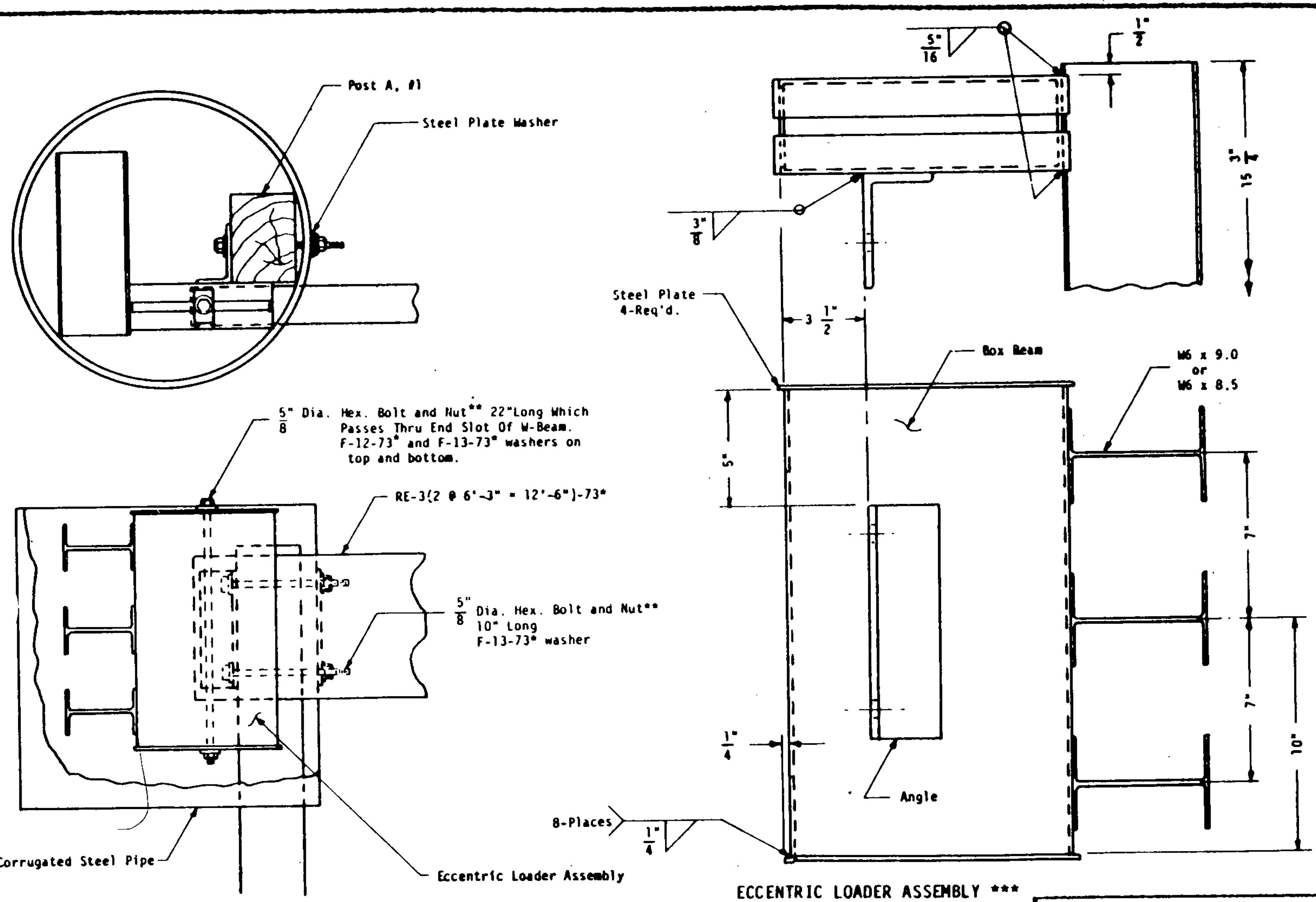
NCHRP REPORT 230 TESTS 40,41,44,45

TEST REF. 8 **DATE** 1985

BARRIER DEVELOPMENT

FOR FHWA

BY SwRI



BARRIER SYSTEM Eccentric Loader BCT Terminal

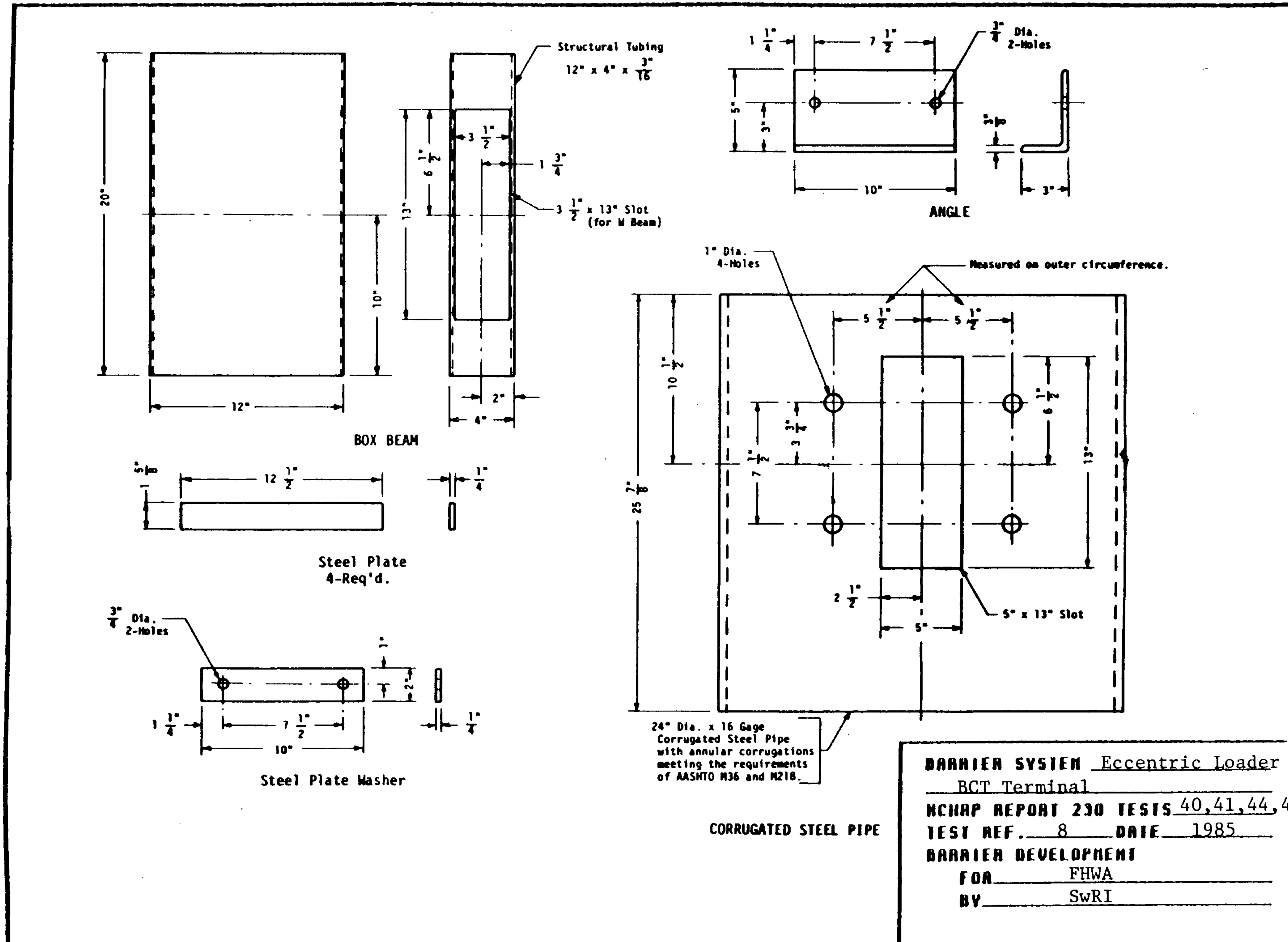
NCHRP REPORT 230 TESTS 40,41,44,4

TEST REF. 8 **DATE** 1985

BARRIER DEVELOPMENT

FOR FHWA

BY SwRI



BARRIER SYSTEM Eccentric Loader BCT Terminal

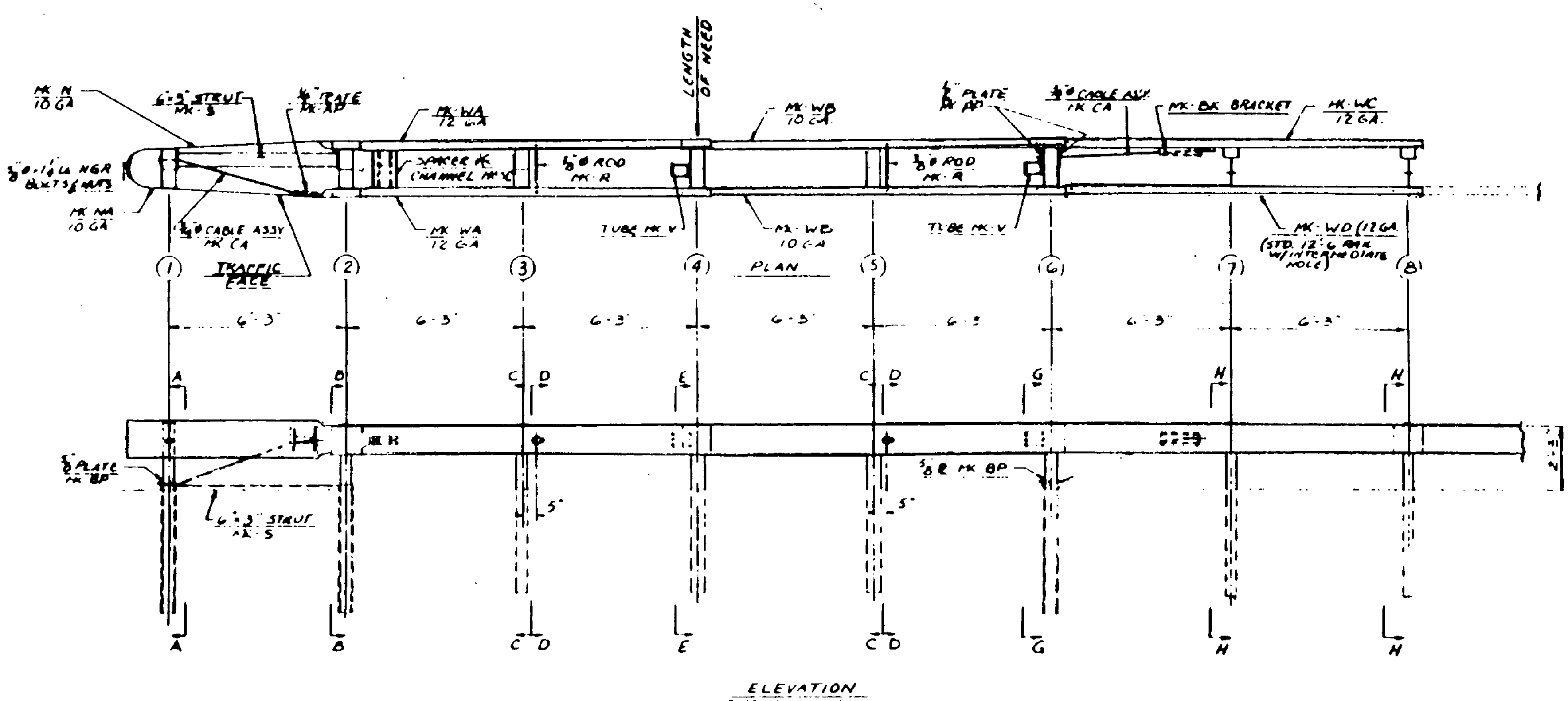
NCHRP REPORT 230 TESTS 40,41,44,45

TEST REF. 8 **DATE** 1985

BARRIER DEVELOPMENT

FOR FHWA

BY SwRI



BARRIER SYSTEM V-A-T Guardrail Terminal

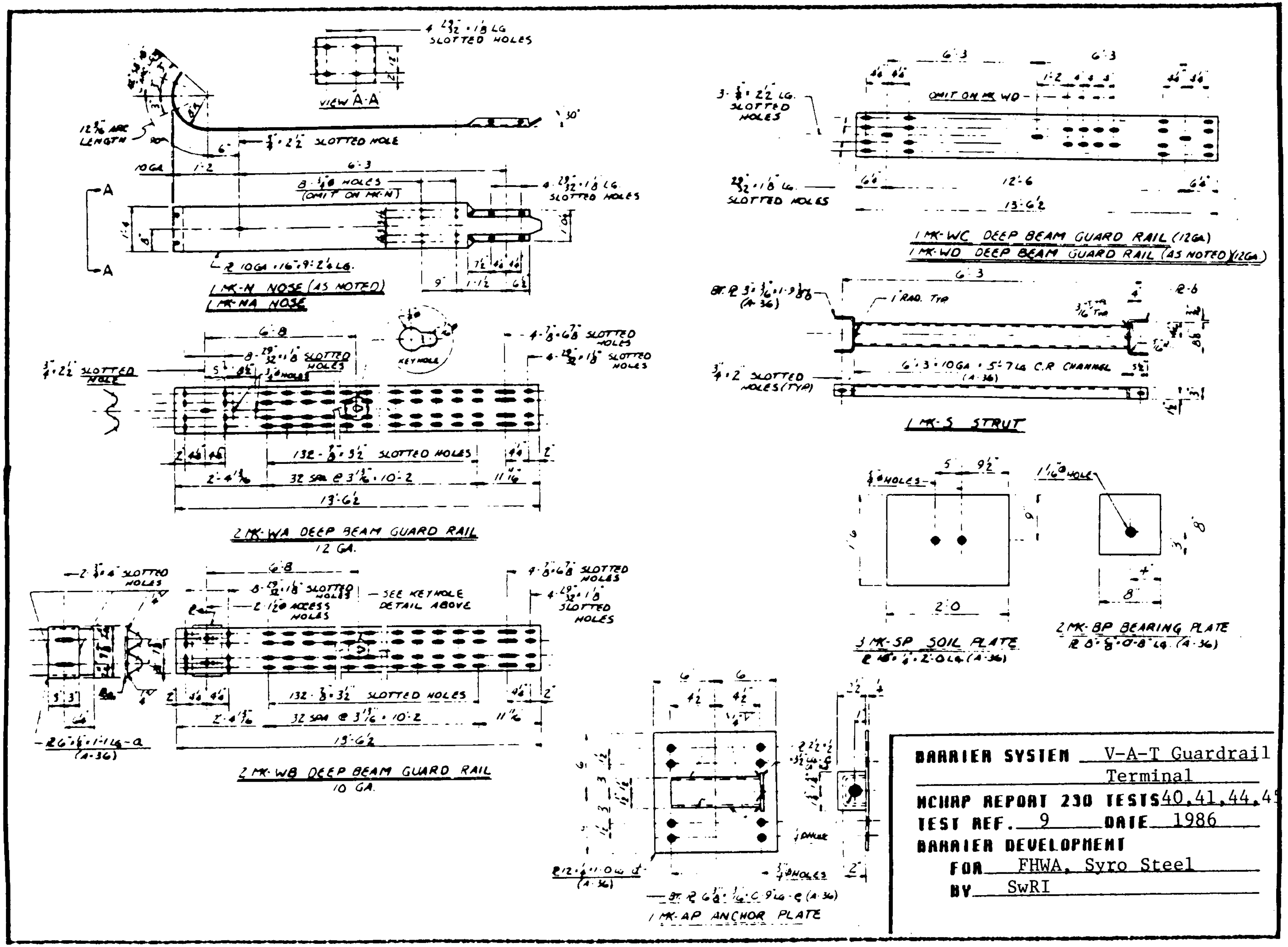
NCHRP REPORT 230 TESTS 40,41,44,45

TEST REF. 9 **DATE** 1986

BARRIER DEVELOPMENT

FOR FHWA, Syro Steel

BY SwRI



BARRIER SYSTEM V-A-T Guardrail Terminal

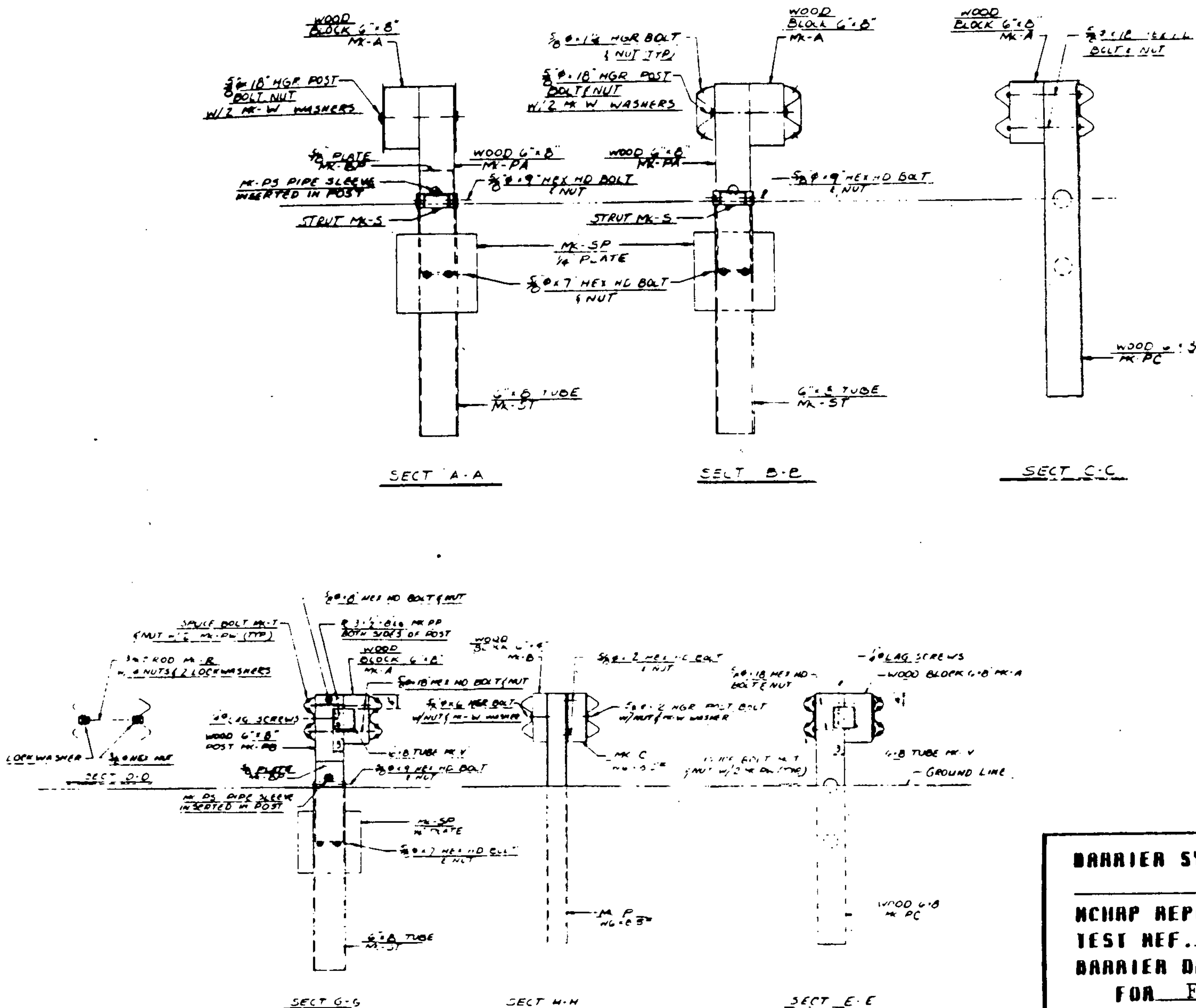
NCHRP REPORT 230 TESTS 40,41,44,45

TEST REF. 9 **DATE** 1986

BARRIER DEVELOPMENT

FOR FHWA, Syro Steel

BY SwRI



BARRIER SYSTEM V-A-T Guardrail Terminal

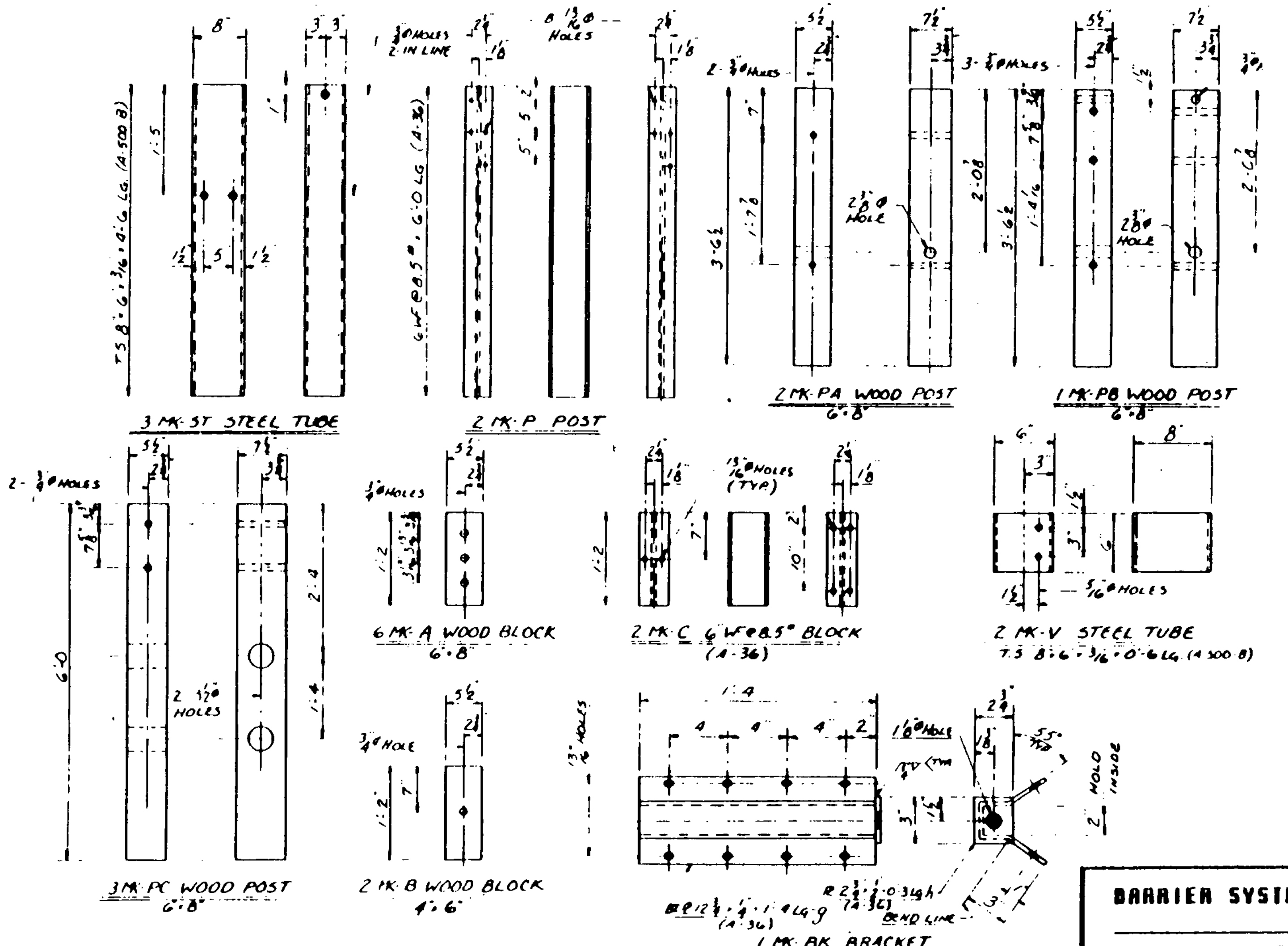
NCHRP REPORT 230 TESTS 40,41,44,45

TEST REF. 9 **DATE** 1986

BARRIER DEVELOPMENT

FOR FHWA, Syro Steel

BY SwRI



BARRIER SYSTEM V-A-T Guardrail Terminal

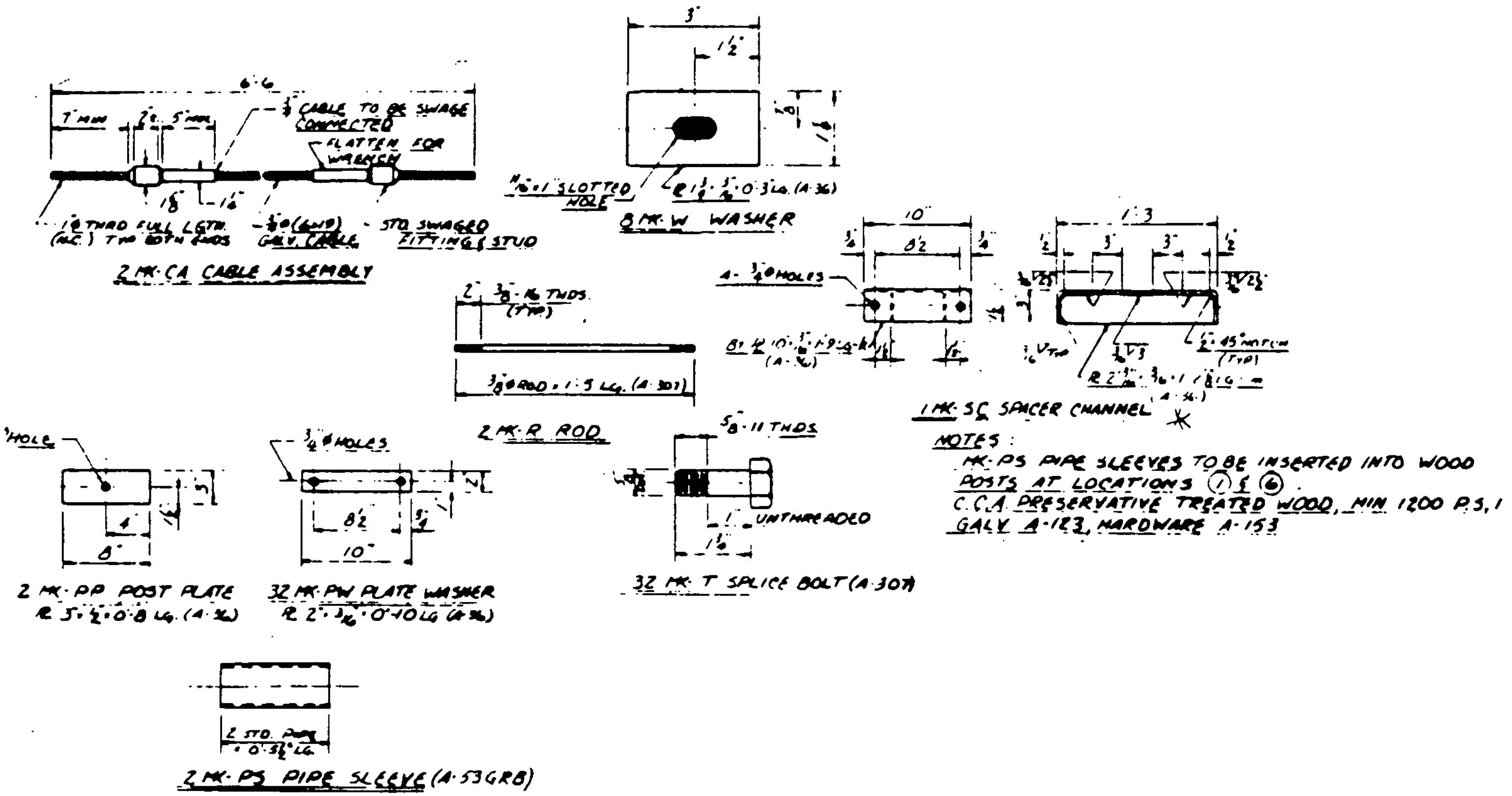
NCHRP REPORT 230 TESTS 40,41,44,45

TEST REF. 9 **DATE** 1986

BARRIER DEVELOPMENT

FOR FHWA, Syro Steel

BY SwRI



BARRIER SYSTEM	V-A-T Guardrail Terminal
NCHRP REPORT 230 TESTS	40,41,44,45
TEST REF.	9
DATE	1986
BARRIER DEVELOPMENT	
FOR	FHWA, Syro Steel
BY	SwRI

Table 1. Bridge rail tests, SwRI (Ref. *13*).

SwRI Test No.	Bridge Rail System (Figure 1)	Impact Conditions: Vehicle Mass (lb)	Impact Conditions: Speed (mph)	Impact Conditions: Angle (deg)	Occupant Risk (fps): Long.	Occupant Risk (fps): Lat.	Veh. 50 ms Accel.: Long.	Veh. 50 ms Accel.: Lat.	Evaluation Guideline A: Vehicle Containment	B: Structural Integrity	C: Vehicle Stability	D: Redirection Smoothness	E: Occupant Risk	F: After Impact Trajectory
NBR-1	A	1746	60.7	19.3	7.2	21.8	5.8	12.6	Pass	Pass	Pass	Pass/Good	Pass	Pass
NBR-2	A	4320	61.4	24.9	3.0	21.6	6.3	8.4	Pass	Pass	Pass	Pass/Good	Pass	Pass
NBBR-1	B	1805	61.4	20.0	1.3	11.4	4.9	13.5	Pass	Pass	Pass	Pass/Fair	Pass	Pass
NBBR-2	B	4370	58.4	24.3	3.8	20.0	5.9	8.2	Pass	Pass	Pass	Pass/Marginal	Pass	Pass
OHBR-1	C	1815	60.6	19.6	7.3	20.6	5.6	11.4	Pass	Pass	Pass	Pass/Good	Pass	Pass?
OHBR-2	C	4460	60.0	25.0	7.0	25.1	6.1	12.1	Pass	Pass	Pass	Pass/Good	Pass*	Pass
NCBR-1	D	1825	59.7	18.8	4.8	22.7	8.1	12.9	Pass	Pass	Pass	Pass/Good	Pass	
NCBR-2	D	4330	60.0	25.0										
OBR-1	E	1829	58.6	18.8	0.8	19.9	3.3	10.2	Pass	Pass	Pass	Pass/Good	Pass	Pass?
OBR-2	E	4430	60.8	24.3	1.3	21.2	5.1	7.9	Pass	Pass	Fail	Pass/Fair	Pass	Pass
KBR-1	F	1806	61.9	20.3	11.5	20.4	7.5	11.2	Pass	Pass	Pass	Pass/Marginal	Pass	Pass
KBR-2	F	4330	60.5	24.0	30.0	23.3	8.3	13.4	Pass	Pass	Fail	Fail	Marginal	
MKS-1	F MOD	1685	59.0	18.9	14.0	18.2	9.5	10.6	Pass	Pass	Pass	Pass/Marginal	Pass	Pass
MKS-2	F MOD	4360	59.2	24.9	13.9	24.9	9.4	12.6	Pass	Pass	Pass	Pass/Marginal	Pass	Pass
OKBR-1	G	1815	58.7	18.9	24.6	19.9	8.7	11.5	Pass	Pass	Pass	Pass/Good	Pass	Pass
OKBR-2	G	4330	59.1	25.4	26.4				Pass	Pass	Pass	Pass/Good	Pass	Pass

Table 1. Continued

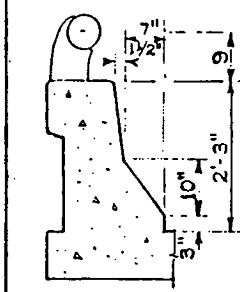
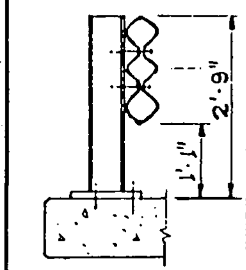
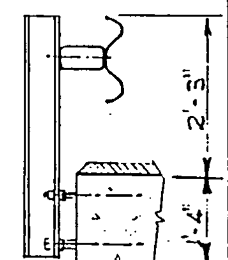
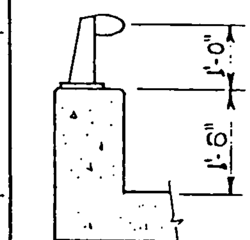
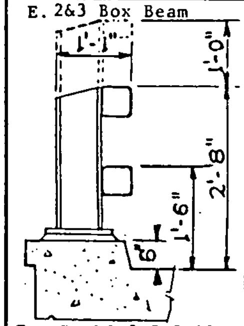
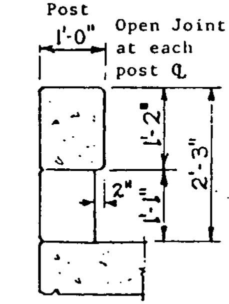
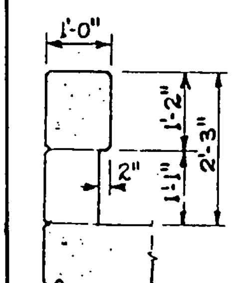
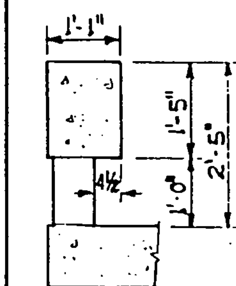
A. Safety Shape  Concrete Safety Shape w/Al. Railing	B. Tubular Thrie on Slap Panels  12-Ga Tubular Thrie Bm W6x25 posts @ 10'-0"	C. Box Beam w/ W-Bm Face  TS 8x4x0.19 Beam on W6x25 posts @ 6'-3"	D. Flat Parapet/ Al. Rail  Reinforced Concrete Parapet w/Al. Railing
E. 2&3 Box Beam  Top Bm TS 3x5x0.19 Lwr Bms TS 5x5x0.19 W6x25 posts @ 12'-6" ctrs	F. Concrete Beam/ Post  Reinforced Concrete Beam - 5 ft wide posts @ 10-ft ctrs	F. Modified  Basically same except for stirrups at post & beam	G. Conc. Beam/Post  Reinforced concrete Beam - 5-ft wide posts @ 10-ft ctrs

Table 2. Summary of thrie beam/wingwall transition tests, SwRI (Ref. *17*).

Test No.	T-1	T-7	T-2	T-3
Guardrail	G4(2W)	G4(1S)	G4(2W)	G4(2W)
Test Vehicle	1978 Plymouth	1978 Dodge	1978 Plymouth	1978 Plymouth
Gross Vehicle Weight, lb	4658	4675	4650	4580
Impact Speed (film), mph	61.5	58.9	64.0	60.8
Impact Angle, deg	25.2	25.1	25.6	23.8
Impact Duration, sec	.34	.39	.32	.39
Maximum Deflection, in				
Dynamic	9.4	13.9	14.4	11.3
Permanent	5.6	6.4	9.0	7.9
Exit Angle, deg				
Film	-11.2	-5.7	-9.1	-12.1
Yaw Rate Transducer	-5.6	-1.4	-2.0	-9.7
Exit Speed, mph				
Film	43.8	40.2	36.8	43.6
Accelerometer	36.8	42.0	35.8	47.4
Maximum 50 ms Avg Accel (film/accelerometer)				
Longitudinal	-5.8/-9.9	-4.5/-5.2	-7.5/-7.9	-5.1/-5.9
Lateral	7.7/16.6	5.9/7.3	-7.4/-13.4	-7.3/-10.4
NCHRP <u>Report 230</u> Evaluation				
Structural Adequacy (A,D)	Passed	Passed	Passed	Passed
Occupant Risk (E)	Passed	Passed	Passed	Passed
Vehicle Trajectory (H,I)	*, **	*, **	*, **	*,
* Exit Angle (60% = 15°)	< 15°	< 15°	< 15°	< 15°
** Δv (15 mph)	> 15 mph	> 15 mph	> 15 mph	> 15 mph

Metric Conversion
1 in = 2.5 cm
1 ft = 30 cm

Table 3. Summary of W-beam/wingwall transition tests, SwRI (Ref. *17*).

Test No.	LA-1	LA-1M	T-5	NC-1	NC-1M	NC-2M	T-6
Guardrail	G4(2W)	G4(2W)	G4(2W)	G4(1S)	G4(1S)	G4(1S)	G4(1S)
Test Vehicle	1978 Plymouth	1978 Plymouth	1978 Plymouth	1978 Dodge	1978 Dodge	1978 Dodge	1978 Dodge
Gross Vehicle Weight, lb	4635	4737	4700	4642	4630	4572	4655
Impact Speed (film), mph	62.2	60.6	58.9	60	60.4	59.8	61.7
Impact Angle, deg	25.1	25.3	25.8	25	25.9	25.4	25.6
Impact Duration, sec	.40	.27	.35	.43	.35	.53	.43
Maximum Deflection, in							
Dynamic	W-beam separated	6.4	10.9	12.6	7.6	29.1	14.1
Permanent	W-beam separated	6	6.0	8.8	4.4	20.0	7.5
Exit Angle, deg							
Film	Did not exit	-5.5	-8.0	Not Avail.	-10.7	-16.9	-14.7
Yaw Rate Transducer	Did not exit	Not Avail.	-6.8	-9.5	-7.1	Not Avail.	-13.3
Exit Speed, mph							
Film	Did not exit	46.7	40.5	Not Avail.	46.1	34.6	40.0
Accelerometer	Did not exit	Not Avail.	37.7	34.0	42.9	Not Avail.	39.7
Maximum 50 ms Avg Accel (film/accelerometer)							
Longitudinal	-12.9	-7.6/Not Avail.	-5.8/-11.1	Not Avail./-12.8	-6.5/-9.8	-5.4/-7.1	-6.2/-10.9
Lateral	-6.0	-6.6/Not Avail.	6.2/11.9	Not Avail./-11.1	-7.7/12.0	-5.5/-5.9	-7.1/-10.0
NCHRP <u>Report 230</u> Evaluation							
Structural Adequacy (A,D)	Failed	Passed	Passed	Passed	Passed	Passed	Passed
Occupant Risk (E)	Failed	Passed	Passed	Passed	Passed	Passed	Passed
Vehicle Trajectory (H,I)	Failed	Passed	*, **	*, **	Passed	*, **	*, **
* Exit Angle (60% = 15°)			< 15°	< 15°		> 15°	< 15°
** ΔV (15 mph)			> 15 mph	> 15 mph		> 15 mph	> 15 mph

Metric Conversion
1 in = 2.5 cm
1 ft = 30 cm

Table 4. Summary of V-A-T crash tests, SwRI (Ref. *20*).

Test No.	Syro-1*	Syro-2*	Syro-4*	Syro-6*	Syro-7
Report 230 Test No.	41	40	44	45	FHWA specification
Barrier	V-A-T	V-A-T	V-A-T	V-A-T	V-A-T median barrier
Test Vehicle	1978 Dodge	1978 Dodge	1980 Honda	1980 Honda	1978 Plymouth
Gross Vehicle Weight, lb	4400	4340	1804	1840	4440
Impact Speed (film), mph	59.3	60.0	60.6	60.6	61.0
Impact Angle, deg	0.5	24.4	16.0	0.9	14.6
Impact Duration, sec	0.68	0.71	0.26	0.42	0.31
Maximum Deflection					
Dynamic	27 ft	3.2 ft	0.5 ft	17.4	13.5
Permanent	25 ft	2.1 ft	0.1 ft	16.0	4.3
Exit Angle, deg					
Film	did not exit	-17.2	-3.6	29.3	-1.7
Yaw Rate Transducer	did not exit	not avail	-2.7	28.6	-1.3
Exit Speed, mph					
Film	did not exit	34.9	50.7	-1.4	53.7
Accelerometer	did not exit	not avail	51.8	-2.3	52.0
Maximum 50 msec Avg Accel (film/accelerometer)					
Longitudinal	-4.9/-8.8	-3.6/-5.6	-2.9/-3.1	-8.0/-9.8	-2.3/-2.9
Lateral	0.2/-1.8	-3.9/-5.7	-5.6/-8.0	-4.0/2.6	-4.1/-4.9
Occupant Risk, NCHRP Report 230** (film/accelerometer)					
ΔV long., fps (30)	24.5/22.6	n/a	12.9/7.9	30.4/27.6	9.0/10.7
ΔV lat, fps (20)	***	n/a	18.8/21.6+	-7.5/-5.6	16.1/16.0
Ridedown Acceleration, g's (accelerometer)					
Longitudinal (15)	-16.3+	n/a	***	-16.9+	-1.1
Lateral (15)	5.4	n/a	-6.6	5.7	-5.9
NCHRP Report 230 Evaluation (Table 6)					
Structural Adequacy	passed (C,D)	passed (C,D)	passed (C,D)	passed (C,D)	passed (C,D)
Occupant Risk	passed (E,F+)	passed (E)	passed (E,F+)	passed (E,F)	passed (E,F)
Vehicle Trajectory	passed (H)	passed (H,I)	passed (H)	passed (H,I++)	passed (H,I)

* See Reference 2.
** Numbers in parentheses are recommended values for NCHRP Report 230.
*** Occupant did not travel the flail distance.
\+ Higher than recommended (Report 230, Table 8) but lower than threshold values (Report 230, Table 6)
++ See Conclusions in text.
n/a - not applicable.

Table 5. New York State DOT tests.

Barrier Description	Test No.	Vehicle Test Conditions Weight (lb)	Speed (mph)	Angle (deg)	NCHRP 230 Criteria Passed	Failed	ER&DB Project No.	ER&DB Project No.
Post spacing for thrie beam bridge rail, 6'-3" spacing	64	4500	60.1	26	x		102-7	118
Post spacing for thrie beam bridge rail, 8'-4" spacing	65	4500	58.8	27	x		"	"
Post spacing for thrie beam bridge rail, 8'-4" spacing	66	1860	59.6	14	x		"	"
Post spacing upstream from transition, 8'-4" spacing	67	4500	58.8	25		x	"	"
Post spacing upstream from transition, 8'-4" spacing	68	4500	59.5	24		x	"	"
Post spacing upstream from transition, 8'-4" spacing	69	4600	54.4	26	x		"	"
Post spacing upstream from transition, 8'-4" spacing	70	1980	57.8	20		x	"	"
Post spacing upstream from transition, 8'-4" spacing	71	1800	60.3	19	x		"	"
Post spacing at transition, 8'-4" spacing	72	4380	57.0	28		x	"	"
Post spacing at transition, 8'-4" spacing	73	4500	56.5	29	x		"	"
Cable guardrail terminal end - upstream end	103	1800	62.3	5	x		102-9	*
Cable guardrail terminal end - 43.5 ft from depart. end	104	1800	61.3	15	x		"	*
Cable guardrail terminal end - 25.5 ft past app. end	105	1800	54.8	15	x		"	*
Cable guardrail terminal end - 38 ft past app. end	107	4850	56.6	25	x		"	*
W-beam-light post to heavy post transition	108	1800	61.2	13	x		102-10	*
W-beam-light post to heavy post transition	109	4600	58.1	27	x		"	*

*Not yet published

Table 6. Texas Transportation Institute (summary of *NCHRP Report 230* evaluations).

SUMMARY OF NCHRP REPORT 230 EVALUATIONS

Barrier Description	Vehicle Test Conditions Weight (lb)	Speed (mph)	Angle (deg)	Report 230 Eval Criteria Passed	Failed	Comments Ref
Colorado Type 5	2,770	56.0	15.1	Passed		1
Colorado Type 5	4,700	62.8	15.0		Failed	1
Colorado Type 5	4,640	61.4	24.5		Failed	1
Colorado Type 5	19,760	59.4	14.3		Failed	1
Texas T101	2,780	57.3	15.0	Passed		1
Texas T101	4,660	60.2	15.0	Passed		1
Texas T101	4,630	59.8	25.8		Failed	1
Texas T101	6,900	53.4	15.0	------	------	1
Texas T101	19,940	55.3	15.2	Passed		1
Texas T101	20,010	52.0	13.2	Passed		1
Texas T101	31,880	58.4	16.0		Failed	1
New Hampshire	1,950	60.9	15.0		Failed	1
New Hampshire	2,780	58.4	15.0		Failed	1
New Hampshire	2,780	59.1	20.5	------	------	1
New Hampshire	4,670	59.2	15.0	Passed		1
North Carolina	19,920	57.3	14.8		Failed	1
Indiana 5A	1,950	57.5	12.5	Passed		1
Indiana 5A	2,780	53.6	19.5	------	------	1
Indiana 5A	4,670	61.6	25.8		Failed	1
Indiana 5A	2,150	54.8	20.0		Failed	1
Mod. Indiana 5A	2,050	55.4	19.0		Failed	1
Instrumented Wall	1,970	59.0	15.5	Passed		1
Instrumented Wall	2,800	58.3	14.8	Passed		1
Instrumented Wall	2,830	56.0	20.0	------	------	1
Instrumented Wall	4,680	54.6	16.5	Passed		1
Instrumented Wall	4,700	58.9	23.8	Passed		1
Instrumented Wall	20,030	57.6	16.5	Passed		1
Instrumented Wall	32,020	56.9	15.8	Passed		1
Instrumented Wall	4,740	59.8	24.0		Failed	1
Instrumented Wall	2,090	58.5	21.0		Failed	1
42-in high Concrete Median Barrier	2,118	59.9	14.5	Passed		2
42-in high Concrete Median Barrier	4,880	58.6	16.5	Passed		2
42-in high Concrete Median Barrier	80,180	52.0	15.0	Passed		2
G4(1S)	2,192	59.9	21.5		Failed	2
G4(1S)	2,100	59.5	15.0	Passed		2
G4(1S)	3,260	60.0	22.0		Failed	2
G4(1S)	4,324	59.2	24.0		Failed	2
G4(1S)	4,179	56.9	23.5		Failed	2
Modified G4(1S) W-Beam (12 ga)	4,644	59.5	15.0	Passed		2
Modified G4(2W) Blocked-out W-Beam (12 ga)	2,129	60.3	19.0	Passed		2
Modified GR1 Cable Guardrail	2,220	59.3	14.5		Failed	2
Modified GR1 Cable Guardrail	4,585	61.2	25.5	Passed		2
Continuous Mod. Safety Shape	2,190	62.6	15.0		Failed	3
Continuous Mod. Safety Shape	80,420	52.8	16.0		Failed	3
10 ga thrie-beam	2,140	58.7	15.5	Passed		4
10 ga thrie-beam	4,510	61.6	25.2	Passed		4
Weak-Post Rail w/Turndown End	4,730	58.1	25.0	Passed		4
Weak-Post Rail w/Turndown End	2,100	60.9	15.0	Passed		4
Weak-Post Rail w/Turndown End	2,145	59.3	15.0	Passed		4
Weak-Post Rail w/Turndown End	3,830	59.1	24.0	Passed		4
Stone Masonry Guardrail	1,820	62.1	14.5	Passed		5
Stone Masonry Guardrail	4,300	58.4	24.5	Passed		5
Aluminum Tru-Beam Bridge Rail	2,150	61.3	21.5	Passed		6

Table 6. Continued

REFERENCES

1. Buth, Eugene, "Safer Bridge Railings," Report FHWA/RD-82/072, Texas Transportation Institute, Texas A&M University, College Station, Texas, June 1984.

2. Buth, C. E., Campise, Wanda L., Griffin III, Lindsay I, Love, M. L., and Sicking, D. L., "Performance Limits of Longitudinal Barrier Systems," Final Report on Contract DTFH61-82-C-00051, Texas Transportation Institute, Texas A&M University, College Station, Texas, May 1985.

3. Buth, C. E., Campise, Wanda L., Marquis, Eugene, L., "Development of a High-Performance Median Barrier, "Final Report on Work Order Number 2 of Contract DOT-FH-11-9485, Texas Transportation Institute, Texas A&M University, College Station, Texas, April 1983.

4. Arnold, Althea, Buth, C. E., Campise, Wanda L., "Weak-Post Guardrails," Final Report on Contract DTFH61-81-C-00039, Texas Transportation Institute, Texas A&M University, College Station, Texas, October 1984.

5. Zimmer, Richard A. and Campise, Wanda L., "Traffic Barriers for Parkways: Performance Evaluation of a Stone Masonry Guardrail," Final Report on Contract DTFH61-85-P-10002, Texas Transportation Institute, Texas A&M University, College Station, Texas, April 1985.

6. Campise, Wanda L. and Buth, C. E., "Crashworthiness of Aluminum Tru-Beam Bridge Railing," Final Report on Contract DTFH61-81-P-30117, Texas Transportation Institute, Texas A&M University, College Station, Texas, September 1982.

Table 7(a) FHWA bridge rail data (bridge rails that meet *NCHRP Report 230* criteria).

Bridge Rails That Meet NCHRP 230 Criteria

BRIDGE RAIL	RAIL HEIGHT IN.	TEST VEHICLE	IMPACT SPEED MPH	IMPACT ANGLE DEGREES	COMMENTS
NCHRP SL1 Thrie Beam, Wood Posts	32	2,250 lb. Car	63.0	18.7	Developed for lower service level use only. (See NCHRP 239.)
		2,250 lb. Car	60.1	15.9	
		4,500 lb. Car	61.9	14.5	
NCHRP SL1 Thrie Beam, Steel Posts	32	1,987 lb. Car	61.4	14.1	Developed for lower service level use only. (See NCHRP 239.)
		2,250 lb. Car	58.6	16.0	
		2,250 lb. Car	60.0	16.0	
		20,000 lb. Bus	44.7	7.7	
Texas Type T6 (Tubular W-beam)	27	2,280 lb. Car	58.0	14.0	
		4,500 lb. Car	61.6	27.5	
Aluminum Tru-Beam (Modified AASHTO BR5)	32	2,150 lb. Car	61.3	21.5	
		4,500 lb. Car	58.9	27.2	
AASHTO BR_2 (California Type 9)	27	1,929 lb. Car	60.9	13.1	
		4,540 lb. Car	57.0	26.0	
Texas Energy Absorbing Bridge Rail	27	1,972 lb. Car	62.6	16.0	
		4,500 lb. Car	61.0	25.5	
Texas T101 Bridge Rail	27	2,780 lb. Car	57.3	15.0	
		4,660 lb. Car	60.2	15.0	
		4,630 lb. Car	59.8	25.8	
		6,900 lb. Bus	53.4	15.0	
		19,940 lb. Bus	55.3	15.2	
		20,010 lb. Bus	52.0	13.2	
		31,880 lb. Bus	58.4	16.0	Bus was contained, but rolled on its side.
Ohio Box Beam Rail (W-beam backed up with box beam)	27	1,980 lb. Car	60.6	19.6	
		4,790 lb. Car	60.0	25.0	
Modified Kansas Corral (Open Concrete Beam & Post)	27	1,971 lb. Car	59.0	18.9	
		4,690 lb. Car	59.2	24.9	
Oklahoma Modified TR-1 Bridge Rail (Open Concrete Beam & Post)	29	1,980 lb. Car	58.7	18.9	
		4,660 lb. Car	59.1	25.4	
Nebraska Tubular Thrie Beam	32	1,970 lb. Car	61.4	20.0	
		4,700 lb. Car	58.4	24.3	
Oregon - 2 Tube Mounted Rail (Curb Mounted)	32	1,994 lb. Car	58.6	18.8	
		4,640 lb. Car	60.0	25.0	
North Carolina - Standard 1 Bar Metal Rail	32	1,990 lb. Car	59.7	18.8	
		4,660 lb. Car	59.6	25.0	
		19,920 lb. Bus	57.3	14.8	Bus was contained, but rolled on its side.
California Type 25 (N. J. Concrete Safety Shape)	32	4,540 lb. Car	38.0	7.0	
		4,540 lb. Car	65.0	7.0	
		4,540 lb. Car	63.0	25.0	

Table 7(a). Continued

Bridge Rails That Meet NCHRP 230 Criteria

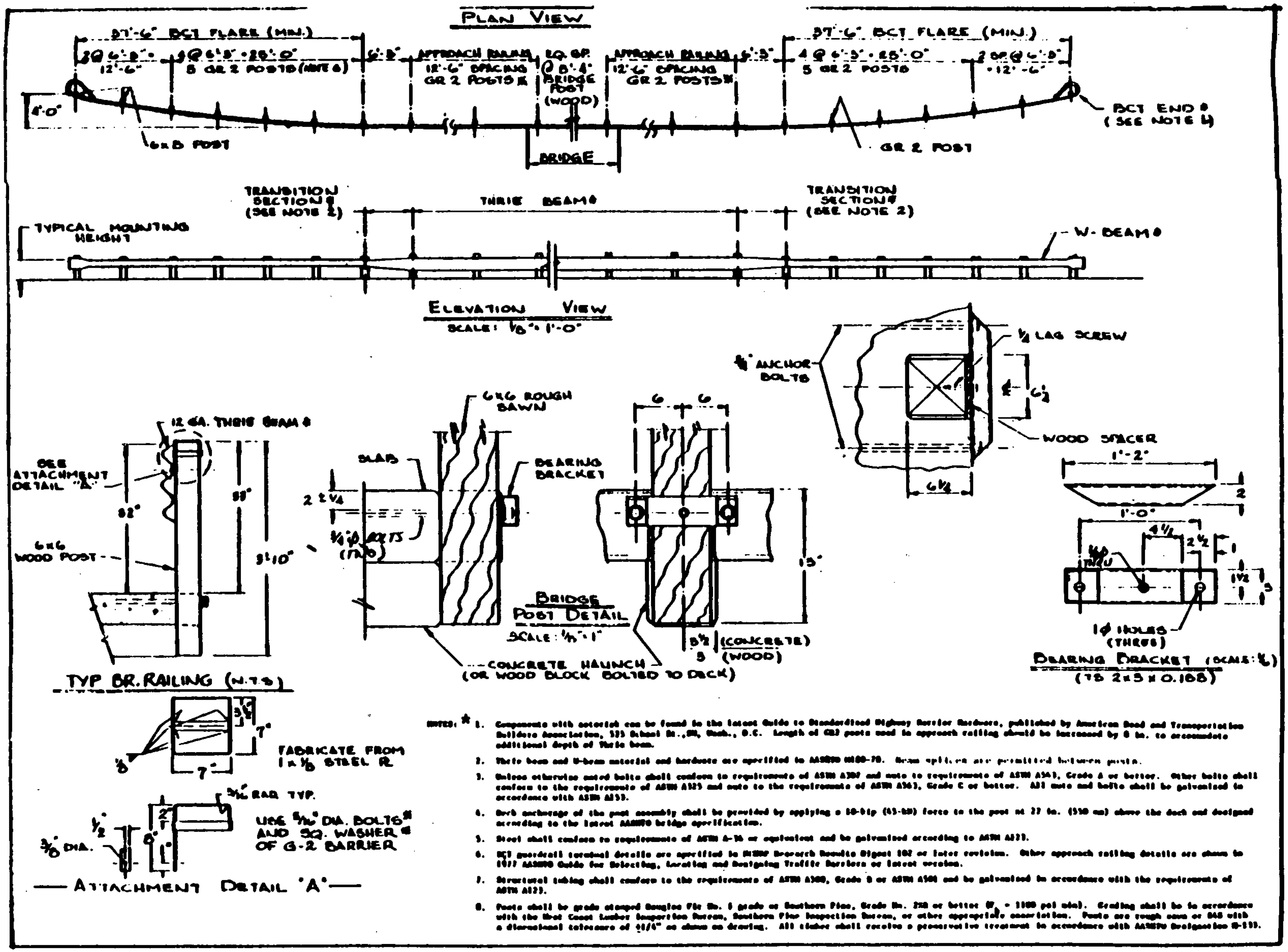
BRIDGE RAIL	RAIL HEIGHT IN.	TEST VEHICLE	IMPACT SPEED MPH	IMPACT ANGLE DEGREES	COMMENTS
N.J. Concrete Safety Shape	32	1,970 lb. Car	60.4	15.0	
		1,968 lb. Car	61.3	20.0	
		4,500 lb. Car	60.1	25.2	
		18,240 lb. Truck	60.1	15.0	Truck rolled over.
		19,990 lb. Bus	60.9	16.0	Bus rolled over.
		20,000 lb. Bus	57.7	15.0	Bus rolled over.
		20,270 lb. Bus	61.6	15.0	Bus overturned.
		40,000 lb. Bus	41.6	11.5	
		40,000 lb. Bus	51.6	6.6	
		40,000 lb. Bus	52.9	16.0	
		40,020 lb. Bus	54.0	16.2	
		40,030 lb. Bus	54.0	14.0	
		40,030 lb. Tractor-Trailer	53.0	15.0	Vehicle mounted and straddled the barrier.
F Profile Concrete Safety Shape	32	2,250 lb. Car	56.4	14.3	
		4,370 lb. Car	61.4	15.2	
		4,500 lb. Car	62.9	25.0	
California Type 18 (See-Through, Collapsing Ring)	36	1,850 lb. Car	59.7	12.0	
		4,530 lb. Car	60.7	23.0	
California Type 20 (N. J. Safety Shape with Rail)	39	4,895 lb. Car	47.0	5.0	
		4,895 lb. Car	54.0	5.0	
		4,895 lb. Car	57.0	5.0	
		4,895 lb. Car	62.0	5.0	
		4,895 lb. Car	57.0	10.0	
		4,895 lb. Car	65.0	15.0	
Nevada Safety Shape Parapet	39	1,911 lb. Car	60.7	19.3	
		4,650 lb. Car	61.4	24.9	
		40,000 lb. Bus	58.9	16.4	
New Jersey Turnpike Heavy Vehicle Barrier (Extended N. J. Safety Shape)	42	2,118 lb. Car	59.9	14.5	
		4,880 lb. Car	58.6	16.5	
		80,180 lb. Tractor-Trailer	52.1	16.5	
Collapsing Ring Bridge Railing	59	2,090 lb. Car	55.7	23.5	
		4,400 lb. Car	62.0	22.7	
		40,000 lb. Bus	53.9	15.1	
		40,000 lb. Tractor-Trailer	57.0	15.6	
		70,000 lb. Tractor-Trailer	44.4	10.0	
Texas T5 Modified (Extended N. J. Safety Shape)	90	80,120 lb. Tank Type Tractor-Trailer	51.4	15.0	

Table 7(b). FHWA bridge rail data

This contains drawings of the following bridge rails:

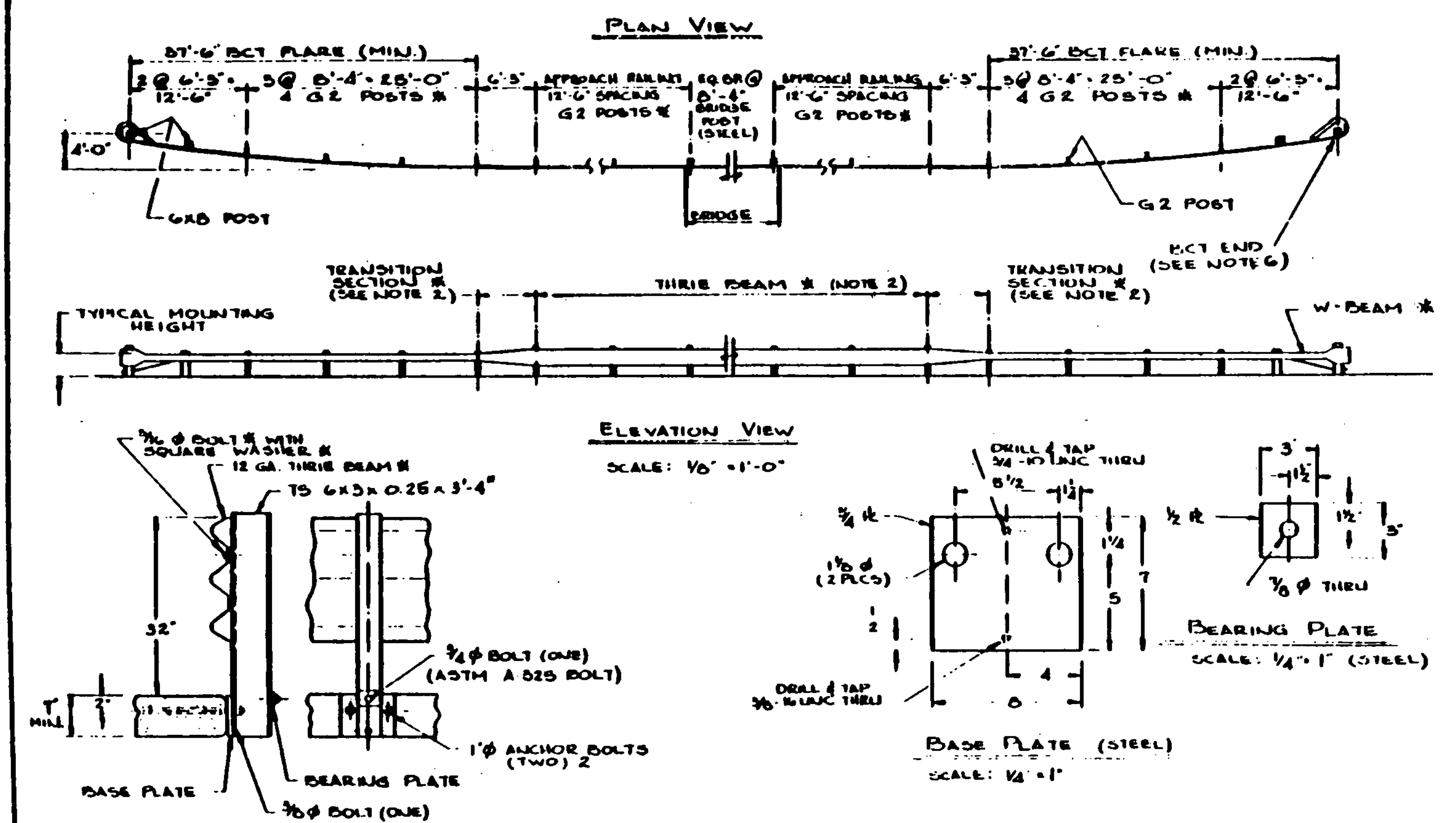
1. NCHRP SL1 Thrie Beam, Wood Post
2. NCHRP SL1 Thrie Beam, Steel Posts
3. Texas Type 6 (Tubular W-beam)
4. Aluminum Tru-Beam (Modified AASHTO BR5)
5. AASHTO BR2 (California Type 9)
6. Texas Energy Absorbing Bridge Rail
7. Texas T101 Bridge Rail
8. Ohio Box Beam Rail (W-beam backed up with box beam)
9. Modified Kansas Corral (Open Concrete Beam & Post)
10. Oklahoma Modified TR-1 Bridge Rail (Open Concrete Beam & Post)
11. Nebraska Tubular Thrie Beam
12. Oregon - 2 Tube Mounted Rail (Curb Mounted)
13. North Carolina - Standard 1 Bar Metal Rail
14. California Type 25 (N. J. Concrete Safety Shape)
15. N. J. Concrete Safety Shape
16. F Profile Concrete Safety Shape
17. California Type 18 (See - Through, Collapsing Ring)
18. California Type 20 (N. J. Safety Shape with rail)
19. Nevada Safety Shape Parapet
20. New Jersey Turnpike Heavy Vehicle Barrier (Extended N. J. Safety Shape)
21. Collapsing Ring Bridge Railing
22. Texas T5 Modified (Extended N. J. Safety Shape)

More detailed drawings are available from the Office of Engineering (HNG-21).



Service level 1 bridge railing drawing—wood post.

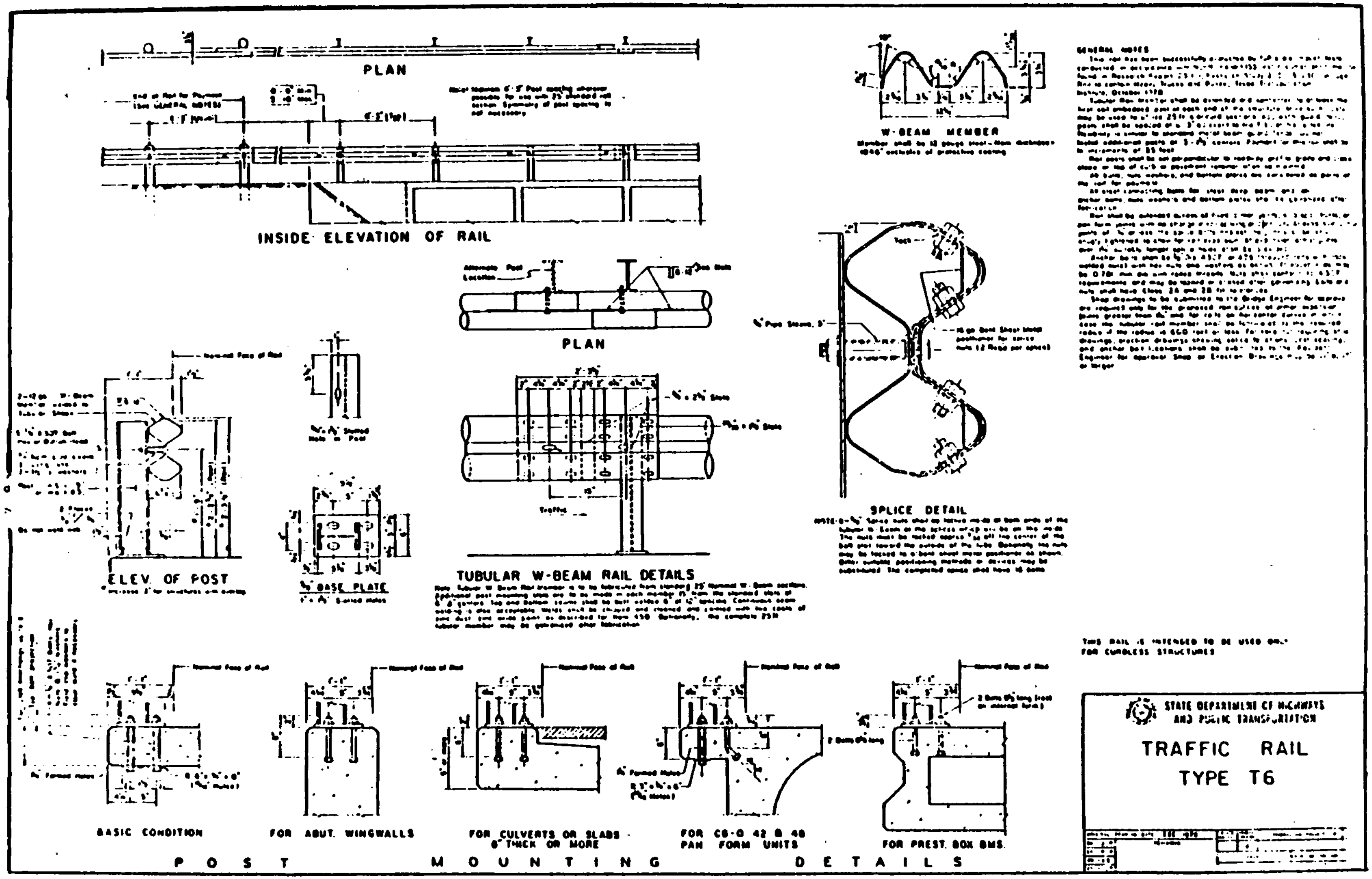
Table 7(b). Continued



NOTES:

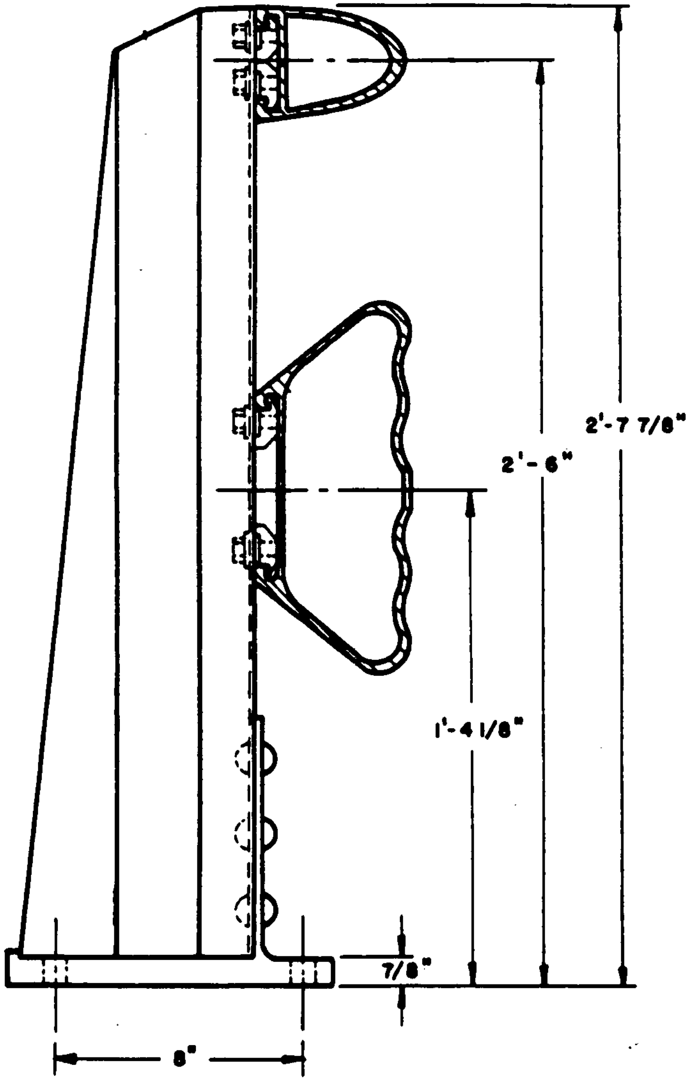
1. Components with asterisk can be found in the latest Guide to Standardized Highway Barrier Hardware, published by American Road and Transportation Builders Association, 525 School St., SW, Wash., D.C. Length of G2 posts used in approach railing should be increased by 8 in. to accommodate additional depth of Thrie beam.
2. Thrie beam and W-beam material and hardware are specified in AASHTO M-180-78.
3. Unless otherwise noted bolts shall conform to requirements of ASTM A307 and nuts to requirements of ASTM A563, Grade A or better. Other bolts shall conform to the requirements of ASTM A325 and nuts to the requirements of ASTM A563, Grade C or better. All nuts and bolts shall be galvanized in accordance with ASTM A153.
4. Deck anchorage of the post assembly shall be provided by applying a 10-kip (45-kN) force to the post at 22 in. (550 mm) above the deck and designed according to the latest AASHTO bridge specification.
5. Steel shall conform to requirements of ASTM A-36 or equivalent and be galvanized according to ASTM A123.
6. BCT guardrail terminal details are specified in NCHRP Research Results Digest 102 or later revision.
7. Post elements shall conform to the requirements of ASTM A500 Grade B or ASTM A501 and be galvanized in accordance with the requirements of ASTM A123.

Service level I bridge railing drawing—steel post.

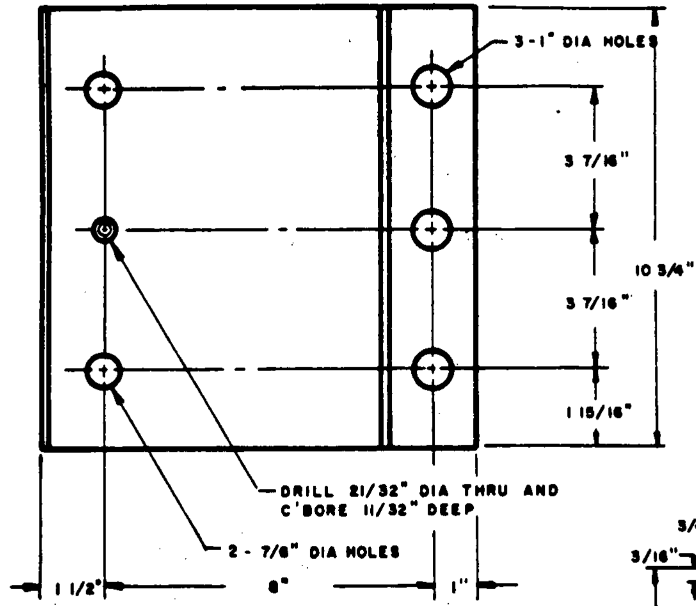


TEXAS TYPE T6 RAILING, SL2

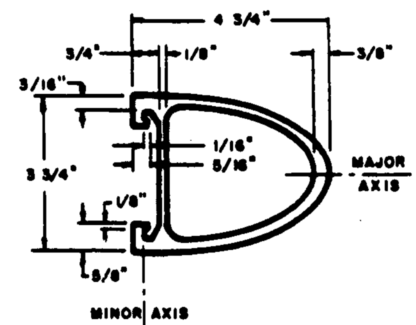
Table 7(b). Continued



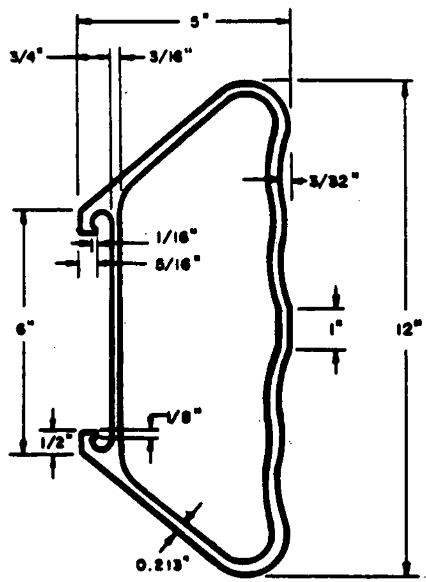
Aluminum Tru-Beam (Modified AASHTO BR5)



BASE PLATE - 7/8" THICK



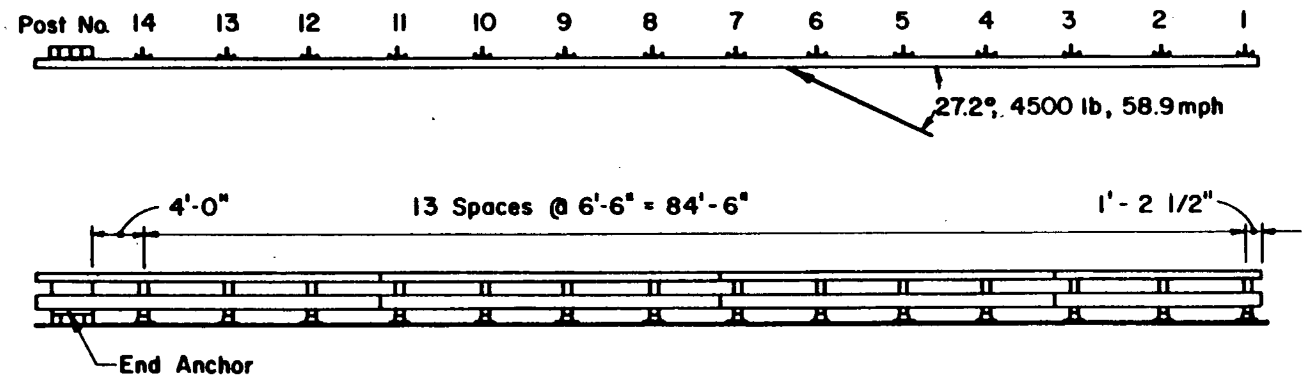
4 3/4" x 3 3/4" SEMI-ELLIPSE RAIL



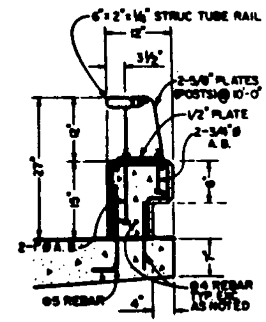
MAGNODE TRU-BEAM RAIL ELEMENT

Post and Rail Element Detail.

SCALE: 3" = 1'-0"

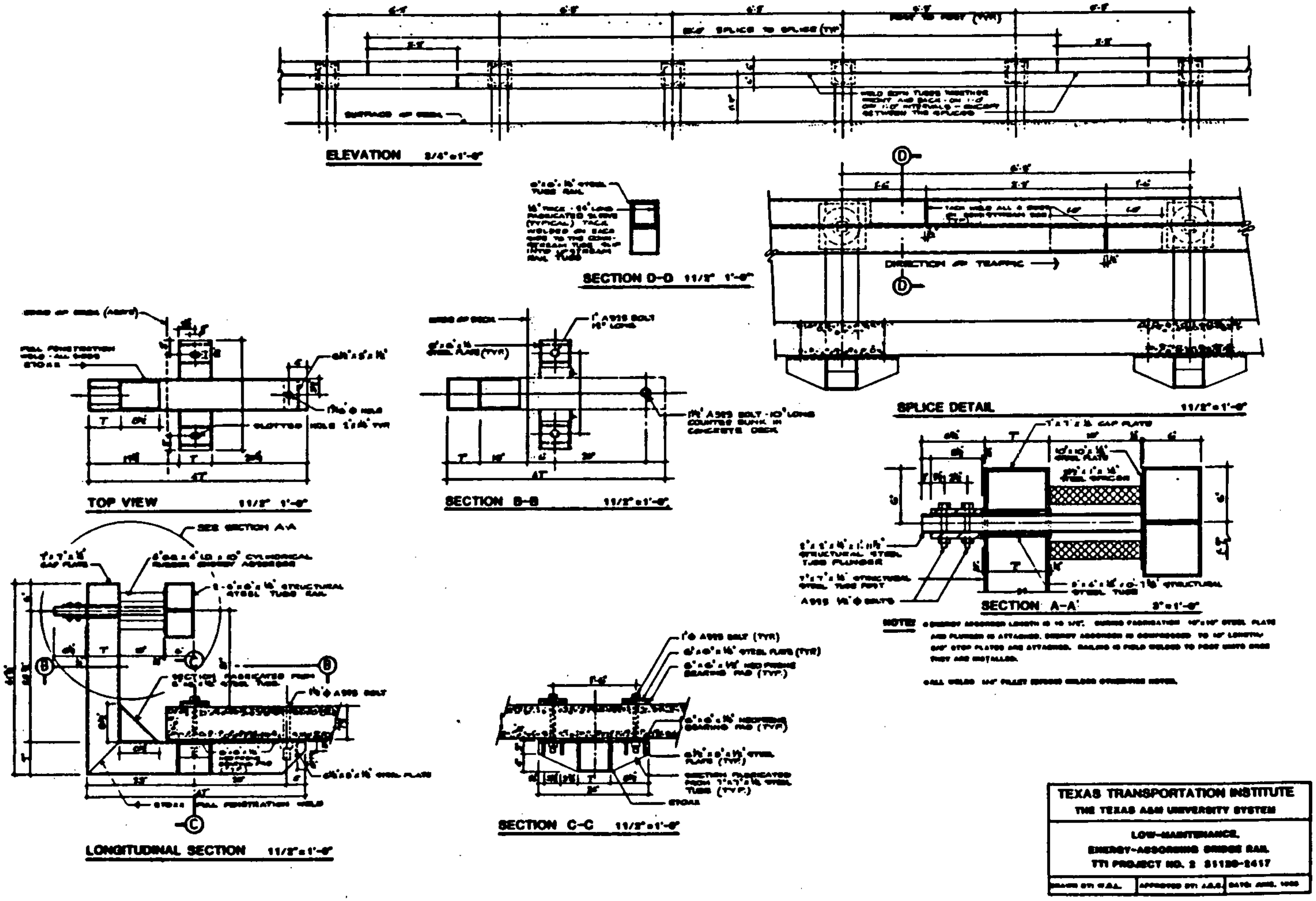


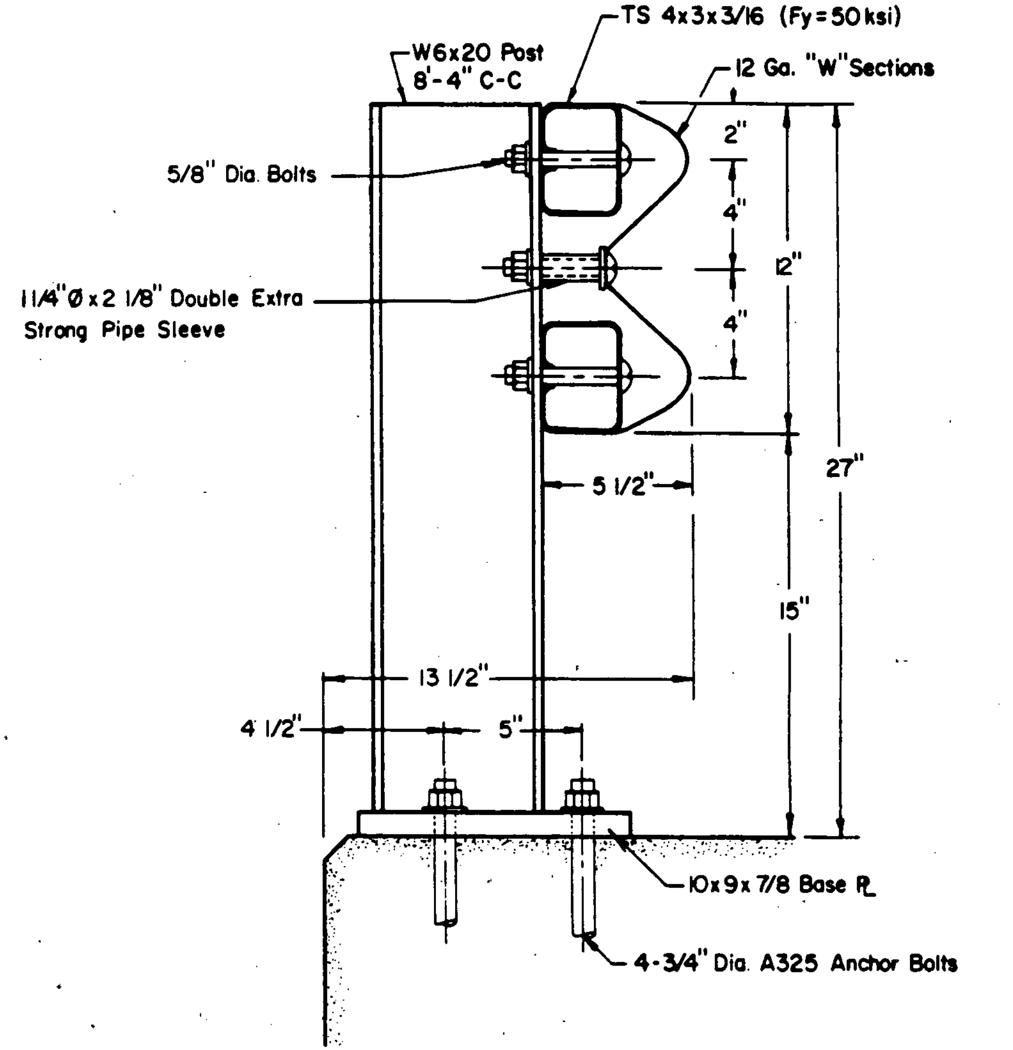
Test Installation of Modified Indiana Bridge Railing with the Magnode Tru-Beam Bottom Rail Element.



TYPE 9

Table 7(b). Continued



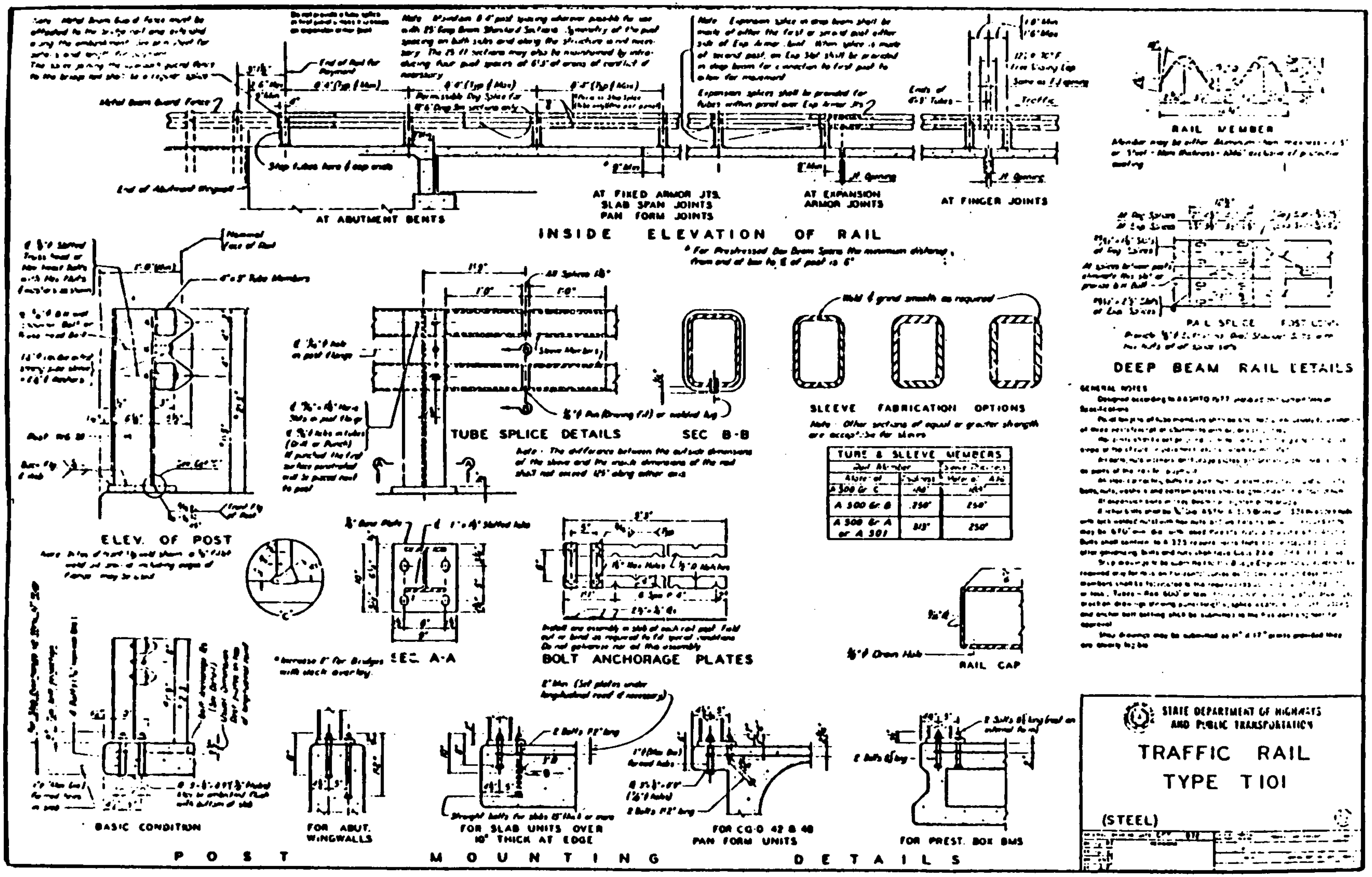


1 in. = 25.40 mm
1 ft = 0.305 m

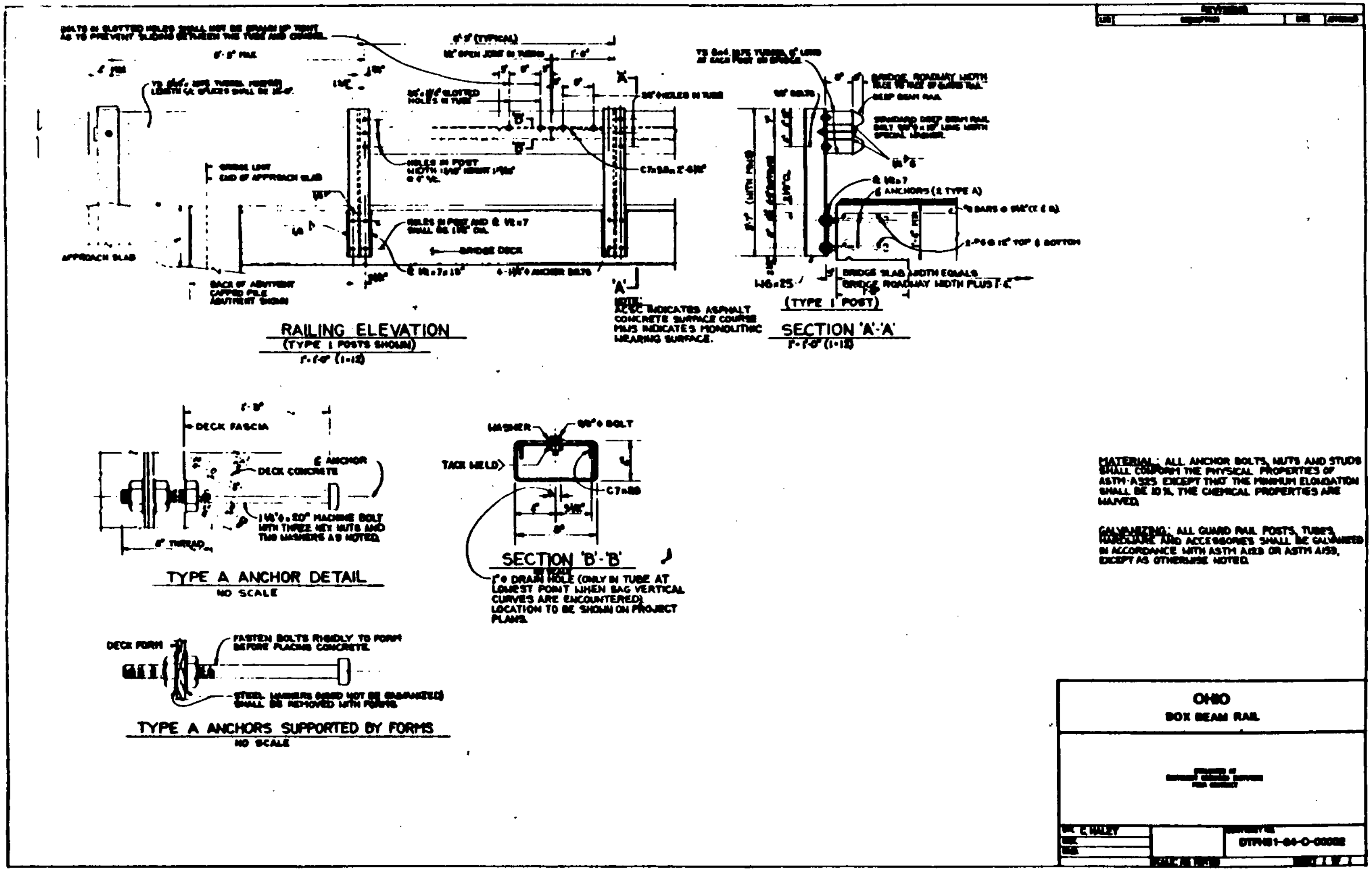
T 101

Cross Section of Texas T101 Railing.

Table 7(b). Continued

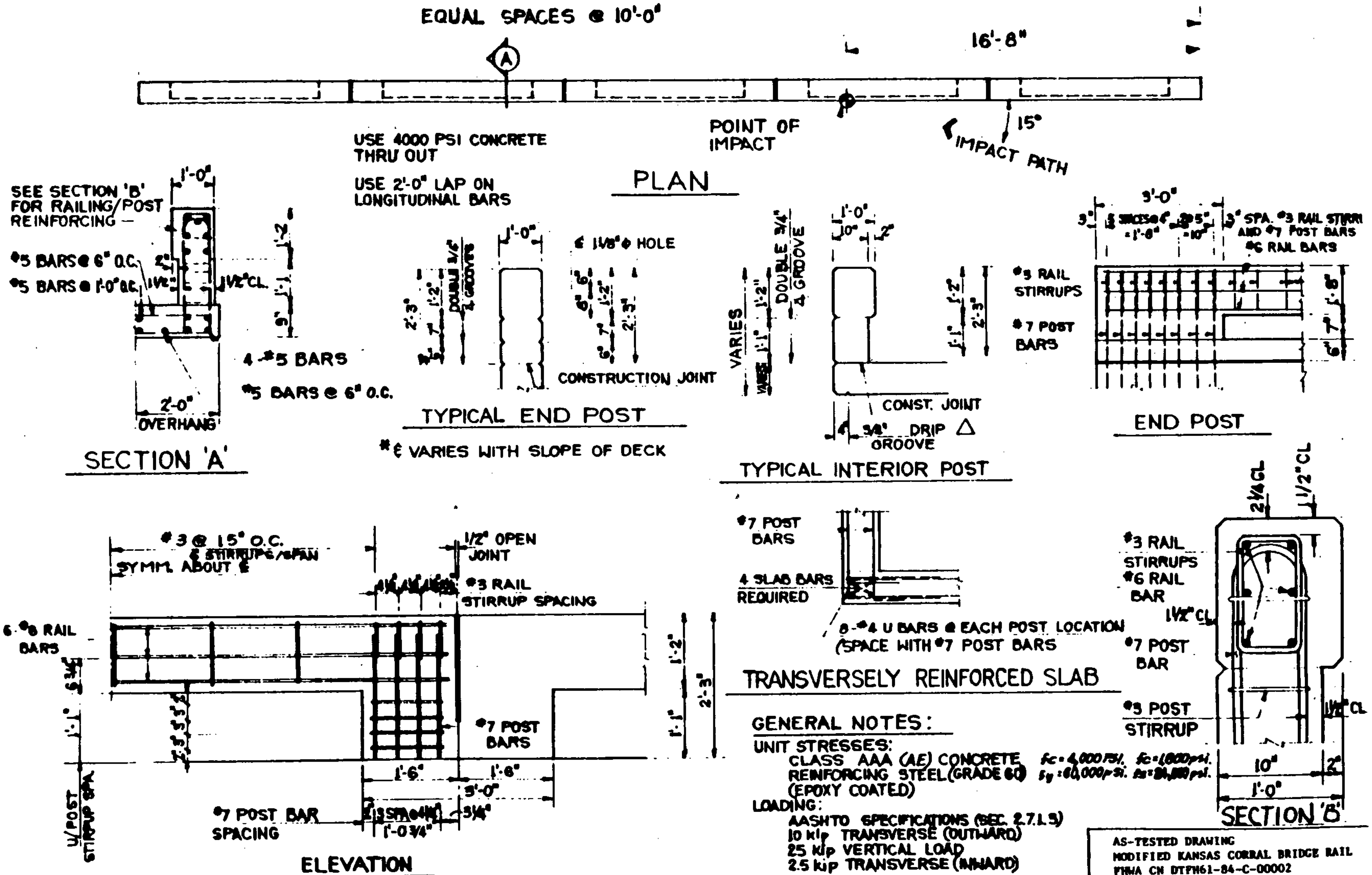


TEXAS TYPE T101 RAILING


RAILING ELEVATION
(TYPE 1 POSTS SHOWN)
SECTION 'A'-'A'
(TYPE 1 POST)
NOTE:
AC SC INDICATES ASPHALT CONCRETE SURFACE COURSE
MWS INDICATES MONOLITHIC WEARING SURFACE.
APPROACH SLAB
BRIDGE DECK
DECK FASCIA
DECK CONCRETE
TYPE A ANCHOR DETAIL
NO SCALE
SECTION 'B'-'B'
WASHER
TACK WELD
1" ⌀ DRAIN HOLE (ONLY IN TUBE AT LOWEST POINT WHEN SAG VERTICAL CURVES ARE ENCOUNTERED) LOCATION TO BE SHOWN ON PROJECT PLANS.
DECK FORM
FASTEN BOLTS RIGIDLY TO FORM BEFORE PLACING CONCRETE.
TYPE A ANCHORS SUPPORTED BY FORMS
NO SCALE
MATERIAL: ALL ANCHOR BOLTS, NUTS AND STUDS SHALL CONFORM THE PHYSICAL PROPERTIES OF ASTM A325 EXCEPT THAT THE MINIMUM ELONGATION SHALL BE 10 %. THE CHEMICAL PROPERTIES ARE WAIVED.
GALVANIZING: ALL GUARD RAIL POSTS, TUBES, HARDWARE AND ACCESSORIES SHALL BE GALVANIZED IN ACCORDANCE WITH ASTM A123 OR ASTM A153, EXCEPT AS OTHERWISE NOTED.
OHIO
BOX BEAM RAIL
DTFH61-84-C-00002

153

Table 7(b). Continued



GENERAL NOTES:

UNIT STRESSES:
CLASS AAA (AE) CONCRETE $f'_c = 4{,}000$ psi, $f_c = 1{,}600$ psi.
REINFORCING STEEL (GRADE 60) $f_y = 60{,}000$ psi, $f_s = 24{,}000$ psi.
(EPOXY COATED)

LOADING:
AASHTO SPECIFICATIONS (SEC. 2.7.1.3)
10 kip TRANSVERSE (OUTWARD)
25 kip VERTICAL LOAD
2.5 kip TRANSVERSE (INWARD)

AS-TESTED DRAWING
MODIFIED KANSAS CORRAL BRIDGE RAIL
FHWA CN DTFH61-84-C-00002

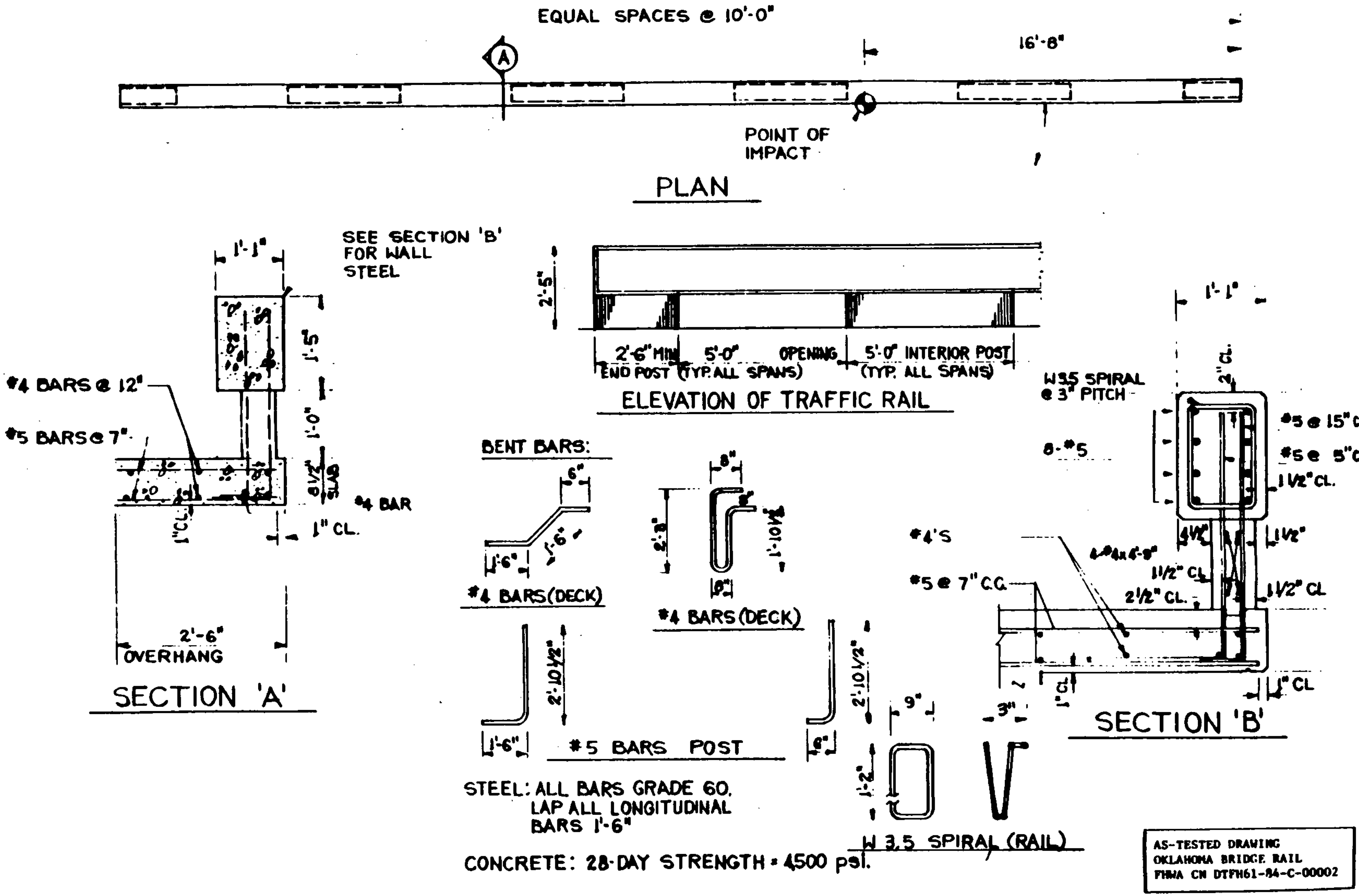
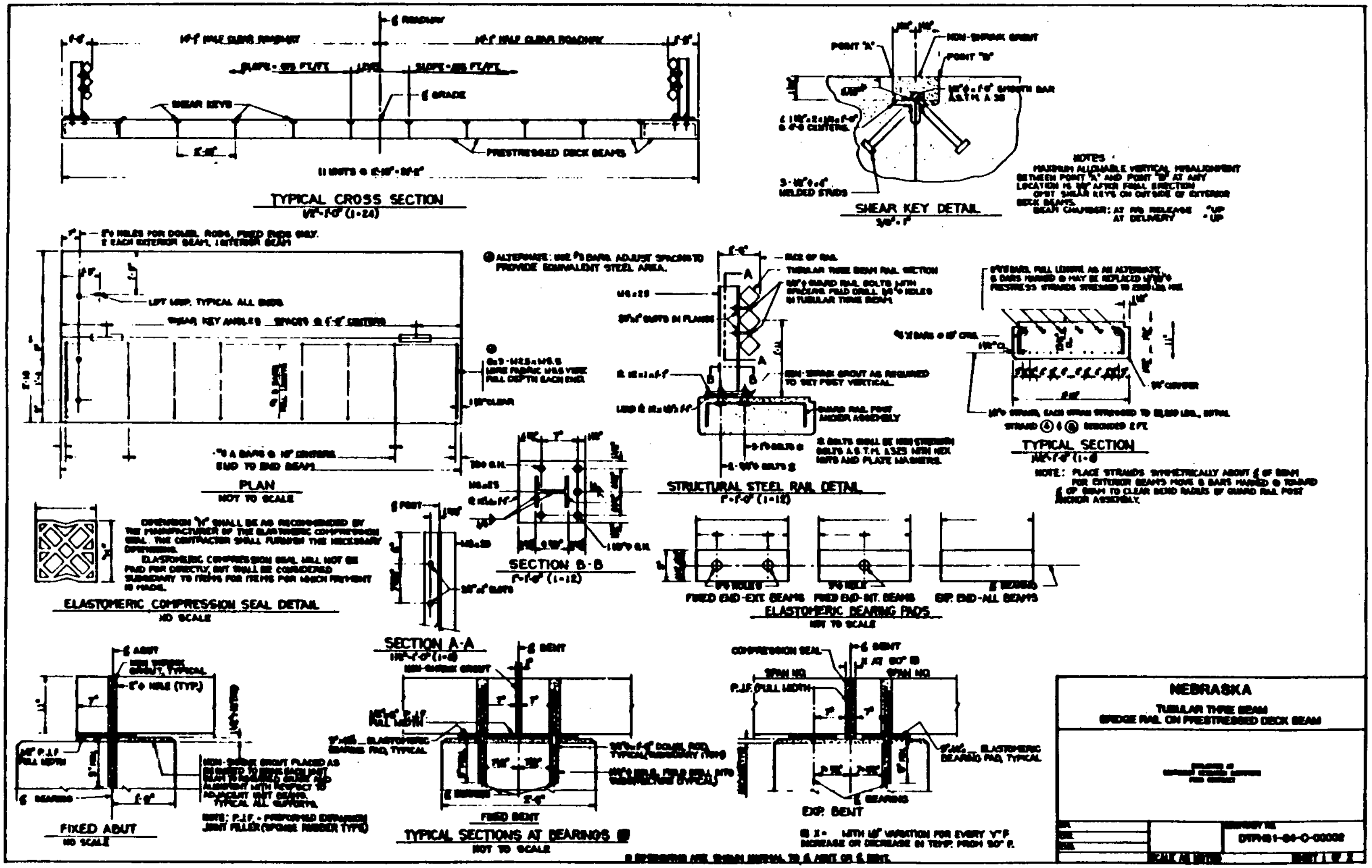

EQUAL SPACES @ 10'-0"
16'-8"
A
POINT OF IMPACT
PLAN
SEE SECTION 'B' FOR WALL STEEL
1'-1"
1'-5"
1'-0"
#4 BARS @ 12"
#5 BARS @ 7"
#4 BAR
1" CL.
2'-6"
OVERHANG
SECTION 'A'
2'-5"
2'-6" MIN END POST
5'-0" OPENING (TYP. ALL SPANS)
5'-0" INTERIOR POST (TYP. ALL SPANS)
ELEVATION OF TRAFFIC RAIL
BENT BARS:
6"
1'-6"
#4 BARS (DECK)
8"
#4 BARS (DECK)
2'-10 1/2"
1'-6"
#5 BARS POST
STEEL: ALL BARS GRADE 60.
LAP ALL LONGITUDINAL BARS 1'-6"
CONCRETE: 28-DAY STRENGTH = 4500 psi.
9"
3"
1'-2"
W 3.5 SPIRAL (RAIL)
W3.5 SPIRAL @ 3" PITCH
8-#5
#5 @ 15" C.C.
#5 @ 5" C.C.
1 1/2" CL.
#4'S
#5 @ 7" C.C.
2 1/2" CL.
1 1/2" CL
1" CL
SECTION 'B'
AS-TESTED DRAWING
OKLAHOMA BRIDGE RAIL
FHWA CN DTFH61-84-C-00002

Table 7(b). Continued



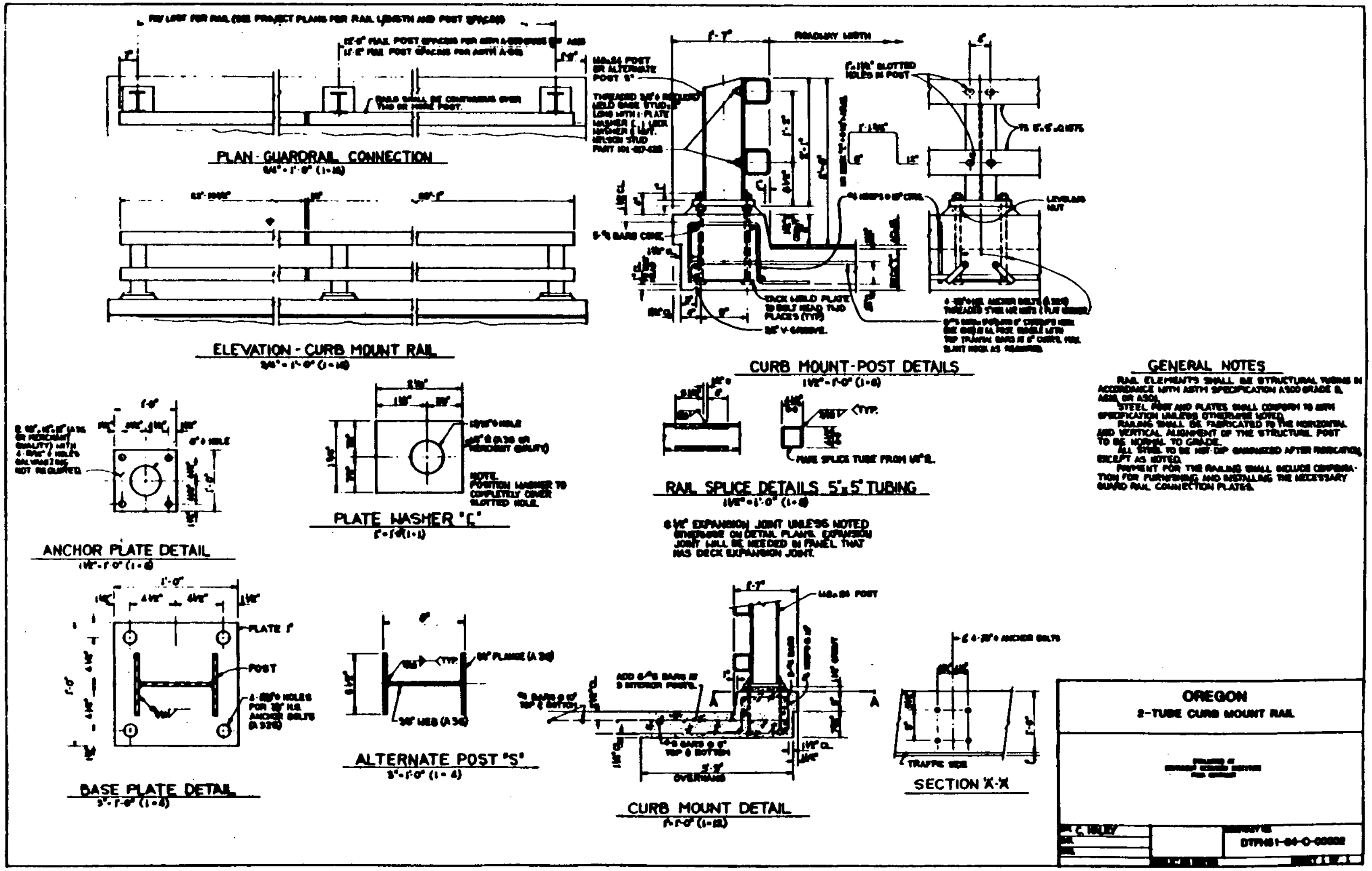
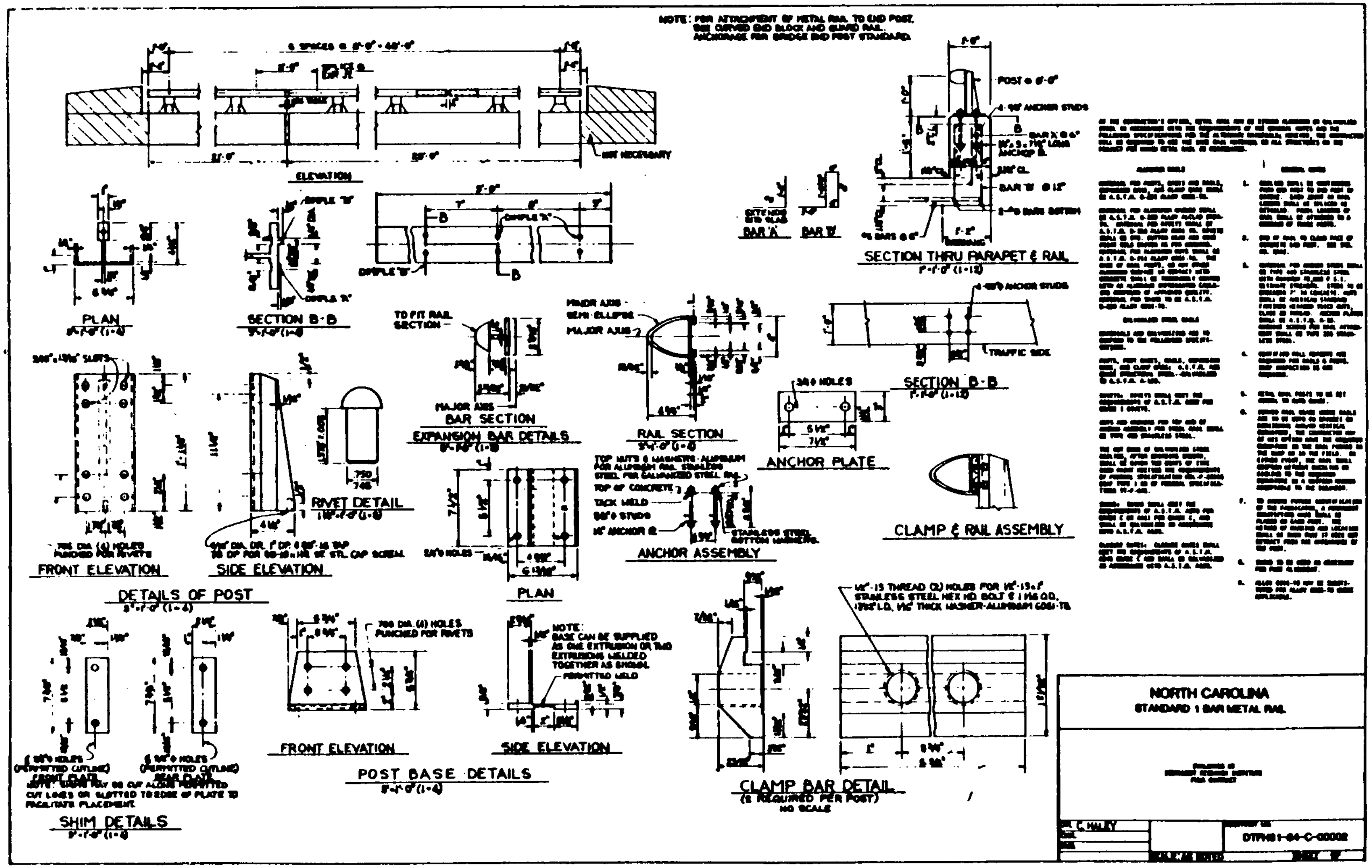
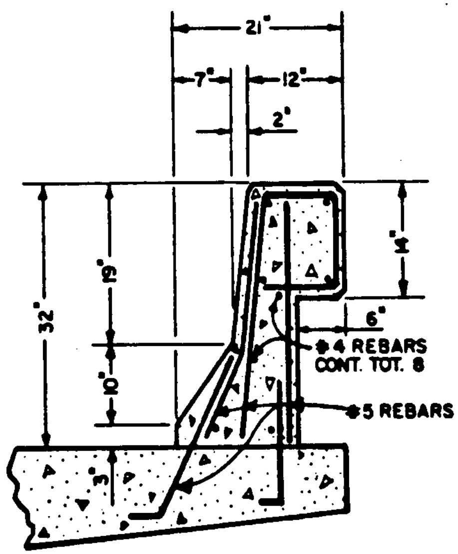

PLAN - GUARDRAIL CONNECTION
ELEVATION - CURB MOUNT RAIL
CURB MOUNT-POST DETAILS
GENERAL NOTES
ANCHOR PLATE DETAIL
PLATE WASHER "C"
RAIL SPLICE DETAILS 5"x5" TUBING
BASE PLATE DETAIL
ALTERNATE POST "S"
CURB MOUNT DETAIL
SECTION 'X-X'
OREGON
2-TUBE CURB MOUNT RAIL

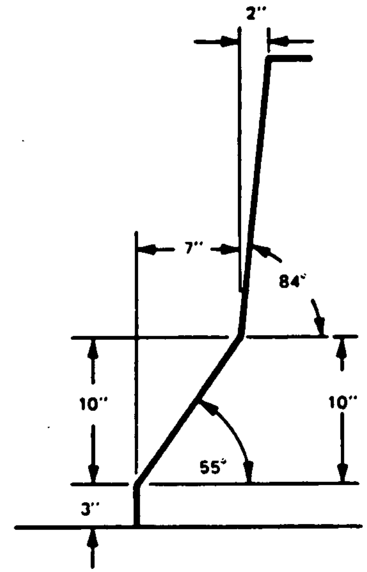
Table 7(b). Continued



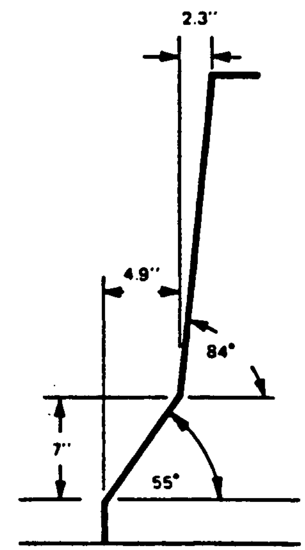


TYPE 25

California Type 25



N. J. Concrete Safety Shape



F Profile Concrete Safety Shape

Table 7(b). Continued

FIGURE E2 TEST BARRIER

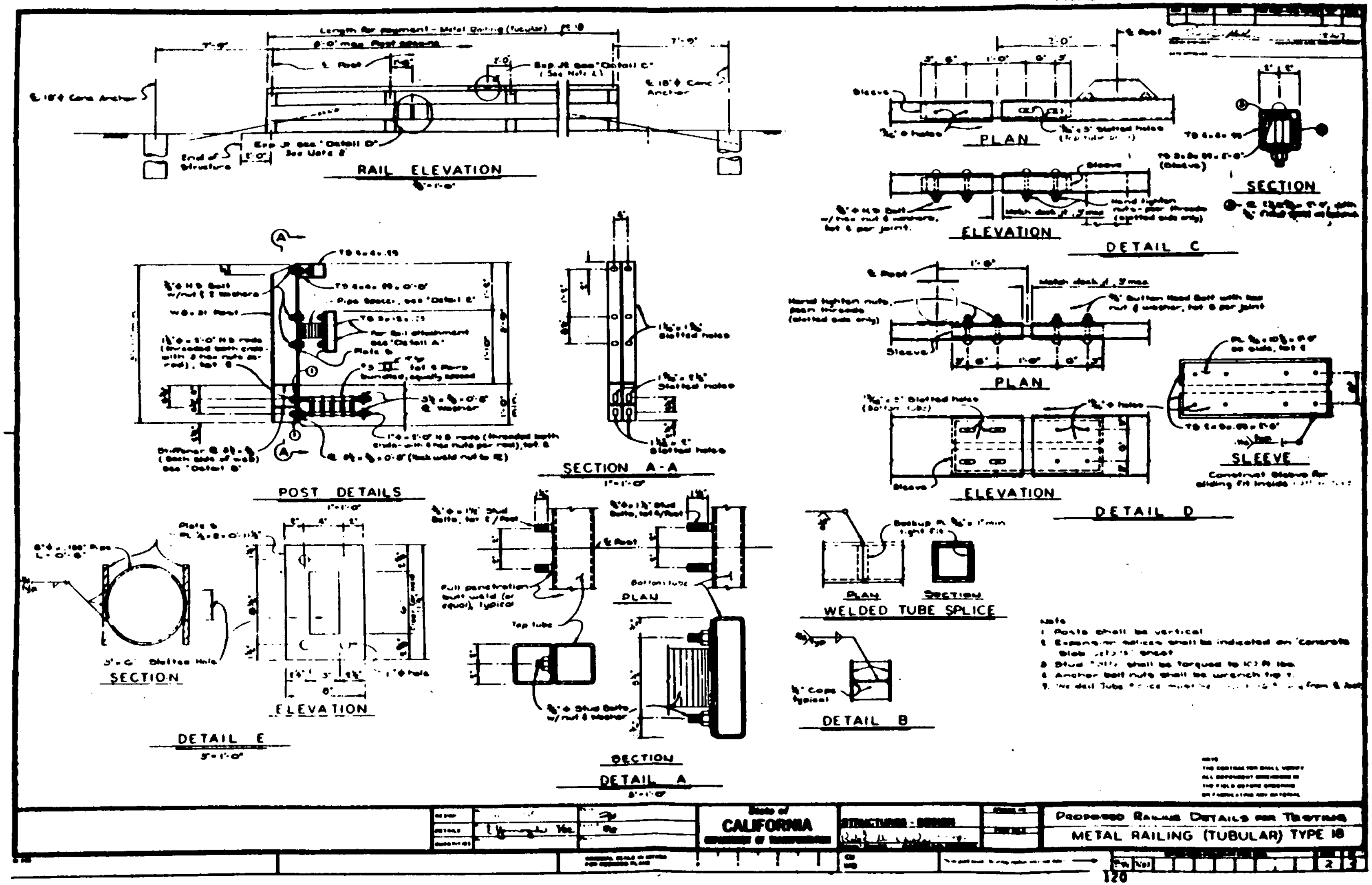
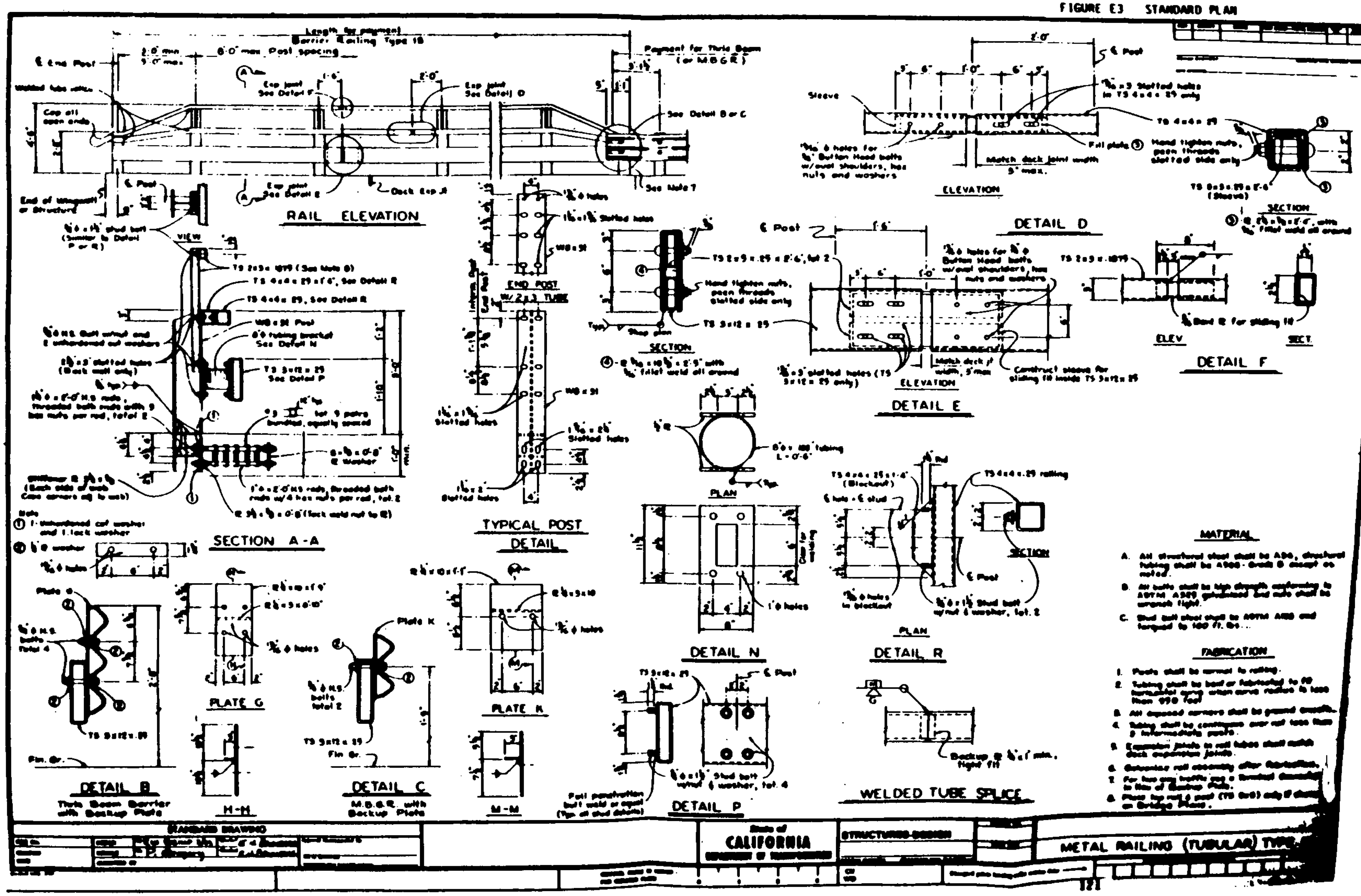
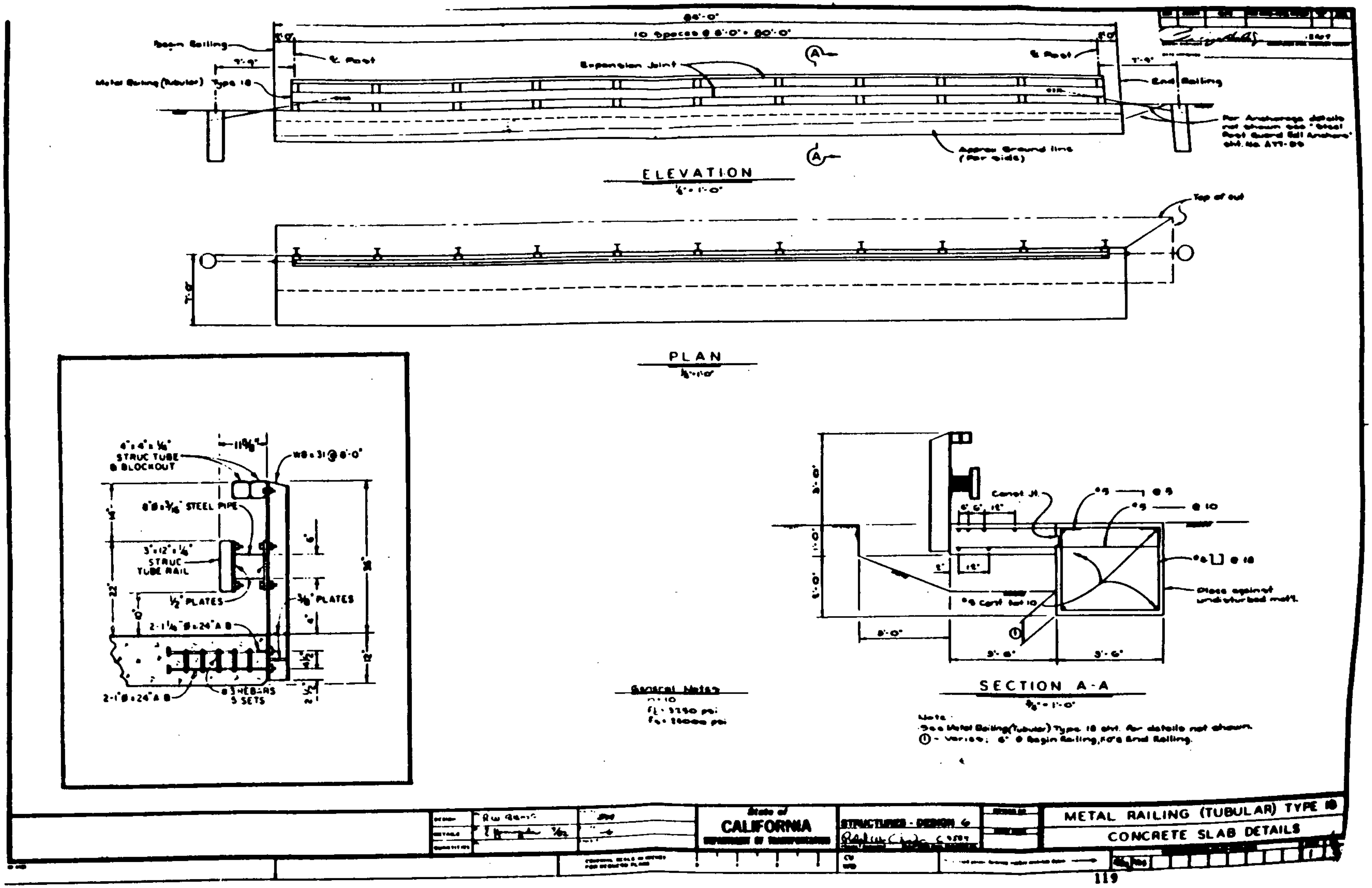
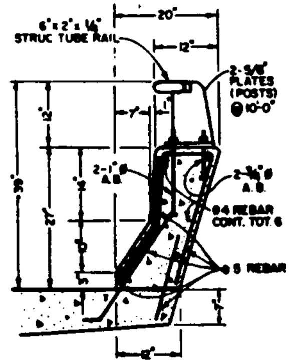


FIGURE E3 STANDARD PLAN




ELEVATION
PLAN
SECTION A-A
STRUC TUBE
STEEL PIPE
STRUC TUBE RAIL
PLATES
PLATES
REBARS
5 SETS
CALIFORNIA
METAL RAILING (TUBULAR) TYPE 18
CONCRETE SLAB DETAILS



California Type 20

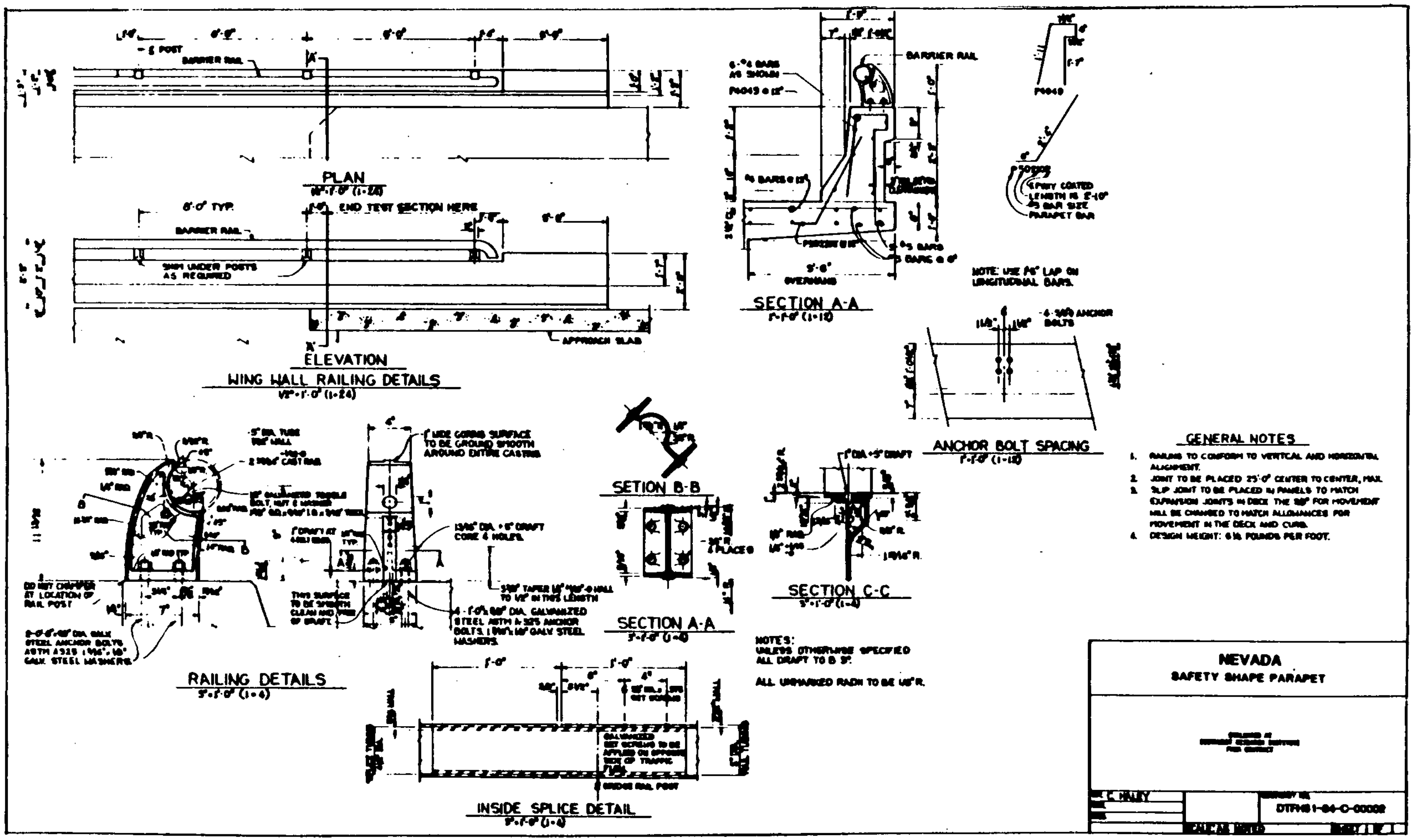
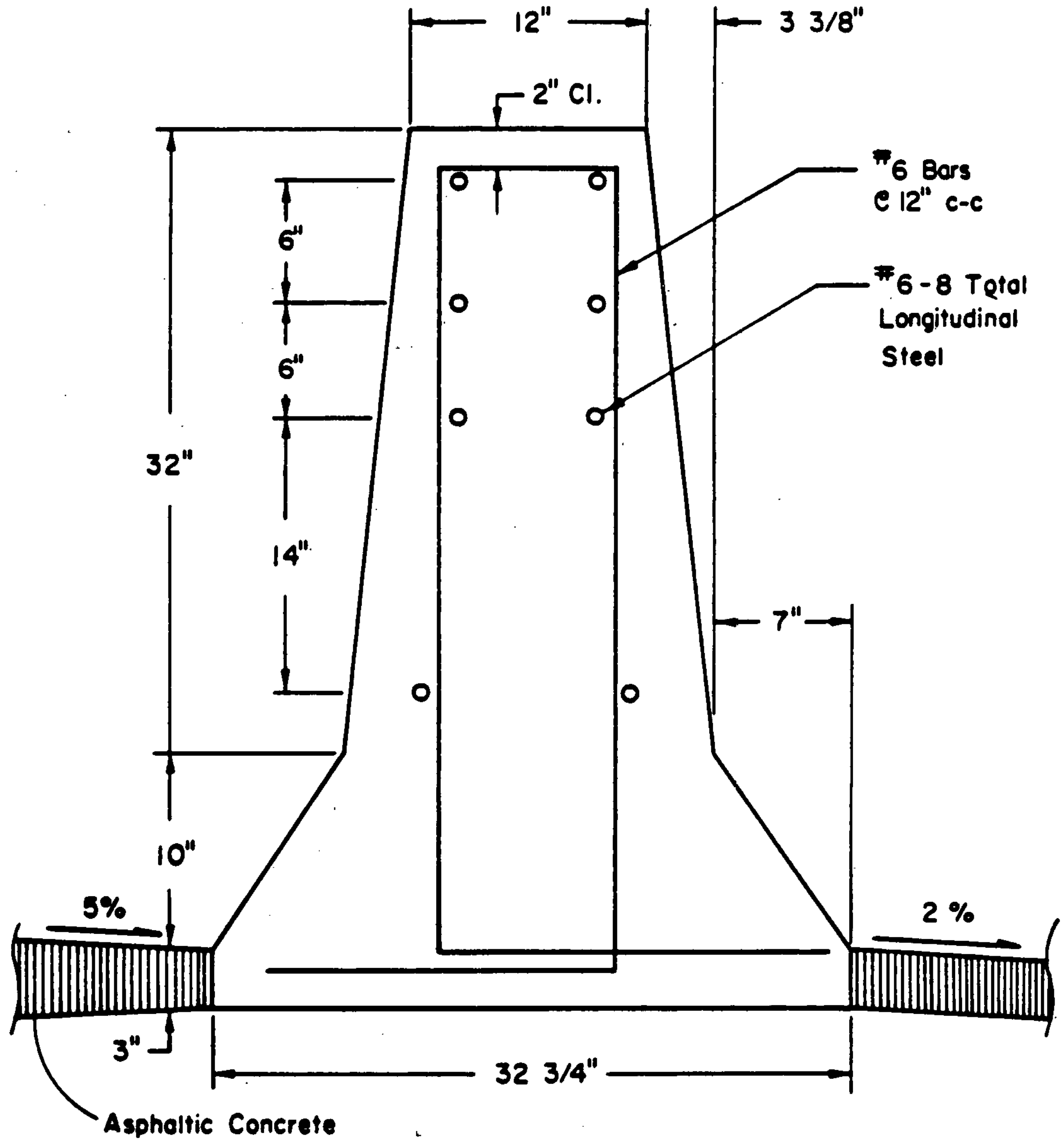
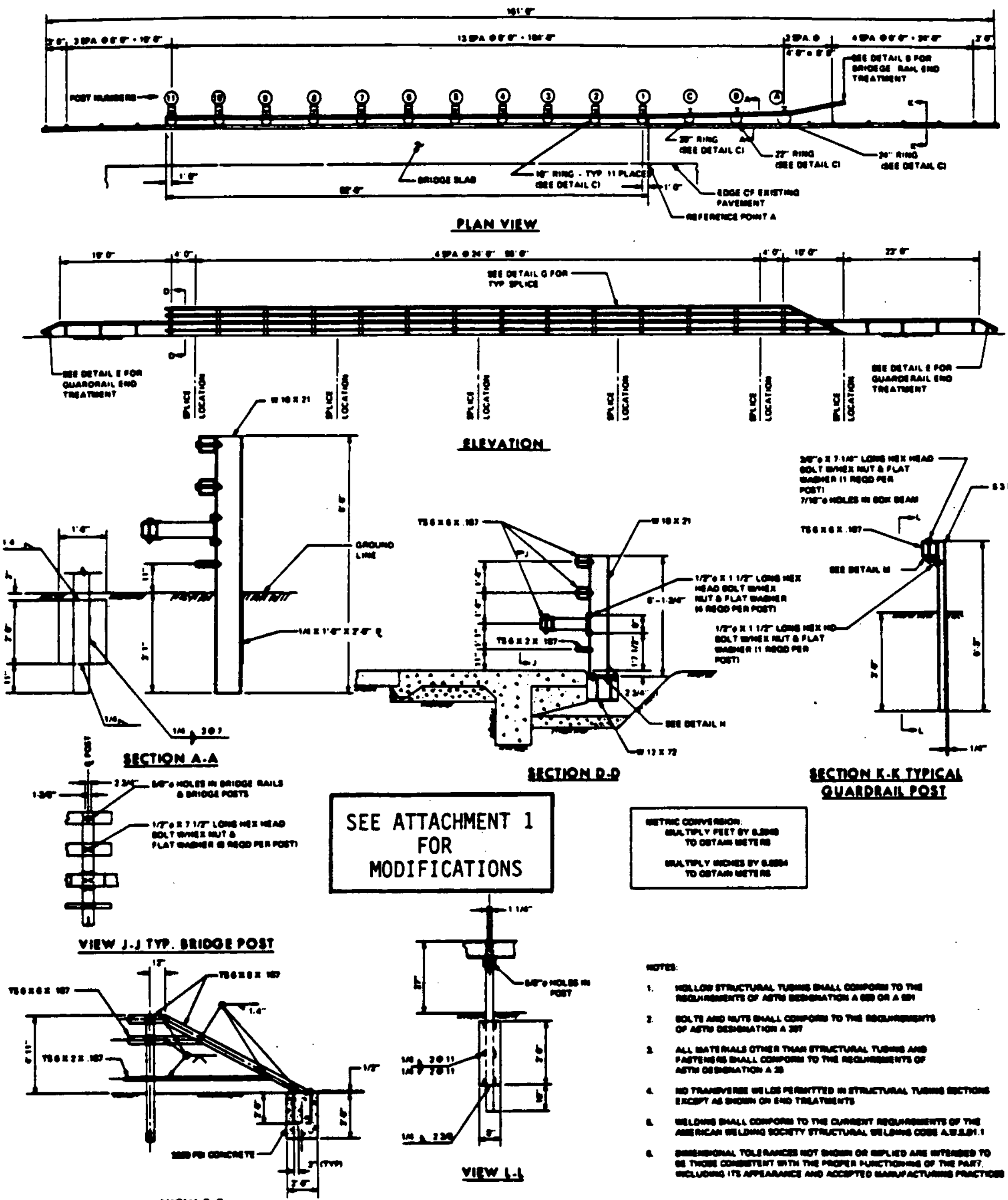


Table 7(b). Continued

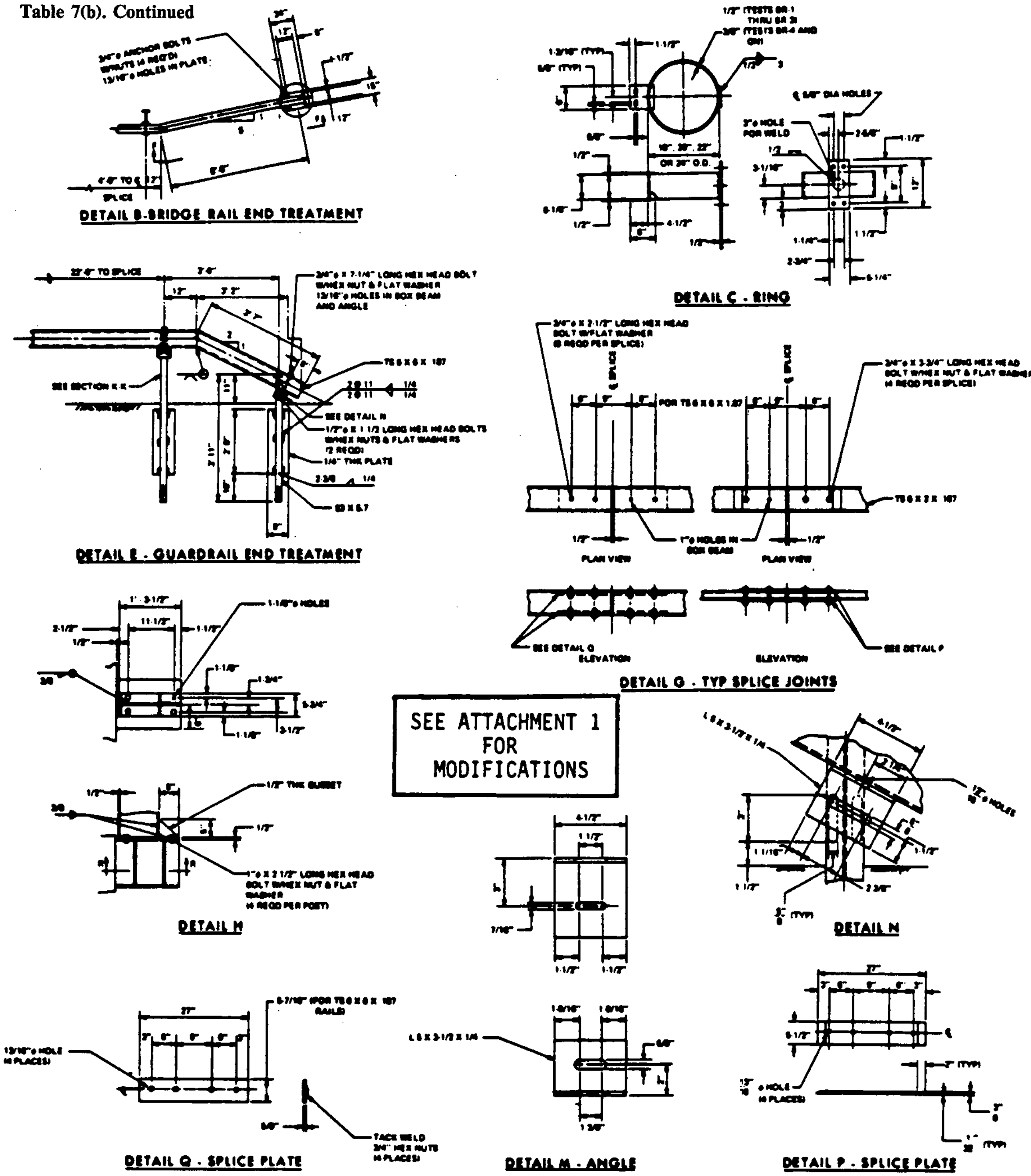


New Jersey Turnpike Heavy Vehicle Barrier



COLLAPSING RING BRIDGERAIL SYSTEM

Table 7(b). Continued



COLLAPSING RING BRIDGERAIL SYSTEM (Cont'd)

ATTACHMENT 1

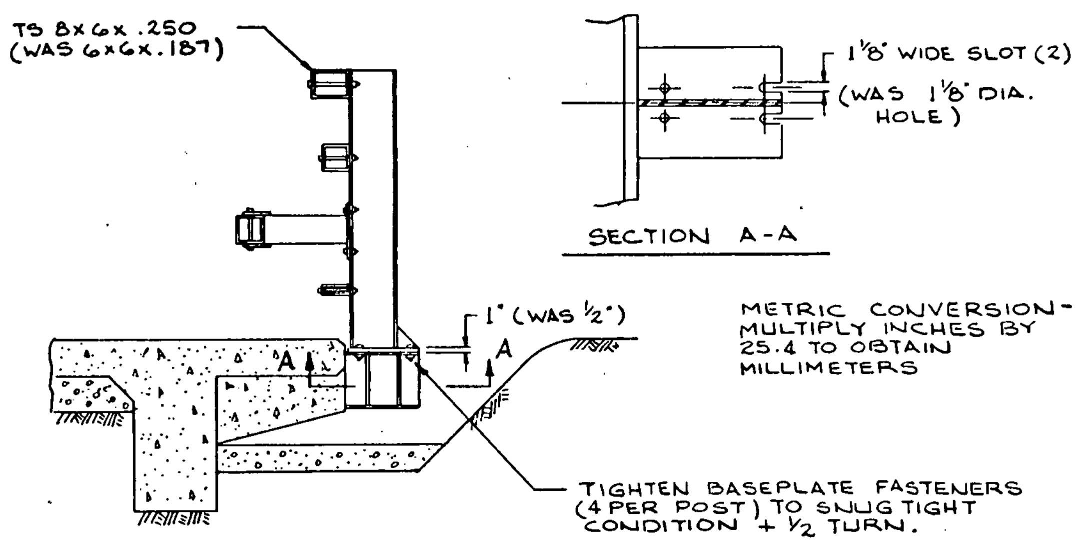
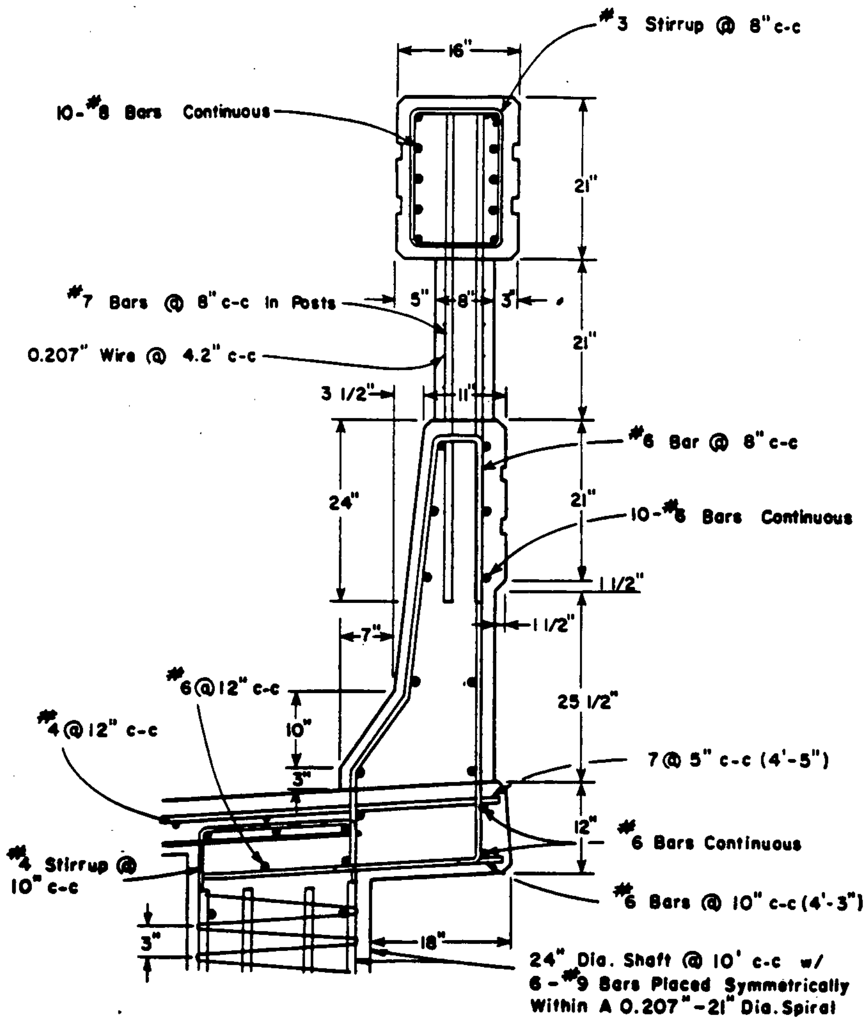
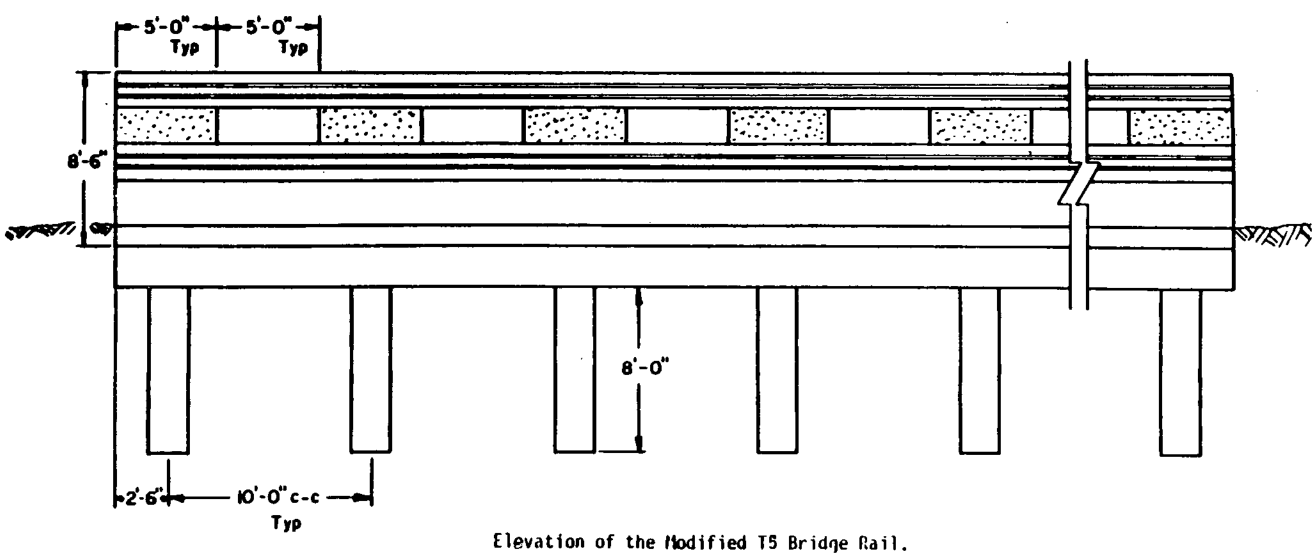


Table 7(b). Continued



Cross Section of the Modified T5 Bridge Rail and Modified Bridge Deck.



Elevation of the Modified T5 Bridge Rail.

APPENDIX B

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