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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
REPORT **129**

GUARDRAIL CRASH TEST EVALUATION

~~NEW CONCEPTS~~ AND ~~END DESIGNS~~

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM REPORT 129

GUARDRAIL CRASH TEST EVALUATION

NEW CONCEPTS AND END DESIGNS

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SOUTHWEST RESEARCH INSTITUTE
SAN ANTONIO, TEXAS

RESEARCH SPONSORED BY THE AMERICAN ASSOCIATION
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WITH THE FEDERAL HIGHWAY ADMINISTRATION

AREAS OF INTEREST:
HIGHWAY DESIGN
HIGHWAY SAFETY

HIGHWAY RESEARCH BOARD
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NATIONAL ACADEMY OF SCIENCES — NATIONAL ACADEMY OF ENGINEERING 1972

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Highway Research Board of the National Academy of Sciences-National Research Council was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as: it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state, and local governmental agencies, universities, and industry; its relationship to its parent organization, the National Academy of Sciences, a private, nonprofit institution, is an insurance of objectvity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway departments and by committees of AASHO. Each year, specific areas of research needs to be included in the program are proposed to the Academy and the Board by the American Association of State Highway Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are responsibilities of the Academy and its Highway Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

NCHRP Report 129

Project 15-1(2) FY '70
ISBN 0-309-02010-7
L. C. Catalog Card No. 72-77532

Price $4.80

This report is one of a series of reports issued from a continuing research program conducted under a three-way agreement entered into in June 1962 by and among the National Academy of Sciences-National Research Council, the American Association of State Highway Officials, and the Federal Highway Administration. Individual fiscal agreements are executed annually by the Academy-Research Council, the Federal Highway Administration, and participating state highway departments, members of the American Association of State Highway Officials.

This report was prepared by the contracting research agency. It has been reviewed by the appropriate Advisory Panel for clarity, documentation, and fulfillment of the contract. It has been accepted by the Highway Research Board and published in the interest of effective dissemination of findings and their application in the formulation of policies, procedures, and practices in the subject problem area.

The opinions and conclusions expressed or implied in these reports are those of the research agencies that performed the research. They are not necessarily those of the Highway Research Board, the National Academy of Sciences, the Federal Highway Administration, the American Association of State Highway Officials, nor of the individual states participating in the Program.

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FOREWORD

By Staff
Highway Research Board

This report is recommended to highway design engineers and others concerned with highway safety. It contains information on a guardrail end design that appears to offer improved safety performance. In addition, results of full-scale tests on a hydraulic post guardrail design and concepts for improved end and transition designs should be of interest to researchers.

Research and development efforts over the last ten years have resulted in reasonably effective guardrail and median barrier designs. However, the terminal and transition details of most longitudinal barriers are not as effective in safety capability as the typical cross-section. Therefore, the phase of NCHRP Project 15-1(2) reported herein was devoted to conceiving and developing improved end and transition designs for longitudinal traffic barriers.

Southwest Research Institute (SwRI) performed a conceptual study that included design considerations, service requirements, and performance evaluation criteria, and resulted in some 15 conceptual designs. Laboratory experiments were performed to provide information for a prototype end design for W-beam rail on strong timber or steel posts. Three full-scale crash tests were conducted to evaluate the new design—the Breakaway Cable Terminal (BCT).

In addition, four full-scale crash tests were conducted on the Christiani & Nielsen hydraulic post barrier. The results of all tests are given herein.

This report is the fifth of five documents reporting on research that originated as NCHRP Project 15-1, "Guardrail Design." The first, *NCHRP Report 36,* was authored by Cornell Aeronautical Laboratory and presents a state-of-the-art review of barrier technology prior to 1967. *NCHRP Report 54,* "Location, Selection, and Maintenance of Highway Guardrails and Median Barriers," reported on follow-on work by Southwest Research Institute and was prepared as an interim report on NCHRP Project 15-1(2) with the purpose of providing an up-to-date, concise instructional manual for highway design engineers. The program findings of NCHRP Project 15-1(2), including results of 25 full-scale crash tests, are reported in *NCHRP Report 115.* The fourth document, *NCHRP Report 118,* "Location, Selection and Maintenance of Highway Traffic Barriers," was prepared as an interim report on NCHRP Project 15-1(2) and supersedes *NCHRP Report 54.*

This document is the final report of NCHRP Project 15-1(2) and presents findings and results exclusive of those that have been previously published in *NCHRP Reports 36, 54, 115,* and *118.*

The need for improved end designs for longitudinal traffic barriers other than the W-beam rail on strong posts is still critical. Therefore, the SwRI research has been extended to provide for an additional series of 25 full-scale crash tests to evaluate other prototype end designs. This work is being done as NCHRP Project 22-2, "Traffic Barrier Performance and Design," and will extend through early 1973.

CONTENTS

ACKNOWLEDGMENTS

The research reported herein was conducted at Southwest Research Institute by the Department of Structural Research. Jarvis D. Michie, Manager, Transportation Structural Systems Section, served as principal investigator. He was assisted by Maurice E. Bronstad, Senior Research Engineer. Others of the Institute staff connected with this work included Dr. Lowell Greimann, who performed computer tasks; Glenn Deel, who was responsible for crash test vehicles; and C. A. Walker and L. B. Ferguson, who were responsible for crash test photography. Dr. R. C. DeHart, Director, and L. U. Rostrelli, Assistant Director, served in the capacity of technical and administrative advisors.

The assistance and cooperation of many persons in state highway departments, manufacturing firms, and government agencies are gratefully asknowledged. In particular, cooperation from G. Persicke, Christiani & Nielsen Ltd. of England, the California Division of Highways, and the Idaho Highway Department is recognized. The General Motors Proving Ground provided the anthropometric dummy used in all full-scale crash tests; guardrail materials used in the full-scale crash test installations were donated by Armco Steel Corporation, Syro Steel Company, Christiani & Nielsen Ltd., and Texas Vermiculite Company.

GUARDRAIL CRASH TEST EVALUATION

NEW CONCEPTS AND END DESIGNS

SUMMARY

Accident reports and test experience have shown that many of the current guardrail terminal designs, in particular the upstream installation end, are hazardous roadside features and may launch or spear an impacting vehicle. Also, poor structural transitions between approach guardrail and bridge rail have caused fatal accidents when impacting vehicles are pocketed at the juncture. The two objectives of the research reported herein were to (1) formulate new traffic barrier terminal and transition concepts and (2) evaluate by full-scale crash tests selected traffic barrier concepts.

Service requirements for traffic barrier terminals were formulated, and twelve terminal and three transition concepts were developed. From these concepts, three for terminal and one for transition were selected for further design and evaluation effort.

Three full-scale crash tests were conducted on the finalized guardrail terminal design, which had been judged to be most promising and was assigned top priority. End-on crash tests of the terminal with and without a horizontal flare were conducted. Results of the tests indicate that both configurations demonstrated adequate performance in view of crash severity; however, the flared terminal demonstrated better performance considering vehicle dynamic stability. A 15-deg angle impact in the second span from the end demonstrated the effectiveness of the new terminal as an anchor; the vehicle was satisfactorily redirected, with no damage or distress in the barrier anchor assembly. All three terminal tests resulted in conformance with the service requirements that had previously been formulated. The breakaway cable terminal is recommended for immediate field use on a trial basis.

Four full-scale crash tests were conducted on the Christiani & Nielsen hydraulic post traffic barrier system, which had been developed and tested in England. A rail element consisting of either a W-beam or a 4-in.-diameter tube was mounted to the unique post, which features an energy absorbing unit. The tubular rail system performed well in a medium-speed test, but was penetrated twice in standard tests (4,000-lb vehicle, 60 mph, 25 deg). The W-beam system performed adequately under the severe conditions. Accordingly, only the W-beam system is recommended for trial use; its use is suggested for locations where numerous moderate impacts occur.

CHAPTER ONE

INTRODUCTION AND RESEARCH APPROACH

The four objectives of this continuation phase of NCHRP Project 15-1(2) were to (1) update *NCHRP Report 54,* (2) prepare a general traffic barrier guide, (3) formulate new guardrail terminal and transition concepts, and (4) evaluate by full-scale crash tests selected traffic barrier concepts. In Task 1, an addendum to *NCHRP Report 54* was prepared in a manner similar to that used in preparing *NCHRP Report 54.** This addendum was widely circulated by the NCHRP staff. Concurrently, a general traffic barrier guide was formulated in Task 2 under the guidance of a second NCHRP advisory group.† Subsequent to the circulation of drafts of these documents, a decision was made to combine the two documents into a single comprehensive traffic barrier design guide. After two drafts of the combined document were circulated by the NCHRP staff, the revised work was published as *NCHRP Report 118.* Inasmuch as the results of Tasks 1 and 2 are documented in *NCHRP Report 118,* this report is primarily concerned with Task 3 (formulate new guardrail terminal and transition concepts) and Task 4 (evaluate traffic barrier systems).

In October 1970, a Task 3 report, "Concepts for Terminals and Transitions for Longitudinal Traffic Barrier Systems," was submitted to NCHRP Advisory Panel C22-1 for review and evaluation. From the twelve concepts of this report, three guardrail terminal concepts and one guardrail/bridge rail concept were selected for experimental evaluation. Design of the "breakaway cable terminal" concept was finalized in Task 4 and three full-scale crash tests were performed to evaluate its dynamic performance.

As a part of Task 4, four full-scale crash tests were performed to evaluate the Christiani & Nielsen barrier system. This barrier, designed and developed by Christiani & Nielsen, Ltd., of England, has been extensively tested in Europe. Although two tests were initially programmed for this system, the number was increased to four in order to more fully evaluate the potential of the system for application in the United States. The results of this test series are presented in Chapter Two and Appendix A.

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* A special NCHRP advisory group (consisting of J. L. Beaton, California Division of Highways; M. D. Graham, New York Department of Transportation; J. D. Lacy, FHWA; and P. C. Skeels, General Motors Proving Grounds) advised the program staff as to content of this addendum.

† The traffic barrier guide group consisted of M. D. Graham; P. C. Skeels; R. M. Olson, Texas Transportation Institute; J. N. Clary, Virginia Department of Highways; and F. J. Tamanini, J. G. Viner, FHWA (Research).

CHAPTER TWO

FINDINGS

Program findings are organized and presented in three areas: (1) conceptual studies of new guardrail terminals and transitions between barrier systems of different lateral flexibility, (2) full-scale crash test evaluation of guardrail terminal concept, and (3) full-scale crash test evaluation of the Christiani & Nielsen traffic barrier.

CONCEPTUAL STUDY

Two special problem areas in highway traffic barrier performance were the subject of an improvement design study:

1. Guardrail/median barrier terminals.
2. Guardrail/bridge parapet transitions.

Selection of these areas for investigation was based on poor results of full-scale crash tests of existing designs and poor in-service performance as evidenced by accident statistics. Performance requirements for both traffic barrier terminals and transitions were established, and new design concepts were formulated. These concepts were submitted to the NCHRP Advisory Panel for review, comment, and selection for further design and evaluation.

Guardrail Terminals

Approach ends of guardrails and median barriers have been recognized (*1*) as some of the more formidable roadside obstacles with which traffic must contend. Full-scale crash tests (*2*, *3*, *4*) have further demonstrated that many of the current end treatments or terminals do not perform in a manner consistent with the safety performance of the length-of-need section. (A typical guardrail installation is composed of three components: (a) upstream terminal section, (b) center section of "length-of-need," and (c) downstream terminal section (*5*).) Ramped terminals, which prevent the guardrail beam element from spearing the car, have launched vehicles impacting within the terminal length. Performance of cable-anchored G4 system end treatments (*3*) presented in *NCHRP Report 54* was judged to be adequate for a vehicle impacting near the end at 25 deg; however, a 0-deg impact on the nose of this same system in a V-shaped configuration (as might be used in a gore) produced excessive vehicle deceleration levels (*2*). Another test of the box-beam guardrail end treatment (*2*) demonstrated acceptable performance (i.e., the vehicle remained stable while penetrating the end section, and vehicle deceleration forces were not excessive). In the two tests that produced acceptable results, the guardrail was penetrated and the vehicle traveled beyond the impact area.

Design Considerations

The approach end of a guardrail or median barrier is a discontinuity and differs from the center portion (or length-of-need section) of a typical installation in both design and service requirements. Whereas the design purpose and general performance criteria have been established and documented for the length-of-need section (*6, 7, 8*), no specific criteria have been established for end treatment performance requirements.

As outlined in *NCHRP Report 54* and *NCHRP Report 118*, properly designed guardrails and median barriers make highways safer by:

1. Preventing errant vehicle penetration.
2. Redirecting errant vehicles to a direction parallel to traffic flow.
3. Minimizing hazard to vehicle occupants during impact.

These objectives are appropriate for the center section or "length-of-need," but only the third one is considered appropriate for a terminal.

Installations should be extended upstream from the warranted limits to prevent vehicle access behind the protective system. It is not necessary to extend the installation downstream past the hazard on highways with one-way traffic. A method to establish the length-of-need of the installation is based on a 400-ft (*7, 9*) encroachment distance; the length-of-need is calculated by (*7*)

$$L = (1 - A/B)400 \qquad (1)$$

where the terms are defined in Figure 1. As an example, for an installation to be located 12 ft from the pavement edge shielding a hazard that is 22 ft from the pavement edge, the length-of-need is $L = (1 - 12/22)400 = 180$ ft. Terminal lengths are added to develop the structural effectiveness of the system at the length-of-need extremities.

Approach terminal ends are subject to end-on as well as angle impacts. A degree of protection consistent with that of the length-of-need section would be furnished by the approach terminal if impacting vehicles are either redirected or permitted to penetrate the end with resulting decelerations within the limit produced by vehicles that impact along the length-of-need. It should be emphasized that, unlike the length-of-need section, penetration of the terminal is permissible if a proper procedure (*7*) is utilized for geometric layout. Basically, the layout procedure shown in Figure 1 is formulated from errant vehicle "recovery distance" statistics.

Service Requirements

Service requirements developed during this research for the guardrail terminals are listed and provide the basis for formulating the performance criteria. The order of emphasis is first to safety, second to economics, and third to aesthetics.

A guardrail terminal should:

1. Develop tensile and/or flexural strength necessary to ensure desirable redirection performance of the length-of-need section.
2. Either by redirection, containment, or controlled penetration, minimize vehicle/occupant decelerations for terminal section impacts. This implies that the impacting vehicle is not launched, rolled, or pocketed. (In some cases end-on impacts can be eliminated; e.g., extending rail end into back slope.)
3. Be designed so that possible penetration of the vehicle passenger compartment by a system component is minimized.
4. Be economical in construction, damage repair, and maintenance.
5. Minimize vehicle damage.
6. Have a pleasing and functional appearance.

Performance Evaluation Method

Although vehicle/barrier interactions during impacts have been analytically characterized, full-scale crash tests are used to evaluate the general performance of guardrail/median barrier installations. In recognition that the guardrail end is at least as difficult to analytically evaluate, full-scale crash tests are recommended for evaluation of terminal effectiveness.

Terminal Concepts

A total of twelve end terminal concepts were formulated during the program; these twelve concepts were the result of a cursory design and analysis effort and indicated potential of satisfying the more significant service requirements. Many other schemes were investigated, but were discarded for lack of potential regarding cost, performance, or some other consideration. Even during the concept formulation and preliminary design stages, an attempt was made to use, where possible, current highway hardware and construction techniques in order to facilitate installation and maintenance cost-effectiveness. The twelve concepts are presented in Appendix B with brief explanations as to how the concepts function. These concepts were submitted to the NCHRP staff and advisory panel for review and the estab-

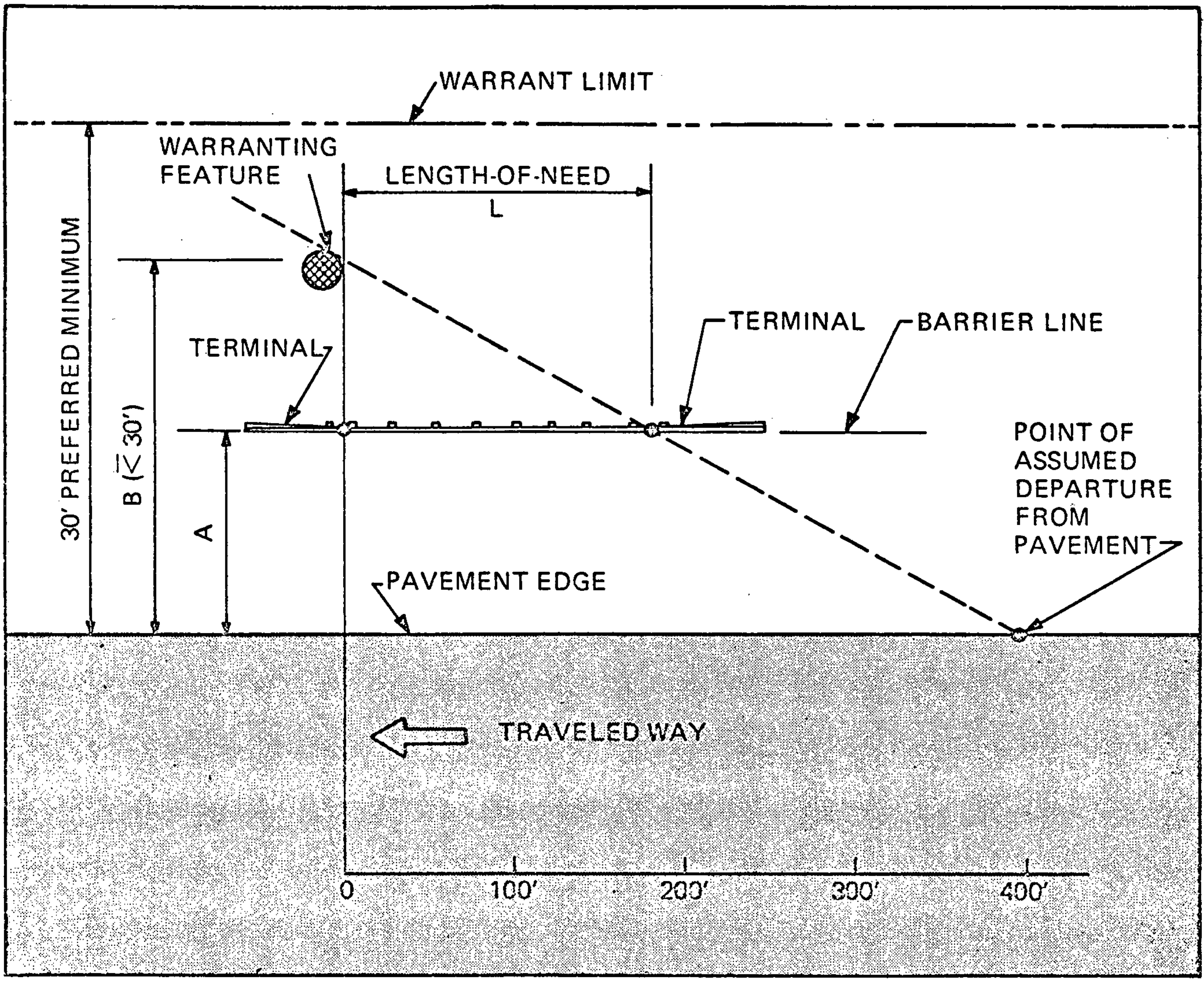


Figure 1. Barrier length-of-need determination.

lishment of an order of preference; the following sequence, in descending priority, was established:

1. A combination of the T6 and T8 designs as suggested in Figure 2.
2. T1 with either the T3 or T4 end post.
3. T12 modified.

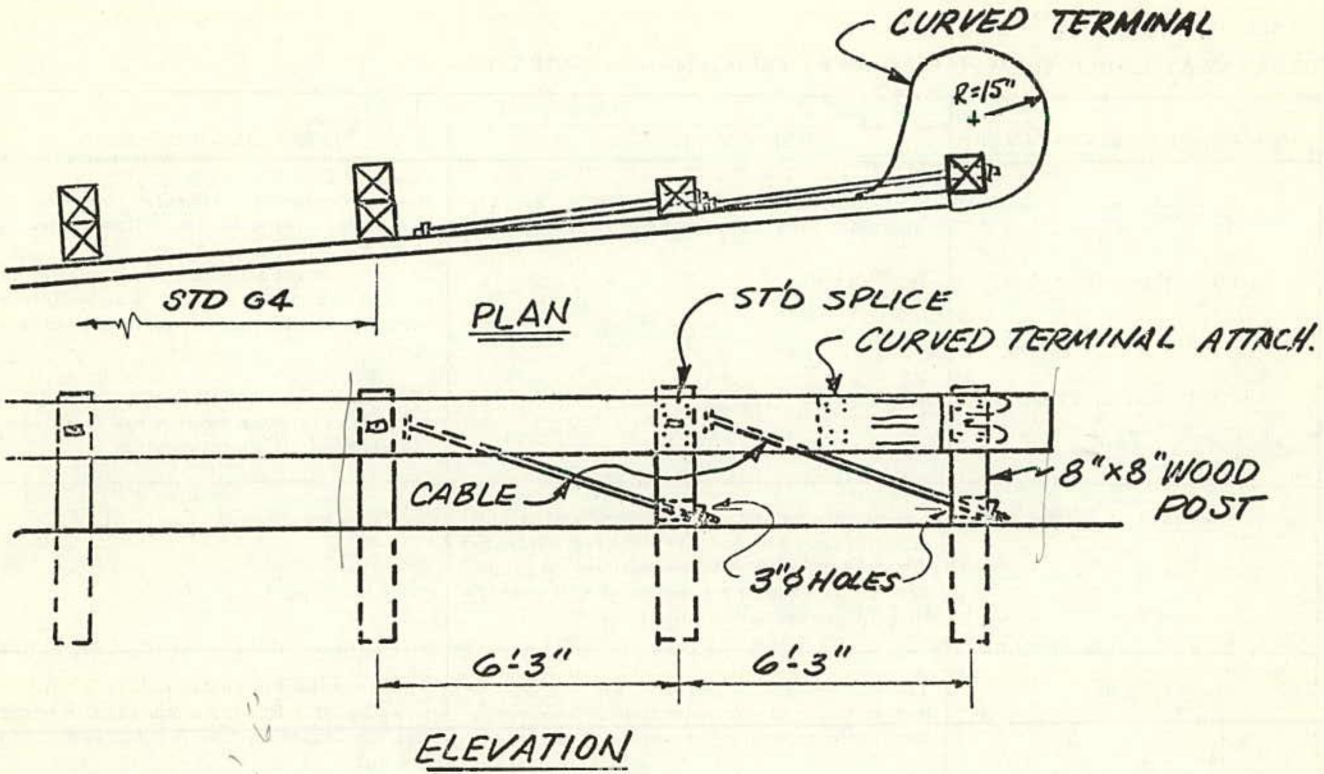
Based on this preference list, the combined concepts of Item 1 (similar to Fig. 2) were selected for final design and test evaluation. This final design, as shown in Figure 3, was constructed to anchor the G4W system of *NCHRP Report 118* and utilized many of the components of the California end anchorage shown on Sheet 2 of *NCHRP Report 118*. Table 1 summarizes the design principle of the selected concept. The basic components of this design employ existing guardrail hardware and thus should require no new tooling. However, the end-nose and the anchor plate fitting may be produced less expensively if some redesign is accomplished.

Guardrail Transition

The need for further research and testing of approach guardrail to bridge rail transitions is indicated by highway accident statistics. Olson (*10*) estimates that 6.9 percent of single-vehicle fixed-object fatal accidents involve guardrail at bridge structures. Many of these fatalities have occurred at the bridge end, where the guardrail and bridge rail installation were simply not compatible either structurally or geometrically.

This phase of the work effort was devoted to concepts for W-beam to concrete parapet transitions exclusively; a number of reasons led to this decision:

1. There are a large number of existing installations that



Advisor Comments

1. Two anchor cables are provided. These anchor cables could be designed for roughly one-half of the 21.4 tons breaking strength of the 3/4" steel cable used in the California design and thus softening the impact for lighter vehicles and perhaps allowing failure of the end in the desired manner at lower impacting speeds.

2. The curved terminal is smaller and more securely attached than the T-8 design (see Appendix B). It is hoped that this would minimize problems regarding out of plane motion of the curved terminal which might increase ramping problems.

3. A simpler cable attachment design at the supporting post is proposed to encourage failure of the anchor posts at the desired cable attachment point and to simplify the construction and maintenance of these posts.

Figure 2. Guardrail terminal concept recommended by NCHRP staff and advisory panel for detailed study.

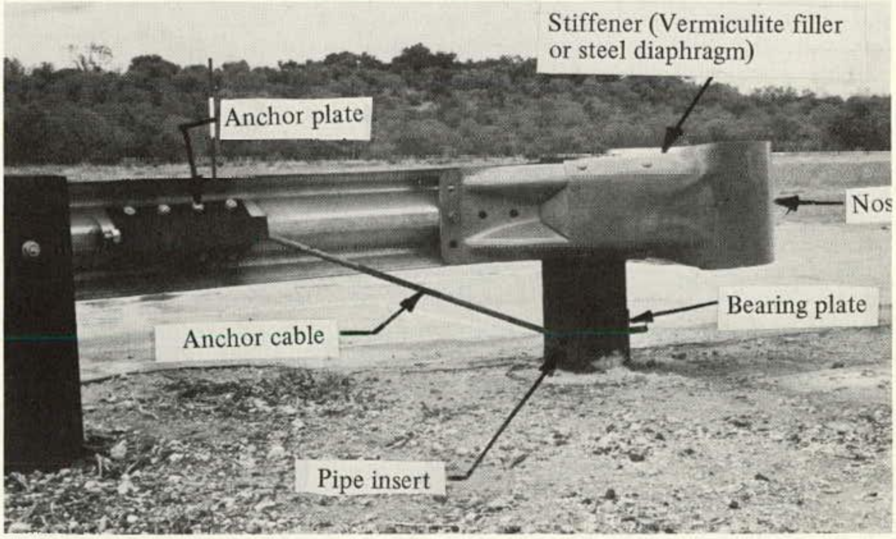


Figure 3. Breakaway cable terminal details.

TABLE 1

BREAKAWAY CABLE TERMINAL CONCEPT PERFORMANCE PRINCIPLES

COMPONENT OR FEATURE	DESIGN FUNCTION	
	END-ON IMPACTS	DOWNSTREAM IMPACTS
1. End Post	Post "breaks-away" at bored hole, releasing cable; thus minimizing spearing forces.	Post is designed to transfer breaking strength of cable to the concrete footing.
(a) Pipe Insert	No Function	Distributes forces due to vertical component of cable to the post. Size was determined from bearing strength of Southern pine.
(b) Bearing Plate	No Function	Distributes horizontal forces from cable to post. Size was determined from bearing strength of Southern pine.
2. End Nose	Large nose is stiffened by vermiculite concrete (Tests 130 and 131) or steel diaframs (Test 132) to distribute loads over a large area; thus reducing chances of rail penetration into passenger compartment.	No Function
3. Anchor Cable	The cable does not perform for end-on impacts, but it is essential that it does not develop spearing forces in the W-beam.	Cable transfers tensile forces from beam to end post. Proper anchorage is essential for angle impacts downstream from the end.
4. Concrete Footing	No Function	Distribute loads from end post to soil.
5. End Flare	For Tests 130 and 131 a horizontal flare was installed to introduce eccentric loads for end-on impacts, thus bending beam away from car.	No Function

consist of a W-beam approach to a concrete parapet or wingwall.

2. Lack of nationwide standardization of bridge rail hardware and design precludes the development of universally applicable railing transition concepts in this study.
3. Research efforts are in progress to develop integrated traffic barriers (guardrail/bridge rail).
4. A transition from a beam/post approach guardrail to GM bridge parapet has not been evaluated by full-scale crash test.

Three similar transition concepts were formulated and are shown in Appendix B. These concepts are similar to the California bridge approach system specified on Sheet 5 of *NCHRP Report 118;* it is to be noted that a rub rail has been added to this basic system and other changes are noted. Concept TR-2 (see Appendix B) was considered by the NCHRP Advisory Panel as the most promising of the three designs.

As the primary program effort was devoted to developing and evaluating a guardrail terminal concept, the TR-2 concept was not finalized or crash-test evaluated.

TERMINAL CONCEPT EVALUATION

Laboratory Experiments

The terminal concept selected for development and evaluation features a timber post that is weakened by a drilled hole near grade. The hole also provides a weak plane, which assures that the post fails at the hole, thereby releasing the cable anchor. In order to acquire general design properties of posts containing drilled holes, a series of four impact tests was conducted in a pendulum facility. A summary of the four pendulum tests is given in Table 2. The full-section posts showed considerable test data scatter for (a) impact duration and (b) linear impulse; however, the peak and average breaking forces range within 10 percent of the average values. The dynamic strength properties for the two weakened post tests are essentially the same, even though the holes were oriented 90 deg apart. Based on these findings, it is concluded that hole orientation is not important and that the two weakened specimens failed principally in a horizontal shear mode. A complete description of the tests and results is presented in Appendix A.

Crash Test Evaluation

The purpose of the full-scale tests was to evaluate terminal (as shown in Fig. 3) performance for (1) end-on impact with horizontally flared end, (2) end-on impact with no horizontal flare, and (3) angular impact downstream of terminal. A summary of test results for the three crash tests is given in Table 3. A brief description of each test follows, with a more comprehensive description presented in Appendix A.

The first test (Test 130) was conducted to evaluate the performance of the concept when impacted end-on. The longitudinal center line of the vehicle was in line with the center of the end post at impact. The nose of the installation was filled with vermiculite concrete to maintain nose geometry and to distribute barrier forces over a large section of the vehicle. The test vehicle impacted the nose at a speed of 61 mph (Fig. 4).

The end post and second post fractured at grade as designed, and the vermiculite-filled nose and the W-beam in the first two panels rotated about the third post to the rear of the installation. No discernible installation damage was observed downstream beyond the third post.

Maximum deceleration forces (10.8*g* averaged over 50 msec) were applied to the vehicle 0.02 sec after impact, and the vehicle was redirected behind the rail. During impact, redirection, and deceleration, the vehicle appeared dynamically stable, exhibiting little tendency to roll, pitch, or yaw. The final vehicle position was 50 ft beyond the initial point of impact. Based on this 50-ft stopping distance, an average deceleration from 61 mph is calculated to be 2.5*g*.

An installation identical to Test 130 was constructed for Test 131. The initial point of impact was in the second 6.25-ft span from the end post. An impact angle of 15 deg was selected to evaluate the anchorage strength of the terminal assembly. Due to the horizontal flare of the terminal, the actual angle at impact was near 25 deg. (The decision to test at 15 deg rather than the standard 25-deg angle was based on the short exposure length of the terminal section; because the initial point of impact was near the end post, the probability of any impact immediately downstream of the end was considered slight when compared to a normal length-of-need section (100 ft or more).

The vehicle impacted the second span with a speed of 59.4 mph and was redirected with a rebound distance of 49 ft (lateral distance from rail line to front of vehicle) before being braked to a stop 108 ft (measured parallel to rail line) from the initial point of impact. Vehicle speed and angle with respect to the rail line were 31 mph and 18 deg, respectively, at time of loss of contact with the barrier. Figure 5 shows sequential photographs of the test. Vehicle deceleration values of 4.6*g* * in both longitudinal and lateral directions (Table 3) are within human tolerance guidelines (*7, 11*) for properly restrained occupants. No distress was observed or noted in the cable anchor system, end post, or foundation.

For end-on impacts, the curvature of the flared terminal causes the vehicle forces to be introduced eccentrically into

TABLE 2

SUMMARY OF TIMBER POST TEST RESULTS

SPECIMEN NO.	WIDTH, W (IN.)	HOLE DIAM. d (IN.)	DEPTH, D (IN.)	AREA, A (IN.^{2})	MOMENT OF INERTIA,[a] I (IN.^{4})	IMPACT VEL. (FT/SEC)	IMPACT DURATION (MSEC)	IMPULSE (LB-SEC)	FRACTURE ENERGY (FT-KIPS)	PEAK FORCE (KIPS)	AVERAGE FORCE (KIPS)
1	8.0	—	7.7	61.8	307	29	30	247	6.6	20.0	8.1
2	7.9	—	8.0	63.2	348	29	42	412	11.0	22.7	10.1
3	7.6	4.0[b]	8.0	61.0 net (30.0)	327 (285)	29	28	140	3.8	12.0	4.9
4	8.0	4.0[c]	7.8	62.4 net (31.4)	316 (158)	29	28	140	3.8	12.5	4.9

[a] About axis perpendicular to applied load.
[b] Hole axis perpendicular to direction of impact.
[c] Hole axis parallel to direction of impact.

---

* Highest 50-msec average determined from micromotion analysis of high-speed movies.

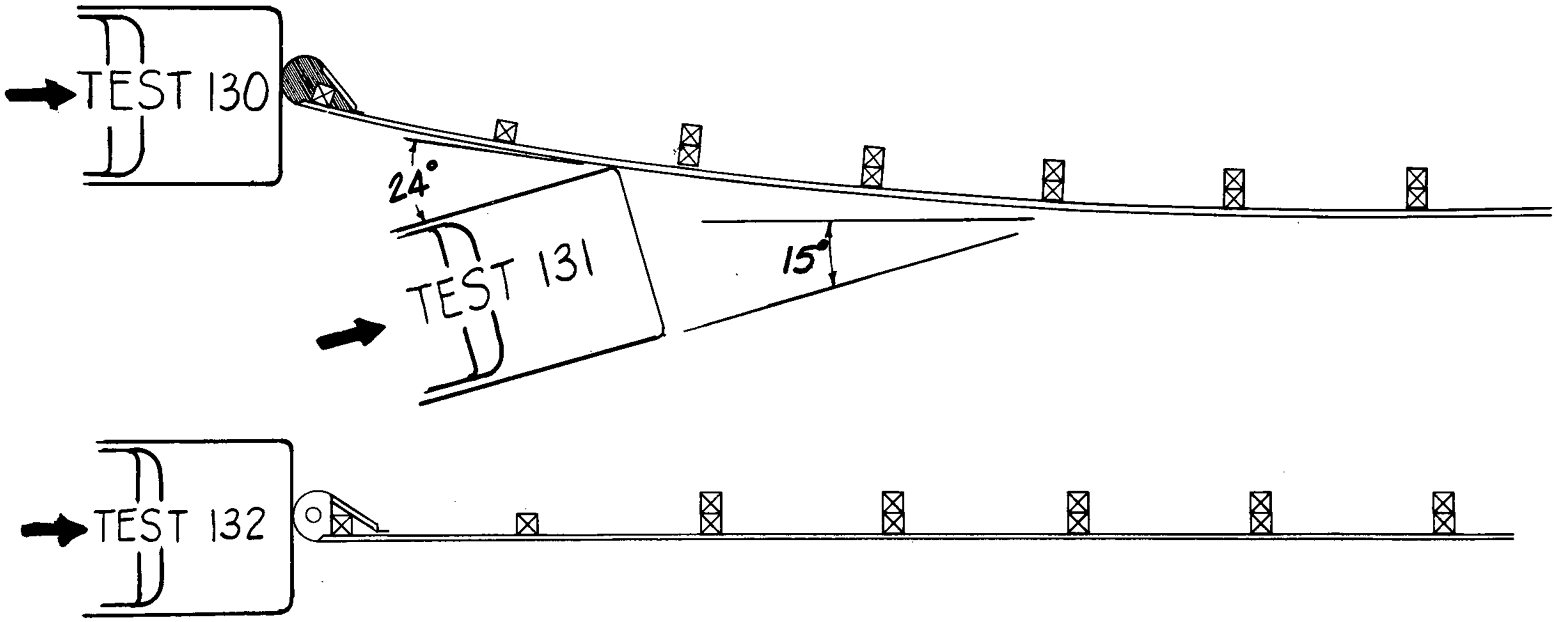
TABLE 3

SUMMARY OF GUARDRAIL TERMINAL TESTS

Test Number	Purpose	Vehicle Weight (lbs)	Vehicle Speed (lbs)	Impact Angle	Maximum Average Decelerations Long. (g's)	Maximum Average Decelerations Lat. (g's)	Remarks
130	End-on impact (with flare)	4,138	61	0	10.8* 2.5+	1.7*	Vehicle was directed behind the rail; vehicle stability was good throughout.
131	Test Anchorage for downstream impact	4,000	59.4	15**	5.0*	4.5*	Vehicle was redirected at large exit angle. No sign of anchorage failure.
132	End-on impact (without flare)	4,100	58.5	0	8.6* 3.4+	1.2*	Vehicle redirected behind rail; considerable upward pitch of the vehicle noted.

---

* Highest 50 msec average.
\+ Computed from stopping distance.
**Measured from line parallel to roadway.



the rail, thereby reducing the column strength of the rail and reducing the magnitude of vehicle/barrier forces. In addition, a flare can result in a reduced installation length and an increase in the distance from the roadway (thus reducing the impact probability). However, this curvature increases the actual impact angle for angular impacts near the end post. The flare used in Tests 130 and 131 results in an actual impact angle of 35 deg for a 25-deg (measured

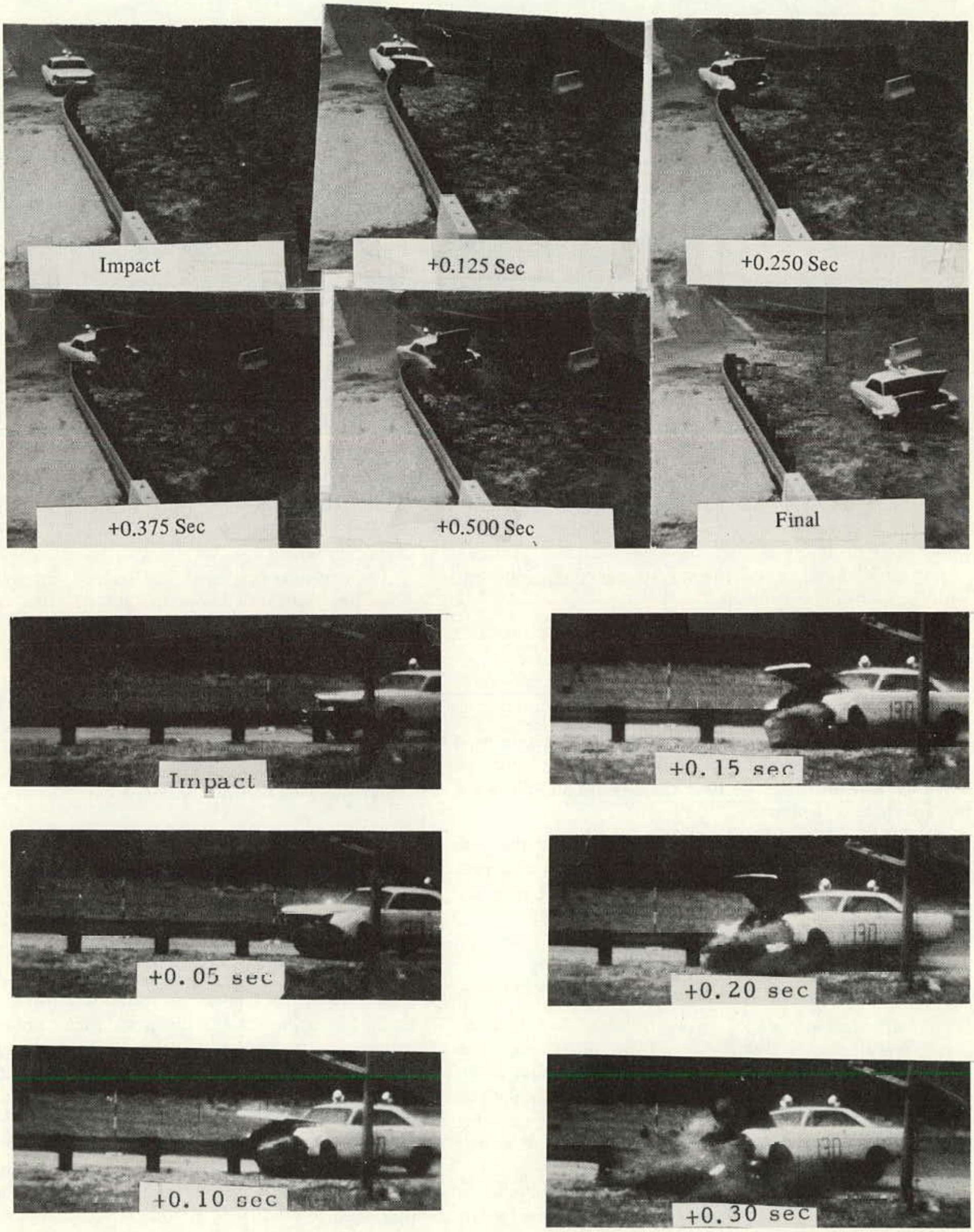
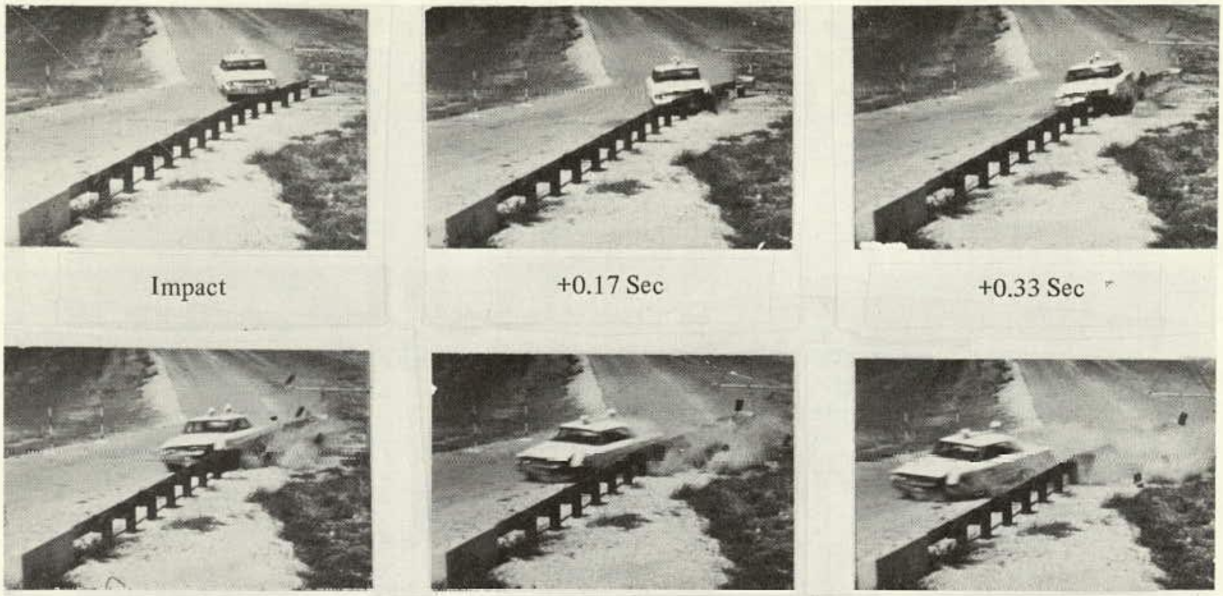


Figure 4. Sequence of events, Test 130.



Impact

+0.17 Sec

+0.33 Sec

+0.50 Sec

+0.67 Sec

+0.83 Sec

Figure 5. Sequence of events, Test 131.

parallel to traveled way) impact occurring at the second post. By eliminating the flare, the initial angle of impact is not increased. In addition, a more direct "load path" from beam to anchor results. Based on these considerations, straight terminal sections have desirable features.

The installation for Test 132 was similar to previous tests with the following exceptions:

1. Steel diaphragms replaced the vermiculite concrete for stabilizing the terminal nose.

2. The horizontal flare was eliminated; hence, the entire installation was parallel to the traveled way.

Although performance of the vermiculite concrete used in Test 130 was judged to be satisfactory, there appeared to be advantages in use of steel diaphragms to stiffen the terminal nose, as follows:

1. The diaphragm would be an integral part of the nose assembly. Shop fabrication and galvanizing would be possible, thus eliminating need for field installation of vermiculite concrete stiffener or handling of a precast unit.

2. No weathering or durability treatments associated with vermiculite concrete would be necessary.

3. The steel diaphragms appear to be more economical.

Diaphragm thickness of 22 ga was selected based on experience with steel-drum crash cushions. No attempt was made to optimize material thickness or number and placement height of diaphragms in the nose. Due to similarities in geometry of the steel-drum crash cushion and the terminal nose, the configuration shown in Figure 6 was selected.

Initial impact conditions for Test 132 were similar to those of Test 130 (i.e., center line of vehicle and center of end post were in-line). The vehicle impacted the end at 58.5 mph at a 0-deg angle and was redirected as shown in Figure 7; the vehicle front end pitched downward initially before pitching upward a maximum of 17 deg at 0.7 sec. Vehicle maximum average (50 msec) longitudinal deceleration was 8.7*g*.

The end post fractured, as designed, through the bored hole; the nose buried into the vehicle front, and initially the first beam panel flexed toward the roadway. At 0.18 sec the rail was still straight, but buckling had begun in the rail at Post 4. The rail buckled down and toward the roadway and the pitch of the vehicle changed. Loss of contact of the rail with the vehicle occurred 0.4 sec after impact. The vehicle front end traversed 34 ft from the initial point of impact before coming to rest. Average deceleration based on this stopping distance is 3.4*g*.

CHRISTIANI & NIELSEN BARRIER TESTS

Barrier Description

The Christiani & Nielsen barrier was designed and developed by Christiani & Nielsen, Ltd., of England. The novel feature of this barrier is a hydraulic shock absorber installed in a hinged post. As restraining forces are applied to an impacting vehicle the posts rotate about the hinge and the shock absorber is compressed as shown in Figure 8. As the post rotates the height of the rail is also increased. The hydraulic post assembly is bolted to a base plate that is attached to either a concrete footing or a steel post (driven to grade); the post bolts are designed to fail before the shock absorber "bottoms out." This design "failure mode" prevents damage to the shock absorber (and foundation) and permits the hydraulic post assembly to be reused by replacing the base plate and post bolts.

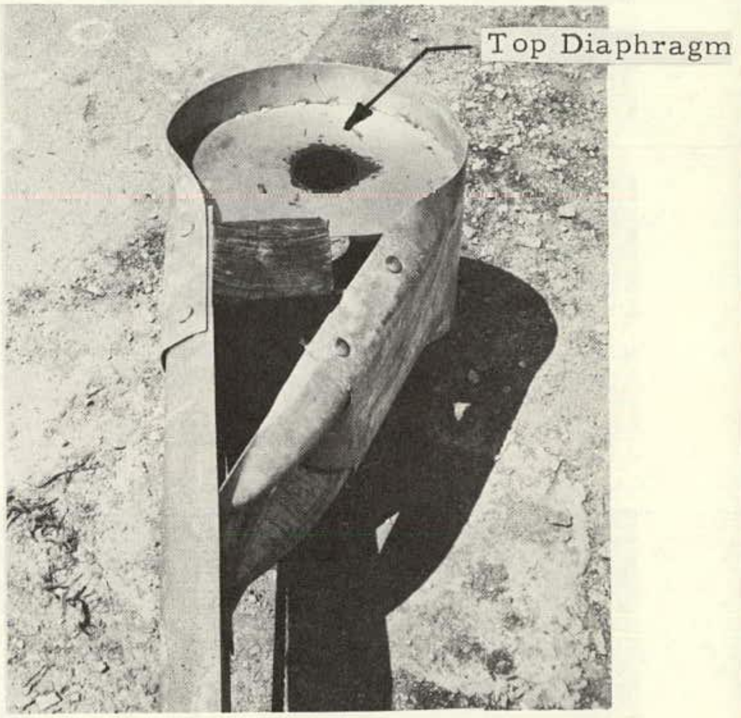


Figure 6. Installation features, Test 132.

Either of two rail elements may be used with the hydraulic post:

1. Standard steel W-beam (Fig. 9a).
2. Christiani & Nielsen steel tube system (Fig. 9b).

The Christiani & Nielsen steel tube rail system has articulated joints on 10-ft centers that increase the flexibility of the system and thus prevent rail damage under moderate impact conditions. The basic 4-in.-dia (0.25-in. wall) steel tube is spliced near the post with a unique splice fitting that permits considerable joint rotation without material deformation. Although the rail-to-post connection develops tensile and compressive forces in a direction normal to the barrier, the rail is not restrained by the post connection in the longitudinal direction.

Full-Scale Crash Tests

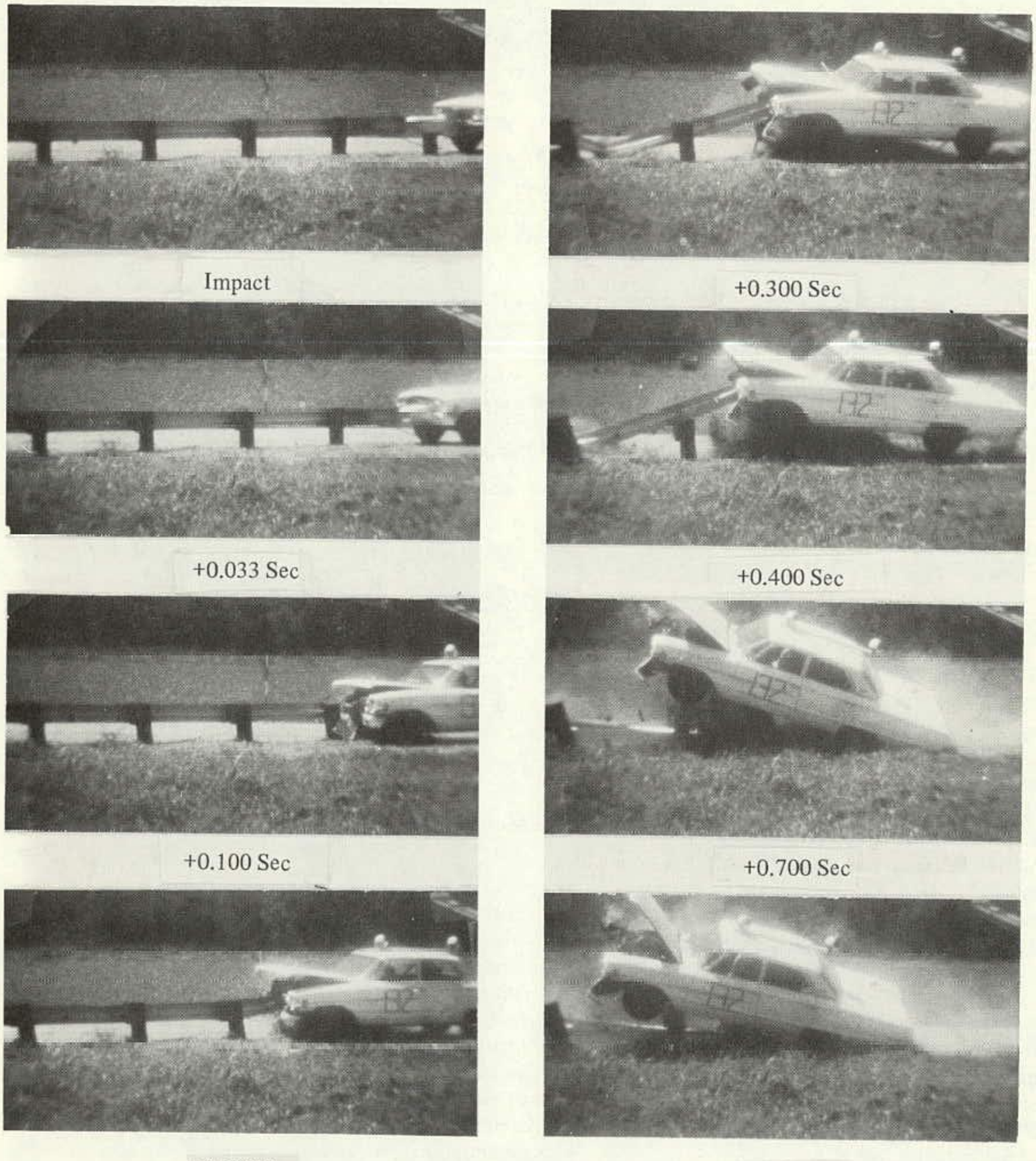
Four full-scale crash tests were conducted on the Christiani & Nielsen barrier system to evaluate the general performance of the system; results from these tests are summarized in Table 4. Prior to running the first test, several low-speed and low-angle (i.e., 20 mph at 0 to 15 deg) impacts were imposed on the barrier by manned vehicles. The system exhibited an excellent capacity for sustaining these impacts and redirecting the car; vehicle damage was slight and no barrier damage resulted. In addition, tests conducted on the system by other agencies are summarized in Table 4.

The first two tests (Tests 126 and 127) were conducted on the tubular rail system. The Test 126 vehicle impacted the rail at 36 mph and an angle of 23.3 deg. Although showing some tendency to mount the rail, the vehicle was smoothly redirected (Fig. 10). Damage to the vehicle and the rail system was moderate. Vehicle exit speed and angle were 27 mph and 6 deg, respectively.

In the second test (Test 127) the vehicle impacted the rail at 60 mph and an angle of 25 deg. The vehicle mounted the rail and proceeded over the rail with little redirection (Fig. 11). The vehicle continued beyond the rail before being braked to a stop.

Penetration of the barrier installation was attributed primarily to the relatively low rail mounting height (centerline of rail 18⅞ in. above grade). After consultation with Christiani & Nielsen personnel it was decided to increase the mounting height for subsequent tests by adding a 2-in. spacer to the post base plate.

For Test 128, the W-beam rail was installed on the posts,



Impact

+0.033 Sec

+0.100 Sec

+0.183 Sec

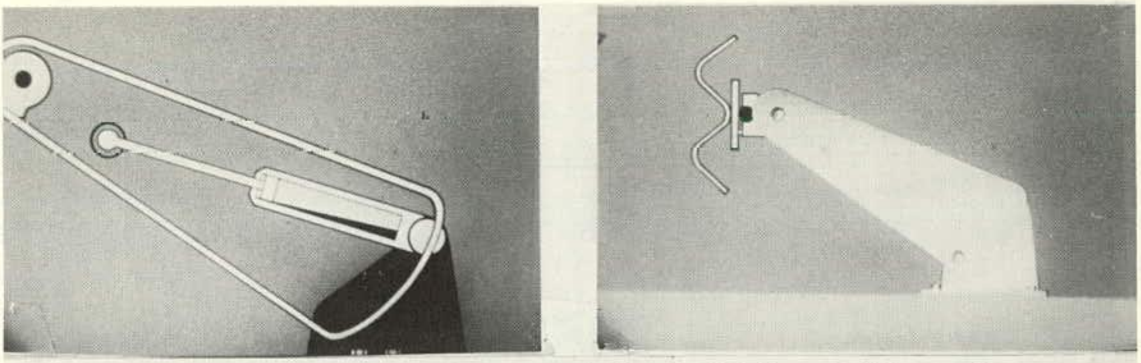
+0.300 Sec

+0.400 Sec

+0.700 Sec

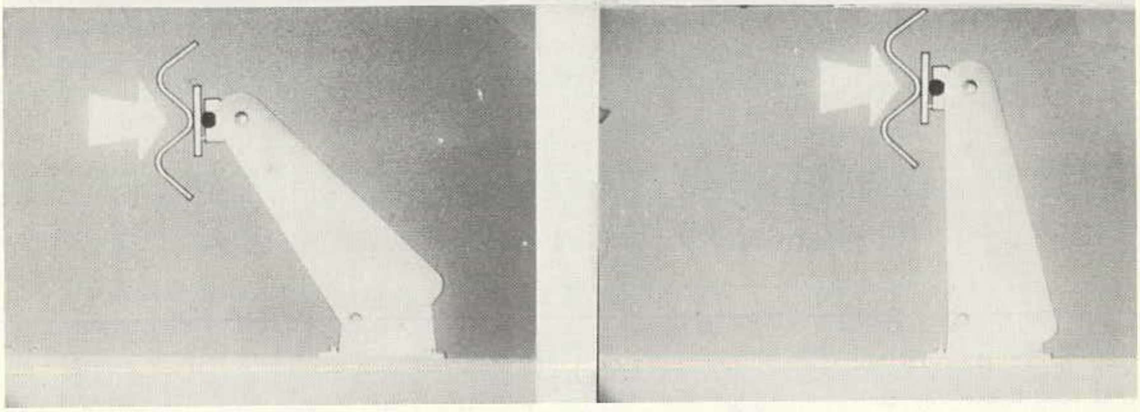
+0.900 Sec

Figure 7. Sequence of events, Test 132.



(a) Cutaway view showing shock absorber

(b) Post with W-beam rail



(c) Lateral force applied to post

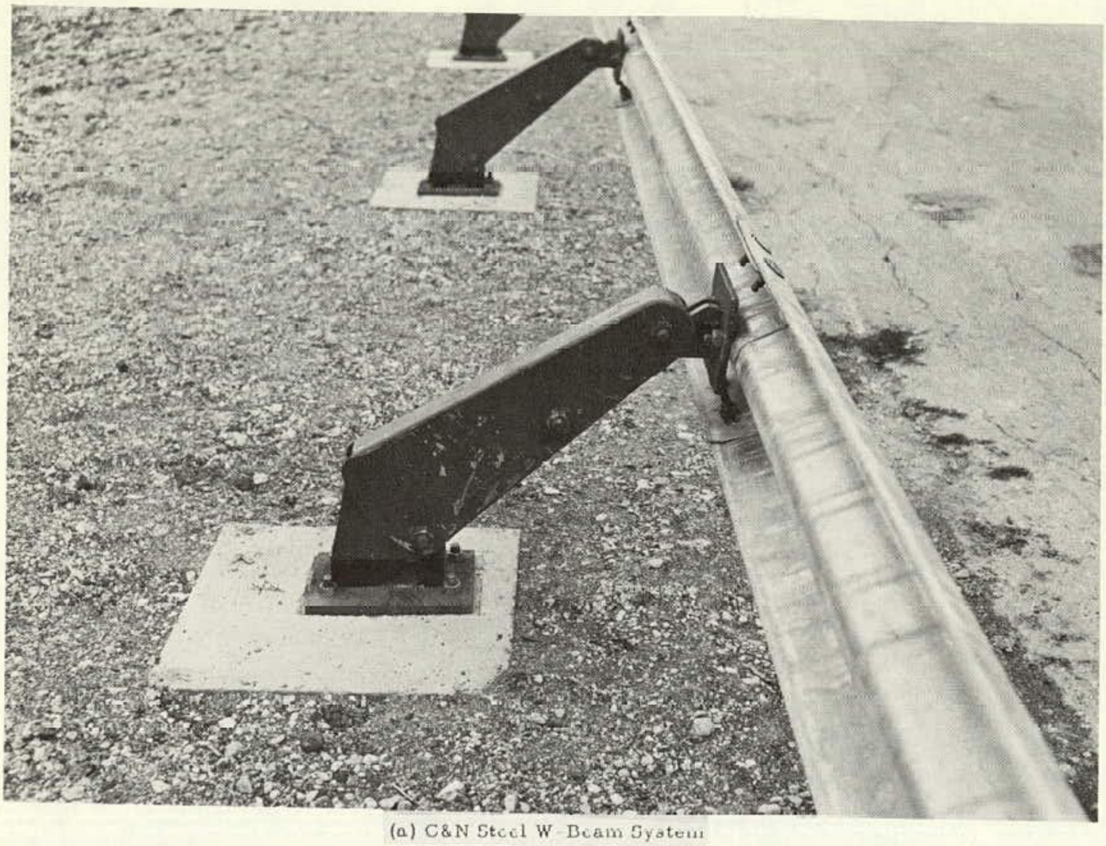
(d) Post nearing "bottom" of shock absorber stroke

Figure 8. Hydraulic post assembly.

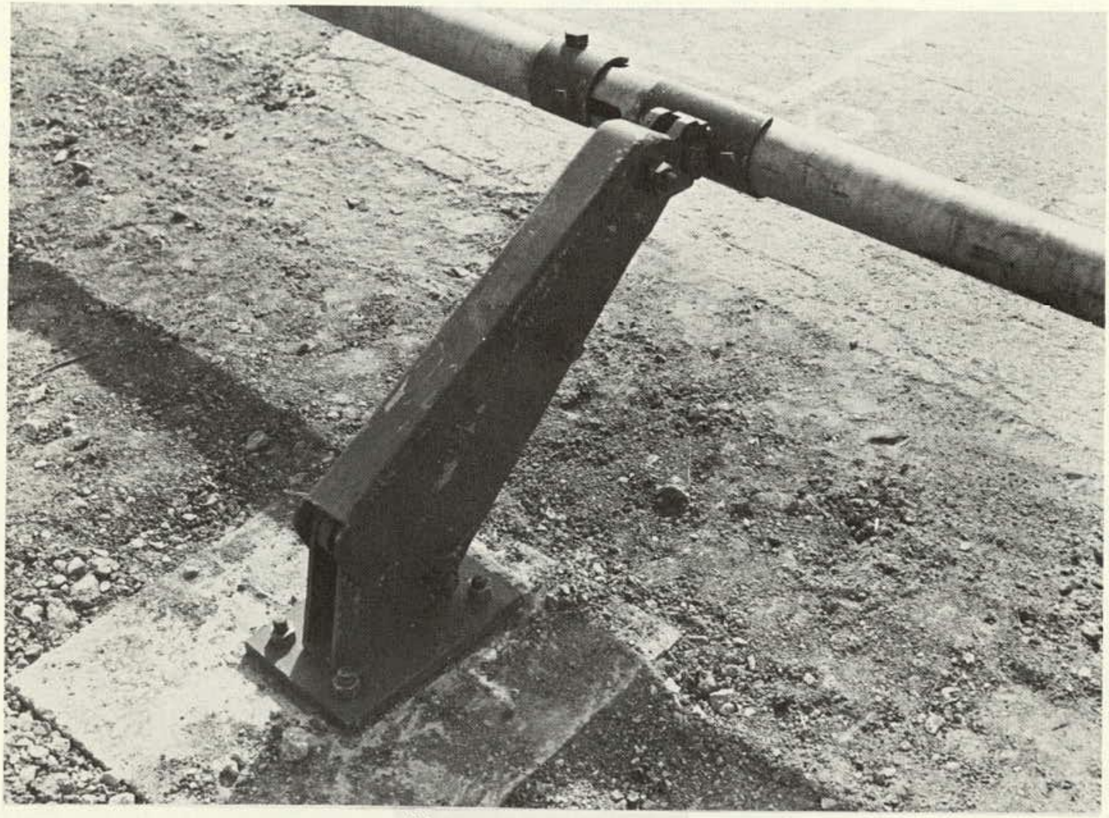
which had been raised 2 in. The vehicle impacted the rail at 59 mph and an angle of 24.3 deg. As shown in Figure 12, the vehicle was redirected, although the rail wedged between the vehicle chassis and the left front wheel. Vehicle exit speed and angle were 40 mph and 10 deg, respectively.

For Test 129, the tubular rail was installed on the raised posts. The vehicle impacted the rail at 61.5 mph and an angle of 24.3 deg. The left front wheel became airborne almost immediately after impact and the vehicle pocketed before climbing over the rail (Fig. 13). As the vehicle was being redirected, the aft end of the vehicle yawed toward the rail (which had dropped) and the vehicle was tripped and launched into a multiple roll-over.

Detailed information on all tests, including photographs, vehicle kinematic and dynamic data, and installation and vehicle damage descriptions, are presented in Appendix A.

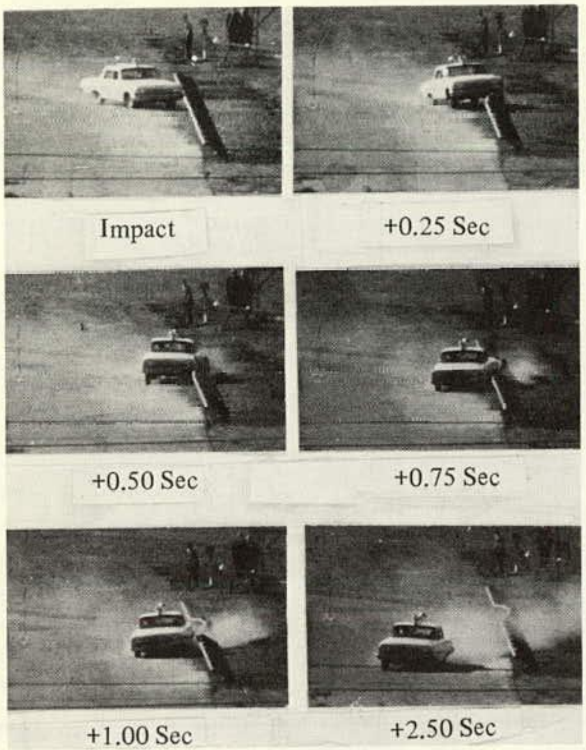


(a) C&N Steel W-Beam System



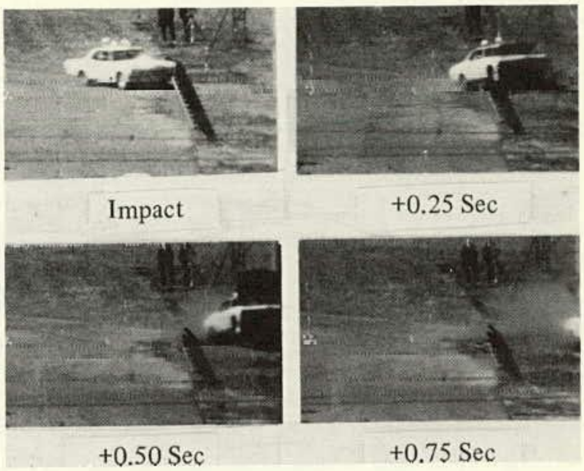
(b) C&N Steel Tube System

Figure 9. Christiani & Nielsen barrier systems.



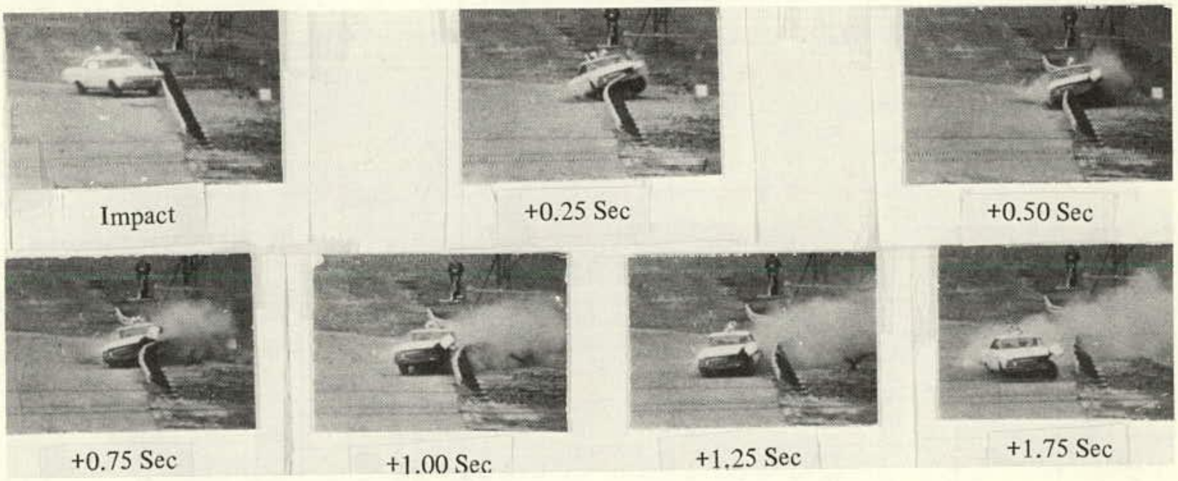
Impact
+0.25 Sec
+0.50 Sec
+0.75 Sec
+1.00 Sec
+2.50 Sec

Figure 10. Sequence of events, Test 126.



Impact
+0.25 Sec
+0.50 Sec
+0.75 Sec

Figure 11. Sequence of events, Test 127.



Impact
+0.25 Sec
+0.50 Sec
+0.75 Sec
+1.00 Sec
+1.25 Sec
+1.75 Sec

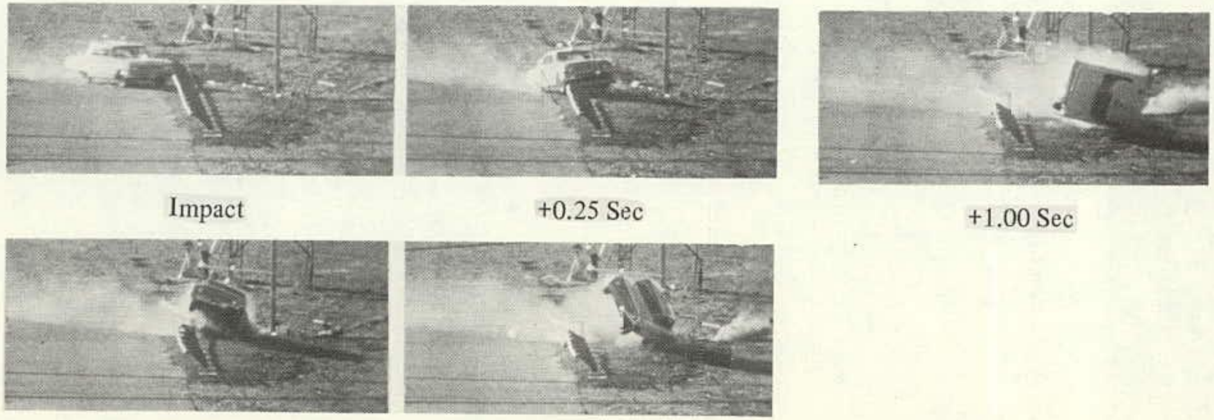
Figure 12. Sequence of events, Test 128.

TABLE 4

SUMMARY OF CHRISTIANI & NIELSEN BARRIER TESTS

	INSTALLATION DESCRIPTION				VEHICLE			VEHICLE DECELERATION[a] (g)			
SWRI TEST NO.	POST TYPE	POST SPACING (FT)	RAIL TYPE	HEIGHT (IN.)	WEIGHT (LB)	SPEED (MPH)	IMPACT ANGLE (DEG)	LONG.	LAT.	MAX. BARRIER DEFL. (FT)	REMARKS
126	C&N	10.0	4-in. dia.	18⅞[b]	4,160	36	23.3	1.6	3.7	3.6	Vehicle smoothly redirected with slight vehicle and barrier damage.
127	C&N	10.0	4-in. dia.	18⅞[b]	4,270	60	25.0	—	—	—	Vehicle penetrated.
128	C&N	10.0	12-ga W	26⅞[c]	4,057	59	24.3	4.13	4.95	6.0	Vehicle redirected; rail wedged between left front wheel and chassis during impact.
129	C&N	10.0	4-in. dia.	20⅞[b]	4,230	61.5	24.3	—	—	—	Vehicle rolled.
Tests by Other Agencies:											
1	C&N	10.0	12-ga W	27⅝[c]	18,000	28	25.0	—	—	—	Vehicle redirected; test performed by Finland T.V.H.
2	C&N	10.0	12-ga W	27⅝[c]	2,000±	65	20.0	—	—	—	Vehicle redirected; car driven by live driver at racetrack in England.
3	C&N	10.0	12-ga W	27⅝[c]	3,210	70.5	20.0	—	—	—	Vehicle redirected parallel to rail; test performed at Boreham Proving Grounds of Ford Motor Co., England.

[a] Highest 50-msec average.
[b] Measured to centerline of rail.
[c] Measured to top of rail.



Impact

+0.25 Sec

+1.00 Sec

+0.50 Sec

+0.75 Sec

Figure 13. Sequence of events, Test 129.

CHAPTER THREE

APPRAISAL AND APPLICATION OF RESULTS

The results of the full-scale testing program reported herein are appraised in the following according to their application to overall highway traffic barrier technology.

TERMINAL CONCEPT FORMULATION

Of the twelve guardrail terminal concepts formulated in the program, several indicate promise of evolving into safe, effective terminals. During the course of the study, the Institute staff deliberately eliminated from consideration all concepts that were overly complex in design principle. Present construction techniques and tolerances were considered reasonable ground rules for new concepts, thus eliminating designs calling for costly, sophisticated construction. Accordingly, the goal of the study was safe, effective terminals designed with current hardware with a cost near that of present terminal designs.

Concepts were presented for all operational guardrail and median barrier systems shown in *NCHRP Report 118* except for the cable and concrete systems. The concept selected for full-scale crash test evaluation is applicable to all W-beam systems, although it was evaluated for only the G4W system. From the initial concept, the breakaway cable terminal was modified during final test installation design. Should other concepts presented in this study be selected for crash test evaluation, it is likely that they too would be modified as a result of a concentrated design effort.

TRANSITION CONCEPT FORMULATION

The transition from a semirigid W-beam approach rail to a rigid concrete bridge parapet is considered to be a particularly hazardous location where many current transition designs have been shown by accident statistics to be unsafe. The three transition concepts conceived in this program could be applied to existing as well as new bridge approach locations. Although these concepts were not evaluated by full-scale crash test, or even considered for finalized design, the basic features may have immediate application. For instance, the practice of using a rub rail for beam/post barrier system approaches to rigid parapets or walls is considered good practice for minimizing vehicle snagging in the transition zone. All of these concepts were formulated with existing hardware and construction methods in mind. A complete design analysis and subsequent evaluation by full-scale crash test is recommended to further develop these concepts.

TERMINAL CONCEPT EVALUATION

The breakaway cable terminal concept, as evaluated in the three full-scale tests, is an effective terminal for W-beam systems and indicates a significant improvement over either the ramped or the blunt-nose terminal. Performance of the terminal is compared to the design purpose and service requirements outlined for guardrail terminals (see Chapter Two) in Table 5.

End-On Impacts

For end-on impacts the guardrail terminal performs in a manner similar to crash cushions. Crash cushion devices are designed primarily for head-on impacts, and their performance criterion (*7*) differs from that of a longitudinal traffic barrier. The criterion states that for direct-on tests of crash cushions (i.e., where vehicle lateral deceleration is minimum), the maximum average vehicle deceleration that is permissible is 12*g* as calculated from vehicle impact speed and stopping distance. This average value is based on the premise that deceleration is relatively uniform and is applicable for a range of vehicle weights from 2,000 to 4,500 lb. That is,

$$a = V^2/2gs \qquad (2)$$

in which

a = average vehicle deceleration (g);
V = vehicle impact velocity (ft/sec);
g = gravitational constant (ft/sec^2); and
s = vehicle stopping distance (ft).

Obviously, deceleration levels of less than 12*g* are desirable. As discussed by Olson et al. (*10*), injuries occur at much lower *g*-levels. The average deceleration values computed for the two end-on impacts were as follows:

TEST	AVG. DECEL. (*g*)
130	2.5
132	3.4

Higher vehicle deceleration may be expected for smaller (i.e., 2,000-lb) test cars.

The advantages of the flared over the nonflared terminal for end-on impacts were demonstrated in the crash tests. Vehicle stability was good throughout Test 130 (flared), whereas considerable pitching and rolling occurred in Test 132 (no flare). Of the two tests, maximum longitudinal vehicle deceleration (50-msec average) was measured in the flared test; however, when considering overall deceleration data and vehicle stability, the flared terminal produced the better results. Figure 14 contains deceleration-time data for the end-on tests. It should be pointed out that the decelerations were not uniform, hence the applicability of comparing the average decelerations to the crash cushion criterion is questionable.

From the results of the two end-on tests, it was difficult to compare performance of the two methods of stabilizing

TABLE 5

CRITIQUE OF TERMINAL PERFORMANCE

SERVICE REQUIREMENTS	REMARKS
A guardrail terminal should:	
1. Develop tensile and/or flexural strength necessary to insure desirable redirection performance of the length-of-need section.	1. Test 131 demonstrated the anchor effectiveness.
2. By redirection, containment, or controlled penetration minimize vehicle/occupant decelerations for terminal section impacts. This implies that the impacting vehicle is not launched, rolled, or pocketed. (In some cases end-on impacts can be eliminated; e.g., extending rail end into back slope).	2. Vehicle was redirected for angular impact near the end (Test 131) and was redirected behind the rail for the two end-on tests (130 and 132). Decelerations were within limits specified for crash cushions for 4,000-lb vehicles, although decelerations were not uniform. Higher decelerations would be expected for a 2,000-lb vehicle. Vehicle stability was good in Tests 130 and 131; no pocketing for angular impact. Undesirable vehicle instability occurred in Test 132.
3. Be designed so that possible penetration of vehicle passenger compartment by system component is minimized.	3. No penetration of passenger compartment occurred in any of the tests.
4. Be economical in construction, damage repair, and maintenance.	4. Terminal construction costs are in line with existing standards. Damage to terminal was not excessive for end-on tests. Several components were reusable.
5. Minimize vehicle damage.	5. Damage to the vehicle front end was severe for the end-on impacts; however, the passenger compartment integrity was not violated.
6. Have a pleasing and functional appearance.	6. Terminal design fulfills this requirement.

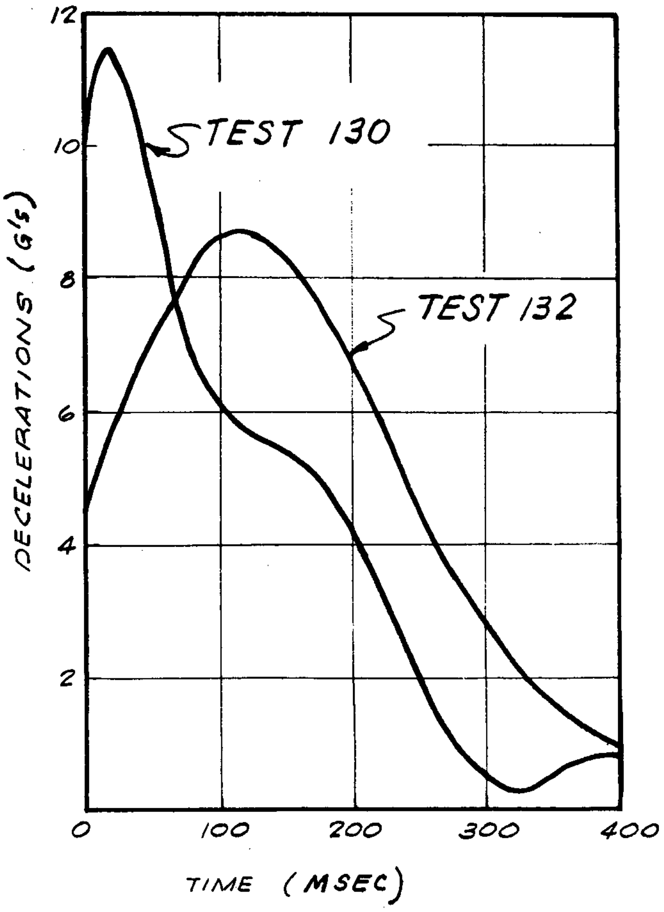


Figure 14. Deceleration vs time for end-on tests.

the nose. Both methods spread the beam loads over a large vehicle frontal area, and no indications of beam intrusion beyond the engine block were evident. (Many of the spectacular "spearing" accidents have occurred due to ability of a smaller end section to "snake" through the engine compartment and penetrate into the passenger compartment.) With both stiffening methods the oversize nose seemed to preclude the spearing possibility.

From overhead views (see Figs. A-22 and A-30), it is evident that significant buckling of the rail elements occurred at 0.05 sec for Test 130 and at 0.18 sec for Test 132. Inasmuch as the dynamic longitudinal strength of the rail is considerable until buckling occurs, the behavior of the terminal in Test 130 was better from this consideration.

Angular Impacts

Test 131 demonstrated that the selected terminal design was effective in developing essential anchorage strength for a severe impact (i.e., 4,000-lb vehicle, 60 mph, 15 deg) within the second span. From observations of the minimal damage (i.e., slight cracking of the concrete footing around the end post) sustained in this test, the design is conjectured to be capable of sustaining even more severe impacts or impacts nearer the end span. For severe impacts within the end span where the end post is directly sheared by the vehicle, the vehicle should penetrate the system with results similar to but less severe than those produced in tests by California (*3*). (The breakaway post offers less resistance than the concrete deadman for cable anchorage.)

Application

The flared breakaway cable terminal with the nose stiffened by either steel diaphragm(s) or vermiculite concrete is considered applicable to Systems G2, G4W, and G4S from *NCHRP Report 118*. Tests 130 and 131 demonstrated the effectiveness of this system in both anchoring the rail and attenuating end-on impacts. Although certain refinements may be made to further soften the end-on impact, this design is recommended for immediate installation for field evaluation. A spray coating of linseed oil is recommended for weatherproofing the vermiculite concrete (*12*).

CHRISTIANI & NIELSEN TESTS

Results of the test series on the Christiani & Nielsen traffic barrier systems indicate that the W-beam system performed satisfactorily; however, the tubular rail system demonstrated performance inadequacies.

Tubular Rail System

Although the tubular system performed exceptionally well for the many moderate impacts with manned vehicles and for the medium speed test (Test 126), system failures occurred in the two standard conditions (i.e., 4,000-lb vehicle, 60 mph, 25-deg angle) tests. The articulated joints, which function well under moderate impacts, are not compatible with the severe impact conditions employed in full-scale testing, as they permit excessive rail deflection. Another important aspect of this system was the interface of the vehicle bumper and the round rail. Many of the bumper profiles of standard U.S. cars (including those used in the test series) actually perform as a ramp when they engage a round surface. Noticeable climbing of the bumper over the rail was evident in both tests where vehicle penetration occurred.

Redesign of the joints and the barrier profile is considered necessary before this system should be considered for use in the United States. It should be noted that Christiani & Nielsen have recently developed a dual-rail system for bridges which utilizes posts similar to those for the single-rail system. The dual rail may be effective in preventing the climbing tendency.

W-Beam System

The C&N W-beam system performs essentially as a weak-post system with large (6 ft) deflections resulting when struck by a 4,000-lb vehicle at 60 mph and 25-deg impact angle. Post damage is minimized when the bolts shear at the base plate; this also prevents the vehicle from snagging on the posts. The rail height in Test 128 was raised 2 in. from the standard 18⅞-in. elevation. This increase in height was based on results from the tubular rail system, and may not be warranted for the W-beam. As the hydraulic posts rock back, the vehicle rises with the rail; therefore, it is important that the mounting height be minimized to prevent excessive pitching of the vehicle during impact.

The C&N W-beam system redirected the vehicle with low decelerations in Test 128. Although considerable damage to the beam resulted, damage to the posts was not extensive. Although vehicle damage was extensive on the left front of the vehicle, the damage was limited primarily to sheet metal. The vehicle was driven from the test area, but the right wheel separated after being driven a short distance.

Economics

No representative cost figures for the C&N systems are available for the United States; however, it is apparent that the hydraulic post assembly is an expensive item when compared to other guardrail posts. Maintenance expense of the barrier system for severe impacts should be comparable to present systems; however, for moderate-speed, small-angle impacts the system is reported by C&N to be practically maintenance free. Vehicle damage is also slight for moderate impacts, as demonstrated in Test 126.

Application

The tubular rail system is not recommended until design modifications are incorporated and the system is tested. A cost analysis would appear to be the next step in considering the C&N W-beam system. If the initial installation costs are not prohibitive, the W-beam system may have application in areas where numerous moderate impacts occur and traffic density endangers the labor crew making repairs to the damaged traffic barrier.

CHAPTER FOUR

CONCLUSIONS AND SUGGESTED RESEARCH

CONCLUSIONS

From the findings and results of the research reported herein, the following conclusions concerning design and performance of highway traffic barrier systems are drawn.

Terminal Service Requirements

The service requirements outlined in Chapter Two are considered to be reasonable criteria for evaluating guardrail terminals.

Guardrail Terminal Evaluation

Full-scale crash tests are necessary for evaluating guardrail terminals. Because the potential combinations of impact locations and conditions (i.e., impact speed and angle) are numerous, no well-defined test matrix has been established at this time; however, any test series should include at least one end-on impact (0-deg impact angle) and one angular impact near the end.

Breakaway Cable Terminal

The breakaway cable terminal has demonstrated acceptable full-scale crash test performance (i.e., for the 4,000-lb vehicle impacting at 60 mph and 0-deg and 15-deg impact angles). Although both the straight and the flared terminal satisfied the traffic barrier service requirements, the performance of the flared terminal was considered to be superior. Further development work on the concept is scheduled, but the results will not be available for several months.

Christiani & Nielsen Barrier Systems

Performance of the C&N *tubular* system was unsatisfactory. Until design modifications are made, the tubular system should not be used in the field. On the other hand, dynamic test performance of the W-beam system is considered to be satisfactory, and may have use in locations where numerous moderate impacts occur.

SUGGESTED RESEARCH

Several barrier systems have demonstrated satisfactory performance in full-scale crash tests and in accident experience. Improvements in current systems, as well as new systems that show potential, need to be evaluated as they develop. The area of guardrail terminals and transitions were objects of study and evaluation efforts in this project. Additional work is needed to update information contained in *NCHRP Report 118,* in particular regarding warrants for traffic barriers.

Several areas of future research in highway guardrail technology are recommended.

Guardrail Terminals

Only one of the twelve guardrail terminal concepts formulated in this study was evaluated by crash tests. Although the performance of this terminal was deemed acceptable, design refinements may improve its costs and dynamic performance; these items are discussed in a succeeding paragraph. Of course, effective and safe terminals are needed for other systems (e.g., the box beam systems and the concrete median barrier) and concept development/evaluation similar to that employed for the breakaway cable terminal should be undertaken.

Guardrail Transitions

Three guardrail transition concepts were formulated in the study. A finalized design effort and subsequent evaluation (full-scale crash tests) are recommended for the TR-2 concept.

Breakaway Cable Terminal

Further effort should be undertaken to reduce the longitudinal impact resistance for end-on impacts. The terminal should also be evaluated for end-on impacts with a 2,000-lb vehicle. Other methods for stabilizing the nose during impact may be required if an alternate to the vermiculite concrete or steel diaphragm is needed. The breakaway cable terminal design should be further appraised for schemes to reduce material and installation costs.

Guardrail Warrants

Recent accident statistics and new accident cost analyses procedures indicate that an updated embankment warrant curve may be needed to replace the one shown in *NCHRP Report 118.* Although other warrant revisions will no doubt be required, the embankment curve should be revised to reflect recent improvement in performance of barrier systems.

New Barrier Systems

New traffic barrier systems that show promise of extending the state-of-the-art and improving highway safety should be evaluated.

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APPENDIX A

EXPERIMENTAL RESULTS

This appendix contains detailed information from the experimental portion of the study. Included is information on full-scale crash tests of Christiani & Nielsen barrier systems (Tests 126 through 129), laboratory tests of timber posts, and full-scale crash tests of a selected guardrail terminal concept (Tests 130, 131, and 132).

CHRISTIANI & NIELSEN TRAFFIC BARRIER TESTS

Four full-scale crash tests were conducted on the Christiani & Nielsen barrier; the test results are summarized in Table A-1. Test 126 was a low-speed test of the C&N tube rail system, and Test 127 was a standard high-speed test of the same system. Test 129 was a repeat of Test 127, except that the rail height was increased from 18⅞ to 20⅞ in. Test 128 evaluated the C&N barrier with a W-beam rail. These tests are described in the following.

Test 126

Test Installation.—The installations for Tests 126 and 127 were identical (Fig. A-1). After Test 126 was conducted, damaged elements were replaced and Test 127 was performed.

The Christiani & Nielsen standard 4-in.-diameter steel-tube rail was mounted (center of tube 18⅞ in. above grade) to the hydraulic posts spaced at 10-ft centers; the posts were mounted to 36-in.-diameter by 36-in.-deep concrete footings. The 170-ft length of the test installation included the standard C&N anchor detail on the upstream end.

Performance.—The 4,160-lb test vehicle, a 1962 four-door sedan, impacted the installation 2.7 ft downstream from Post 7, as shown in Figure A-2. This initial point of impact was 62.7 ft from the first upstream post (Post 1) and 97.3 ft from the downstream end post (Post 17). Impact conditions were 36 mph with an angle of 23.3 deg. to the rail. Although the vehicle showed some tendency to mount the rail, the vehicle was smoothly redirected as shown in Figure A-2.

Vehicle kinematic and dynamic data derived from microanalysis of high-speed cine are given in Table A-2. Maximum vehicle accelerations of $-1.8g$ (longitudinal) and $-3.7g$ (lateral) were determined at the center of gravity of the vehicle. A maximum dynamic barrier deflection of 3.6 ft was measured.

Installation Damage.—Damage to the installation was confined to the impact area. Post 9 was separated from the system, as shown in Figure A-3. The system permanent displacement was limited to less than 1-in. set in the rail sections between Posts 7 and 8, and Posts 8 and 9. Although Post 9 was displaced from the system, no damage was sustained by the hydraulic post assembly. Separation of the post occurred according to design; the mounting bolts pulled through the threads of the base plate. Replacement of the base plate and two bolts was necessary in order to return the system to service; the rail sections would probably not require replacement in actual field installations.

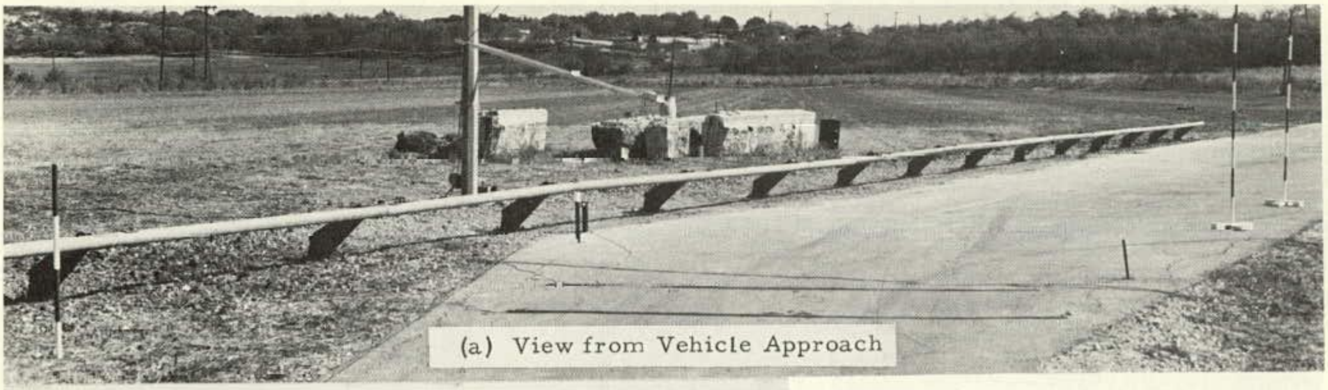
Vehicle Damage.—Damage to the vehicle was slight, as shown in Figure A-4. The vehicle was fully driveable, and damage to the front suspension was moderate.

TABLE A-1

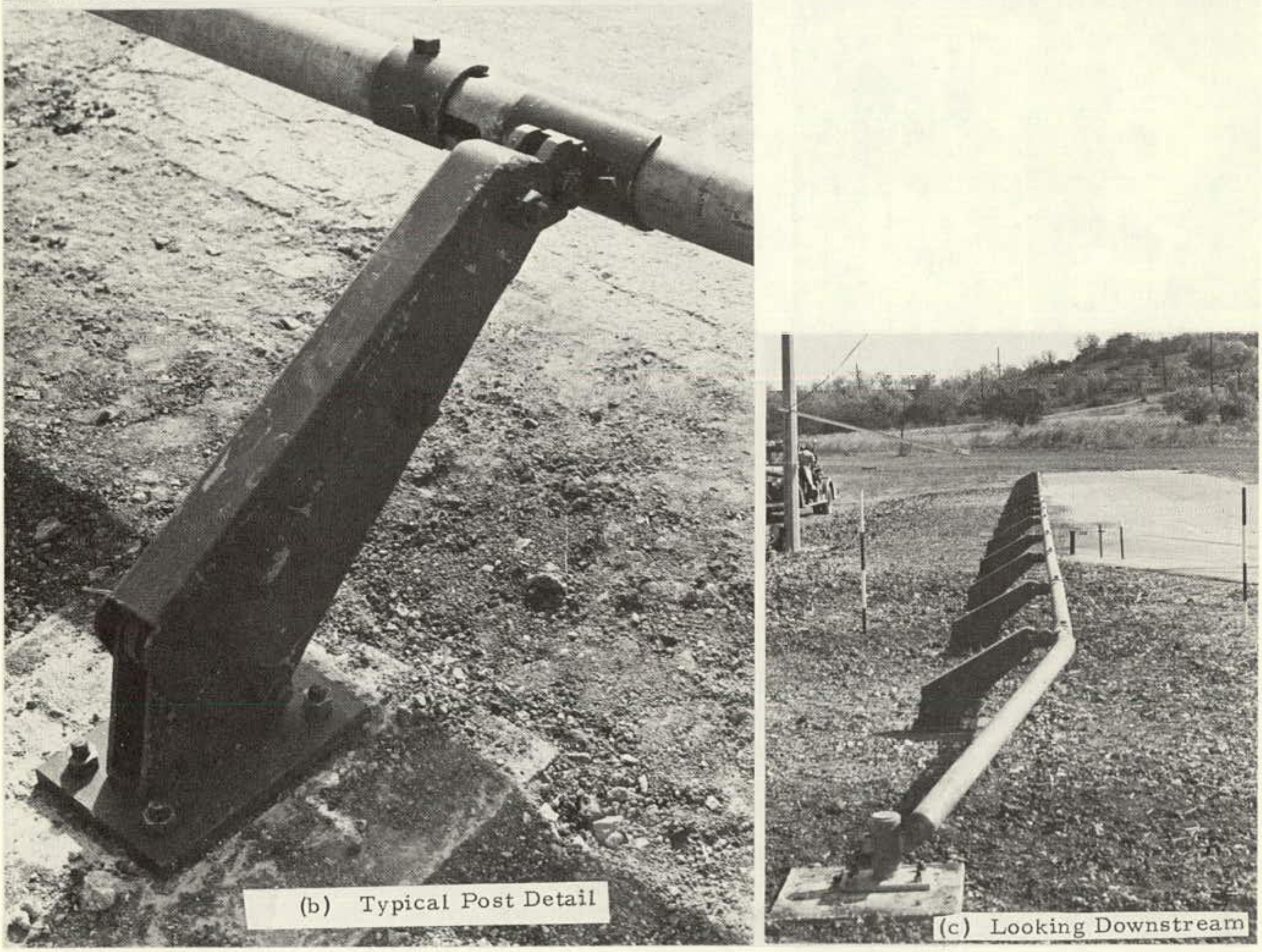
SUMMARY OF CHRISTIANI & NIELSEN BARRIER TESTS

	INSTALLATION DESCRIPTION				VEHICLE			VEHICLE DECELERATION[a] (g)			
	POST		RAIL								
SWRI TEST NO.	TYPE	SPACING (FT)	TYPE	HEIGHT (IN.)	WEIGHT (LB)	SPEED (MPH)	IMPACT ANGLE (DEG)	LONG.	LAT.	MAX. BARRIER DEFL. (FT)	REMARKS
126	C&N	10.0	4-in. dia.	18⅞[b]	4,160	36	23.3	1.6	3.7	3.6	Vehicle smoothly redirected with slight vehicle and barrier damage.
127	C&N	10.0	4-in. dia.	18⅞[b]	4,270	60	25.0	—	—	—	Vehicle penetrated.
128	C&N	10.0	12-ga W	26⅞[c]	4,057	59	24.3	4.13	4.95	6.0	Vehicle redirected; rail wedged between left front wheel and chassis during impact.
129	C&N	10.0	4-in. dia.	20⅞[b]	4,230	61.5	24.3	—	—	—	Vehicle rolled.
Tests by Other Agencies:											
1	C&N	10.0	12-ga W	27⅝[c]	18,000	28	25.0	—	—	—	Vehicle redirected; test performed by Finland T.V.H.
2	C&N	10.0	12-ga W	27⅝[c]	2,000±	65	20.0	—	—	—	Vehicle redirected; car driven by live driver at racetrack in England.
3	C&N	10.0	12-ga W	27⅝[c]	3,210	70.5	20.0	—	—	—	Vehicle redirected parallel to rail; test performed at Boreham Proving Grounds of Ford Motor Co., England.

[a] Highest 50-msec average.
[b] Measured to centerline of rail.
[c] Measured to top of rail.



(a) View from Vehicle Approach



(b) Typical Post Detail

(c) Looking Downstream

Figure A-1. Christiani & Nielsen barrier test installation, Tests 126 and 127.

Test 127

Performance.—The 4,270-lb test vehicle, a 1965 four-door sedan, impacted the installation 4.1 ft downstream from Post 6, as shown in Figure A-5. This initial point of impact was 54.1 ft from the first upstream post (Post 1) and 105.9 ft from the downstream end post (Post 17). Impact conditions were 60 mph at an angle of 25 deg. As shown in Figure A-5, little redirection occurred, because the vehicle mounted the rail. Separation of the rail occurred at the end anchor approximately 0.21 sec after impact. However, this failure * is considered secondary inasmuch as the vehicle had already mounted the rail and forced it down.

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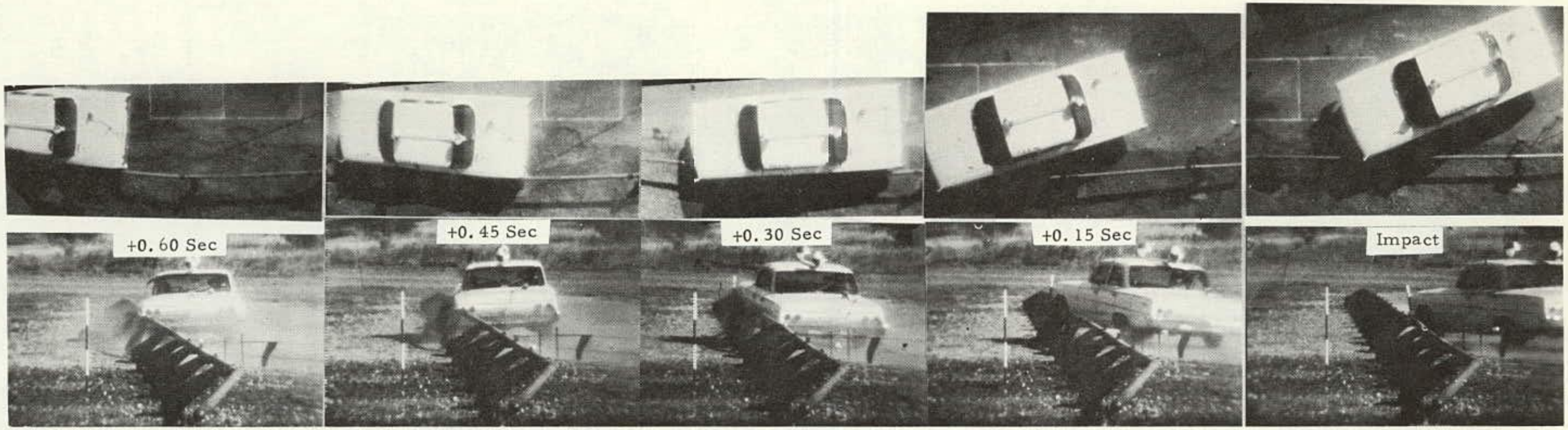
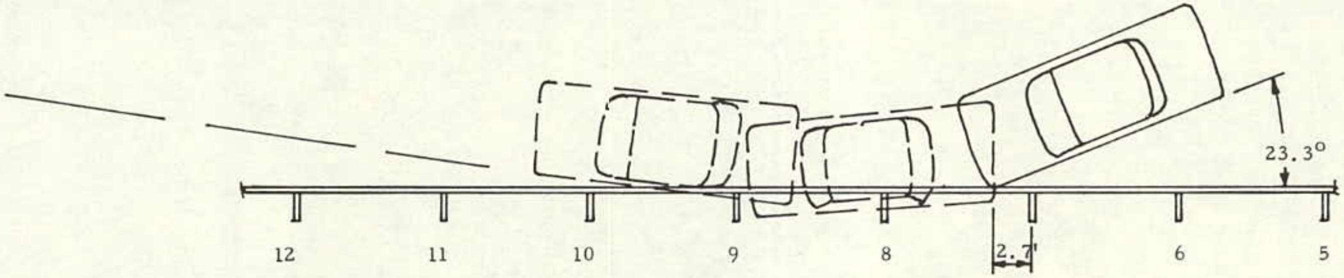
* Failure of the end anchor is attributed to a Christiani & Nielsen shop weld that lacked proper penetration.





Test Installation *
Posts .... C & N Hydraulic
Post Spacing .... 10.0 ft
Rail .... 4 in dia x 0.25 in wall
Length of Installation .... 170 ft
Ground Condition .... Dry
Max. Dynamic Deflection ... 3.6 ft

Test No. 126
Date 11-20-70
Vehicle ...... 1962 Chevrolet
Vehicle Weight ..... 4160 lb
Impact Speed ...... 36 mph
Impact Angle ...... 23.3 deg

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*Refer to Christiani and Nielsen Drawing Nos. 116-9, 155-1, and 156-1 for other details.

Figure A-2. Summary of results, Test 126.

TABLE A-2

SUMMARY OF VEHICLE KINEMATIC AND DYNAMIC DATA, TEST 126

Time After Impact (sec)	Vehicle C. G. Coordinates		Heading Angle (deg)	Vehicle Velocity (ft/sec)		Vehicle Accelerations (ft/sec^2)	
	X (ft)	Y (ft)		Longitudinal	Lateral	Longitudinal	Lateral
0.0000	-16.9489	-5.7336	23.2828	52.6678	-.5600	-43.9539	-40.5551
.0100	-16.5249	-5.5314	23.1225	52.1971	-.9381	-53.5111	-52.5979
.0200	-16.0237	-5.3362	22.9059	51.6394	-1.3731	-57.9179	-63.3600
.0300	-15.5454	-5.1490	22.6352	51.0613	-1.8424	-58.3230	-71.4795
.0400	-15.0697	-4.9706	22.3143	50.4962	-2.3169	-55.7943	-76.2030
.0500	-14.5962	-4.8013	21.9485	49.9753	-2.7659	-51.3021	-77.2641
.0600	-14.1247	-4.6411	21.5437	49.5080	-3.1597	-45.7026	-74.7747
.0700	-13.6546	-4.4995	21.1061	49.1036	-3.4724	-39.7232	-69.1290
.0800	-13.1456	-4.3457	20.6417	48.7621	-3.6835	-33.9534	-60.9184
.0900	-12.7187	-4.2089	20.1555	48.4784	-3.7787	-28.8407	-50.8573
.1000	-12.2512	-4.0776	19.6517	48.2430	-3.7505	-24.6932	-39.7180
.1100	-11.7853	-3.9513	19.1333	48.0440	-3.5980	-21.6988	-28.2766
.1200	-11.3206	-3.8261	18.6017	47.8485	-3.3267	-19.8882	-17.2688
.1300	-10.8573	-3.7073	18.0571	47.7032	-2.9475	-19.2522	-7.3550
.1400	-10.3955	-3.5477	17.4985	47.5359	-2.4759	-19.6599	.9047
.1500	-9.9357	-3.4687	16.9235	47.3560	-1.9311	-20.9285	7.0684
.1600	-9.4782	-3.3497	16.3294	47.1551	-1.3349	-22.8317	10.8219
.1700	-9.0229	-3.2302	15.7123	46.9273	-.7106	-25.1170	11.9822
.1800	-8.5705	-3.1103	15.0687	46.6691	-.0820	-27.5224	10.4956
.1900	-8.1210	-2.9902	14.3950	46.3800	.5275	-29.7910	6.4318
.2000	-7.6745	-2.8701	13.6879	46.0622	1.0959	-31.6840	-.0266
.2100	-7.2311	-2.7509	12.9453	45.7202	1.6034	-32.7936	-8.5972
.2200	-6.7906	-2.6332	12.1659	45.3608	2.0326	-33.5539	-18.9136
.2300	-6.3533	-2.5161	11.3499	44.9925	2.3699	-33.2505	-30.5440
.2400	-5.9184	-2.4066	10.4990	44.6252	2.6050	-32.0281	-43.0105
.2500	-5.4862	-2.3000	9.6162	44.2695	2.7318	-29.8962	-55.8104
.2600	-5.0555	-2.1993	8.7063	43.9358	2.7482	-26.9309	-68.4384
.2700	-4.6266	-2.1059	7.7756	43.6339	2.6561	-23.2733	-80.4073
.2800	-4.1993	-2.0207	6.8316	43.3719	2.4613	-19.1235	-91.2686
.2900	-3.7722	-1.9447	5.8829	43.1559	2.1726	-14.7299	-100.6301
.3000	-3.3456	-1.8341	4.9390	42.9889	1.8020	-10.3749	-108.1712
.3100	-2.9196	-1.8823	4.0099	42.8707	1.3634	-6.3564	-113.6528
.3200	-2.4932	-1.9365	3.1053	42.7978	.8721	-2.9672	-116.9241
.3300	-2.0664	-1.9955	2.2349	42.7632	.3446	-.4733	-117.9234
.3400	-1.6393	-2.0562	1.4074	42.7569	-.2028	.9072	-116.6754
.3500	-1.2118	-2.1234	.6302	42.7664	-.7540	1.0234	-113.2842
.3600	-.7840	-2.1903	-.0906	42.7776	-1.2937	-.1933	-107.9229
.3700	-.3563	-2.2578	-.7510	42.7761	-1.8075	-2.7177	-100.8226
.3800	.0709	-2.3252	-1.3492	42.7478	-2.2826	-6.4259	-92.2592
.3900	.4974	-2.3919	-1.8856	42.6803	-2.7073	-11.0951	-82.5412
.4000	.9224	-2.3628	-1.8790	42.5641	-3.0718	-16.4100	-71.9970
.4100	1.3455	-2.7857	-1.8240	42.3937	-3.3677	-21.9744	-60.9642
.4200	1.7661	-3.1611	-1.7805	42.1679	-3.5886	-27.3279	-49.7777
.4300	2.1837	-3.4972	-1.7486	41.8909	-3.7300	-31.9675	-38.7590
.4400	2.5979	-3.8033	-1.7285	41.5723	-3.7896	-35.3738	-28.2047
.4500	3.0084	-4.0890	-1.7200	41.2270	-3.7677	-37.0414	-18.3748
.4600	3.4151	-4.3635	-1.7228	40.8748	-3.6668	-36.5141	-9.4803
.4700	3.8181	-4.6344	-1.7365	40.5397	-3.4921	-33.4259	-1.6731
.4800	4.2177	-4.9075	-1.7601	40.2486	-3.2510	-27.5481	4.9623
.4900	4.6147	-5.1854	-1.7930	40.0297	-2.9533	-18.8445	10.4110

The vehicle continued beyond the rail before being braked to a stop in the final position shown in Figure A-6. Because the barrier system did not contain and redirect the car, performance of this system was judged unsatisfactory.

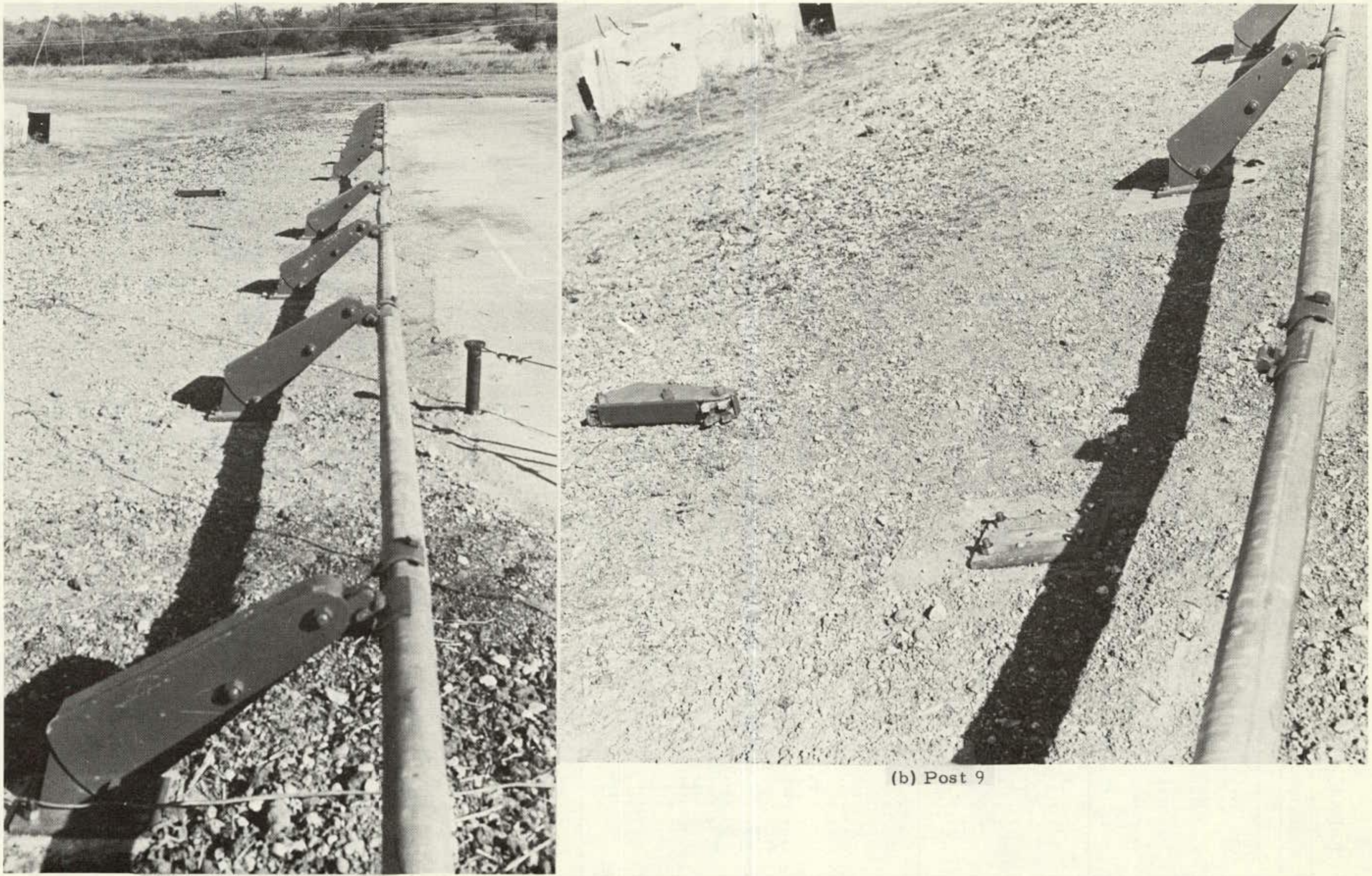
Installation Damage.—Damage to the installation was extensive, as shown in Figure A-6. Inasmuch as installation damage under these conditions (vehicle penetrated the installation) is considered somewhat meaningless, no further discussion of the damage is presented.

Vehicle Damage.—Vehicle damage was moderate, as shown in Figure A-7.

Test 128

Test Installation.—Pre-test installation views of Test 128 are shown in Figure A-8. The posts were mounted to the concrete footings used in Tests 126 and 127; no damage to the anchor bolts or concrete footings was observed throughout the four-test series.

The rail height for Test 128 was increased 2 in. by welding 2 × 3 × 8½-in. steel plates to the standard base plates. These plates were drilled and tapped to accommodate two ⅝-in. diameter socket head cap screws that attach the post to the base plate. The top of the rail before test was 26⅞ in. above grade.



(a) Looking downstream

(b) Post 9

Figure A-3. Installation damage, Test 126.


(a) Before Test

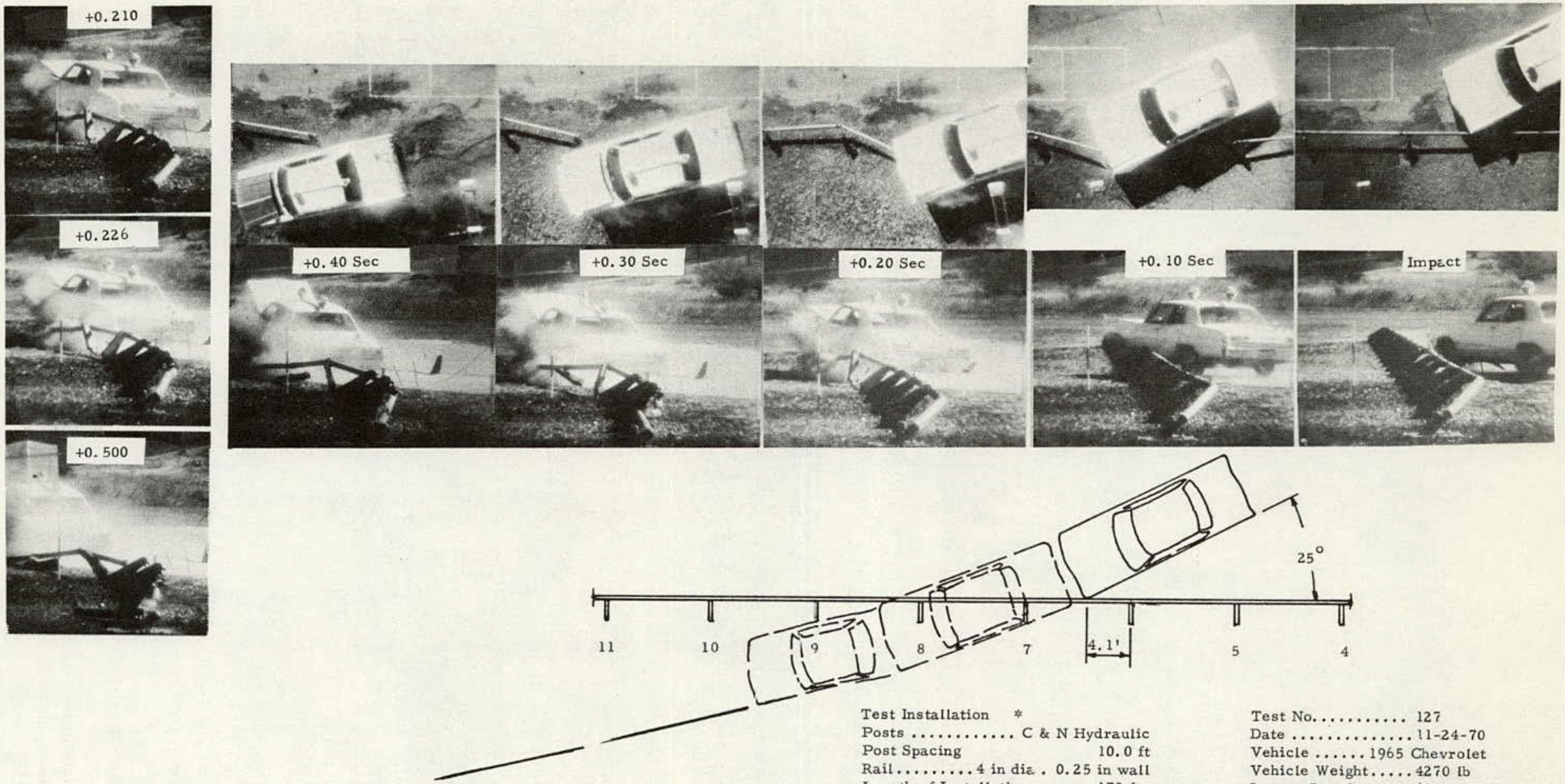

(b) After Test

Figure A-4. Vehicle damage, Test 126.

The beam element for Test 128 was similar to the standard 12-gage steel W-section used in the United States, with the following exceptions:

1. Rail element modular length was 10 ft (12.5-ft module in U.S.)
2. Six rail splice bolts (U.S. standard uses eight).
3. The middle two rail splice bolts also act as post attachment bolts.

Performance.—A 1964 two-door, hardtop sedan weighing 4,057 lb impacted the installation 3.8 ft upstream from Post 7 (posts are numbered consecutively from the upstream end). This initial point of impact was 56.2 ft from the first upstream post (Post 1) and 103.8 ft from the downstream post (Post 17). Impact conditions were 59 mph with an angle of 24.3 deg to the rail. The vehicle remained in contact with the rail for approximately



Test Installation *
Posts .... C & N Hydraulic
Post Spacing 10.0 ft
Rail.........4 in dia . 0.25 in wall
Length of Installation....... 170 ft
Ground Condition ... . Dry

Test No........... 127
Date 11-24-70
Vehicle ......1965 Chevrolet
Vehicle Weight.....4270 lb
Impact Speed...... 60 mph
Impact Angle...... 25 deg

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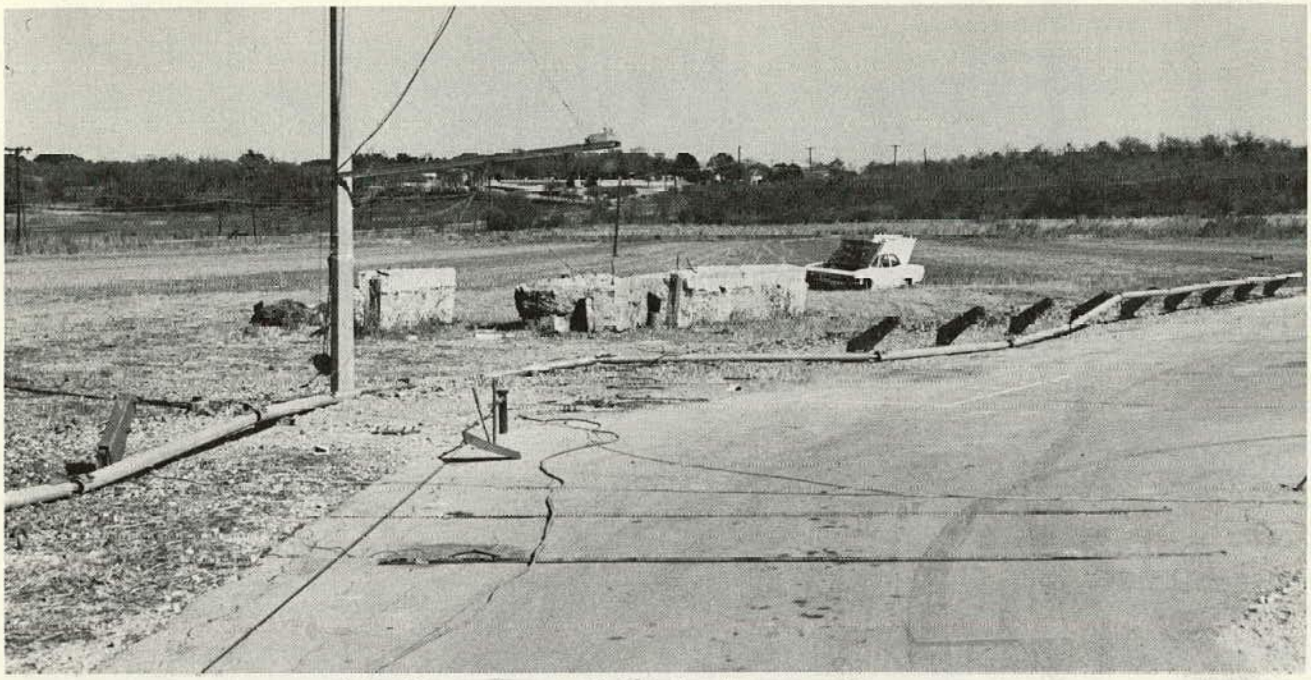
*Refer to Christiani and Nielsen Drawing Nos. 116-9, 155-1, and 156-1 for other details.

Figure A-5. Summary of results, Test 127.



(a) View from Vehicle Approach

(b) Looking Downstream

Figure A-6. Installation damage and final vehicle position, Test 127.

1.0 sec and was redirected as shown in Figure A-9. The beam wedged between the left front wheel and the vehicle chassis approximately 0.2 sec after impact. The left front wheel was airborne for almost 0.3 sec, and a maximum roll angle of 12 deg occurred at 0.4 sec after impact.

Vehicle kinematic and dynamic data derived from microanalysis of high-speed cine are given in Table A-3. Maximum vehicle accelerations of $-5.22g$ (longitudinal) and $-5.98g$ (lateral) were determined at the center of gravity of vehicle. Also, the maximum 50-millisec average vehicle decelerations were determined to be $4.13g$ (lateral) and $4.95g$ (longitudinal). A maximum dynamic deflection of 6 ft was measured.

Installation Damage.—Damage to the installation was confined to the impact area. Four posts were sheared (bolt shear) from the bases and displaced as follows:

Figure A-7. Vehicle damage, Test 127.

POST NO.	FINAL LOCATION
8	10 ft behind Post 10
9	17 ft behind Post 12
10	9 ft behind Post 17
11	12 ft behind Post 14

Posts 8, 10, and 11 were undamaged (i.e., the basic post assembly that mounts to the base plate) and could be reused. Post 9 sustained local bending near the lower portion of the housing. Post 7 also sustained local damage as shown in Figure A-10. Permanent set measured in the posts and rail is given in Table A-4.

Six 10-ft rail sections were severely damaged; rail sections between Posts 6 through 12 would warrant replacement. Significant damage occurred at rail splices located at Posts 9 and 10, as follows:

Post 9—Middle splice bolt heads pulled through upstream rail section (Fig. A-10).

Post 10—Upstream middle bolt head pulled through upstream rail section.

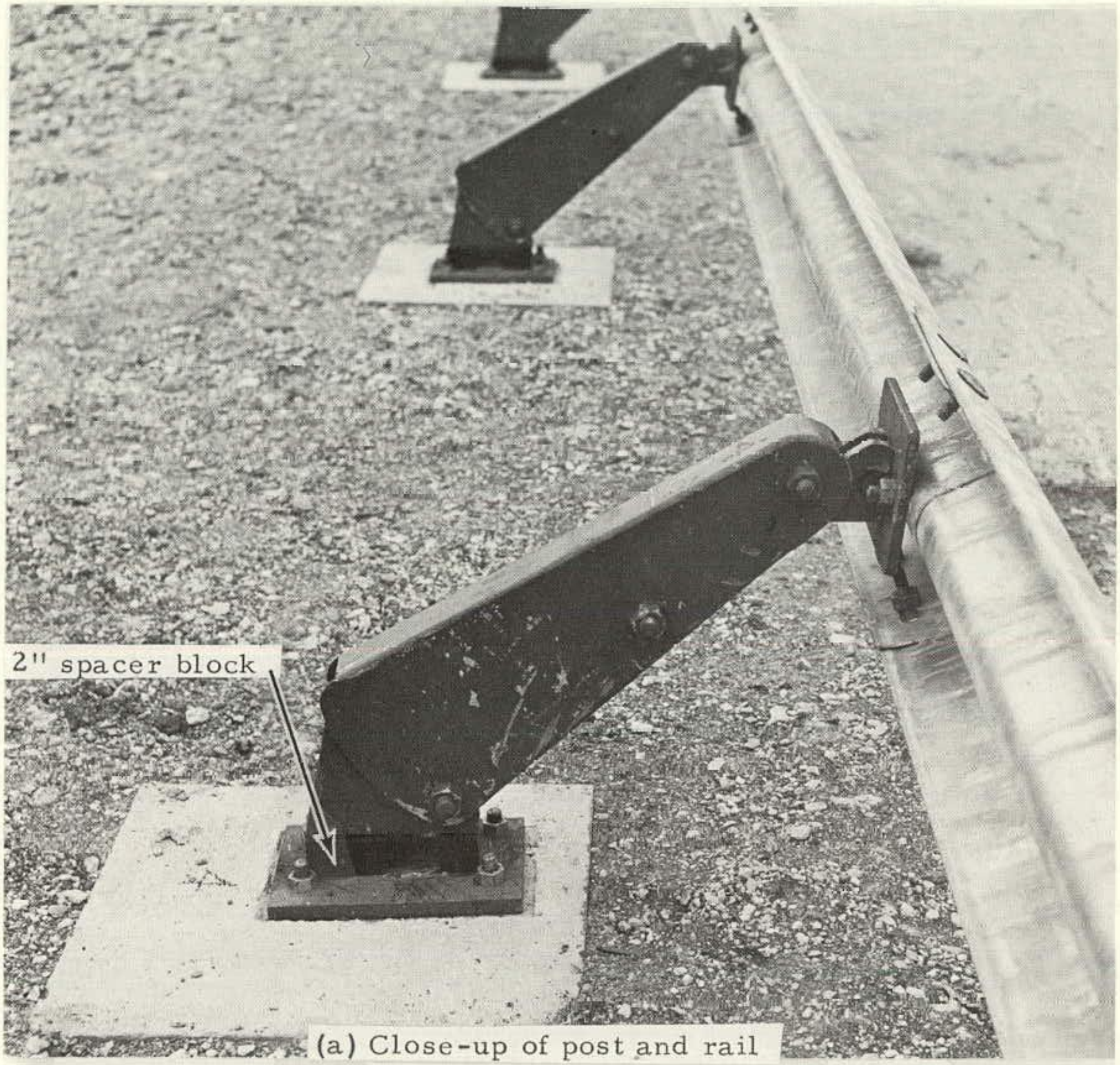
Vehicle Damage.—Severe left front end damage was sustained by the vehicle, as shown in Figure A-11. Although the left front tire was damaged, it remained inflated and the vehicle was driven from the crash test site. The right front wheel separated from the vehicle after being driven for approximately one mile. Engine compartment damage was slight and no evidence of intrusion into the passenger compartment was noted.

Test 129

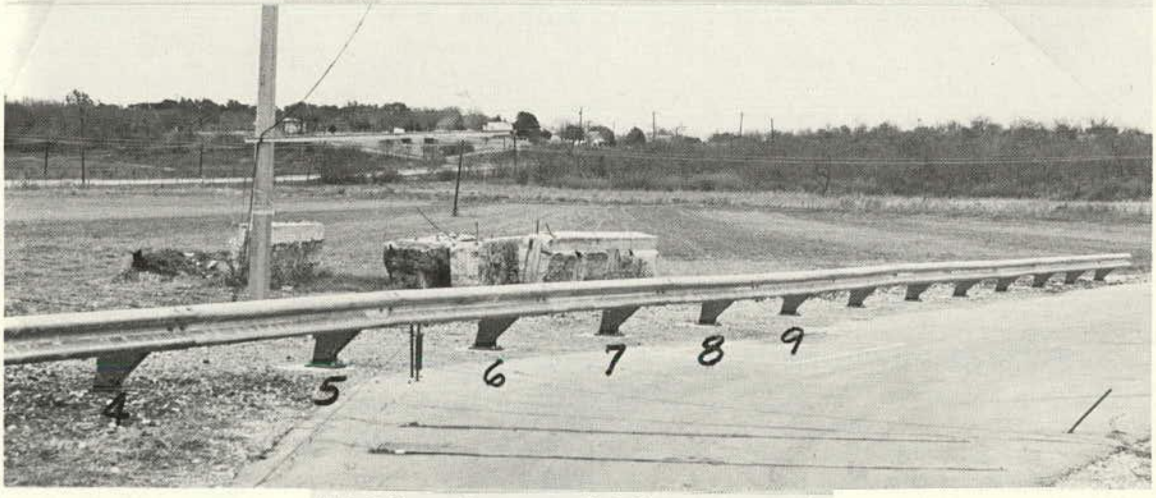
Test Installation.—Pre-test installation views of Test 129 are shown in Figure A-12. The installation was identical to that for Tests 126 and 127 with the following exceptions:

1. The 2-in. spacer used in Test 128 was used to increase rail height. The top of the rail before test was 22⅞ in.
2. The installation was anchored with steel cable at the upstream end instead of the standard "turned down" end.
3. The installation length was 120 ft.

Performance.—A 1964 four-door sedan weighing 4,230 lb impacted the installation 4 ft downstream from Post 4, as shown in Figures A-13 and A-14. This initial point of impact was 34 ft from the upstream end post (Post 1) and 86 ft from the downstream end post (Post 13). Impact conditions were 61.5 mph with an angle of 24.3 deg to the rail. The left front wheel became airborne almost immediately after impact and both front wheels had cleared the ground by 0.2 sec after impact. Lateral dynamic deflection of 6 ft occurred at 0.2 sec, as shown in Figure A-13. The vehicle pocketed and pitched severely as the left front wheel climbed over the rail. The vehicle



(a) Close-up of post and rail



(b) View from vehicle approach

Figure A-8. Christiani & Nielsen barrier test installation, Test 128.

TABLE A-3

SUMMARY OF VEHICLE KINEMATIC AND DYNAMIC DATA, TEST 128

TIME AFTER IMPACT(SEC)	VEHICLE C. G. COORDINATES(FT)		HEADING ANGLE (DEG)	VEHICLE VELOCITY (FT/SEC)		VEHICLE ACCELERATION(G'S)				APPROX. BARRIER FORCES(LB)**	
						AT TIME T		AVERAGE+ OVER .05 SEC.			
	X	Y		LONG *	LAT *	LONG*	LAT*	LONG*	LAT *	X	Y
0.000	-23.39	-5.28	24.26	86.87	2.56	-2.85	.19	0.00	0.00	10697	3980
.010	-22.61	-4.90	24.54	86.16	1.99	-1.61	-1.07	0.00	0.00	4098	6557
.020	-21.84	-4.53	24.80	85.85	1.06	-.45	-2.22	0.00	0.00	-2100	8817
.030	-21.06	-4.16	25.02	85.85	-.13	.38	-3.15	-.37	-2.45	-6720	10775
.040	-20.28	-3.81	25.15	86.04	-1.46	.77	-3.80	.17	-3.22	-9252	12446
.050	-19.49	-3.46	25.18	86.29	-2.80	.71	-4.16	.36	-3.73	-9656	13846
.060	-18.69	-3.12	25.09	86.47	-4.02	.27	-4.26	.18	-4.00	-8196	14989
.070	-17.89	-2.80	24.86	86.46	-5.03	-.46	-4.16	-.31	-4.05	-5313	15890
.080	-17.08	-2.49	24.50	86.20	-5.79	-1.37	-3.93	-1.02	-3.94	-1524	16565
.090	-16.27	-2.19	24.00	85.66	-6.27	-2.34	-3.62	-1.85	-3.72	2649	17028
.100	-15.47	-1.91	23.39	84.82	-6.47	-3.26	-3.30	-2.71	-3.46	6738	17295
.110	-14.67	-1.64	22.67	83.72	-6.42	-4.06	-3.01	-3.50	-3.19	10356	17382
.120	-13.87	-1.38	21.86	82.40	-6.18	-4.68	-2.78	-4.16	-2.96	13222	17303
.130	-13.09	-1.14	20.98	80.91	-5.80	-5.07	-2.63	-4.64	-2.79	15165	17074
.140	-12.32	-.91	20.06	79.34	-5.34	-5.22	-2.54	-4.91	-2.67	16120	16710
.150	-11.56	-.69	19.11	77.75	-4.85	-5.14	-2.51	-4.95	-2.61	16116	16226
.160	-10.82	-.49	18.16	76.22	-4.38	-4.84	-2.53	-4.80	-2.60	15261	15639
.170	-10.09	-.30	17.21	74.79	-3.95	-4.38	-2.56	-4.46	-2.60	13725	14963
.180	-9.37	-.12	16.28	73.53	-3.58	-3.81	-2.59	-3.99	-2.62	11712	14214
.190	-8.66	.04	15.39	72.46	-3.29	-3.17	-2.61	-3.43	-2.62	9443	13408
.200	-7.95	.20	14.55	71.60	-3.06	-2.52	-2.59	-2.83	-2.61	7137	12560
.210	-7.25	.34	13.75	70.93	-2.90	-1.91	-2.54	-2.24	-2.57	4990	11685
.220	-6.56	.48	13.00	70.44	-2.78	-1.38	-2.45	-1.71	-2.49	3163	10800
.230	-5.87	.61	12.31	70.10	-2.70	-.96	-2.33	-1.26	-2.38	1771	9920
.240	-5.18	.73	11.67	69.87	-2.65	-.67	-2.17	-.92	-2.24	874	9061
.250	-4.49	.84	11.08	69.71	-2.60	-.51	-2.00	-.69	-2.08	481	8238
.260	-3.80	.94	10.53	69.58	-2.55	-.48	-1.81	-.58	-1.90	547	7468
.270	-3.11	1.04	10.03	69.44	-2.48	-.54	-1.62	-.57	-1.72	983	6766
.280	-2.42	1.14	9.55	69.27	-2.41	-.67	-1.45	-.64	-1.55	1669	6148
.290	-1.74	1.23	9.11	69.04	-2.31	-.83	-1.29	-.76	-1.39	2463	5630
.300	-1.05	1.31	8.69	68.77	-2.20	-.99	-1.17	-.89	-1.27	3222	5227
.310	-.37	1.39	8.29	68.44	-2.08	-1.12	-1.09	-1.01	-1.17	3816	4957
.320	.31	1.47	7.89	68.08	-1.95	-1.19	-1.05	-1.10	-1.12	4149	4834
.330	.98	1.54	7.50	67.70	-1.83	-1.19	-1.07	-1.13	-1.12	4171	4876
.340	1.65	1.61	7.11	67.34	-1.73	-1.12	-1.14	-1.10	-1.16	3895	5097
.350	2.32	1.67	6.71	67.01	-1.65	-1.00	-1.27	-1.03	-1.26	3396	5514
.360	2.99	1.73	6.30	66.72	-1.60	-.87	-1.45	-.94	-1.41	2818	6144
.370	3.65	1.78	5.86	66.47	-1.59	-.77	-1.68	-.87	-1.62	2358	7002
.380	4.31	1.83	5.39	66.24	-1.64	-.75	-1.96	-.86	-1.87	2241	8105
.390	4.97	1.88	4.89	66.00	-1.74	-.87	-2.30	-.95	-2.19	2685	9468
.400	5.63	1.91	4.35	65.70	-1.92	-1.17	-2.70	-1.17	-2.56	3836	11109
.410	6.29	1.94	3.75	65.27	-2.18	-1.63	-3.16	-1.51	-3.00	5691	13043
.420	6.94	1.95	3.11	64.68	-2.56	-2.20	-3.71	-1.92	-3.52	7990	15287
.430	7.58	1.96	2.42	63.92	-3.08	-2.71	-4.35	-2.23	-4.13	10082	17858
.440	8.22	1.94	1.69	63.05	-3.79	-2.84	-5.11	0.00	0.00	10751	20771
.450	8.84	1.92	.93	62.28	-4.75	-2.10	-5.98	0.00	0.00	8012	24043

---

*These values are resolved along the longitudinal and lateral axes of the vehicle.

+A "running" average acceleration based on a .05 sec time interval is computed and presented in these columns.

**These "forces" are determined from resolving vehicle accelerations into barrier coordinates and multiplying these vehicle g's by 4,000 lbs (approximate vehicle weight).

was redirected; as the aft end of the vehicle yawed toward the rail (which had dropped), the vehicle was tripped and launched into a multiple roll-over.

Vehicle kinematic and dynamic data derived from microanalysis of high-speed cine are given in Table A-5. This configuration of the C&N barrier system was judged unsuccessful because vehicle penetration occurred.

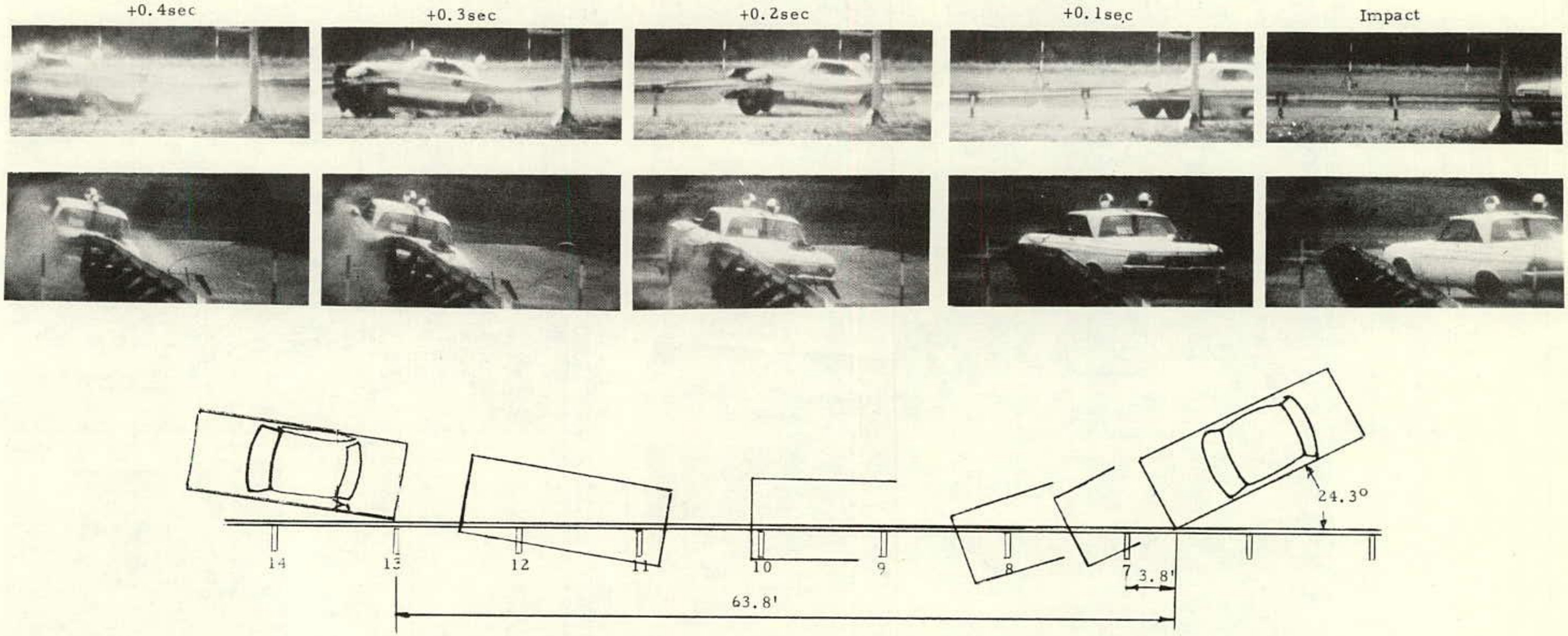
Installation Damage.—Damage to the installation was extensive, as shown in Figure A-15. Installation damage evaluation for unsuccessful tests (vehicle penetrated, rolled over) is considered somewhat meaningless; hence, these details are not presented.

Vehicle Damage.—Vehicle damage was severe, as shown in Figure A-16.

LABORATORY TESTS

The primary feature of the guardrail end terminal concept that was selected for evaluation in this program is the weak end post. Before preliminary design of the terminal could be made, laboratory tests of weakened posts were necessary to generate basic structural properties of the posts. These tests were performed in a pendulum impact facility.

Impact Tests.—Four 8 × 8 × 72-in. Douglas fir posts were selected for test in a rigid fixture. Two of the specimens were full 8 × 8-in. sections, and two had 4-in.-diameter holes drilled through them with the hole center 4 in. above the rigid base (Fig. A-17).



Test Installation ... *
Posts ...... C&N Hydraulic
Post Spacing .... 10.0 ft
Rail ... 12 ga steel "W" beam
Length of Installation .. 170 ft
Ground Condition .... Dry
Max. Dynamic Deflection. 6 ft

Test No. 128
Date 12/14/70
Vehicle .....1964 Plymouth
Vehicle Weight.....4057 lb
Impact Speed ......59 mph
Impact Angle ...... 24.3 deg

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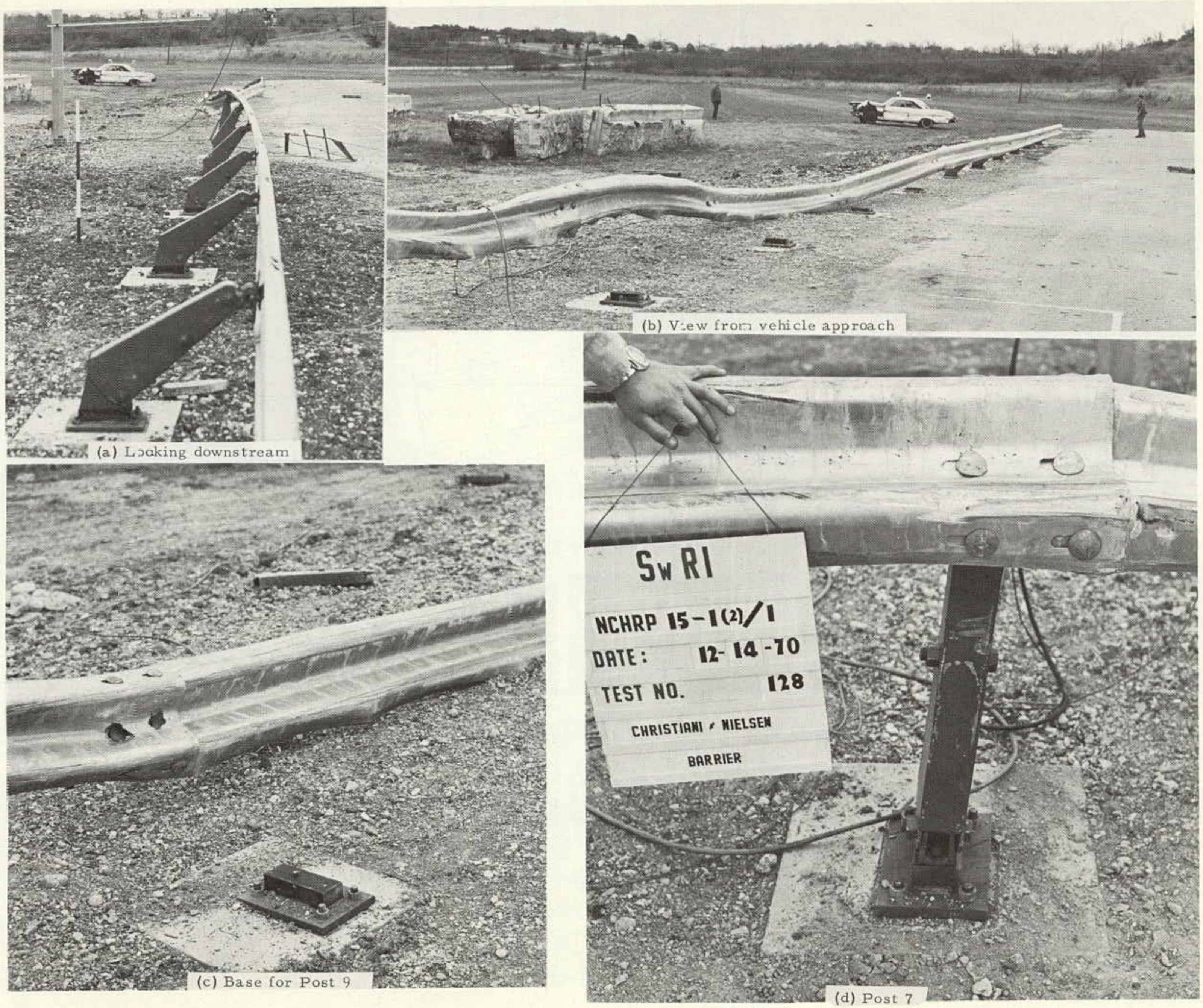
*Refer to Christiani and Nielsen Drawing Nos. 116-9, 155-1 and 156-1 for other details.

Figure A-9. Summary of results, Test 128.



(a) Looking downstream

(b) View from vehicle approach

(c) Base for Post 9

(d) Post 7

Figure A-10. Installation damage, Test 128.

Test Conditions.—Test conditions, identical for all four tests, are summarized as follows:

Pendulum mass weight	2,290 lb
Impact velocity	29 ft/sec
Point of impact	20 in. above support
Contact surface of pendulum mass	1-in. thick 70 Durometer neoprene pad

The four test specimens are described as follows; Figure A-18 shows the drilled specimens:

Specimen 1	Full section
Specimen 2	Full section
Specimen 3	4-in. hole (axis normal to force)
Specimen 4	4-in. hole (axis parallel to force)

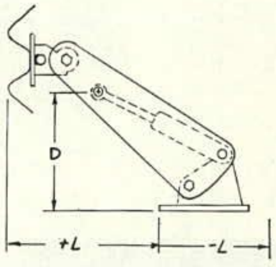
Pendulum mass decelerations were measured with a piezoelectric accelerometer and recorded on a high-speed magnetic tape recorder. The recorded signals were played back through both an unfiltered and a 200-hertz low-pass filtered circuit and then recorded on a Honeywell visicorder. Unfiltered data from the accelerometer are shown in Figure A-19. The results are summarized in Table A-6.

Discussion.—The two full-section posts showed considerable test data scatter for impact duration and linear impulse; however, the peak and average breaking forces range within 10 percent of the average value. The dynamic strength properties for the two weakened-post tests are essentially the same, even though the holes were oriented 90 deg apart. Based on the data and observations after the tests, it was concluded that all specimens failed principally in horizontal shear. The orientation of the 4-in.-diameter hole appeared to have insignificant effect on the post dynamic shear strength, as illustrated by the data for Specimens 3 and 4.

TABLE A-4

SUMMARY OF PERMANENT DEFORMATION MEASURED AT POSTS

POST	*L* (IN.)	*D* (IN.)
Typical [a]	20¾	15
4	19½	15
5	18	16¼
6	14	18
7	0	19½
8	−24½	— [b]
9	−31	— [b]
10	−18	— [b]
11	10	— [b]
12	22	13¾
13	21	14

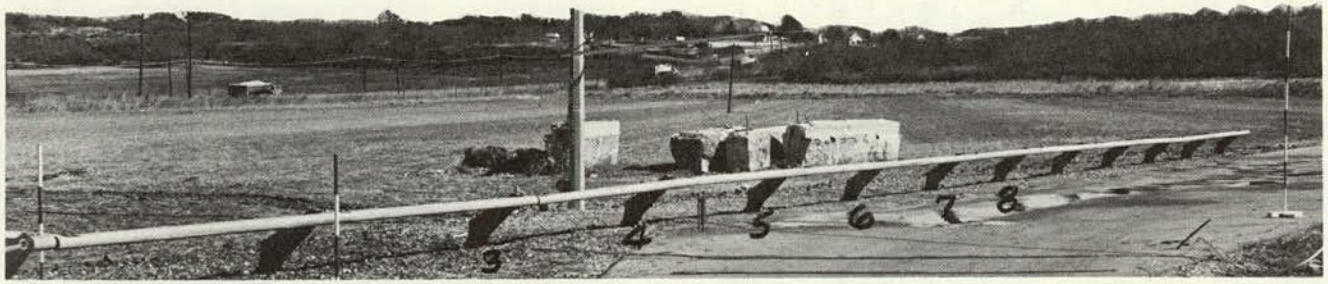


[a] Before impact.

[b] Post sheared at base plate.

Due to the range of values from the data for Specimens 1 and 2, it is not feasible to compare the dynamic strength properties of the whole section to the drilled sections. From the results of the two drilled specimens, it is apparent that net area at the failure zone was the chief geometric strength factor. Because the load was applied 20 in. above the failure plane for the whole sections and only 16 in. above

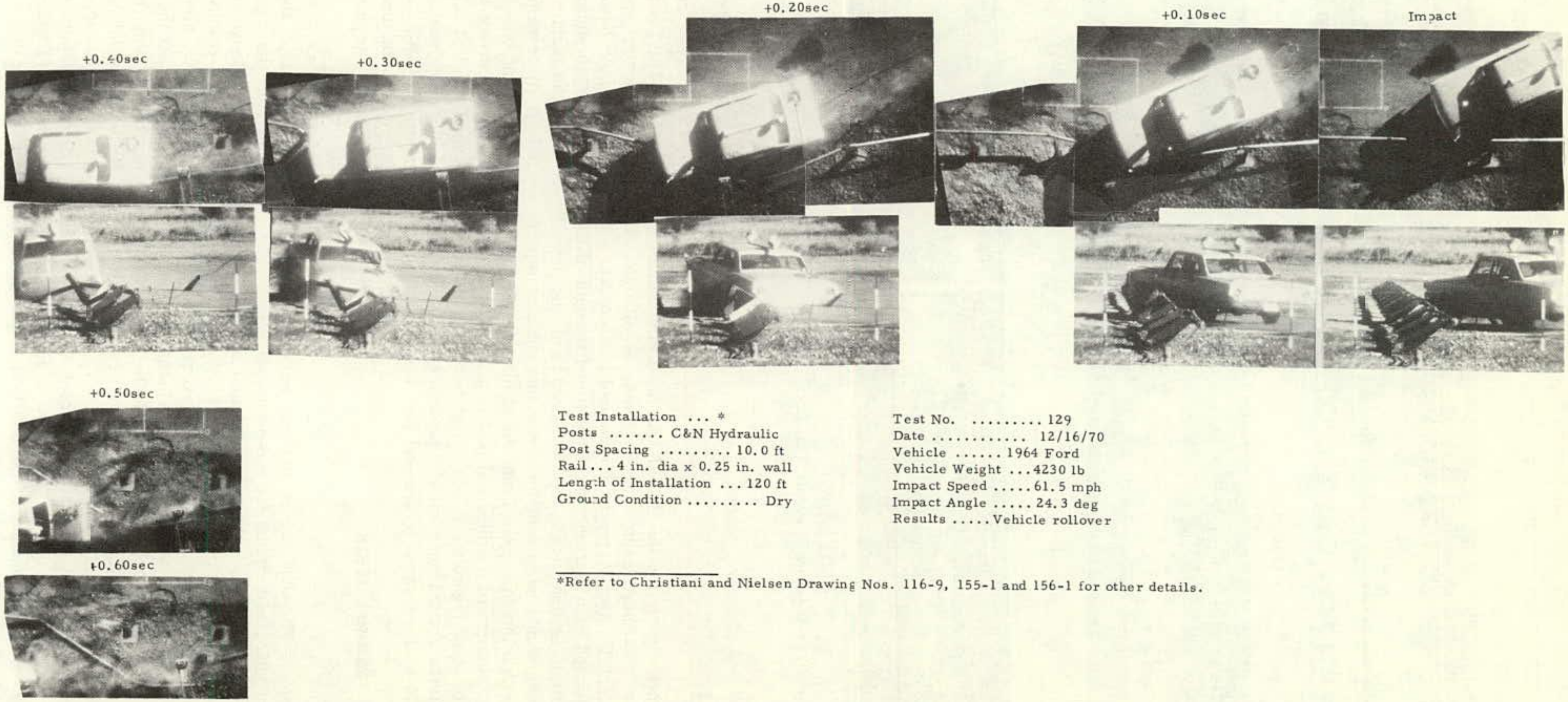
Figure A-11. Vehicle damage, Test 128.



(a) View from vehicle approach

(b) Close-up of Test 129 Installation

Figure A-12. Christiani & Nielsen barrier test installation, Test 129.



Test Installation ... *
Posts .... C&N Hydraulic
Post Spacing .... 10.0 ft
Rail... 4 in. dia x 0.25 in. wall
Length of Installation ... 120 ft
Ground Condition .... Dry

Test No. 129
Date 12/16/70
Vehicle ...... 1964 Ford
Vehicle Weight ...4230 lb
Impact Speed .....61.5 mph
Impact Angle ..... 24.3 deg
Results .....Vehicle rollover

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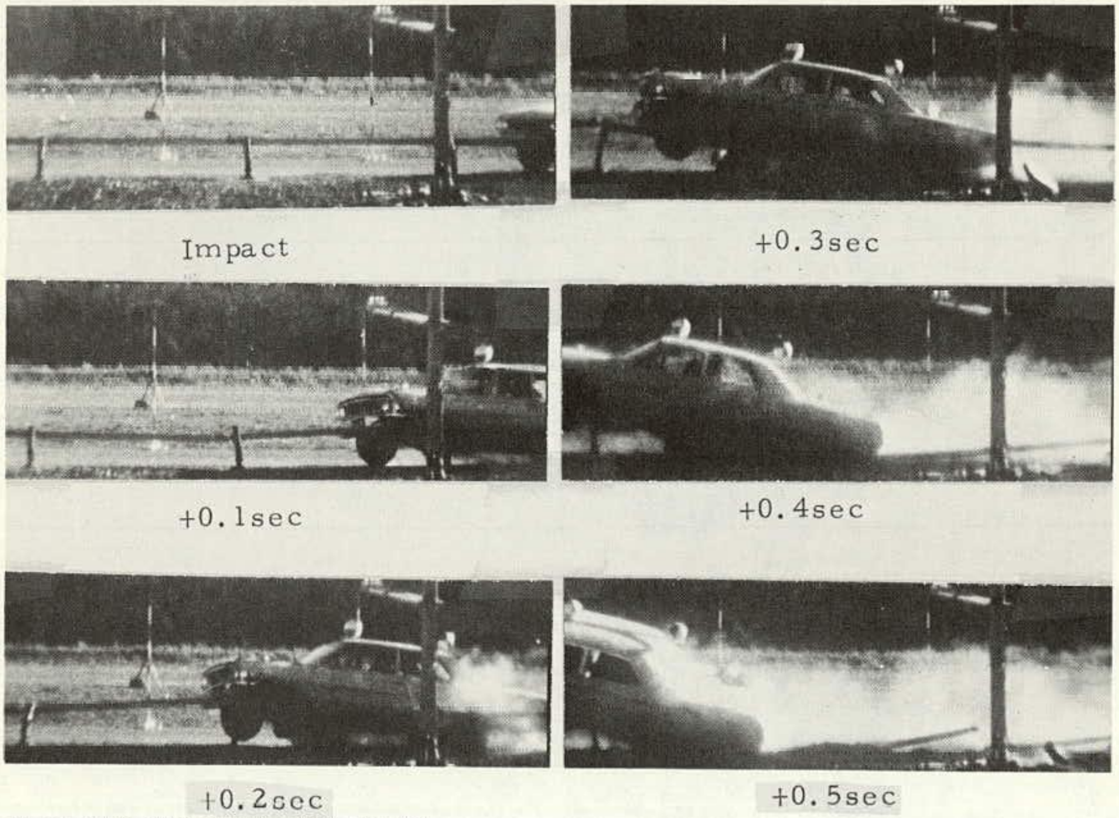
*Refer to Christiani and Nielsen Drawing Nos. 116-9, 155-1 and 156-1 for other details.

Figure A-13. Summary of results, Test 129.



Impact

+0.3sec

+0.1sec

+0.4sec

+0.2sec

+0.5sec

Figure A-14. Sequence of events, Test 129.

the net section for the drilled specimens, the modes of failure regarding flexure and shear may be different. In Concept T-8 (see Appendix B) the end post concept was formulated such that only the longitudinal strength of the approach section would be weakened and the lateral strength would be present for redirecting vehicles impacting within the end span. From the results of Tests 3 and 4, the strength of a drilled end post (square cross-section) will be equal regardless of hole orientation, thus the potential force exerted on a vehicle impacting end-on and the lateral load resistance by the end post would be identical.

END TERMINAL TESTS

Test 130

Purpose.—The objective of this test was to evaluate the flared guardrail terminal for end-on impact.

Test Installation.—The terminal design, shown in Figure A-20, consists of a 37.5-ft length of System G4 that is parabolically flared away from the pavement edge. The overall length of the installation, including the terminal, was 87.5 ft. At the downstream end, the G4 system was anchored to a 10-ft section of MB5 barrier to simulate the mass of a long installation.

The principal features of the concept are the end post and the beam end design. As shown in Figure A-20, the anchor cable is attached to the end post, which is set in concrete. The 2⅜-in.-diameter hole in the end post weakens the member in flexure and shear for forces applied above the hole; however, the post exhibits adequate strength for forces introduced via the anchor cable. When impacted end-on, the anchor post breaks at the hole, preventing the cable from developing "beam spearing" forces. Accordingly, the end post is weak for direct or near direct hits but sufficiently strong to develop cable load for barrier hits beyond the first 6.25-ft panel. The beam end, a special 11-in.-radius bend, is filled with a lightweight concrete to prevent collapse and possible beam spearing tendency during direct-on hits.

Views of the installation prior to the test are shown in Figure A-21.

Performance.—A 4,138-lb vehicle impacted the terminal nose at 61 mph and at an angle of 0 deg (i.e., measured relative to the typical barrier line), as shown in Figure A-22. As designed, the first post, and subsequently the second post, readily sheared at grade during the initial impact sequence; however, extensive damage was caused to the vehicle. As the beam pivoted about Post 3, the vehicle was forced away from the barrier line and came to a stop 50 ft from point of impact. During impact and deceleration the vehicle appeared stable, with little tendency to roll. The more important aspects of the terminal performance are shown in Figure A-23. A summary of vehicle kinematic and dynamic data is presented in Table A-7.

TABLE A-5

SUMMARY OF VEHICLE KINEMATIC AND DYNAMIC DATA, TEST 129

TIME AFTER IMPACT(SEC)	VEHICLE C. G. COORDINATES(FT)		HEADING ANGLE (DEG)	VEHICLE VELOCITY (FT/SEC)		VEHICLE ACCELERATION(G'S) AT TIME T		AVERAGE+ OVER .05 SEC.		APPROX. BARRIER FORCES(LB) **	
	X	Y		LONG *	LAT *	LONG *	LAT *	LONG *	LAT *	X	Y
0.000	-25.31	-4.74	24.32	90.20	.94	-7.49	2.12	0.00	0.00	30777	4605
.010	-24.50	-4.36	24.64	88.02	.85	-5.89	.32	0.00	0.00	21943	8663
.020	-23.71	-3.99	24.90	86.45	.24	-3.93	-1.58	0.00	0.00	11616	12347
.030	-22.93	-3.63	25.02	85.44	-.70	-2.47	-3.06	-3.72	-1.84	3790	15259
.040	-22.16	-3.28	24.97	84.77	-1.76	-1.78	-3.89	-2.78	-2.89	-107	17101
.050	-21.38	-2.95	24.75	84.22	-2.73	-1.80	-4.05	-2.32	-3.42	-250	17727
.060	-20.60	-2.63	24.41	83.59	-3.49	-2.30	-3.66	-2.36	-3.44	2329	17146
.070	-19.83	-2.32	24.02	82.76	-3.98	-3.01	-2.91	-2.72	-3.03	6276	15518
.080	-19.06	-2.03	23.60	81.71	-4.18	-3.67	-1.97	-3.20	-2.36	10297	13119
.090	-18.30	-1.74	23.21	80.48	-4.11	-4.09	-1.05	-3.61	-1.58	13383	10300
.100	-17.55	-1.47	22.85	79.17	-3.81	-4.16	-.26	-3.80	-.84	14926	7440
.110	-16.81	-1.20	22.50	77.89	-3.32	-3.88	.28	-3.73	-.24	14753	4904
.120	-16.08	-.93	22.13	76.75	-2.68	-3.31	.54	-3.40	.14	13071	2996
.130	-15.37	-.67	21.71	75.81	-1.94	-2.59	.51	-2.89	.27	10385	1929
.140	-14.66	-.41	21.19	75.11	-1.13	-1.88	.25	-2.32	.18	7376	1801
.150	-13.96	-.15	20.54	74.60	-.27	-1.34	-.19	-1.83	-.10	4762	2586
.160	-13.26	.11	19.77	74.22	.59	-1.10	-.70	-1.53	-.50	3174	4134
.170	-12.57	.37	18.86	73.84	1.45	-1.22	-1.22	-1.50	-.93	3039	6189
.180	-11.87	.62	17.87	73.34	2.26	-1.71	-1.66	-1.77	-1.34	4489	8415
.190	-11.18	.86	16.83	72.62	3.00	-2.51	-1.97	-2.30	-1.67	7315	10435
.200	-10.50	1.09	15.79	71.60	3.64	-3.44	-2.11	-2.99	-1.88	10956	11878
.210	-9.83	1.32	14.81	70.28	4.18	-4.31	-2.07	-3.67	-1.94	14543	12426
.220	-9.16	1.53	13.91	68.73	4.63	-4.84	-1.86	-4.12	-1.84	17002	11867
.230	-8.51	1.74	13.12	67.10	5.03	-4.76	-1.49	-4.13	-1.61	17202	10139
.240	-7.88	1.94	12.42	65.62	5.43	-3.86	-1.03	0.00	0.00	14172	7360
.250	-7.25	2.13	11.78	64.59	5.90	-2.00	-.57	0.00	0.00	7366	3848

---

*These values are resolved along the longitudinal and lateral axes of the vehicle.

+A "running" average acceleration based on a 0.05-sec time interval is computed and presented in these columns.

**These "forces" are determined from resolving vehicle accelerations into barrier coordinates and multipying these vehicle g's by 4,000 lb (approximate vehicle weight).

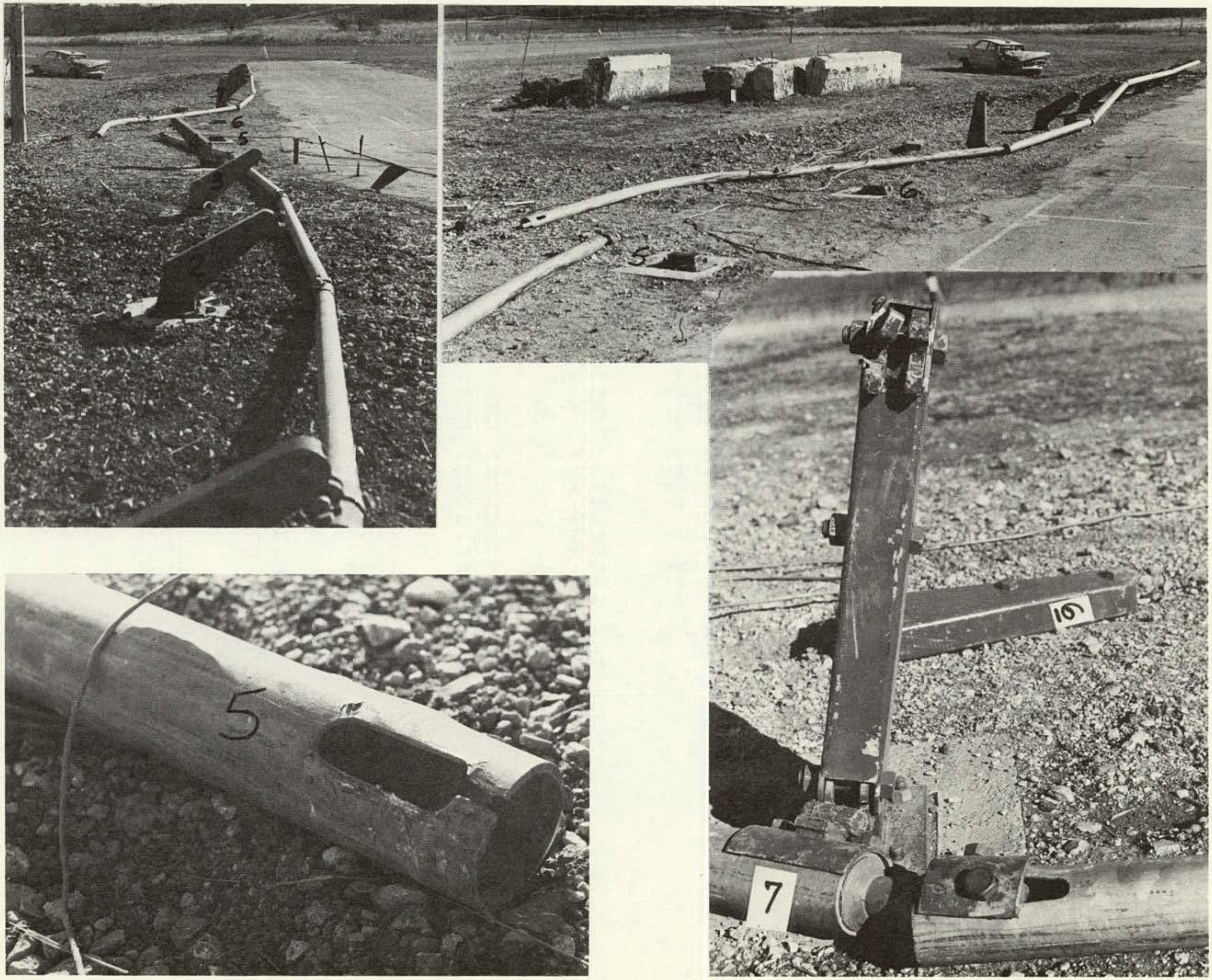


Figure A-15. Installation damage, Test 129

Figure A-16. Vehicle damage, Test 129.

Installation Damage.—The first two posts fractured near grade level (Fig. A-23), and the first two 6.25-ft beam panels bent and pivoted about the third post to the rear of the barrier system. The lightweight concrete separated from the circular end piece and fractured into several large parts. The circular end piece was only partially deformed during impact. Posts 3 and 4 deformed slightly in the soil (less than 2-in. gap at grade); otherwise the installation

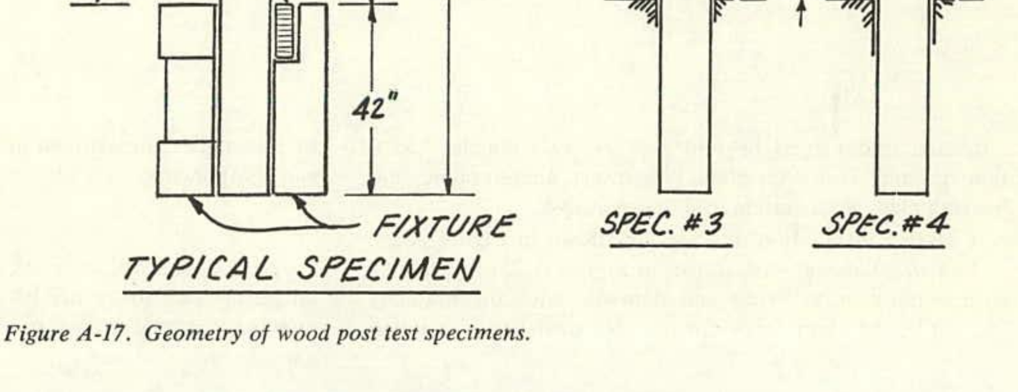
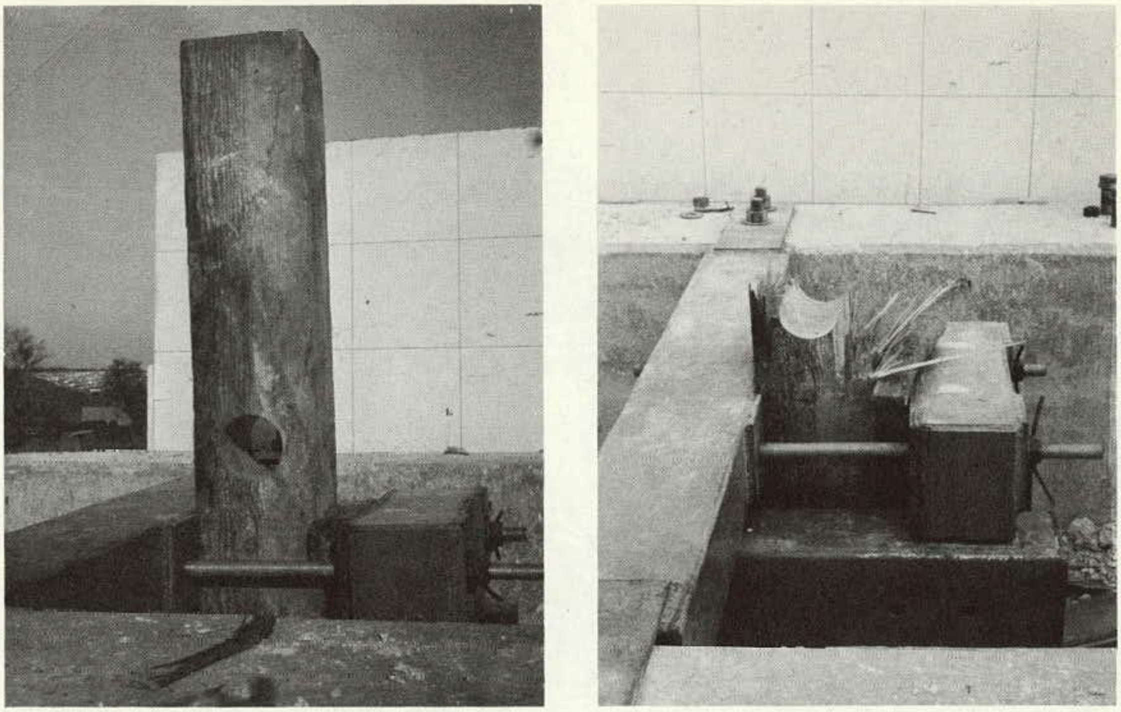
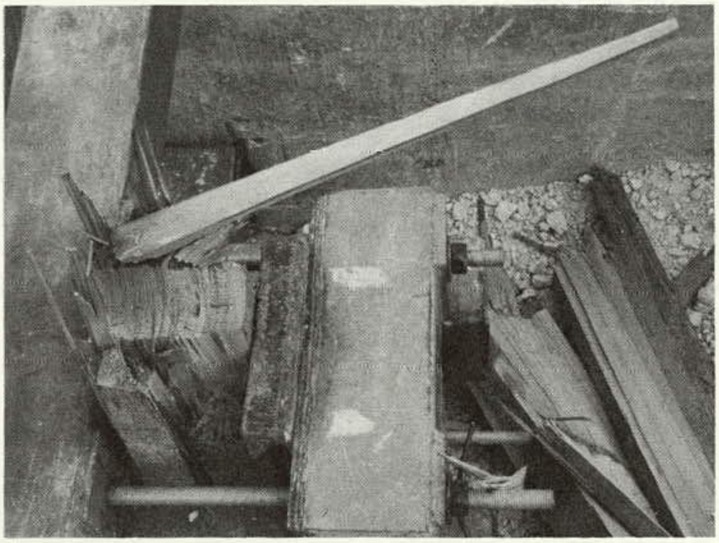


Figure A-17. Geometry of wood post test specimens.



(a) Specimen 3 in fixture

(b) Specimen 3 after test



(c) Specimen 4 after test

Figure A-18. Damage to weakened posts.

appeared undamaged beyond the first two panels. Components such as anchor plate, pipe insert, anchor cable, and bearing plate were undamaged and reusable.

Views of installation damage are shown in Figure A-24.

Vehicle Damage.—As shown in Figure A-25, the vehicle sustained extensive front end damage, with the majority located at the right front corner. No evidence was noted of passenger compartment intrusion by the engine or guardrail components.

Test 131

Purpose.—The objective of this test was to evaluate the anchorage adequacy of the system when subjected to an angular impact downstream from the end post.

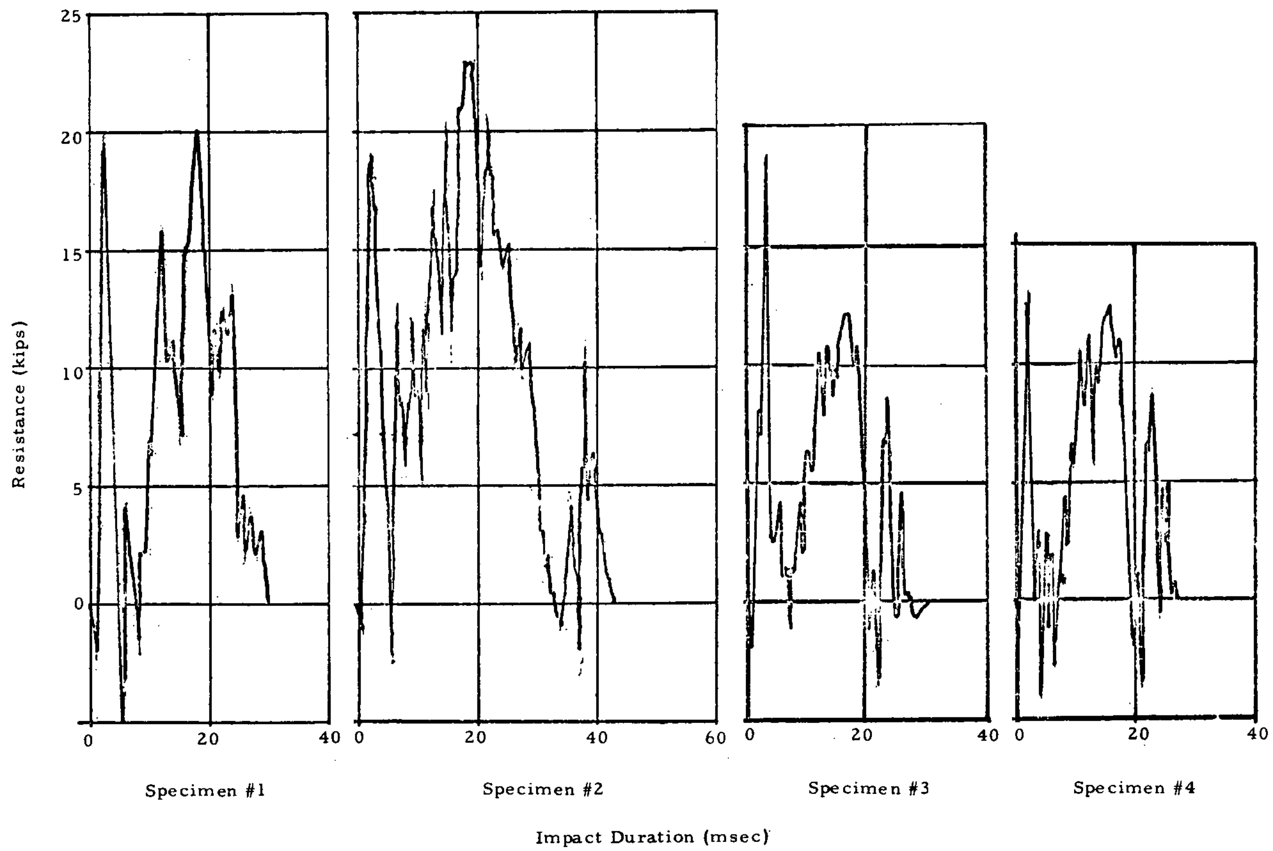


Figure A-19. Resistance vs time, timber post specimens.

Test Installation.—The installation was identical to that used for Test 130, as shown in Figure A-26.

Performance.—The 4,000-lb vehicle impacted the rail at 59.4 mph 4 ft downstream from the second post at an angle of 15 deg to the typical rail line, as shown in Figure A-27. The vehicle was redirected and came to rest with the front of the car 108 ft from the initial impact point. Maximum dynamic deflection of 3.3 ft occurred between Posts 4 and 5. A summary of vehicle kinematic and dynamic data is given in Table A-8.

Installation Damage.—No indications of anchor failure were evident; slight cracking of the concrete footing at the end post occurred. Four rail sections in the impact area were damaged beyond repair. No posts were broken, al-

TABLE A-6

SUMMARY OF TIMBER POST RESULTS

SPECIMEN NO.	WIDTH[a], W (IN.)	DEPTH, D (IN.)	AREA, A (IN.^{2})	MOMENT OF INERTIA[b], I (IN.^{4})	IMPACT VELOCITY (FT/SEC)	IMPACT DURATION (MSEC)	IMPULSE (LB-SEC)	FRACTURE ENERGY (FT-KIPS)	PEAK FORCE (KIPS)	AVERAGE FORCE (KIPS)
1	8.0	7.7	61.8	307	29	30	247	6.6	20.0	8.1
2	7.9	8.0	63.2	348	29	42	412	11.0	22.7	10.1
3	7.6	8.0	61.0 net (30.0)	327 (285)	29	28	140	3.8	12.0	4.9
4	8.0	7.8	62.4 net (31.4)	316 (158)	29	28	140	3.8	12.5	4.9

[a] See Figures A-17 and A-18; measurements taken at failure zone.

[b] About axis perpendicular to applied load.

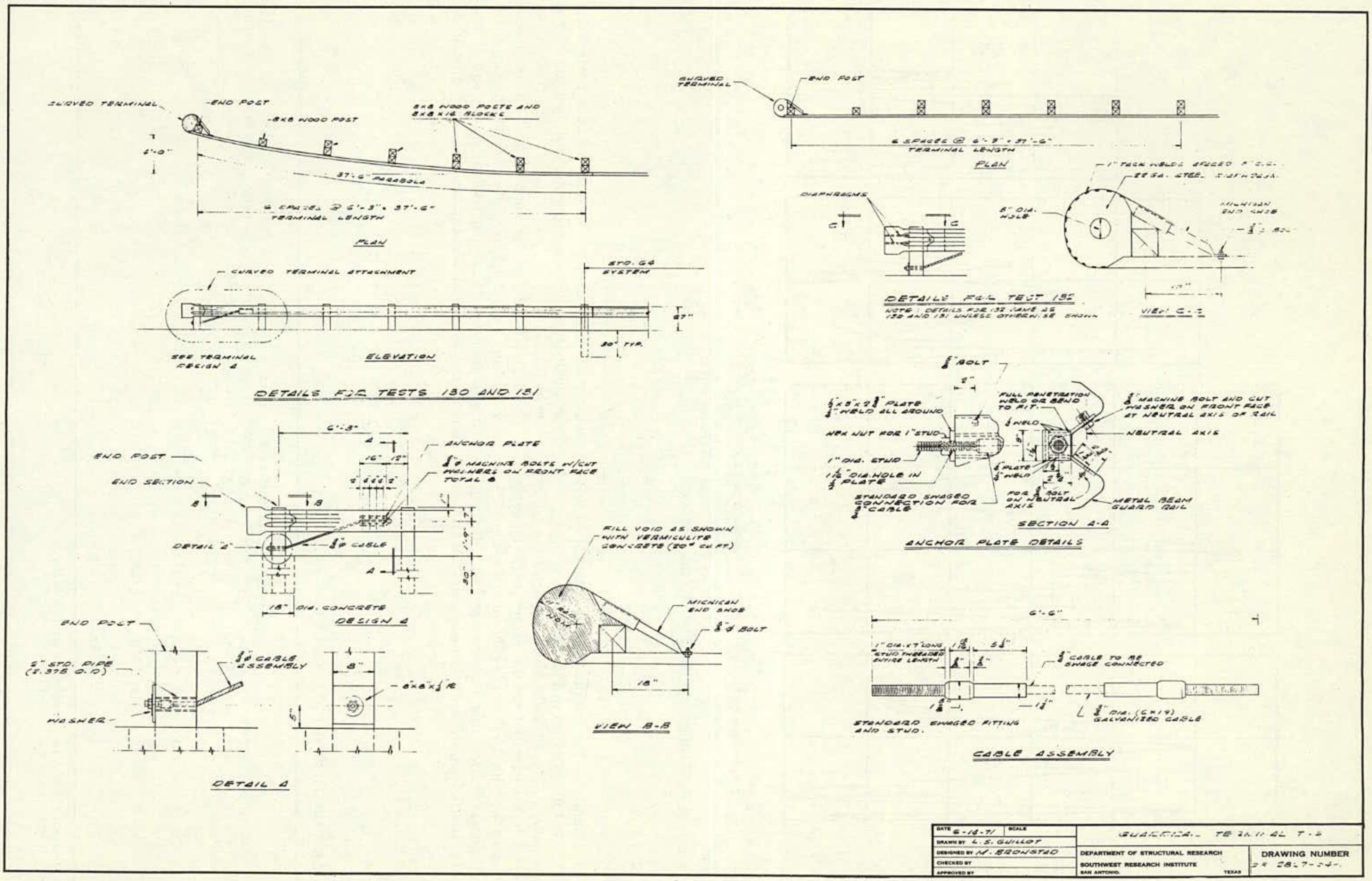
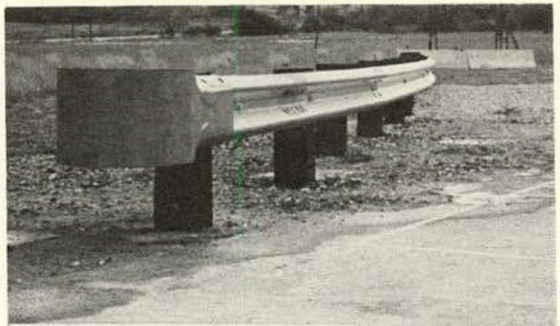
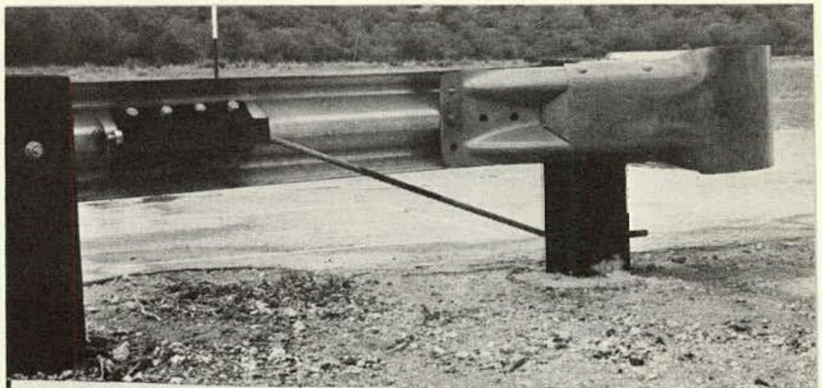


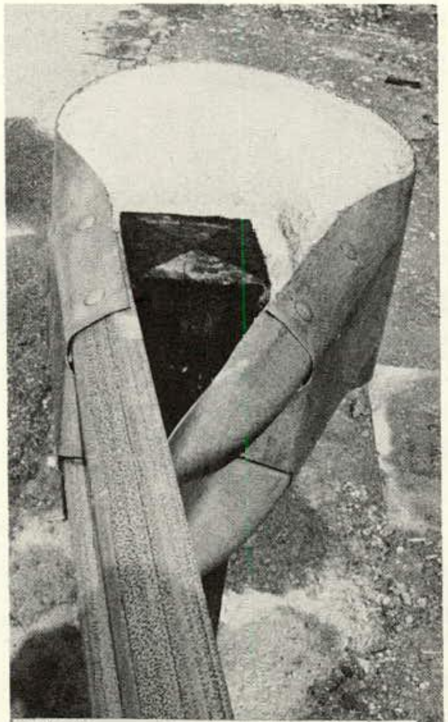
Figure A-20. Installation drawing, Tests 130, 131, and 132.

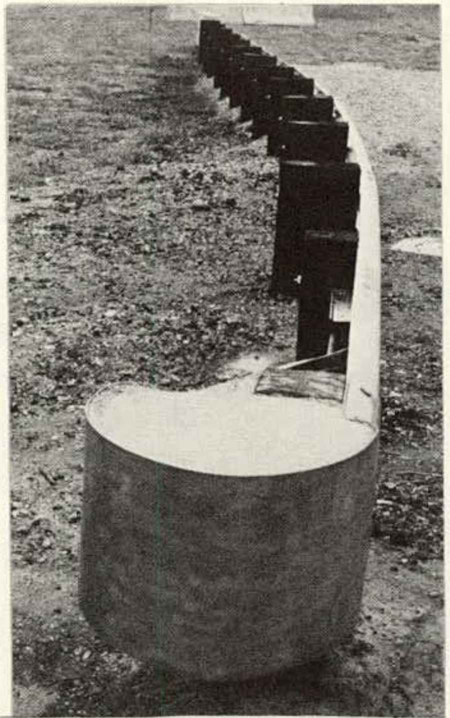

(a) Terminal section


(b) Test approach angle


(c) Overall view


(f) anchor cable details


(d) Terminal nose detail


(e) View from terminal nose

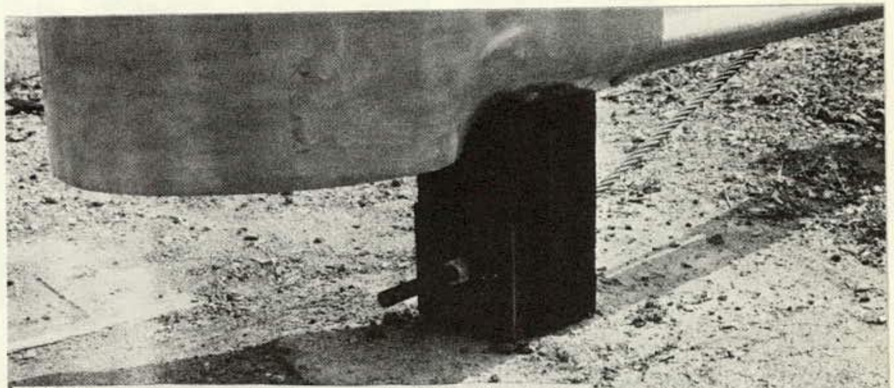
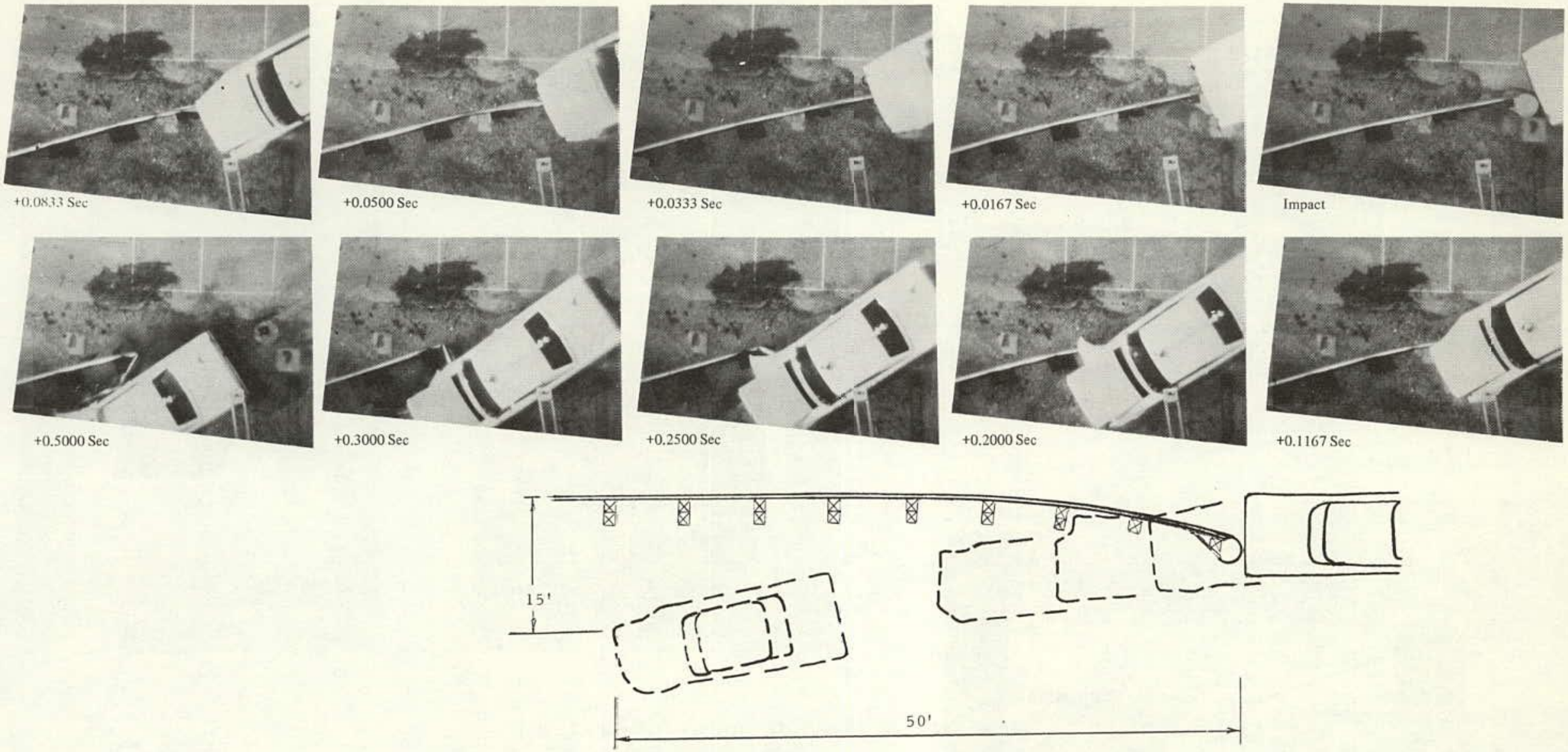

(g) Anchor cable to post attachment

Figure A-21. Installation details, Test 130.



+0.0833 Sec

+0.0500 Sec

+0.0333 Sec

+0.0167 Sec

Impact

+0.5000 Sec

+0.3000 Sec

+0.2500 Sec

+0.2000 Sec

+0.1167 Sec

Test Installation . . . Flared Terminal*
Posts . . . . 8 x 8 Timber
Post Spacing . . . . 6.25 ft
Rail . . . . Standard 12ga. W beam
Length of Installation . . . . 87.5 ft
Ground Condition . . . . Dry

Test No. 130
Date 6-11-71
Vehicle . . . . . . 1965 Ford
Vehicle Weight . . 4138 lbs
Impact Speed . . . . 61 mph
Impact Angle . . . . . 0 deg**

Figure A-22. Summary of results, Test 130.

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*Flared terminal for NCHRP Report 118 System G4W, see Figure A-20.
**Measured from typical rail line


(a) Impact zone


(b) Rear view of installation


(c) Overall view


(d) Beam pivoted about Post 3

Figure A-23. Installation damage, Test 130.

TABLE A-7

SUMMARY OF VEHICLE KINEMATIC AND DYNAMIC DATA, TEST 130

TIME AFTER IMPACT(SEC)	VEHICLE C. G. COORDINATES(FT)		HEADING ANGLE (DEG)	VEHICLE VELOCITY (FT/SEC)		VEHICLE ACCELERATION(G'S)				APPROX. BARRIER FORCES(LB)**	
						AT TIME T		AVERAGE+ OVER .05 SEC.			
	X	Y		LONG*	LAT*	LONG*	LAT*	LONG*	LAT*	X	Y
0.000	.16	.44	-1.61	89.59	-.59	-9.55	-.31	0.00	0.00	38222	180
.010	1.04	.41	-1.50	86.23	-.81	-11.09	-.04	0.00	0.00	44362	-995
.020	1.88	.38	-1.37	82.57	-.96	-11.46	.27	0.00	0.00	45798	-2177
.030	2.69	.35	-1.21	78.92	-1.06	-11.10	.58	-10.76	.43	44356	-3271
.040	3.46	.33	-.98	75.45	-1.13	-10.36	.88	-10.47	.72	41369	-4215
.050	4.20	.30	-.69	72.25	-1.19	-9.46	1.13	-9.83	.99	37772	-4972
.060	4.91	.28	-.31	69.35	-1.25	-8.55	1.34	-9.04	1.22	34184	-5526
.070	5.59	.27	.14	66.72	-1.33	-7.74	1.49	-8.25	1.40	30979	-5878
.080	6.24	.26	.66	64.32	-1.43	-7.07	1.59	-7.53	1.54	28344	-6039
.090	6.87	.26	1.24	62.12	-1.55	-6.55	1.65	-6.94	1.62	26332	-6031
.100	7.48	.26	1.87	60.06	-1.67	-6.17	1.67	-6.47	1.67	24900	-5881
.110	8.07	.26	2.52	58.10	-1.81	-5.92	1.67	-6.13	1.69	23948	-5619
.120	8.65	.27	3.17	56.20	-1.93	-5.75	1.64	-5.89	1.68	23346	-5275
.130	9.20	.29	3.83	54.34	-2.04	-5.64	1.60	-5.72	1.65	22952	-4882
.140	9.73	.30	4.46	52.51	-2.12	-5.55	1.55	-5.59	1.61	22628	-4468
.150	10.25	.33	5.06	50.72	-2.17	-5.45	1.50	-5.47	1.56	22257	-4056
.160	10.75	.35	5.62	48.96	-2.18	-5.32	1.45	-5.34	1.50	21745	-3675
.170	11.23	.38	6.13	47.26	-2.16	-5.14	1.39	-5.17	1.45	21025	-3339
.180	11.69	.41	6.60	45.62	-2.10	-4.89	1.34	-4.95	1.39	20060	-3062
.190	12.14	.44	7.03	44.08	-2.01	-4.59	1.28	-4.68	1.34	18845	-2854
.200	12.57	.48	7.41	42.65	-1.89	-4.22	1.24	-4.35	1.29	17345	-2722
.210	12.99	.51	7.76	41.34	-1.75	-3.81	1.19	-3.98	1.24	15752	-2666
.220	13.40	.55	8.07	40.17	-1.60	-3.36	1.15	-3.56	1.20	13971	-2663
.230	13.79	.59	8.36	39.16	-1.44	-2.90	1.13	-3.12	1.16	12120	-2770
.240	14.18	.64	8.64	38.29	-1.26	-2.43	1.11	-2.67	1.14	10272	-2916
.250	14.55	.68	8.91	37.58	-1.09	-1.98	1.10	-2.22	1.12	8500	-3111
.260	14.92	.73	9.17	37.01	-.90	-1.56	1.10	-1.81	1.12	6870	-3342
.270	15.29	.78	9.42	36.56	-.71	-1.20	1.11	-1.43	1.12	5442	-3547
.280	15.65	.84	9.68	36.22	-.51	-.89	1.13	-1.10	1.13	4261	-3860
.290	16.00	.90	9.93	35.98	-.30	-.65	1.16	-.83	1.15	3355	-4118
.300	16.36	.96	10.18	35.80	-.08	-.48	1.19	-.63	1.18	2735	-4357
.310	16.71	1.02	10.41	35.66	.17	-.38	1.23	-.49	1.22	2345	-4564
.320	17.06	1.09	10.63	35.54	.43	-.35	1.27	-.42	1.25	2308	-4728
.330	17.41	1.16	10.83	35.43	.72	-.37	1.30	-.40	1.28	2436	-4838
.340	17.75	1.24	11.00	35.31	1.04	-.43	1.33	-.43	1.31	2722	-4888
.350	18.09	1.32	11.13	35.15	1.39	-.53	1.34	-.49	1.33	3102	-4872
.360	18.44	1.40	11.23	34.97	1.76	-.63	1.34	-.58	1.33	3507	-4787
.370	18.77	1.49	11.29	34.76	2.15	-.72	1.32	-.66	1.32	3866	-4632
.380	19.11	1.58	11.31	34.51	2.56	-.79	1.28	-.73	1.28	4113	-4410
.390	19.44	1.67	11.29	34.25	2.98	-.83	1.22	-.77	1.23	4194	-4125
.400	19.77	1.77	11.24	33.98	3.39	-.81	1.13	-.77	1.15	4068	-3784
.410	20.09	1.87	11.16	33.72	3.78	-.75	1.01	-.73	1.05	3717	-3396
.420	20.42	1.98	11.07	33.49	4.14	-.63	.88	-.65	.93	3147	-2970
.430	20.74	2.08	10.96	33.31	4.46	-.47	.73	-.52	.79	2390	-2520
.440	21.05	2.19	10.86	33.18	4.73	-.27	.58	-.35	.65	1507	-2058
.450	21.37	2.30	10.78	33.12	4.94	-.07	.42	-.18	.50	586	-1598
.460	21.69	2.41	10.71	33.12	5.09	.12	.27	-.00	.36	-265	-1154
.470	22.00	2.52	10.67	33.18	5.18	.26	.14	.13	.22	-921	-740
.480	22.32	2.63	10.66	33.28	5.21	.33	.03	.21	.11	-1255	-370
.490	22.64	2.75	10.66	33.38	5.21	.29	-.04	.20	.03	-1154	+56

*These values are resolved along the longitudinal and lateral axes of the vehicle.

+A "running" average acceleration based on a .05 sec time interval is computed and presented in these columns.

**These "forces" are determined from resolving vehicle accelerations into barrier coordinates and multiplying these vehicle g's by 4,000 lb (approximate vehicle weight).

though Posts 3 and 5 were split and would require replacement. A summary of the installation damage is given in Table A-9 and Figure A-28.

Vehicle Damage.—Considerable left front end damage was sustained by the vehicle, as shown in Figure A-28. The damage is typical of that sustained in vehicle crash tests with the G4W rail system.

Test 132

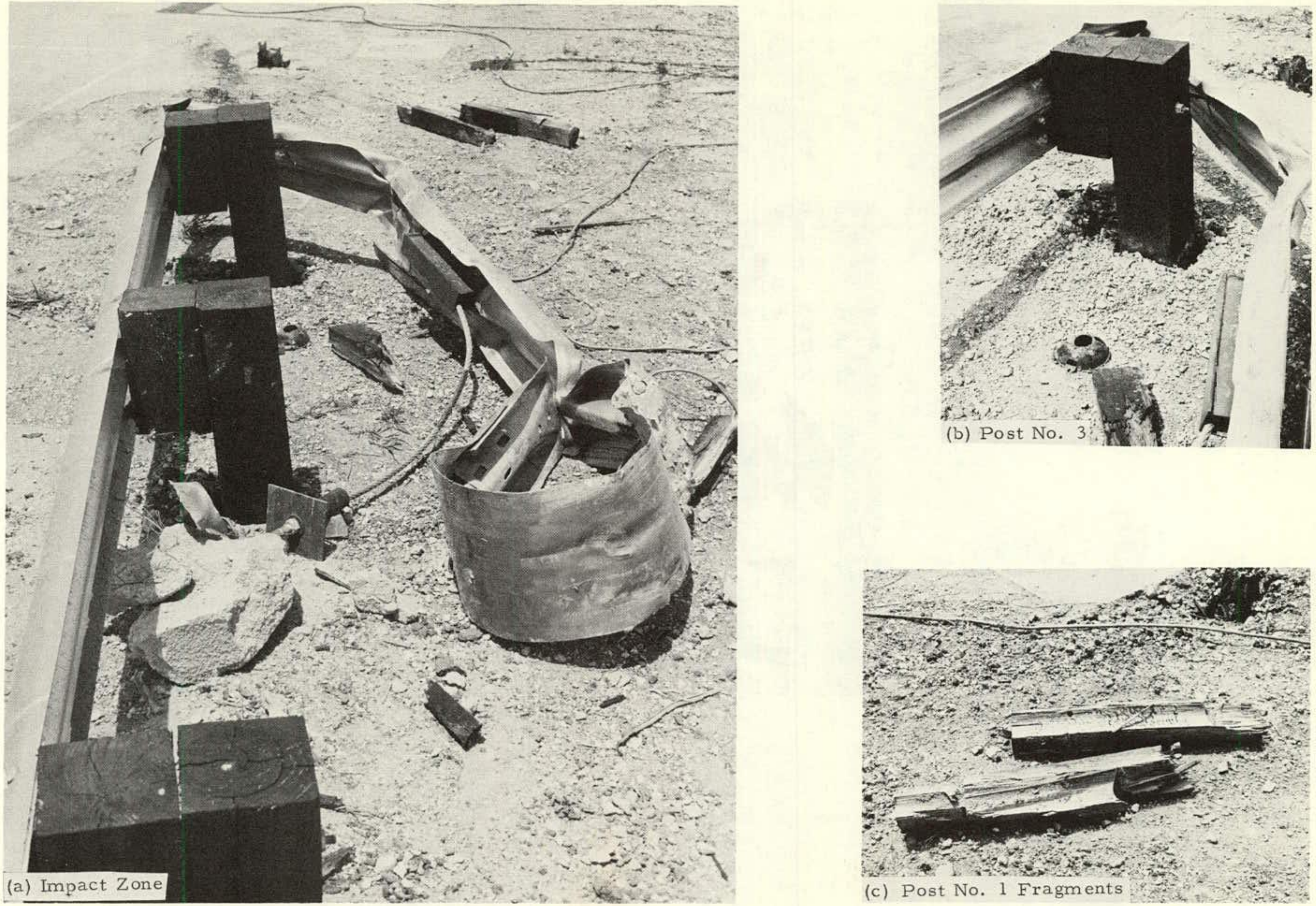
Purpose.—The objective of this test was to evaluate the straight guardrail terminal for end-on impact.

Test Installation.—The terminal design is similar to that of previous tests with the following exceptions:

1. The terminal was installed without a flare; the entire installation was parallel to the traveled way.
2. Steel diaphragms replaced the vermiculite concrete for stabilizing the nose.
3. Standard flat plate washers (between bolt head and rail) were omitted on Posts 3, 4, 5, and 6.

Other details were identical to those for Tests 130 and 131 as shown in Figures A-20 and A-29.

Performance.—A 4,100-lb vehicle impacted the terminal

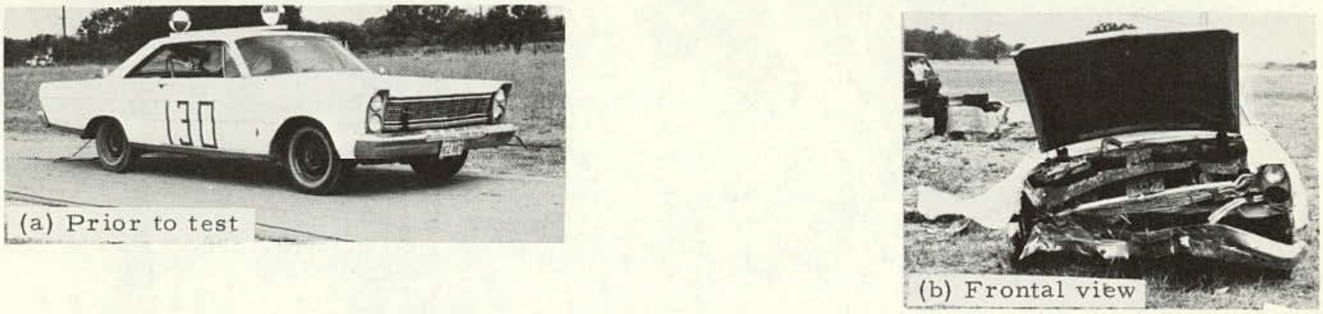


(a) Impact Zone

(b) Post No. 3

(c) Post No. 1 Fragments

Figure A-24. Installation damage, Test 130.


(a) Prior to test

(b) Frontal view


(c) Left front corner view


(d) Right front corner view

Figure A-25. Vehicle damage, Test 130.

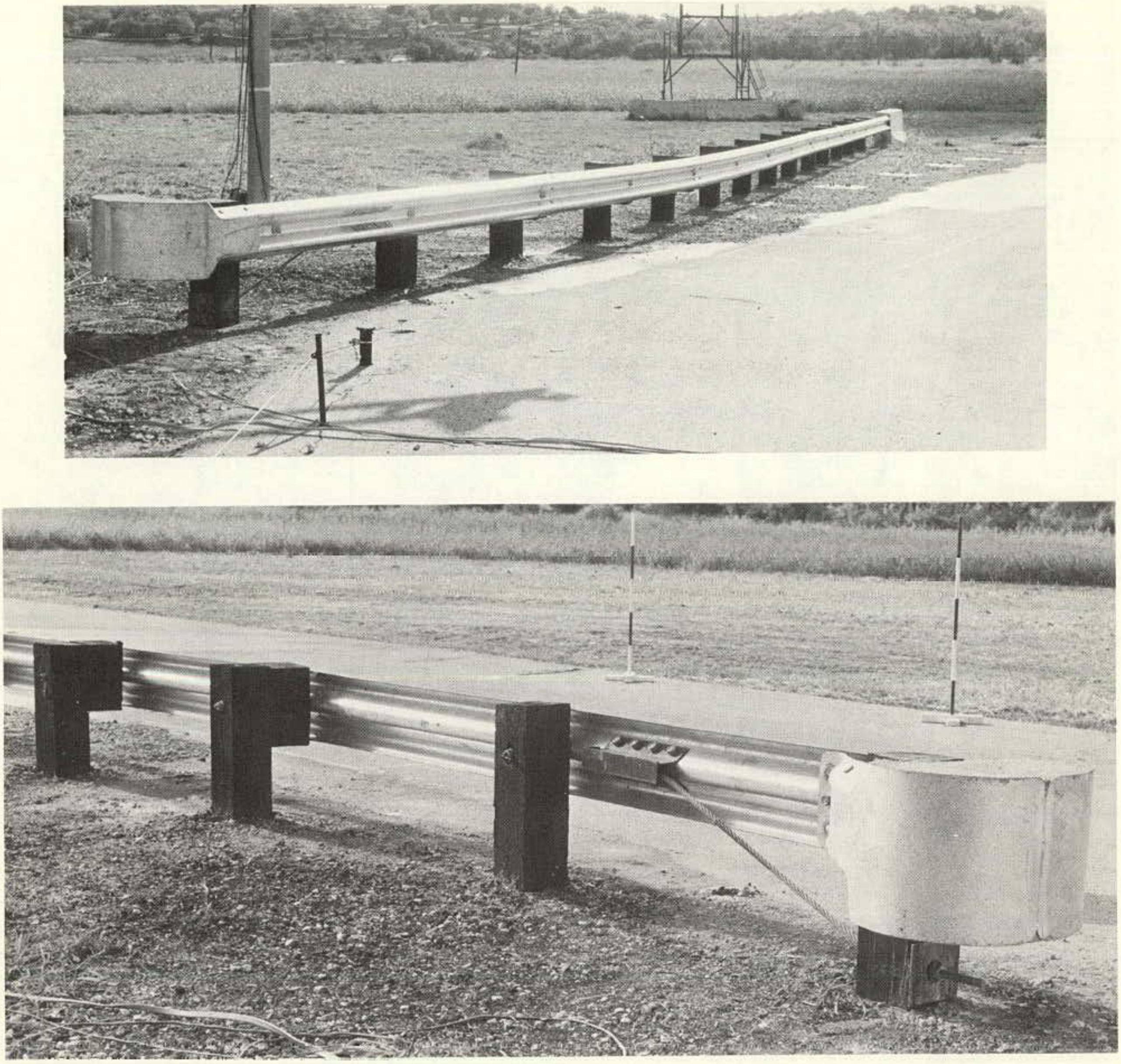
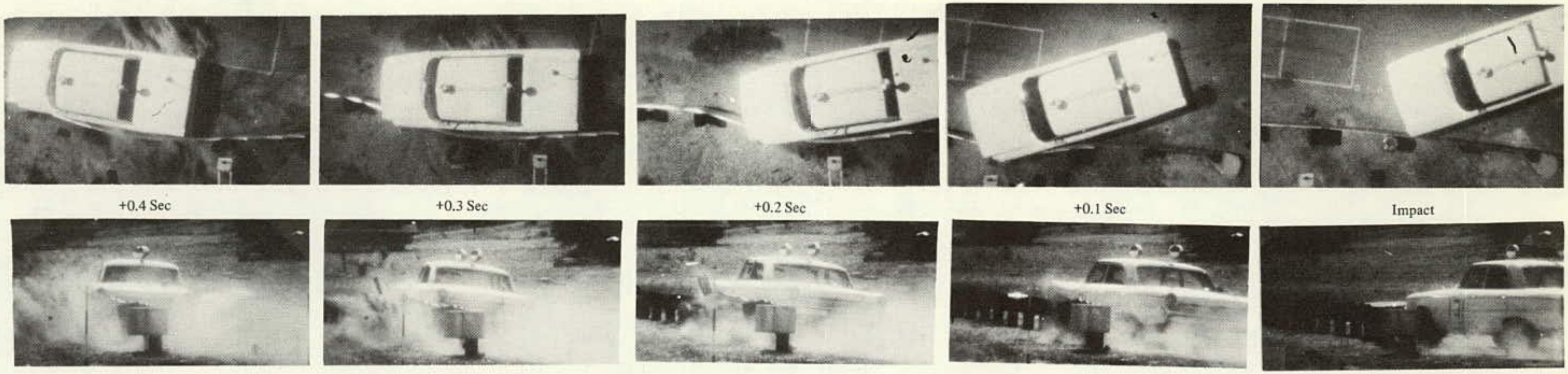
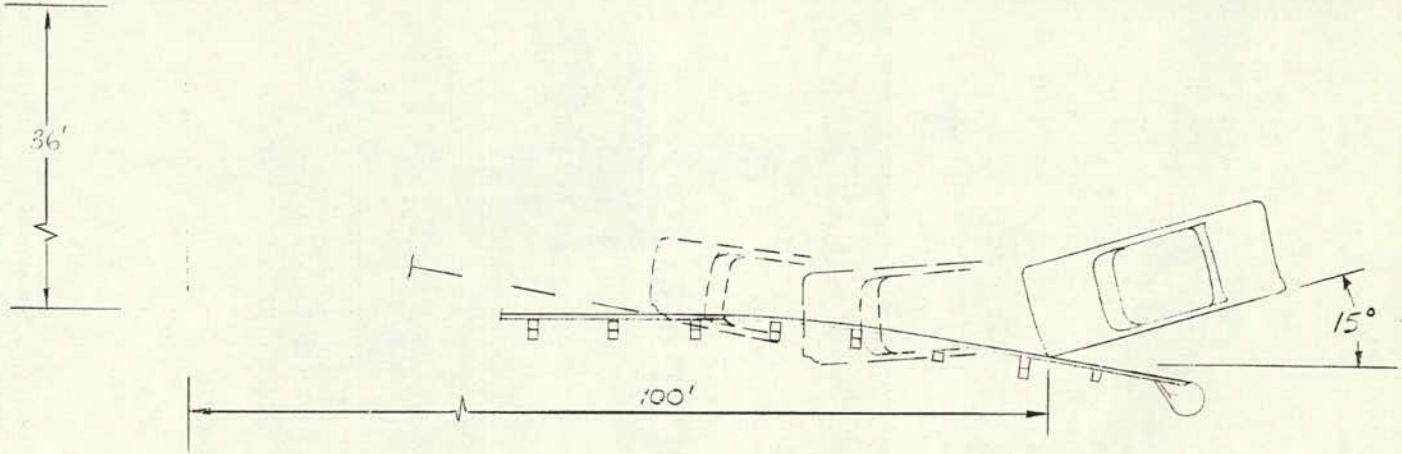


Figure A-26. Installation details, Test 131.

nose at 58.5 mph and at an angle of 0 deg (i.e., measured from the rail line), as shown in Figure A-30. As designed, the first post readily sheared at grade during the initial impact sequence. Unlike Test 130, the second post did not shear, but was pushed over (essentially undamaged) in the soil, as shown in Figure A-31. (Ground conditions varied from dry for Test 130 to wet for Test 132.) The beam initially flexed toward the roadway (see Fig. A-30, 0.05 sec) and only the two end spans were visually affected. At 0.18 sec after impact considerable rotation of Post 3 had occurred and buckling of the rail had started at Post 4 (see Fig. A-30, 0.0183 sec). As this buckling occurred the attitude of the vehicle changed from vehicle front down to vehicle front up. This front upward pitch continued, reaching a maximum of 17 deg at 0.7 sec, as shown in Figure A-30. The omission of the flat plate washer in achieving rail separation from the post is considered to be a major factor in the buckling mode. Figure A-31 shows the final position of the rail system and the separation of the rail from the posts. No rail separation occurred at Post 7 (which had a flat plate washer) and beyond. The omission of these washers is not considered to be detrimental to system performance for angular impacts within these end spans. Tests 121 and 122 reported in *NCHRP Report 115* (*2*) conducted on identical installations with the exception that the Test 121 installation had no washers





Test Installation	Flared Terminal*	Test No.	131
Posts	8 x 8 Timber	Date	7-17-71
Post Spacing	6.25 ft	Vehicle	1963 Ford
Rail	Standard 12ga. W beam	Vehicle Weight	4000 lbs
Length of Installation	87.5 ft	Impact Speed	59.4 mph
Ground Condition	Dry	Impact Angle	15 deg

Figure A-27. Summary of results, Test 131.

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*Flared terminal for NCHRP Report 118 System G4W, see Figure A-20.

TABLE A-8

SUMMARY OF VEHICLE KINEMATIC AND DYNAMIC DATA, TEST 131

TIME AFTER IMPACT(SEC)	VEHICLE C. G. COORDINATES(FT)		HEADING ANGLE (DEG)	VEHICLE VELOCITY (FT/SEC)		VEHICLE ACCELERATION(G'S) AT TIME T		AVERAGE+ OVER .05 SEC.		APPROX. BARRIER FORCES(LB)**	
	X	Y		LONG*	LAT*	LONG*	LAT*	LONG*	LAT*	X	Y
0.000	1.02	-1.11	14.45	87.94	2.09	-3.05	2.39	0.00	0.00	14256	-6096
.010	1.86	-.86	15.23	86.91	1.45	-3.40	-.40	0.00	0.00	12701	5132
.020	2.69	-.62	15.45	85.76	1.15	-3.75	-2.33	0.00	0.00	11977	12968
.030	3.51	-.39	15.54	84.51	.06	-4.07	-3.57	-3.88	-2.38	11853	18110
.040	4.32	-.17	15.45	83.15	-1.09	-4.34	-4.29	-4.16	-3.50	12143	21159
.050	5.12	.04	15.21	81.73	-2.18	-4.55	-4.62	-4.40	-4.15	12701	22623
.060	5.91	.22	14.81	80.26	-3.13	-4.71	-4.68	-4.58	-4.44	13411	22328
.070	6.69	.39	14.31	78.75	-3.92	-4.82	-4.56	-4.71	-4.49	14186	22125
.080	7.45	.53	13.72	77.23	-4.55	-4.90	-4.31	-4.81	-4.36	14959	21397
.090	8.21	.66	13.09	75.69	-5.04	-4.95	-4.00	-4.88	-4.14	15682	20069
.100	8.95	.78	12.42	74.15	-5.40	-4.98	-3.67	-4.92	-3.65	16318	18614
.110	9.68	.88	11.74	72.61	-5.67	-5.00	-3.34	-4.94	-3.55	16844	17157
.120	10.40	.96	11.07	71.07	-5.85	-4.99	-3.05	-4.95	-3.25	17244	15788
.130	11.10	1.04	10.40	69.54	-5.96	-4.96	-2.79	-4.93	-2.99	17504	14563
.140	11.79	1.10	9.73	68.02	-6.03	-4.92	-2.58	-4.90	-2.76	17637	13509
.150	12.46	1.15	9.08	66.51	-6.06	-4.85	-2.42	-4.84	-2.58	17627	12636
.160	13.12	1.19	8.41	65.04	-6.06	-4.76	-2.31	-4.77	-2.44	17483	11934
.170	13.76	1.22	7.75	63.59	-6.05	-4.65	-2.24	-4.67	-2.34	17211	11382
.180	14.39	1.24	7.06	62.19	-6.01	-4.51	-2.20	-4.54	-2.27	16820	10953
.190	15.01	1.25	6.36	60.84	-5.96	-4.35	-2.18	-4.39	-2.24	16318	10612
.200	15.62	1.26	5.63	59.54	-5.90	-4.16	-2.18	-4.22	-2.22	15716	10324
.210	16.21	1.25	4.88	58.31	-5.83	-3.96	-2.19	-4.03	-2.21	15024	10056
.220	16.79	1.24	4.10	57.15	-5.75	-3.73	-2.18	-3.81	-2.21	14265	9778
.230	17.36	1.22	3.30	56.07	-5.66	-3.49	-2.17	-3.58	-2.19	13444	9463
.240	17.92	1.19	2.47	55.06	-5.55	-3.24	-2.14	-3.34	-2.16	12574	9093
.250	18.46	1.16	1.63	54.14	-5.43	-2.98	-2.08	-3.09	-2.12	11685	8655
.260	19.00	1.11	.78	53.30	-5.29	-2.72	-2.00	-2.84	-2.05	10782	8143
.270	19.53	1.06	-.08	52.54	-5.12	-2.47	-1.89	-2.59	-1.95	9885	7561
.280	20.05	1.01	-.94	51.86	-4.93	-2.22	-1.77	-2.34	-1.84	9012	6917
.290	20.57	.95	-1.79	51.26	-4.71	-2.00	-1.62	-2.11	-1.70	8181	6228
.300	21.07	.88	-2.63	50.72	-4.46	-1.79	-1.46	-1.89	-1.55	7404	5515
.310	21.58	.81	-3.46	50.23	-4.17	-1.60	-1.30	-1.70	-1.40	6711	4804
.320	22.07	.74	-4.27	49.80	-3.85	-1.44	-1.14	-1.53	-1.24	6102	4124
.330	22.56	.66	-5.07	49.41	-3.50	-1.32	-1.00	-1.39	-1.10	5594	3505
.340	23.05	.58	-5.86	49.05	-3.13	-1.22	-.87	-1.28	-.97	5138	2977
.350	23.53	.50	-6.64	48.71	-2.73	-1.15	-.78	-1.20	-.87	4418	2569
.360	24.01	.42	-7.41	48.38	-2.32	-1.11	-.72	-1.14	-.80	4754	2305
.370	24.49	.33	-8.18	48.06	-1.90	-1.09	-.71	-1.11	-.77	4718	2205
.380	24.96	.24	-8.95	47.73	-1.49	-1.09	-.75	-1.10	-.78	4784	2281
.390	25.42	.15	-9.72	47.39	-1.11	-1.12	-.83	-1.11	-.84	4960	2538
.400	25.89	.06	-10.44	47.04	-.76	-1.15	-.97	-1.13	-.95	5213	2969
.410	26.35	-.03	-11.27	46.67	-.46	-1.18	-1.14	-1.16	-1.10	5526	3560
.420	26.80	-.13	-12.04	46.29	-.23	-1.21	-1.35	-1.19	-1.28	5872	4284
.430	27.25	-.23	-12.82	45.90	-.08	-1.23	-1.59	-1.20	-1.49	6216	5102
.440	27.70	-.34	-13.58	45.50	-.03	-1.23	-1.83	-1.21	-1.72	6522	5968
.450	28.14	-.45	-14.32	45.11	-.07	-1.21	-2.07	-1.19	-1.94	6754	6825
.460	28.57	-.56	-15.02	44.73	-.22	-1.16	-2.28	-1.15	-2.15	6859	7609
.470	29.00	-.68	-15.69	44.37	-.47	-1.08	-2.45	-1.08	-2.32	6808	8251
.480	29.42	-.81	-16.29	44.04	-.81	-.97	-2.54	-.98	-2.43	6559	8681
.490	29.84	-.95	-16.82	43.76	-1.23	-.82	-2.55	-.85	-2.47	6084	8835

*These values are resolved along the longitudinal and lateral axes of the vehicle.

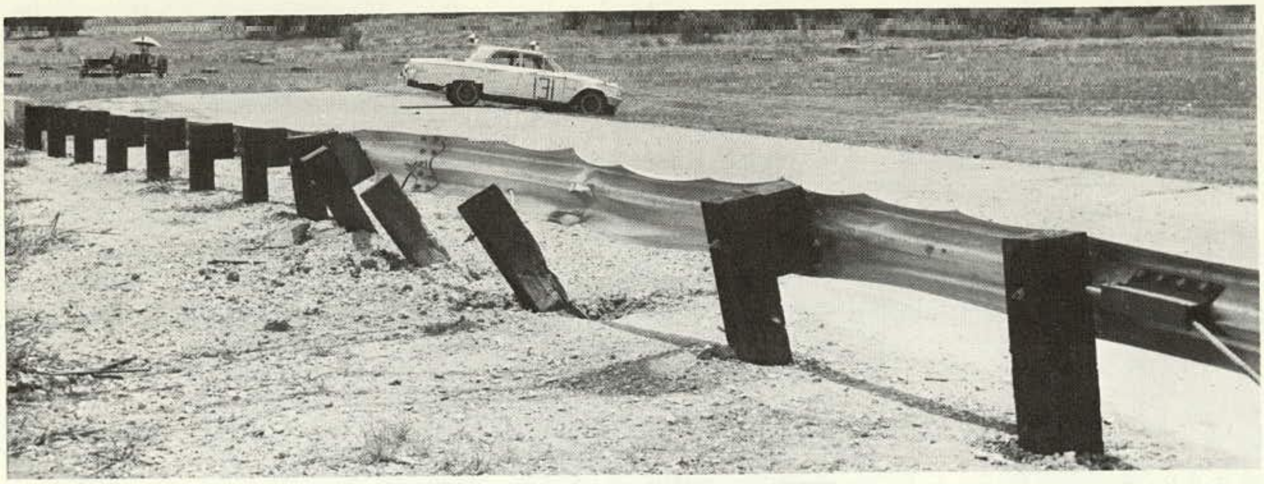
+A "running" average acceleration based on a .05 sec time interval is computed and presented in these columns.

**These "forces" are determined from resolving vehicle accelerations into barrier coordinates and multiplying these vehicle g's by 4,000 lb (approximate vehicle weight).

and the test installation did. Results of the two tests indicate that no significant difference resulted from this disparity. Vehicle kinematic and dynamic performance data are given in Table A-10 for Test 132.

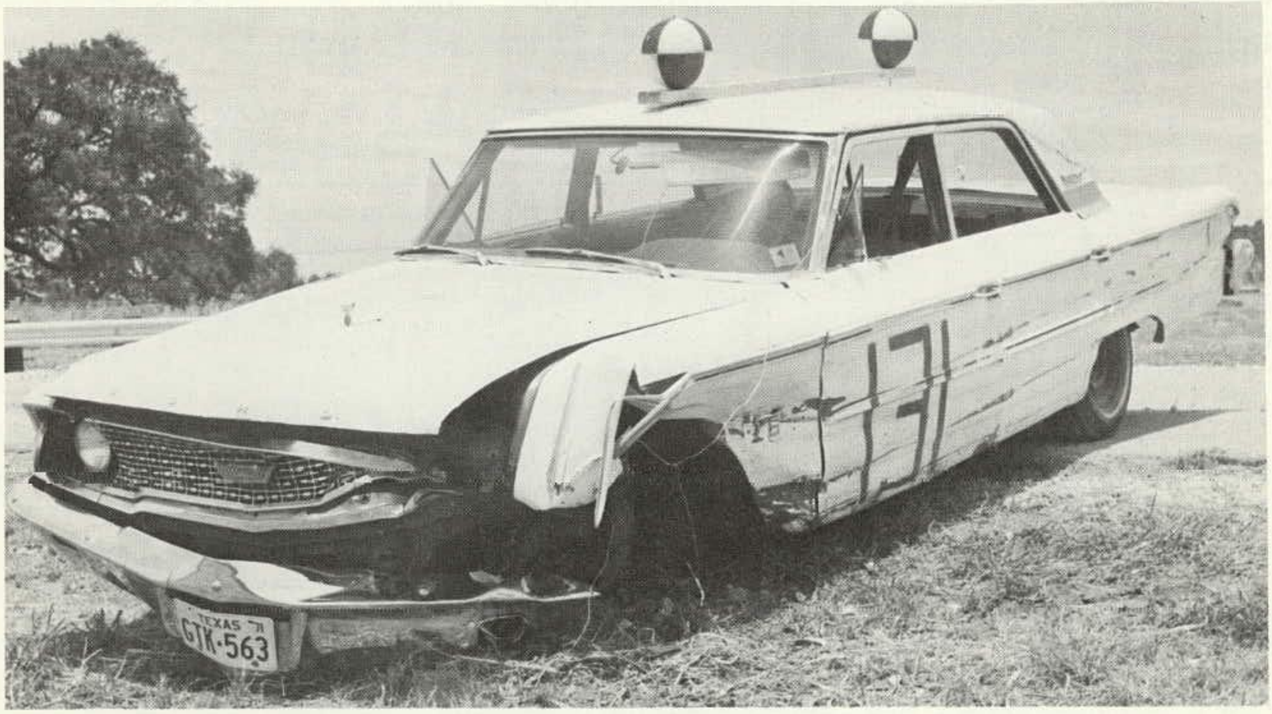
Installation Damage.—The end post (Post 1) fractured near grade level at the bored hole location. Posts 2 and 3 were gouged by the vehicle, but were not structurally damaged. Post 2 remained embedded in the soil, but was leveled by the vehicle, as shown in Figure A-32. All other posts and blocks were undamaged. The first three 12.5-ft rail sections were damaged beyond repair. Components such as anchor plate, anchor cable, bearing plate, and pipe insert were undamaged and reusable.

Vehicle Damage.—As shown in Figure A-31, the vehicle sustained extensive front end damage; the most severe damage was sustained at the right front corner. No passenger compartment intrusion by engine or guardrail components occurred.



(a) View showing final position of vehicle

(b) View from vehicle approach



(c) Vehicle damage

Figure A-28. Installation and vehicle damage, Test 131.

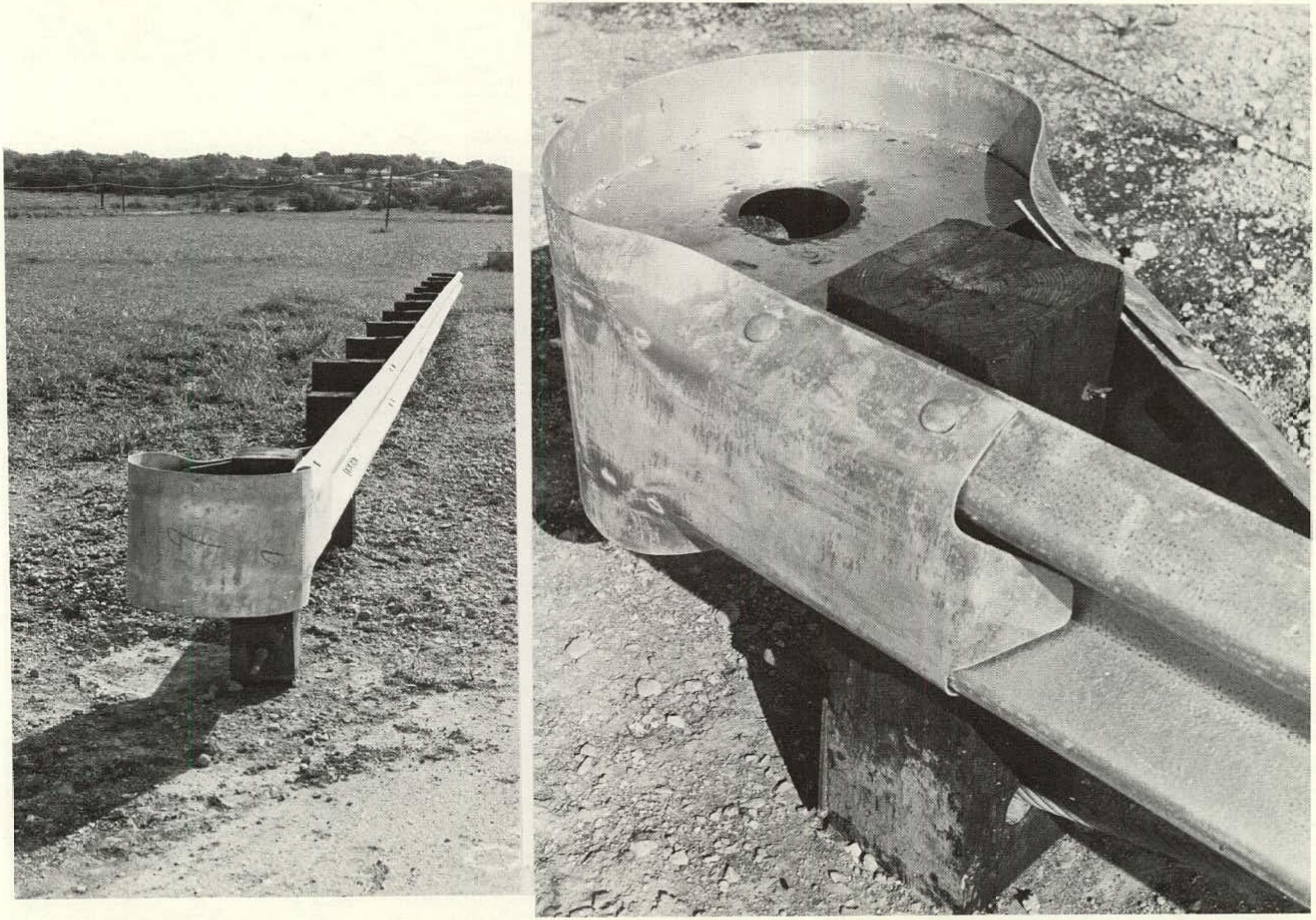
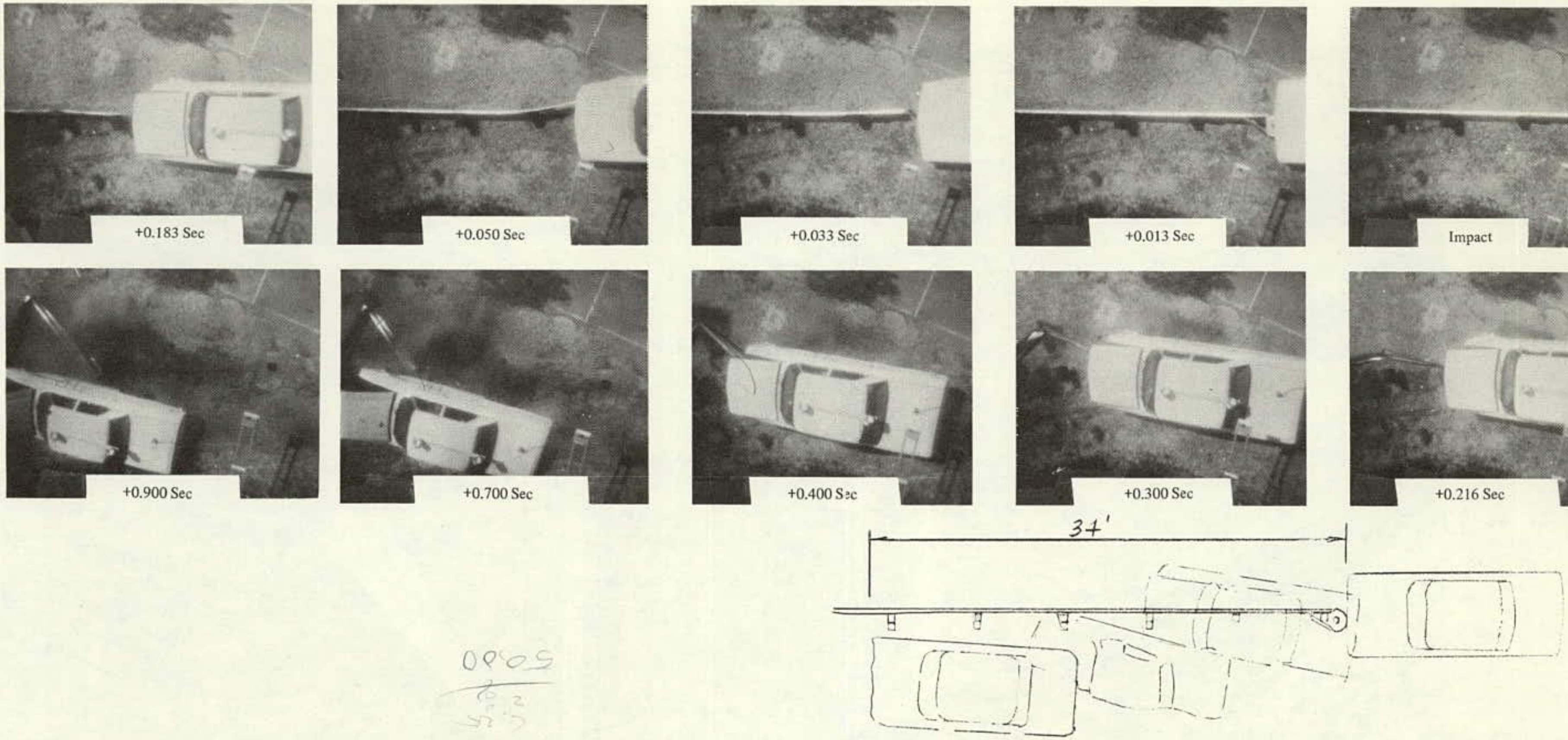


Figure A-29. Installation details, Test 132.



Test Installation . . . Straight Terminal*
Posts . . . . 8 x 8 Timber
Post Spacing . . . . 6.25 ft
Rail. . . . . Standard 12ga. W beam
Length of Installation . . . . 87.5 ft
Ground Condition . . . . Wet

Test No. 132
Date 8-16-71
Vehicle . . . . 1964 Ford
Vehicle Weight . . 4100 lbs
Impact Speed . . . 58.5 mph
Impact Angle . . . . . . 0 deg

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*Straight terminal for NCHRP Report 118 System G4W, see Figure A-20.

Figure A-30. Summary of results, Test 132.

TABLE A-9

SUMMARY OF INSTALLATION DAMAGE, TEST 131

POST NO.	POST SPLIT	BLOCK SPLIT	PERM. DEFL. (IN.)[a]	REMARKS
1			0	Slight cracking of concrete footing around post; otherwise no damage.
2			4L	
3	X		7L 5V	
4		X	21L 6½V	Block split and displaced, washer forced through rail, post gouged by vehicle.
5	X	X	31L 7V	
6		X	18½L 4V	Post pushed back, but undamaged.
7			4L	Bolt slightly bent.
8		X	0	

[a] L indicates lateral deflection, V indicates vertical deflection. Four rail sections (12′-6″ nom. length) were damaged beyond repair.

Figure A-31. Vehicle and installation damage, Test 132.

TABLE A-10

SUMMARY OF VEHICLE KINEMATIC AND DYNAMIC DATA, TEST 132

SUMMARY OF VEHICLE KINEMATIC AND DYNAMIC DATA GUARDRAIL TEST 132 8/19/71

TIME AFTER IMPACT(SEC)	VEHICLE C. G. COORDINATES(FT) X	VEHICLE C. G. COORDINATES(FT) Y	HEADING ANGLE (DEG)	VEHICLE VELOCITY (FT/SEC) LONG*	VEHICLE VELOCITY (FT/SEC) LAT*	VEHICLE ACCELERATION(G'S) AT TIME T LONG*	VEHICLE ACCELERATION(G'S) AT TIME T LAT*	VEHICLE ACCELERATION(G'S) AVERAGE+ OVER.05 SEC. LONG*	VEHICLE ACCELERATION(G'S) AVERAGE+ OVER.05 SEC. LAT*	APPROX. BARRIER FORCES(LB)** X	APPROX. BARRIER FORCES(LB)** Y
0.000	3.46	.33	.63	86.08	-.37	-4.61	1.52	0.00	0.00	18524	-5881
.010	4.32	.34	.71	84.53	-.04	-5.02	1.34	0.00	0.00	20140	-5091
.020	5.15	.35	.80	82.84	.25	-5.50	1.19	0.00	0.00	22053	-4450
.030	5.97	.37	.86	80.98	.52	-6.01	1.07	-5.77	1.16	24104	-3936
.040	6.77	.39	.89	78.97	.80	-6.53	.98	-6.26	1.05	26162	-3531
.050	7.55	.41	.89	76.78	1.12	-7.02	.91	-6.74	.97	28126	-3214
.060	8.31	.43	.84	74.45	1.46	-7.47	.85	-7.20	.89	29916	-2971
.070	9.04	.46	.75	71.98	1.85	-7.86	.80	-7.61	.83	31473	-2786
.080	9.75	.49	.61	69.39	2.27	-8.18	.75	-7.96	.77	32756	-2647
.090	10.43	.52	.42	66.70	2.72	-8.43	.70	-8.24	.72	33740	-2543
.100	11.08	.55	.19	63.95	3.20	-8.60	.64	-8.45	.66	34412	-2464
.110	11.70	.59	-.09	61.14	3.70	-8.69	.59	-8.58	.60	34770	-2401
.120	12.30	.62	-.40	58.32	4.21	-8.71	.53	-8.63	.53	34821	-2349
.130	12.87	.66	-.75	55.49	4.72	-8.65	.46	-8.62	.47	34579	-2300
.140	13.41	.70	-1.14	52.69	5.22	-8.53	.39	-8.53	.40	34065	-2252
.150	13.93	.75	-1.54	49.94	5.70	-8.34	.33	-8.38	.33	33303	-2200
.160	14.41	.79	-1.97	47.25	6.16	-8.09	.26	-8.17	.26	32319	-2143
.170	14.88	.84	-2.42	44.64	6.59	-7.80	.19	-7.91	.19	31144	-2079
.180	15.31	.88	-2.88	42.12	6.99	-7.47	.13	-7.60	.13	29808	-2007
.190	15.73	.93	-3.35	39.72	7.35	-7.10	.07	-7.26	.07	28341	-1927
.200	16.11	.98	-3.82	37.43	7.68	-6.71	.01	-6.89	.01	26774	-1840
.210	16.48	1.04	-4.29	35.27	7.97	-6.30	-.03	-6.49	-.04	25136	-1747
.220	16.83	1.09	-4.75	33.25	8.23	-5.88	-.07	-6.08	-.08	23454	-1650
.230	17.16	1.15	-5.21	31.36	8.46	-5.45	-.11	-5.66	-.12	21755	-1550
.240	17.47	1.20	-5.65	29.60	8.66	-5.03	-.13	-5.24	-.14	20063	-1448
.250	17.77	1.26	-6.09	27.99	8.83	-4.61	-.15	-4.83	-.16	18398	-1348
.260	18.05	1.32	-6.50	26.50	8.98	-4.20	-.16	-4.42	-.18	16779	-1252
.270	18.31	1.38	-6.90	25.15	9.10	-3.81	-.17	-4.02	-.18	15223	-1161
.280	18.57	1.44	-7.28	23.92	9.21	-3.44	-.17	-3.65	-.18	13743	-1077
.290	18.81	1.50	-7.64	22.81	9.31	-3.09	-.16	-3.29	-.18	12349	-1004
.300	19.05	1.56	-7.99	21.81	9.39	-2.77	-.15	-2.95	-.17	11051	-941
.310	19.27	1.63	-8.31	20.92	9.46	-2.47	-.14	-2.64	-.15	9853	-891
.320	19.49	1.69	-8.61	20.12	9.53	-2.20	-.12	-2.36	-.13	8760	-855
.330	19.70	1.75	-8.90	19.40	9.60	-1.95	-.09	-2.10	-.11	7772	-834
.340	19.90	1.82	-9.17	18.76	9.66	-1.73	-.07	-1.87	-.09	6888	-828
.350	20.10	1.88	-9.42	18.19	9.72	-1.54	-.04	-1.66	-.06	6107	-838
.360	20.29	1.95	-9.66	17.68	9.79	-1.37	-.01	-1.48	-.03	5424	-863
.370	20.48	2.02	-9.89	17.23	9.86	-1.23	.01	-1.32	-.00	4833	-903
.380	20.66	2.09	-10.10	16.82	9.93	-1.11	.05	-1.19	.03	4329	-957
.390	20.85	2.15	-10.31	16.44	10.01	-1.01	.08	-1.07	.06	3903	-1024
.400	21.02	2.22	-10.50	16.10	10.09	-.92	.11	-.98	.09	3548	-1101
.410	21.20	2.29	-10.69	15.78	10.19	-.85	.14	-.90	.12	3254	-1188
.420	21.37	2.37	-10.88	15.48	10.29	-.80	.17	-.84	.15	3014	-1281
.430	21.54	2.44	-11.06	15.19	10.40	-.76	.20	-.79	.19	2818	-1378
.440	21.71	2.51	-11.24	14.92	10.52	-.72	.23	-.75	.21	2657	-1476
.450	21.88	2.59	-11.43	14.66	10.64	-.70	.26	-.72	.24	2525	-1572
.460	22.04	2.66	-11.61	14.40	10.78	-.67	.29	-.69	.27	2412	-1664
.470	22.20	2.74	-11.79	14.16	10.92	-.65	.31	-.67	.29	2311	-1746
.480	22.36	2.82	-11.98	13.91	11.07	-.64	.33	-.65	.32	2217	-1817
.490	22.52	2.90	-12.18	13.67	11.22	-.62	.35	-.63	.33	2124	-1873
.500	22.68	2.98	-12.37	13.44	11.38	-.60	.36	-.61	.35	2027	-1910
.510	22.83	3.06	-12.58	13.21	11.55	-.57	.37	-.58	.36	1923	-1926
.520	22.98	3.15	-12.78	12.99	11.71	-.55	.37	-.56	.36	1808	-1917
.530	23.14	3.23	-13.00	12.77	11.88	-.52	.36	-.53	.36	1682	-1881
.540	23.29	3.32	-13.21	12.57	12.04	-.48	.35	-.49	.35	1543	-1816
.550	23.44	3.41	-13.43	12.37	12.20	-.44	.34	-.46	.34	1392	-1718
.560	23.58	3.50	-13.66	12.19	12.35	-.39	.31	-.41	.32	1231	-1588
.570	23.73	3.59	-13.88	12.02	12.50	-.34	.28	-.36	.29	1060	-1423
.580	23.88	3.69	-14.11	11.87	12.63	-.29	.24	-.31	.25	884	-1224
.590	24.02	3.78	-14.34	11.74	12.75	-.23	.20	-.26	.21	704	-990
.600	24.17	3.88	-14.56	11.62	12.85	-.17	.14	-.20	.16	525	-722
.610	24.31	3.97	-14.79	11.52	12.93	-.11	.08	-.14	.10	351	-421
.620	24.46	4.07	-15.01	11.45	12.99	-.05	.01	-.08	.04	185	-91
.630	24.60	4.16	-15.22	11.39	13.02	.01	-.07	-.02	-.03	33	267
.640	24.75	4.26	-15.43	11.36	13.03	.07	-.15	.04	-.11	-103	649
.650	24.89	4.35	-15.62	11.34	13.00	.12	-.24	.09	-.20	-219	1050
.660	25.03	4.45	-15.81	11.35	12.95	.17	-.33	.14	-.29	-310	1465
.670	25.18	4.54	-15.99	11.37	12.86	.22	-.43	.19	-.38	-376	1888
.680	25.32	4.63	-16.15	11.41	12.74	.26	-.53	.23	-.48	-415	2313
.690	25.47	4.72	-16.30	11.47	12.59	.29	-.63	.27	-.58	-426	2733
.700	25.61	4.81	-16.44	11.54	12.40	.32	-.72	.30	-.67	-409	3139
.710	25.76	4.89	-16.56	11.62	12.17	.34	-.82	.32	-.77	-366	3524
.720	25.91	4.98	-16.65	11.71	11.91	.35	-.91	.34	-.86	-299	3879
.730	26.05	5.05	-16.74	11.81	11.62	.35	-.99	.35	-.94	-214	4196
.740	26.20	5.13	-16.80	11.91	11.31	.35	-1.06	.35	-1.01	-115	4466
.750	26.35	5.20	-16.84	12.01	10.96	.34	-1.12	.34	-1.08	-9	4680
.760	26.49	5.27	-16.86	12.12	10.60	.33	-1.16	.33	-1.13	97	4830
.770	26.64	5.34	-16.86	12.22	10.22	.31	-1.19	.32	-1.16	194	4909
.780	26.79	5.40	-16.83	12.32	9.83	.29	-1.19	.30	-1.17	274	4911
.790	26.93	5.45	-16.79	12.42	9.44	.27	-1.18	.28	-1.17	327	4829
.800	27.08	5.50	-16.73	12.51	9.05	.25	-1.14	.26	-1.14	344	4659
.810	27.22	5.55	-16.64	12.61	8.68	.24	-1.08	.25	-1.09	316	4401
.820	27.37	5.60	-16.53	12.70	8.32	.23	-.99	.24	-1.01	237	4054
.830	27.52	5.64	-16.41	12.79	7.99	.23	-.88	.24	-.91	100	3622
.840	27.66	5.68	-16.26	12.88	7.70	.24	-.74	.24	-.79	-96	3111
.850	27.81	5.72	-16.10	12.99	7.45	.26	-.58	.26	-.65	-353	2531
.860	27.95	5.75	-15.91	13.10	7.24	.29	-.41	.28	-.49	-662	1898
.870	28.10	5.78	-15.72	13.22	7.10	.33	-.23	.31	-.31	-1015	1230
.880	28.24	5.82	-15.50	13.36	7.00	.37	-.04	.35	-.14	-1391	554
.890	28.39	5.85	-15.28	13.52	6.97	.42	.14	.39	.04	-1763	-97
.900	28.54	5.88	-15.05	13.69	6.98	.46	.30	.43	.20	-2095	-686
.910	28.69	5.91	-14.81	13.87	7.05	.49	.43	.46	.33	-2334	-1163
.920	28.85	5.94	-14.57	14.06	7.14	.49	.51	.46	.41	-2418	-1473
.930	29.00	5.98	-14.33	14.24	7.25	.45	.52	.42	.43	-2265	-1549
.940	29.16	6.01	-14.11	14.40	7.35	.35	.43	.33	.37	-1774	-1312
.950	29.32	6.05	-13.89	14.51	7.40	.16	.21	.16	.19	-825	-673
.960	29.47	6.09	-13.71	14.54	7.37	-.15	-.16	-.12	-.14	730	471
.970	29.63	6.13	-13.56	14.44	7.19	-.61	-.72	-.54	-.64	3066	2239
.980	29.79	6.16	-13.46	14.16	6.81	-1.28	-1.53	-1.15	-1.37	6388	4765
.990	29.94	6.19	-13.42	13.61	6.14	-2.18	-2.63	-1.98	-2.37	10936	8200

*These values are resolved along the longitudinal and lateral axes of the vehicle.

+A "running" average acceleration based on a .05 sec time interval is computed and presented in these columns.

**These "forces" are determined from resolving vehicle accelerations into barrier coordinates and multiplying these vehicle g's by 4,000 lb (approximate vehicle weight).

Figure A-32. Installation damage, Test 132.

APPENDIX B

TERMINAL AND TRANSITION CONCEPTS

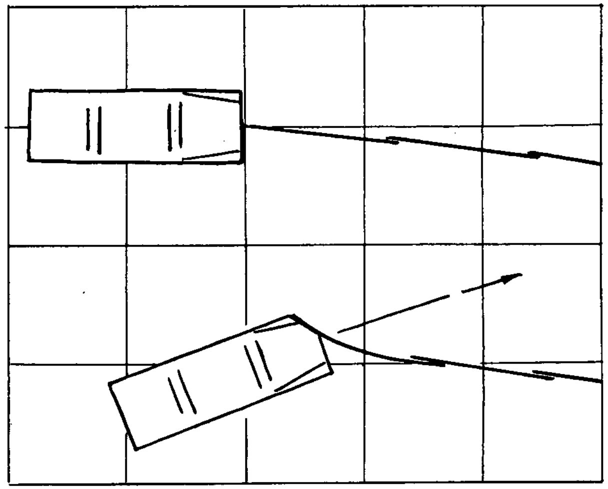
This appendix contains twelve terminal and three transition concepts as submitted in an interim report of this study in Task 3. A brief description of each concept and its performance principle is given. These designs are conceptual and have not been subjected to a detailed design analysis. They are not recommended for trial installation without a detailed design effort and a crash-test evaluation program.

CONCEPT T-1

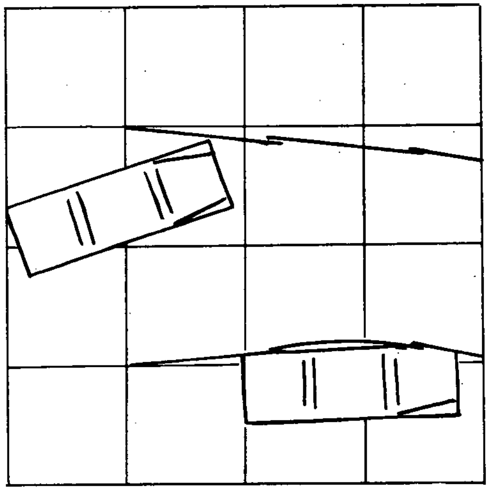
System: Flexible W-Beam End Length

Description: Three sections of standard 12 ga W-beam (12'-6" nominal length) mounted on standard posts comprise the end length. The splice bolts and post bolts are omitted within the end length. Connection of the lapped rail sections is by two 3/4" dia steel cables nested in the contour of the W shape. The approach ends of the cables attach to an end anchor (several different end anchors may be used). Other ends of cables are anchored to the third end beam section which is spliced conventionally to the first typical rail section.

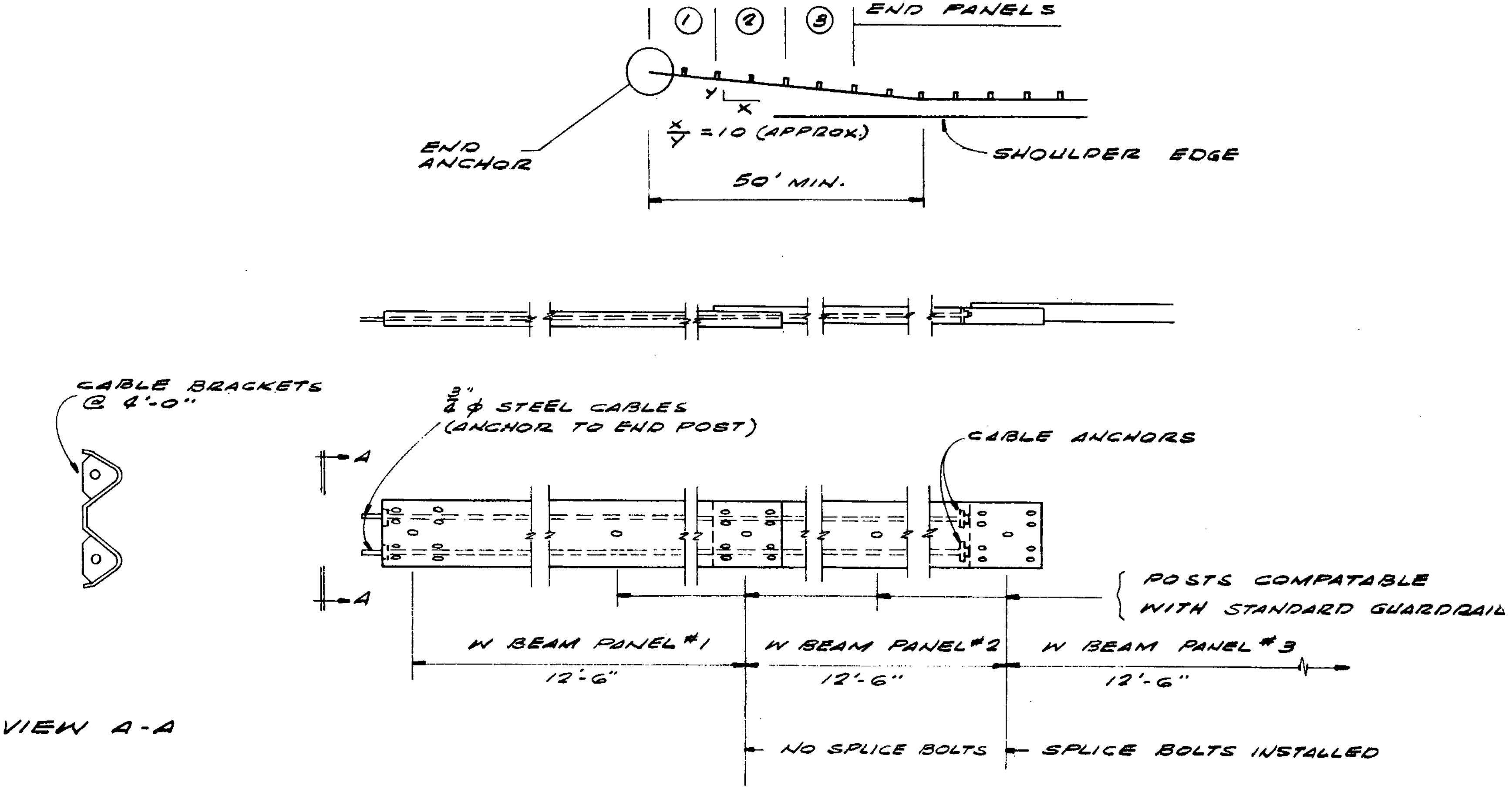
Principle: For end-on impacts the end W-sections collapse in telescoping fashion thus preventing spearing of the car. The end anchor must be direction "sensitive" such that it develops tension strength of rail for impacts within the beam span, but "breaks away" for end impacts without developing excessive stopping forces. Vehicle will penetrate the system for end-on impacts, but will be redirected for impacts beyond the end anchor.



END-ON IMPACT



IMPACT WITHIN LENGTH-OF-NEED



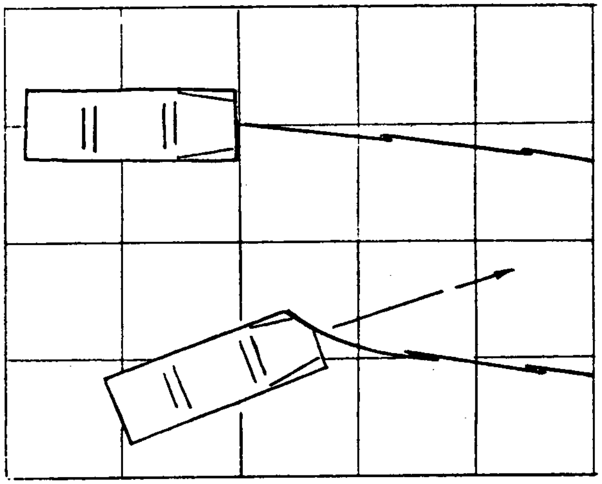
CONCEPT T-1 FLEXIBLE W-BEAM END LENGTH

CONCEPT T-2

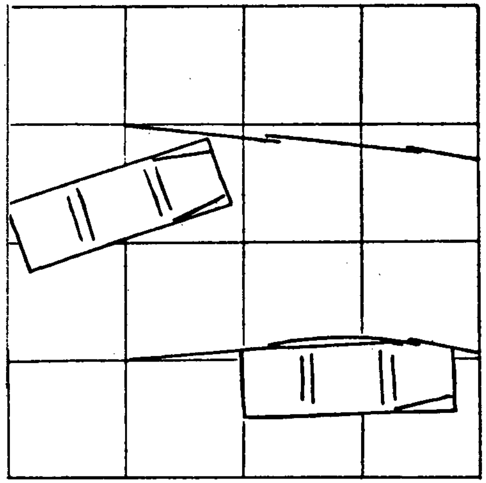
System: Telescoping Box Beam End Length

Description: Sections of 4 x 4-in. tubing, 5 x 5-in. tubing, and 6 x 6-in. tubing form the end length for the NCHRP Report 54, G4 standard. The end sections are nested in a telescoping manner into the standard 6 x 6-in. tube. A steel cable threaded through the sections provides the only physical connection. One end of the cable is attached to the end anchor; the other end is attached to the far end of the 6 x 6-in. end section. This 6 x 6-in. end section is spliced to the first typical box beam section with the conventional splice. The end length is supported by the standard posts although the 3/8" bolt is omitted in the end length to facilitate telescoping sliding action.

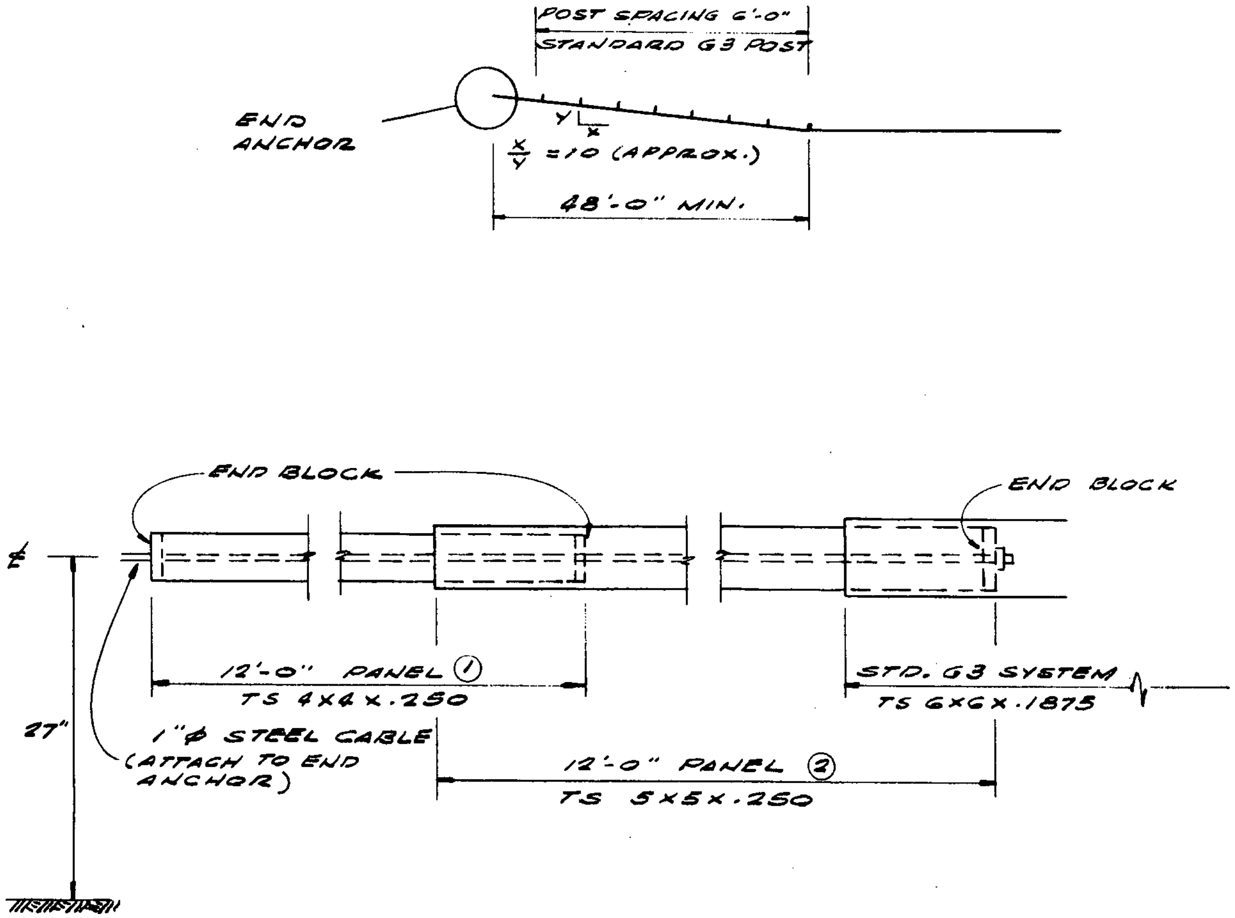
Principle: For impacts within the end length the vehicle is redirected; the cable provides tensile continuity, and the end anchor provides necessary longitudinal and lateral restraint. For end-on impacts the end anchor "breaks away", and the telescoping ends collapse and prevent spearing of the car. Although the system will not stop a car impacting at 60 mph, it is anticipated that eccentric loading will cause the box beam to bend away from the car and prevent vehicle contact with a blunt end.



END-ON IMPACT



IMPACT WITHIN LENGTH-OF-NEED



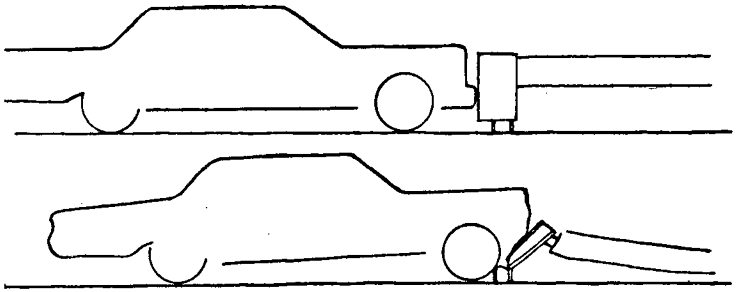
CONCEPT T-2 TELESCOPING BOX BEAM END LENGTH

CONCEPT T-3

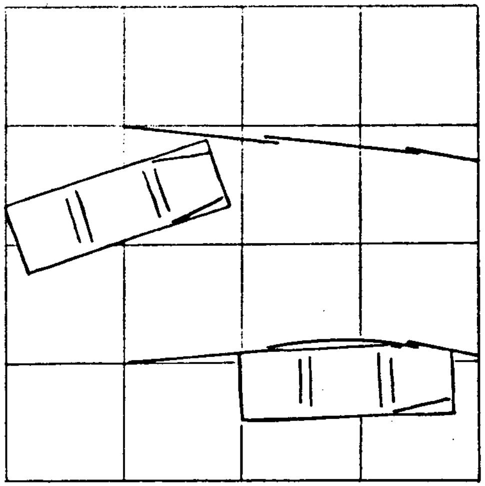
System: Breakaway Post Design, W-Beam and Box Beam

Description: Breakaway end post develops 50,000 lb longitudinal load in beam. Beams are not physically attached to post. Longitudinal beam load is applied to post by cables, and the lateral support block reacts lateral loads. Breaking action of post is achieved by cutting the post flange on the approach side. This cut is "spliced" by members of the end unit which mate with studs on cut flanges. The end unit which forms the front of the post is held in place by the splice feature. This end post is designed to be used with the T-1 and T-2 concept end lengths and is the anchor for these systems.

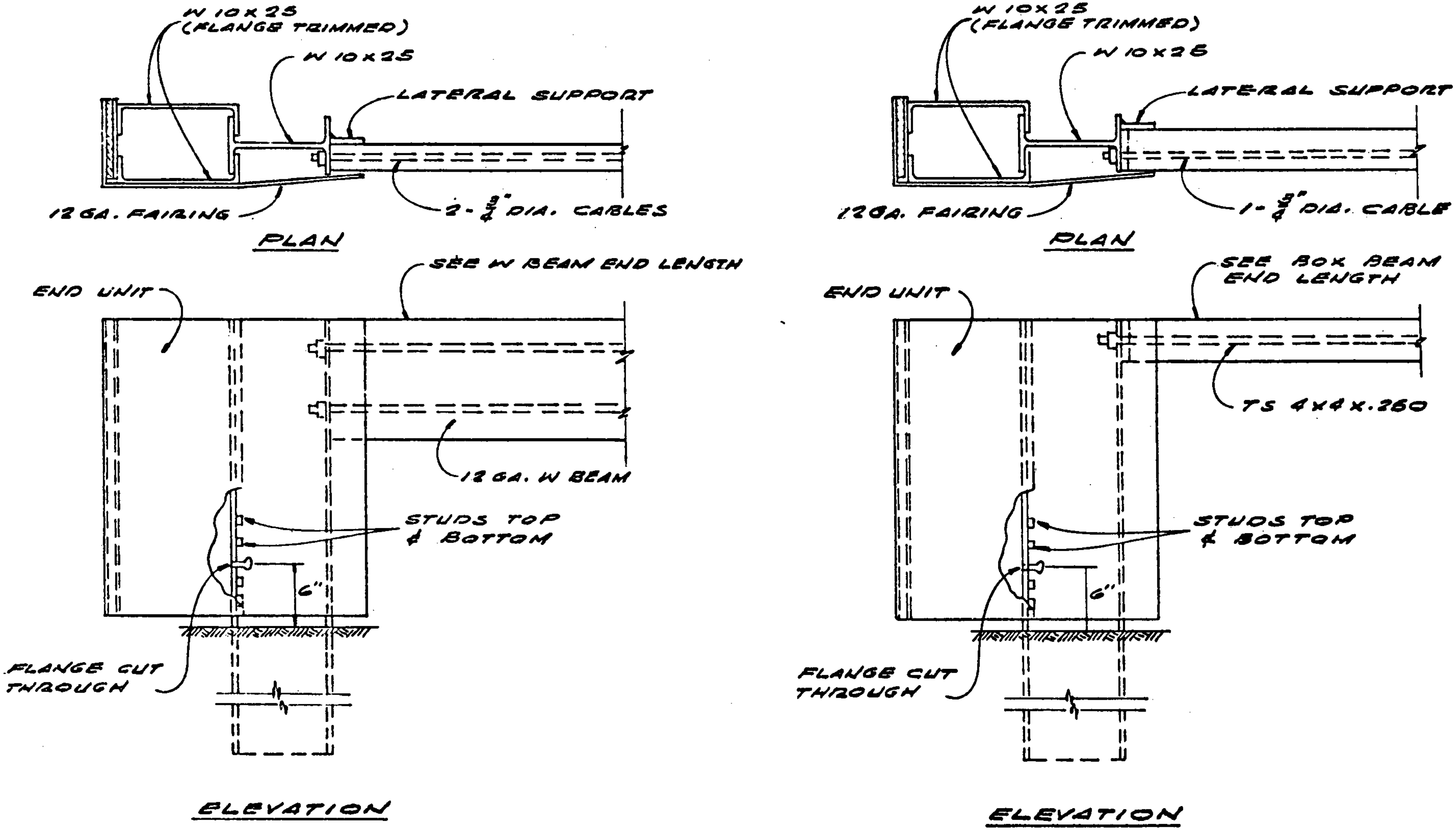
Principle: For end-on impacts the vehicle forces the end unit forward, thus disengaging the flange splice and permits the vehicle to pass over the end post without developing excessive forces. Since the end beam panels are not restrained for loads applied in this direction, spearing or abrupt stopping forces are minimized. For angle hits, the vehicle is redirected.



END-ON IMPACT



IMPACT WITHIN LENGTH-OF-NEED



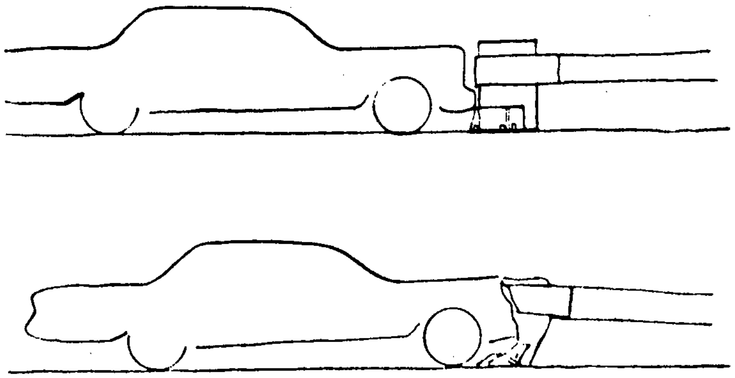
CONCEPT T-3 BREAKAWAY POST DESIGN,
W-BEAM AND BOX BEAM

CONCEPT T-4

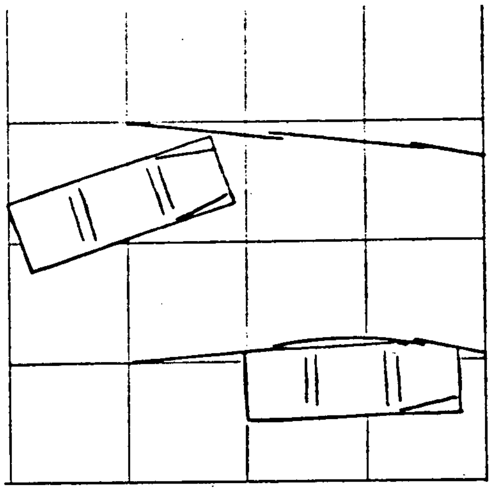
System: Barrel End Anchor

Description: A standard 55 gal steel drum is used to anchor the end of a W-beam or box beam system. A special strap connects the beam to the barrel. Tension strength for reacting longitudinal and lateral load induced moments at the base are developed by anchor bolts in a concrete footing. These bolts mate with a special welded assembly attached to the barrel base. The telescoping end lengths shown in Concepts T-1 and T-2 are utilized for the end beam spans.

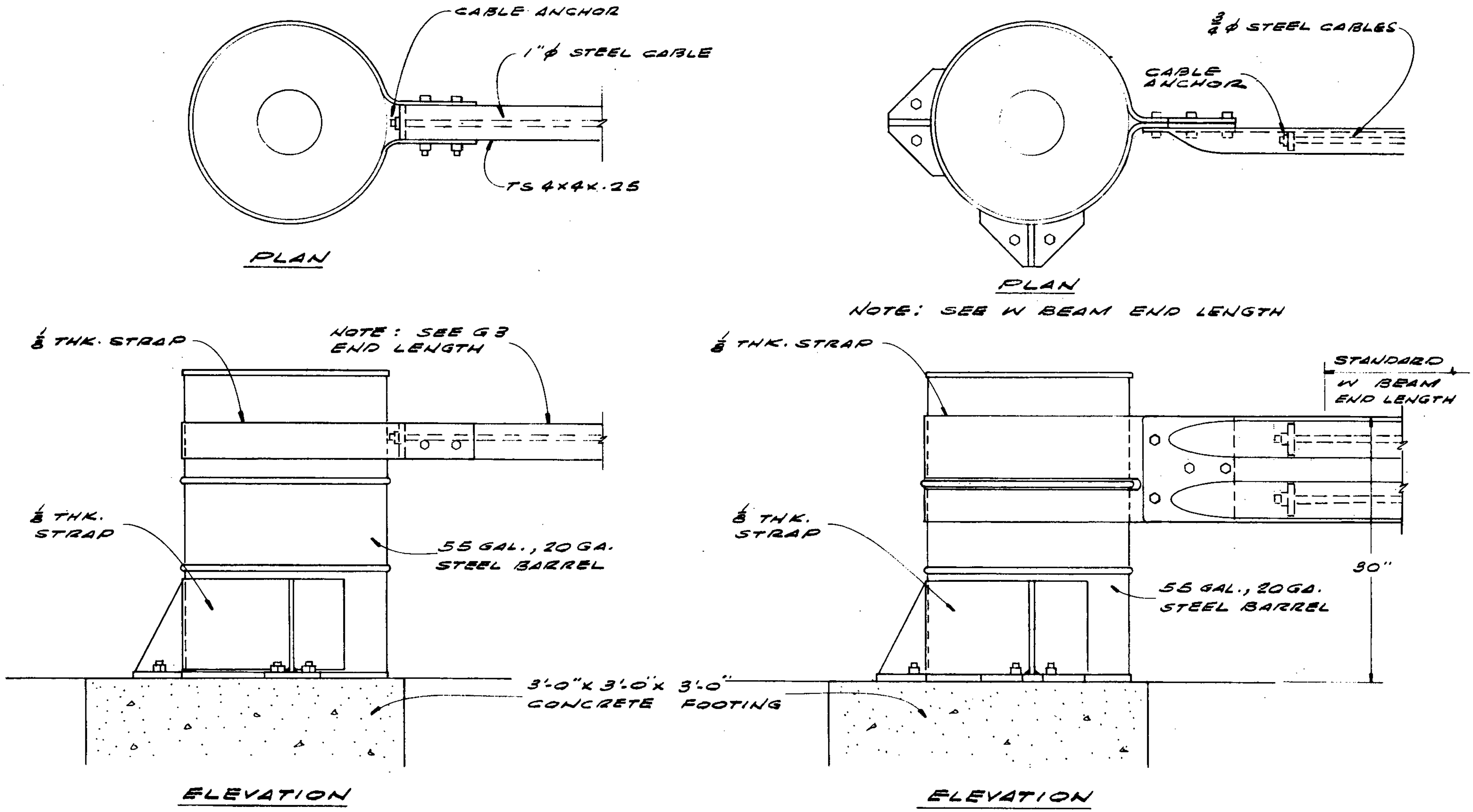
Principle: The vehicle is redirected for impacts within the end span. For end-on impacts the crushing of the barrel by the car destroys the structural integrity of the end anchor, and thus excessive stopping forces are not developed. Spearing forces are minimized by the telescoping beam ends. Eccentric loading of the beam causes the beam elements to bend away and direct the car away from the more longitudinally stiff beam elements downstream.



END-ON IMPACT



IMPACT WITHIN LENGTH-OF-NEED



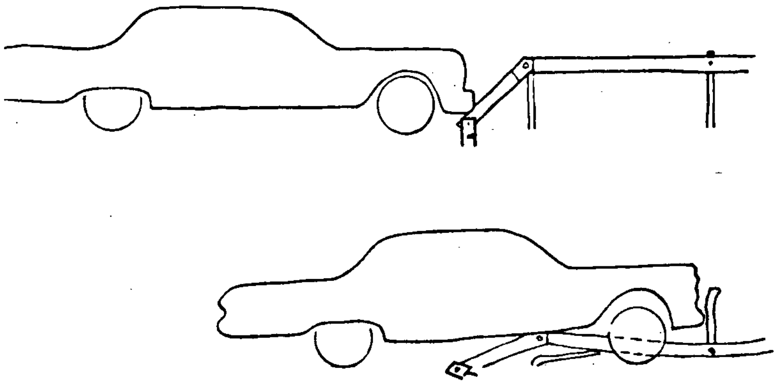
CONCEPT T-4 BARREL END ANCHOR

CONCEPT T-5

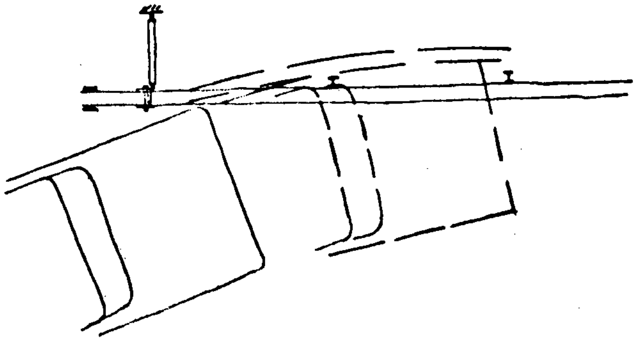
<u>System</u>: Collapsing Box Beam

<u>Description</u>: **A short ramp anchoring the box beam (NCHRP Report 54, G3) is hinged at both ends of the ramp. A lateral strut is installed at the hinge point to develop lateral loads. A vertical strut provides essential support at the hinge. Special mounting of the beam to post is featured in the end length.**

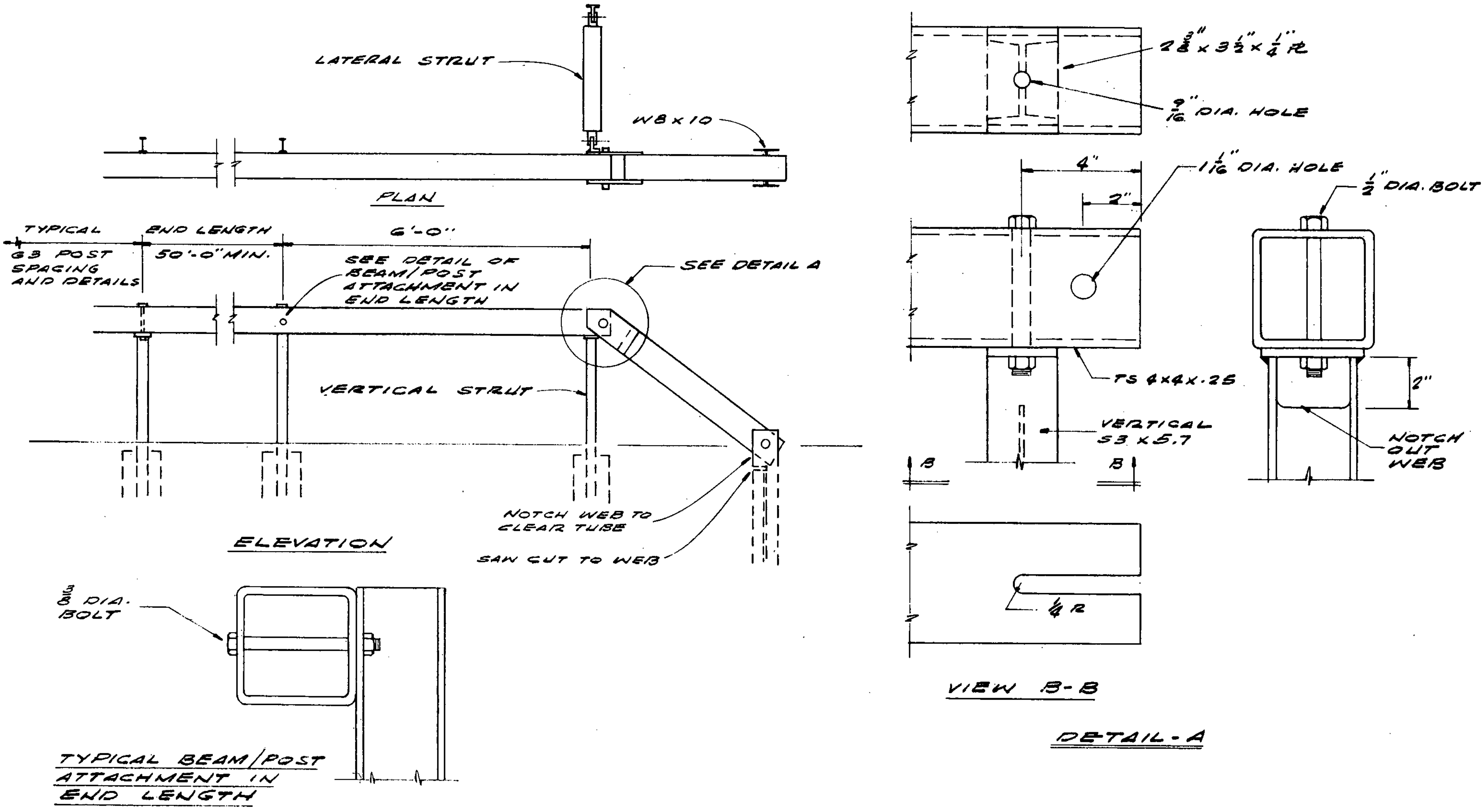
<u>Principle</u>: **The system effectively redirects vehicles for impact beyond the hinge. For end-on impacts the ramp folds at the hinge line; the lateral strut readily gives way, and the saw cuts in the earth anchor flange permit the ramp to flatten. Due to the mounting detail in the end length, the box beam drops as the 3/8" dia bolts shear permitting the vehicle to "ride" the beam down.**



END-ON IMPACT



IMPACT WITHIN LENGTH-OF-NEED



CONCEPT T-5 COLLAPSING BOX BEAM

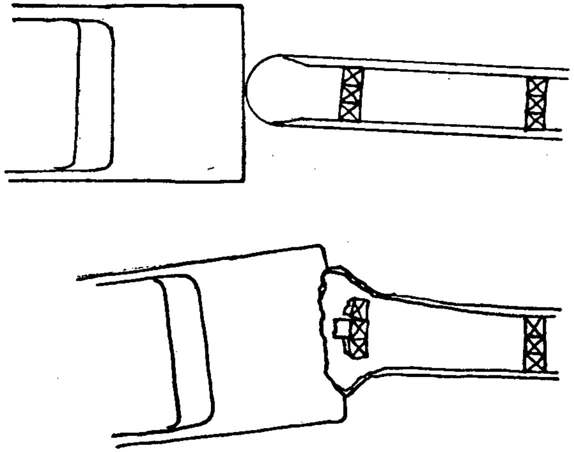
CONCEPT T-6

System: Idaho Highway Department Penetration Guardrail Terminal*

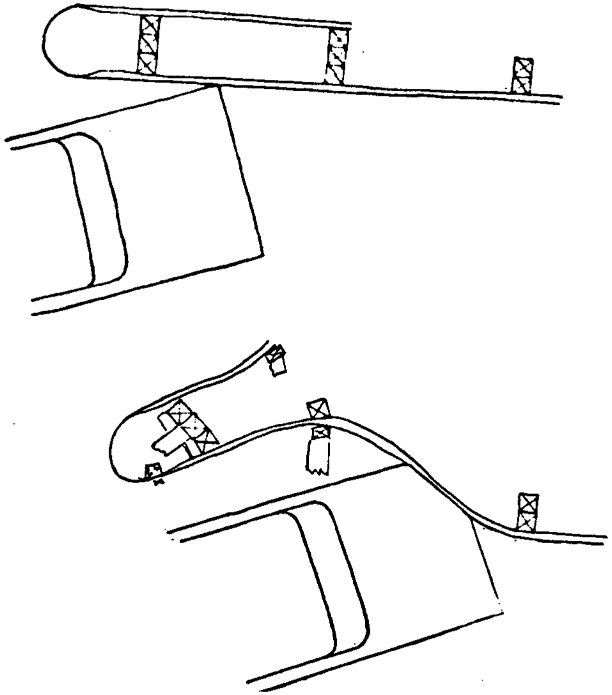
Description: Timber posts utilizing bored holes for breakaway performance are combined with a terminal nose of 30 in. diameter to form the terminal length. A diagonal brace rod provides end anchorage to develop necessary tension in beam.

Principle: The ballooning nose is produced by allowing the guardrail to break loose from the first post and mushroom out and around a vehicle impacting at the end. The nose is held low to provide protection for small cars. The anchor assembly is to redirect the vehicle through the area of need. It is anticipated that vehicles hitting the guardrail between the nose and anchor point will be effectively redirected since the posts will be drilled primarily for head-on collisions and will retain much of their lateral strength.

The modification of existing guardrail can be readily accomplished by inserting the ballooning nose on the existing buried ends, drilling holes for breakaway action and inserting the intermediate anchor assembly.



END-ON IMPACT



END IMPACT

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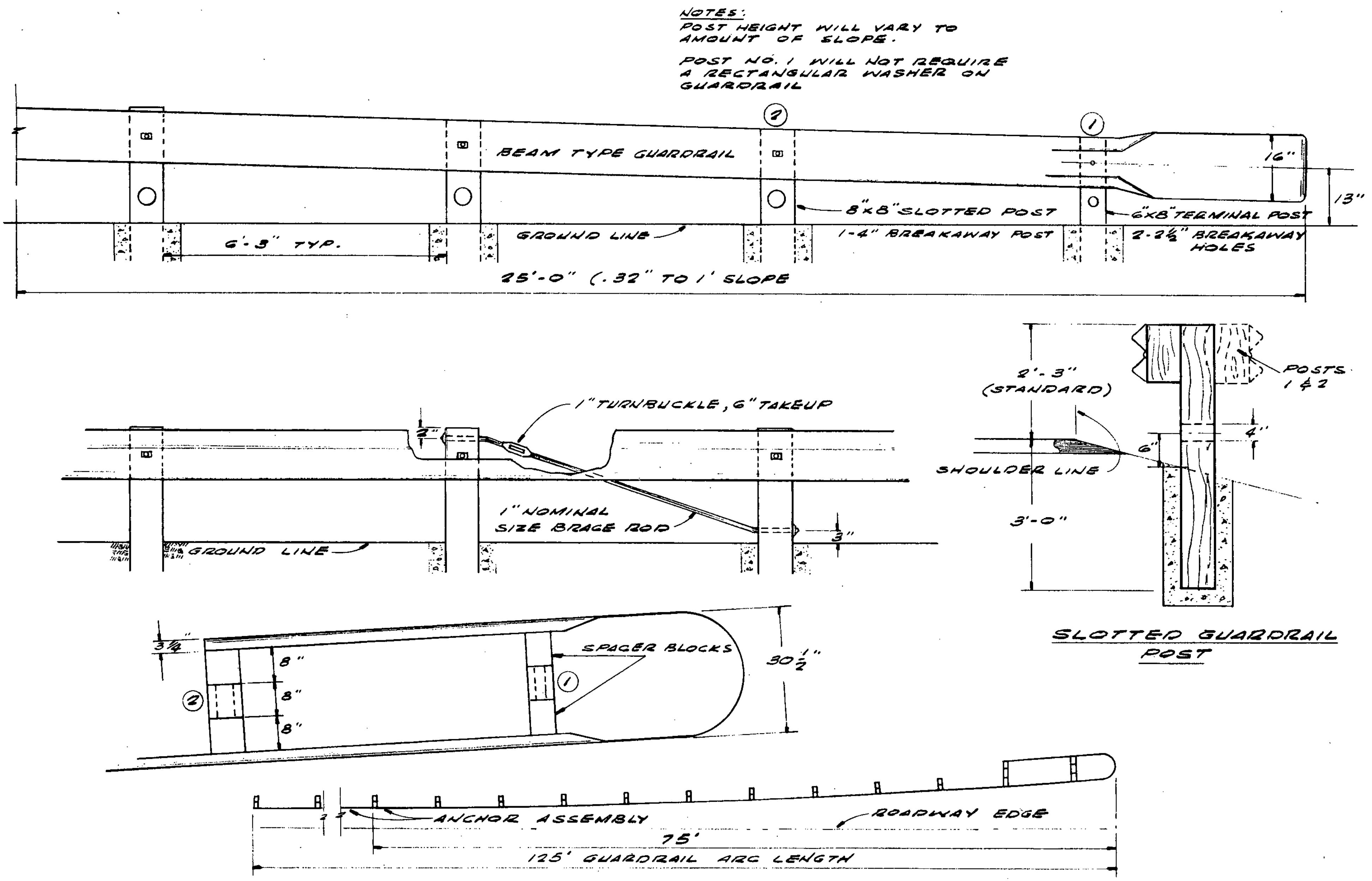
*Proposed design furnished by Idaho Highway Department.



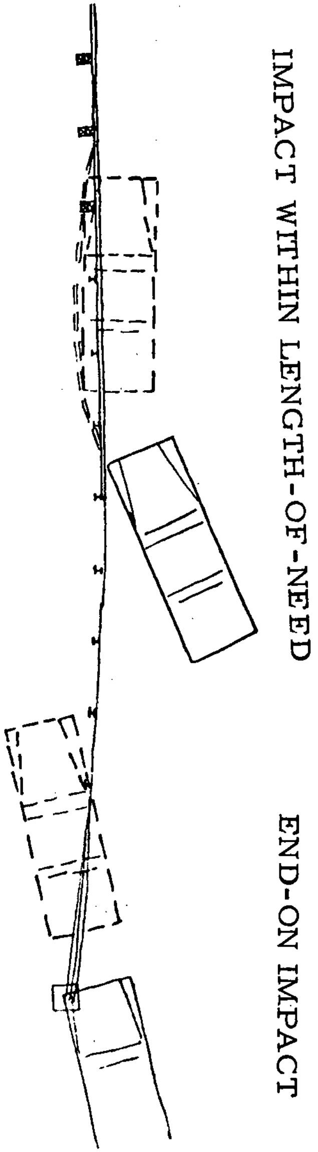
CONCEPT T-6 IDAHO HIGHWAY DEPARTMENT
PENETRATION GUARDRAIL TERMINAL

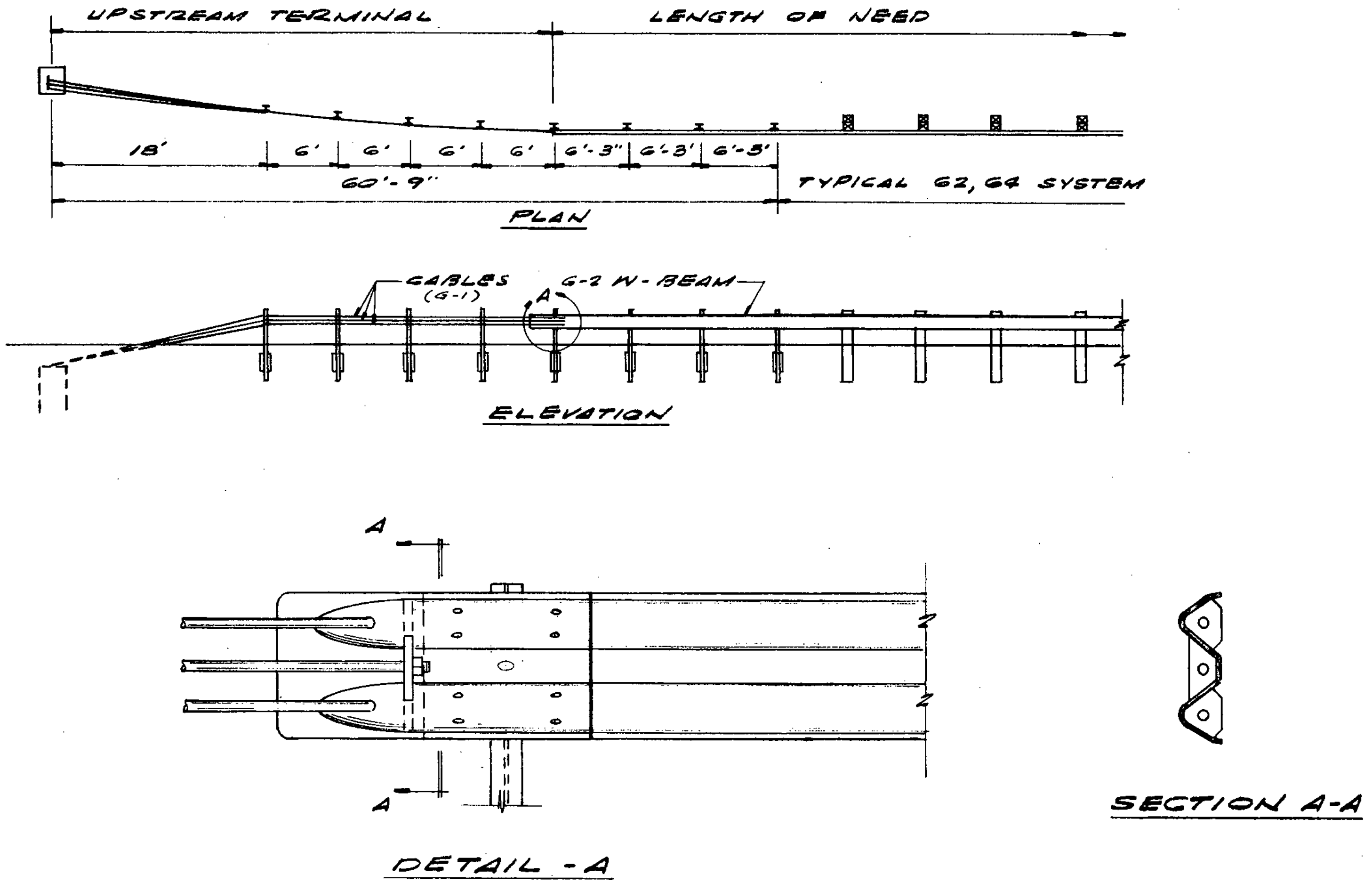
CONCEPT T-7

System: Cable Terminal for G2, G4 Systems

Description: A standard approach terminal for the G1 system (NCHRP Report 54) is used to develop tensile strength of G2 or G4 systems. For the G4 (or strong post) installation, a transition is effected to the more flexible G2 system and then to the cable terminal. For the G2 system, the 42-ft long cable terminal is attached directly to the length-of-need section.

Principle: For end-on impacts, the vehicle will force the cables down, and the weak posts will absorb a portion or all the vehicle kinetic energy; for higher speed impacts, the vehicle will also force the W-beam down in the weak post section. For angle impacts, the vehicle striking within the initial 18 to 24 feet will probably penetrate; however, this is deemed acceptable if the car remains upright. A vehicle striking the installation from 24 to 60 feet from the upstream end will be redirected, and the lateral system deflections are estimated to vary from 12 to 4 feet according to impact point.





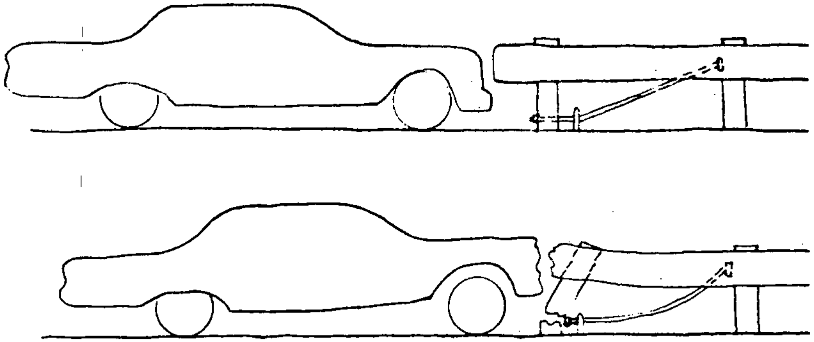
CONCEPT T-7 CABLE TERMINAL FOR
G2, G4 SYSTEMS

CONCEPT T-8

System: Cable End Anchor

Description: A steel cable anchors NCHRP Report 54 Standard G4. One end of the anchor cable is attached to the rail while the other end is threaded through a U-bar and attached to the anchor post. The U-bar and anchor post are set in a concrete footing.

Principle: The vehicle is redirected for impacts at and beyond the length of need. For end-on impacts ahead of the length-of-need,the anchor post breaks away at the weakened section permitting the anchor cable to slip through the U-bar; this removes the "anchor" strength from the rail, thereby reducing considerably the stopping forces of the system. The balloon shape of the end furnishes a large frontal area which reduces "spearing" potential of the end.



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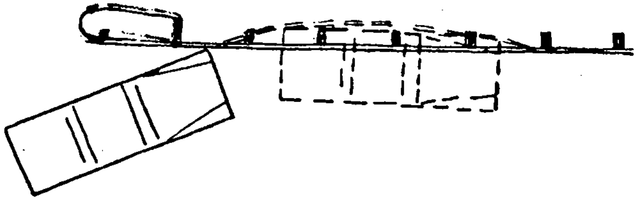
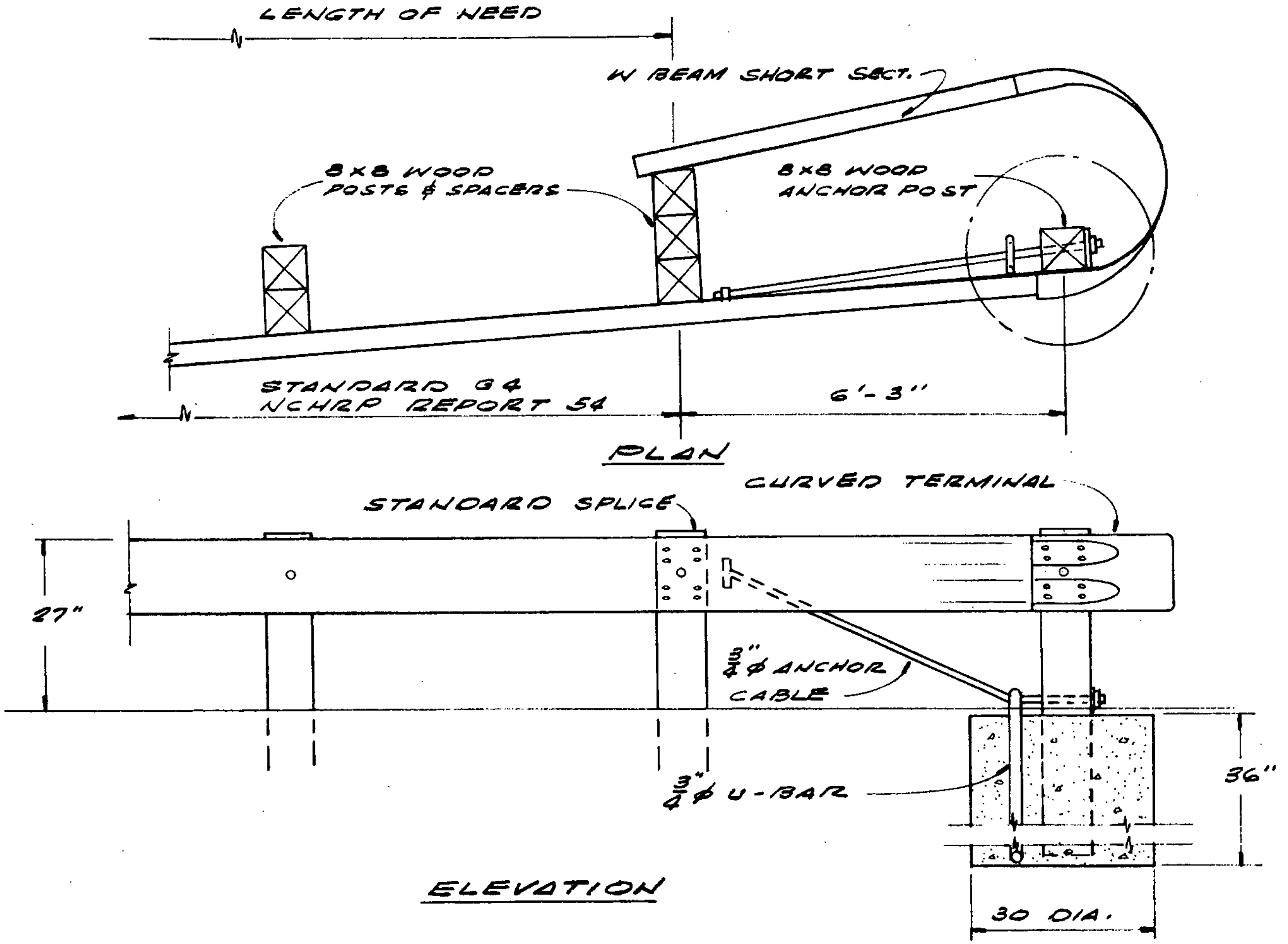


IMPACT WITHIN LENGTH-OF-NEED



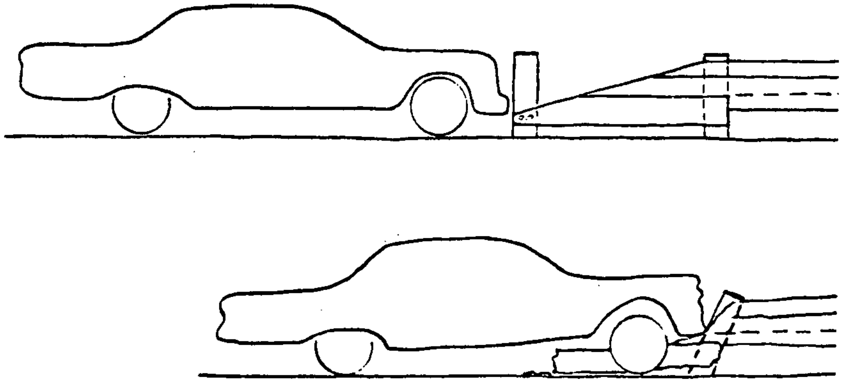
CONCEPT T-8 CABLE END ANCHOR

CONCEPT T-9

System: Multiple W-Beam End Length

Description: The beam is anchored by overlapping sections of W-beam in two end panels. The beams are spot welded at the overlap locations to develop strength of rail. A special W-beam section with a flat lower contour is utilized in the end panel. The end span is sloped by trimming the beam sections.

Principle: The system redirects vehicles impacting within the length-of-need. For angular or end-on impacts within the end span the vehicle rides the rail down and either penetrates the system or is redirected. The end post is left full height to serve as a delineator and to facilitate breaking for direct impacts.



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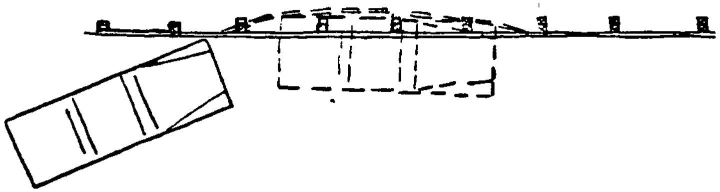
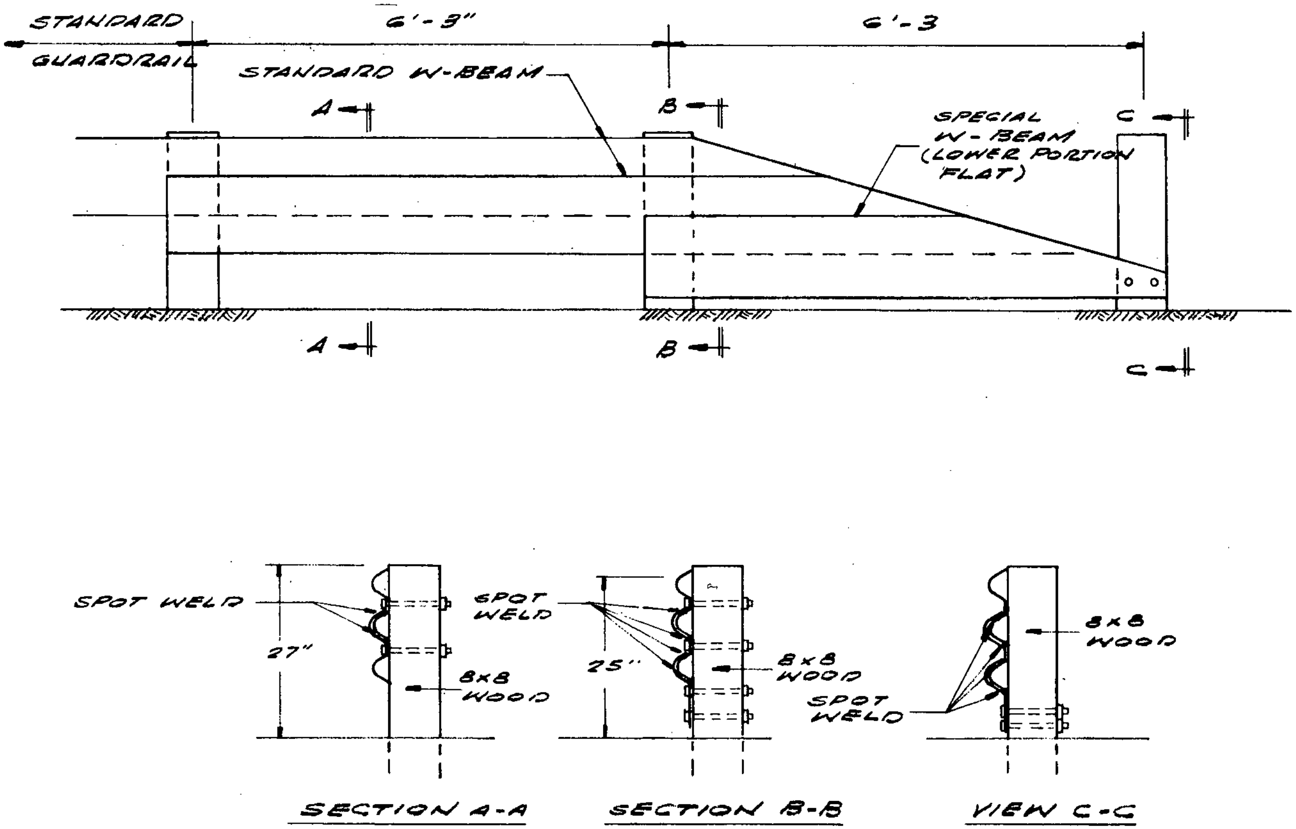


IMPACT WITHIN LENGTH-OF-NEED



NOTE:

END PANELS TO BE SPOT WELDED BEFORE GALVANIZING TO DEVELOP STRENGTH OF RAIL.

CONCEPT T-9 MULTIPLE W-BEAM
END LENGTH

CONCEPT T-10

System: "Texas Taper*"

Description: A short "in plane" ramp anchors the standard W-beam. Special hardware includes a welded W-beam assembly which provides a 24° ramp angle from the horizontal rail line.

Principle: This concept is not necessarily less hazardous than the current Texas Twist; however, the "length-of-hazard" is only 1/4 that of the standard "Texas Twist" terminal.

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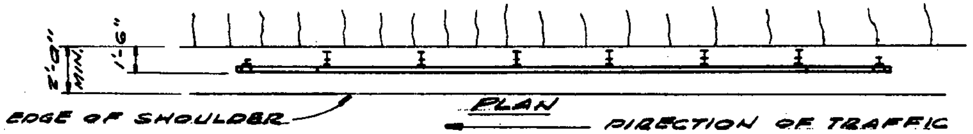
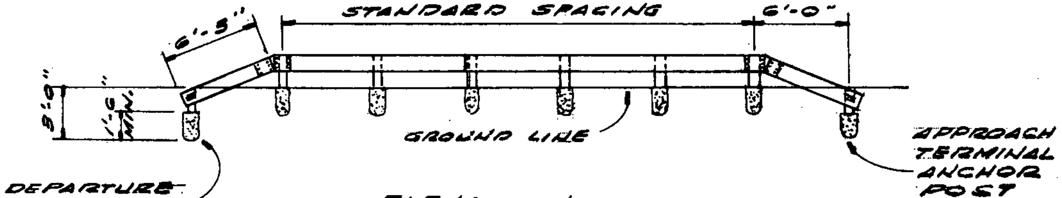
*This is a Texas Highway Department design presently specified on standard drawings as a "departure" terminal. It is being proposed here as an approach terminal also.



PLAN



ELEVATION

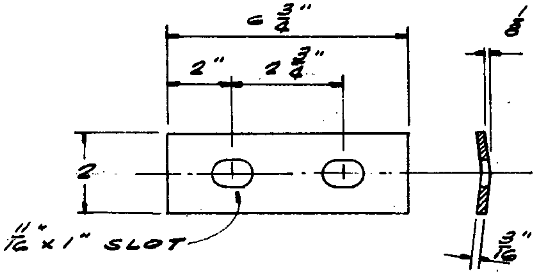
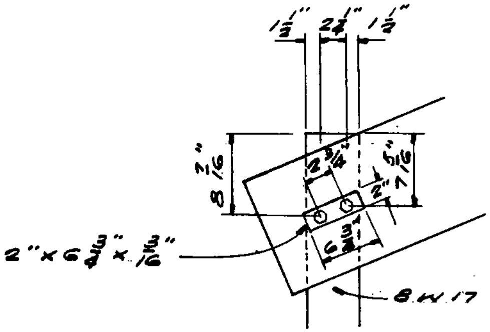
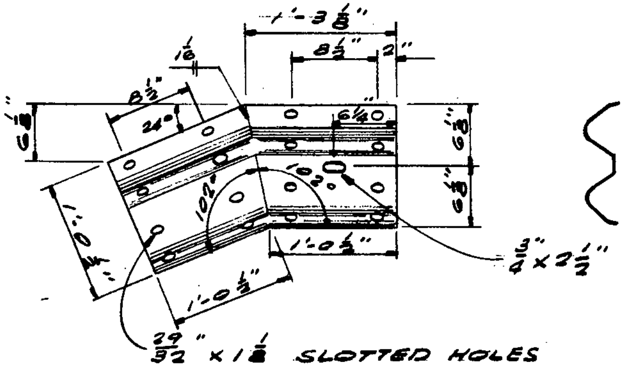


PLATE WASHER FOR METAL BEAM
(GALVANIZE AFTER FABRICATION)



TERMINAL ANCHOR POST



RAIL ADAPTER
CLASS A RAIL -10 GAUGE
(GALVANIZE AFTER FABRICATION)

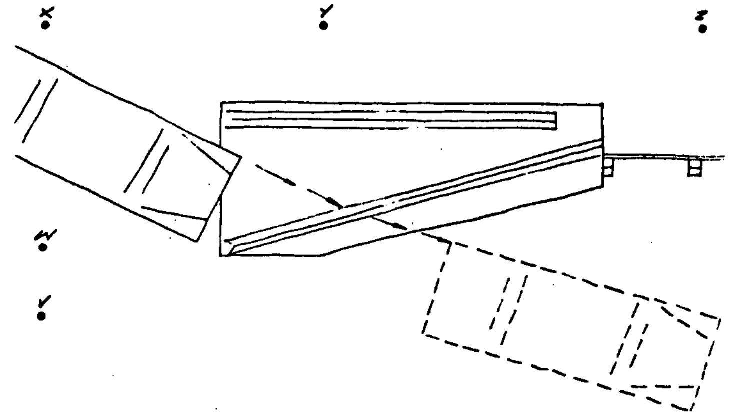
CONCEPT T-10 TEXAS TAPER

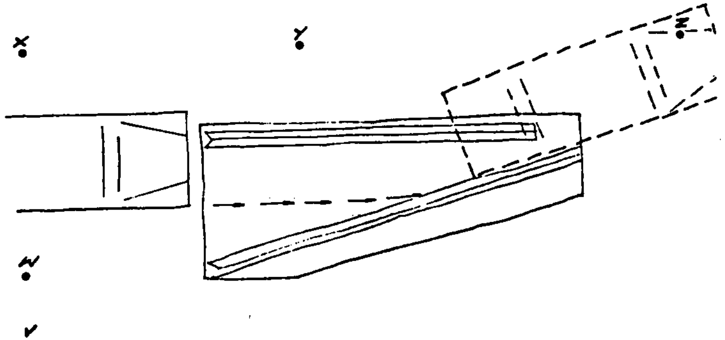
CONCEPT T-11

System: Curb Field End Treatment

Description: Two low curbs, located upstream from guardrail system, are cast integrally with concrete surface. One curb, aligned parallel to the traveled way, has a maximum height of 8 inches; the second curb, aligned at a 15° angle with the traveled way, has a maximum height of 13 inches.

Performance Principle: Vehicle approaching guardrail installation through window W-X-Y (see attached sketch) at any angle from 0 to 25° will be redirected by either or both curbs; vehicles entering this critical window at a greater angle than 25° will vault both curbs. Vehicles entering through window W-V are considered noncritical. Vehicle entering through window Y-Z will strike the effective portion of the guardrail installation.





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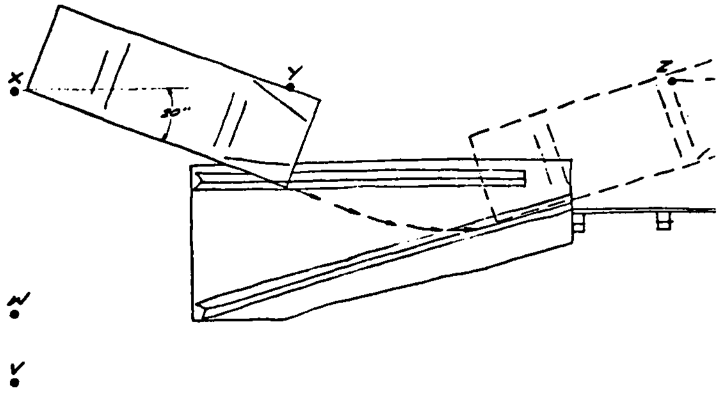
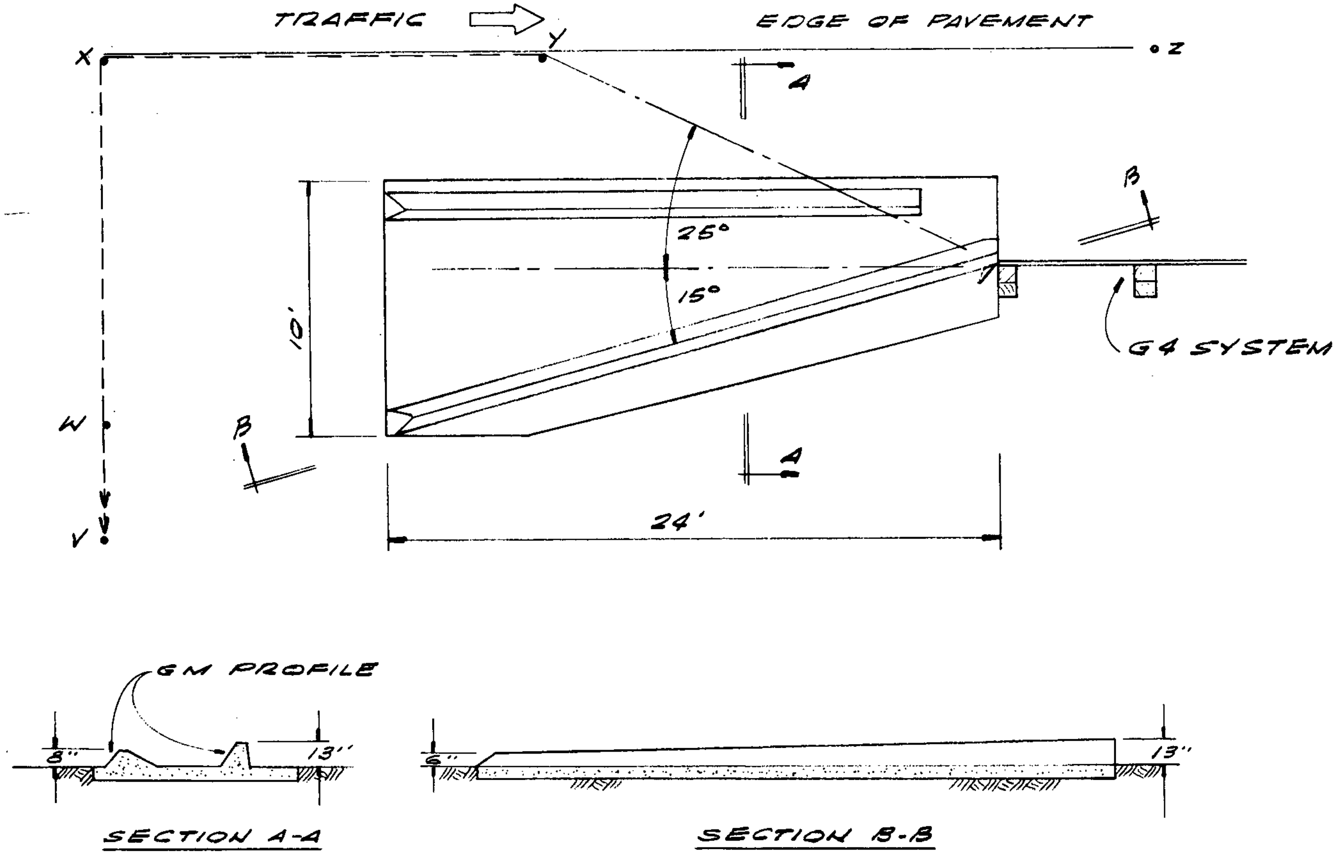




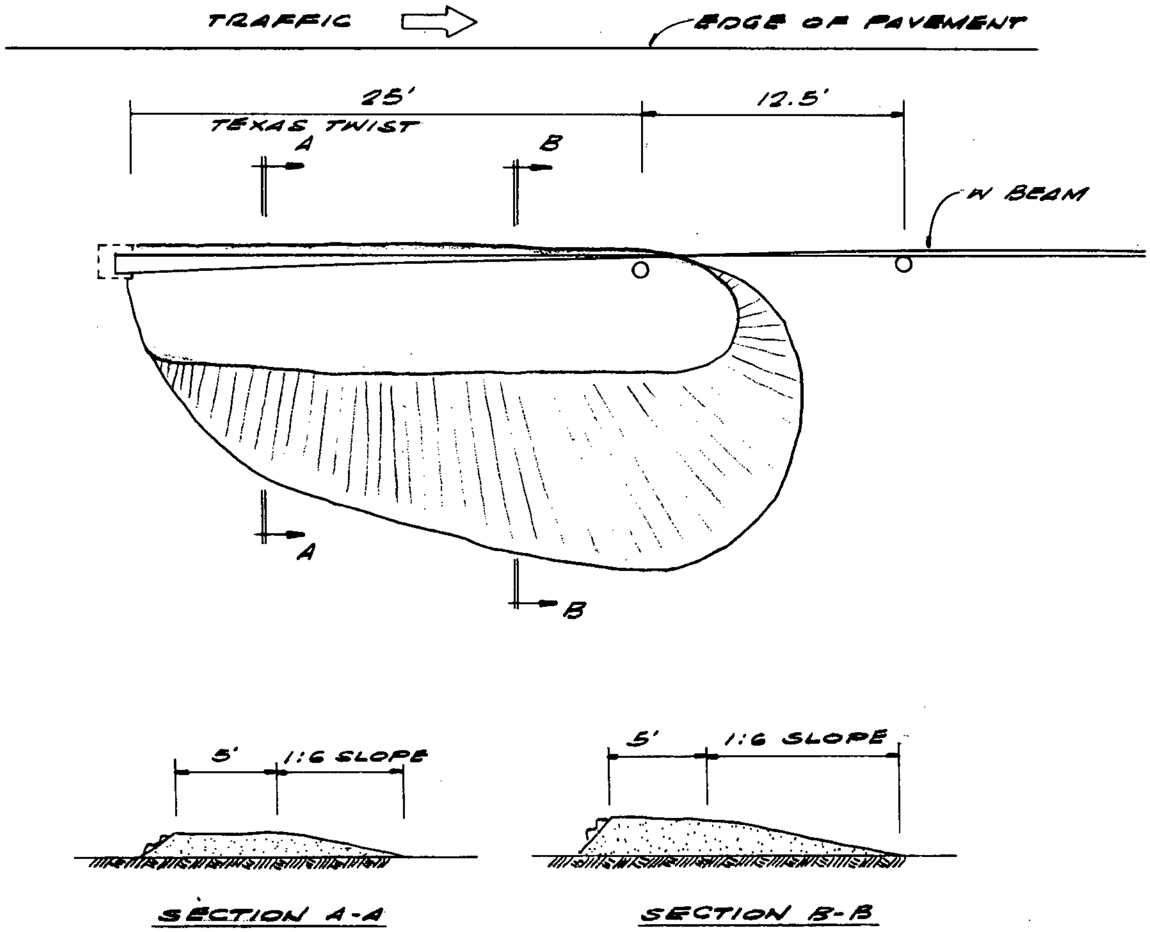
CONCEPT T-11 CURB FIELD END TREATMENT

CONCEPT T-12

System: Earth Mound End Treatment

Description: Earth mound is built behind standard "Texas Twist" end treatment. Mound geometry consists of a gradual 5-ft wide ramp that is parallel and immediately behind 25-ft long approach. Traffic side of mound follows contour of twisted W-beam, and the reverse side has a 1:6 slope.

Performance: Typical "tripping" tendency of "Texas Twist" is minimized by mound although vehicles may be launched. Vehicles approaching end design between 0 and 25 deg will remain in upright attitude or be slightly rolled toward pavement.



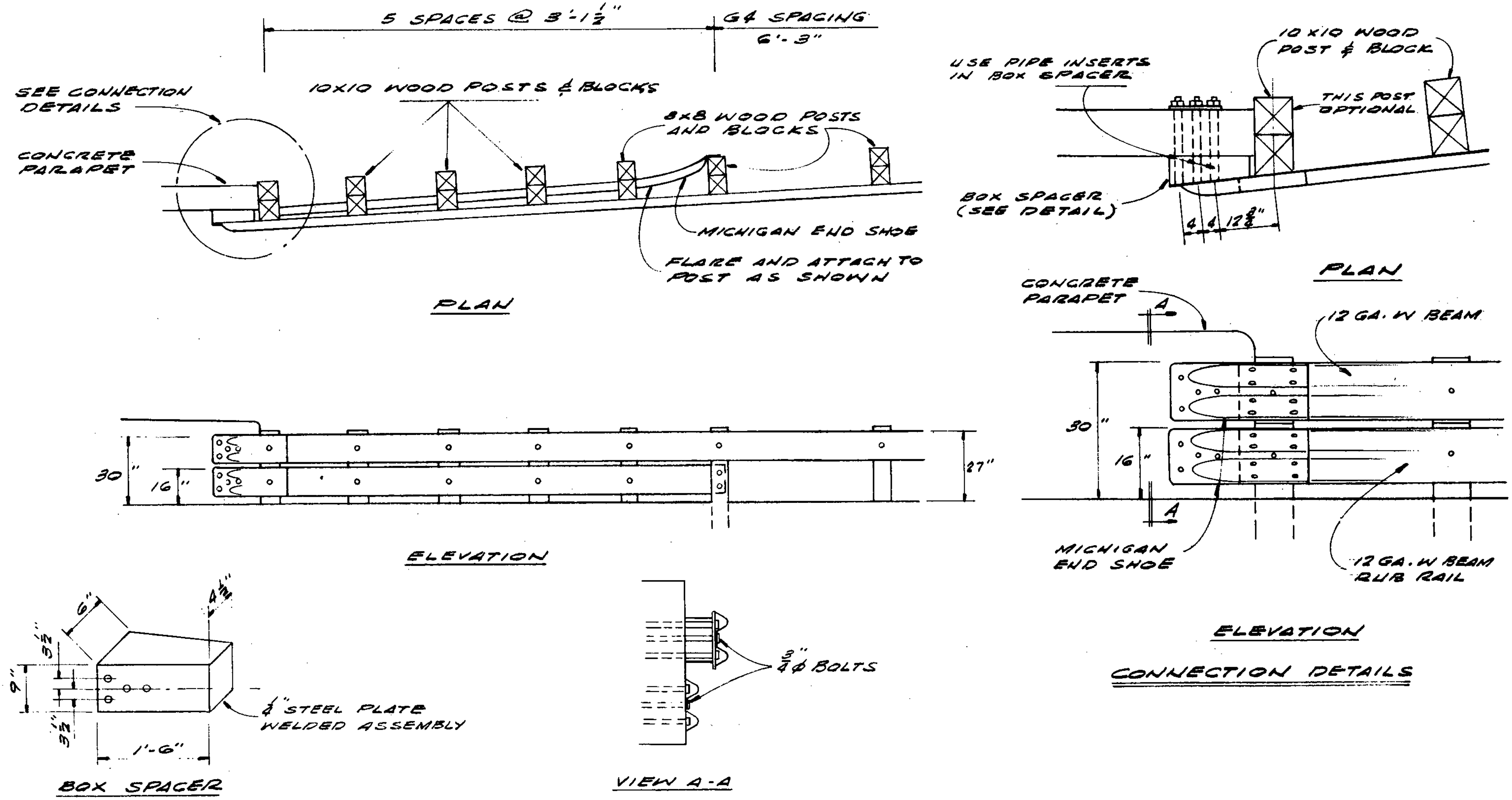
CONCEPT T-12 EARTH MOUND
END TREATMENT

CONCEPT TR-1

System: Modified California Guardrail/Bridge Parapet Transition

Description: The transition is quite similar to that specified in Sheet 8 of NCHRP Report 54. A standard W-beam rub rail has been added and the spacer box modified to permit use of Michigan End Shoe. The rub rail is terminated at the last post spaced at 3'-1-1'2".

Principle: The rub rail has been added to minimize the effect of the wheels snagging on the timber posts and the parapet end.



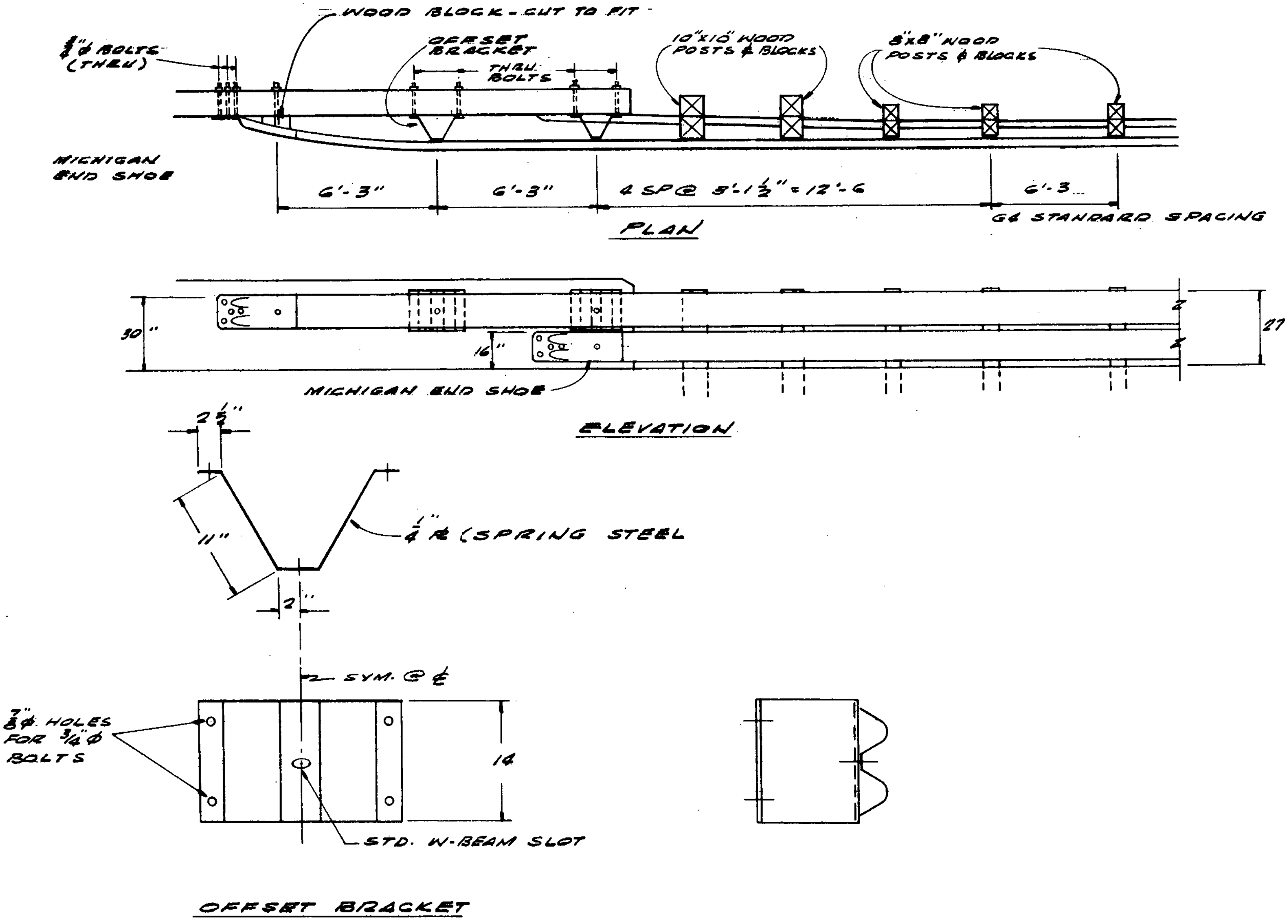
CONCEPT TR-1 MODIFIED CALIFORNIA GUARD-RAIL/BRIDGE PARAPET TRANSITION

CONCEPT TR-2

System: W-Beam/Spring Bracket Transition to Flush Bridge Parapet

Description: Steel spring brackets offset the standard W-beam from the parapet wall. The beam is faired into the wall and this is suitable for two way traffic. A standard W-beam rub rail is utilized and can be terminated similar to modified California design or continued throughout installation length.

Principle: The spring brackets are added to provide a more graduated transition from the guardrail to the rigid wall. The rub rail is added to prevent snagging in posts and parapet end.



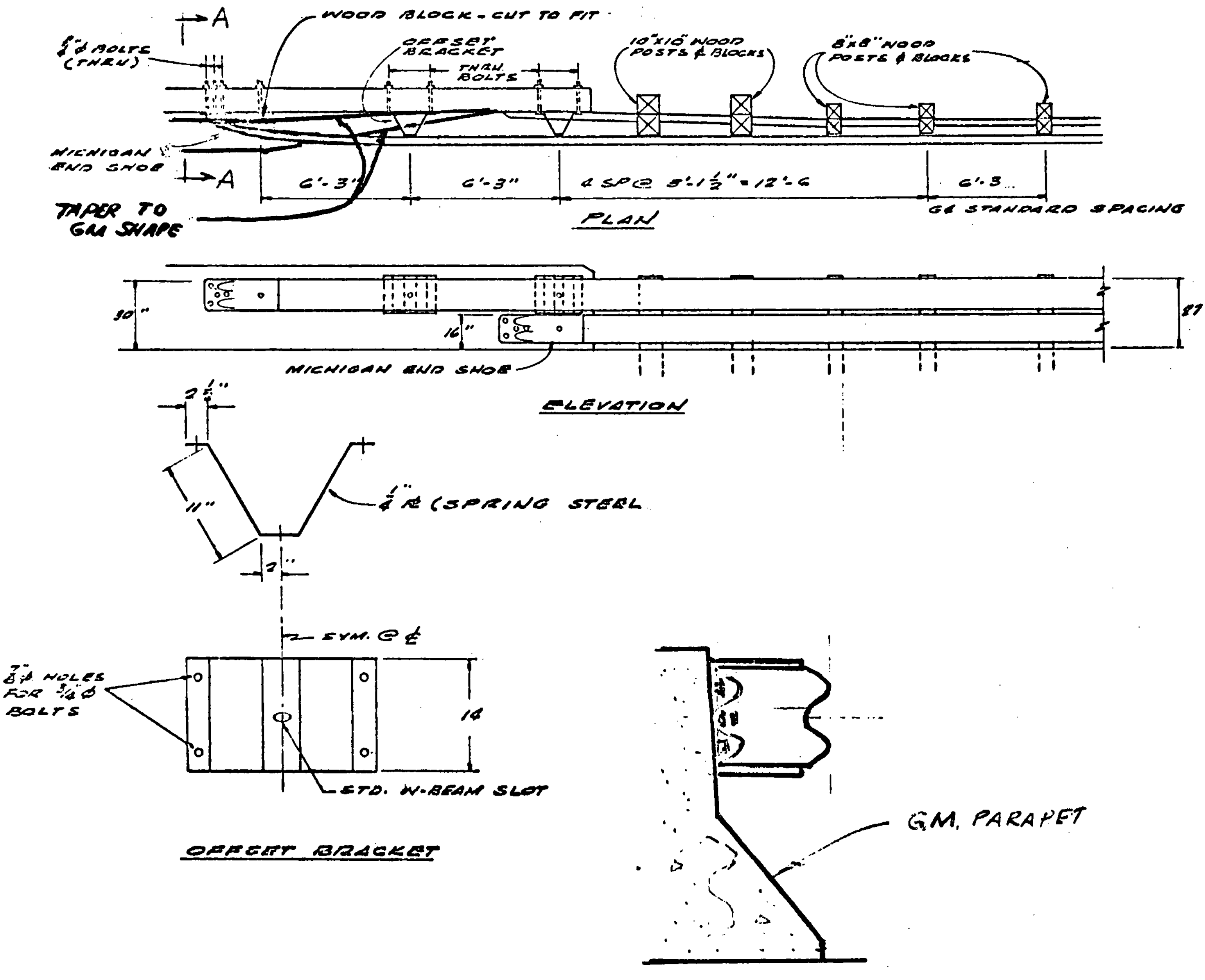
CONCEPT TR-2 W-BEAM/SPRING BRACKET
TRANSITION TO FLUSH BRIDGE PARAPET

CONCEPT TR-3

System: W-Beam/Spring Bracket Transition to GM Parapet

Description: A system similar to TR-2 is installed in the flush end of a General Motors Bridge Parapet. The full GM profile emerges at the end of a tapered section beginning at the rub rail termination.

Principle: An attempt is made to move the impacting vehicle from a beam/post system to a system relying on another operational principle without producing a "conflict of systems."



CONCEPT TR-3 W-BEAM/SPRING BRACKET
TRANSITION TO GM PARAPET

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