Report No. FHWA-RD- 77-40

UPGRADING SAFETY PERFORMANCE IN RETROFITTING TRAFFIC RAILING SYSTEMS

September 1976
Final Report

Document is available to the public through
the National Technical Information Service
Springfield, Virginia 22161

Prepared for
FEDERAL HIGHWAY ADMINISTRATION
Offices of Research & Development
Washington. D. C. 20590

FOREWORD

The purpose of this research project was to develop a series of hardware modifications that will upgrade sub-standard bridge rails and bridge rail/guardrail transitions to currently acceptable structural and safety performance levels. The project included an in-depth survey of bridge rail systems in use. Those designs that were deficient with regard to safety and most predominant in actual use were identified and considered for retrofit development. Several bridge rail retrofit concepts were developed and tested under full scale passenger vehicle impacts. The evaluation was limited to passenger vehicles only. Heavy vehicle impact consideration was beyond the scope of this study. A new type of rail element was developed and extensively utilized in the new concepts (Tubular Thrie Beam). The new rail element is potentially applicable to many other roadside barrier concepts.

This report is being distributed by FHWA Bulletin to insure proper exposure of these new retrofit concepts to the highway engineering profession. A limited number of additional copies are available from the Structures and Applied Mechanics Division, Office of Research.

Copies may also be obtained from the National Technical Information Service (NTIS), Department of Commerce, 5285 Port Royal Road, Springfield, Virginia 22161. A small charge is imposed for copies provided by NTIS.

Charles F. Scheffey
Director, Office of Research
Federal Highway Administration

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA-RD-77-40		

4. Title and Subtitle
Upgrading Safety Performance in Retrofitting Traffic Railing Systems

5. Report Date
September 1976

6. Performing Organization Code

7. Author(s)
Jarvis D. Michie and Maurice E. Bronstad

8. Performing Organization Report No.
03-3717

9. Performing Organization Name and Address
Southwest Research Institute
8500 Culebra Road
San Antonio, Texas 78284

10. Work Unit No. (TRAIS)
FCP 31G2-054

11. Contract or Grant No.
DOT-FH-11-8100

12. Sponsoring Agency Name and Address
U. S. Department of Transportation
Federal Highway Administration
Washington, D.C. 20590

13. Type of Report and Period Covered
Final
7/1/73 - 6/1/76

14. Sponsoring Agency Code
S0729

15. Supplementary Notes

FHWA Contract Manager: Morton S. Oskard (HRS-12)

16. Abstract

From bridge rail information of 51 State highway agencies and personal interviews with five selected highway agencies, current state-of-the-art of bridge railing safety performance was assessed. Based on the analysis of 14 specific railing designs, an estimated assessment of the performance of bridge rails on a national scale is presented. The data indicates that a significant percentage of existing railings may be below currently attainable safety performance standards.

Bridge railing designs are grouped into four categories according to profile geometry and features that are amenable to a common retrofit design. Two categories, II and III, represent about 82 percent of existing installations. Five retrofit designs for Categories II and III were developed and evaluated by a 22-crash test program.

Although not crash-test evaluated, an improved approach guardrail design features a thrie beam rail element and a breakaway cable terminal.

17. Key Words	18. Distribution Statement
Highway Safety, Bridge Rail Design, Single Vehicle Accidents, Automobile Dynamics, Retrofit Modifications	No Restrictions. This document is available through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified		A13-A01

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

ACKNOWLEDGMENTS

The work reported herein was conducted by the Department of Structural Research, Southwest Research Institute. Assisting the authors in the vehicle crash evaluation of retrofit designs were G. W. Deel, T. H. Conard, R. P. Guillot, B. M. Johnson, C. F. Berger and C. A. Walker. Ms. J. Baker's contribution in preparing the final report manuscript, as well as progress reports submitted throughout the program, is recognized. Dr. R. C. DeHart, Vice President, served in the capacity of technical and administrative advisor.

The 44 state highway agencies that participated in the state-of-the-art questionnaire survey and especially the highway agencies of California, Colorado, Iowa, Minnesota, and Missouri, which provided in-depth information during project staff visits, are recognized for their contribution.

Louisiana Department of Highways developed the concept for the R(IIN)-3 retrofit design and provided funding for the five crash tests used in evaluating the installation. The support and contribution of Mr. David S. Huval, Bridge Design Engineer, in this effort is acknowledged.

James Wentworth of the Federal Highway Administration (FHWA) served as contract manager during Phase I and Mort Oskard (FHWA) served as contract manager for Phase II. Both contributed to the program with technical guidance and constructive report reviews.

ATTENTION

AS NOTED IN THE NTIS ANNOUNCEMENT, PORTIONS OF THIS REPORT ARE NOT LEGIBLE. HOWEVER, IT IS THE BEST REPRODUCTION AVAILABLE FROM THE COPY SENT TO NTIS.

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Cont'd)

LIST OF ILLUSTRATIONS (Cont'd)

LIST OF ILLUSTRATIONS (Cont'd)

LIST OF TABLES

I. INTRODUCTION

A. Background

Olson[(1)]* showed that about one-third of all freeway fatal accidents during the period 1965-67 involved a vehicle running off the road and hitting a fixed object; furthermore, he showed that about 22 percent of these fixed objects were bridge barrier railing systems.† Hosea[(2)] reported that a bridge railing system element was the first object struck in 18 percent of fixed-object fatal accidents on completed sections of the Interstate Highway System in 1968. An analysis of bridge railing accidents by location in Figure 1 shows that 73 percent of errant vehicles impacted the approach guardrail and bridge end and 27 percent collided with the bridge railing.[(1)] Performance of the barrier systems in these accidents was judged inadequate as evidenced by the fact that 16 percent of the vehicles either vaulted or penetrated the installation and 52 percent pocketed or snagged.

In 1967 AASHTO published the "yellow book" entitled, "Highway Design and Operational Practices Related to Highway Safety." One of the safety improvements emphasized in this widely distributed report was the need for a structurally sound transition between guardrails on bridge approaches and the bridge rail. Several states, one of which was California, initiated intensive programs to upgrade existing bridge railing installations per "yellow book" recommendations. Accident statistics from California[(3)] as shown in Table 1 indicate that this effort has been most successful as the freeway fatal accident rate per 100 million vehicle miles (MVM) for bridge railing decreased in the period from 1965 to 1973 by about 50 percent and decreased even more significantly in 1974 and 1975 when the maximum 55 mph (24.6 m/s) speed limit was set. This improvement in highway safety, which has been confirmed by other states, may be partially attributable to improvements that evolved in the same 10-year period in vehicle crashworthiness and occupant restraint systems. Nevertheless, the California statistics indicate that effort used in upgrading bridge railing installations has resulted in reduction of fatal accidents.

A promising approach for further reducing highway fatalities is to upgrade substandard bridge railing installations with a cost-effective device or devices that can be easily retrofitted to existing bridges. Such modifications should be readily amenable to a majority of existing bridges and be quickly and economically adapted in the field.

B. Objective

The purpose of this program was to develop a series of standard modifications that will upgrade substandard bridge rails and bridge rail/guardrail transitions to acceptable structural and safety performance levels.

C. Scope

To achieve program objectives, it was first necessary to identify types and mileage of bridge railing systems in use; this was performed by letter survey of 51 state highway agencies and project staff visits to six of these agencies. Designs from 44 reporting agencies were assembled and classified into four basic SwRI-defined categories according to profile geometry. Bridge railing designs within a category present common retrofit constraints that are amenable to a common retrofit design.

*Number denotes references.
†Bridge railing system includes approach guardrail, transition and the bridge railing.

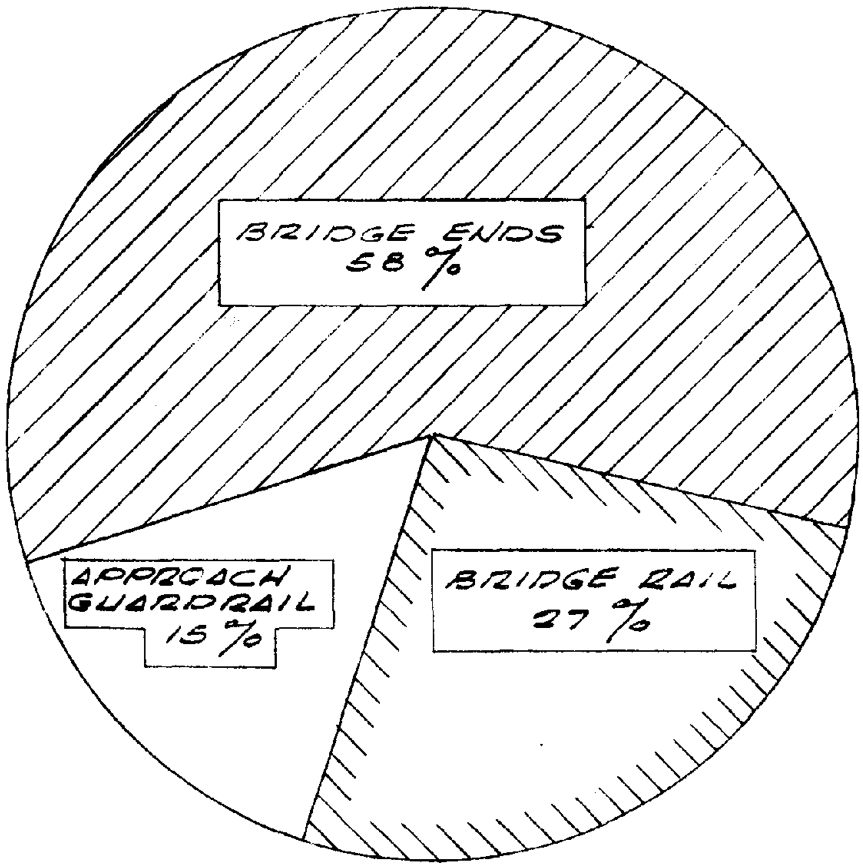


FIGURE 1. ANALYSIS OF 350 SINGLE VEHICLE FATAL ACCIDENTS INVOLVING BRIDGE RAILING

TABLE 1

CALIFORNIA FREEWAY FIXED OBJECT FATAL ACCIDENTS INVOLVING BRIDGE RAILING

	Period (year)										
	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974[c]	1975[c]
Bridge Rail	23	26	29	29	30	17	15	27	25	9	5
Bridge End Posts[a] @ Gore	3	10	5	3	5	6	2	8	5	6	3
Guardrail @ Fixed Objects[b] (39%)	14	16	14	11	13	7	9	13	16	12	5
Total Possible Bridge Rail	40	52	48	43	48	30	26	48	46	27	13
Travel (MVM) [d]	23,000	25,970	28,870	33,713	36,978	39,465	42,543	46,267	49,290	48,945	52,468
Freeway Miles Compl. @ End of Year [d]	1,788	2,059	2,386	2,603	2,736	3,012	3,194	3,427	3,576	3,673	3,727
Fatal Accident Rate per Bridge Rail (per 100 MVM)	0.17	0.20	0.17	0.13	0.13	0.08	0.06	0.10	0.09	0.06	0.02

(a) This item is actually not a bridge railing problem to be solved by a retrofit design but rather a head-on impact situation best handled by a crash cushion; it is included to permit comparison to NCHRP Report 86.

(b) Estimated to be 39 percent of the guardrail adjacent to fixed objects.

(c) Maximum speed limit was 55 mph (24.6 m/s).

(d) Multiply miles by 1.609 to obtain kilometers.

Representative bridge railing designs from the four categories were appraised as to conformance to current safety performance standards in order to determine specific needs of safety improvements. Modification concepts were formulated for upgrading the more predominant (as measured by installed mileage), deficient bridge railing systems.

The more promising concepts were selected for final design. Five retrofit designs were installed on typical installations and evaluated by vehicle crash tests. These five retrofit designs were judged suitable for carefully monitored in-service use.

II. BRIDGE RAILING MODIFICATION REQUIREMENTS

A. Current Inventory

Prior to 1965, the AASHTO specification provided only a broad bridge rail design load scheme, and the designers were given wide latitude in devising railing configurations. Consequently, the number of unique rail system installations designed during the earlier period are innumerable. Beginning with the 1965 AASHTO Specifications, four basic traffic railing and three combination traffic and pedestrian railing configurations were suggested, and although the designers were permitted latitude in specific geometries, the suggested shapes undoubtedly influenced a move toward uniformity. Subsequently, aluminum and steel producers began producing and promoting standardized railing components, especially rails. A further step toward standardization of bridge rail systems is the work of the AASHTO-ARBA Task 13 Committee, which published recommendations[4] in 1973 for standard bridge rail components. This movement toward standardization is too recent to have significant effect on reducing the large number of different bridge rail systems in service. Unfortunately, the large number of bridge rail systems in service complicates the development of a limited number of retrofit concepts that will suitably upgrade a majority of the bridge rail systems.

B. Bridge Rail Design

In conventional structural design, *structural strength* is the basic design criterion. Design loads are analytically imposed on a schematic of the structure, and the structural members are chosen so that the stresses will not exceed those allowable. Effective bridge rail systems could be designed in a similar manner if structural strength were the only criterion. However, *safety* of the occupants of impacting vehicles and other traffic is also a primary service requirement, and these two factors (i.e., structural strength and occupant safety), being interdependent, must be considered simultaneously in system design in order to achieve optimum bridge rail performance. For instance, it may be necessary to reduce the rigidity of a system in order to lessen the abruptness and severity of an impact, thereby improving safety.

Olson[1,5] and Viner[6] concluded that specifications of AASHTO (1965) or BPR (1962) were not sufficient to provide the design engineer with assurance of a bridge rail safety performance. Whereas the specifications may have been acceptable in sizing bridge rail members to sustain vehicle impacts, the problems of vaulting and snagging of the vehicle were not properly accommodated. (Full-scale vehicle testing of a barrier system is recognized in 1965, 1969 and 1973 AASHTO Specifications as an *alternate* to the analytical design approach; however, very few states have used the testing approach.) Based on their experience in developing new traffic barrier designs using both sophisticated computer simulation models as well as the simple static load design procedures of AASHTO specifications, the authors conclude that dynamic behavior of the barrier and vehicle during collision cannot be predicted with adequate assurance. Hence, full-scale dynamic testing, as recommended by Viner and Olson, to fully explore and demonstrate bridge railing safety performance is believed to be a necessary final step in the development of *every* bridge railing system.

Considerable progress is being made to upgrade performance of bridge railing design standards, and the resulting new designs are beginning to be introduced into the highway system. Moreover, approach guardrail and the proper transition between approach guardrail and bridge railing have been retrofitted to existing installations by several states, and this effort has reduced fatal accidents occurring at the end of bridge railings.[5] On the other hand, older bridge railing installations that do not perform satisfactorily according to today's standards remain in service. Two examples of bridge railing failure are illustrated in Figure 2.

C. Retrofit Service Requirements

In developing modification schemes, a proper perspective must be maintained with regard to service requirements. As with any traffic barrier, priority should be given first to safety performance, second to economics, and third to appearance.[7]

Safety performance of a modified bridge rail is directly related to its dynamic performance during vehicle collision. In particular, a bridge rail must restrain a selected vehicle. (The selected vehicle is one that is representative of a large majority of the vehicle population.) This implies that when a vehicle of specified weight, dimensions, velocity, and approach angle strikes a bridge rail system, it will not climb over, break through, or wedge under the installation. A barrier that is impacted by a selected vehicle must redirect the vehicle in such a manner that passengers restrained by seat belts can survive, preferably uninjured. A bridge rail system should redirect the selected vehicle in such a manner as to minimize hazard to following or adjacent traffic. Ideally, the vehicle should remain close to the barrier installation and not be directed back into the traffic stream. During impact, the barrier must function in such a fashion that vehicle occupants and other traffic are not likely to be endangered by vehicle or barrier fragments or barrier elements that could intrude into the passenger compartment or be deposited on the traveled way. Recommended properties of the selected vehicles and impact conditions are presented in NCHRP *Report 153*.[8]

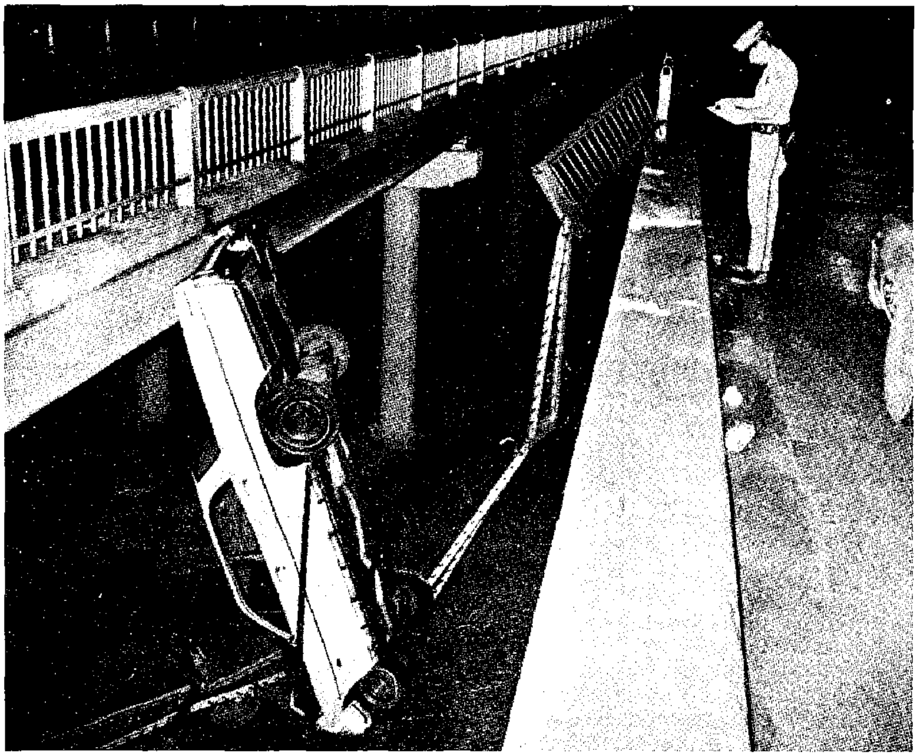
For cost considerations, the modification scheme should be economical in construction, installation, and maintenance. Incorporated in these costs is the general applicability of a scheme to upgrade a variety of different existing bridge rail systems. Design performance of bridge rail systems should minimize damage to impacting vehicles; this consideration includes not only the high-speed, high-angle impacts, but also the more frequent minor "brush" accidents.

Another consideration of a modification scheme is that it should be easily installed and amenable to quick repairs when damaged. Also, it should exhibit weather durability, i.e., against moisture, snow and ice, salt, sunlight, and temperature excursions. A final consideration is for the modification scheme to have a pleasing and functional appearance.

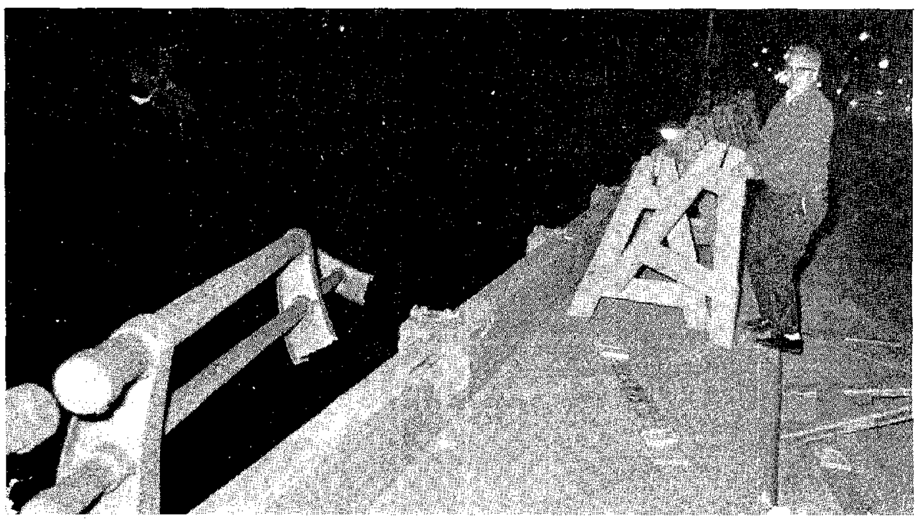
D. Retrofit Design Constraints

From review of bridge rail design drawings and interviews with bridge design engineers, the following constraints may be applicable to retrofit design in addition to the general bridge rail service requirements:

- A majority of bridges of interest are *narrow*. Although pavements and shoulders have been widened in recent years, highways have been left with narrow bridges because of the expense and technical difficulty required for their modification. Intense accident frequency rates at bridge ends have been attributed to both the minimum width aspect and the funnel effect of transitioning from a wide highway to a narrow bridge. Consequently, a large part of bridges that may be candidates for a retrofit bridge railing design cannot tolerate reduction of bridge deck width due to encroachment of a bridge railing concept. Accordingly, bridge railing retrofit designs should maintain present bridge deck widths.



(a) Panel type bridge rail failure



(b) Failure mode of metal rails/concrete parapet system

FIGURE 2. FATAL ACCIDENTS INVOLVING PRE-1965 BRIDGE RAILINGS

- Curbs and walks extending out from a bridge railing installation are only marginally effective in redirecting errant vehicles. Furthermore, vehicles impacting curbs are caused to jump and thereby may strike the backup structure in an unpredictable attitude. Current design standards have minimized use of curbs in front of longitudinal traffic barriers for this reason. In reviewing the drawings from the states and discussing with state highway personnel the possibility of removing curbs from existing bridges, it has become evident that the curbs are an integral part of the bridge structure in a number of designs and cannot be removed unless major redesign of the bridge is performed. Accordingly, retrofit concepts should accommodate the existing curb conditions.

- A majority of bridges of interest have short spans; hence, addition of bridge railing retrofit weight should have no effect on the load carrying capacity of the bridge. For longer span bridges, i.e., 100 feet (30.5 m) or longer, the retrofit weight may have to be considered.

III. EXISTING BRIDGE RAILING SYSTEMS

A. Survey of Bridge Railing Installations

A letter survey of 51 state highway agencies was performed in September, 1974. The purpose of the survey was to determine (a) the most predominant bridge railing systems that are currently in existence, (b) the type of approach guardrail in use, and (c) accident experience with the bridge railing designs.

A summary of the responses is presented in Table 2. A total of 44 state highway agencies responded, at least in part, to the questionnaire. Ten states submitted drawings of bridge railing systems that are in extensive use, whereas 27 states provided recent (1965 to 1971) standards; seven states provided only current (1972 or later) standards. Twenty agencies reported a total installed bridge railing length of 2,450 miles or about 15 to 20* percent of the estimated bridge railing in the U.S.; this is considered a significant and meaningful sample. Twenty-two agencies reported percentage of bridge railing that had approach guardrails. Apparently, accident statistics are not being maintained for the bridge railing systems; only nine states reported accident information with their designs, and even the reported information was inadequate to provide a basis for determining bridge railing design performance.

As with most surveys, the data base is incomplete. It is surmised that the data are slightly biased toward the more recent bridge railing designs. Although care should be exercised in analyzing and interpreting the findings, the reported mileage (2,450 miles) is significant and provides a sound base for estimating existing state-of-the-art bridge railing technology.

In Table 3, bridge railing designs collected from the 44 state agencies are grouped according to four SwRI-defined categories. Category I is characterized as having no curb or walk; generally, the railing is attached flush to the bridge deck or elevated on a low curb. Category II systems are comprised of a concrete parapet with no curb or walk; one to four rails may be attached to the top of the parapet. Category III systems feature a metal rail or concrete parapet set on a curb and walk; one to three rails may be installed on the parapet. This category may be further described as IIIN, where the walk is less than 2 ft (0.61 m) wide, and IIIW, where the walk is 2 ft (0.61 m) or more in width. The Category IV system uses a General Motors or New Jersey safety shape. These four categories were established with the intended goal that a bridge railing modification concept developed for any particular system in a category would be applicable to all other systems in that category with, at most, minor modifications.

A further analysis of bridge railing usage is presented in Table 4. Each of the four categories and subcategories are evaluated as to number of states using the general design and the reported installed mileage. The objective of this analysis was to identify the most predominant systems and categories in service so that development effort for retrofit designs could be appropriately directed. Category II has the top ranking for retrofit development consideration based on both number of states and installed mileage. Category III is ranked second based on installed mileage. The two categories represent more than 81 percent of reported installed length of bridge railing. Category I represents about 13 percent of reported installed length of bridge railing and is ranked third.

*FHWA (Office of Engineering, Bridge Div.) estimated in 1970 that there were 563,500 bridges in the U.S. with a combined length of from 6,400 to 7,700 miles; length of bridge railing is assumed twice the bridge length. About 50 percent of these bridges are on Federal Aid highway systems.

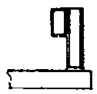
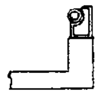
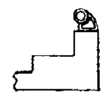
TABLE 2

GENERAL SURVEY RESPONSE

		Number of Highway Agencies
I.	Response	
	Surveyed	51
	Responded	44
II.	Predominate Bridge Railing Designs Reported	
	Existing Installations	10
	Recent Standards	27
	Current Standards	7
III.	Bridge Railing Mileage	
	Reported	20
	Unknown	24
IV.	Installed Approach Guardrail	
	Existing Percentage	22
	Unknown	22
V.	Accident Data Reported	
	Detailed	0
	Minimum	9
	None	35

TABLE 3

BRIDGE RAILING CATEGORIES BY STATE

STATE	CATEGORY I (No Curb or Walk)			CATEGORY II (Parapet But No Curb)					CATEGORY III (Parapet and Curb)				CATEGORY IV (Safety Shape)	
														
	1 Rail	2 Rails	3 Rails	No Rail	1 Rail	2 Rails	3 Rails	4 Rails	No Rail	1 Rail	2 Rails	3 Rails	No Rail	Rail or Rails
Alabama														
Alaska	(S)	(S)												
Arizona														
Arkansas										125(S/A)	89(A)		5(C)	
California					450(S)				75(C)	250(C)				
Colorado					15.7(S)	(S)			(C)	(S)				
Connecticut										7 (S/A)	64(S)			
Delaware										A	(A)		(C)	
District of Columbia		(S)									(S)		(C)	
Florida					(C)								(C)	
Georgia														
Hawaii										(A)	(A)	(A)	(C)	
Idaho						1(A)	0.5(A)						5(C)	
Illinois	15.1(S)				31.8(A)	14(S)					0.7(A)		(C)	
Indiana						(A)	(A)							
Iowa						11.3(A)								
Kansas					(S/A)				(C)					
Kentucky					(A)	(A)							(C)	
Louisiana	(S)				(C)								(C)	
Maine		(A)	(A)											
Maryland														
Massachusetts														
Michigan		85.3(S)			107.7									53.4(A)
Minnesota				1(C)	45(C)						1(S)			5(S)
Mississippi					(C)	(C)							(C)	
Missouri					105(A/S)				23(C)	70(A)	35(S)			
Montana						12(S)				30(S)				
Nebraska	(S)				(S)								(C)	
Nevada		0.6 (S)			11.29 (S)	3.26 (S)								
New Hampshire		21.5(S/A)					7.8(A)							
New Jersey					(A)						(A)			
New Mexico		(S)	(S)				(S)							
New York					34(A)		4.6(A)	9.3(S)			100(S)			
North Carolina					(A)	(A)	(A)						(C)	
North Dakota					(A)	(A)								
Ohio	(S)										(A)		(C)	
Oklahoma														
Oregon			7(S/A)			8(S/A)							15(C)	
Pennsylvania													(C)	(S/A)
Rhode Island														
South Carolina										(C/A)	(A)			(A)
South Dakota					(S)	(S)								
Tennessee														
Texas	118.7(S)				54.6									
Utah				(C)										
Vermont					0.9(S)	8.7(S/A)	7.5(A)							
Virginia														40(A)
Washington									25(C)	25(A)				
West Virginia						(S/A)								(S/A)
Wisconsin										108.8(S/A)	24.8(S/A)			
Wyoming		80 (S)												
States Reported Use														
Steel	6	7	2	-	8	7	1	1	-	5	6	-	-	3
Aluminum		2	2	-	9	9	6	-	-	7	8	1	-	5
Concrete				2	4	1	-	-	5	2	-	-	15	-
Total	6	8	3	2	20	15	7	1	5	10	13	1	15	6
Reported Mileage	133.8	187.40	7	1	930.39	58.26	20.4	9.3	123.0	545.8	314.5	-	25	98.4

Notes: S, A, C denote steel, aluminum or concrete rail element; numbers denote mileage reported.

Metric Conversion: Multiply miles by 1.609 to obtain kilometers.

TABLE 4

ANALYSIS OF BRIDGE RAILING USAGE

Bridge Railing Category/System	Systems/Categories Used By States							
	System				Category			
	Number of States	Ranking (Number)	Installed Mileage*	Ranking (Mileage)	Number of States	Ranking (Number)	Installed Mileage*	Ranking (Mileage)
Category I (No Curb or Walk)								
A. One Rail	6	7	133.8	6				
B. Two Rails	8	5	187.4	5	14	4	328.2	3
C. Three Rails	3	9	7.0	12				
Category II (Parapet, No Curb)								
A. No Rail	2	10	1.0	13				
B. One Rail	20	1	930.4	1				
C. Two Rails	15	2	58.3	4	29	1	1019.4	1
D. Three Rails	7	6	20.4	10				
E. Four Rails	1	11	9.3	11				
Category III (Curb and Walk)								
A. No Rail	5	8	123.0	7				
B. One Rail	10	4	545.8	2	18	3	983.3	2
C. Two Rails	13	3	313.5	3				
D. Three Rails	1	11	-	14				
Category IV (Safety Shape)								
A. No Rail	15	2	25.0	9	20	2	123.4	4
B. Rail	6	7	98.4	8				
						Total:	2454.3	

*Multiply miles by 1.609 to obtain kilometers.

Category IV is the safety shape and is one of the newer designs; based on current information, collision performance of this design has been satisfactory and hence should not entail safety performance upgrading. However, a suitable transition from an approach guardrail other than a safety shape is required.

B. Analysis of Existing Bridge Railing Designs

1. Conformance to AASHTO Specifications.

From information assembled in the survey of state highway agencies, fourteen representative bridge rail designs, with reported length of 1655.6 miles, were evaluated with respect to (a) their conformance to the 1973 AASHTO Bridge Specifications and (b) their predicted (or observed) performance during vehicle crash tests. It is recognized that all of the systems were designed prior to the adoption of the 1973 Specifications and, hence, one should not expect conformance. However, the 1973 Specifications are used as a current safety performance reference. Dynamic (safety) performance of a bridge rail installation is a most complex phenomenon, and at present the authors believe the only effective method of *assuring* acceptable performance is by means of full-scale crash tests. Improvement in bridge rail designs has been achieved through changes in the AASHTO Bridge Specifications in recent years. However, it is believed that conformance with even the latest (1973) AASHTO Bridge Specification does not necessarily *assure* proper dynamic performance of a system. Accordingly, full-scale crash testing is recommended for every design.

Table 5 summarizes findings of the evaluation of 14 typical bridge rail systems. Selection of the examples was based on those systems with 35 or more installation miles and with sufficient design information. The combined mileage of the 14 examples is 67 percent (1,655.6 out of 2,454.3 miles) of all that was reported in the survey. Examples were selected from all categories with exception of Category IV. In Section I of Table 5, each railing is appraised according to conformance with the 1973 AASHTO Bridge Specifications. In Section II, the railing design is appraised as to its probable dynamic performance. Full-scale vehicle crash test results are available for SwRI Cases 1, 5, 9, and 14; for other cases, a subjective judgment was made by the authors. An overall appraisal is presented in Section III and is made in reference to available technology.

A further summary of the 14 cases is presented in Table 6 with respect to conformance with the 1973 AASHTO Bridge Specifications.*

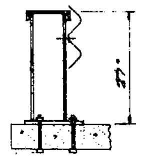
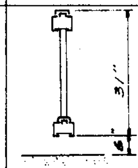
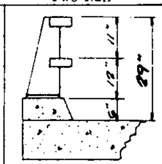
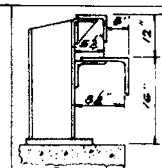
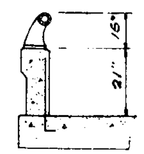
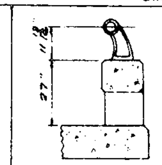
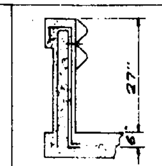
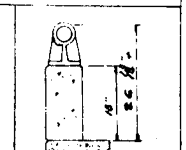
- Only one system conforms.
- One system is considered marginal.
- Twelve out of the 14 designs do not conform with one or more provisions of the specifications.

On the basis of mileage, 68 percent of the installations analyzed did not conform, and another 27 percent of the installations were determined to be marginal.

*Does not take into consideration vehicle redirection performance.

TABLE 5

ANALYSIS OF TYPICAL BRIDGE RAIL SYSTEMS

Bridge Railing Classification		Category I (No Curb, Parapet or Walk)				Category II (Parapet But No Curb)			
		One Rail	Two Rail			One Rail			
Sketch									
SwRI Case Number Date of Drawing/Latest Revision Reported Mileage		1 1972/- 118.7	2 1940/1960 85.3	3 -/1971 80	4 21.5	5 1968/- 450	6 1961/1972 107.7	7 -/1972 54.6	8 105
I. Conformance with AASHTO 1973 Bridge Specifications*	Applicable AASHTO Paragraph Number								
A. Geometry									
1. Curb									
(a) width	1.1.8	●	-	-	-	-	-	-	-
(b) height	1.1.8	●	-	-	-	-	-	-	-
2. Rail Position									
(a) top rail	1.1.9A	●	●	●	X	●	●	●	X
(b) spacing	1.1.9A	●	X	●	●	●	●	●	●
B. Railing Features									
1. Continuity of Face	1.1.9A	●	X	●	●	O	X	●	●
2. Post Set Back	1.1.9A	O	X	●	●	●	●	●	●
3. Structural Continuity	1.1.9A	●	O	●	●	O	●	●	●
4. Anchorage	1.1.9A	●	O	●	●	●	●	●	O
5. Joints	1.1.9A	●	●	●	●	●	●	●	●
C. Mechanical Properties									
1. Materials									
(a) rail	1.1.9A	●	●	●	●	●	●	●	●
(b) post	1.2.11C(3)	●	●	●	●	●	●	●	●
(c) parapet	1.2.11C(3)	●				●	●	●	●
2. Stresses									
(a) rail	1.2.11C(1)	X	X	●	X	●	●	-	X
(b) post	1.2.11C(1)	●	●	●	●	●	●	-	X
(c) parapet	1.2.11C(1)	-	-	-	-	●	●	X	●
(d) anchor bolts	1.2.11C(1)	●	X	●	●	●	●	-	●
D. Evaluation		X	X	●	X	O	X	X	X
II. Vehicle Redirection**									
A. Containment		O	O	●	O	●	O	●	O
B. Severity									
1. Occupant Hazard		O	X	●	X	O	O	O	O
2. Traffic Involvement		●	X	●	O	●	O	O	●
C. Railing Damage		O	X	O	O	●	O	●	O
D. Vehicle Damage		O	X	O	●	●	O	O	●
III. Overall Appraisal***		P	P	G	P	F	P	P	P
Total Mileage Reported By All States		133.8		165.9			824.5		
Total of States Reporting Use of Similar System		6		7			19		

*● - Conforming
O - Marginal
X - Nonconforming
- - Not Applicable

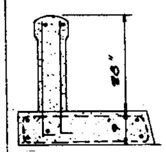
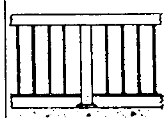
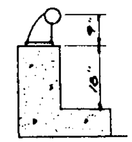
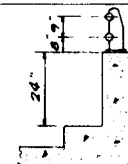
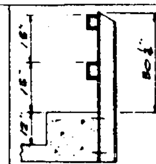
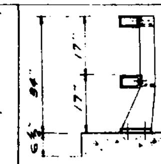
n/a - Not Available

**Subjective Evaluation
***G - Good
F - Fair
P - Poor

Metric Conversion:
Multiply inches by 0.0254 to obtain meters.
Multiply miles by 1.609 to obtain kilometers.

TABLE 5 (Cont'd)

ANALYSIS OF TYPICAL BRIDGE RAIL SYSTEMS

Bridge Railing Classification		Category III (Parapet and Curb)					
		No Rail	One Rail		Two Rail		
Sketch							
SwRI Case Number Date of Drawing/Latest Revision Reported Mileage		9 75	10 1965/- 250	11 -/1971 108.8	12 1963/- 64	13 1964/- 35	14 1973/- 100
I. Conformance with AASHTO 1973 Bridge Specifications*	Applicable AASHTO Paragraph Number						
A. Geometry							
1. Curb							
(a) width	1.1.8	●	n/a	●	●	n/a	-
(b) height	1.1.8	●	n/a	●	n/a	X	-
2. Rail Position							
(a) top rail	1.1.9A	●	●	●	●	●	●
(b) spacing	1.1.9A	●	X	●	●	●	●
B. Railing Features							
1. Continuity of Face	1.1.9A	●	O	O	●	●	●
2. Post Set Back	1.1.9A	O	O	●	●	O	●
3. Structural Continuity	1.1.9A	●	X	●	●	●	●
4. Anchorage	1.1.9A	●	●	●	●	X	●
5. Joints	1.1.9A	●	●	●	●	●	●
C. Mechanical Properties							
1. Materials							
(a) rail	1.1.9A	-	n/a	●	●	●	●
(b) post	1.2.11C(3)	-	n/a	●	●	●	●
(c) parapet	1.2.11C(3)	●	-	●	n/a	●	-
2. Stresses							
(a) rail	1.2.11C(1)	-	X	X	X	X	X
(b) post	1.2.11C(1)	-	X	●	O	●	X
(c) parapet	1.2.11C(1)	X	-	●	●	-	-
(d) anchor bolts	1.2.11C(1)	-	-	●	●	X	●
D. Evaluation		X	X	X	X	X	X
II. Vehicle Redirection**							
A. Containment		X	X	O	O	O	●
B. Severity							
1. Occupant Hazard		X	X	O	O	O	●
2. Traffic Involvement		X	O	O	O	O	●
C. Railing Damage		X	X	O	O	O	●
D. Vehicle Damage		X	X	O	O	O	●
III. Overall Appraisal***		P	P	P	P	P	F
Total Mileage Reported By All States		123	650.8		314.5		
Total of States Reporting Use of Similar System		5	12		13		

*● - Conforming
O - Marginal
X - Nonconforming
- - Not Applicable

n/a - Not Available

**Subjective Evaluation
***G - Good
F - Fair
P - Poor

Metric Conversion:
Multiply inches by 0.0254 to obtain meters.
Multiply miles by 1.609 to obtain kilometers.

TABLE 6

SUMMARY OF BRIDGE RAILING EVALUATION

Categories	Example Installations				Reported Installed Miles			
Category I								
Conforming	1				80.0			
Marginal		0				0		
Nonconforming			3				225.5	
Subtotal				4				305.5
Category II								
Conforming	0				0			
Marginal		1				450.0		
Nonconforming			3				267.3	
Subtotal				4				717.3
Category III								
Conforming	0				0			
Marginal		0				0		
Nonconforming			6				632.8	
Subtotal				6				632.8
Total	1	1	12	14	80.0	450.0	1,125.6	1,655.6

Metric Conversion:
Multiply miles by 1.609 to obtain kilometers.

2. Computer Simulation Studies.

Zobel[9] theoretically investigated redirective performance of curbs and curb/guardrail combinations and concluded that properly designed curbs can redirect a large percentage (27 percent) of vehicles accidentally leaving the road. Moreover, Zobel concluded that there was no evidence of vaulting over a guardrail that was set behind a curb; however, a recommendation was made to adjust the height of a guardrail based on setback distance. Two aspects of the vehicle-curb interaction not discussed by Zobel were (1) influence of curb on redirection severity and (2) hazard of vehicle striking end of a curb.

Deleys[10] stated:

> "The idea that the redirection effectiveness of curbs justifies their use as a means for increasing the level of safety of traversal on moderate- and high-speed urban expressways is controversial. The fact that curbs represent a continuous roadside vertical discontinuity which can easily be struck with a consequent high potential for producing loss of control, vehicle damage or a reduction of the effectiveness of more positive safety barriers must be weighed against their limited ability to contain vehicles on the roadway. Furthermore, their functions of serving to delineate the edge of the road and to aid drainage control could probably be provided with greater safety and at lesser cost by use of small reflectorized markers and gutter type drainage systems."

Moreover, Deleys stated that the practice of using a curb in conjunction with a safety barrier should be avoided whenever possible.

From data collected from state highway agencies, it is found that approximately 32 percent of existing bridge railing systems incorporate a barrier curb. These curbs vary in height, width, and batter. To examine the effect of a curb in combination with a safety barrier and parapet on vehicle redirection severity, a series of computer simulations was performed using the HVOSM (Texas Transportation Institute modified version of V-3). HVOSM is an 11 degree-of-freedom representation of a passenger vehicle developed over a period of years by Calspan.[10] It is recognized that the program is limited in projecting accurate vehicle dynamics for certain interactions. Zobel[9] et al, stated:

> "The actual mechanics of curb mounting, e.g., the tire sidewall/curb face friction interactions, are not well represented [by HVOSM]. The tire is represented as a thin disc with springs emanating radially outward from its center. Friction forces on the sidewall are not calculated, since the program was not developed for that purpose. Situations where the tire strikes the curb at a high enough angle and where scrubbing is not a factor are well simulated, however. This kind of situation (i.e., where the impact angle is 10 deg or more) is the type which was examined in these exercises."

A number of HVOSM cases were performed to examine curb height and batter and walk width. Findings from this effort are presented in Appendix C. The reader should exercise caution in appraising these findings as the HVOSM program has not been verified by experimentation for these conditions. Moreover, the predicted vehicle behavior is most sensitive to input parameters that must be estimated, that range widely between vehicles, and that change during the vehicle life (i.e., suspension, deterioration).

The findings indicate that the curb is not an effective barrier and can easily be mounted at moderate speeds and angles. The curb and walk, besides introducing high accelerations and causing severe damage to the vehicle undercarriage, cause the vehicle to pitch upward and strike the parapet or rail in an unstable attitude.

A comparison of vehicle behavior, when impacting a vertical wall and General Motors safety shape, indicates that:

- The vehicle has a lower change in speeds during contact with the GM safety shape.
- Less friction work is expended with the GM safety shape.
- Vehicle exit angle for the GM shape is about 50 percent of the values predicted for the vertical wall.

These findings confirm the fact that the GM or NJ shapes are safer barriers than a vertical wall, even though the three barriers satisfy AASHTO specifications.

C. Approach Guardrail/Transition

Historically, traffic barriers have been designed and specified by at least two highway groups: bridge departments have designed bridge rails, and roadway design departments have had responsibility for shoulder guardrails. This compartmentalization of responsibilities has resulted in many cases with discontinuity or incompatibility of barrier structures at the interface. The hazard of the exposed bridge rail ends was not recognized by AASHTO Bridge Specifications until 1965. In Section 1.1.9 (Railings), the designer was alerted to the newly revealed hazard:

> "Careful attention should be given to the treatment of railing at the bridge ends. Exposed rail ends and sharp changes in the geometry of the railing should be avoided."

In the subsequent (1969) AASHTO Specifications, the following sentence was added:

> "A smooth transition by means of a continuation of the bridge barrier, guard rail anchored to the bridge end, or other effective means shall be provided to protect the traffic from direct collision with the bridge rail ends."

Hence, it is seen that highway engineers have been given a minimum of guidance for approach guardrail design, and these guidelines have been established only in recent years.

In surveying state highway departments for existing installations, it is evident that there are numerous approach guardrail designs. In recent years there has been a concerted effort by federal and many state highway agencies to upgrade the designs. A summary of current state *design* practice is shown in Table 7; unfortunately, this practice has been utilized only in the past few years and mostly on new construction. Older installations are categorized by the following features:

- Bridge without approach guardrails; the ends of bridge railing are exposed to traffic.
- Approach guardrail design inadequate; basic system will not safely redirect impacting vehicle.
- Approach guardrail terminals hazardous; blunt ends will spear and ramped ends will upset impacting vehicles.
- Improper layout of approach guardrail; horizontal flares, topography of vehicle approach, proximity of curbs and dikes were not properly considered.

TABLE 7

SUMMARY OF STATE PRACTICE*

W-BEAM APPROACH TO CONCRETE BRIDGE PARAPET

Item	% of States (Based on 35 states)
1. Rail bolted to parapet	100
2. Metal spacer used	6
3. Transition post spacing	
6 @ 3'-1-1/2"	31
4 @ 3'-1-1/2"	14
8 @ 3'-1-1/2"	11
All others	44
4. Transition post	
W6x8.5	32
8x8 wood	20
6x8 wood	17
10x10 wood	12
W6x15.5	7
All others	12
5. Special features	
Rub rail used in approach	9
Special offsets from parapet used	11
Transition posts set in concrete footings	3

*Current design practice and does not represent actual installations.

Metric Conversions:
Multiply inches by 25.4 to obtain millimeters
Multiply feet by 0.305 to obtain meters

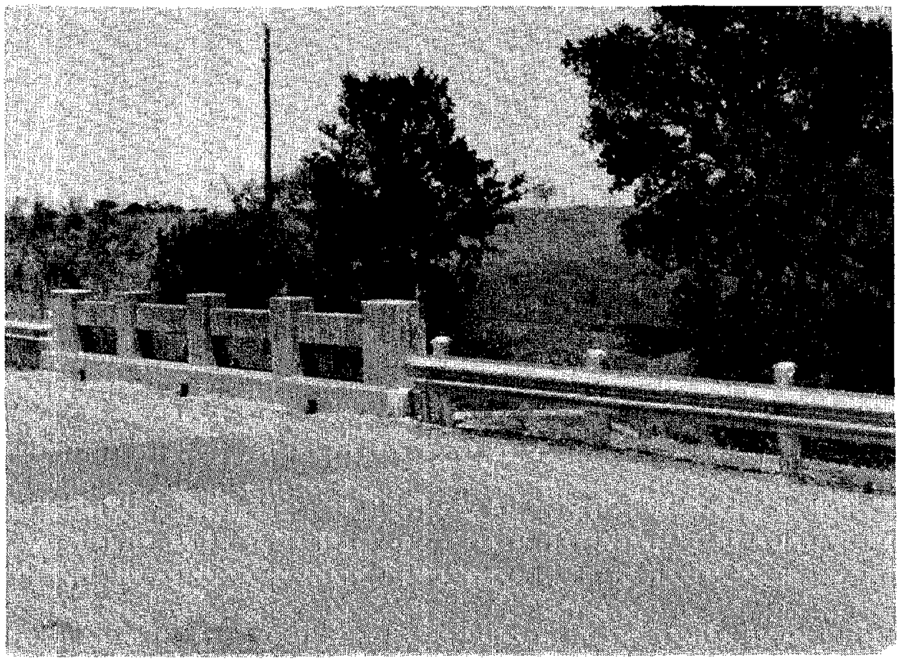
- Connection between approach and bridge rails inadequate; the joint lacks tensile strength and/or a gradual lateral stiffness transition property.

There are numerous unique approach guardrail designs presently in service, and only a limited number of these have been evaluated for safety performance. However, accident experience has clearly indicated deficient performance. Two examples are shown in Figure 3. In Figure 3a, the approach guardrail is mounted directly to the posts without offset; there is no transition of lateral stiffness (i.e., decreasing post spacing toward the bridge); and the rail is not connected to the bridge railing. In Figure 3b, some improvement is noted as the rail is attached to the concrete end structure, and post spacing is appropriately varied; however, this design lacks acceptable performance for a large portion of highway traffic. Two fatal accidents occurred at bridge ends as shown in Figures 4 and 5. The approach rail was mounted to a post *behind* the end structure in Figure 5; excessive lateral deformation of the unattached beam caused the vehicle to pocket and spin out.

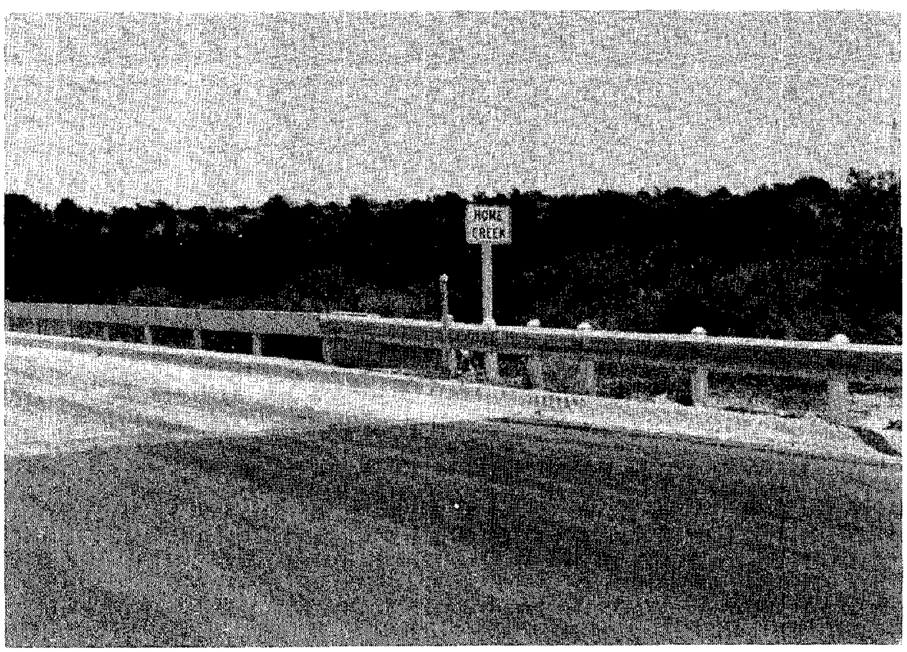
In recent years, there has been a strong movement in the state highway departments to standardize on usage of a few well-proven barrier systems. These barrier systems were first recognized in NCHRP *Report 54* and later revised in NCHRP *Report 118*. Whereas other designs may perform in a safe manner, a decision was made to limit the scope of the program to four approach guardrail designs: G2, G3, G4S/W and MB5/6.

In 1971, NCHRP *Report 118* presented the latest traffic barrier technology. Included in this document are recommended approach guardrail systems with suggested layouts, terminals, and connections to bridges. However, recent innovations in traffic barrier technology have outdated considerable material that was presented. For instance, the BCT (Breakaway Cable Terminal)[(11)] is an improvement over the ramped end or anchored upright end; the thrie beam appears to have a greater performance range as compared to the standard W-beam;[(12)] and new bridge railing systems such as the collapsing ring concept have been developed.[(13)] These improved elements can be easily combined into a generally applicable barrier system.

The critical point of the approach guardrail-bridge rail transition is the connection. From the survey of states, the most predominant bridge railing is the concrete parapet with and without a walk. Presently, the standard W-beam is hard mounted to the concrete parapet by means of a Michigan end shoe. Whereas sufficient tensile force in the W-beam is developed, and reduced post spacing in proximity of the bridge end stiffens the approach guardrail, greatly reducing vehicle pocketing tendency, redirection of a vehicle impacting at the connection may be severe. A connection with energy absorbing capacity might lessen the severity of the vehicle redirection although specific needs of such a device have not been identified.



(a) Unattached



(b) Attached

FIGURE 3. EXISTING APPROACH GUARDRAIL INSTALLATIONS (1974)

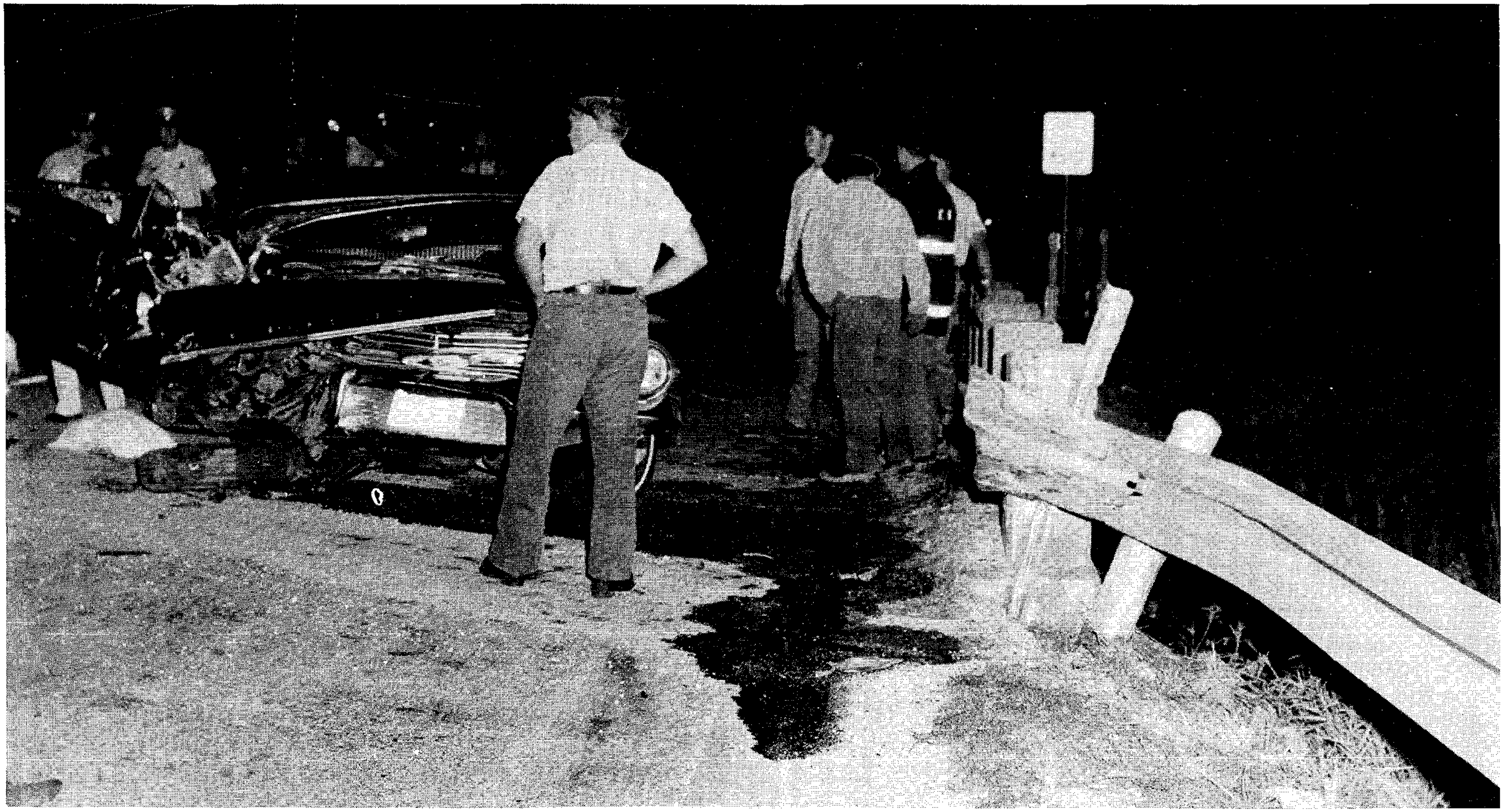


FIGURE 4. FATAL ACCIDENT RESULTING FROM VEHICLE POCKETING AT GUARDRAIL/BRIDGE RAIL TRANSITION

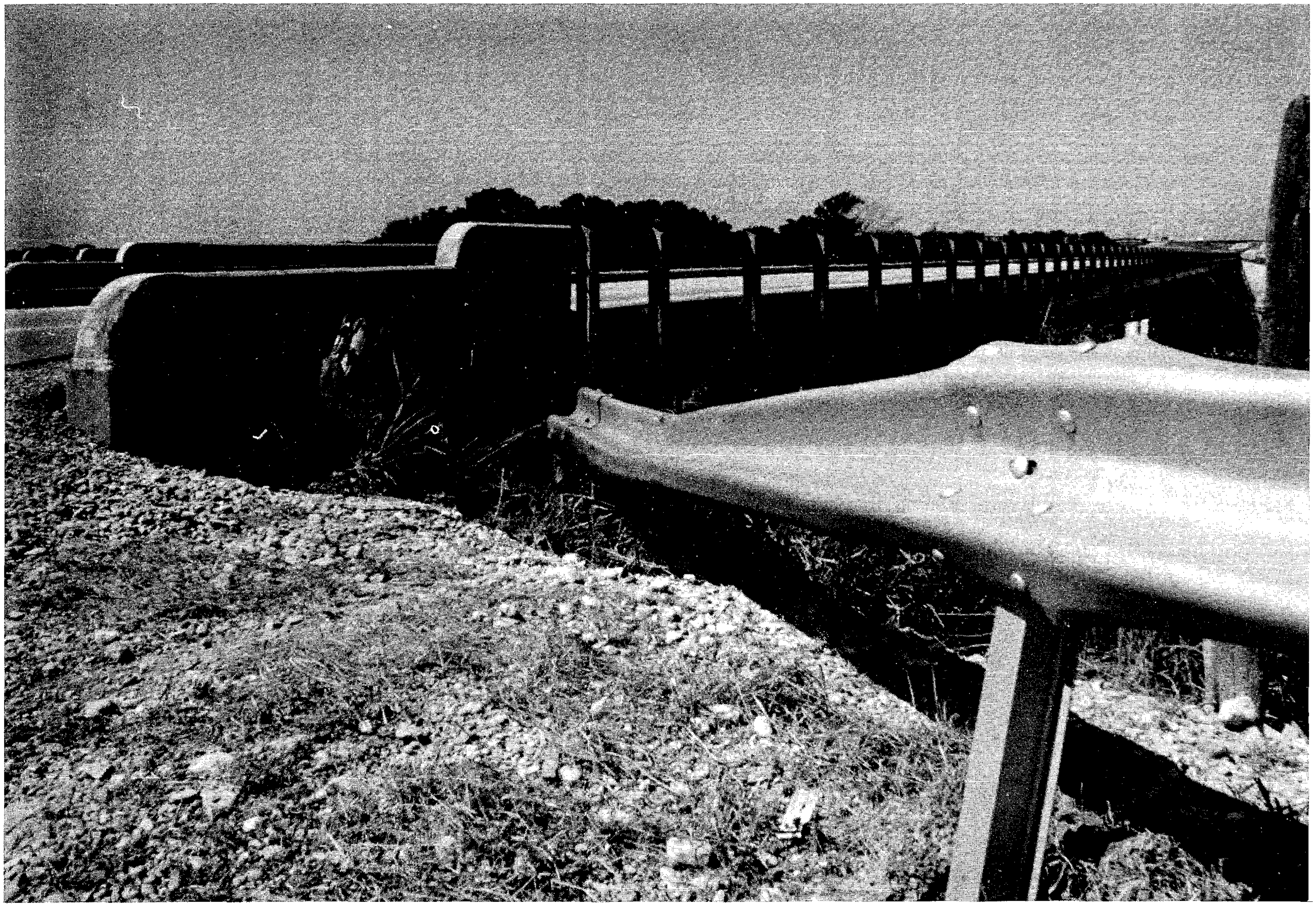


FIGURE 5. FATAL ACCIDENT RESULTING FROM APPROACH GUARDRAIL MOUNTED BEHIND BRIDGE STRUCTURE

IV. DESIGN AND EVALUATION OF RETROFIT MODIFICATIONS

Existing bridge railing designs, regardless of their safety performance capability, can be placed in one of four categories which are illustrated and described in Figure 6. The definitions of these four SwRI categories are based on bridge railing *profile geometry* and were specifically delineated so that all bridge railings within a category that are determined to lack adequate safety performance capability are amenable to a common retrofit modification. The fact that a specific bridge railing is exactly or only remotely similar to one of the four categories is not intended to imply its level of safety performance. The purpose of the four categories is to reduce the number of retrofit modification designs whereby a retrofit design developed for one category is applicable to all bridge railings in that category.

In developing retrofit modifications for the four categories, a majority of program effort was directed to Category II and Category III for the following reasons:

- Category I represents less than 14 percent by mileage of existing bridge railing installations; moreover, it is considered that these designs can be upgraded by simple procedures such as a rail replacement or may be economically replaced by a conforming design. (While least prevalent, some Category I barriers may be the most hazardous and may warrant high priority for upgrading where exposure is high.)

- About 82 percent of existing bridge railing installations are either Category II (42 percent) or Category III (40 percent).

- Category IV represents less than 6 percent of existing bridge railing installations; more important, most Category IV designs will satisfy 1973 AASHTO requirements and perform satisfactorily during vehicle crash tests.

In this program, *bridge railing system* includes (1) approach guardrail and terminal, (2) bridge railing, and (3) transition from approach guardrail to the bridge railing; it is important for safety collision performance for these elements to behave in an integral manner. Hence, the full extent of a bridge railing system should be considered during the design phase. In this program, research emphasis was directed to the bridge railing and transition elements, and less consideration was given to the approach guardrail and terminal. The transition elements in the retrofit designs do include a portion of the approach guardrail, but no upstream guardrail terminals were evaluated in the test phase. Suitable terminals have been developed and evaluated in other programs.[11]

A. Category I Retrofit Designs

Characteristics of a Category I bridge railing are a metal rail and metal posts mounted flush to a bridge deck. A curb or walk, if present, does not project more than 6 inches (0.15 m) above the bridge deck In cases where the curb and/or walk is more than 6 inches (0.15 m), the installation would be considered a Category II or Category III design.

It is possible that upon analyzing an existing bridge railing installation, the engineer will identify a simple and economical modification that will bring the installation into conformance with current AASHTO specifications. This may entail the addition or replacement of a rail member, the strengthening of connections, or the providing of continuity throughout the installations. This approach should be investigated for all Category I installations to provide a reference cost.

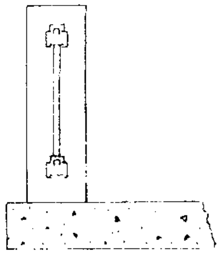
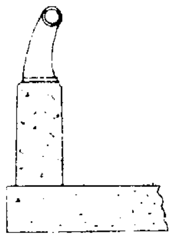
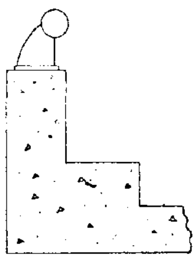
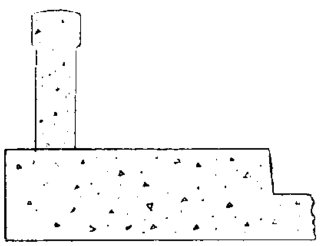
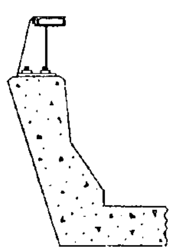
CATEGORY I 	Characteristics of a Category I bridge railing are a metal rail and metal posts mounted flush to a bridge deck. A curb and/or walk, if present, does not project more than 6 in. (0. 15m) above the bridge deck. In cases where the curb and/or walk is more than 6 in. (0. 15m) the installation would be a Category II or III design.
CATEGORY II 	Characteristics of a Category II bridge railing are a concrete baluster rail or a concrete parapet with up to four metal rails. The installation has no curb or walk that projects into the traffic lane beyond the face of the rail.
CATEGORY IIIN 	Characteristics of a Category IIIN bridge railing are the concrete parapet with a walk and curb; one to three metal rails may be attached to the top of the parapet. To further delineate this category, only walks with a width less than 2 ft (0. 61m) are considered narrow.
CATEGORY IIIW 	Characteristics of a Category IIIW bridge railing are the concrete parapet with a walk and curb; one to three metal rails may be attached to the top of the parapet. To further delineate this category, only walks with a width of 2 ft (0. 61m) or more are considered wide
CATEGORY IV 	Characteristics of a Category IV bridge railing are the concrete safety shape with or without one to two metal rails. A number of barrier shapes are classified as a safety shape. Findings have adopted the New Jersey (MB5) or General Motors (MB6) shapes or a modification of one of these.

FIGURE 6. SwRI CATEGORIES FOR EXISTING BRIDGE RAILING CLASSIFICATION

Several candidate bridge railing designs are shown in Table 8; this group is not intended to be exclusive. These systems were designed and evaluated in other programs, and the specific design details can be found in the cited references.

B. Category II Retrofit Design

Characteristics of a Category II bridge railing are a concrete baluster rail or a concrete parapet with up to four metal rails. The installation has no curb or walk that projects into the traffic lane beyond the face of the rail.

A representative Category II bridge railing design is shown in Figure 7. The design, a current state standard, conforms with the 1969 AASHTO Specifications but does not conform to the 1973 AASHTO Specification provision that requires the rail to be centered between 15 and 20 in. (0.38 to 0.51 m).

1. System R(II)-1 Features

Primary element of the R(II)-1 design is a new beam rail element known as the tubular thrie beam. It is fabricated by welding two thrie (or triple corrugated) beams together as shown in Figure 8. The beam is joined to and blocked out from the concrete baluster rail by 6-in. (0.15 m) dia collapsing tubes spaced at 8.33 ft (2.5 m); no attempt was made to space the tube supports to the concrete post in the test installation. Dimensions of the 6-in. (0.15 m) dia, 0.125-in. (3.2 mm) thick by 22-in. (0.56 m) long tubes were established by the equation

$$\text{Dynamic Tube Energy Absorbed} = 4.8\, \sigma_0\, Lt^2 \qquad (1)$$

that was empirically established from another FHWA program.[17] In this equation a design energy of 60,000 in.-lbs (6,780 joule) [10,000-lb (4536 kg) crush force × 6-in. (0.15 m) stroke] was used with a static initial yield stress (σ_0) of 36,000 psi (2.48 × 10^8 Pa) and tube length (L) of 22 in. (0.56 m); required tube thickness t (in.) was determined. Equation (1) is independent of tube diameter with the condition that the tube is fully collapsed during the dynamic loading.

The tubular thrie beam was extended 8.33 ft (2.5 m) upstream from the bridge end and transitioned to a single thrie beam. As shown in Figure 9, the approach railing was structurally anchored but did not have an acceptable terminal as the terminal evaluation was beyond the program scope. Engineering drawings of the installation are contained in Appendix A.

Principal attributes of the retrofit design are the following:

- The 20-in. (0.51 m) wide tubular thrie section provides a large contact area with the impacting vehicle, thereby assuring probable contact with the vehicle hard points and minimizing knifing of the beam into the car structure and snagging potential. Also, mounting height for optimum contact with a range of vehicles is less critical.

- The collapsing tubes and relatively stiff beam reduce the intensity and distribute impact forces over an increased length of existing bridge railing, thereby permitting upgrading of otherwise understrength installations.

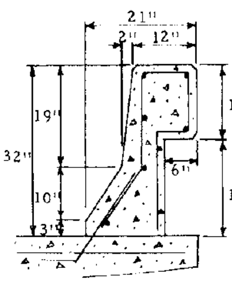
- The design is somewhat flexible in its adaptation to existing installations.

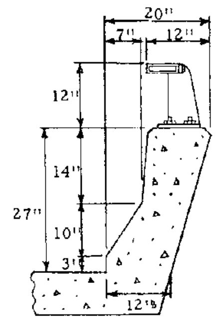
TABLE 8

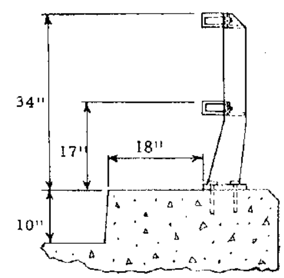
REPLACEMENT CANDIDATES FOR CATEGORY I INSTALLATIONS

Metric Conversions:

1 ft = 0.305 m
1 in. = 25.4 mm
1 mph = 0.447 m/s
1 lb = 0.454 kg







System	BR1		BR2		BR3	
Barrier Description Post Spacing Post Type Beam Type Offset Brackets Mountings Footings	Continuously poured, reinforced, sloped face concrete section. Shape of system similar to MB5. Barrier anchored to bridge deck with appropriate reinforcing steel.		6" x 2" x 12.02 lb/ft steel rail mounted on a reinforced, sloped face concrete section similar to MB5 shape. Barrier anchored to bridge deck with appropriate reinforcing steel.		8' 9" Fabricated steel Two TS 5"x3"x1/4" steel None UNAV Bridge deck	
Impact Performance	Impact Angle = 15°	Impact Angle = 25°	Impact Angle = 15°	Impact Angle = 25°	Impact Angle = 15°	Impact Angle = 25°
Impact Conditions Speed (mph) Vehicle Weight (lb)	No test (see remarks below)	No test (see remarks below)	64.0 4900	66.0 4900	No test	55.0 3500
Barrier Dynamic Deflection (ft)			0	0		0
Vehicle Accelerations (G's)[1] Lateral Longitudinal Total			4.8 <1.0 UNAV	9.1 14.8 UNAV		UNAV UNAV 12.3
Vehicle Trajectory Exit Angle (deg) Roll Angle (deg) Pitch Angle (deg)			10 UNAV UNAV	3 UNAV UNAV		1 ≃0 ≃0
Barrier Damage			Negligible	Slight		Slight
References			14	14		15
Remarks	Safety aspects of barrier shape have been evaluated by full scale crash tests. Structural adequacy has not been evaluated by crash tests.		California Highway Department bridge rail Type 20.		Tested with 10" curb. Curb severely damaged the steering. Subsequent studies have shown that curb should not be used.	

UNAV - unavailable

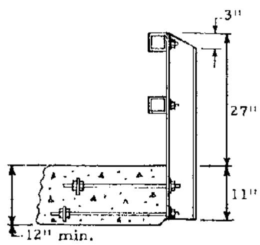
[1]50 millisecond average unless otherwise noted

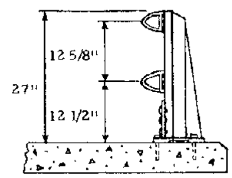
TABLE 8 (Cont'd)

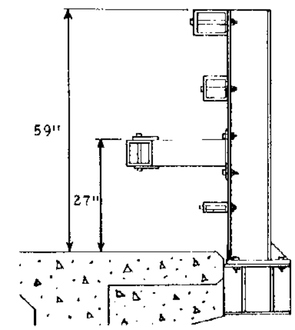
REPLACEMENT CANDIDATES FOR CATEGORY I INSTALLATIONS

Metric Conversions:

1 ft = 0.305 m
1 in. = 25.4 mm
1 mph = 0.447 m/s
1 lb = 0.454 kg

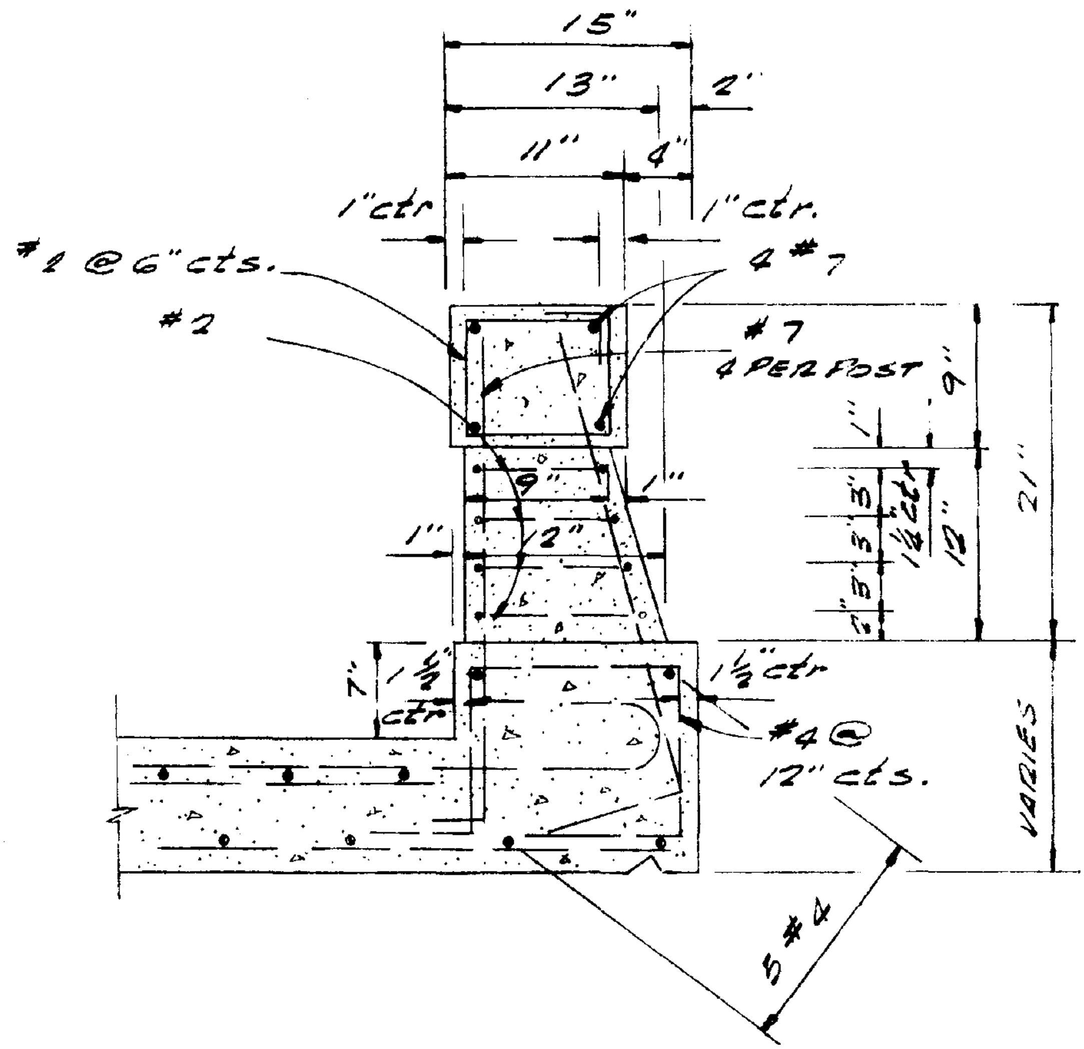






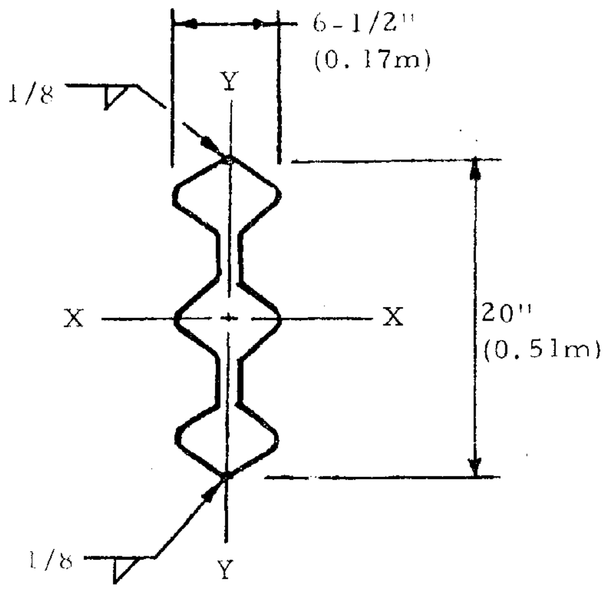
System	BR4		BR5		BR6	
Barrier Description						
Post Spacing	6' 3"		6' 6"		8' 10"	
Post Type	WF6x25 steel		Fabricated aluminum		W10x21 steel	
Beam Type	Two TS 3-1/2" x 3-1/2" x 0.25" (steel)		Two aluminum extrusions		Two TS6"x6"x0.187" (steel) One TS8"x6"x0.250" (steel) One TS6"x2"x0.187" (steel)	
Offset Brackets	None		None		One 18"O.D. x 6" wide x 0.5" dia ring	
Mountings	3/4" diameter steel stud bolts		UNAV		1/2" base plate (steel)	
Footings	Bridge deck		Bridge deck		W12 x 72 stub beam embedded in bridge deck	
Impact Performance	Impact Angle = 12°	Impact Angle = 25°	Impact Angle = 15°	Impact Angle = 27°	Impact Angle = 24°	Impact Angle = 24°
Impact Conditions						
Speed (mph)	64.0	No test	No test	58.0	55.7	56.1
Vehicle Weight (lb)	4550			1956 Plymouth	2090	3910
Barrier						
Dynamic Deflection (ft)	0.21			1.4	6.0	16.5
Vehicle Accelerations (G's)[1]						
Lateral	9.0			UNAV	12.2	6.6
Longitudinal	4.7			UNAV	6.2	5.6
Total	UNAV			UNAV	UNAV	UNAV
Vehicle Trajectory						
Exit Angle (deg)	3			≃0	13	12
Roll Angle (deg)	5			UNAV	UNAV	UNAV
Pitch Angle (deg)	0			UNAV	UNAV	UNAV
Barrier Damage	15' of rail section and 3 posts			UNAV	3 rings and one 24-ft rail section	3 rings and one 24-ft rail section
References	16			7	13	13
Remarks	This bridge rail was designed for use on secondary highways with maximum bridge widths of 32 ft.		This system is similar to many state standards.		This bridge rail has been evaluated under a series of 14 crash tests. Vehicles ranged from subcompact to 70,000-lb tractor/trailer truck.	

UNAV - unavailable
[1]50 millisecond average unless otherwise noted



Metric Conversion:
Multiply inches by 0.0254 to obtain meters.

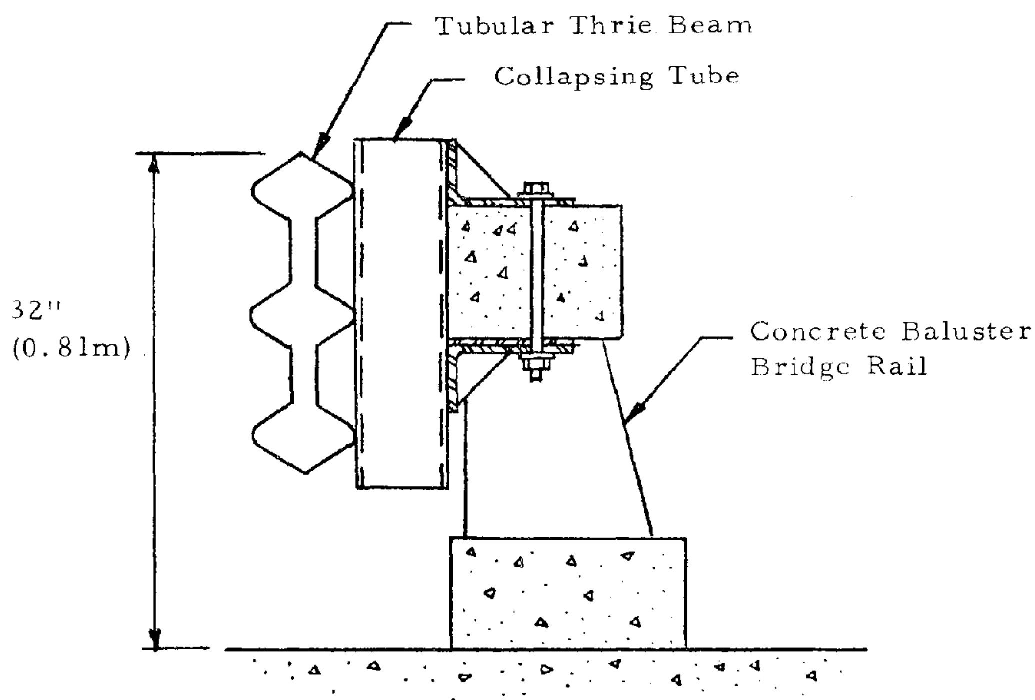
FIGURE 7. REPRESENTATIVE CATEGORY II BRIDGE RAILING



Section Properties:

I_{xx} = 296 in.^{4} ($1.23 \times 10^{-4} m^4$)
I_{yy} = 23.35 in.^{4} ($9.72 \times 10^{-6} m^4$)
S_{xx} = 29.6 in.^{3} ($4.85 \times 10^{-4} m^3$)
S_{yy} = 7.78 in.^{3} ($1.27 \times 10^{-4} m^3$)
Area = 7.80 in.^{2} ($5.03 \times 10^{-3} m^2$)
Weight = 26.56 lb/ft (39.53 kg/m)

(a) Cross Section of Tubular Thrie Beam



(b) Retrofit of Concrete Baluster Bridge Rail

FIGURE 8. FEATURES OF THE R(II)-1 DESIGN

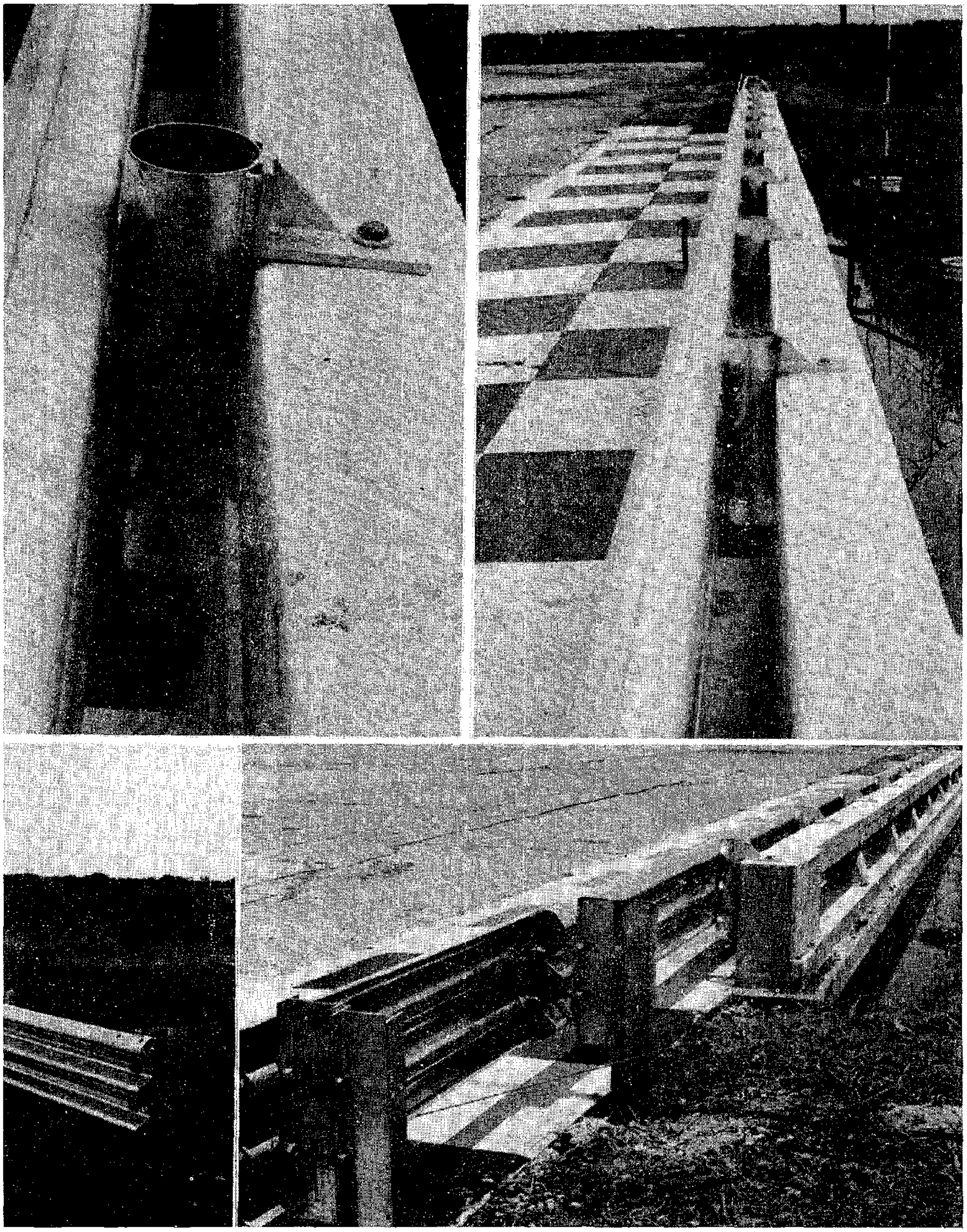


FIGURE 9. TYPICAL CATEGORY II BRIDGE RAILING INSTALLATION MODIFIED WITH R(II)-1 RETROFIT DESIGN

- The design encroaches only 12 in. (0.30 m) into existing bridge deck space, a most important consideration for narrow bridges.

Although an upstream terminal was not evaluated, the tubular thrie beam design is considered an integrated bridge railing that is comprised of terminal, approach railing, transition and bridge railing.

2. Crash Test Evaluation

The program was comprised of two baseline tests and three system evaluation experiments. Procedures and test conditions were based on guidelines presented in NCHRP *Report 153*. A summary of crash test findings is presented in Table 9. A brief description of each test is contained in the following paragraphs.

Two baseline tests (RF-3 and RF-4) were performed on a representative Category II bridge railing installation. The R(II)-1 design was then installed and two tests (RF-5 and RF-6) were performed using the same test conditions of RF-3 and RF-4. Test RF-7 was a test of the transition from the tubular thrie beam to a single thrie beam, which was used as the approach guardrail to the bridge.

Test RF-3. The 4500-lb (2041 kg) 1972 Ford Galaxie impacted the concrete baluster rail at 60.3 mph (27.0 m/s) and 30.0-deg angle. As shown in Figure 10, the vehicle impacted the installation approximately 14 ft (4.3 m) upstream of the end post, broke posts 8 and 9 (posts are numbered consecutively beginning at the upstream end) and caused the rail member downstream of posts 7 and 8 to form a plastic hinge allowing partial penetration of the vehicle through the rail. Maximum 50-ms average vehicle accelerations determined from high-speed cine data were −10.7-g longitudinal and −12.3-g lateral.* Installation and vehicle damage is shown in Figures 11 and 12.

Test RF-4. The 2130-lb (966 kg) Toyota Corona impacted the concrete baluster rail at 57.0 mph (25.5 m/s) and 15.5-deg angle. As shown in Figure 13, the vehicle impacted the installation 23 ft (7.0 m) upstream of the end post and was smoothly redirected. Maximum 50-ms average vehicle accelerations determined from high-speed cine data were −4.1-g longitudinal and −7.1-g lateral. Installation and vehicle damage is shown in Figure 14.

Test RF-5. This was the initial test of the R(II)-1 retrofit system. The vehicle used was a 2250-lb (1021 kg) 1971 Ford Pinto, and impact conditions were 58.0 mph (25.9 m/s) and 17.1-deg angle. As shown in Figure 15, the vehicle impacted midway between tubes 5 and 6 (tubes are numbered consecutively beginning at the upstream end) and was smoothly redirected. Maximum 50-ms average vehicle accelerations determined from accelerometer data were −4.1-g longitudinal and −8.4-g lateral; maximum permanent rail deflection was 0.5 in. (12.7 mm). Installation and vehicle damage is shown in Figure 16. The vehicle was driven back to the impact area following the test.

Test RF-6. The 4500-lb (2041 kg) 1973 Mercury Monterrey impacted the R(II)-1 installation at 60.6 mph (27.1 m/s) and 25-deg angle. As shown in Figure 17, the vehicle impacted midway between tubes 5 and 6, partially collapsed those tubes, and was smoothly redirected. Maximum 50-ms average vehicle accelerations determined from accelerometer data were −5.9-g longitudinal and 11.7-g lateral; maximum permanent rail deflection was 5.0 in. (127 mm). Installation and vehicle damage is shown in Figure 18. The vehicle was driven back to the impact area following the test.

*As defined for this program, a positive acceleration occurred when the vehicle center-of-mass increased in velocity in the forward, right, or upward directions with respect to the driver's attitude.

TABLE 9

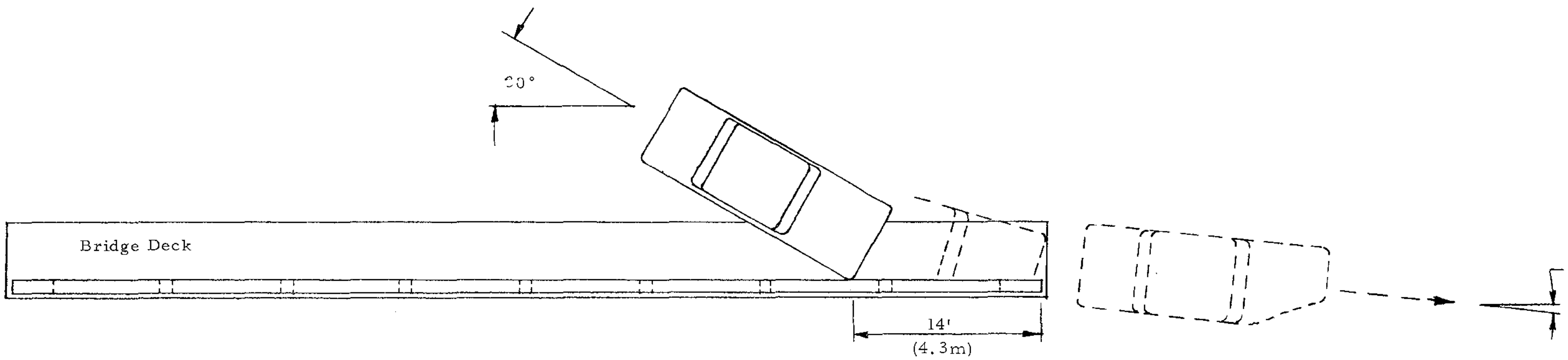
SUMMARY OF CRASH TEST FINDINGS FOR R(II)-1 DESIGN

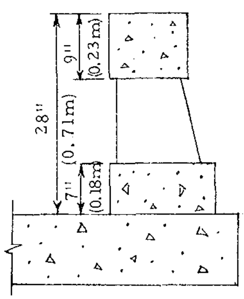
Test No.	Vehicle Weight (lbs)	Impact Speed (mph)	Impact Angle (deg)	Vehicle Exit Conditions Angle (deg)	Vehicle Exit Conditions Speed (mph)	Max. Avg. Vehicle Accelerations* Longitudinal (g's)	Max. Avg. Vehicle Accelerations* Lateral (g's)	Max. Permanent Rail Deflection (in.)	Purpose of Test
RF-3	4500	60.3	30.0	2.0	30.8	-10.7	-12.3	-	Structural test of Category II bridge railing
RF-4	2130	57.0	15.5	5.8	46.0	- 4.1	- 7.1	-	Impact severity test of Category II bridge railing
RF-5	2250	58.0	17.1	6.8	54.0	- 4.1	- 8.4	0.5	Impact severity test of R(II)-1 retrofit design
RF-6	4500	60.6	25.0	6.0	51.0	- 5.9	-11.7	5.0	Structural test of R(II)-1 retrofit design
RF-7	4700	60.1	25.0	10.0	48.0	- 4.0	- 7.5	21.6	Transition test of retrofit design

Metric conversion:
- Multiply pounds by 0.454 to obtain kilograms
- Multiply miles per hour by 0.447 to obtain meters per second
- Multiply inches by 25.4 to obtain millimeters

*Maximum acceleration over 50 millisecond duration obtained from accelerometers or high-speed cine.

Impact | 0.1 sec | 0.2 sec | 0.3 sec | 0.4 sec | 0.5 sec





Category II

Test No. RF-3
Date 2/12/75
Drawing .... SwRI 03-3717-10
Rail .... Concrete, 9 in. (0.23m) x 11 in. (0.28m) x 69.8 ft (21.3m)
Post .... Concrete, 12 in. (0.30m) x 10 in. (0.25m) x 12 in. (0.30m)
Bridge Post Spacing .... 8.83 ft (2.69m)
Length of Installation .... 76.2 ft (23.2m)
Pavement Conditions .... Dry

Vehicle .... 1972 Ford Galaxie
Vehicle Mass .... 4500 lb (2041kg)
(w/instrumentation)
Impact Speed .... 60.3 mph (27.0m/s)
Impact Angle .... +30.0 deg
Exit Angle .... +2.0 deg
Vehicle Accel (max 50ms avg)
Lateral (cine)....................... -12.3g
Longitudinal (cine)..................-10.7g
Vehicle Rebound Distance .... 6 ft (1.8m)
Vehicle Damage
TAD 1-RFQ-7
VDI 01RFAS9

FIGURE 10. SUMMARY OF RESULTS, TEST RF-3

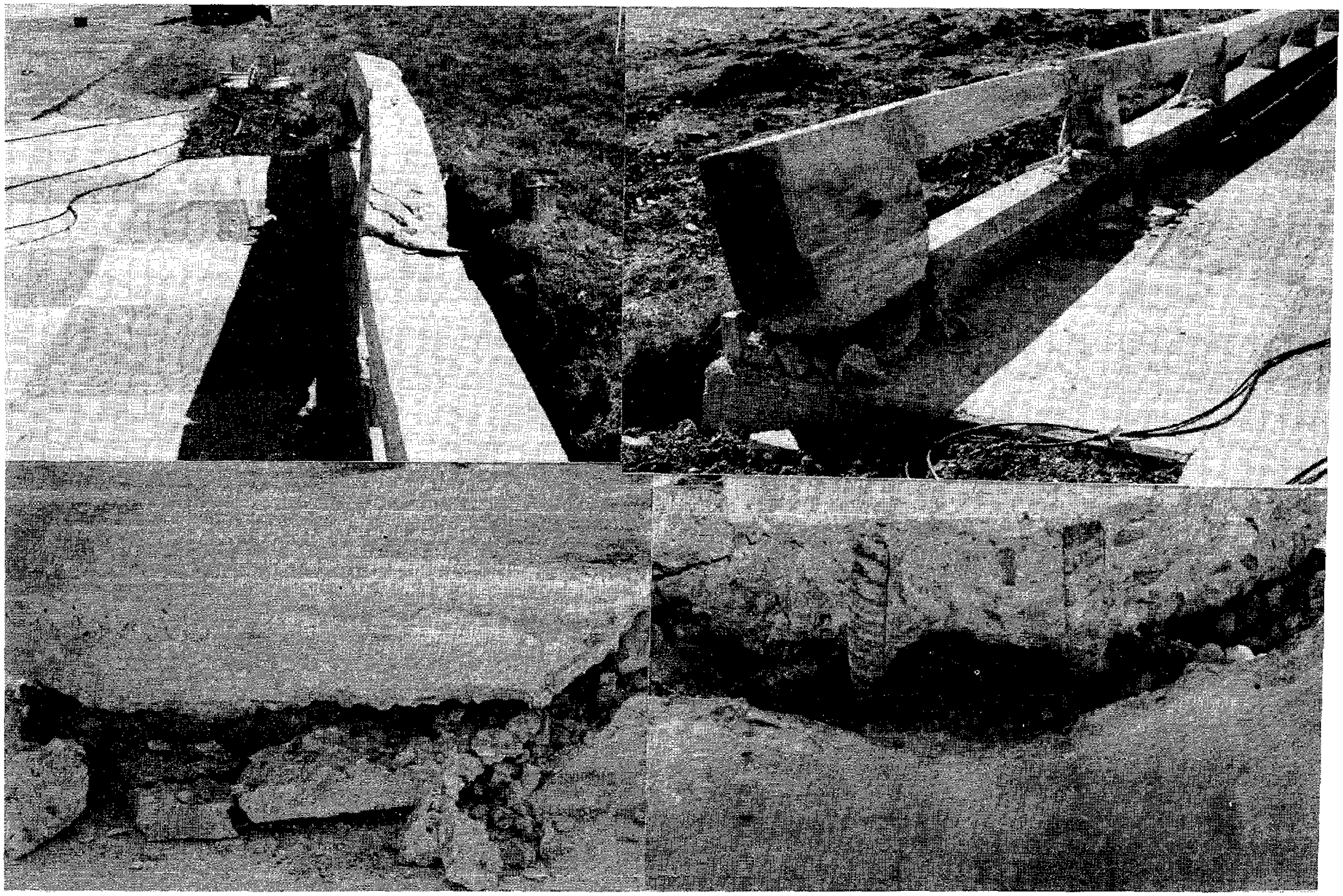
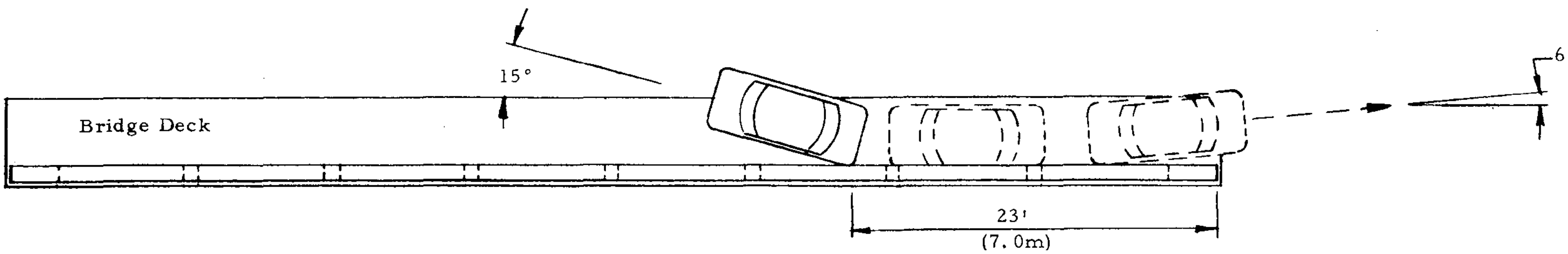
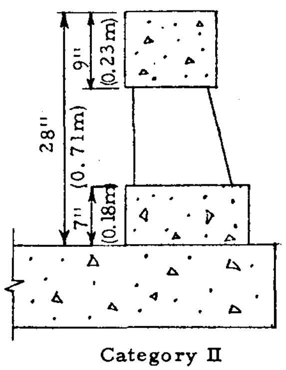


FIGURE 11. VIEWS OF TEST RF-3 INSTALLATION DAMAGE

FIGURE 12. VIEWS OF VEHICLE BEFORE AND AFTER TEST RF-3





Test No.	RF-4
Date	2/7/75
Drawing	SwRI 03-3717-10
Rail	Concrete, 9 in. (0.23m) x 11 in. (0.28m) x 69.8 ft (21.3m)
Post	Concrete, 12 in. (0.30m) x 10 in. (0.25m) x 12 in. (0.30m)
Bridge Post Spacing	8.83 ft (2.69m)
Length of Installation	76.2 ft (23.2m)
Pavement Conditions	Dry

Vehicle	1969 Toyota Corona
Vehicle Mass (w/instrumentation)	2130 lb (966 kg)
Impact Speed	57.0 mph (25.5m/s)
Impact Angle	+15.5 deg
Exit Angle	-5.8 deg
Vehicle Accel (max 50ms avg)	
Lateral (cine)	-7.1g
Longitudinal (cine)	-4.1g
Vehicle Rebound Distance	8 ft (2.4m)
Vehicle Damage	
TAD	1-RFQ-4
VDI	01RFES3

FIGURE 13. SUMMARY OF TEST RESULTS, TEST RF-4

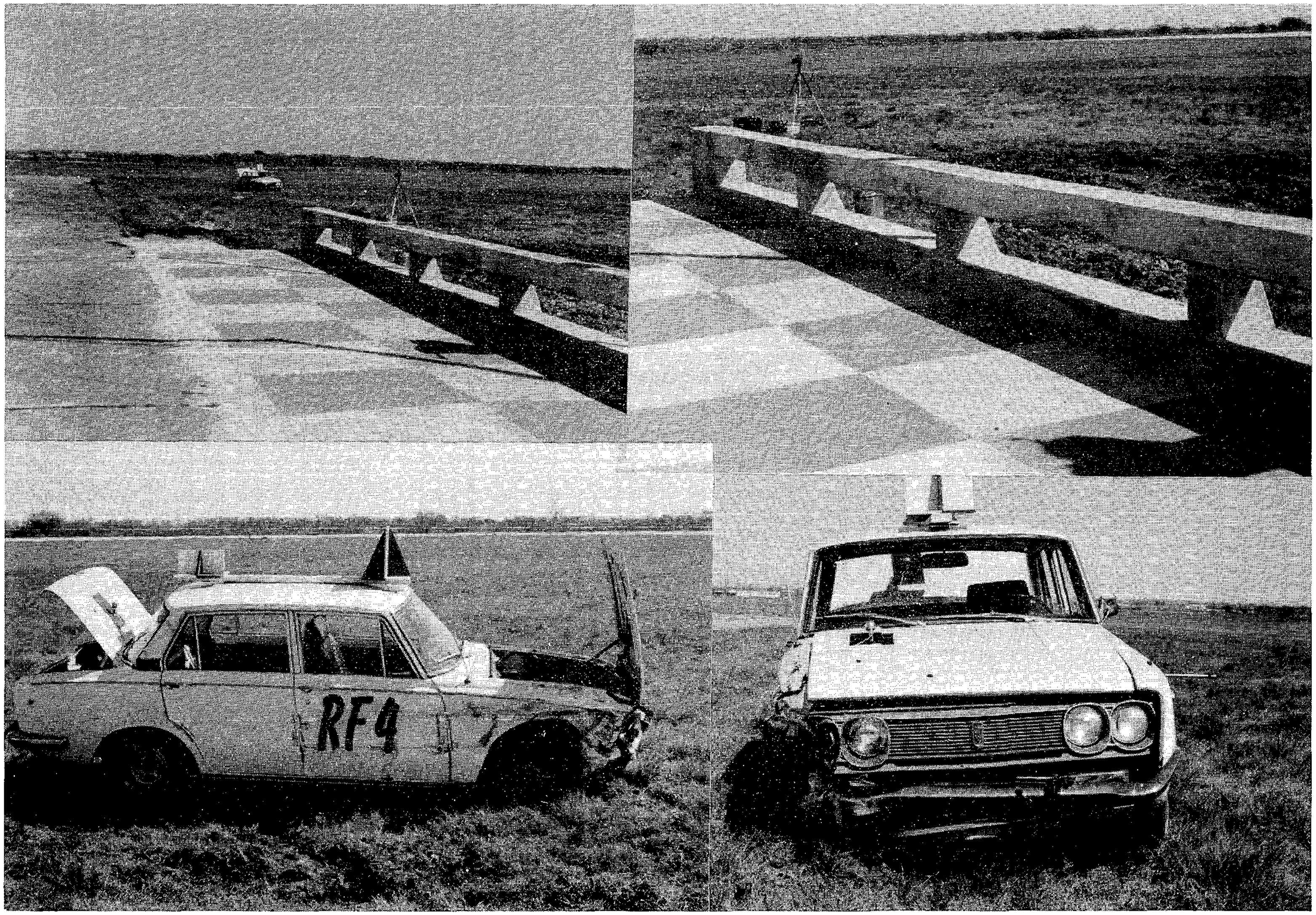
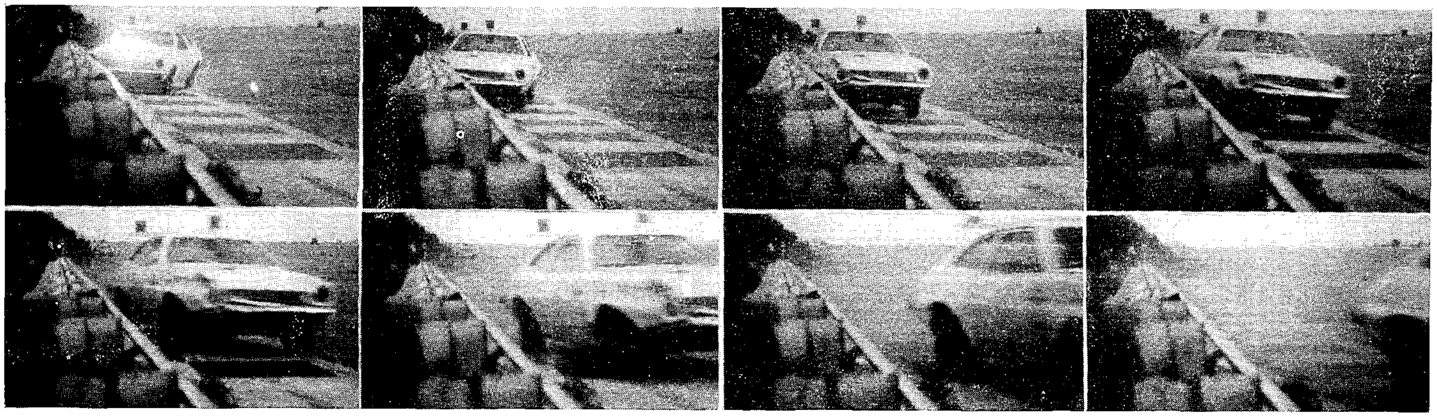
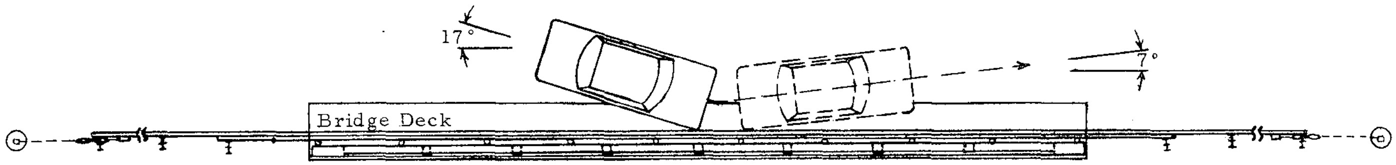
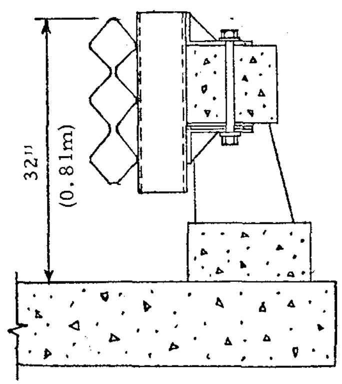


FIGURE 14. VIEWS OF VEHICLE AND INSTALLATION AFTER TEST RF-4







R(II)-1 Design

Test No.	RF-5
Date	7/15/75
Drawing	SwRI 03-3717-14
Rail (front)	Steel Tubular Thrie Beam (10 ga.)
Rail (backup)	Concrete, 9 in. (0.23m) x 11 in. (0.28m) x 69.8 ft (21.3m)
Post	Concrete, 12 in. (0.30m) x 10 in. (0.25m) x 12 in. (0.30m)
Steel Tubes	0.125 in. (3.1mm) thk x 6 in. (0.15m) O.D. x 22 in. (0.56m) long
Bridge Post Spacing	8.83 ft (2.69m)
Tube Spacing	8.33 ft (2.54m)
Length of Installation	126 ft (38.4m)
Pavement Conditions	Dry

Vehicle	1971 Ford Pinto
Vehicle Mass (w/instrumentation)	2250 lb (1021kg)
Impact Speed	58.0 mph (25.9m/s)
Impact Angle	+17.1 deg
Exit Angle	-6.8 deg
Vehicle Accel (max 50ms avg)	
Lateral(elect)	-8.4g
Longitudinal(elect)	-4.1g
Vehicle Rebound Distance	15.0 ft (4.57m)
Vehicle Damage	
TAD	1-RFQ-4
VDI	01RFES2
Max Dynamic/Permanent Rail Deflection	0.5 in. (12.7mm)/0.5 in. (12.7mm)

FIGURE 15. SUMMARY OF RESULTS, TEST RF-5

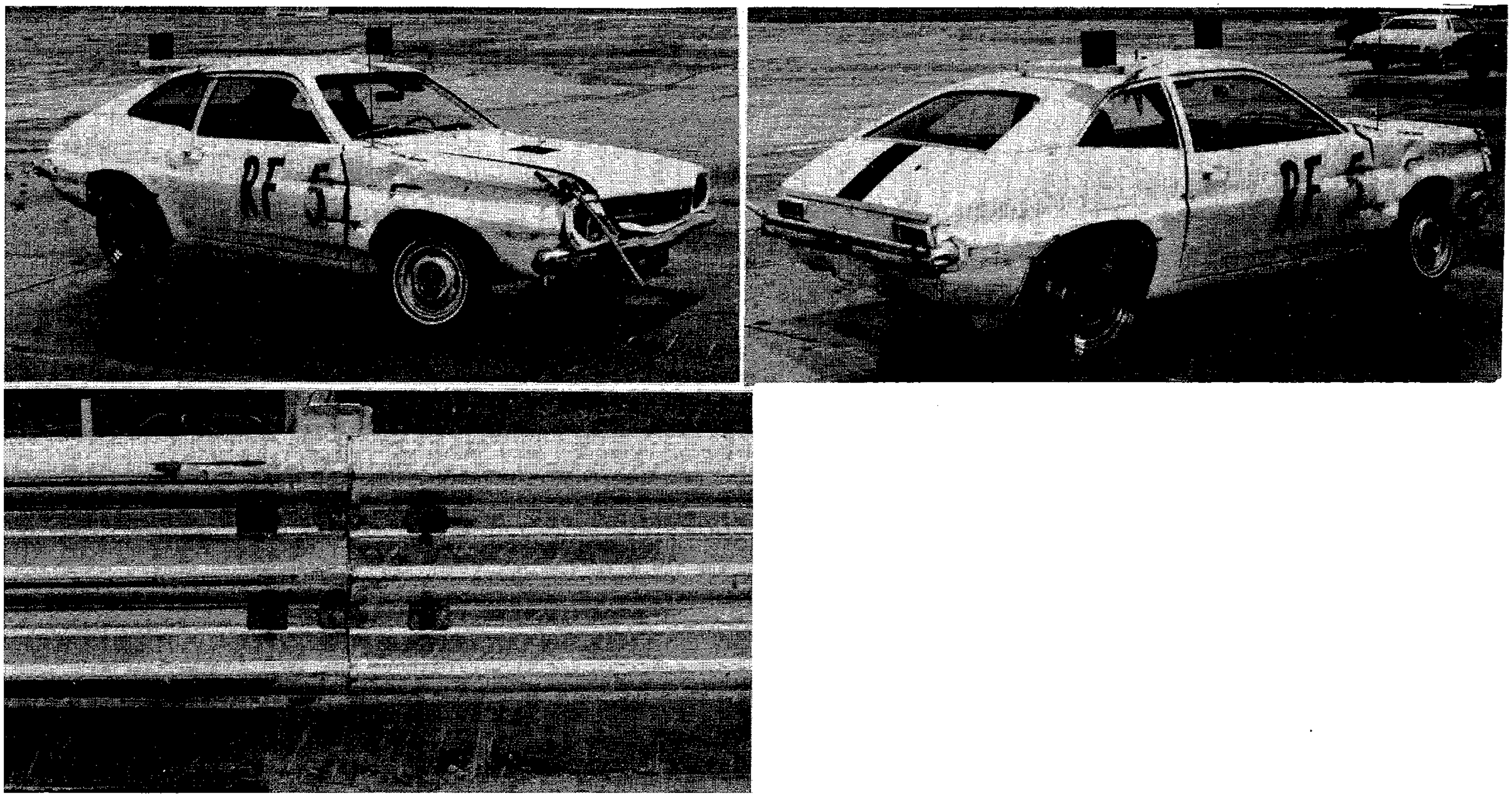
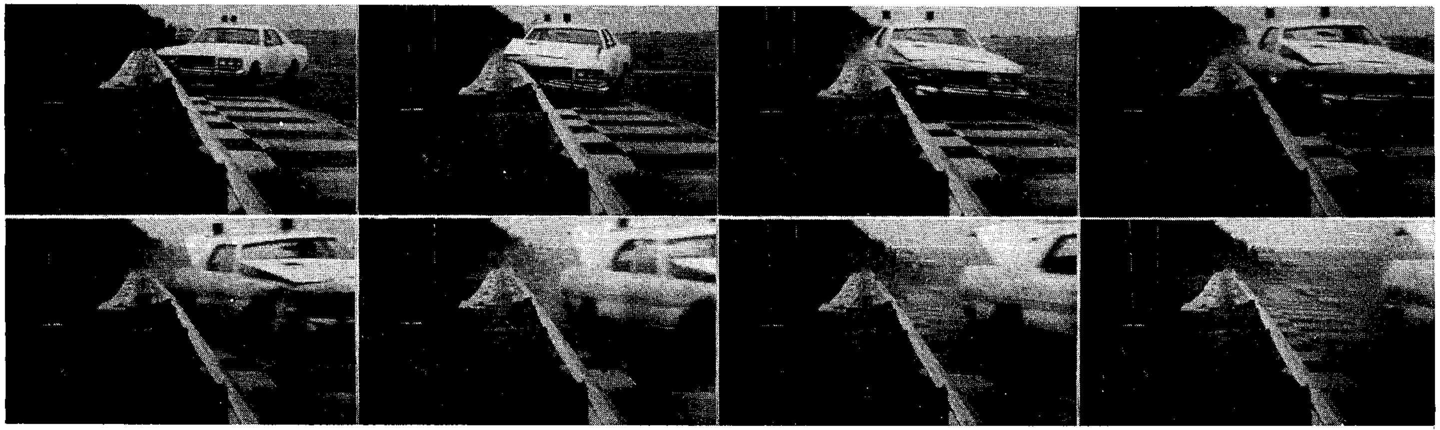
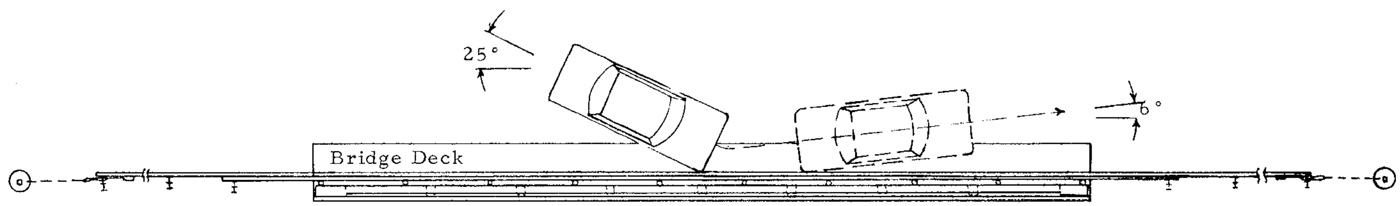
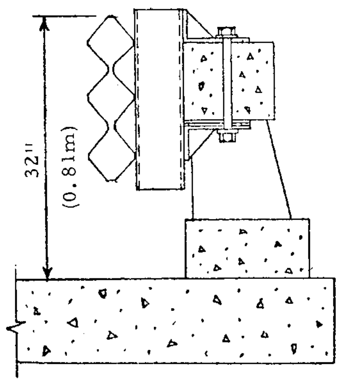


FIGURE 16. TEST RF-5 VEHICLE AND INSTALLATION DAMAGE







R(II)-1 Design

Test No.	RF-6
Date	7/16/75
Drawing	SwRI 03-3717-14
Rail (front)	Steel Tubular Thrie Beam (10 ga.)
Rail (backup)	Concrete, 9 in. (0.23m) x 11 in. (0.28m) x 69.8 ft (21.3m)
Post	Concrete, 12 in. (0.30m) x 10 in. (0.25m) x 12 in. (0.30m)
Steel Tubes	0.125 in. (3.1mm) thk x 6 in. (0.15m) O.D. x 22 in. (0.56m) long
Bridge Post Spacing	8.83 ft (2.69m)
Tube Spacing	8.33 ft (2.54m)
Length of Installation	126 ft (38.4m)
Pavement Conditions	Dry

Vehicle	1973 Mercury Monterrey
Vehicle Mass (w/instrumentation)	4500 lb (2041kg)
Impact Speed	60.6 mph (27.1m/s)
Impact Angle	+25.0 deg
Exit Angle	-6.0 deg
Vehicle Accel (max 50ms avg)	
Lateral (elect)	-11.7g
Longitudinal (elect)	-5.9g
Vehicle Rebound Distance	20 ft (6.1m)
Vehicle Damage	
TAD	1-RFQ-5
VDI	01RFES2
Max Dynamic/Permanent Rail Deflection	5.0 in. (127mm)/5.0 in. (127mm)

FIGURE 17. SUMMARY OF RESULTS, TEST RF-6

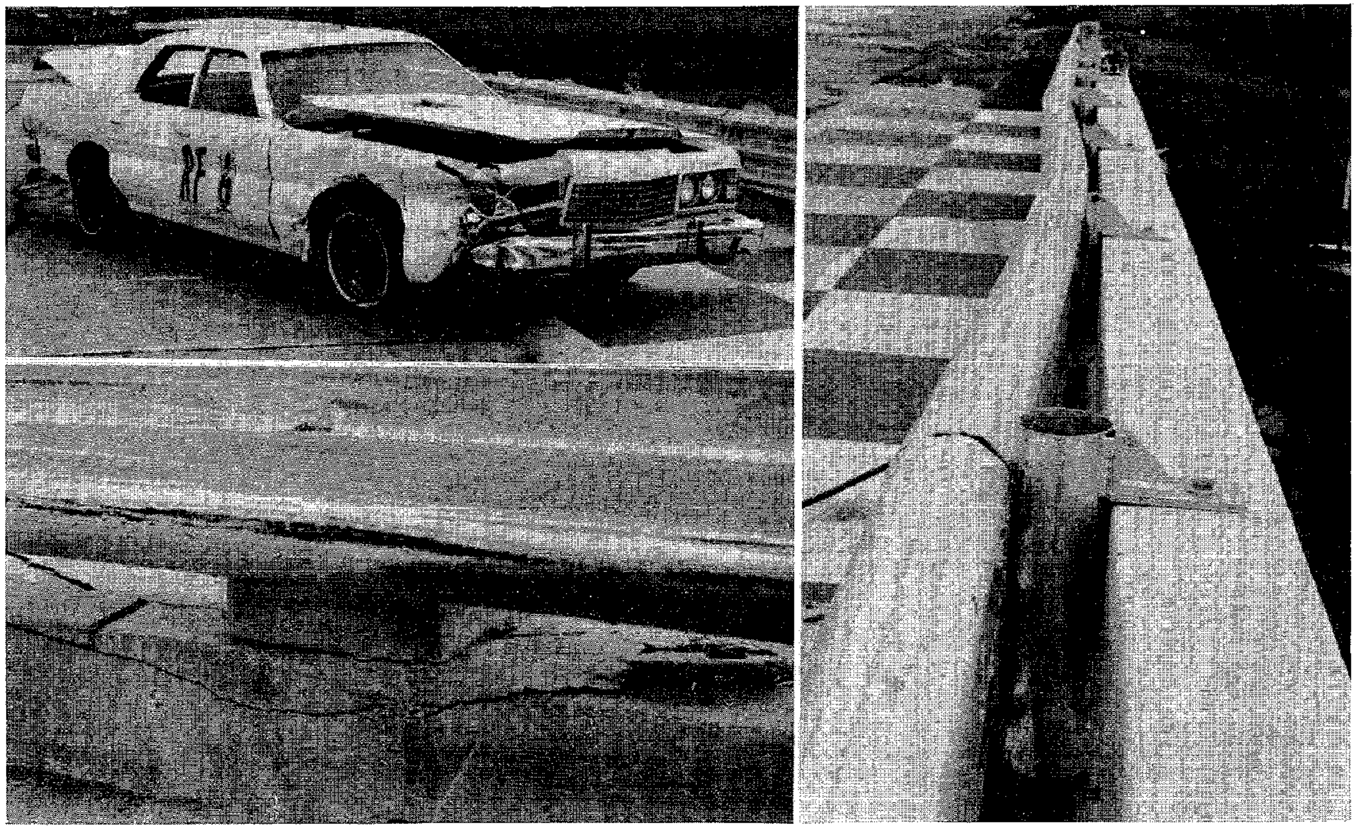


FIGURE 18. TEST RF-6 VEHICLE AND INSTALLATION DAMAGE

Test RF-7. The 4700-lb (2132 kg) 1969 Cadillac Sedan deVille impacted the single thrie beam rail in the transition area at 60.1 mph (26.9 m/s) and 25-deg angle. As shown in Figure 19, the vehicle impacted the rail 4.6 ft (1.4 m) upstream of the second guardrail post off the bridge deck and was smoothly redirected. Maximum 50-ms average vehicle accelerations determined from accelerometer data were −4.0-g longitudinal and −7.5-g lateral; maximum permanent rail set was 1.8 ft (0.55 m) after reaching a maximum dynamic deflection of 3.65 ft (1.11 m). Installation and vehicle damage is shown in Figure 20. The vehicle was driven back to the impact area following the test.

3. Appraisal of R(II)-1 Design

Analysis of data taken from these tests revealed the following:

- The tubular thrie beam increases the strength of the bridge rail.
- Damage to the vehicle is greatly reduced; all three vehicles tested with the R(II)-1 system (Tests RF-5, RF-6, and RF-7) were driveable following the tests.
- The single thrie beam to tubular thrie beam provides a continuous effective guardrail to bridge rail transition.
- The R(II)-1 design is an effective retrofit system that has minimal encroachment to the bridge deck.

From these findings and results, the authors believe the R(II)-1 design is suitable for in-service performance demonstration.

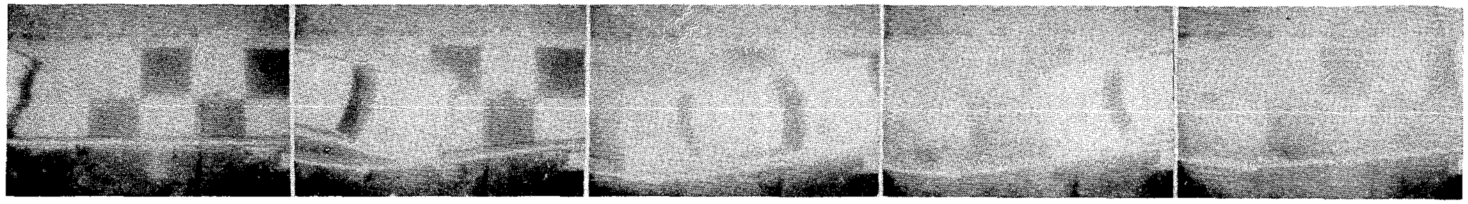
C. Category III Narrow Walk

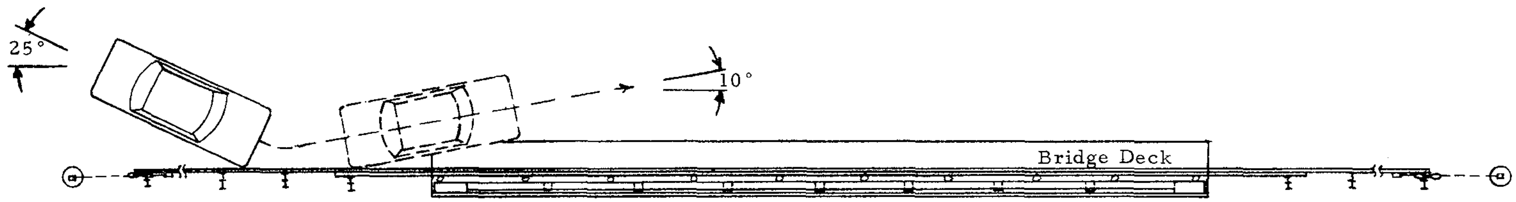
The distinguishing features of this category are the concrete parapet with a walk and curb; one to three metal rails may be attached to the top of the parapet. This category is further delineated according to the walk width: narrow (IIIN) and wide (IIIW), where walks less than 2 ft (0.61 m) are considered narrow.

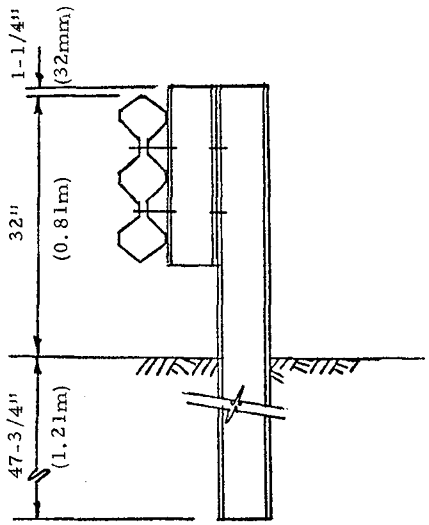
For Category IIIN, it was decided in the program that the walk would be sacrificed rather than permitting the retrofit installation to encroach on the bridge deck. This approach is consistent with current AASHTO specification trends in eliminating safety walks. In contrast, functional use of the walk was considered important for Category IIIW installations as many of these installations exist in urban areas and carry heavy pedestrian traffic.

1. Baseline Tests

A representative Category IIIN installation is shown in Figure 21. Essentially, the IIIN installation has a 10-in. (0.25 m) high curb and 16-in. (0.41 m) wide walk. On top of the 15-in. (0.38 m) parapet, a single 4-in. (0.10 m) O.D. aluminum rail is supported by brackets spaced at 8-ft (2.4 m) centers. Two baseline tests were performed on this installation: small car redirection severity and standard car structural adequacy tests. Views of the installation before Test RF-8 are shown in Figure 22.







R(II)-1 Transition

Test No.	RF-7
Date	7/24/75
Drawing	SwRI 03-3717-14
Rail	Steel Thrie Beam (10 ga.)
Post	Steel W6 x 8.5
Post Spacing	6.33 ft (1.93m)
Length of Guardrail	34.33 ft (10.46m)
Ground Conditions	Dry

Vehicle	1969 Cadillac Sedan DeVille
Vehicle Mass (w/instrumentation)	4700 lb (2132 kg)
Impact Speed	60.1 mph (26.9m/s)
Impact Angle	+25.0 deg
Exit Angle	-10.0 deg
Vehicle Accel (max 50ms avg)	
Lateral (elect)	-7.5g
Longitudinal (elect)	-4.0g
Vehicle Rebound Distance	14 ft (4.27m)
Vehicle Damage	
TAD	1-RFQ-5
VDI	01RFES2
Max Dynamic/Permanent Rail Deflection	3.65 ft (1.11m)/1.80 ft (0.55m)

FIGURE 19. SUMMARY OF RESULTS, TEST RF-7

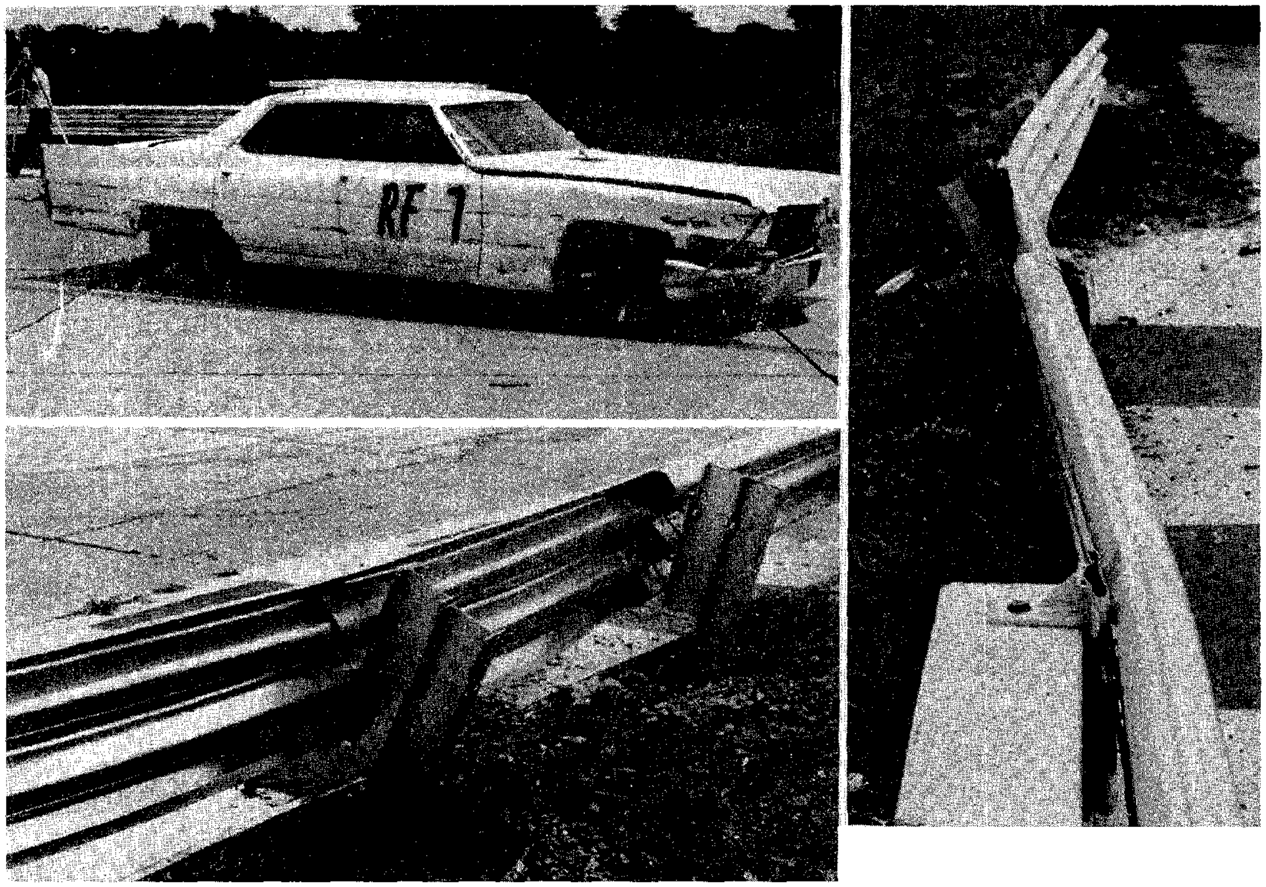


FIGURE 20. TEST RF-7 VEHICLE AND INSTALLATION DAMAGE

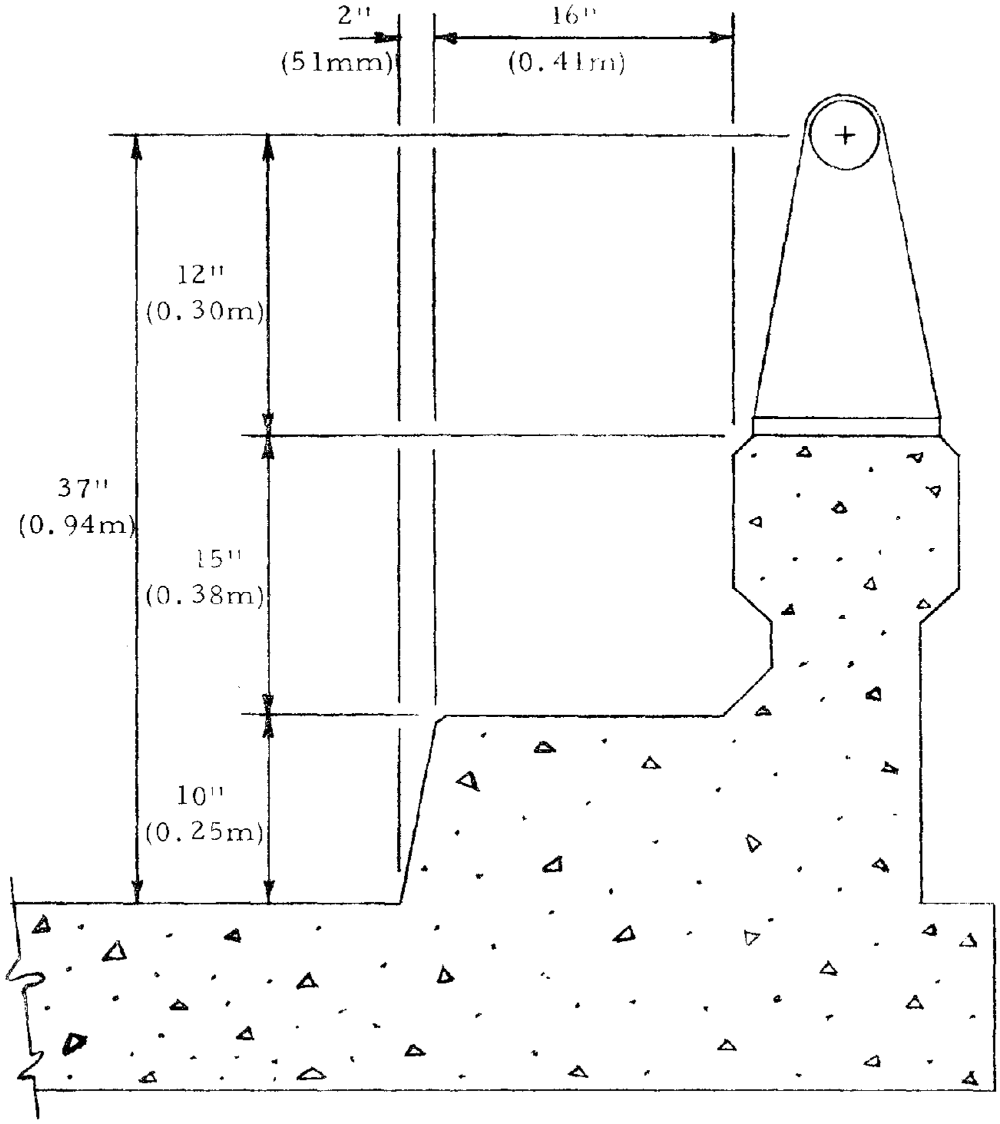


FIGURE 21. REPRESENTATIVE CATEGORY IIIN INSTALLATION

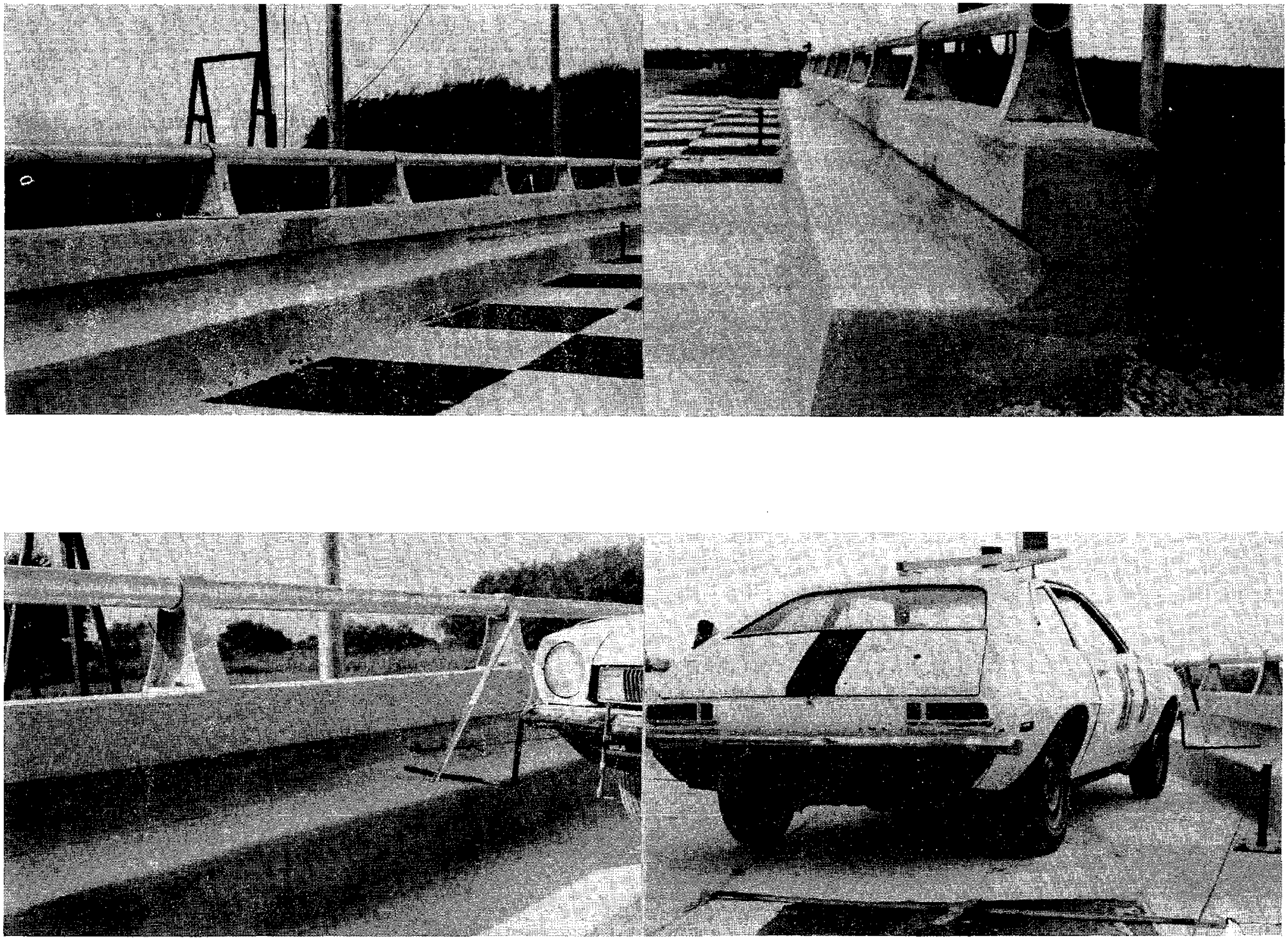


FIGURE 22. INSTALLATION AND VEHICLE PRIOR TO TEST RF-8

Test RF-8. Impact conditions for the 2140-lb (971 kg) car were 62.7 mph (28.0 m/s) and a 15.9-deg angle. The right front wheel of the vehicle mounted the 10-in. (0.25 m) safety curb although the wheel was severely crushed rearward. As the right side of the car rode up on the safety walk and partially on the baluster, a rolling action away from the barrier was imparted to the car. Some scuffing of the aluminum railing was detected after the test. The vehicle continued along the barrier with the right front and rear wheels riding atop one edge of the parapet (see photographs in Figure 23); the vehicle appeared to be rolling away from the barrier and may have completely rolled had the installation been extended farther downstream.* However, after passing the end of the installation, the vehicle quickly rolled to an upright attitude, decelerated to a stop approximately 200 ft (61 m) downstream from the system.

A summary of test data is presented in Figure 23; vehicle redirection was smooth. Maximum 50-ms average vehicle accelerations were –5.3-g lateral and –3.7-g longitudinal, as determined from high-speed cine.

Installation and vehicle damage is shown in Figure 24. Bridge rail damage was minor and consisted of scuffing of concrete safety walk and aluminum railing. One aluminum bracket was displaced slightly. Damage to the right front panel, wheel, and suspension system disabled the vehicle. The right front wheel assembly was deformed rearward approximately 12 in. (0.3 m).

Test RF-9. Impact conditions for the 4723-lb (2142 kg) car were 58.3 mph (26.1 m/s) and 29.4-deg angle. The vehicle was contained and was redirected with an exit angle of 11.2 deg.

A summary of test information is presented in Figure 25. Maximum 50 ms average vehicle accelerations were –4.2-g lateral and –9.6-g longitudinal, as determined from high-speed cine. The longitudinal value is moderately high but not unexpected with the 29-deg impact angle. Vehicle and installation damage are shown in Figures 26 and 27, respectively.

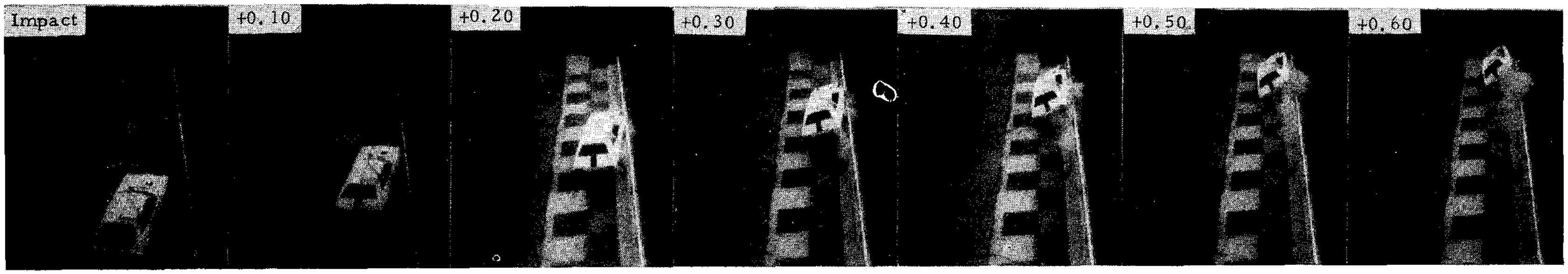
2. Appraisal of Category IIIN Performance

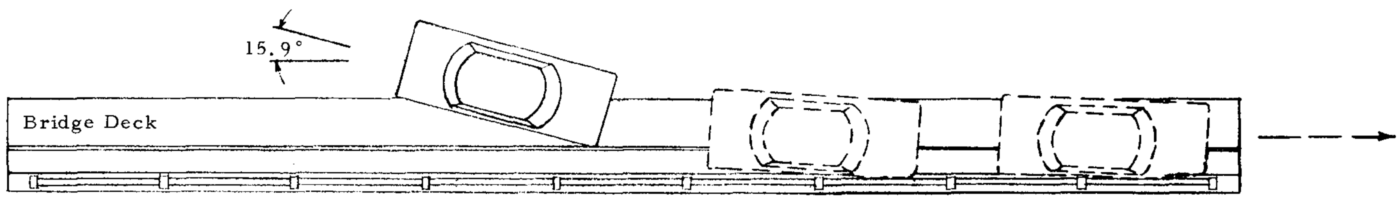
Actual vehicle accelerations, which were measured by two independent experimental methods, are lower than the predicted values, especially for the lateral direction. HVOSM predicted rollover for the small car (i.e., 380 deg at the end of 1.0 s), which did not occur in the crash test. However, the car may have rolled had the bridge rail been longer.

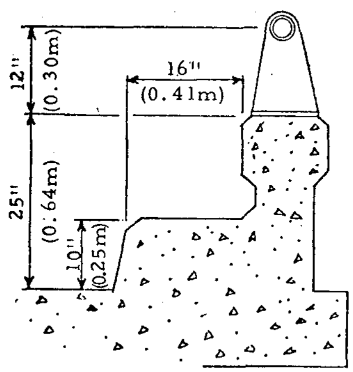
Although extensive damage was sustained by the bridge rail, Test RF-9 clearly showed that the system is structurally adequate to redirect a large percentage of traffic and will serve as excellent support for a retrofit design.

In several accidents on the baseline IIIN design it was reported that the vehicle vaulted over the installation. This vaulting tendency was not exhibited in either baseline test which indicates that the standard impact conditions, 4500-lb (2041 kg) car at 60 mph (26.8 m/s) and 25 deg and 2250-lb (1021 kg) car at 60 mph (26.8 m/s) and 15 deg, did not approximate critical values of the reported accidents. Since actual in-service experience has precedence over crash test results, the IIIN design was judged lacking in safety performance and in need of retrofit upgrading.

*HVOSM computer simulations of this test predict vehicle rollover.







Category IIIN

Test No.	RF-8
Date	8/27/75
Drawing	SwRI-03-3717-16
Rail	4" (102mm) O.D. 3.75 (95mm) I.D. Alum. Tube
Parapet	10" (0.25m) curb, 18" (0.46m) walk, 14" (0.36m) wall
Length of Installation	75 ft (22.9m)
Pavement Conditions	Dry
Vehicle	1971 Ford Pinto
Vehicle Mass (w/instrumentation)	2140 lb (971kg)

Impact Speed	62.7 mph (28.0 m/s)
Impact Angle	+15.9 deg
Exit Angle	+7.4 deg
Vehicle Accel (max 50 ms avg.)	
Lateral (cine/elect.)	-5.3g/-4.5g
Long. (cine/elect.)	-3.7g/-2.2g
Resultant (elect.)	5.0g
Vehicle Rebound Distance	0 ft
Vehicle Damage	
TAD	1-FR-4
VDI	01FREW4
Max. Rail Deflection (dynamic/permanet)	n/a

FIGURE 23. SUMMARY OF RESULTS, TEST RF-8

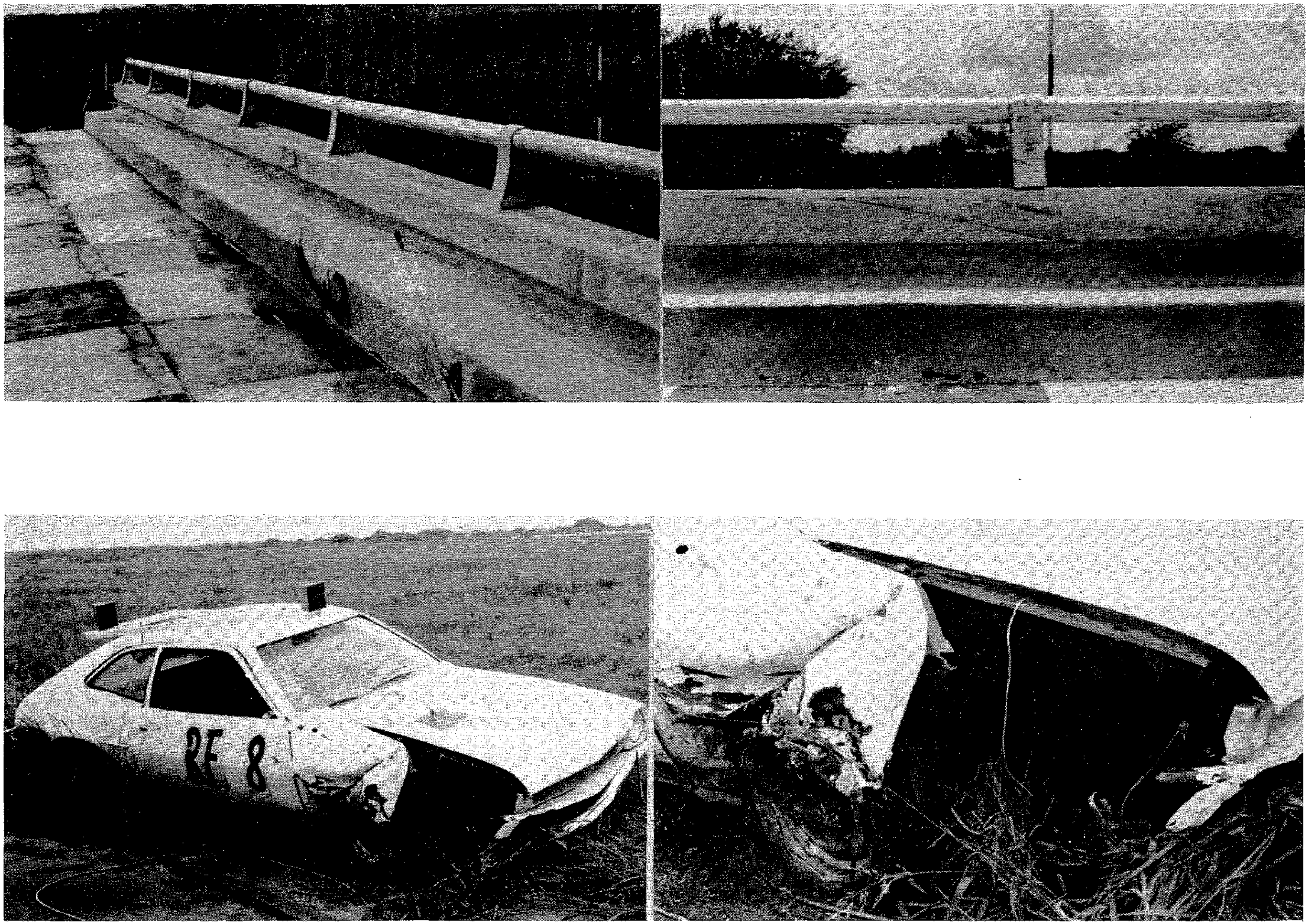
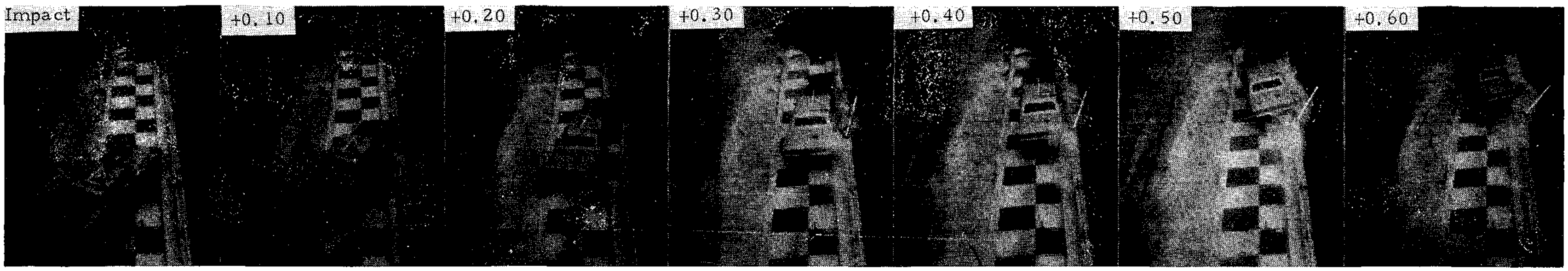
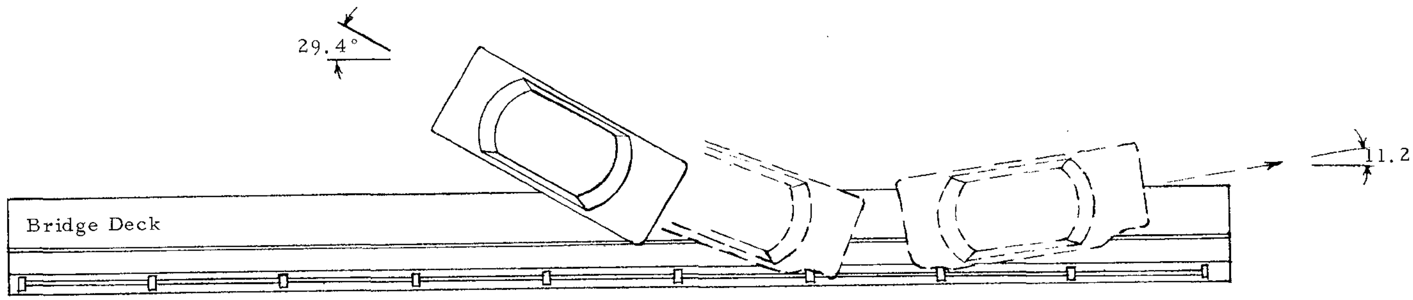
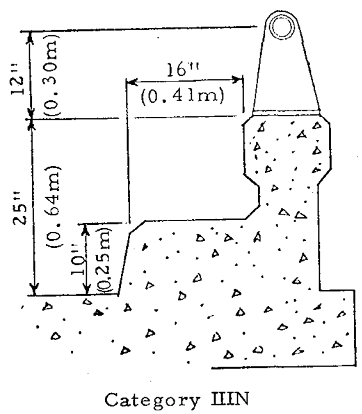


FIGURE 24. INSTALLATION AND VEHICLE DAMAGE, TEST RF-8



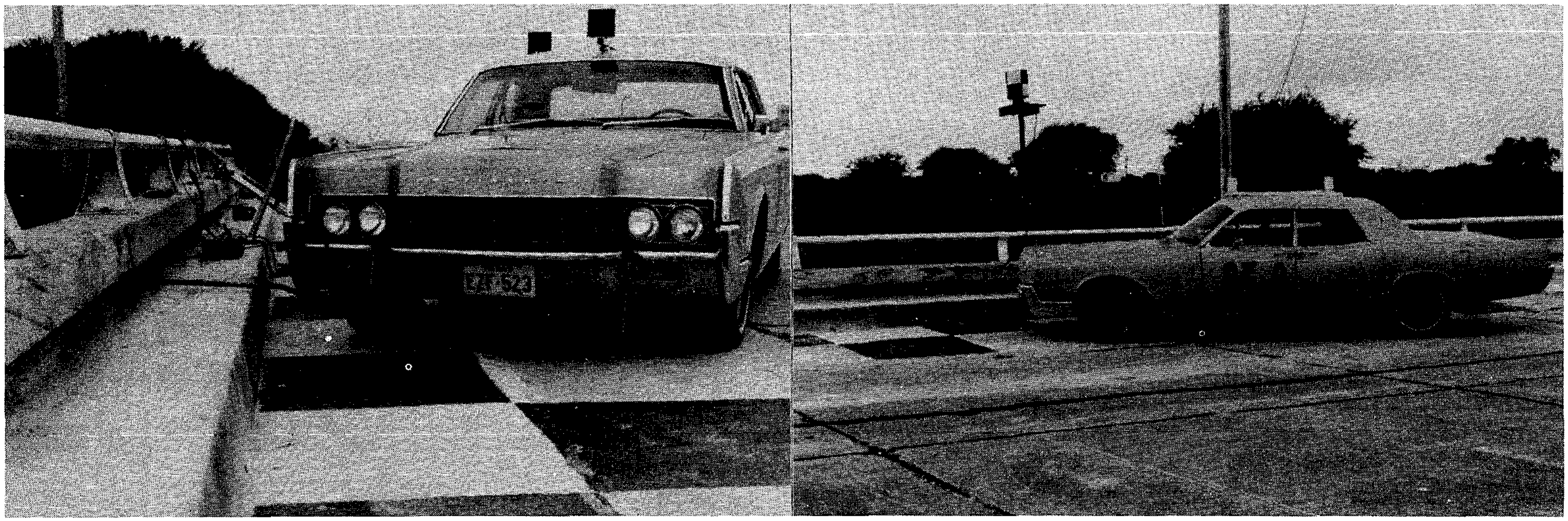




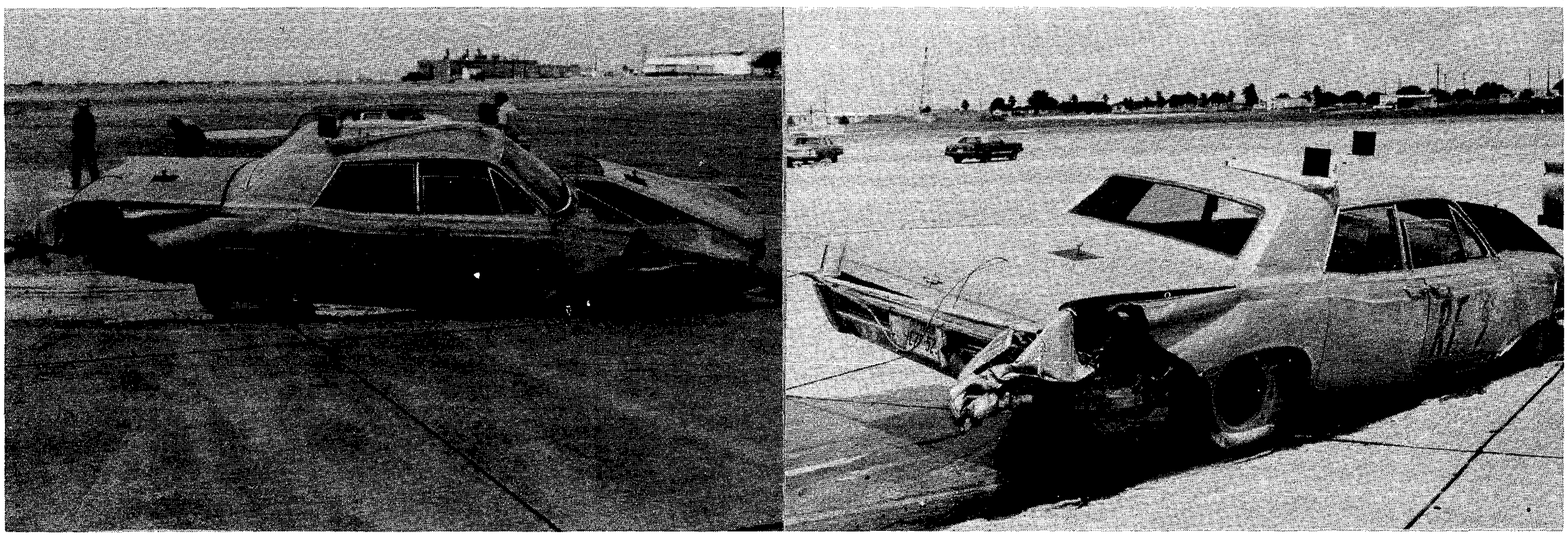
Test No.	RF-9
Date	8/28/75
Drawing	SwRI-03-3717-16
Rail	4" (102mm) O.D., 3.75" (95mm) I.D. Alum. Tube
Parapet	10" (0.25m) curb, 18" (0.46m) walk, 14" (0.36m) wall
Length of Installation	75 ft (22.9m)
Pavement Condition	Dry
Vehicle	1969 Lincoln Continental
Vehicle Mass (w/instrumentation)	4723 lb (2142kg)

Impact Speed	58.3 mph (26.1m/s)
Impact Angle	+29.4 deg
Exit Angle	-11.2 deg
Vehicle Accel. (max. 5 ms avg.)	
Lateral (cine/elect.)	-4.2g/-6.1g
Long. (cine/elect.)	-9.6g/-10.5g
Resultant (elect.)	12.1g
Vehicle Rebound Distance	70 ft (21.3m)
Vehicle Damage	
TAD	1-FR-6
VDI	01 FREW8
Max. Rail Deflection (dynamic/permanent)	n/a

FIGURE 25. SUMMARY OF RESULTS, TEST RF-9



(a) Prior to test



(b) Vehicle damage

FIGURE 26. VIEWS OF VEHICLE BEFORE AND AFTER TEST RF-9

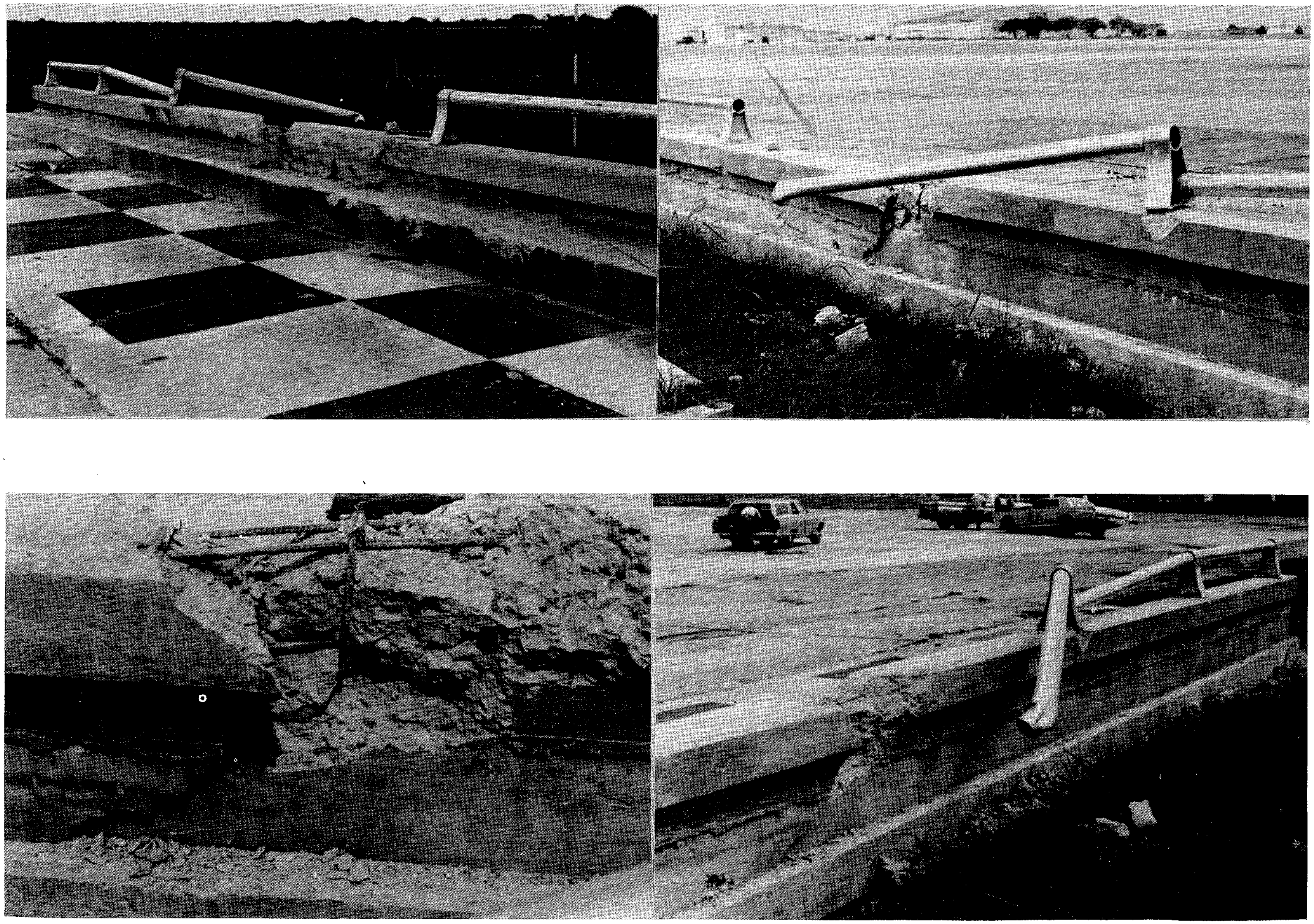


FIGURE 27. VIEWS OF BRIDGE RAIL DAMAGE DUE TO TEST RF-9

D. Category IIIN Retrofit—R (IIIN)-1 Design

1. Design Features

Sectional view of the RIIIN-1 design is shown in Figure 28, and installation details are contained in Appendix A. Essential features of the design are the tubular thrie beam that is blocked out from the concrete parapet by brackets spaced at 8.33-ft (2.5 m) centers.* A relatively stiff TS 6 X 6 X 3/16 (152 X 152 X 4.8 mm) box section and a 6-in. (152 mm) diameter tube section with a 1/8-in. (3.2 mm) wall comprise the bracket. Engineering properties of the tubular thrie beam are presented in Figure 8. The traffic face of the tubular thrie beam is in line with the curb, and therefore, does not encroach on existing bridge deck. Obviously, the retrofit system eliminates use of the walkway. The collapsing tubes provide 6 in. (152 mm) of dynamic deflection, thus attenuating lateral redirection forces on the car. Whereas a larger deflection would further soften the vehicle redirection, the stiff box sections are used in the brackets to minimize exposure of the curb and walk to the car, to about 6 in. (152 mm); otherwise, a more exposed walk and curb could interfere with the vehicle redirection.

To effect a gradual stiffness transition, the tubular thrie beam extends upstream from the bridge deck 12.3 ft (3.75 m), where it changes to a single thrie beam.. Although a crashworthy terminal was not used, the single thrie beam was anchored 40 ft (12.2 m) from the bridge deck. Views of the test installation are shown in Figure 29.

2. Crash Test Evaluation

Test RF-1. Impact conditions for the 2140-lb (971 kg) car were 63.6 mph (28.4 m/s) and 16.8-deg angle. The bumper contacted the barrier 16 ft (4.9 m) from the upstream end of the bridge deck at the third collapsing tube/blockout bracket. The vehicle remained in contact with the tubular thrie beam for a distance of 10.8 ft (3.3 m) and was smoothly redirected parallel to the installation. Views from high-speed cine showed that the vehicle front pitched upward slightly during redirection; this was probably caused by the right front tire climbing the exposed face of the concrete curb. Vehicle roll was not evident during redirection; the rear wheels remained in contact with the bridge deck throughout the impact events. After redirection, the vehicle proceeded almost parallel to the installation, coming to a stop 443 ft (135 m) from the impact point.

A summary of test data is presented in Figure 30. Maximum 50-ms average vehicle accelerations calculated from high-speed cine data were −6.1-g lateral, −3.7-g longitudinal and 6.3-g resultant.

Installation damage was slight and consisted of permanent deformation of two tubes and scuffing of the tubular thrie beam and curb (see lower left view of Figure 29). Subsequent safety performance of the bridge rail would not be impaired by this damage. Damage to the vehicle is shown in Figure 31. Although the vehicle was driveable after the test, the frame was bent, resulting in the relatively high damage indices.

Test RF-2. The installation was used without repair to the minimum damage sustained in Test RF-1. Impact conditions for the 4300-lb (1950 kg) car were 66.6 mph (29.8 m/s) and 23.9-deg angle. The vehicle contacted the barrier 14.7 ft (4.5 m) from the upstream end of the bridge deck

*It is believed that the spacing may range from 6 to 9 ft (1.8 to 4.6 m) in order to suit local conditions without affecting barrier collision performance.

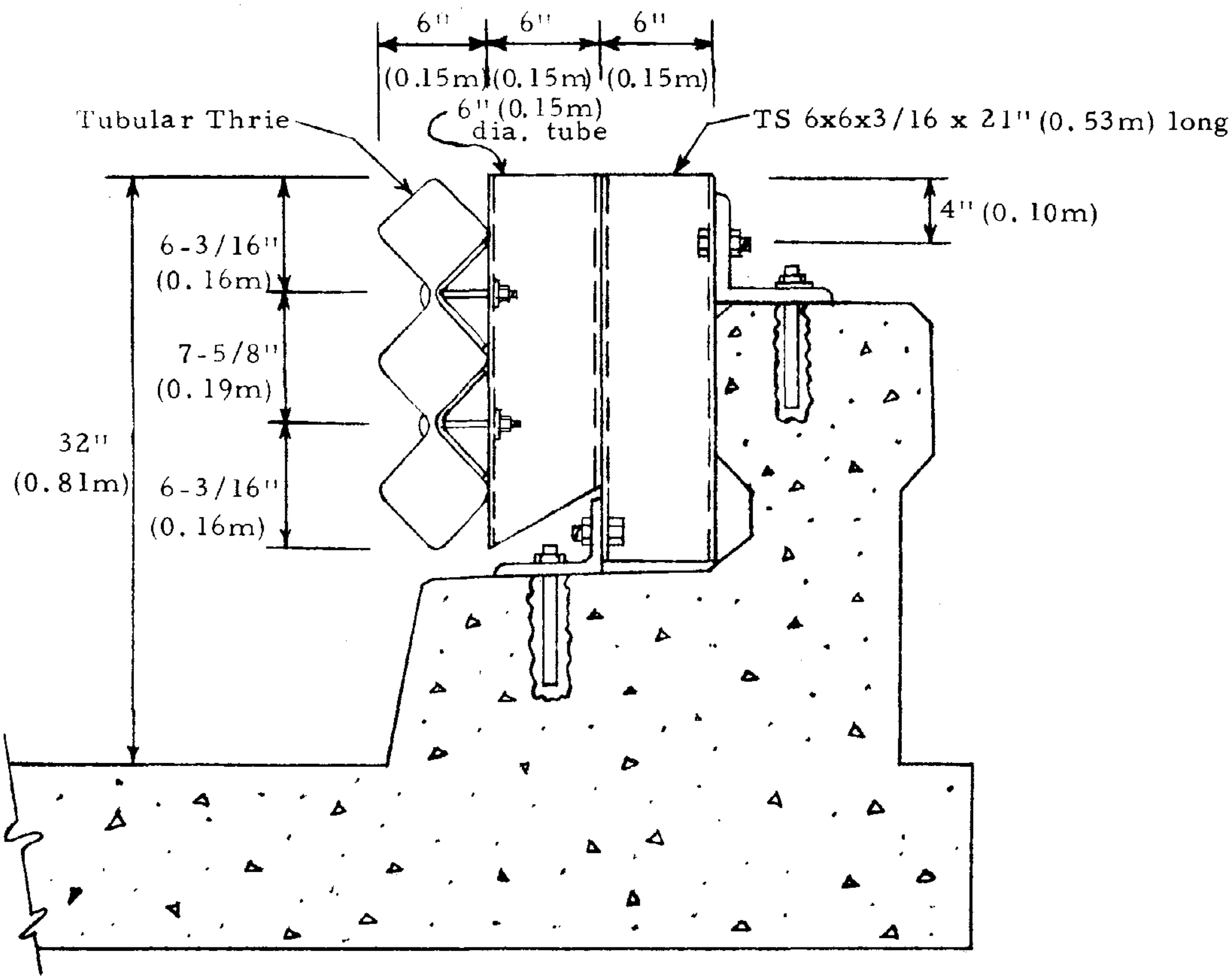


FIGURE 28. FEATURES OF THE R(IIIN)-1 DESIGN

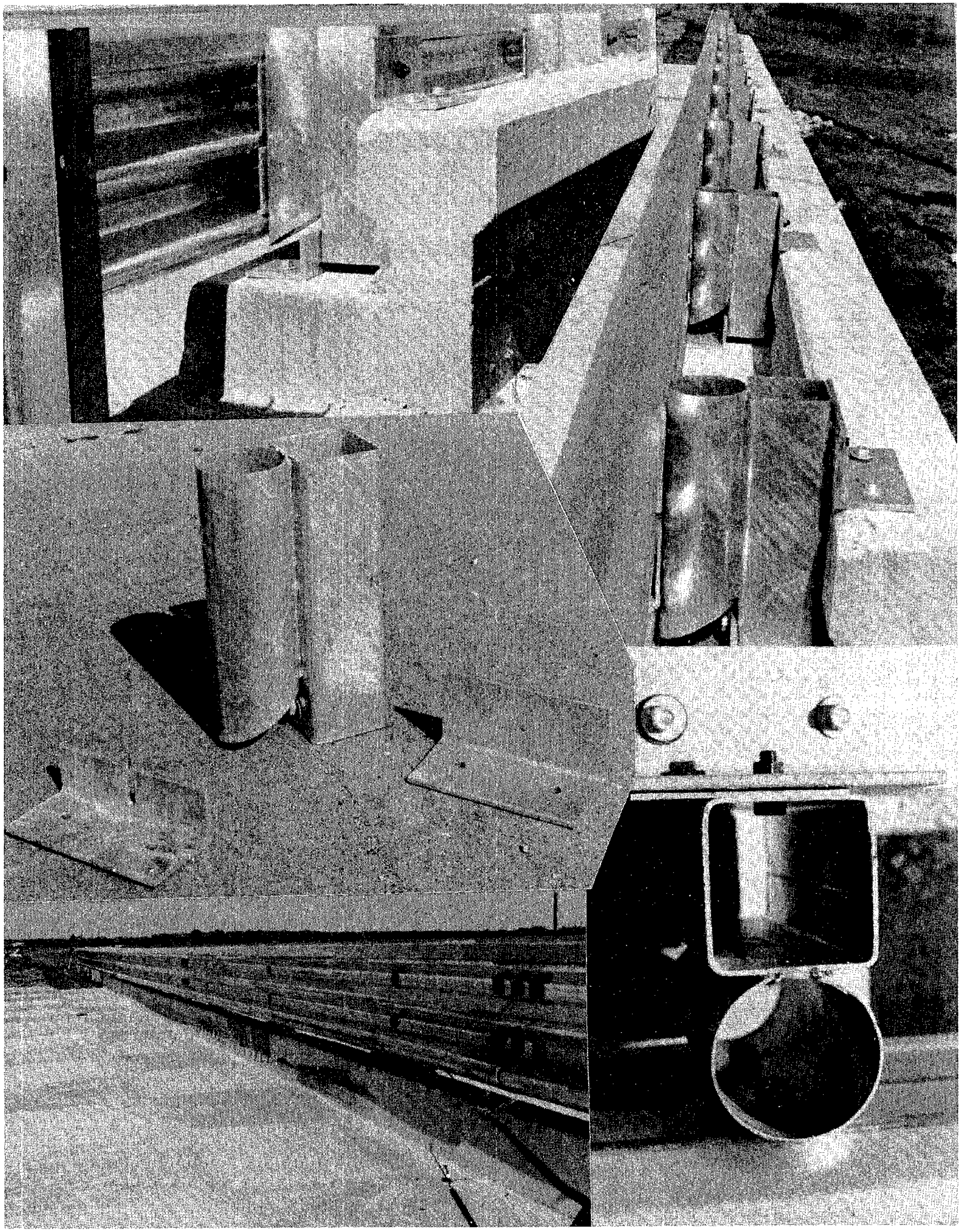
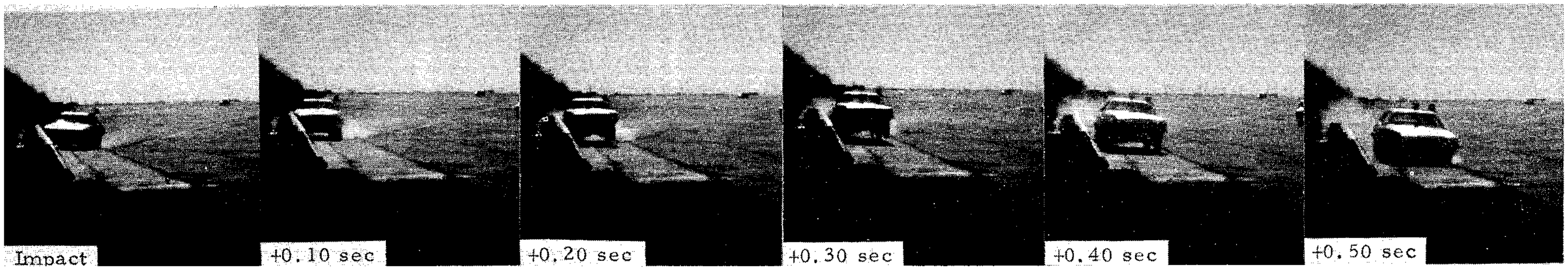
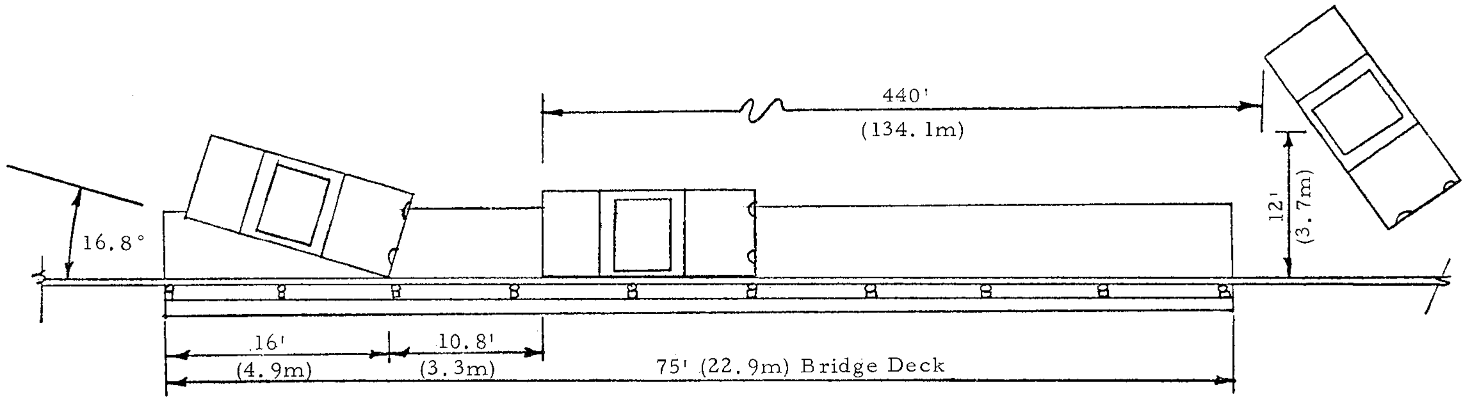
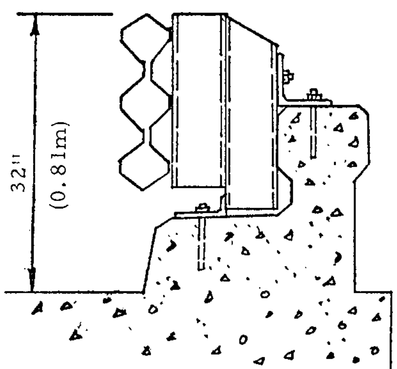


FIGURE 29. VIEWS OF CRASH TEST RF-1 INSTALLATION







R(IIIN)-1 Design

Test No.	RF-1
Date	2/26/76
Drawing	SwRI No. 03-3717-22
Rail	Tubular Thrie
Parapet	Narrow Walk
Length of Installation	306 ft (93.3m)
Pavement Condition	Dry
Vehicle	1971 Ford Pinto
Vehicle Mass (w/instrumentation)	2140 lb (971kg)

Impact Speed	63.6 mph (28.4m/s)
Exit Speed	55.6 mph (24.9m/s)
Impact Angle	+16.8 deg
Exit Angle	0 deg
Vehicle Accel (max 50 ms avg)	
Lateral (cine/elect)	-6.1 g/n.a.
Long. (cine/elect)	-3.7 g/n.a.
Resultant (cine/elect)	6.3 g/n.a.
Vehicle Rebound Distance	0 ft
Vehicle Damage	
TAD	1-RFQ-5
VDI	01RFES6
Max. Rail Deflection (dynamic/permanent)	0.1 ft (30mm)/ 0.09 ft (27mm)

FIGURE 30. SUMMARY OF CRASH TEST RF-1 RESULTS

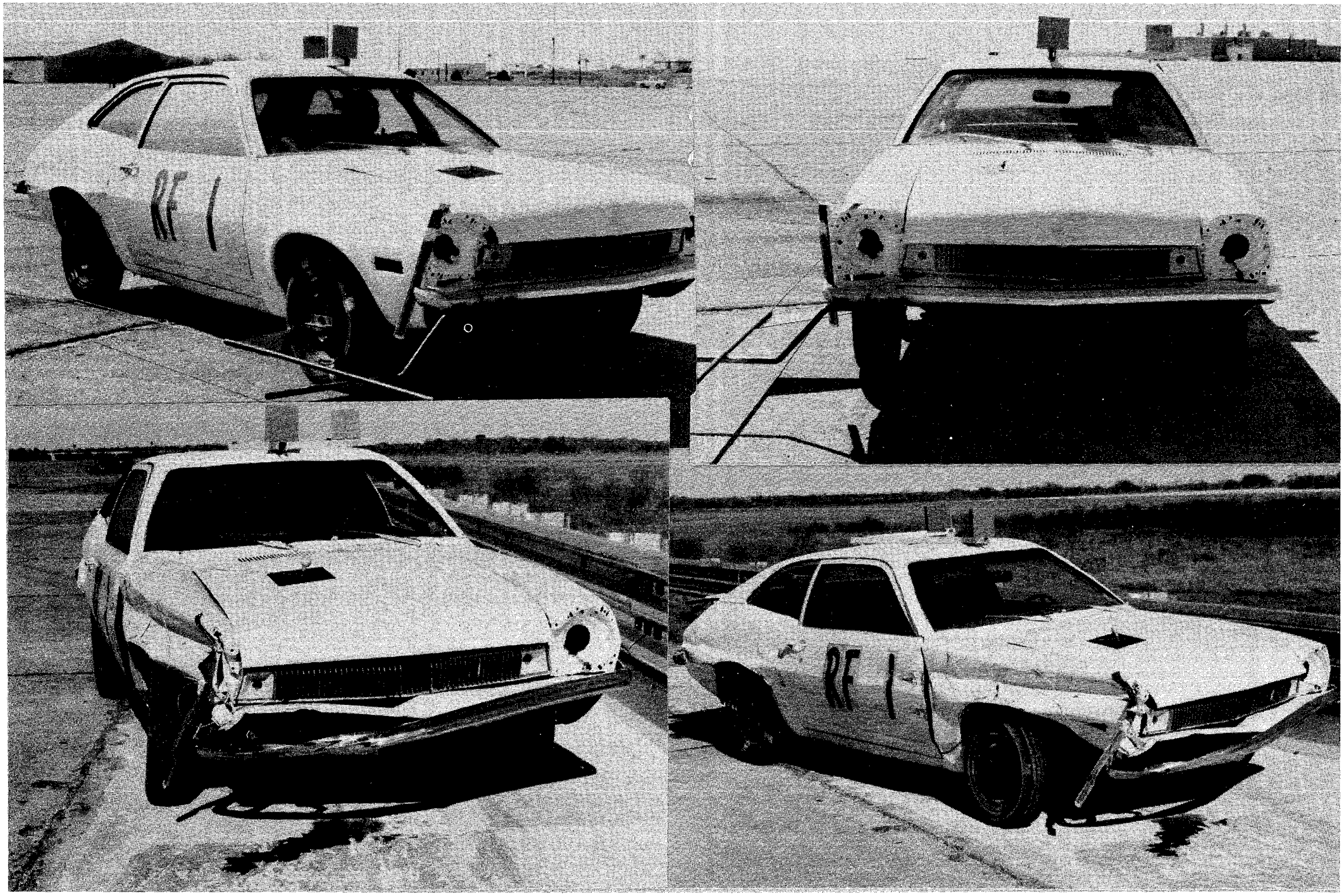


FIGURE 31. VIEWS OF RF-1 TEST VEHICLE BEFORE AND AFTER TEST

and 2.2 ft (0.7 m) upstream from the third collapsing tube/blockout bracket. The vehicle remained in hard contact with the barrier for a distance of 14.2 ft (4.3 m) and was smoothly redirected; exit angle was −2.9 deg. Views of the redirection from high-speed cine show that the vehicle was stable throughout redirection and exhibited little tendency to roll or pitch. Maximum roll angle of the vehicle while in contact with the system was 6 deg away from the barrier. After redirection, the vehicle continued for a distance of 192 ft (58.5 m) from the point of contact.

A summary of test data is presented in Figure 32. Maximum 50-ms average vehicle accelerations calculated from high-speed cine data were −8.2-g lateral, −8.2-g longitudinal, and 11.0-g resultant.

Installation damage is shown in Figure 33. As shown in the figure, two tubes were entirely collapsed, and two tubes were partially collapsed. A maximum permanent set of 5.75 in. (0.15 m) was sustained by the beam. The installation maintained its structural integrity and could sustain additional collisions in the impact zone although the cushioning stroke was expended. There was no damage to the concrete parapet and curb with the exception of curb scuffing. Damage to the vehicle, as shown in Figure 34, was severe, although typical of a 25-deg test. Front end damage disabled the driveability of the car.

Test RF-13. Test RF-13 was performed on the installation without repairs to damage sustained in Tests RF-1 and RF-2. Views of the installation and car before test are shown in Figure 35. Impact conditions for the 4500-lb (2041 kg) car were 65.1 mph (29.1 m/s) and 26.1-deg angle. The vehicle contacted the barrier 14.25 ft (4.34 m) upstream from the bridge deck and at the third soil-mounted post from the bridge deck. The vehicle remained in hard contact with the barrier for a distance of 24.25 ft (7.39 m) and was redirected at a near 0-deg angle. During redirection, the vehicle reached a maximum roll angle of 3 deg away from the barrier. Maximum dynamic deflection of the beam was 2.75 ft (0.84 m) in the transition section. As the beam deflected laterally, the curb end was exposed and caused severe damage to the vehicle right side suspension. Also, when the first tube was fully collapsed, a force concentration on the parapet corner caused a local failure. After leaving the impact zone, the vehicle traveled 184 ft (56.1 m) to its final position. A summary of test data is presented in Figure 36. Maximum 50-ms average vehicle accelerations determined from accelerometer data were −8.7-g lateral, −7.2-g longitudinal, and 10.7-g resultant.

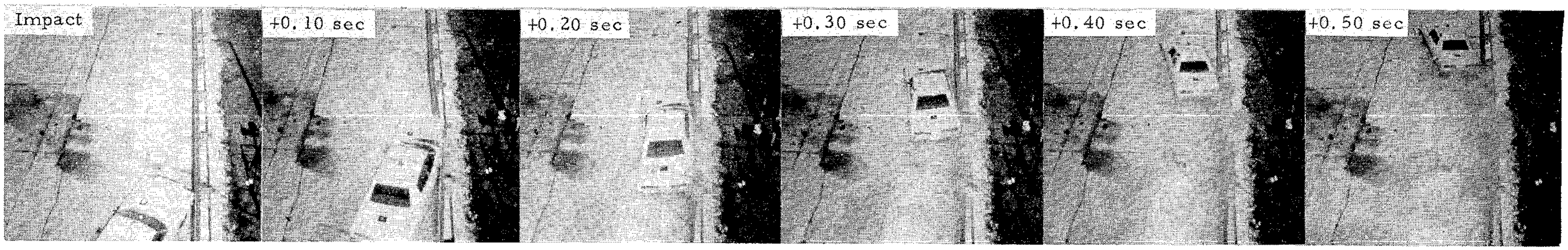
Installation damage is shown in Figure 37. Three soil-mounted posts were pushed back in the foundation, and two tubes that were not previously damaged in Tests RF-1 and RF-2 were fully collapsed. The corner of the concrete parapet was broken, although held together by reinforcing steel. The installation maintained its structural integrity for this severe impact; however, repairs to the system would be required.

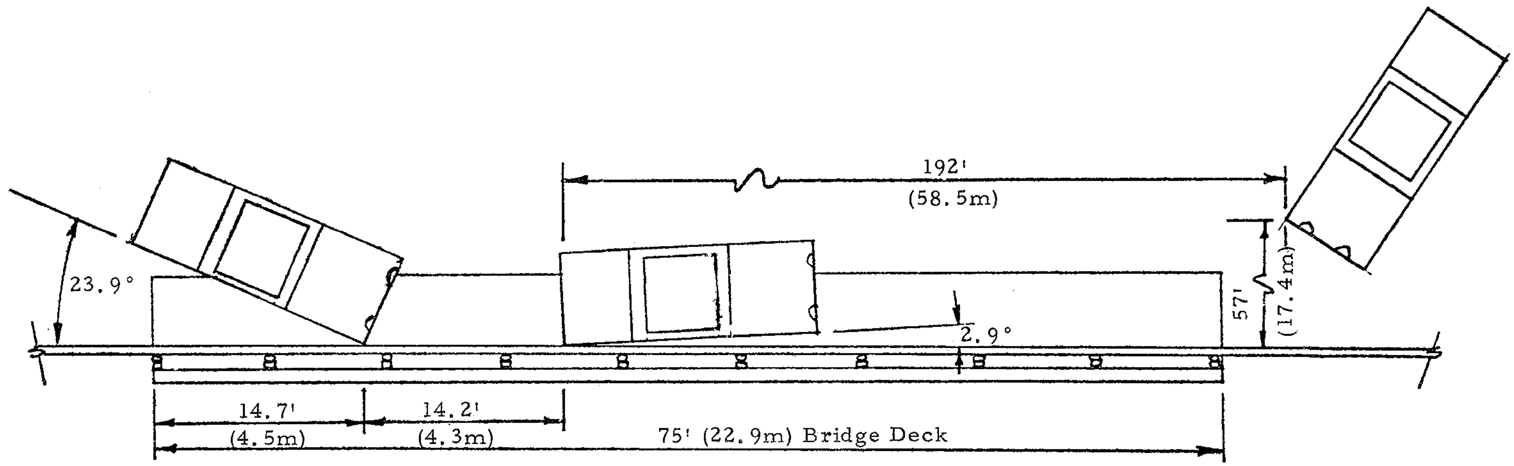
Damage to the vehicle, as shown in Figure 38, was severe. A major portion of this damage was caused by the curb end that was exposed for direct impact when the beam deflected laterally. The car was disabled by the damage.

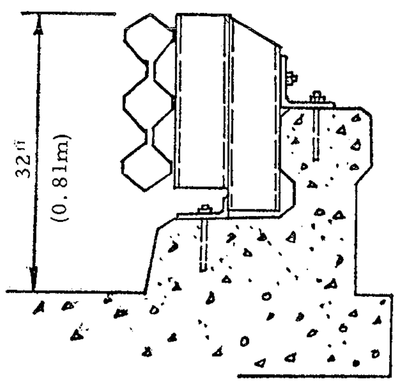
For an application of this retrofit design, it is recommended that the curb end be flared back from the traffic to prevent end-on impacts.

3. Appraisal of R(IIIN)-1 Design

Structural Adequacy. Vehicles impacting in the bridge rail section (Tests RF-1 and RF-2) were contained and smoothly redirected. The installation remained intact during the collisions and could have sustained additional hits prior to damage repair.







R(IIIN)-1 Design

Test No.	RF-2
Date	2/27/76
Drawing	SwRI No. 03-3717-22
Rail	Tubular Thrie
Parapet	Narrow Walk
Length of Installation	306 ft (93.3m)
Pavement Condition	Dry
Vehicle	1974 AMC Ambassador
Vehicle Mass (w/instrumentation)	4300 lb (1950kg)

Impact Speed	66.6 mph (29.8m/s)
Exit Speed	52.6 mph (23.5m/s)
Impact Angle	+23.9 deg
Exit Angle	-2.9 deg
Vehicle Accel (max 50 ms avg)	
Lateral (cine/elect)	-8.2g/n.a.
Long. (cine/elect)	-8.2g/n.a.
Resultant (cine/elect)	11.0g/n.a.
Vehicle Rebound Distance	57 ft (17.4m)
Vehicle Damage	
TAD	1-RFQ-5
VDI	01RFES5
Max. Rail Deflextion (dynamic/permanent)	0.5 ft (0.15m)/ 0.5 ft (0.15m)

FIGURE 32. SUMMARY OF CRASH TEST RF-2 RESULTS

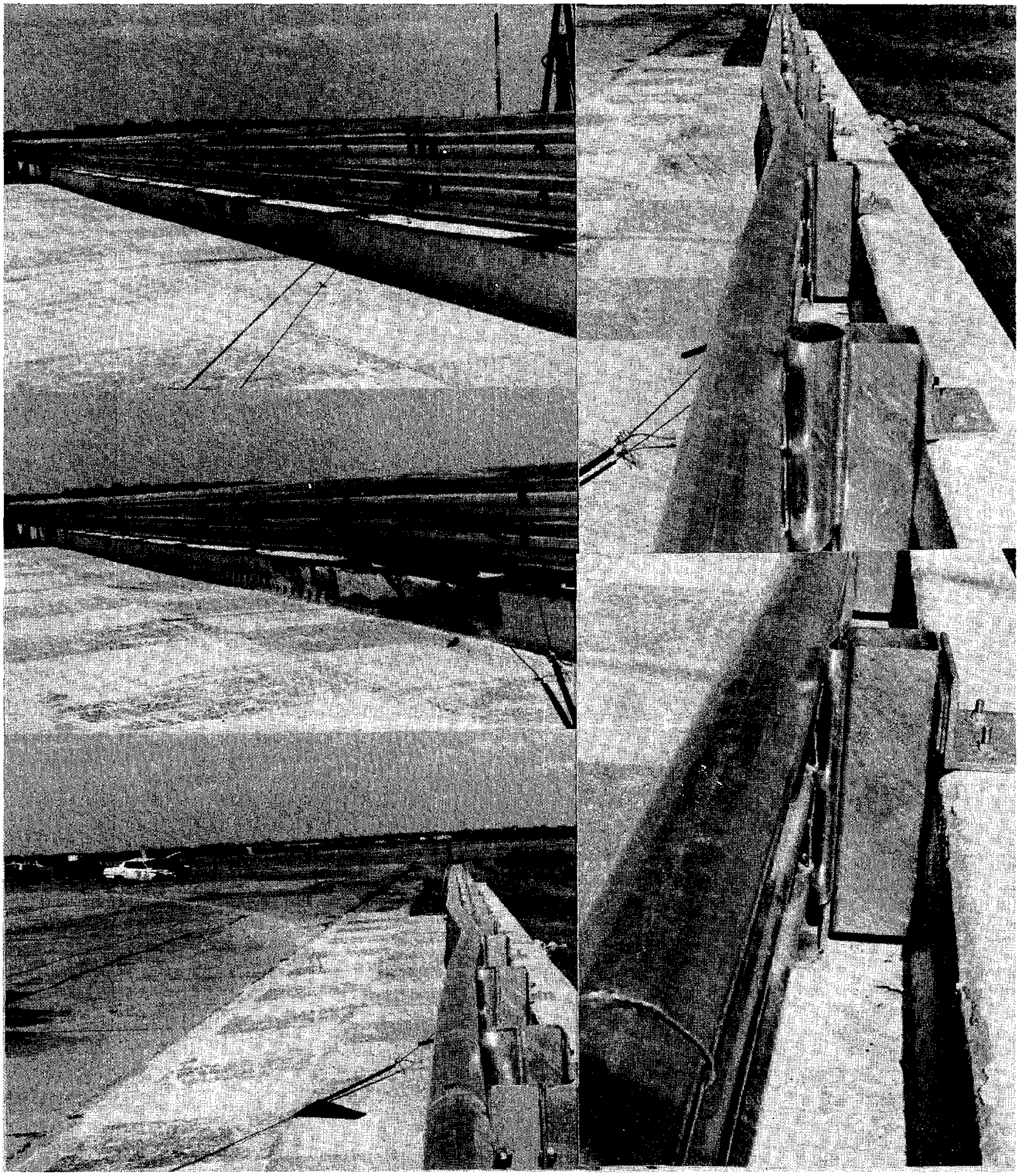


FIGURE 33. VIEWS OF TEST RF-2 INSTALLATION DAMAGE

FIGURE 34. VIEWS OF VEHICLE BEFORE AND AFTER TEST RF-2

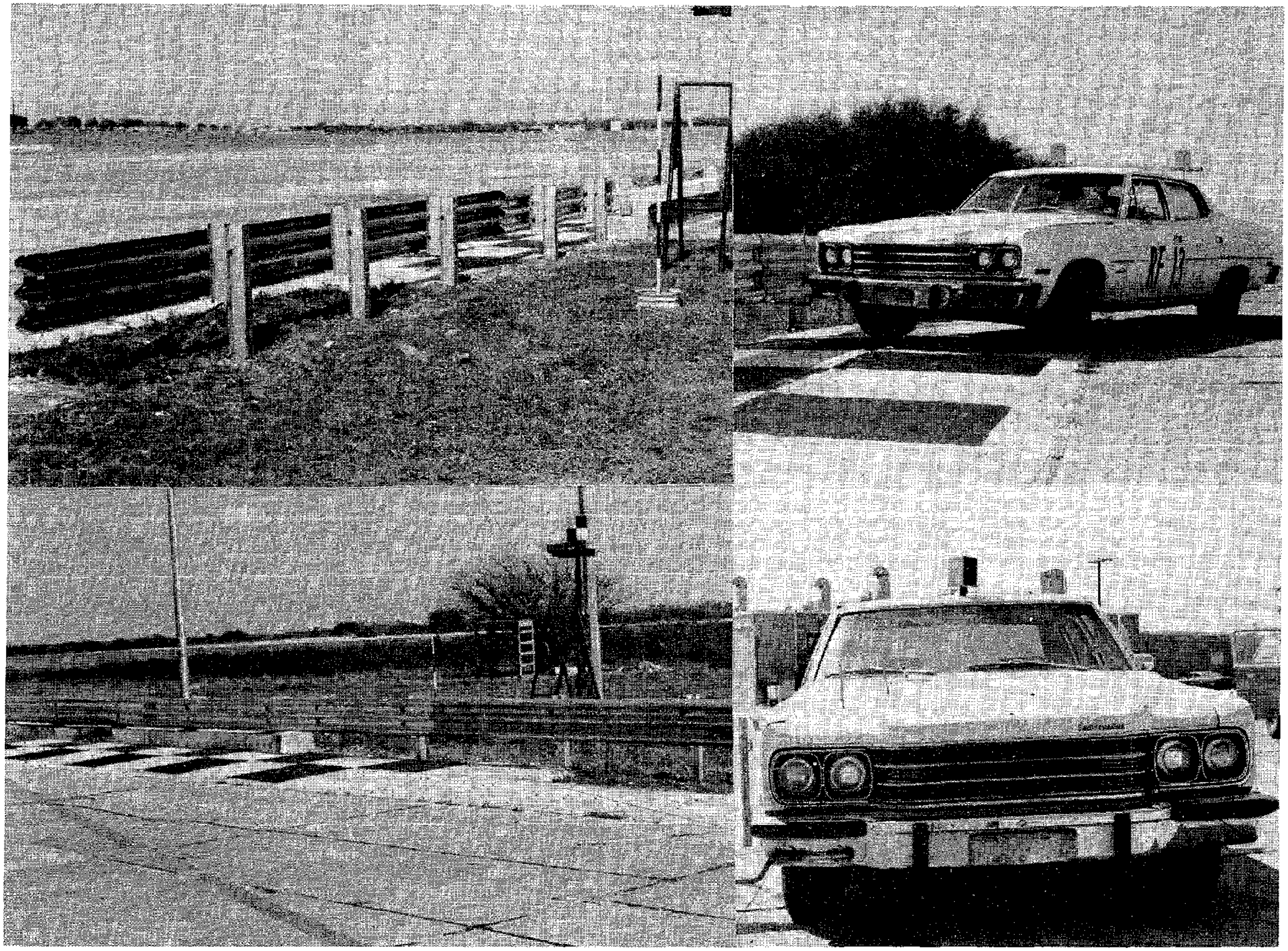
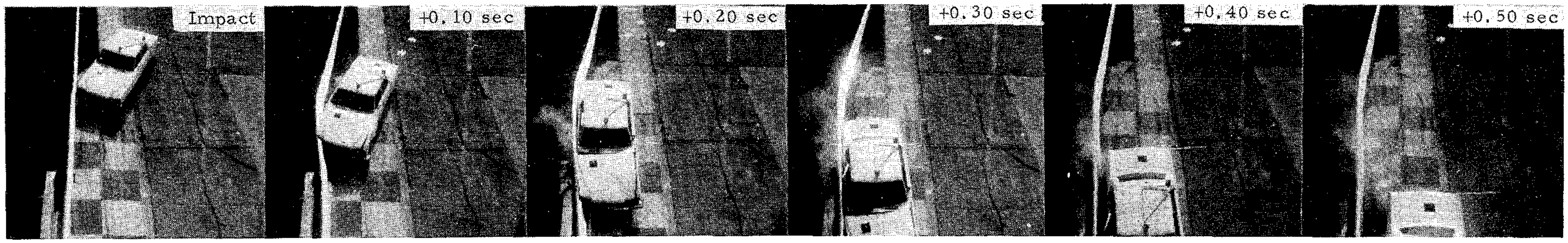
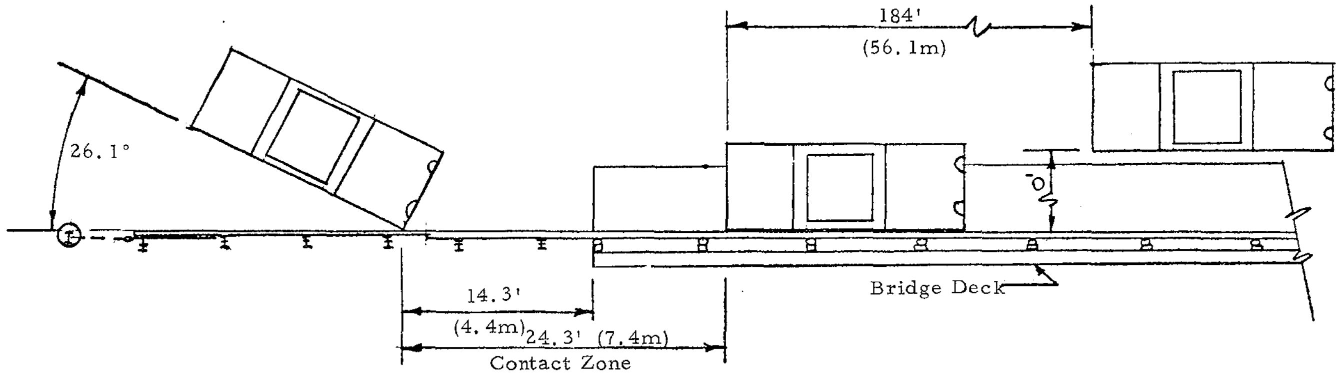
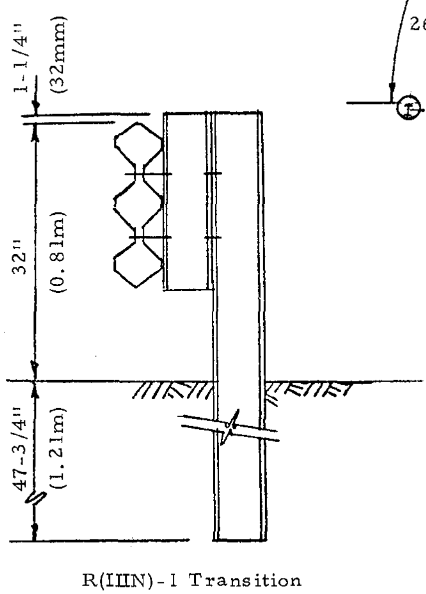


FIGURE 35. VIEWS OF VEHICLE AND INSTALLATION PRIOR TO TEST RF-13







Test No. RF-13
Date 3/2/76
Drawing .... SwRI No. 03-3717-22
Rail .... Tubular Thrie
Parapet .... n.a.
Length of Installation ... 306 ft (93.3m)
Pavement Condition .... Dry
Vehicle ...... 1974 AMC Ambassador
Vehicle Mass .... 4500 lb (2041kg)
(w/instrumentation)

Impact Speed ...... 65.1 mph (29.1m/s)
Exit Speed .... 43.9 mph (19.6m/s)
Impact Angle .... +26.1 deg
Exit Angle .... -0.7 deg
Vehicle Accel (max 50 ms avg)
Lateral (cine/elect) .... -7.1g/-8.7g
Long. (cine/elect)........-5.4g/-7.2g
Resultant (cine/elect) ... -8.7g/10.7g
Vehicle Rebound Distance ... 12 ft (3.7m)
Vehicle Damage
TAD 1-RFQ-6
VDI 01RFES5
Max. Rail Deflection ... 2.8 ft (0.84m)/
(dynamic/permanent) 1.5 ft (0.48m)

FIGURE 36. SUMMARY OF TEST RF-13 RESULTS

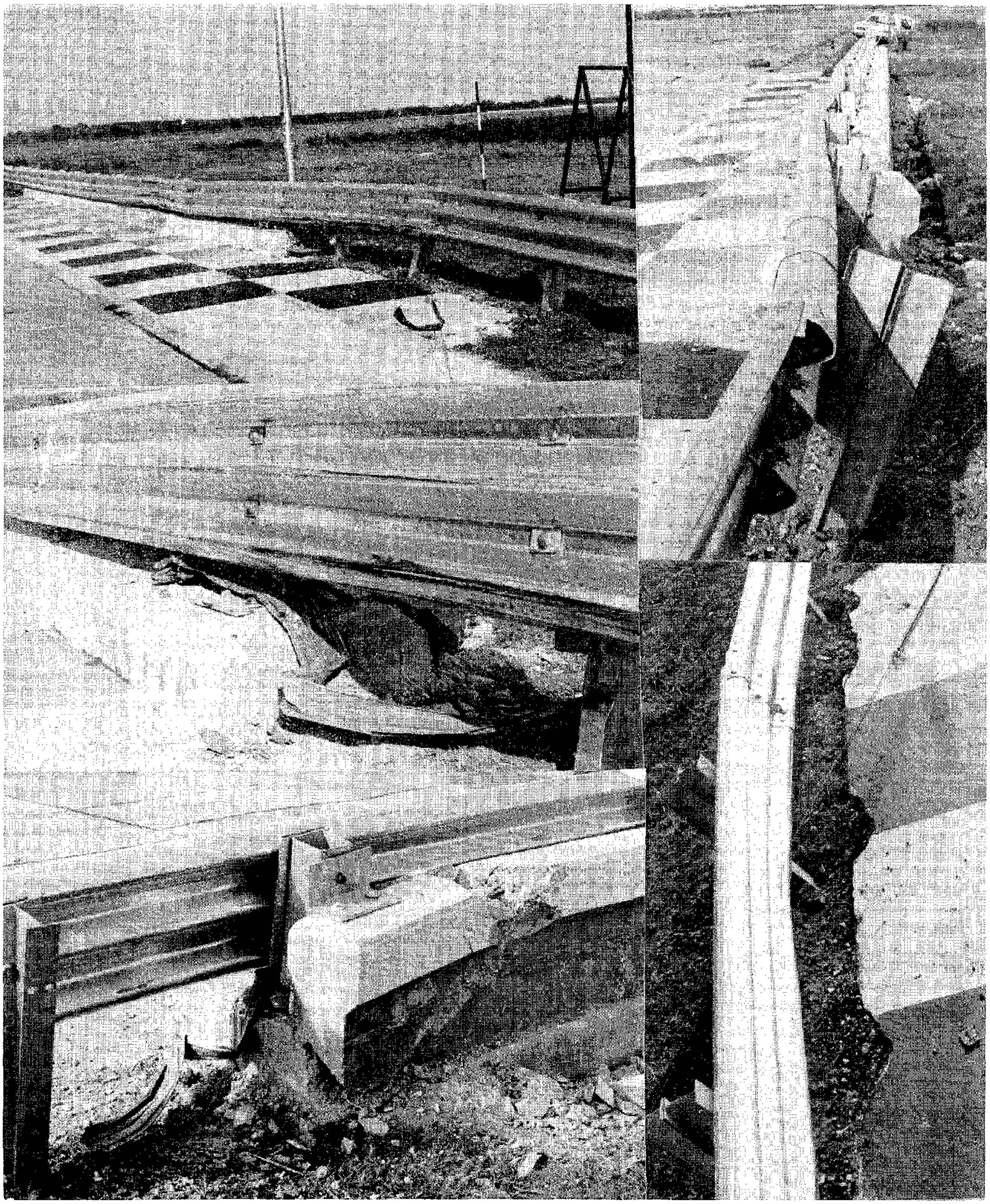


FIGURE 37. VIEWS OF TEST RF-13 INSTALLATION DAMAGE

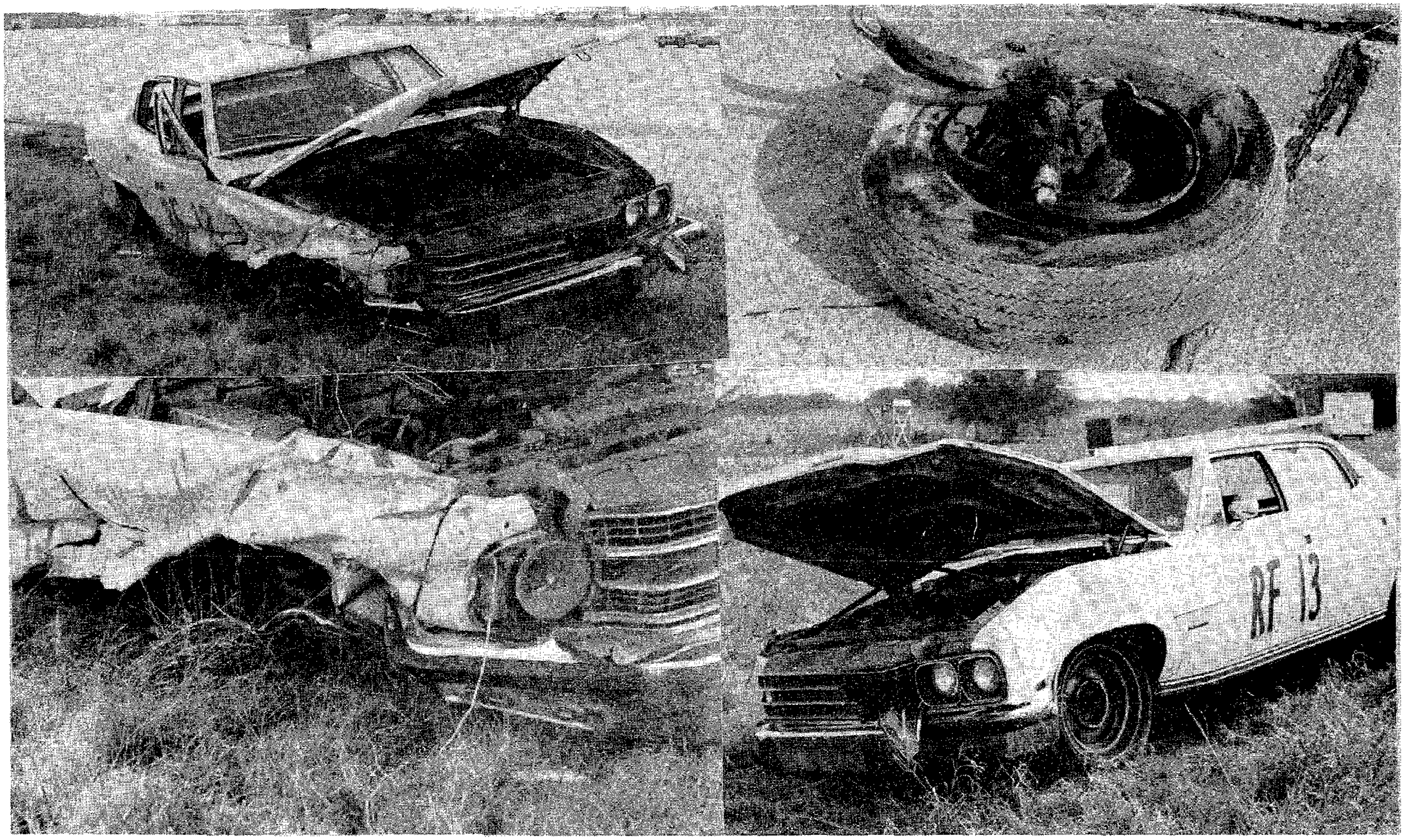


FIGURE 38. VIEWS OF TEST RF-13 VEHICLE DAMAGE

Redirection Severity. Vehicle accelerations were about equal to the baseline case. However, the small car in RF-1 was very stable throughout the redirection, whereas the vehicle in RF-8 (baseline) was unstable and appeared at the verge of rolling over.

Transition. The installation performed in an acceptable manner as the vehicle was contained and smoothly redirected. The walk end, which was left unmodified, became exposed as the barrier deflected and caused extensive damage to the car. It is recommended that for field installations, the curb be flared away from the pavement to prevent possible vehicle snagging.

E. Category IIIN Retrofit—R(IIIN)-2 Design

1. Design Features

The design, as shown in Figure 39, consists of two 6-7/8-in. (0.17 m) deep, semi-elliptical aluminum rails with mounting heights of 15 and 27 inches (0.38 and 0.69 m). The rails are blocked out from the concrete parapet with rigid brackets spaced at 8-ft (2.4 m) centers. Engineering properties of the rail sections are contained in Figure 39. The traffic face of the rail is about on the curb line; for walks of other widths, the bracket geometry would require adjustment in order to maintain the approximate alignment of the rails and curb. Attachment of the brackets to the Category IIIN installation is provided by six, 3/4-in. (19.0 mm) dia anchor bolts embedded 6 in. (0.15 m) into the concrete parapet and walk.

The transition from the approach guardrail to the bridge railing is effected by a stepped reduction in soil-mounted post spacing from 8 to 3 ft (2.4 to 0.9 m) and the use of posts with soil bearing plates.

Engineering details of the R(IIIN)-2 design are contained in Appendix A; views of the installation prior to testing are contained in Figure 40.

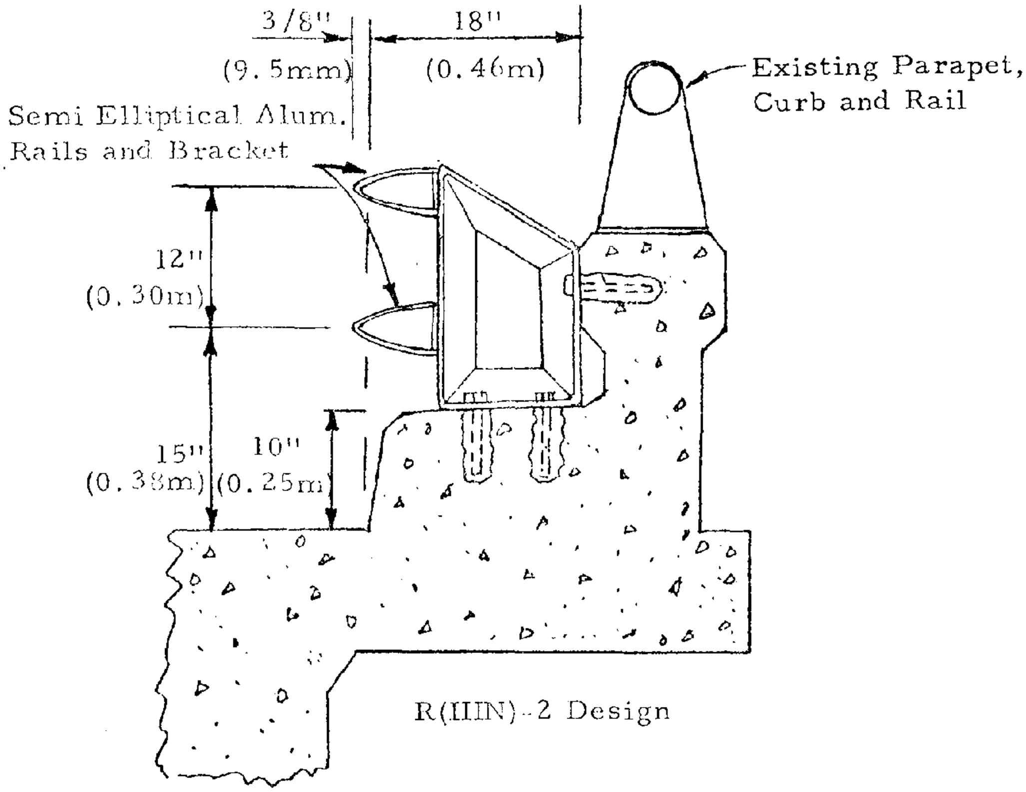
2. Crash Test Evaluation

Test RF-10. Impact conditions for the 4352-lb (1974 kg) car were 60.0 mph (26.8 m/s) and 21.7-deg angle. Point of impact was 11 ft (3.4 m) from bridge rail end. The vehicle remained in hard contact with the aluminum rails for approximately 13 ft (4.0 m) and then exited from the installation at an angle of 3.5 deg. During redirection, the vehicle appeared stable, exhibiting little tendency to pitch or roll. After leaving the rail, the vehicle continued in a trajectory parallel to the bridge rail, with a rebound distance of 15 ft (4.6 m).

A summary of test results is contained in Figure 41. Vehicle redirection was smooth. Maximum 50-ms average vehicle accelerations determined from high-speed cine data were 5.9-g lateral and −4.2-g longitudinal.

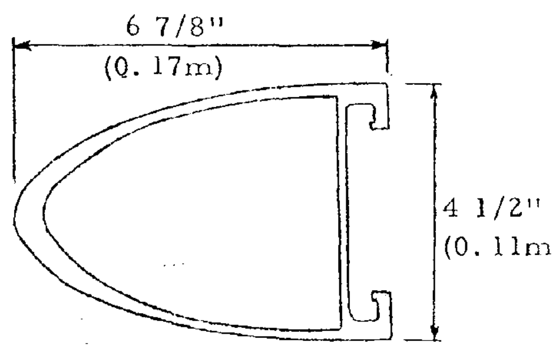
Vehicle and installation damage is shown in Figure 42. Bridge rail damage was minor and consisted of scuffing concrete curb and aluminum rails; no permanent deformation of aluminum rails or support brackets was detected. Damage to the right front panel and wheel assembly disabled the vehicle.

Test RF-11. No repairs were made to the installation after Test RF-10. Impact conditions for the 2050-lb (930 kg) car were 64.5 mph (28.8 m/s) and 15.1-deg angle; the point of impact was 23.5 ft (7.2 m) from the upstream end of the bridge. The vehicle was smoothly redirected and



R(IIIN)-2 Design

Section Properties:
- I_{xx} = 27.02 in.^{4} (1.12 x 10^{-5} m^4)
- S_{xx} = 7.85 in.^{3} (1.29 x 10^{-4} m^3)
- Area = 4.90 in.^{2} (3.16 x 10^{-3} m^2)
- Weight = 5.76 lb/ft (8.57 kg/m)
- Alum. Alloy = ASTM B221, Alloy 6061-T6 or 6351-T5



Rail Section

FIGURE 39. FEATURES OF THE R(IIIN)-2 DESIGN

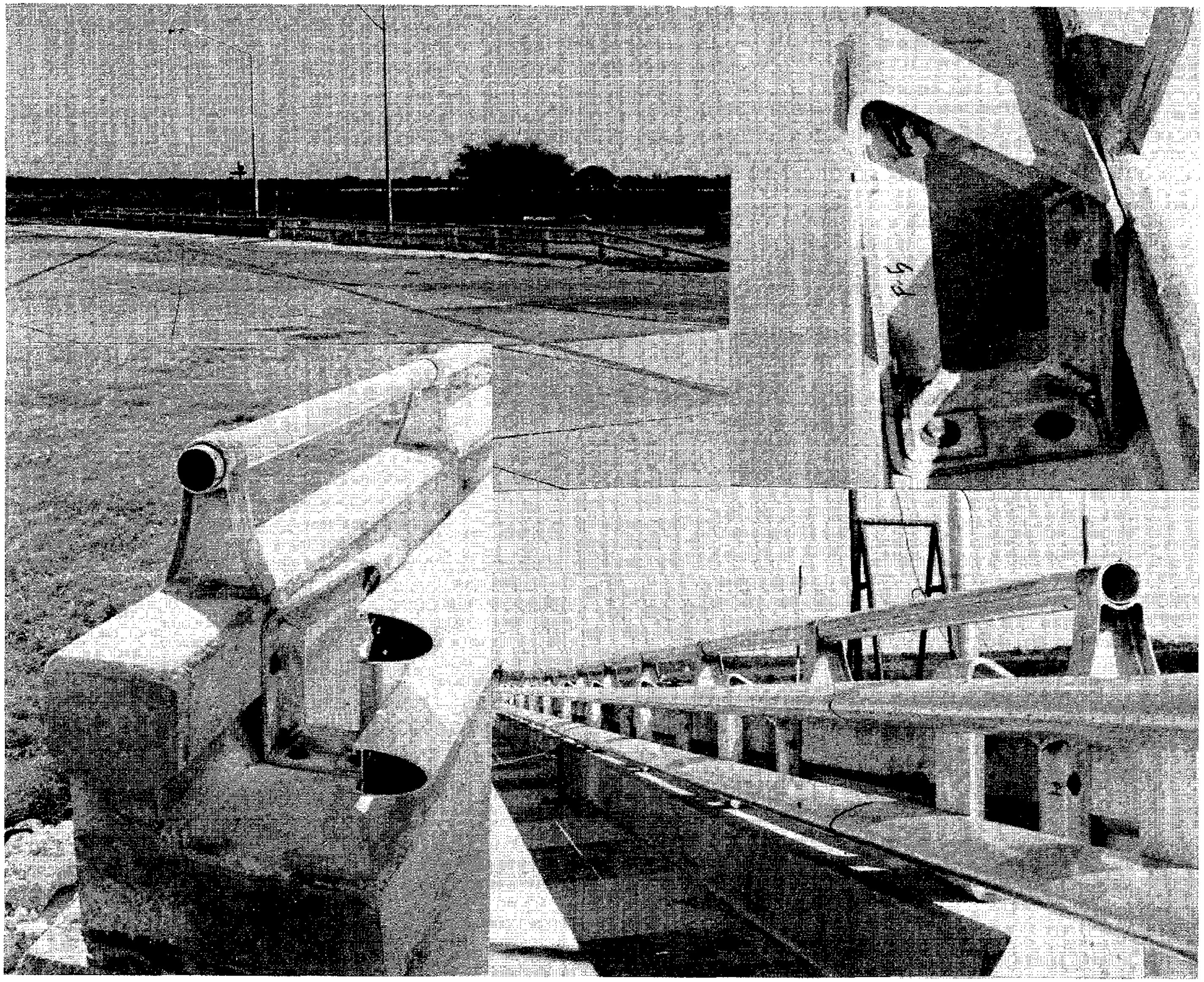
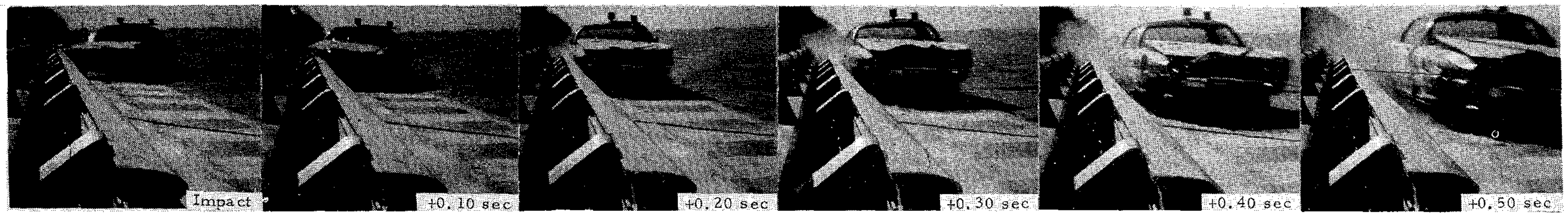
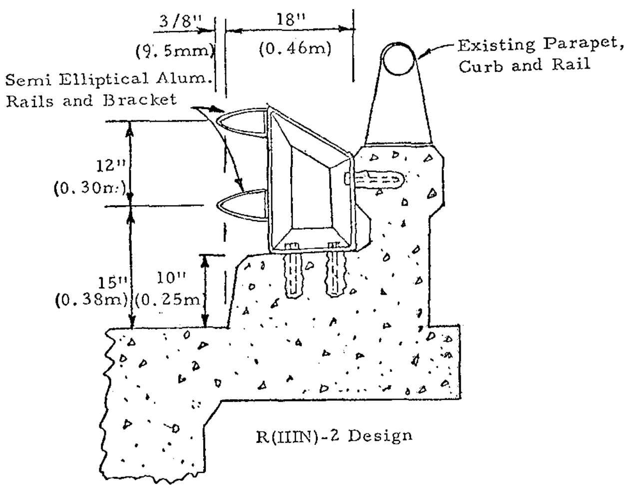
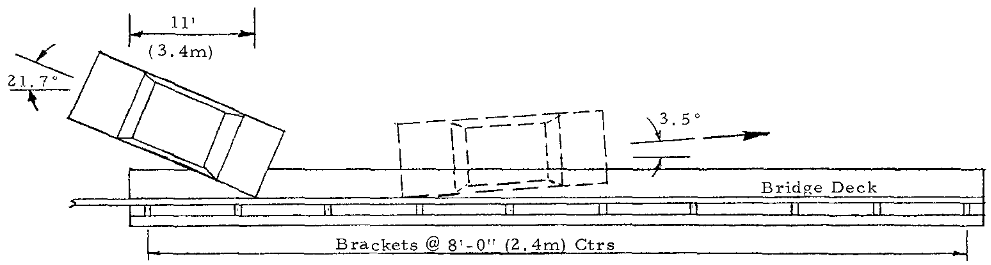


FIGURE 40. VIEWS OF INSTALLATION PRIOR TO TEST RF-10







Test No. RF-10	Impact Speed ...... 60.0 mph (26.8m/s)
Date 12/2/75	Impact Angle .... +21.7 deg
Drawing .... SwRI 03-3717-17	Exit Angle .... -3.5 deg
Rail .... Semi Elliptical Alum Alloy 6061-T6 or 6351-T5	Vehicle Accel (max 50 ms avg)
Parapet. 25-in. (0.64m) conc. with 10 in. (0.25m) high x 18-in. (0.46m) wide walk	Lateral (cine/elect) ...... -5.9g/n.a.
Length of Installation ....153.5 ft (46.8m)	Long. (cine/elect) ...... -4.2g/n.a.
Pavement Condition .... Dry	Resultant (elect) .... n.a.
Vehicle .... 1969 Chrysler	Vehicle Rebound Distance ... 15 ft (4.6m)
Vehicle Mass .... 4352 lb (1974kg) (w/instrumentation)	Vehicle Damage
	TAD 1-FR-6
	VDI 1FREW5
	Max. Rail Deflection .... 0 (dynamic/permanent)

FIGURE 41. SUMMARY OF RF-10 TEST RESULTS

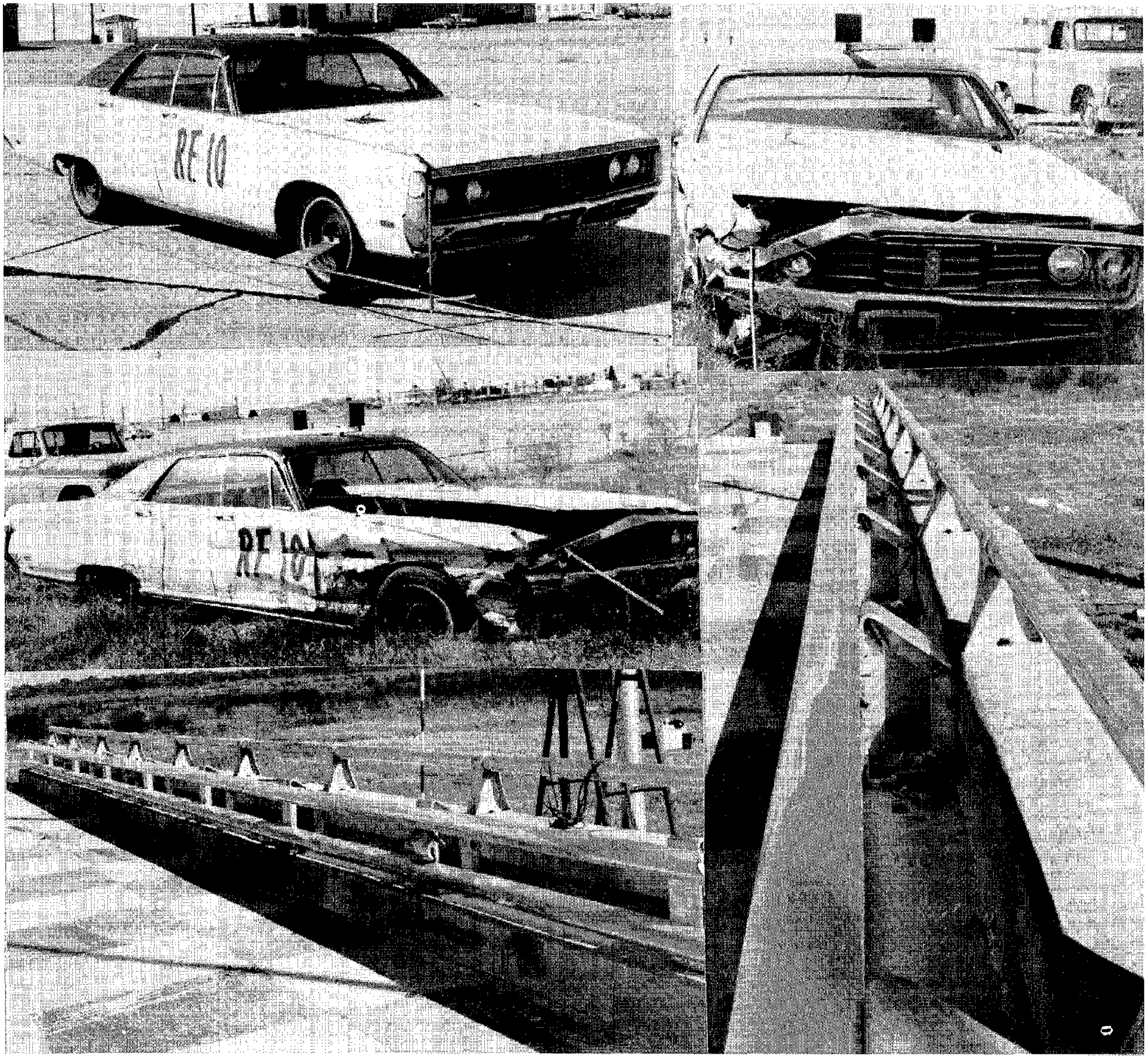


FIGURE 42. VEHICLE AND INSTALLATION DAMAGE SUSTAINED IN TEST RF-10

showed no tendency to roll or pitch. As evidenced by rail and curb scuff marks, the vehicle was in hard contact with the installation for a distance of 9.5 ft (2.9 m). After the vehicle exited at an angle of 9.0 deg, it traveled in a trajectory nearly parallel to the test installation with a maximum rebound distance of 10 ft (3 m). Maximum 50-ms average vehicle accelerations were –5.9 and –10.5-g lateral for high-speed cine and electronic data, respectively, and –3.8 and –6.2-g longitudinal for cine and electronic data, respectively; maximum resultant was 12.2 g. A summary of RF-11 test results is presented in Figure 43.

Installation and vehicle damage is shown in Figure 44. Bridge rail damage was minor and consisted of scuffing of concrete curb and the two aluminum rails. No permanent deformation of the rails was detected. Vehicle damage was confined to the right front panel. After sheet metal was bent away from wheel contact, the vehicle was operable and could have been driven at least a short distance from the collision site.

Test RF-12. No repairs to the installation were made after Test RF-11; views of the installation and car are shown in Figure 45. Impact conditions for the 4423-lb (2006 kg) car were 79.6 mph (35.6 m/s) and 19.9-deg angle. Point of impact was 27 ft (8.2 m) upstream from the bridge and between posts 5 and 6 (posts are numbered consecutively from the upstream end). The vehicle remained in hard contact with the installation for a distance of 25.0 ft (7.6 m), as determined by scuff marks on the rails, and then departed the installation at an angle of 8.1 deg. The vehicle right front wheel was trapped under the lower rail at post 2 and was stripped from the car. A peak longitudinal acceleration of 25.6 g occurred at 0.27 s after initial impact, and this peak probably corresponds with the wheel snagging event. After leaving the rail, the vehicle veered in a long arc, coming to a stop with a rebound distance of 105 ft (32 m).

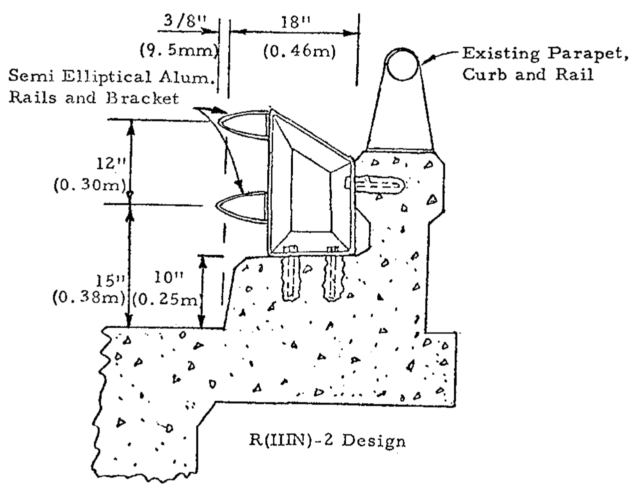
A summary of test results is presented in Figure 46. Maximum 50-ms average vehicle accelerations were –8.2/–9.1-g lateral and –5.9/–7.6-g longitudinal for high-speed cine and electronic data, respectively. Even though wheel snagging occurred, with attendant high instantaneous vehicle acceleration, the 50-ms average values were not overly affected. Moreover, the vehicle redirection appeared smooth, as evidenced by the gradual variation in longitudinal acceleration throughout the impact sequence.

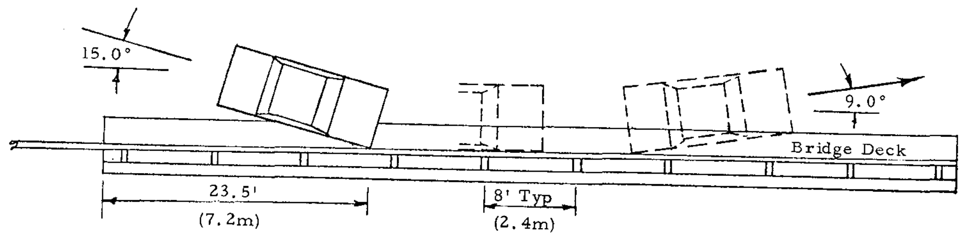
Vehicle and installation damage is shown in Figures 47 and 48. Two rail sections, one each top and bottom, were severely bent and would require replacement. In addition, five posts were damaged to the extent that they would require replacement for a similar in-service collision. Vehicle damage to the right front panel was considerable, with the wheel being stripped from the suspension system. No passenger compartment intrusion was noted. This damage is considered typical in view of the high impact speed.

3. Appraisal of R(IIN)-2 Design

Structural Adequacy. In comparing test RF-10 to the baseline test, RF-9, both vehicles were contained and smoothly redirected by the installation. Considerable damage was sustained by the baseline installation (see Section IV.C), whereas only minor scuffing of the curb and rails occurred in the retrofit case.

Redirection Severity. Vehicle accelerations were higher for the retrofit design (RF-11) than for the baseline case (RF-8), and the lateral acceleration of –10.5 g exceeds the acceptable value recommended in NCHRP *Report 153*. On the other hand, redirection of the small car was smooth and the vehicle was stable throughout redirection, exhibiting little tendency to roll or pitch.





Test No.	RF-11
Date	12/10/75
Drawing	SwRI 03-3717-17
Rail	Semi Elliptical Alum Alloy 6061-T6 or 6351-T5
Parapet	.25-in. (0.64m) conc. with 10-in. (0.25m) high x 18-in. (0.46m) wide walk
Length of Installation	153.5 ft (46.8m)
Pavement Condition	Dry
Vehicle	1970 Opel Kadette
Vehicle Mass (w/instrumentation)	2050 lb (930kg)

Impact Speed	64.5 mph (28.8m/s)
Impact Angle	+15.1 deg
Exit Angle	-9.0 deg
Vehicle Accel (max 50 ms avg)	
Lateral (cine/elect)	-5.9g/-10.5g
Long. (cine/elect)	-3.8g/ -6.2g
Resultant (elect)	12.2g
Vehicle Rebound Distance	10 ft (3m)
Vehicle Damage	
TAD	1-FR-4
VDI	1FREW3
Max. Rail Deflection (dynamic/permanent)	0

FIGURE 43. SUMMARY OF TEST RF-11 TEST RESULTS

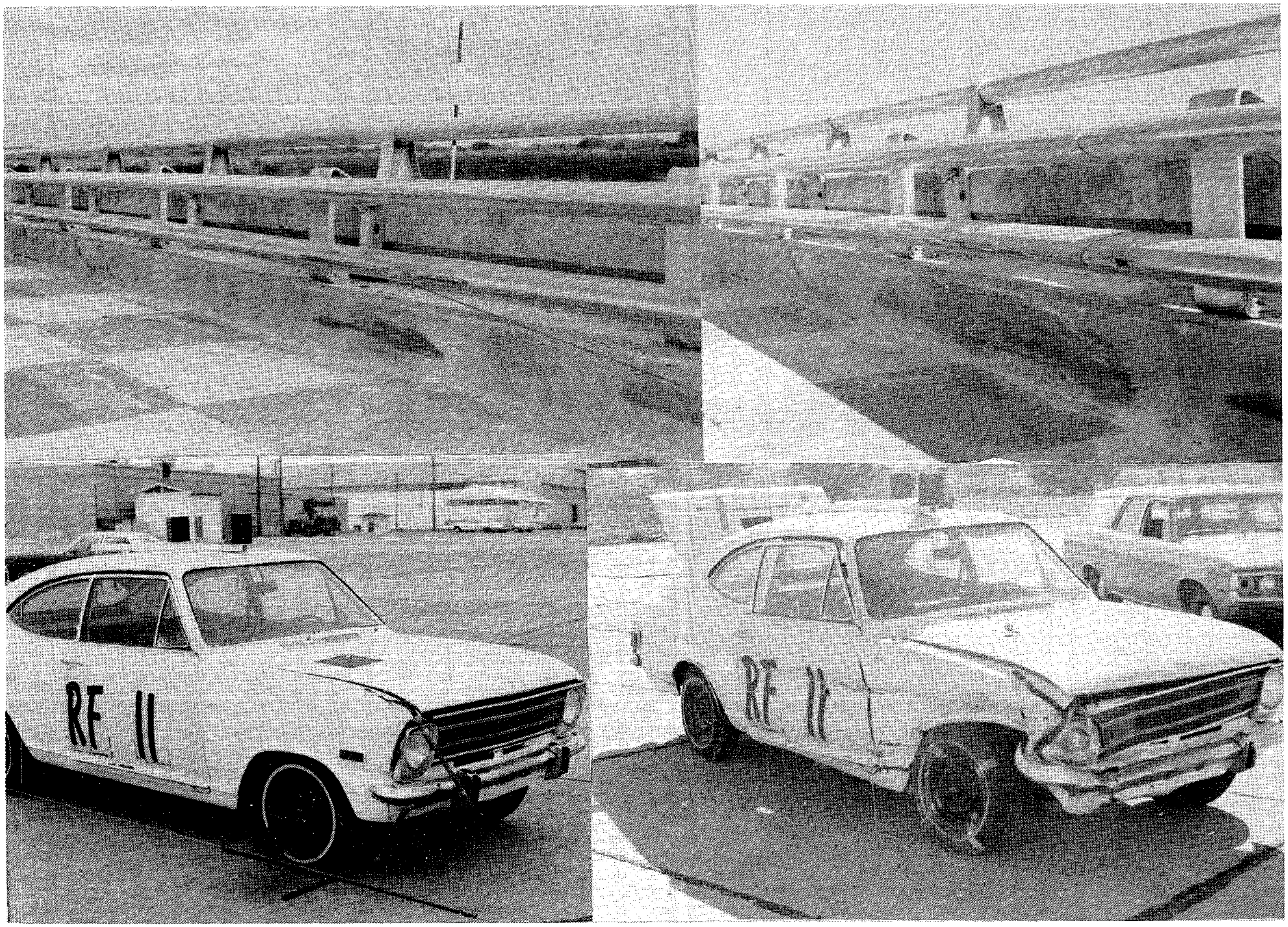


FIGURE 44. BARRIER AND VEHICLE BEFORE AND AFTER TEST RF-11

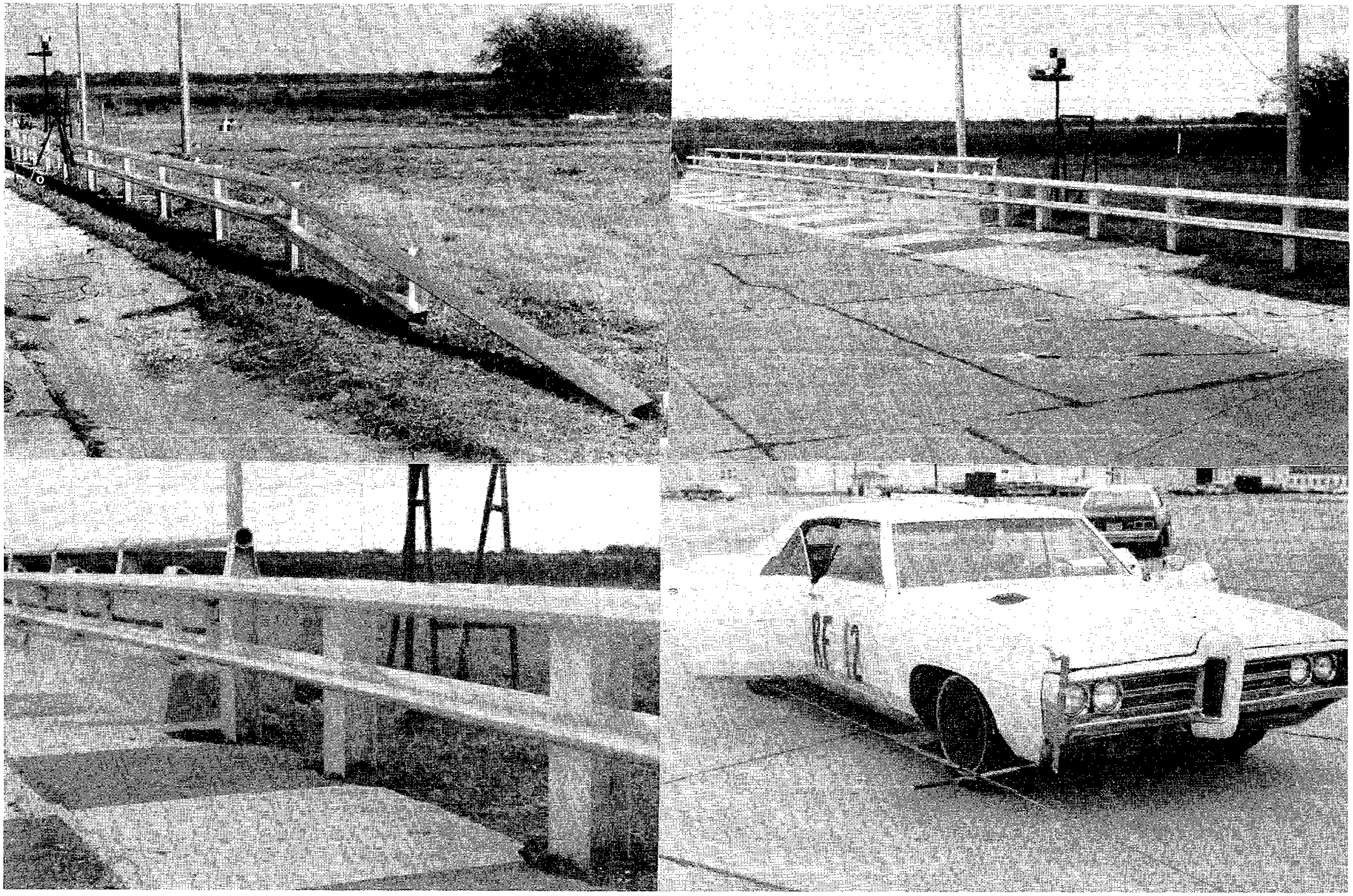
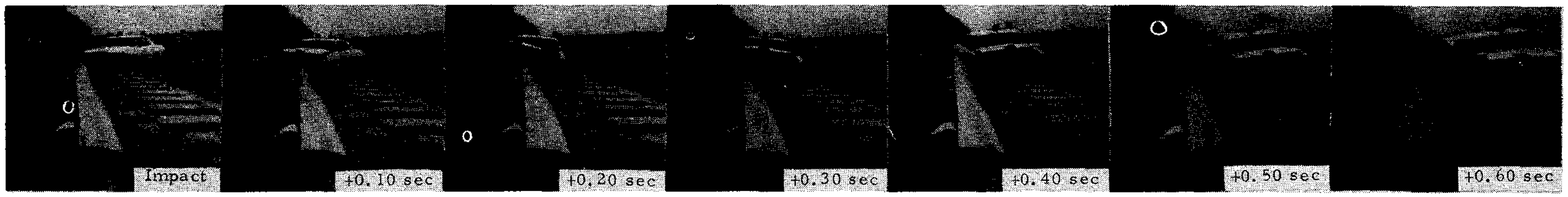
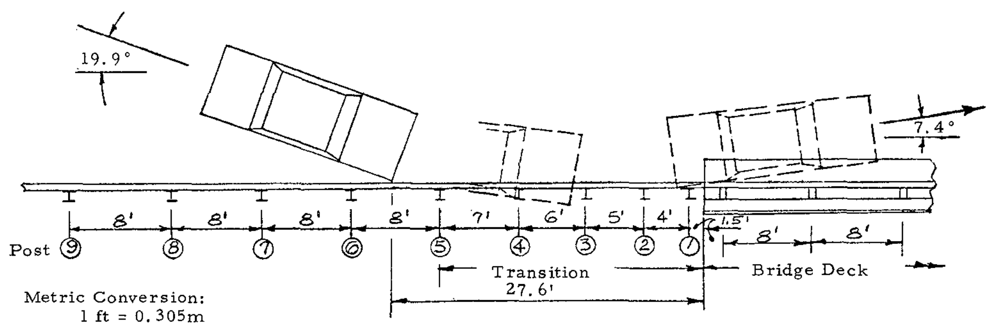
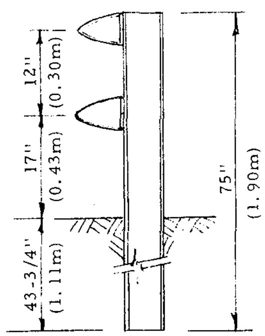


FIGURE 45. INSTALLATION AND VEHICLE PRIOR TO TEST RF-12







R(IIIN)-2 Transition

Test No.	RF-12
Date	12/12/75
Drawing	SwRI 03-3717-17
Rail	Semi Elliptical Alum Alloy 6061-T6 or 6351-T5
Parapet	25-in. conc with 10-in. high x 18-in. wide walk
Length of Installation	153.5 ft (46.8m)
Pavement Condition	Dry
Vehicle	1969 Pontiac Bonneville
Vehicle Mass (w/instrumentation)	4423 lb (2006 kg)

Impact Speed	79.6 mph (35.6 m/s)
Impact Angle	19.9 deg
Exit Angle	-8.1 deg
Vehicle Accel (max. 50 ms avg)	
Lateral (cine/elect)	-8.2g/-9.1g
Long. (cine/elect)	-5.9g/-7.6g
Resultant (elect)	10.8g
Vehicle Rebound Distance	105 ft (32m)
Vehicle Damage	
TAD	1-FR-7
VDI	1FREW7
Max. Rail Deflection (dynamic/permanent)	2.7/1.2 ft (0.8/0.4m)

FIGURE 46. SUMMARY OF CRASH TEST RF-12 RESULTS

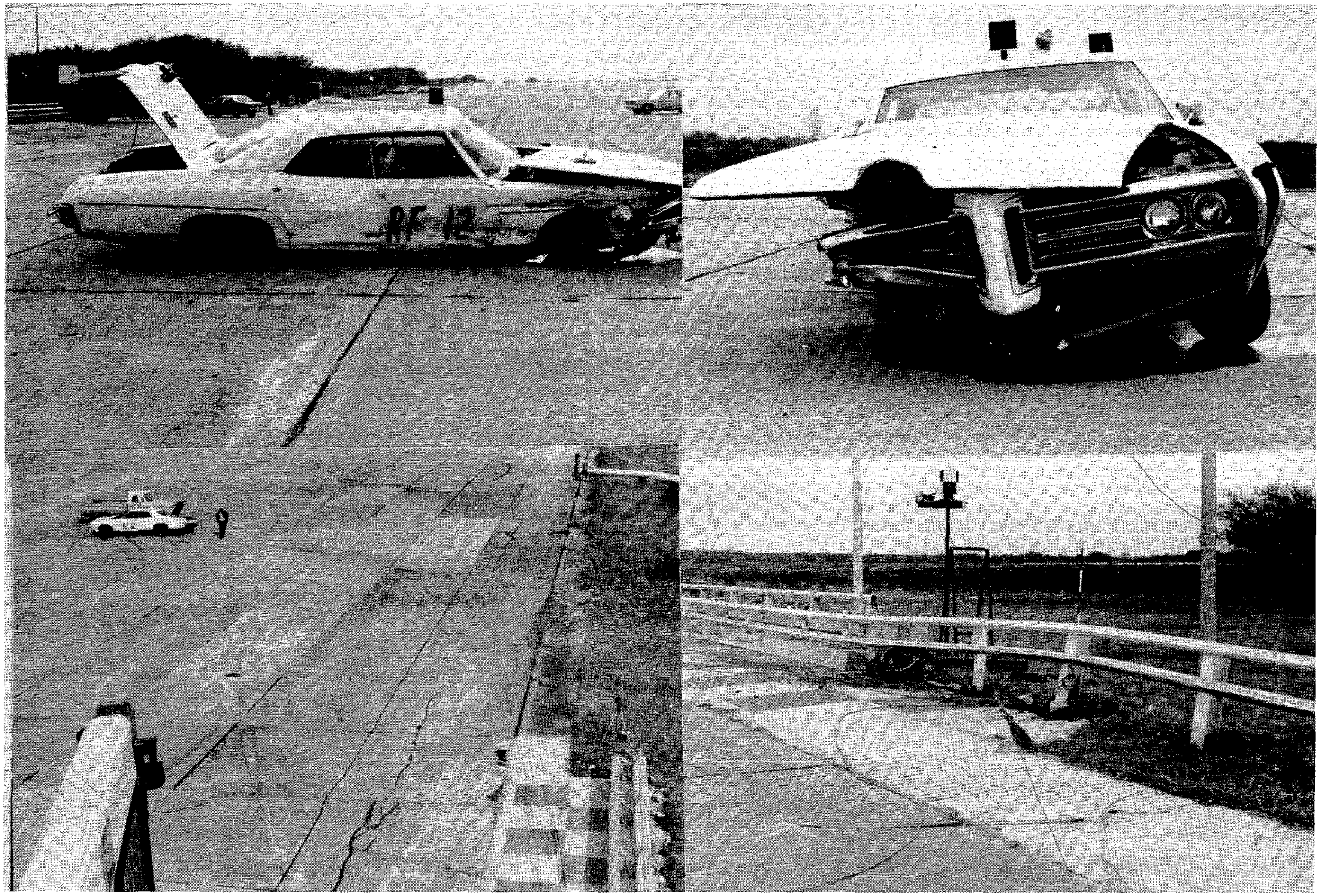


FIGURE 47. VEHICLE DAMAGE SUSTAINED IN TEST RF-12

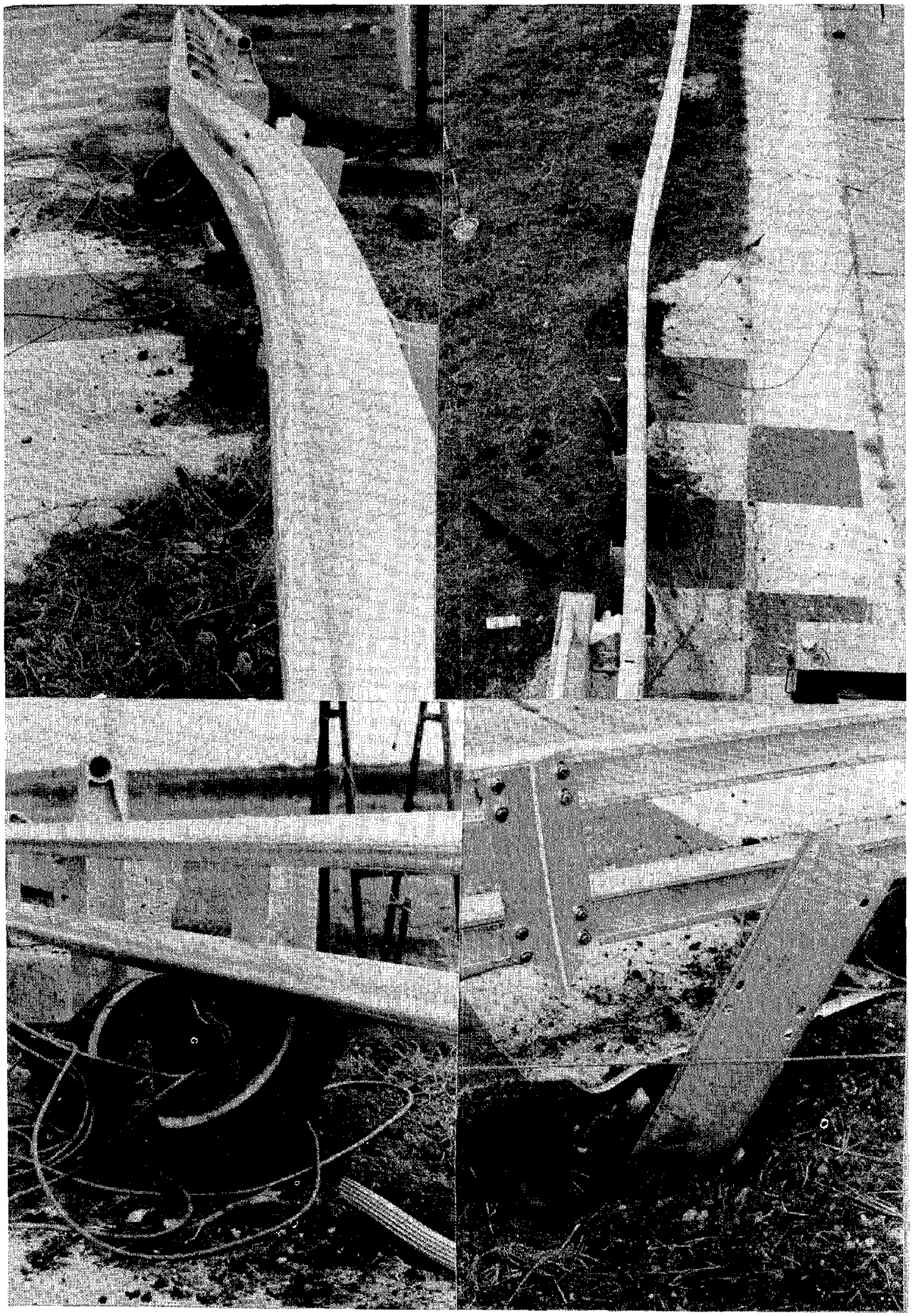


FIGURE 48. INSTALLATION DAMAGE SUSTAINED IN TEST RF-12

In contrast, the vehicle in RF-8 climbed high on the parapet and reached a most unstable attitude during redirection and may have rolled over had the impact conditions been slightly changed or had the installation been longer.

Vehicle and installation damage was minimum for both cases and comparable.

Transition. Since the test is essentially a structural adequacy experiment, the installation performed in an acceptable manner as the vehicle was contained and smoothly redirected even though the impact speed was nearly 80 mph (35.8 m/s). The vehicle was stable throughout the impact and redirection sequence, although the right front wheel was stripped from the car; the loss of the wheel is attributed to the excessive impact speed. Installation damage consisted of two deformed rails and five posts that would require replacement. Vehicle damage was severe but is considered representative for this type of test.

In summary, the R(IIIN)-2 design increases the redirection severity because of its rigidity and thus may increase hazard for the small car type of accident. However, the retrofit improves the vehicle containment capability of the baseline structure and should eliminate vehicle vaulting accidents with the Category IIIN installations that have been reported. The retrofit transition design performed in an acceptable manner.

The upstream terminal for the approach rail has not been tested according to guidelines of NCHRP *Report 153*. These tests were beyond the program scope.

F. Category IIIN Retrofit—R(IIIN)-3 Design*

1. Design Features

In establishing profile geometry of the R(IIIN)-3 design, four candidate profiles were formulated and evaluated with the use of the HVOSM computer program. Profiles of the four candidates are shown in Figure 49.

HVOSM predicts the trajectory and dynamics of a vehicle during and after impact with a highway barrier. These results will vary with vehicle size and properties and impact speed and angle. In accord with recommendations of NCHRP *Report 153*[8], two vehicle types were used: 2250- and 4500-lb (1021- and 2041-kg) cars. Four concepts and 21 HVOSM cases were performed; the HVOSM case matrix is shown in Table 10.

Results of computer simulations are presented in Table 11. Although the HVOSM produces extensive documentation on the vehicle dynamics and kinematics, the three most important performance factors are (1) vehicle lateral accelerations, (2) vehicle longitudinal accelerations, and (3) vehicle roll angle. Presently, the goal of barrier designers is to keep the maximum vehicle accelerations under 5-g lateral and 10-g longitudinal and to maintain the vehicle in an upright and stable condition, i.e., minimum roll.

Concept A subjects the small car to high lateral accelerations, 11.9 g; a second run with minor modifications to the profile resulted in higher lateral acceleration (−13.7 g). Both lateral and longitudinal accelerations are low for Concept B; however, the roll angle is high for the 15-deg impacts. Concept C would probably roll a large number of small cars. Concept D produces minimum roll in all vehicles, although lateral acceleration in the small-car impact is somewhat high (−8.1 g).

*Design, analysis and crash test evaluation of this design was funded by the Louisiana Department of Highways.

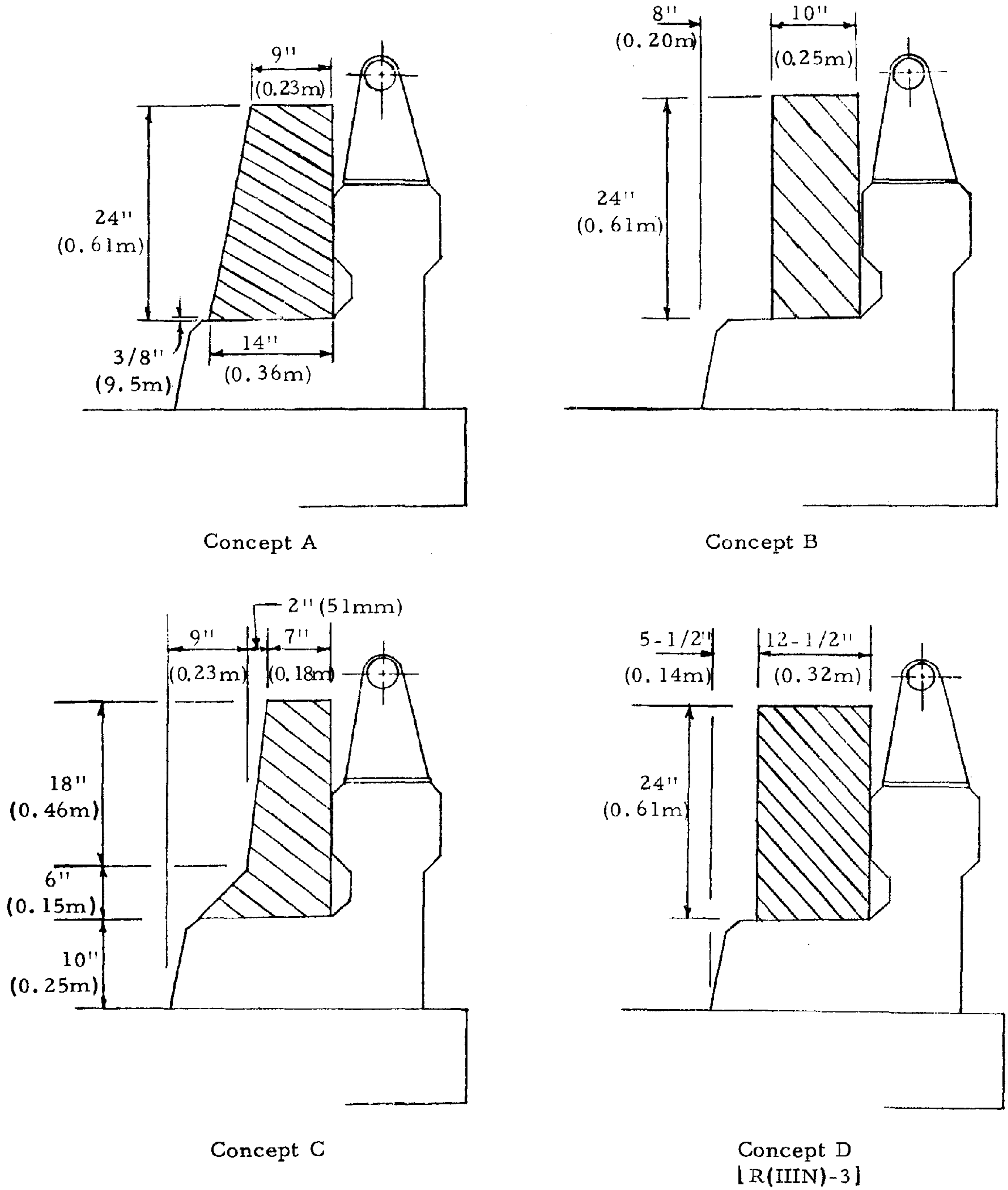


FIGURE 49. GEOMETRY OF MODIFICATION CONCEPTS

TABLE 10

CASE MATRIX FOR HVOSM STUDIES

Case No.	Barrier Concept	Weight (lb)	Speed (mph)	Angle (deg)	Remarks
1	A	2250	60	7	
2	A	2250	60	15	
3	A	2250	60	15	Adjust profile geometry
4	A	4500	60	7	
5	A	4500	60	15	
6	A	4500	60	15	Adjust profile geometry
7	B	2250	60	7	
8	B	2250	60	15	
9	B	4500	60	7	
10	B	4500	60	15	
11	B	4500	60	15	Adjust profile geometry
12	C	2250	60	7	
13	C	2250	60	15	
14	C	4500	60	7	
15	C	4500	60	15	
16	D	2250	60	7	
17	D	2250	60	15	
18	D	4500	60	7	
19	D	4500	60	15	
20	Baseline	2250	62.7	15.9	Compare to Crash Test RF-8
21	Baseline	4500	60	15	

Metric Conversions:
Multiply lb by 0.454 to obtain kg
Multiply mph by 0.447 to obtain m/s

TABLE 11

SUMMARY OF HVOSM COMPUTER SIMULATIONS OF CATEGORY IIIN BRIDGE RAILING MODIFICATIONS[1]

Vehicle		Vehicle Dynamics														
		Long. Accel. (max 50ms avg), g's					Lat. Accel. (max 50ms avg), g's					Roll Angle (toward/away from barrier), deg				
Wt/Speed (lb/mph)	Angle (deg)	Base Line	A	B	C	D	Base Line	A	B	C	D	Base Line	A	B	C	D
2250/60	7		-0.89	-0.68	-0.65	-1.16		-5.98	-5.98	-6.03	-6.40		~/6.91	~/13.9	~/16.5	~/4.97
	15		-4.08 -4.03	-3.81	-3.27	-3.87		-11.94 -13.70	-5.01	-7.49	-8.13		16.9/11.6 2.7/23.02	30.0/17.5	74/~	10.9/8.3
2250/62.7	15.9	-4.44 (3.7)**					-9.13 (5.30)**					380/~				
4500/60	7		-1.01	-0.73	-0.57	-1.20		-3.79	-4.02	-4.22	-4.45		~/6.18	~/5.79	14.2/2.7	~/6.04
4500/60	15	-1.69	-3.06 -3.63	-2.84 -2.86	-2.72	-3.13	-8.82	-7.11 -8.08	-6.71 -9.38	-7.80	-6.93	8.3/~ 19.4	5.36/15.78* 4.19/6.76*	7.7/19.1* 8.4/26.6	9.2/20.0*	4.6/12.7*
4723/58.3	29.4	(9.6)**					(4.2)**									

(1)See Fig. 49 for modification profiles.
*Max. roll of 0.5s after impact.
**Crash test results.

Metric Conversions:

From these findings, Concept D was selected for evaluation by full-scale vehicle crash tests and subsequently identified as R(IIIN)-3.

Concrete beams with sectional dimensions shown in Figure 49, Concept D, were cast at the test installation using concrete with 3000 psi (2.07×10^7 Pa), 28-day compressive strength. Reinforcing consisted of a No. 4 bar in each corner, and that was continuous for the length of the beam (27.875 ft [8.50 m]); tie bars were No. 4 size and spaced at 26 in. (0.66 m) along the beam. Anchor bolts, 1-in. (25 mm) diameter, were cast into the rear side of the beams 3 in. (76 mm) from the base on typical 8.0-ft (2.4 m) spacings and projected horizontally 12 in. (0.30 m). After a 28-day field cure, the beams were lifted into place on the 16-in. (0.41 m) wide walk and set in a leveling grout with the following design:

Component	Parts
Sand	3
Cement	1
Water	1 to 2
Sika Latex	4 gal. ($0.015\ m^3$)

During setting the beam, the anchor bolts were inserted through a 1-1/2-in. (38 mm) drilled hole in the parapet and locked into place. Details of the test installation are shown in Appendix A.

2. Crash Test Evaluation

Five crash tests were performed to evaluate R(IIIN)-3 performance; test conditions and findings are summarized in Table 12.

Test RF-18. Impact conditions for the 4423-lb (2006 kg) car were 65.3 mph (29.2 m/s) and 7.5-deg angle. The right front wheel of the vehicle scuffed the protruding part of the 10-in. (0.25 m) high curb and mounted it. The right front fender panel then contacted the concrete beam retrofit, and the vehicle was redirected nearly parallel to the installation. After departing the 75-ft (22.9 m) long installation, the vehicle came to rest about 600 ft (183 m) from the point of impact. During redirection, the vehicle was stable, exhibiting little tendency for rolling.

A summary of test data is presented in Figure 50. Maximum 50-ms average vehicle accelerations, calculated from high-speed cine data, were −5.6-g lateral, −6.5-g longitudinal, and 7.9-g resultant.

Installation and vehicle damage are shown in Figure 51. Bridge rail damage was minor and consisted of scuffing of concrete curb and retrofit beam. Subsequent safety performance of the bridge rail would not be impaired by this damage. Damage to the right front panel was minimum and did not affect the driveability of the vehicle.

Test RF-19. The test installation is the same as described in Test RF-18 report. No repairs were performed on the installation after Test RF-18.

Impact conditions for the 4423-lb (2006 kg) car were 60.6 mph (27.1 m/s) and 11.5-deg angle. The right front fender panel contacted the precast beam 16 ft (4.9 m) from the downstream end. As the vehicle was redirected, the right front tire came in contact with the protruding portion

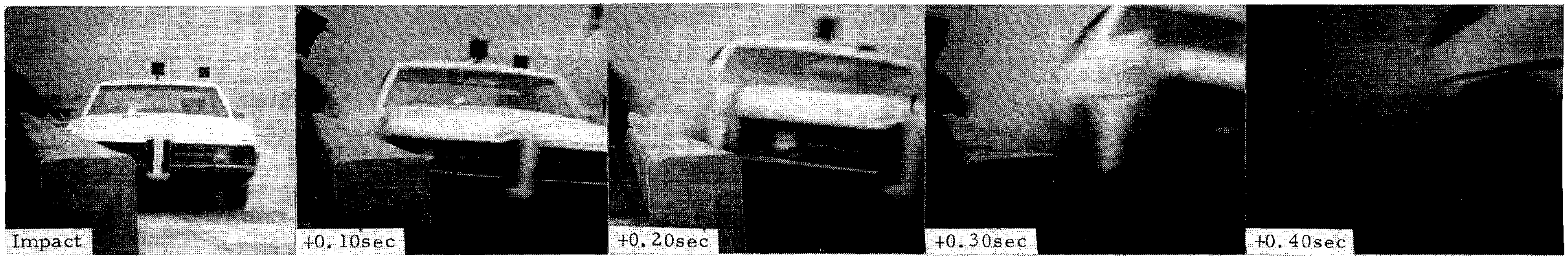
TABLE 12

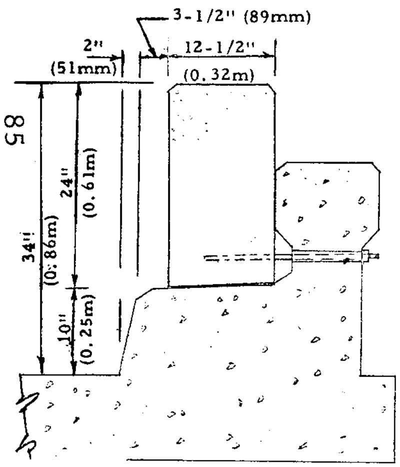
SUMMARY OF FULL-SCALE CRASH TEST RESULTS

	Vehicle Impact Conditions			Vehicle Accelerations[1]-g's (Max. 50ms avg)			Vehicle	Vehicle Damage Indices		Barrier
Test No.	Weight (lb)	Speed (mph)	Angle (deg)	Long.	Lat.	Result.	Max. Roll Angle (deg)[2]	TAD	VDI	Impact Damag
RF-18	4423	65.3	7.5	-2.6	-4.5	5.1	+13	1-RFQ-2	01FRES2	Minor scuffing
RF-19	4423	60.6	11.5	-4.4	-4.9	6.3	+12	1-RFQ-4	01FRES4	Minor scuffing
RF-20	2140	55.4	9.2	-4.3	-8.3	9.4	+14	1-RFQ-2	01FRES2	Minor scuffing
RF-21	2140	44.1	16.2	-5.2	-6.3	8.1	+8	1-RFQ-3	01FRES4	Minor scuffing
RF-22	2140	61.9	18.3	-8.2	-16.1	17.7	+17	1-RFQ-5	01FRES6	Minor scuffing

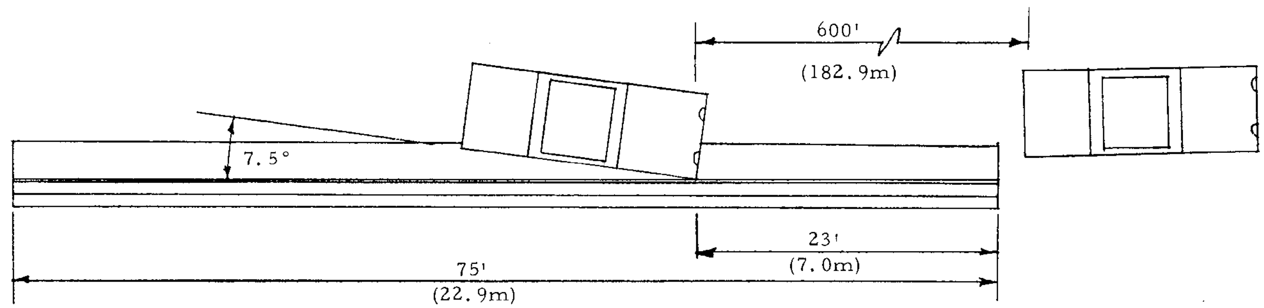
(1)Data from accelerometers
(2)Positive sign is away from the barrier

Metric Conversions:
Multiply lb by 0.454 to obtain kilograms
Multiply mph by 0.447 to obtain m/s





R(IIIN)-3 Design



Test No.	RF-18
Date	12/18/75
Drawing	SwRI 03-3717-25
Rail	Precast Conc. Beam
Parapet	Conc. w/Narrow Walk
Length of Installation	75 ft (22.9m)
Pavement Condition	Dry
Vehicle	1969 Pontiac Bonneville
Vehicle Mass (w/instrumentation)	4423 lb (2006kg)

Impact Speed	65.3 mph (29.2 m/s)
Impact Angle	7.5 deg
Exit Angle	4.8 deg
Vehicle Accel (max 50 ms avg)	
Lateral (cine/elect.)	-5.6g/-4.5g
Long. (cine/elect.)	-6.5g/-2.6g
Resultant (cine/elect.)	7.9g/5.1g
Vehicle Rebound Distance	10 ft (3m)
Vehicle Damage	
TAD	1-RFQ-2
VDI	01FRES2
Max. Rail Deflection (dynamic/permanent)	0/0

FIGURE 50. SUMMARY OF CRASH TEST RF-18 RESULTS

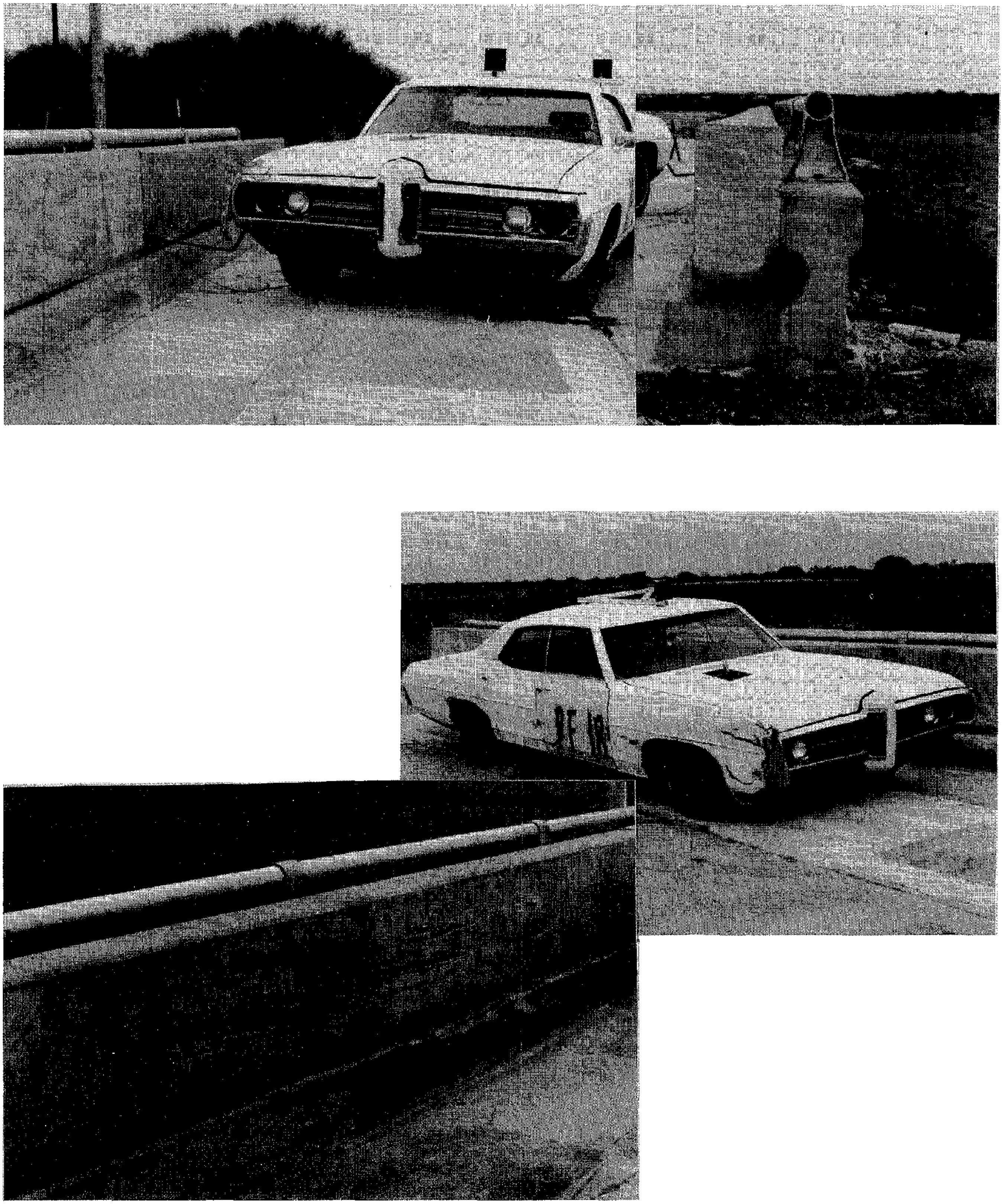


FIGURE 51. VIEWS OF BARRIER AND VEHICLE
BEFORE AND AFTER TEST RF-18

of the 10-in. (0.25 m) high curb, and the wheel climbed the curb; these actions are evidenced by scuff marks on the barrier shown in Figure 52. After departing the 75-ft (22.9 m) long installation, the vehicle traveled about 400 ft (122 m) downstream and toward the traffic side of the barrier 126 ft (38.3 m). During redirection, the vehicle was stable and exhibited little tendency to roll.

A summary of test data is presented in Figure 53. Maximum 50-ms average vehicle accelerations, calculated from accelerometer data, were –4.9-g lateral, –4.4-g longitudinal, and 6.3-g resultant.

Installation and vehicle damage is shown in Figure 52. Bridge rail damage was minor and consisted of scuffing of concrete curb and retrofit beam. Subsequent safety performance of the bridge rail installation would not be impaired by this damage. Damage to the right front panel was moderate, although the vehicle was driveable from the impact site.

Test RF-20. The test installation is the same as described in Test RF-18 report. No repairs were performed on the installation after Test RF-19, although the curb was painted white to highlight vehicle contact marks. Impact conditions for the 2140-lb (971 kg) car were 55.4 mph (24.8 m/s) and 9.2-deg angle. The right end of the front bumper and right front tire contacted the barrier 23.3 ft (7 m) from the upstream end, and the wheel climbed atop the protruding curb element. The vehicle remained in contact with the barrier for 16 ft (4.9 m) and departed the installation at 12 deg. After traveling about 150 ft (45.6 m) from the downstream end of the installation, the vehicle came to rest. During redirection, the vehicle was stable and exhibited little tendency to roll. A summary of test data is presented in Figure 54. Maximum 50-ms average vehicle accelerations, calculated from accelerometer data, were –8.3-g lateral, –4.3-g longitudinal, and 9.4-g resultant.

Installation and vehicle damage is shown in Figure 55. Bridge rail damage was minor and consisted of scuffing of concrete curb and retrofit beam. Subsequent safety performance of the bridge rail would not be impaired by this damage. Damage to the vehicle was a bent front bumper that was slightly jammed into the grill. The vehicle was used in subsequent Test RF-21 without repairs.

Test RF-21. The test installation is the same as described in Test RF-18 report. No repairs were performed on the installation after Test RF-20.

Impact conditions for the 2140-lb (971 kg) car were 44.1 mph (19.7 m/s) and 16.2-deg angle; the vehicle did not attain the desired 60 mph (26.8 m/s). The vehicle right front panel and bumper contacted the installation 20.7 ft (6.3 m) from the upstream end; remained in contact with the barrier for 13.7 ft (4.2 m); and then departed the barrier at a small exit angle of 1.6 deg. After leaving the barrier, the vehicle brakes (rear only) were applied, which caused the vehicle to turn to the left. During redirection, the vehicle was stable and exhibited little tendency to roll.

A summary of test data is presented in Figure 56. Maximum 50-ms average vehicle accelerations, calculated from accelerometer data, were –6.3-g lateral, –5.2-g longitudinal, and 8.1-g resultant.

Installation and vehicle damage is shown in Figure 57. Bridge rail damage was minor and consisted of scuffing of concrete curb and retrofit beam. Subsequent safety performance of the bridge rail would not be impaired by this damage. Damage to the vehicle was concentrated at the right front panel and grill area. The bumper and grill were jammed into the radiator.

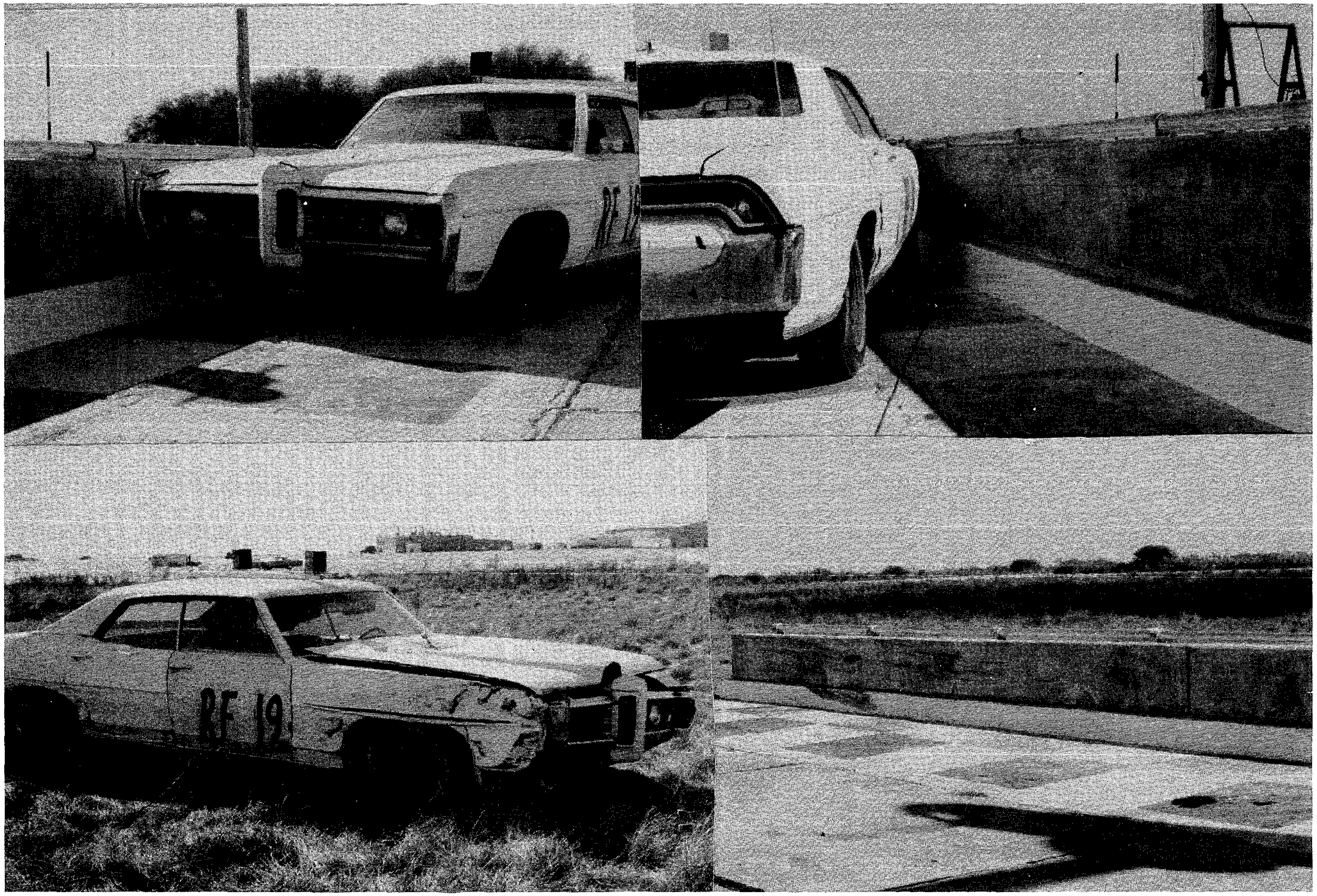
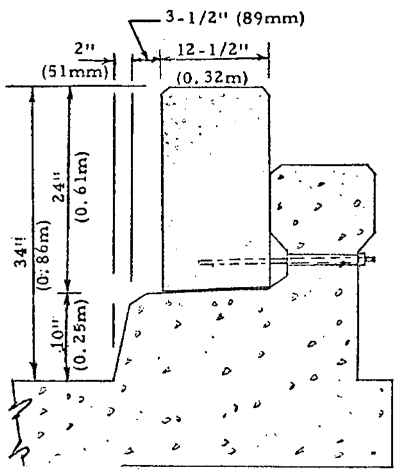
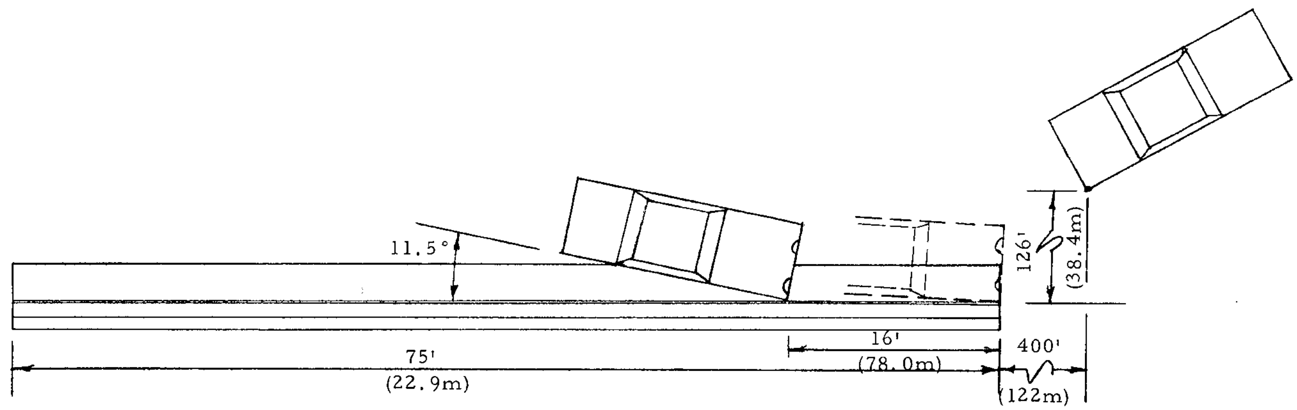


FIGURE 52. VIEWS OF BARRIER INSTALLATION AND VEHICLE BEFORE AND AFTER TEST RF-19



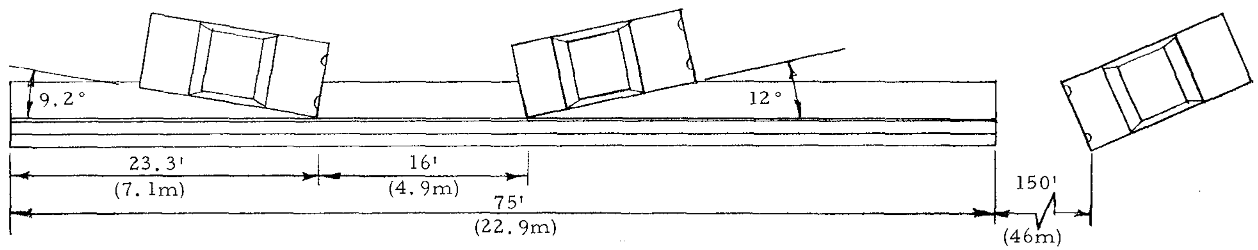
R(IIIN)-3 Design

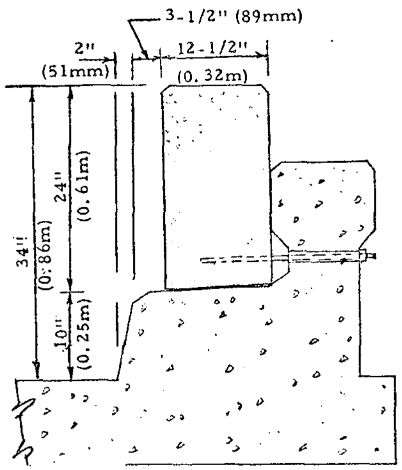


Test No.	RF-19
Date	1/9/76
Drawing	SwRI 03-3717-25
Rail	Precast Conc. Beam
Parapet	Conc. w/Narrow Walk
Length of Installation	75 ft (22.9m)
Pavement Condition	Dry
Vehicle	1969 Pontiac Bonneville
Vehicle Mass (w/instrumentation)	4423 lb (2006kg)

Impact Speed	60.6 mph (27.1m/s)
Impact Angle	+11.5
Exit Angle	+2.5
Vehicle Accel (max 50 ms avg)	
Lateral (cine/elect)	-7.5g/-4.9g
Long. (cine/elect)	-6.3g/-4.4g
Resultant (cine/elect)	9.8g/6.3g
Vehicle Rebound Dist.	126 ft (38.4m)
Vehicle Damage	
TAD	1-RFQ-4
VDI	01FRES4
Max. Rail Deflection (dynamic/permanent)	0/0

FIGURE 53. SUMMARY OF CRASH TEST RF-19 RESULTS





R(IIIN)-3 Design

Test No.	RF-20
Date	1/13/76
Drawing	SwRI 03-3717-25
Rail	Precast Conc. Beam
Parapet	Conc. w/Narrow Walk
Length of Installation	75 ft (22.9m)
Pavement Condition	Dry
Vehicle	1971 Ford Pinto
Vehicle Mass (w/instrumentation)	2140 lb (971kg)

Impact Speed	55.4 mph (24.8m/s)
Impact Angle	+9.2 deg
Exit Angle	-12.0 deg
Vehicle Accel (max 50 ms avg)	
Lateral (cine/elect.)	-1.6g/-8.3g
Long. (cine/elect.)	-2.1g/-4.3g
Resultant (cine/elect.)	2.6g/9.4g
Vehicle Rebound Distance	15 ft (4.6m)
Vehicle Damage	
TAD	1-RFQ-2
VDI	01FRES2
Max. Rail Deflection (dynamic/permanent)	0/0

FIGURE 54. SUMMARY OF CRASH TEST RF-20 RESULTS

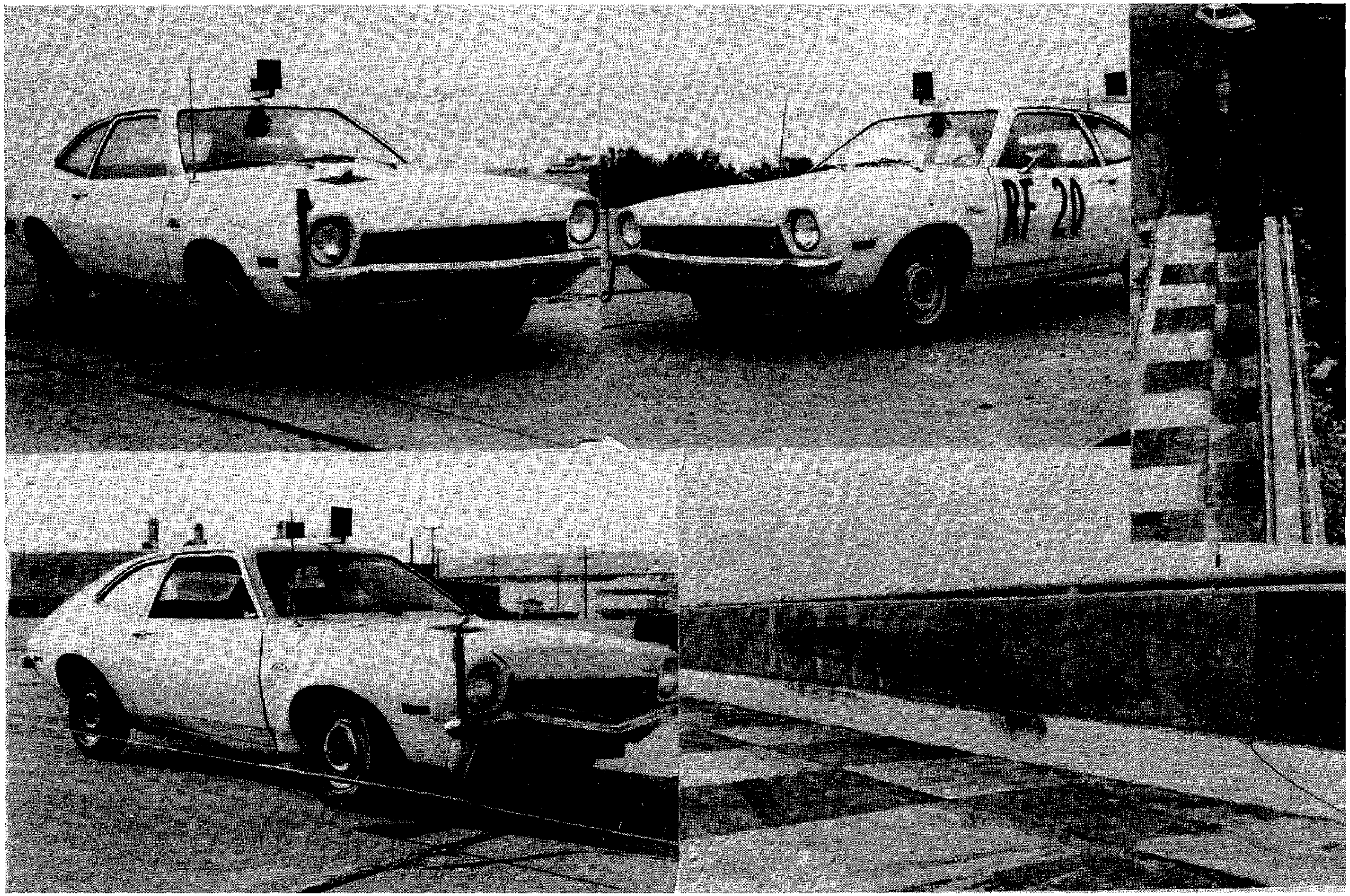
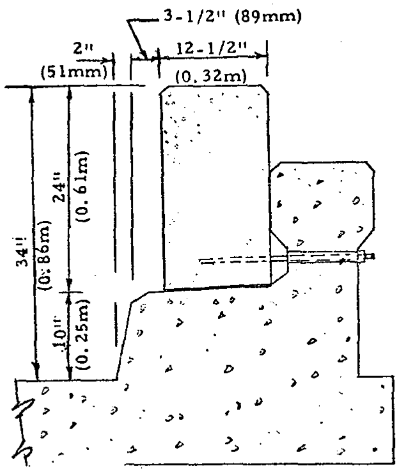
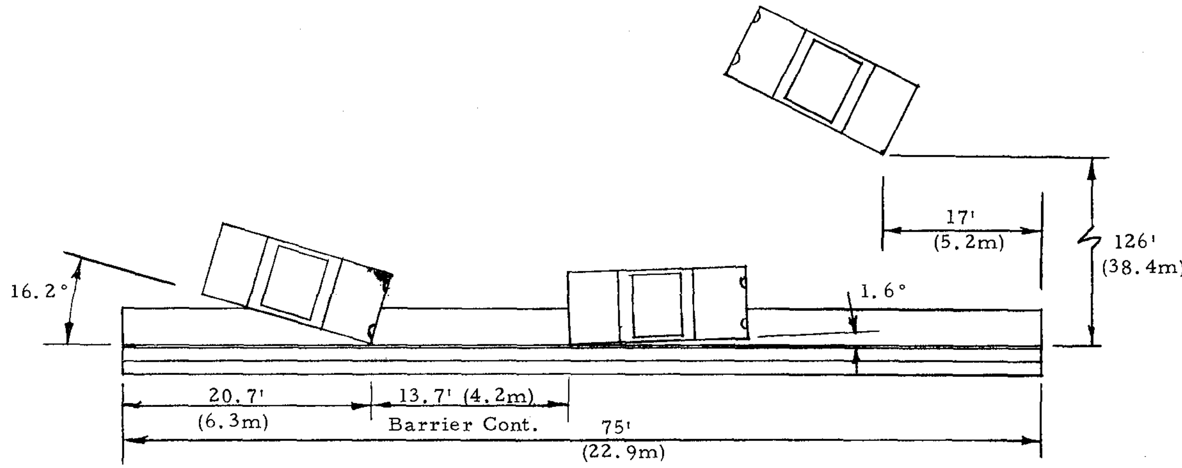


FIGURE 55. VIEWS OF INSTALLATION AND VEHICLE BEFORE AND AFTER TEST RF-20



R(IIIN)-3 Design



Test No.	RF-21
Date	1/13/76
Drawing	SwRI 03-3717-25
Rail	Precast Conc. Beam
Parapet	Conc. w/Narrow Walk
Length of Installation	75 ft (22.9m)
Pavement Condition	Dry
Vehicle	1971 Ford Pinto
Vehicle Mass (w/instrumentation)	2140 lb (971kg)

Impact Speed	44.1 mph (19.7m/s)
Impact Angle	16.2 deg
Exit Angle	-1.6 deg
Vehicle Accel (max 50 ms avg)	
Lateral (cine/elect.)	-4.1g/-6.3g
Long. (cine/elect.)	-3.6g/-5.2g
Resultant (elect.)	5.4g/8.1g
Vehicle Rebound Distance	126 ft (38.4m)
Vehicle Damage	
TAD	1-RFQ-3
VDI	01FRES4
Max. Rail Deflection (dynamic/permanent)	0/0

FIGURE 56. SUMMARY OF CRASH TEST RF-21 RESULTS

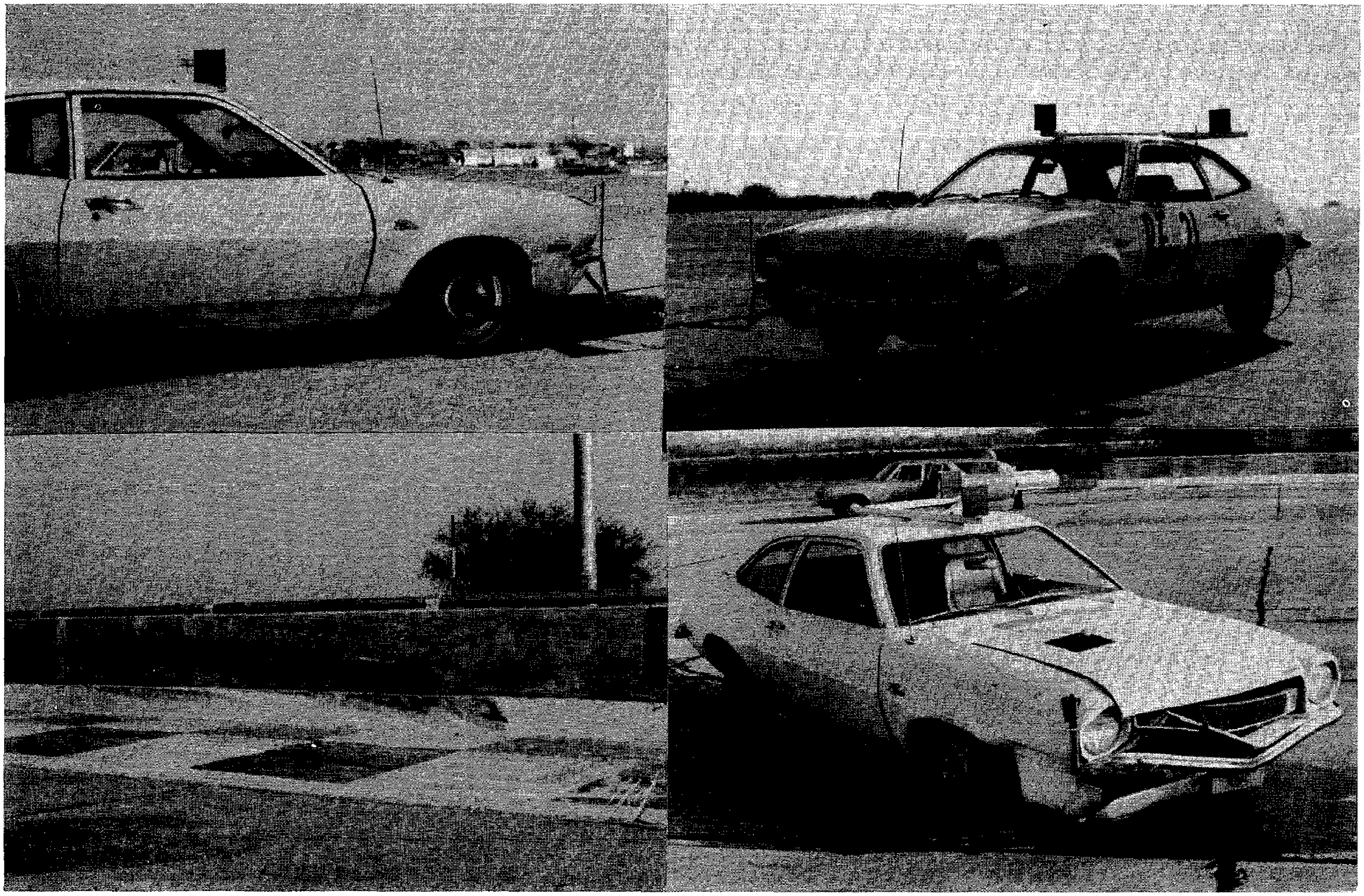


FIGURE 57. VIEWS OF VEHICLE BEFORE AND AFTER TEST RF-21

Test RF-22. No repairs were performed on the installation after Test RF-21, although the curb and beam were painted white to highlight vehicle contact marks. Impact conditions for the 2140-lb (971 kg) car were 61.9 mph (27.7 m/s) and 18.3-deg angle. The vehicle contacted the barrier 24.5 ft (7.5 m) from the upstream end; remained in contact for a distance of 13.7 ft (4.2 m); and then departed the installation at a near zero angle. After departing the barrier, the vehicle brakes were remotely applied to the rear wheels only, causing the vehicle to turn sharply to the left. During redirection, the vehicle was stable and exhibited little tendency to roll.

A summary of test data is presented in Figure 58. Maximum 50-ms average vehicle accelerations, calculated from accelerometer data, were −16.1-g lateral, −8.2-g longitudinal, and 17.7-g resultant. These values are high in comparison with recommended levels presented in NCHRP *Report 153*.

Installation and vehicle damage is shown in Figure 59. Bridge rail damage was minor and consisted of concrete curb and retrofit beam scuffing. Subsequent safety performance of the bridge rail would not be affected by this damage. Vehicle damage was concentrated at the right front panel, wheel assembly, and hood, which was stripped during redirection; the right front wheel was jammed rearward.

3. Appraisal of R(IIIN)-3 Design

- The barrier smoothly redirected the vehicle in all cases, although the protruding portion of the existing curb did considerable damage to the vehicle wheels and suspension. From high-speed cine, there appeared to be no tendency for the vehicle to snag on the barrier during redirection.

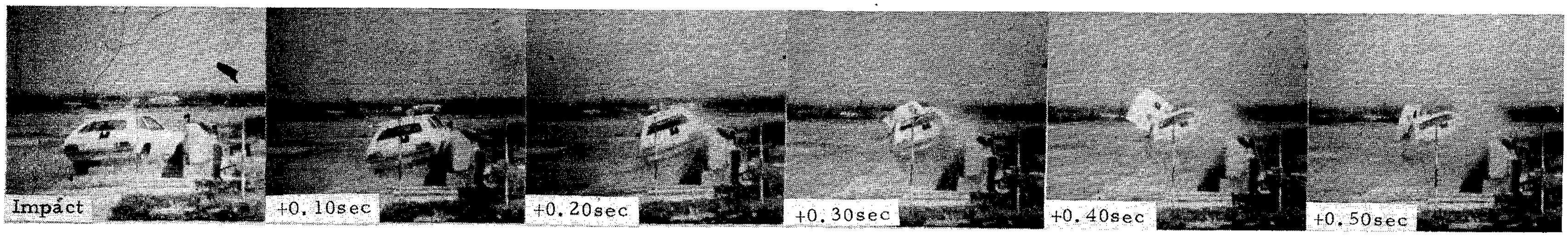
- Maximum roll angle for the five tests was a modest +17 deg (away from the barrier) in Test RF-22. Maximum roll angles for the other tests were +12 to +14 deg for 60-mph (26.8 m/s) tests and +8 deg for the low-speed experiment. No tendency for the vehicle to roll or vault over the barrier was exhibited in the high-speed cine.

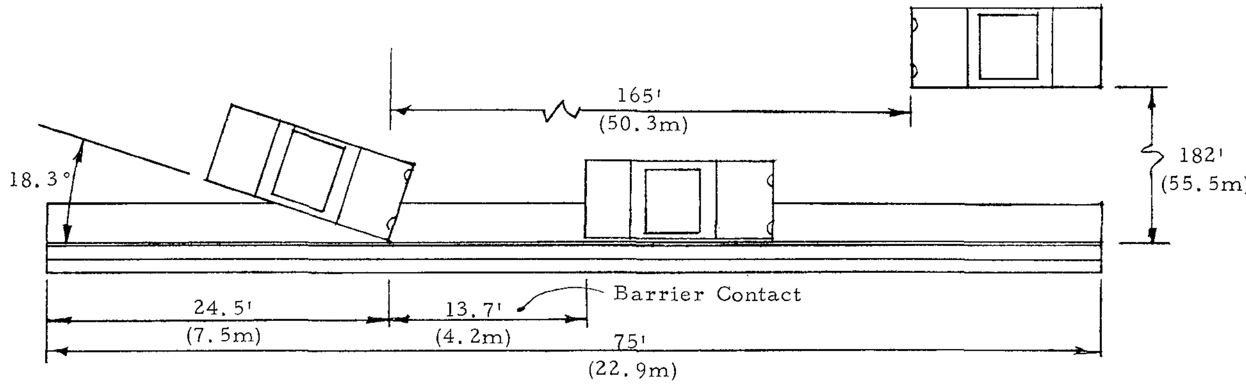
- Minimum impact damage was done to the barrier in the tests. Tire and sheet metal scuff marks, while possibly detracting from the barrier appearance, did not warrant repair prior to subsequent tests.

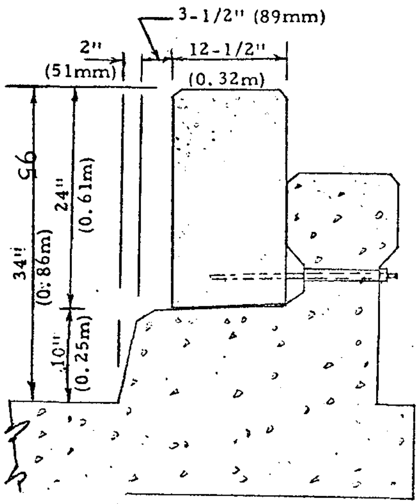
- Vehicle redirection accelerations were high, especially for Test RF-22 in which maximum 50-ms average lateral acceleration was −16.1-g. Both lateral and longitudinal accelerations were about twice the HVOSM predicted values.

- The method of fabricating the beams and securing them to the existing structure was judged to be adequate. An inspection of the installation after the five-test program revealed no distress in the beams or connections.

- Note that no approach guardrail or transition between approach guardrail and R(IIIN)-3 design was included in the test installation. Since R(IIIN)-3 design has a profile geometry similar to typical concrete parapet end posts found in many current bridge railings, it is recommended that the approach guardrail be a G4 system and that it be transitioned to the R(IIIN)-3 installation with details shown in NCHRP *Report 118* pages 53 to 59.(7)







R(IIIN)-3 Design

Test No. RF-22
Date 1/29/76
Drawing .... SwRI 03-3717-25
Rail ....Precast Conc. Beam
Parapet ....Conc. w/Narrow Walk
Length of Installation .... 75 ft (22.9m)
Pavement Condition .... Dry
Vehicle ....1971 Ford Pinto
Vehicle Mass .... 2140 lb (971kg)
(w/instrumentation)

Impact Speed .... 61.9 mph (27.7m/s)
Impact Angle .... +18.3 deg
Exit Angle .... +0.7 deg
Vehicle Accel (max 50 ms avg)
Lateral (cine/elect.) n.a./-16.1g
Long. (cine/elect.) n.a./-8.2g
Resultant (cine/elect.) n.a./17.7g
Vehicle Rebound Distance ... 182 ft (55.5m)
Vehicle Damage
TAD 1-RFQ-5
VDI 01FRES6
Max. Rail Deflection 0/0
(dynamic/permanent)

FIGURE 58. SUMMARY OF CRASH TEST RF-22 RESULTS

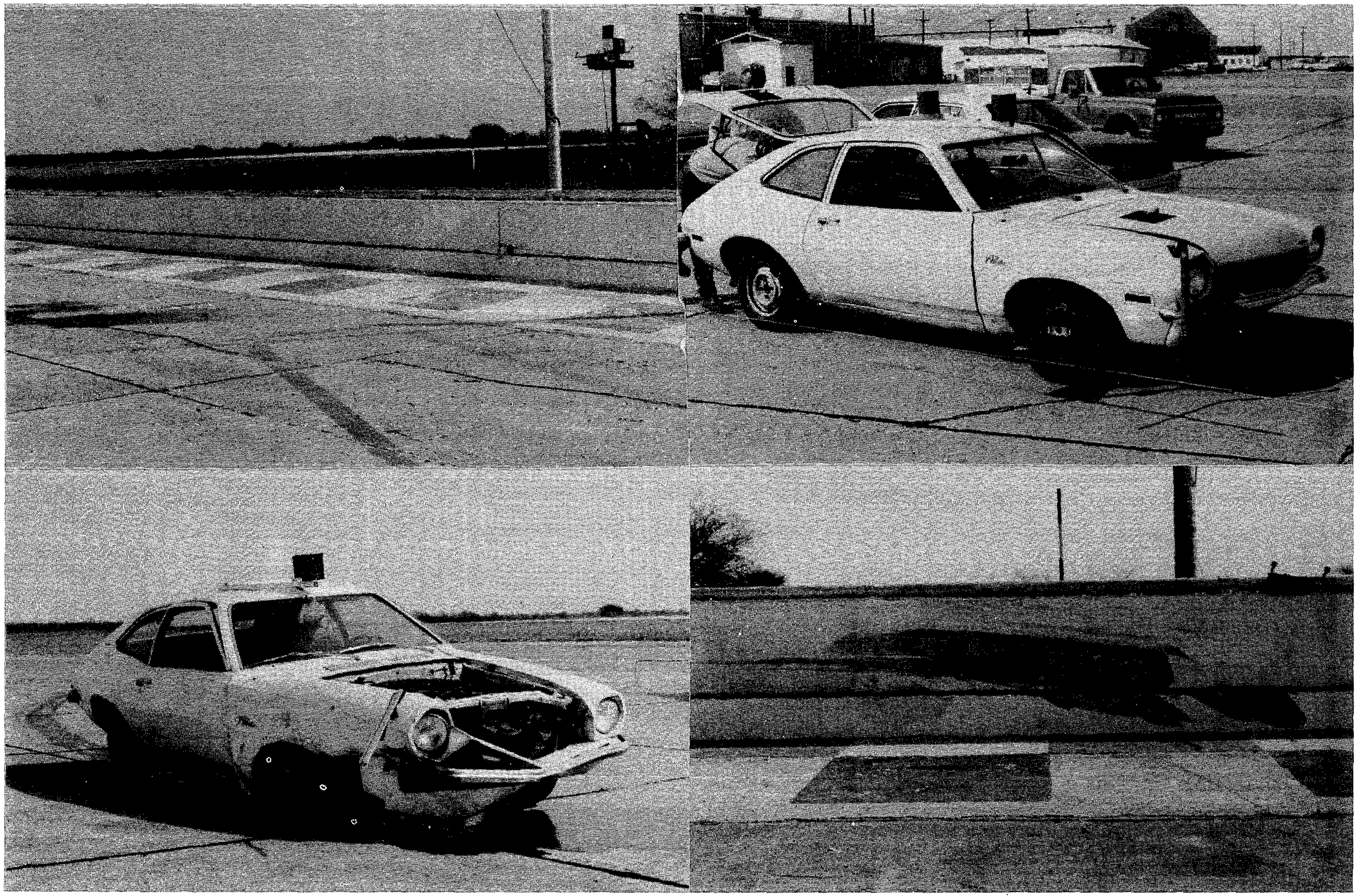


FIGURE 59. VIEWS OF INSTALLATION AND VEHICLE BEFORE AND AFTER CRASH TEST RF-22

G. Category III—Wide Walk

The distinguishing features of this category are the curb, wide walk (equal to or greater than 2 ft [0.61 m]), and a concrete parapet or all metal rail. A representative Category IIIW installation is shown in Figure 60a. The curb is 9 in. (0.23 m) with a 2-in. (0.05 m) batter, a 4-ft (1.2-m) wide walk, and a metal panel-type rail. Although this design category is usually found in urban areas with low traffic speeds and heavy pedestrian traffic, it is also found on rural bridges with high traffic speeds. The metal panel rail system has also been used on the Interstate Highway system (see Figure 2).

For Category IIIW, it was assumed that the walk is an important feature of the bridge and should be maintained. Accordingly, the retrofit design for Category IIIW provides for a new barrier rail at the curb line, keeping the pedestrian walkway intact. The approach negates the unpredictable performance of the curb on the vehicle trajectory.

1. Design Features of R(IIIW)-1 System

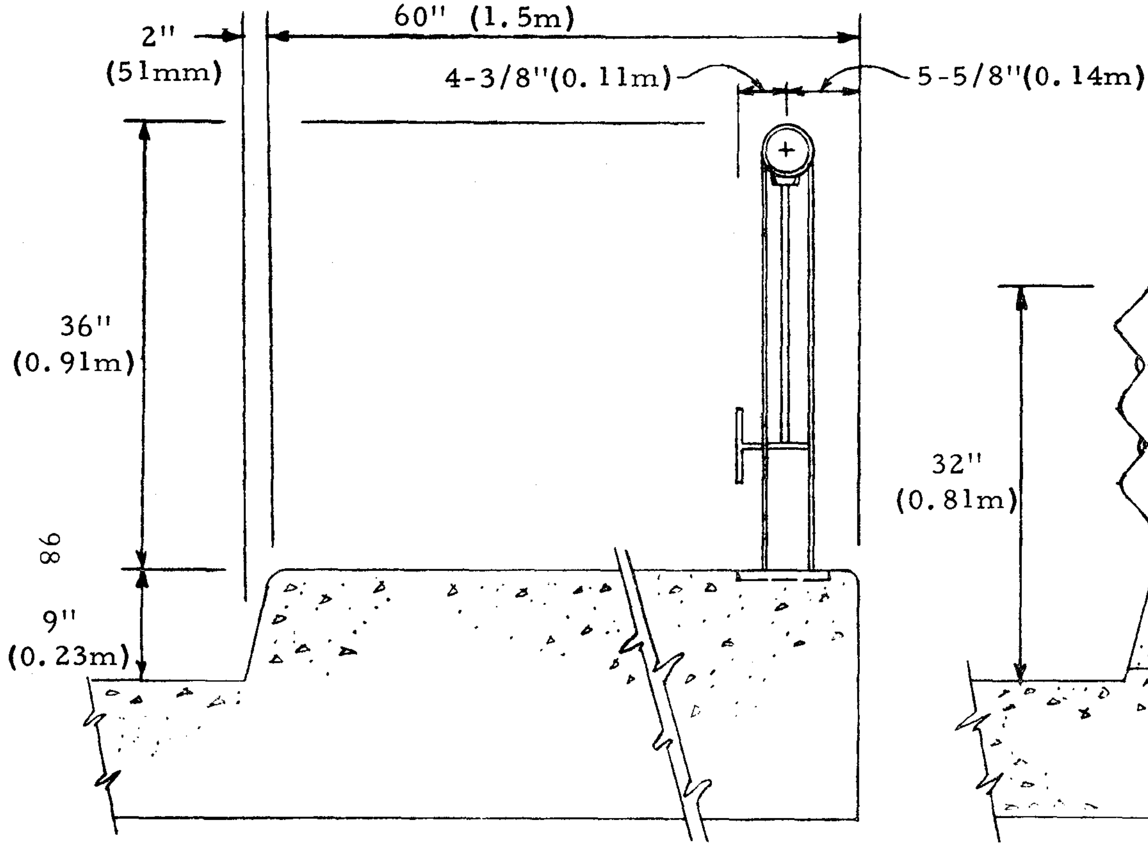
Sectional view of the R(IIIW)-1 design is shown in Figure 60b; engineering drawings of the retrofit design are contained in Appendix A. A tubular thrie beam with a 32-in. (0.81 m) mounting height is supported on W6 X 8.5 posts spaced at 8.33 ft (2.54 m). To provide lateral flexibility to the design, the post-to-baseplate weldments are portioned to break at the AASHTO loading of 10,000 lb (4536 kg). The foundation beam has the purpose of distributing the impact forces and movements so that no damage is sustained by the concrete during impact. Hence, repairs after an impact will consist of replacing one or more posts.

2. Crash Test Evaluation

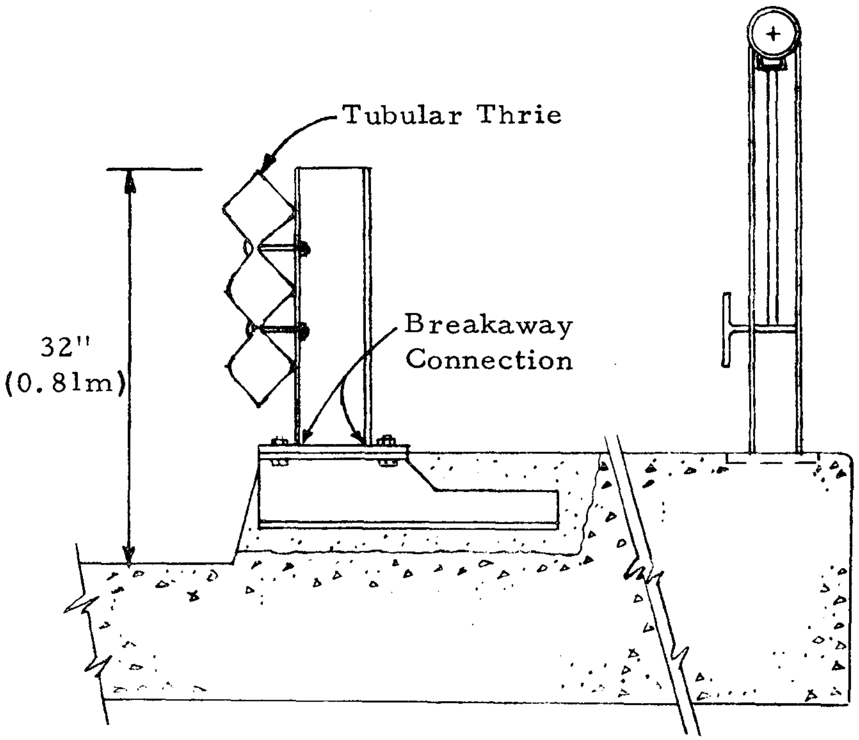
The test series consisted of four tests: a baseline experiment to examine the safety performance of a typical Category IIIW installation and three tests to evaluate performance of R(IIIW)-1 design.

Test RF-14. Views of the test installation and vehicle are shown in Figure 61. Impact conditions for the 4285-lb (1944 kg) vehicle were 61.9 mph (27.7 m/s) and 25.3-deg angle. The vehicle contacted the curb 29.1 ft (8.9 m) from the upstream end of the bridge deck. The vehicle mounted the 9-in. (0.23 m) high safety curb and contacted the metal parapet 39.5 ft (12.0 m) from the upstream end of the bridge deck. Impacting the metal parapet, the vehicle began to roll away from the bridge rail. The metal parapet anchorage system failed, however, allowing the vehicle to continue over the walk. After the vehicle had traveled the length of the metal parapet, the left side of the passenger compartment contacted the concrete parapet located at the downstream end of the bridge deck. The vehicle immediately came to rest with the concrete parapet lodged inside the passenger compartment of the vehicle. A summary of findings is presented in Figure 62. Maximum 50-ms average vehicle accelerations, determined from high-speed cine data, were −3.3-g lateral, −4.5-g longitudinal, and 4.8-g resultant.

Installation and vehicle damage is shown in Figure 63. Bridge rail damage was considerable and consisted of complete anchorage failure of the metal parapet in the impact zone. This downstream section of the metal parapet was completely torn and twisted from the concrete walk. Damage to the concrete parapet on which the vehicle came to rest was minor and consisted of scraping of the concrete because of sheet metal contact.



a. Typical Installation



b. R(IIIW)-1 Retrofit Design

FIGURE 60. CATEGORY III BRIDGE RAILING - BARRIER WITH WIDE WALK

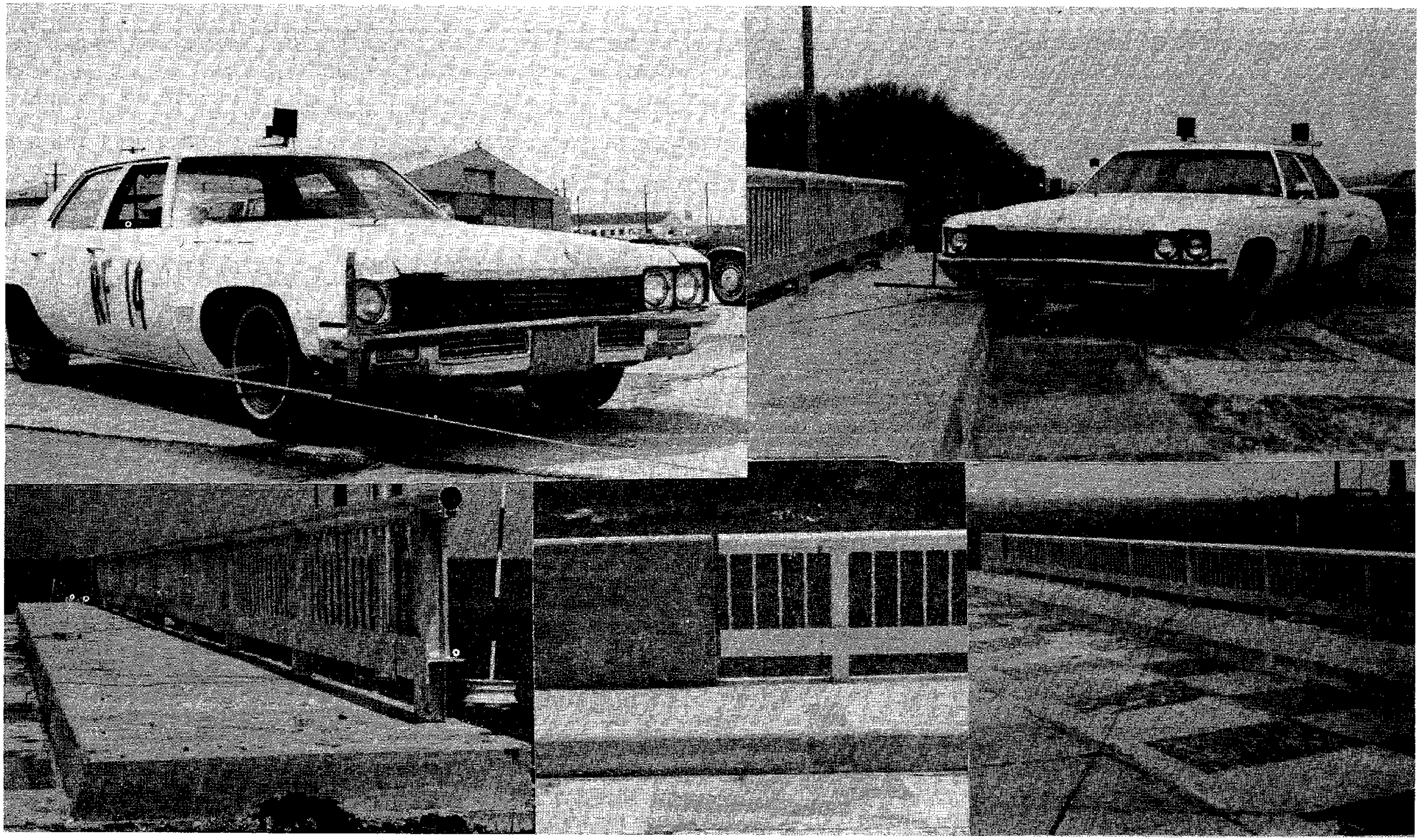
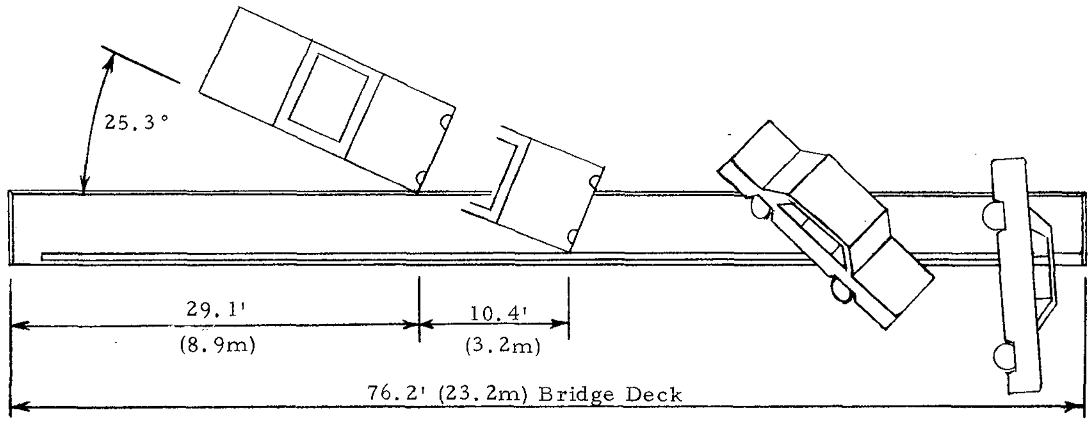
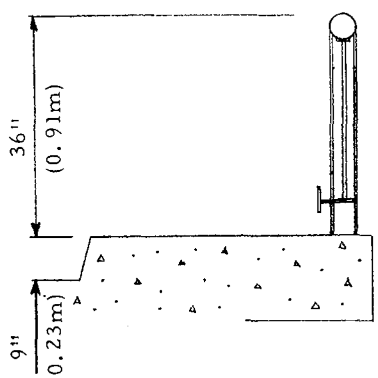


FIGURE 61. VIEWS OF VEHICLE AND INSTALLATION PRIOR TO TEST RF-14





Category IIIW

Test No.	RF-14
Date	3/26/76
Drawing	SwRI 03-3717-24
Rail	Metal Panel System
Parapet	Metal w/Wide Walk
Length of Installation	76.2 ft (23.2m)
Pavement Condition	Dry
Vehicle	1972 Buick Le Sabre
Vehicle Mass (w/instrumentation)	4285 lb (1944kg)

Impact Speed	61.9 mph (27.7m/s)
Impact Angle	+25.3 deg
Exit Angle	n.a.
Exit Speed	n.a.
Vehicle Accel (max 50 ms avg)	
Lateral (cine/elect)	-3.3g/-7.0g
Long. (cine/elect)	-4.5g/-14.4g
Resultant (cine/elect)	4.8g/14.5g
Vehicle Rebound Distance	0 ft (0m)
Vehicle Damage	
TAD	1-FR-7
VDI	01FREW9
Max. Rail Deflection (dynamic/permanent)	n.a./n.a.

FIGURE 62. SUMMARY OF CRASH TEST RF-14 RESULTS

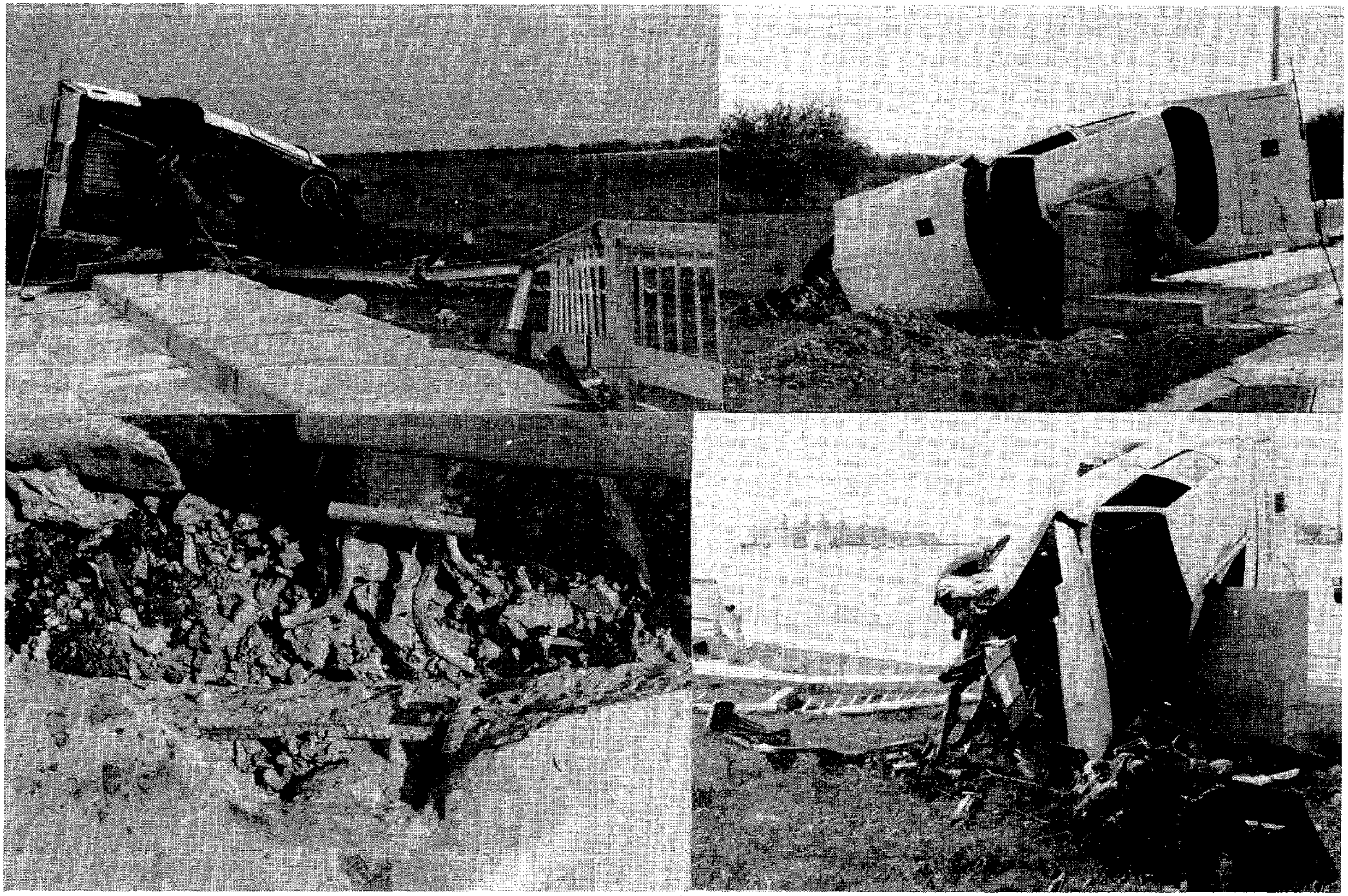


FIGURE 63. TEST RF-14 VEHICLE AND INSTALLATION DAMAGE

Damage to the vehicle was severe. The entire front section of the vehicle was severely damaged; the radiator and engine block were thrown clear of the engine compartment. Damage to the passenger compartment on the left side was also severe due to vehicle involvement with the concrete parapet.

Test RF-15. The test installation, the R(IIIW)-1 design, consisted of the Category III bridge rail (see Test RF-14 for description) and a tubular thrie beam retrofit as detailed in Appendix A. The tubular thrie beam railing was mounted on W6 X 15.5 posts. The posts were located on the walk at the face of the curb. The system was independent of the metal rail and therefore did not eliminate use of the walkway. The traffic face of the tubular thrie beam was approximately 3 in. (76 mm) outside the base of the curb to reduce vehicle wheel contact with the curb. Features of the R(IIIW)-1 installation are shown in Figure 64 prior to the redirection severity test. Impact conditions for the 2110-lb (957 kg) vehicle were 62.7 mph (29.0 m/s) and a 13.5-deg angle. The vehicle contacted the barrier 18.3 ft (5.6 m) from the upstream end of the bridge deck, and 1.1 ft (0.3 m) downstream from post 3 (posts are numbered consecutively from upstream end of bridge deck). The vehicle remained in hard contact with the barrier for a distance of 8.8 ft (2.7 m) and was smoothly redirected; exit angle was 5.7 deg. During redirection, the vehicle appeared stable, with little tendency to pitch or roll. After leaving the rail, the vehicle continued for a distance of 245 ft (74.7 m) from the point of contact. A summary of findings is contained in Figure 65. Maximum 50-ms average vehicle accelerations, determined from high-speed cine data, were –5.5-g lateral, –1.8-g longitudinal, and 5.8-g resultant.

Installation and vehicle damage is shown in Figure 66. Bridge rail damage was minor and consisted of concrete curb and retrofit beam scuffing. Post 4 was separated from its base plate because of weld failure at the joint. Subsequent safety performance of the bridge rail would not be affected by this damage.

Vehicle damage was confined to the right front panel. Although the right front wheel had been considerably damaged, the vehicle was driven back to the impact site.

Test RF-16. The test installation was the same as described in Test RF-15 report. Replacement of the post/base plate system at post 4 (posts are numbered consecutively from upstream end of bridge deck) was the only repair performed prior to test.

Impact conditions for the 4337-lb (1967 kg) test vehicle were 62.7 mph (28.0 m/s) and a 25.8-deg angle. The vehicle contacted the barrier 24.6 ft (7.5 m) from the upstream end of the bridge deck, and 1.0 ft (0.3 m) upstream from post 4. The vehicle remained in hard contact with the barrier for 37.8 ft (11.5 m) and was smoothly redirected; exit angle was 3.9 deg. During redirection, the right wheels of the vehicle climbed the curb and rode the walk because of large barrier deflections caused by post/base plate weld failures. Maximum dynamic deflection of the beam was 2.5 ft (0.76 m). Maximum roll angle of the vehicle while in contact with the system was 6 deg away from the barrier. After leaving the rail, the vehicle continued for a distance of 210 ft (64 m) from the point of contact. A summary of test findings is presented in Figure 67. Maximum 50-ms average vehicle accelerations, determined from high-speed cine data, were –6.2-g lateral, –4.4-g longitudinal, and 7.6-g resultant.

Installation damage is shown in Figure 68. Bridge rail damage consisted of scraping of the concrete curb and scuffing of the retrofit beam. Permanent beam deflection of 0.20 ft (61 mm) was noted between posts 4 and 5. Weld cracks were evident at the post/base plate connection at posts 1, 2 and 9, with weld failures and deformed posts at posts 3 thru 8.

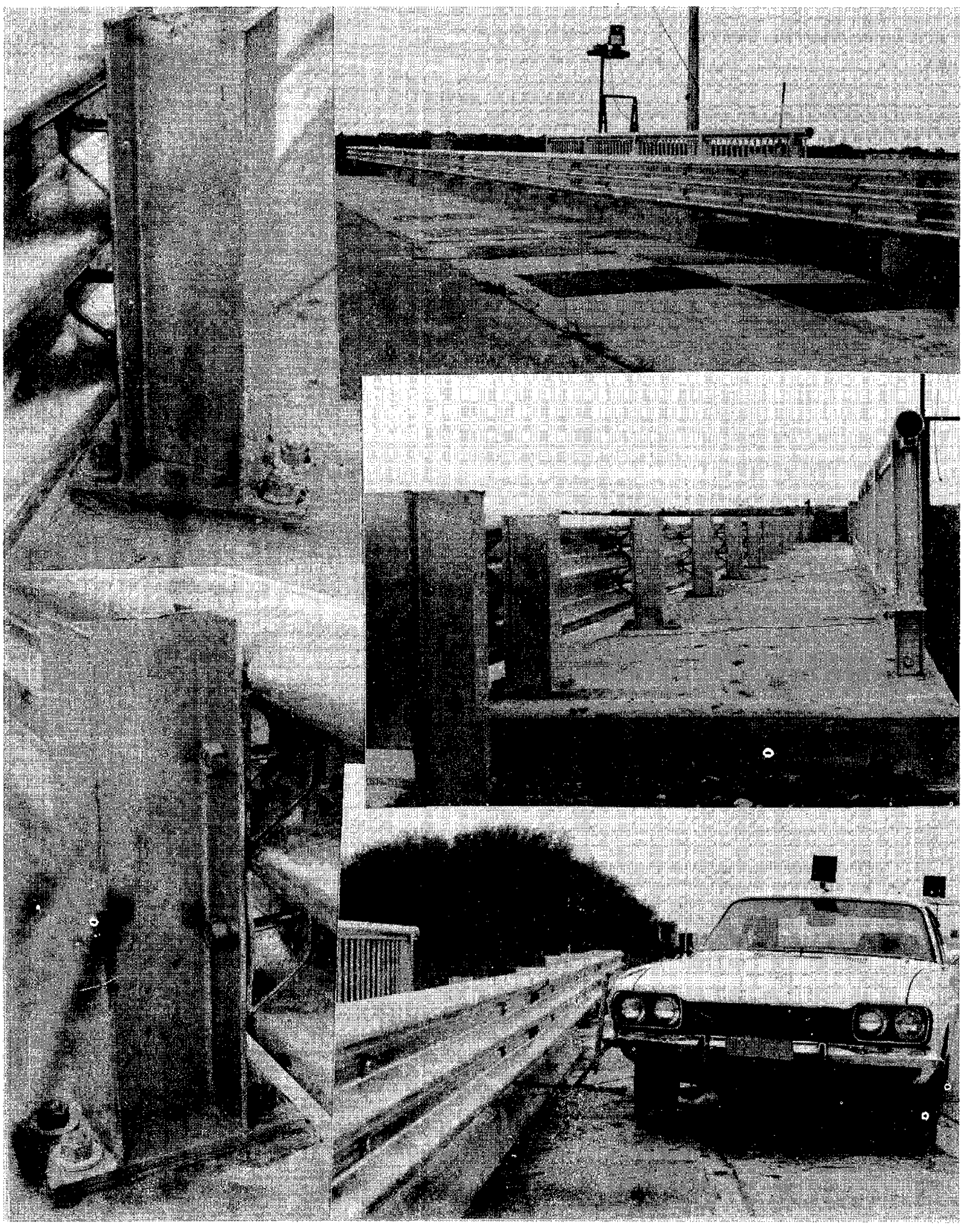
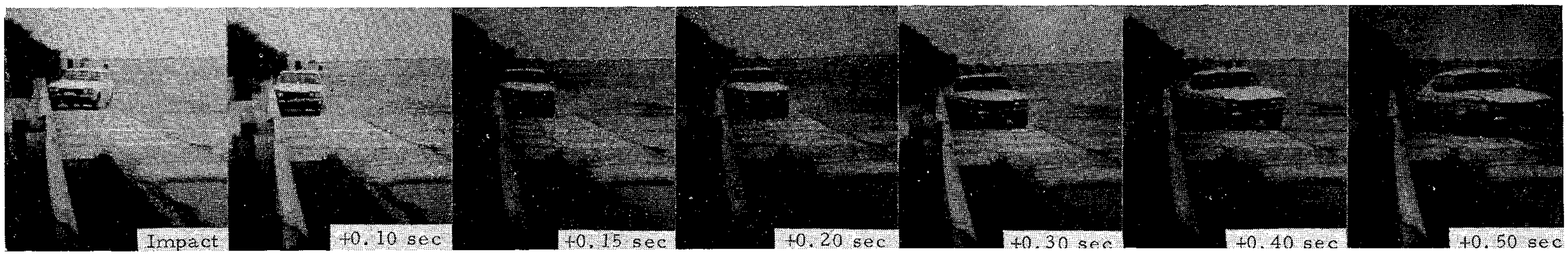
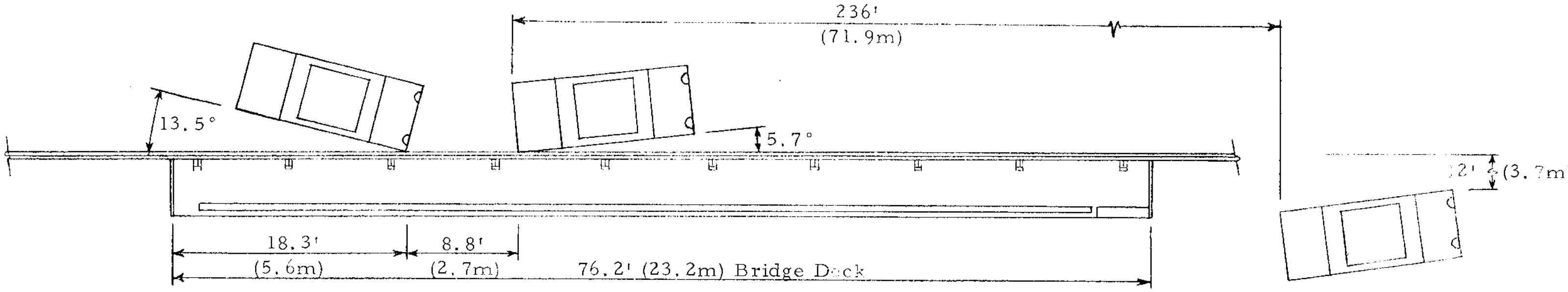
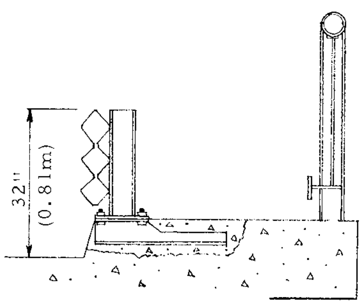


FIGURE 64. VIEWS OF R(HHW)-1 INSTALLATION PRIOR TO TEST RF-15







R(IIIW)-1 Design

Test No.	RF-15
Date	4/12/76
Drawing	SwRI 03-3717-23
Rail	Tubular Thrie
Parapet	Wide Walk
Length of Installation	155.8 ft (47.5m)
Pavement Condition	Dry
Vehicle	1972 Capri
Vehicle Mass (w/instrumentation)	2110 lb (957kg)

Impact Speed	62.7 mph (28.0m/s)
Impact Angle	+13.5 deg
Exit Angle	-5.7 deg
Exit Speed	58.3 mph (26.1m/s)
Vehicle Accel (max 50 ms avg)	
Lateral (cine/elect)	-5.5g/-9.8g
Long. (cine/elect)	-1.8g/-4.5g
Resultant (cine/elect)	5.8g/10.8g
Vehicle Rebound Distance	18 ft (5.5m)
Vehicle Damage	
TAD	1-RFQ-3
VDI	01FREW3
Max. Rail Deflection (dynamic/permanent)	0.09 ft (0.03m)/ 0.04 ft (0.01m)

FIGURE 65. SUMMARY OF CRASH TEST RF-15 RESULTS

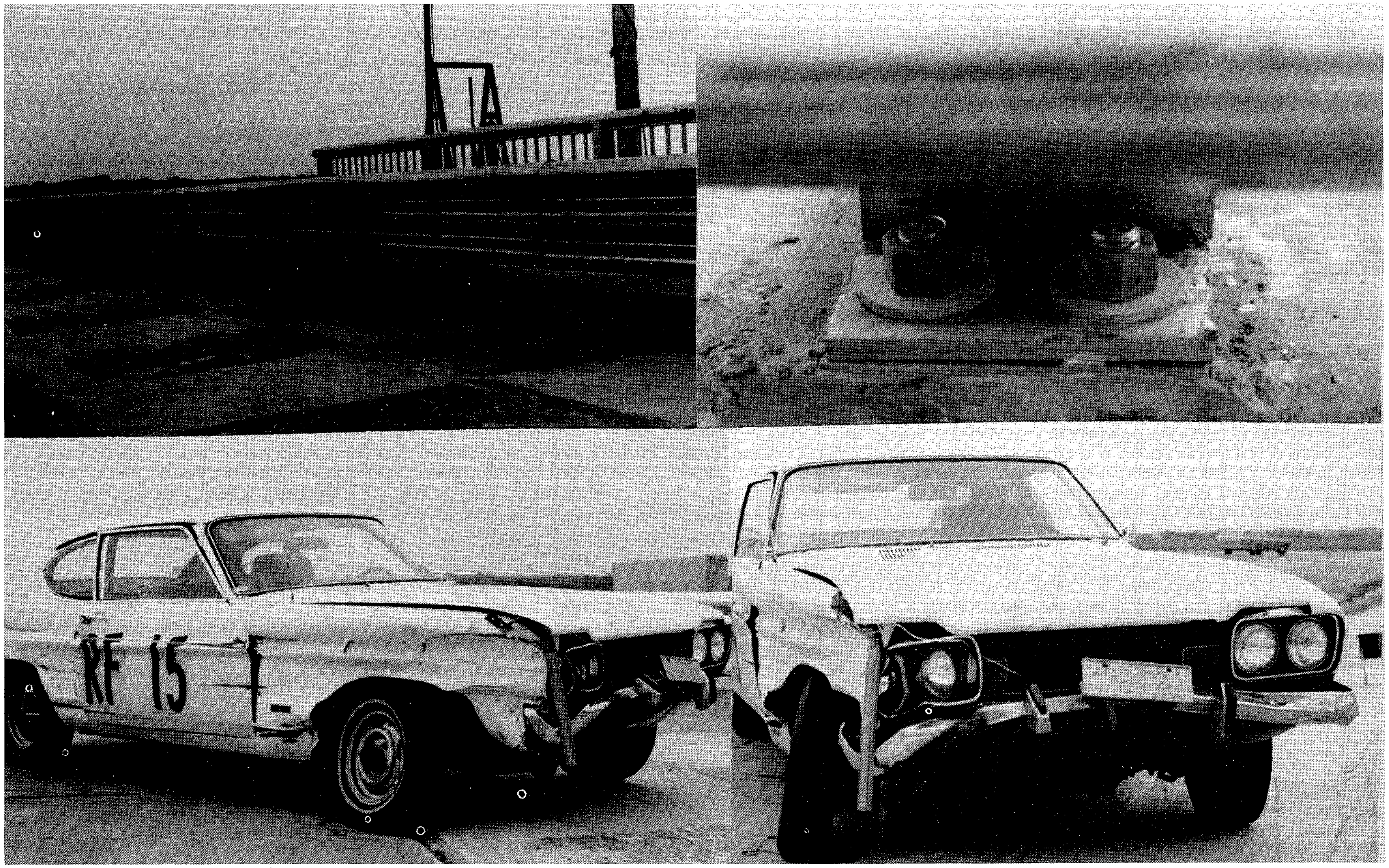
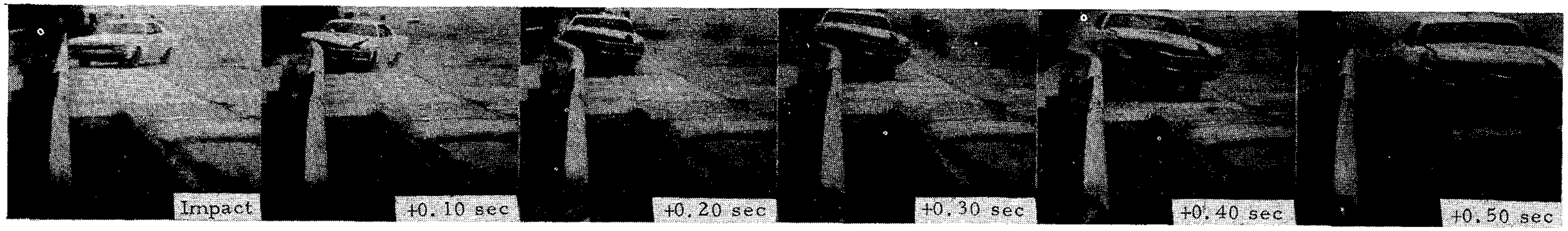
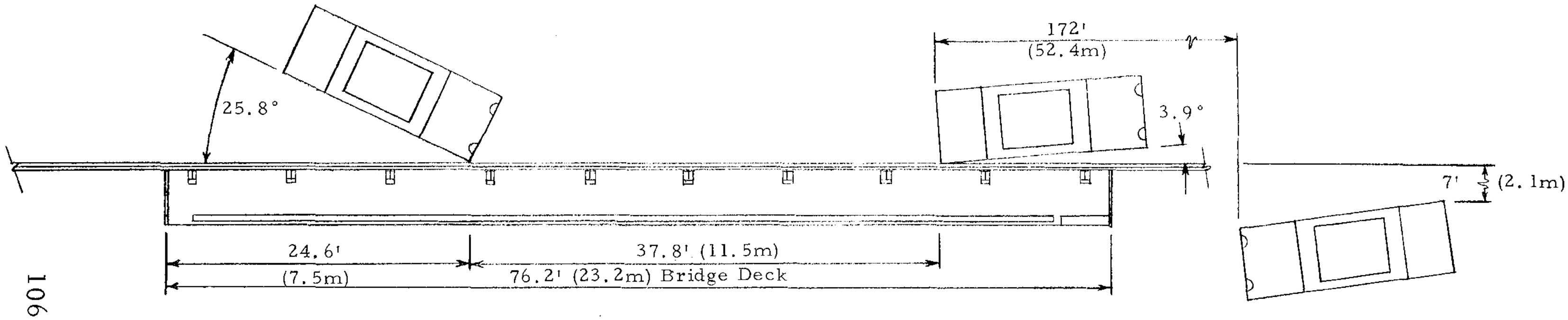
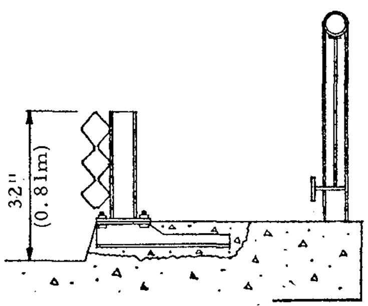


FIGURE 66. TEST RF-15 VEHICLE AND INSTALLATION DAMAGE







R(IIIW)-1 Design

Test No.	RF-16
Date	4/13/76
Drawing	SwRI 03-3717-23
Rail	Tubular Thrie
Parapet	Wide Walk
Length of Installation	155.8 ft (47.5m)
Pavement Condition	Dry
Vehicle	1970 Plymouth Gran Coupe
Vehicle Mass (w/instrumentation)	4337 lb (1967kg)

Impact Speed	62.7 mph (28.0m/s)
Impact Angle	+25.8 deg
Exit Angle	-3.9 deg
Exit Speed	50.7 mph (22.7m/s)
Vehicle Accel (max 50 ms avg)	
Lateral (cine/elect)	-6.2g/-12.1g
Long. (cine/elect)	-4.4g/-11.0g
Resultant (cine/elect)	7.6g/16.4g
Vehicle Rebound Distance	10 ft (3.0m)
Vehicle Damage	
TAD	1-RFQ-4
VDI	01FREW4
Max. Rail Deflection (dynamic/permanent)	2.5 ft (0.76m)/ 0.20 ft (61mm)

FIGURE 67. SUMMARY OF CRASH TEST RF-16 RESULTS

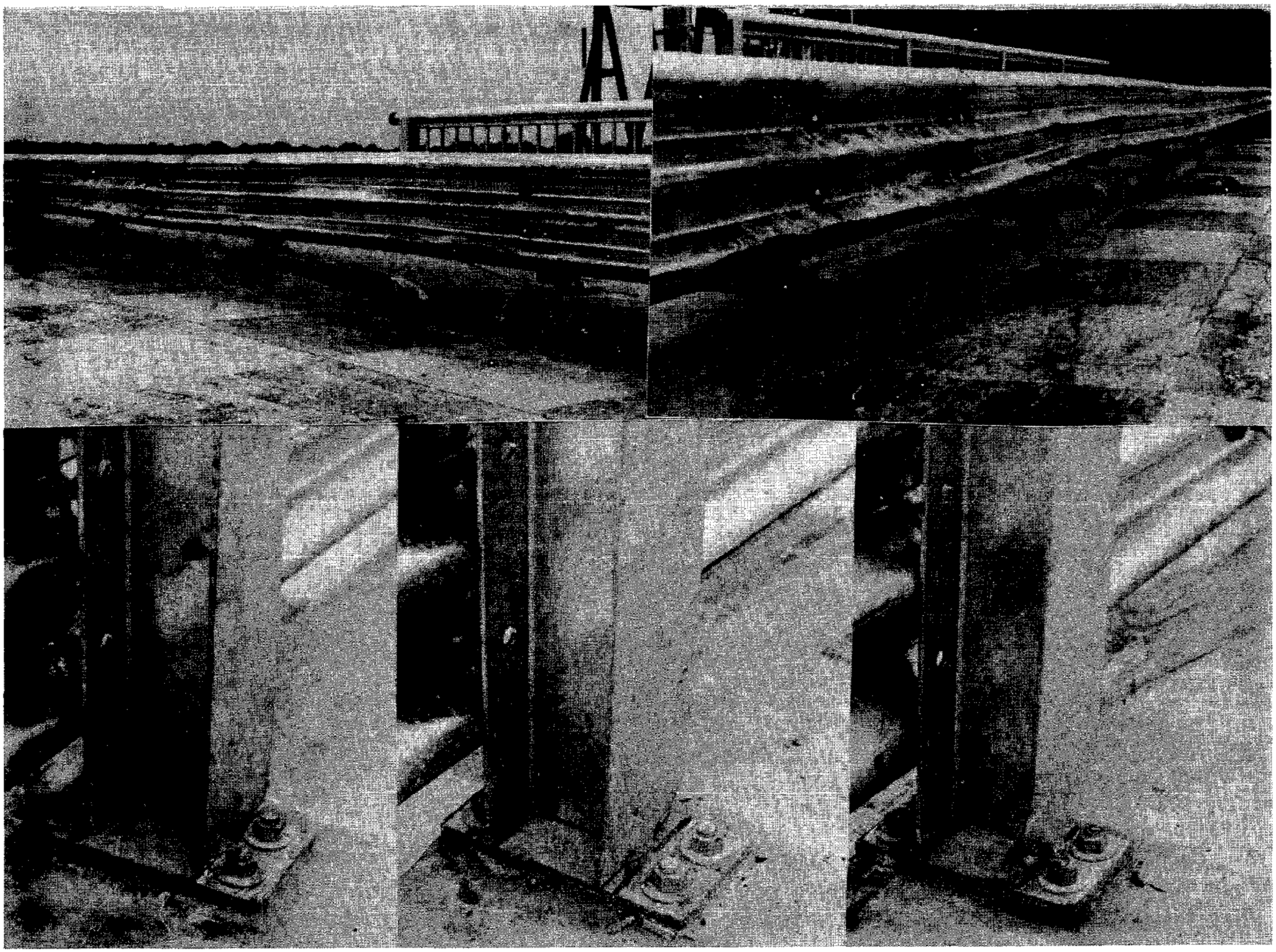


FIGURE 68. TEST RF-16 INSTALLATION DAMAGE

As shown in Figure 69, damage to the right front panel, wheel, and suspension system disabled the vehicle.

Test RF-17. The test installation, as shown in Figure 70, was the same as described in Test RF-15 report. Repairs from the previous test included rewelding of the post/base plate connections along the bridge deck, with the first two posts from the upstream end being welded continuously along the entire face of the post flange.

Impact conditions for the 4455-lb (2021 kg) vehicle were 48.0 mph (21.5 m/s) and 28.6-deg angle; the vehicle did not attain the desired 60 mph (26.8 m/s). The vehicle contacted the barrier 7.1 ft (2.2 m) upstream from the bridge deck, and 2.25 ft (0.69 m) downstream from the second soil-mounted post from the bridge deck. The vehicle remained in hard contact with the barrier for a distance of 15.75 ft (4.80 m) and was redirected at a 4.8-deg angle. During redirection, the maximum dynamic deflection of the beam was 1.1 ft (0.34 m) in the transition section. As the beam deflected laterally, the curb end was exposed and caused severe damage to the vehicle right side suspension. The rear of the vehicle pitched upward slightly; this was probably caused by the right rear tire climbing the exposed face of the concrete curb. After leaving the impact zone, the vehicle traveled 135 ft (41.1 m) to its final position. A summary of test findings is presented in Figure 71. Maximum 50-ms average vehicle accelerations, determined from high-speed cine data, were –4.3-g lateral, –4.6-g longitudinal, and 6.3-g resultant.

Installation damage is shown in Figure 70. Four soil-mounted posts were pushed back in the foundation, and weld failures were evident at the post/base plate connection for the first five posts along the upstream end of the bridge deck. Damage to the bridge deck was confined to minor scraping of the concrete at the corner of the curb.

Damage to the vehicle, as shown in Figure 72, was severe. A major portion of the damage was caused by the curb end that was exposed to direct impact when the beam deflected laterally. The car was disabled by the damage.

3. Appraisal of R(IIIW)-1 Design

Structural Adequacy. Both the small car (Test RF-15) and large car (Test RF-16) were smoothly redirected by the retrofit. Although the barrier deflected 2.5 ft (0.76 m) in Test RF-16, the vehicle remained very stable and exhibited little tendency to roll. The design met all structural adequacy requirements.

Redirection Severity. The small car (Test RF-15) was smoothly redirected with low longitudinal and moderate lateral accelerations. In comparison to the baseline test (Test RF-14), the retrofit design greatly improved installation safety.

Transition. Structural adequacy of the retrofit transition was demonstrated in Test RF-17; however, the walk and curb end became exposed as the beam deflected laterally and caused damage to the vehicle. It is recommended that the curb line be flared away from the pavement for field installations to prevent possible vehicle snagging.

H. Category IV Retrofit Designs

Category IV bridge railings are characterized by a concrete safety shape, with or without one to two metal rails. This category has been used only in the past 10 to 15 years. Although the use of this category is rapidly increasing, presently (Dec 1974), only about 6 percent of existing bridge railings are in this classification.

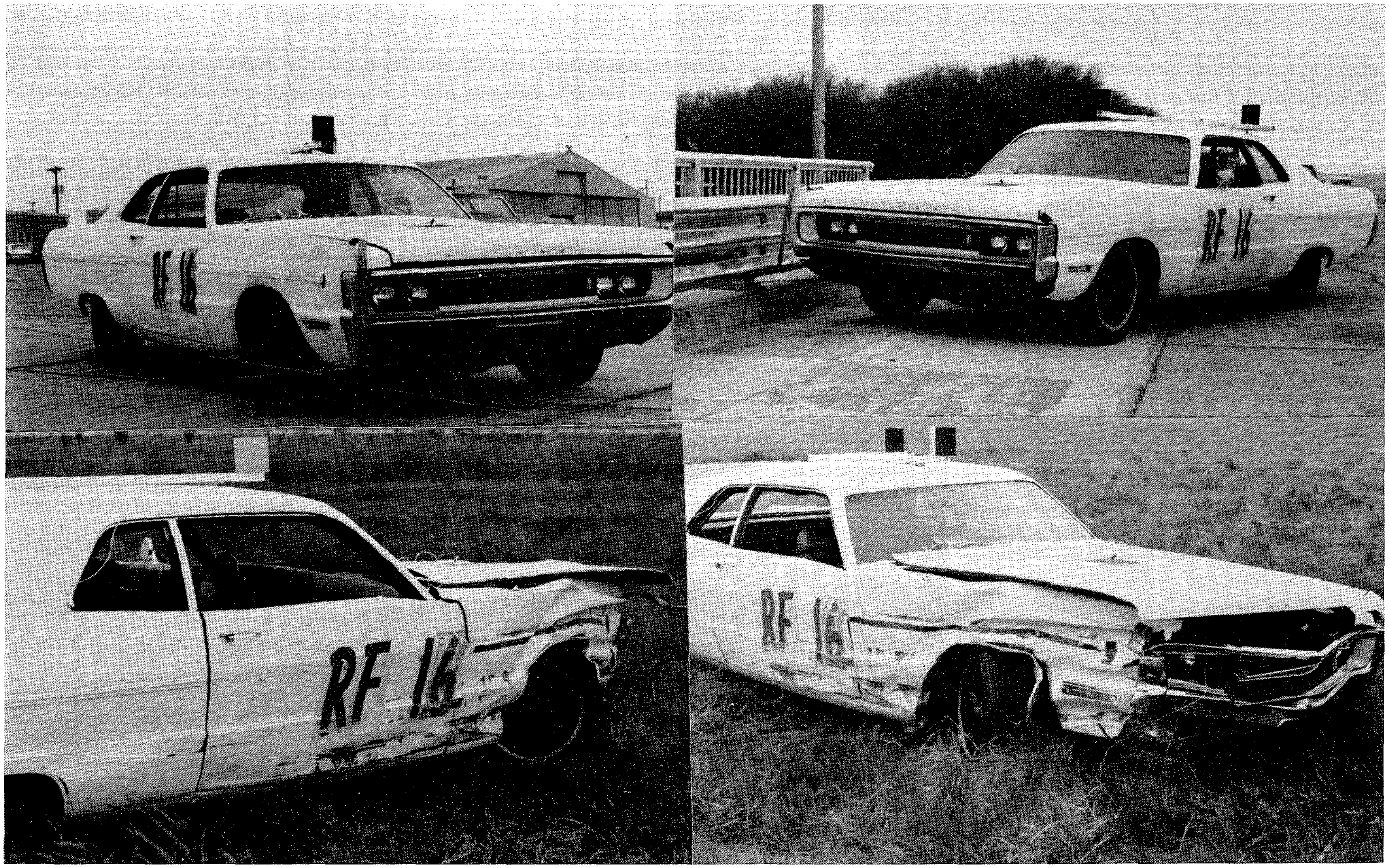


FIGURE 69. VIEW OF VEHICLE BEFORE AND AFTER TEST RF-16

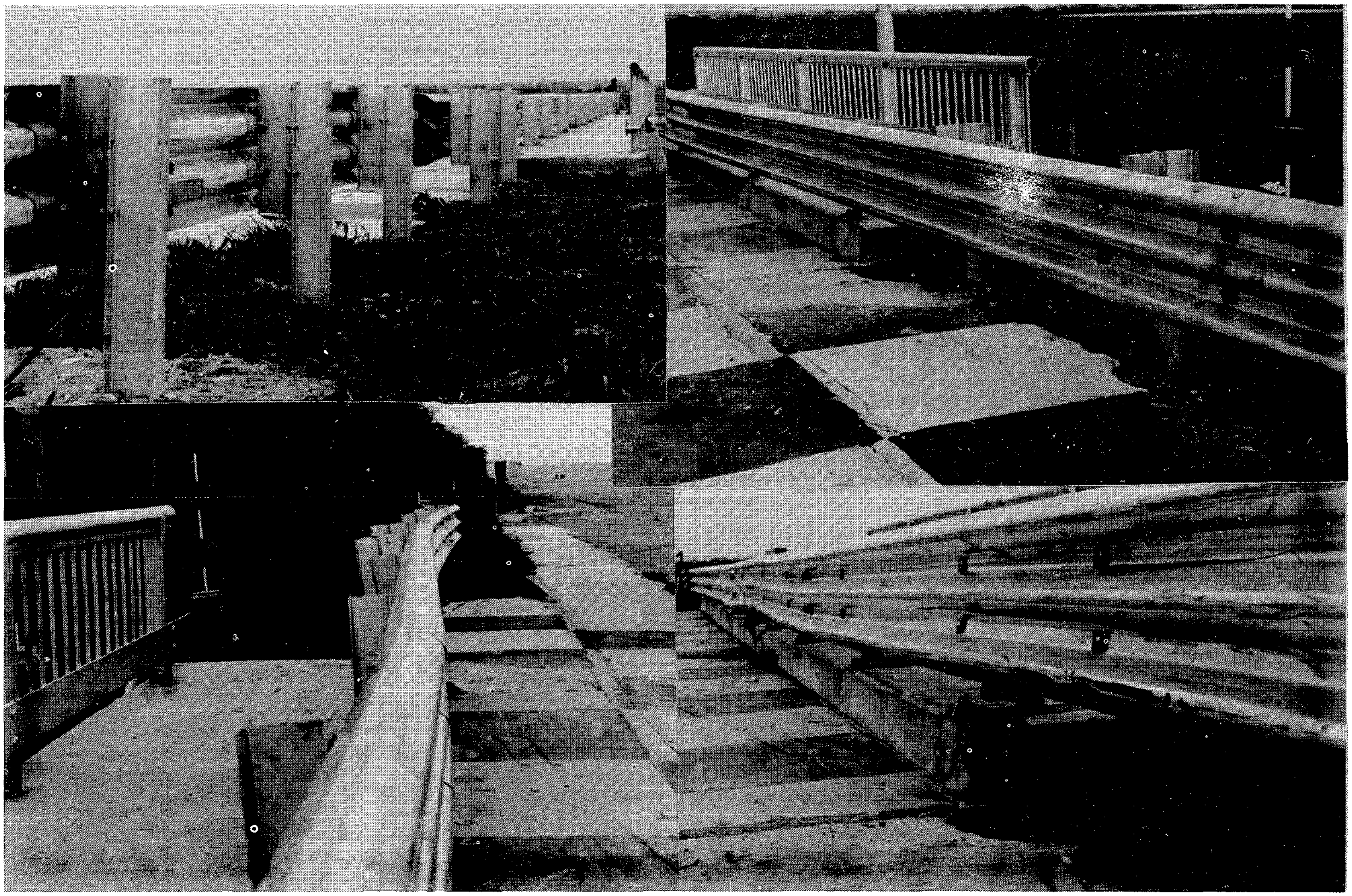
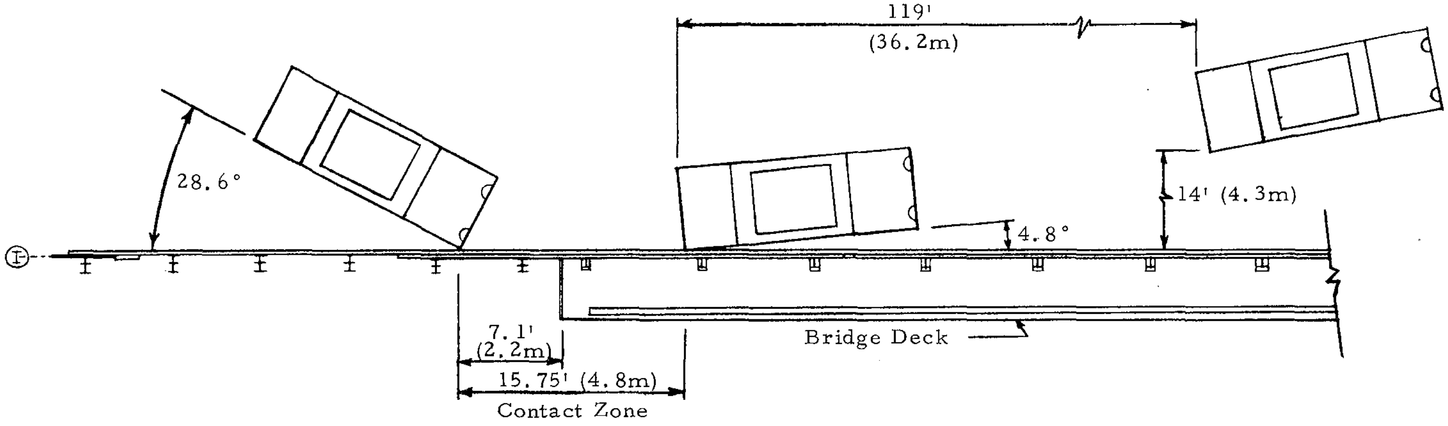
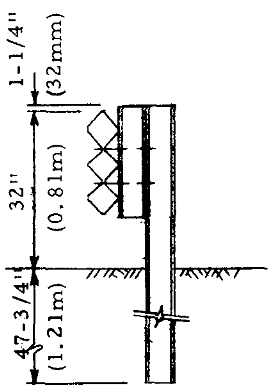


FIGURE 70. VIEWS OF INSTALLATION BEFORE AND AFTER TEST RF-17





R(IIIW)-1 Transition

Test No.	RF-17
Date	4/15/76
Drawing	SwRI 03-3717-23
Rail	Tubular Thrie
Parapet	n.a.
Length of Installation	155.8 ft (47.5m)
Pavement Condition	Dry
Vehicle	1970 Chevrolet Impala
Vehicle Mass (w/instrumentation)	4455 lb (2021kg)

Impact Speed	48.0 mph (21.5m/s)
Impact Angle	+28.6 deg
Exit Angle	-4.8 deg
Exit Speed	31.1 mph (13.9m/s)
Vehicle Accel (max 50 ms avg)	
Lateral (cine/elect)	-4.3g/n.a.
Long. (cine/elect)	-4.6g/n.a.
Resultant (cine/elect)	6.3g/n.a.
Vehicle Rebound Distance	14 ft (4.3m)
Vehicle Damage	
TAD	1-RFQ-5
VDI	01FREW5
Max. Rail Deflection (dynamic/permanent)	1.1 ft (0.34m)/ 0.51 ft (0.16m)

FIGURE 71. SUMMARY OF CRASH TEST RF-17 RESULTS

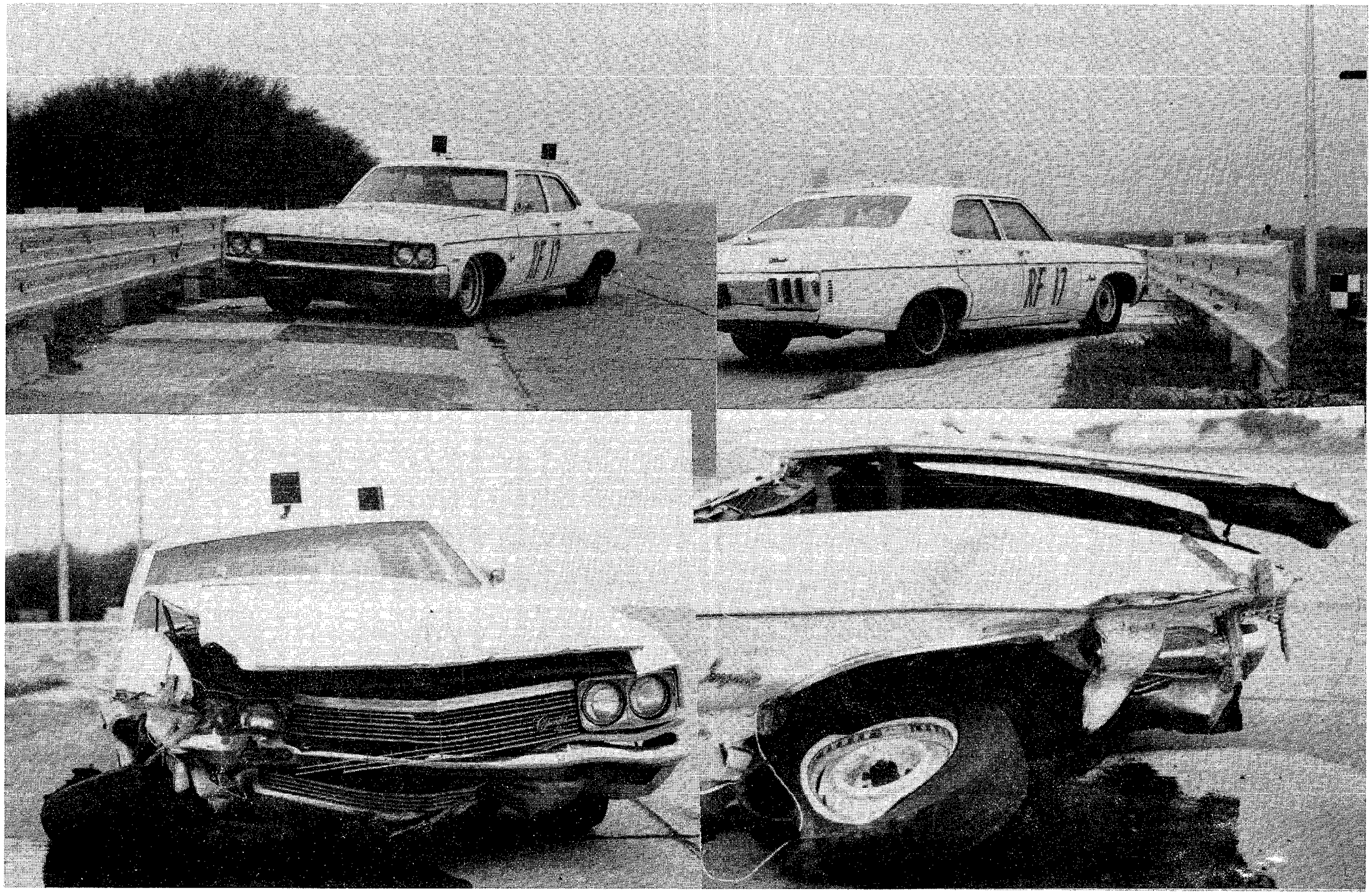


FIGURE 72. VIEWS OF VEHICLE BEFORE AND AFTER TEST RF-17

A number of barrier profiles are classified as a safety shape. The forerunner was the New Jersey profile, which was followed by the General Motors shape. Various states have adopted either the New Jersey (MB5) or General Motors (MB6) shapes or a modification of one of these. Recent research and accident statistics have shown the criticality of the profile geometry in safely redirecting colliding vehicles.(18) The findings indicate that the New Jersey profile is superior to the General Motors shape, and the designer should refrain from changing the profile geometry.

In the present form, the safety shape satisfies AASHTO bridge design specifications and has performed adequately in numerous crash tests, although high-angle impacts can be very severe. Accordingly, a retrofit modification is not warranted for the Category IV designs.

The designer must be concerned with the approach guardrail and transition system to assure an integrally performing barrier system. Techniques for attaching approach guardrail to the safety shape are discussed in the following section.

V. OTHER RETROFIT DESIGN FEATURES

In this section, design treatments to upgrade the safety performance of existing bridge railing systems are presented. These features were not evaluated by crash tests in this program. However, the features have either been developed and evaluated in other programs, or they represent a modest extension of a proven design.

A. Bridge Approach Barrier and Transition

A bridge approach barrier design is shown in Figure 73. This design is an improvement over designs that are presented in NCHRP *Report 118*.(7) Primary features of the concept are (a) the terminal, (b) approach rail, (c) transition, and (d) connection to a rigid bridge parapet.

The terminal is a breakaway cable terminal (BCT) that was recently developed on NCHRP 22-2.(11) For end-on impacts, the end post or posts, break away and the vehicle is directed behind the installation. The vehicle is redirected to the traffic lane for angle impacts downstream from the end posts. It should be noted that the BCT was developed with a standard 12-in. (0.30-m) wide W-beam. Since performance of the BCT with the thrie beam has not been full-scale crash test evaluated, a 37.5-ft (11.4-m) length of 12-in. (0.30-m) wide W-beam is recommended and then this element transitioned to the thrie beam. The W-beam-to-thrie beam transition hardware is presently being standardized by AASHTO-ARBA Task 13 committee and is available from one or two fabricators.

Use of the thrie beam, in lieu of the 12-in. (0.30 m) wide W-beam, will greatly improve the performance range of the approach rail because it decreases the sensitivity of barrier mounting height, increases the width of vehicle contact, decreases the tendency for wheel-post snagging, and increases both tensile and bending strength of the beam.(12) Hence, the approach rail will redirect a greater range of vehicle sizes and a greater range of impact conditions.

A gradual change in lateral stiffness of the barrier system must be achieved in the transition from the approach rail to the more rigid bridge rail system; otherwise, there is a serious tendency for impacting vehicles to pocket at the bridge end. The design (Figure 73) utilizes the method of decreasing post spacing of the approach segment near the bridge end and introduces lateral flexibility for the rail support on the bridge. The 10-in. (0.25 m) deep offset brackets are designed to plastically deform when they are within the impact zone.

The connection to the bridge must provide tensile anchorage for the thrie beam. Accordingly, a special end piece similar to the Michigan end shoe will be required. Since the connection, transition, and approach rail may be subjected to impacts from crossover traffic, the connection provides a smooth, horizontal transition into the bridge rail. The thrie beam end piece is being fabricated on a limited basis by at least two companies.

Another method for providing lateral flexibility of the thrie beam on the bridge is illustrated in Figure 74. Collapsing tubes are used in lieu of the offset brackets shown in Figure 73 and are designed to perform in a similar manner. Design of the collapsing tube for the thrie beam can be based on results from the collapsing ring bridge rail program.(13) Ring or tube geometry of 18-in. (0.46 m) dia × 0.375-in. (9.5 mm) thick × 6.125-in. (0.16 m) wide has performed satisfactorily during 14 full-scale vehicle crash tests of the system. The basic expression of the ring for a 10,000-lb (4536 kg) deforming force is:

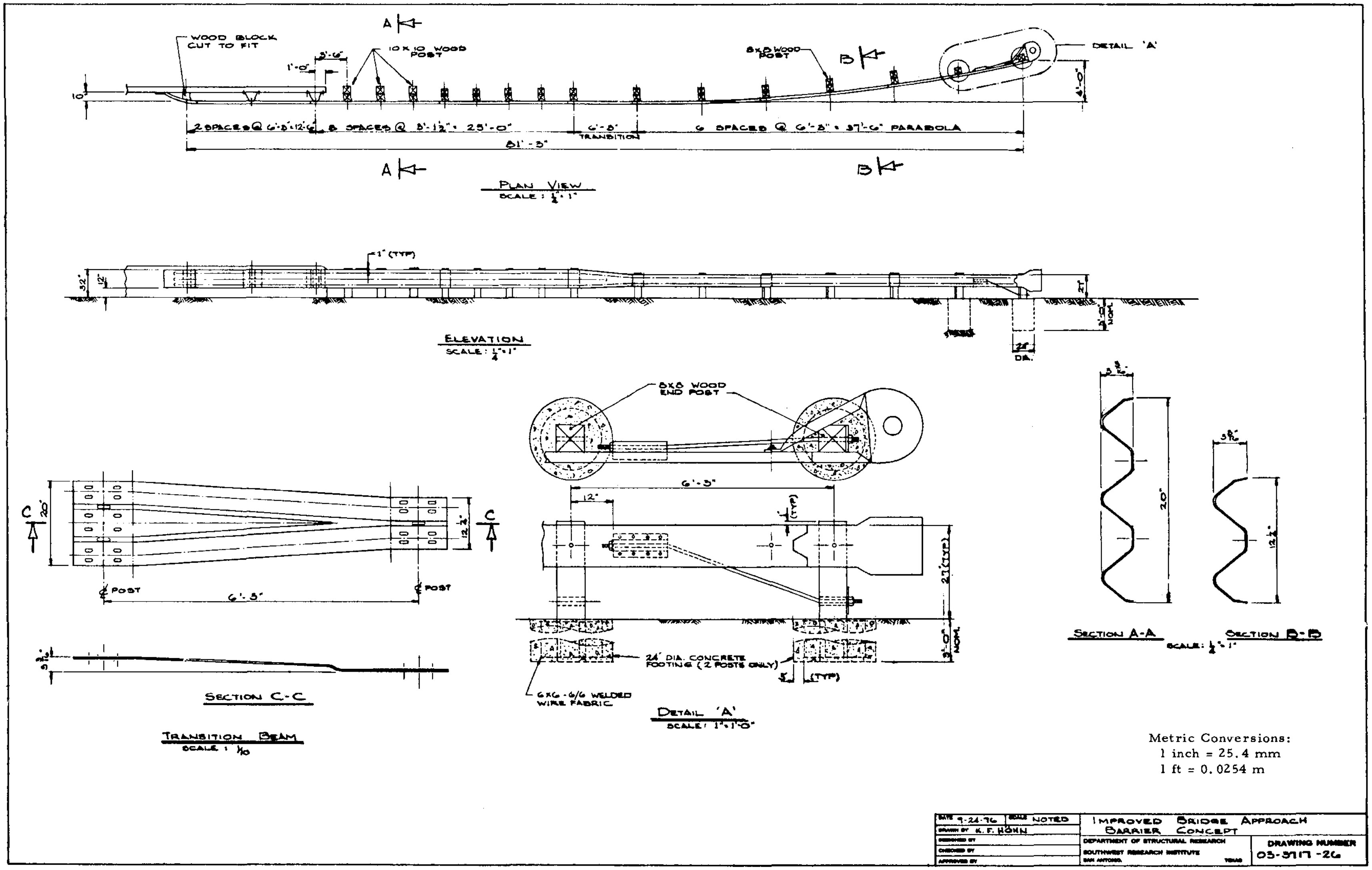


FIGURE 73. IMPROVED BRIDGE APPROACH BARRIER CONCEPT

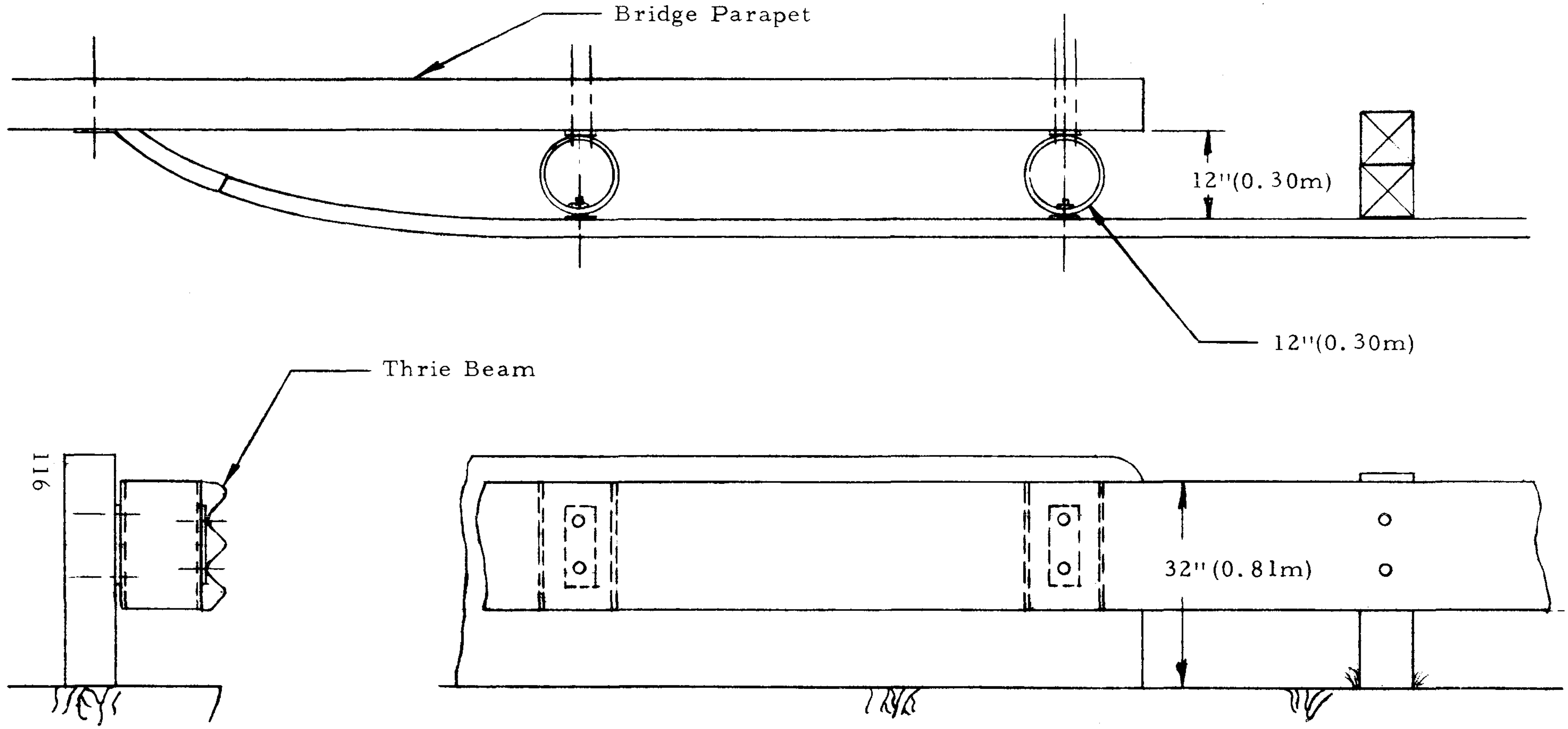


FIGURE 74. COLLAPSIBLE RING TRANSITION CONCEPT

$$\frac{B t^2}{R} = C \qquad (1)$$

where B is the width, R is the radius, t is the plate thickness, and C is the crush constant; C is determined to be 0.0957. For the 21-in. (0.53 m) wide thrie beam, a 22-in. (0.56 m) wide ring is required. Ring thickness is shown in Figure 75 for various diameter rings.

B. Bridge Railing Modifications

The concrete safety shape, although not crash tested in this program, is considered an operational retrofit design. The basic profile has been extensively tested [18] as a median barrier and bridge rail and has been used in several bridge rail retrofit programs, such as the access road to Dulles Airport, Washington, D.C.

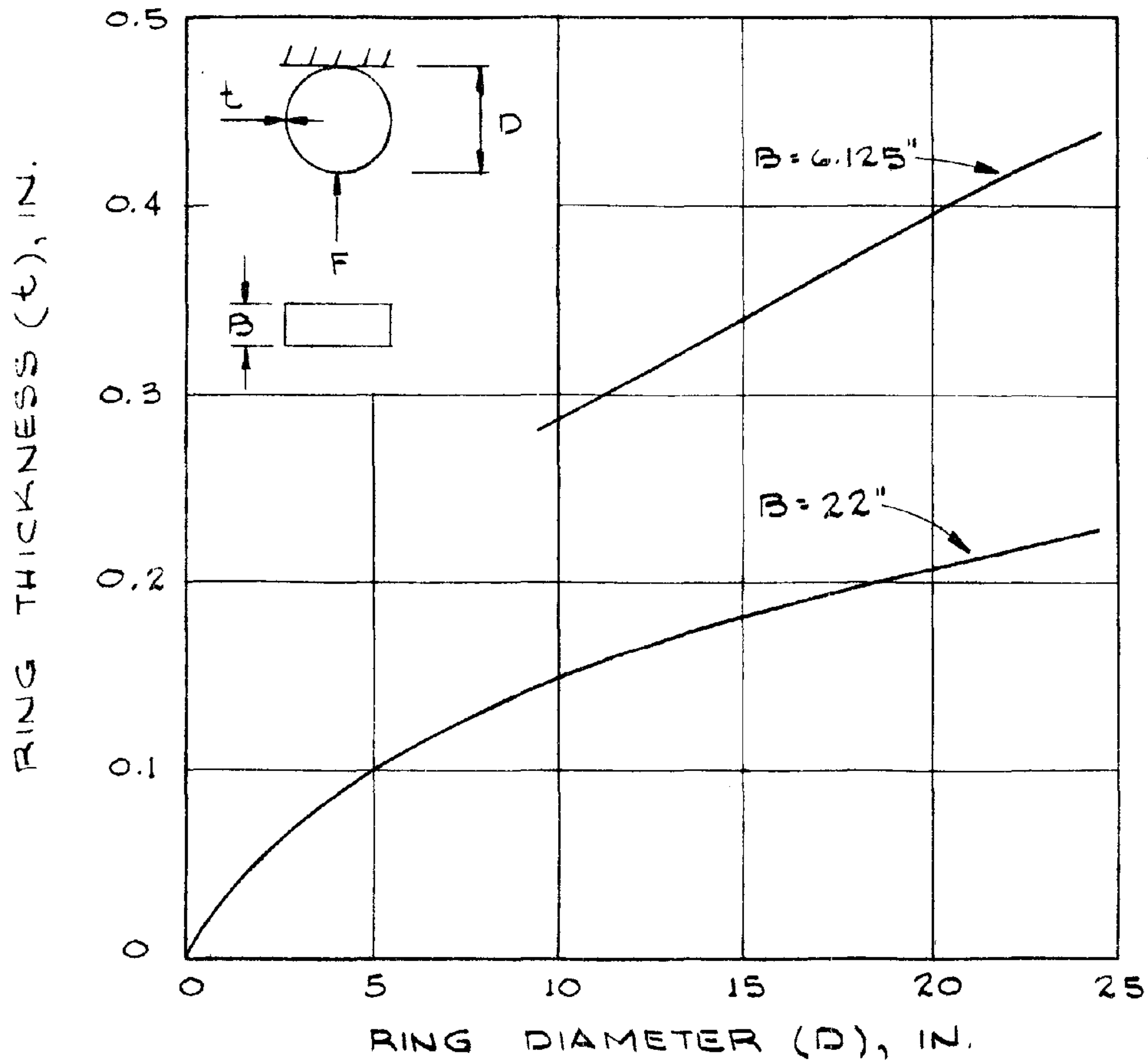
Development of the concrete median barrier has progressed since 1955. Principal dimensions of the shape are illustrated in Figure 76 for a median barrier and a bridge barrier system. As a vehicle contacts the shape, the inside wheels ride up the lower slope and bank the vehicle back toward the pavement. For shallow-angle impacts (less than 8 deg), generally no sheet metal damage is done to the car. Moreover, the barrier redirects the numerous shallow-angle impacts as well as more severe impacts with minimum barrier damage. Hence, the barrier remains in service for multiple impacts at the same point, the cost of repairing barrier damage is low, and traffic hazard exposure to barrier repair crews is minimal.

Application of the safety shape to existing bridge rail installation may vary. The shape can be cast in front of the existing barrier where bridge deck or walk space is available, or it can be cast in the same location after the inadequate structure is removed. A metal barrier with the safety shape is acceptable in situations where weight of the concrete safety shape exceeds the bridge load capacity.

Whereas the "see-thru" feature of bridge rails has been an important consideration in the past, the current design trend has been to downgrade this to an optional factor. Accordingly, the full-height safety shape (32 in. [0.81 m]) is considered acceptable design practice for most bridges, as well as the short safety shape with metal beam combination.

Typical applications of the concrete safety shape to bridge railing categories are shown in Figure 77. It is recognized that these are general design schemes and do not show specific details that will undoubtedly vary from bridge to bridge. Sound engineering judgment and detailed design procedures will be required for application of the concepts.

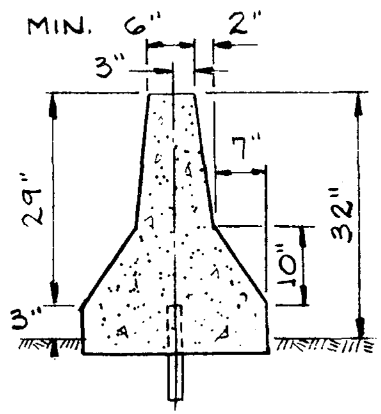
A summary of crash test results of the collapsing ring bridge rail, the concrete safety shape, and the thrie beam guardrail is contained in Table 13.



Metric Conversion:
Multiply inches by 25.4 to obtain millimeters.

FIGURE 75. COLLAPSING RING THICKNESS REQUIREMENT

Metric Conversions:
Multiply inches by 0.0254 to obtain meters
Multiply feet by 0.305 to obtain meters
Multiply lb/ft by 1.488 to obtain kg/m



SYSTEM MB5

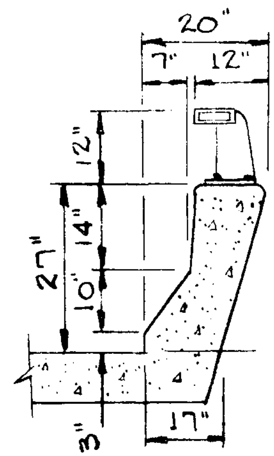
Dowels (into existing pavement): 1" dia x 8" long steel rod

Dowel Spacing: 4'-0"

Concrete: AASHO Class B

Developed By: New Jersey

(a) Median Barrier



SYSTEM BR-2

Post Spacing: 10'-0"

Post: Fabricated steel with concrete parapet

Beam: TS6x2 (12.02 lb/ft)

Offset Brackets: -

Developed By: California

(b) Bridge Barrier

FIGURE 76. GEOMETRY OF CONCRETE SAFETY SHAPE

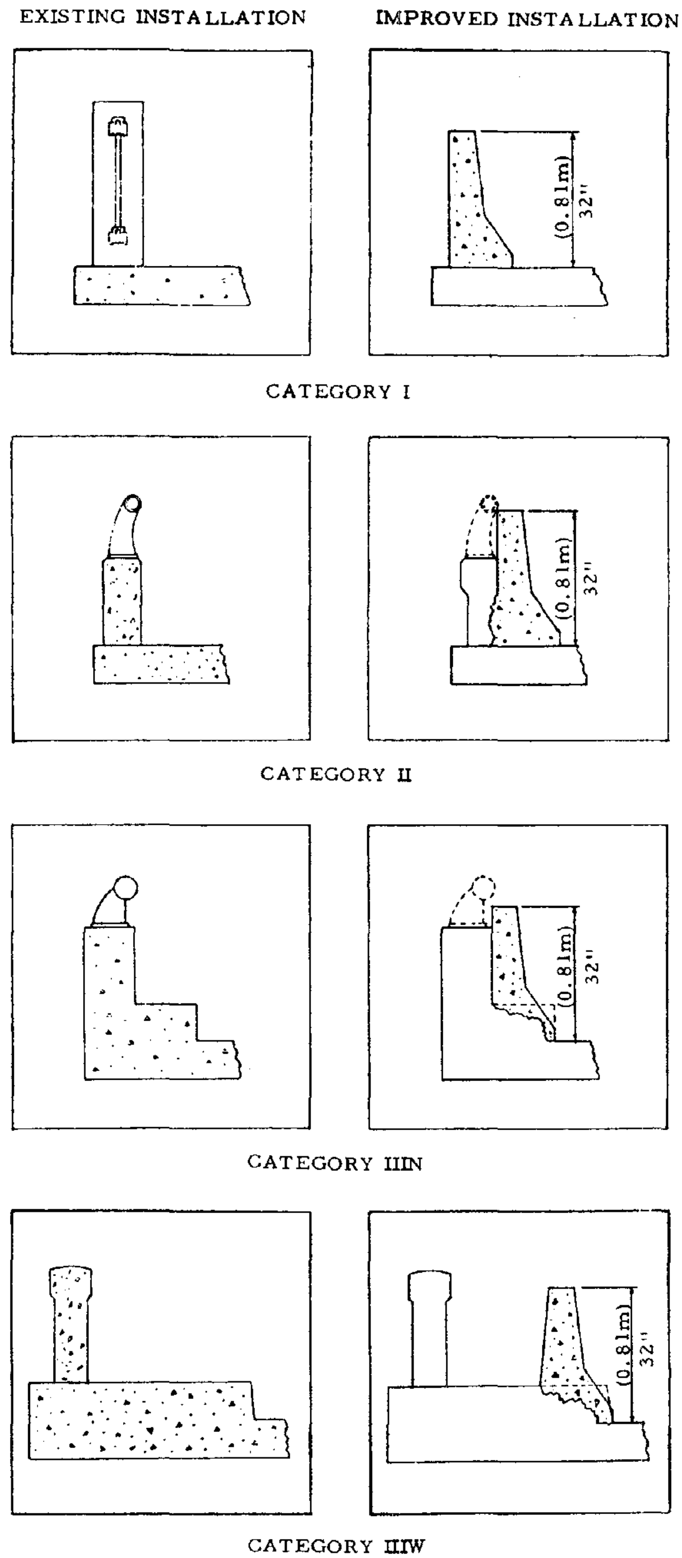


FIGURE 77. CONCRETE SAFETY SHAPE RETROFIT APPLICATIONS

TABLE 13

SUMMARY OF BARRIER CRASH TESTS

System	Ref	Test No.	Vehicle Weight (lbs)	Vehicle Speed (mph)	Impact Angle (deg)	Remarks
1. Collapsing Ring Bridge Rail						
	13	BR-5	3910	56.1	23.9	Vehicle redirected at 12° angle
	13	BR-6	2090	55.7	23.5	Vehicle redirected at 12° angle
Transition Test	13	BR-7	4230	56.7	29.1	Vehicle redirected at 12° angle
2. Concrete Safety Shape (MB5)						
	19	162	4540	63.0	25	Vehicle airborne 20 ft, exit angle 16 deg, max. roll angle 25 deg
	18	262	4960	59.0	25	Vehicle rolled over
	18	263	4960	66.0	25	Vehicle rolled over
	18	264	4860	64.0	25	Exit angle 5°, max. vehicle rise 3'
	18	265	4780	62.0	24	Exit angle 4°, max. vehicle rise 3.7'
	20	CMB-1	4000	62.4	25	Exit angle 7°, max. roll of vehicle approx. 30° away from barrier
	20	CMB-2	4230	55.7	25	Exit angle 7°, max. roll of vehicle approx. 25° away from barrier
	20	CMB-4	4210	60.7	15	Exit angle 11.5°, max. roll of vehicle approx. 25° away from barrier
	18	CMB-4	4370	55.9	16	Vehicle left front tire and rim damaged beyond repair, max. roll angle 20°
	18	CMB-9	2250	58.9	16	Vehicle redirected, max. roll angle 20°
3. Thrie Beam Guardrail						
	12	AS-2	4000	67.1	28.7	Vehicle redirected at large exit angle
	12	AS-3	2200	54.1	16.8	Vehicle redirected with little damage to barrier or vehicle; driveable after test
	12	AS-4	4500	59.1	15.9	Vehicle redirected with little damage to barrier or vehicle; driveable after test
	12	AS-5	4000	56.4	25.2	Vehicle redirected with little damage to barrier or vehicle; driveable after test

Metric Conversions:
Multiply lb by 0.454 to obtain kilograms
Multiply mph by 0.447 to obtain m/s

VI. IMPLEMENTATION OF RETROFIT DESIGNS

A. General

With an average of four to ten unique bridge railing designs in service in each state, the total number of designs is estimated to exceed 200 configurations. Moreover, since most of these systems were designed and installed prior to the recent emphasis on vehicle collision safety performance, a large proportion does not satisfy minimum safety standards; this situation was verified during the field survey phase of this program.

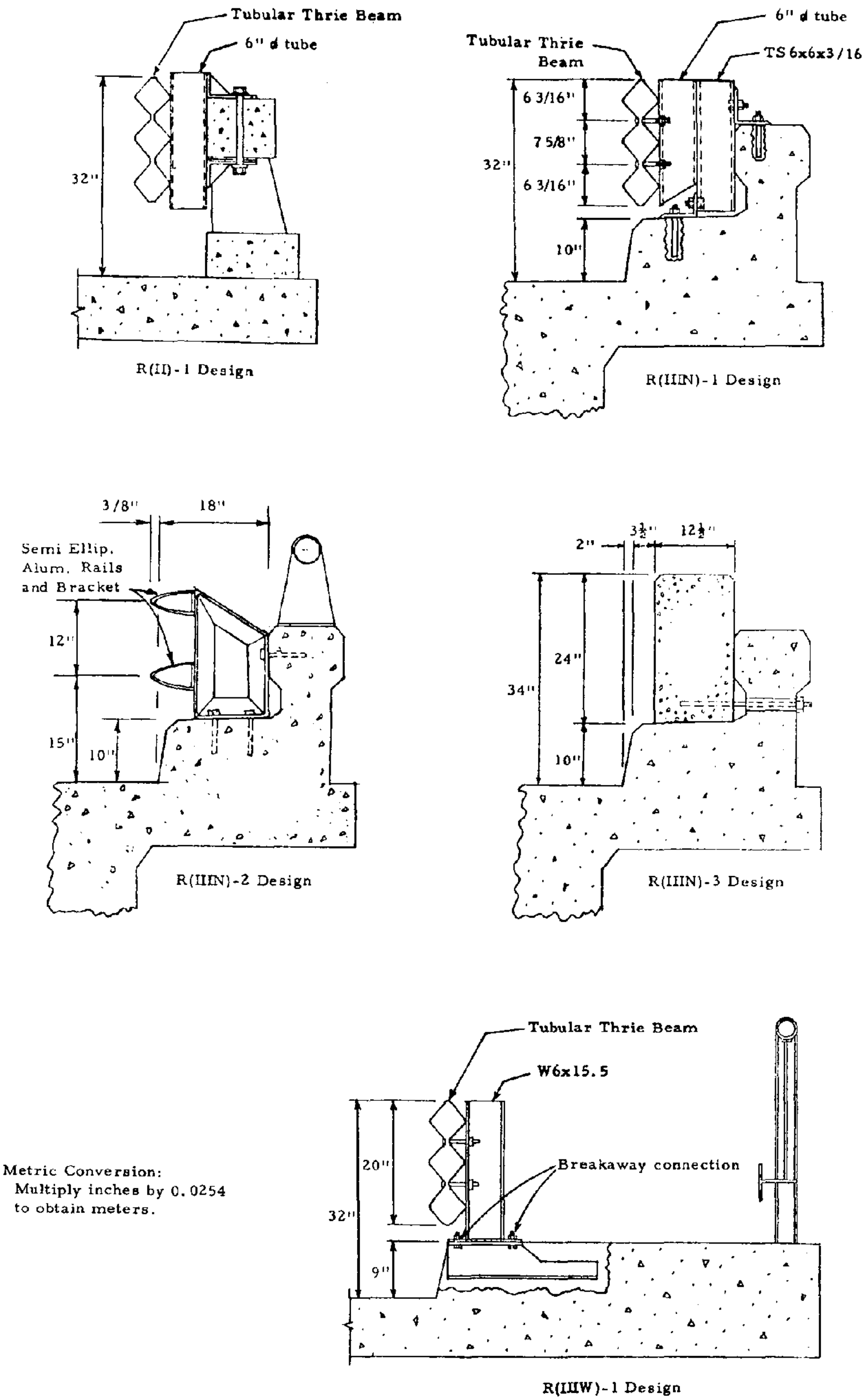
To upgrade a specific installation to satisfy current safety requirements, it may require (1) only minor modifications such as replacing or reinforcing a rail member, (2) a major modification in which a complete new railing system is integrated into the existing installation, or (3) a complete removal of the existing installation and replacement of it with an acceptable design. In actual practice, all three techniques will be used with the decision being based on local conditions. For those installations requiring only minor modifications, the local highway engineers should ascertain those features not in compliance with AASHTO specifications and develop the necessary structural modification. For those installations requiring major modification, retrofit designs developed and crash-test evaluated in this program are available. And finally, for those bridge railing installations that are not amenable for upgrading, or where the upgrading work is more costly than a removal and replacement alternative, recommended bridge railing designs are presented.

For installations in which the bridge railing is to be replaced, suggested bridge railing designs are summarized in Table 8. For cases where the existing installation is to be modified, suggested applications of the concrete safety shape are illustrated in Figure 77; a summary of retrofit designs developed in this program is presented in Figure 78.

B. Staged Upgrading

Effective bridge railing must be considered as a *system* consisting of three interrelated elements: (a) bridge rail, (b) approach guardrail, and (c) the transition from the approach guardrail to the bridge rail. A deficient or inadequate design of any one or combination of these elements can cause fatalities in impacting vehicles. As illustrated in Figure 1, 58 percent of fatal accidents occur at the bridge end (poor transition design), 27 percent occur with the bridge rail, and the remaining 15 percent involve the approach guardrail. As an alternative to identifying the more hazardous bridge railing installations and fully upgrading them to current safety standards, an administrative decision may be made to simultaneously upgrade all installations to a lesser level of safety consistent with available funding. That is, all installations in an area or region would be partially upgraded in stages with each stage being accomplished as funds became available. In this manner, the more hazardous features of all bridge railing installations could be treated first leaving the less dangerous conditions for a later treatment. This could result in a more cost effective approach.

Based on statistics presented in Figure 1, a first stage would consist of providing all bridges with conforming approach guardrails that are properly transitioned and attached to the bridge rail. Such improvements would address about 73 percent of bridge railing installation hazards. In a later stage, the railing on all bridges would be upgraded to current standards, thus completing the improvement program.



Metric Conversion:
Multiply inches by 0.0254 to obtain meters.

FIGURE 78. RETROFIT DESIGNS EVALUATED IN PROGRAM

The basic staging approach can be refined by establishing upgrading priorities for selected installations that exhibit unusually severe hazard features, high exposure rates and/or adverse accident experience.

C. Suggested Implementation Procedures

In order to identify bridge barrier installations that require safety performance improvement and to effect the necessary upgrading, the following procedures are suggested.

Existing bridge rail systems should be screened and appraised according to their functional and safety performance. The systems can be grouped into *conforming* installations of either preferred or acceptable designs or into *nonconforming* installations. Screening guidelines for this grouping and recommended upgrading action are delineated in Table 14. In general, nonconforming installations should be upgraded to preferred designs.

Specific screening and design of existing systems include the following steps:

1. Analyze bridge rail according to 1973 AASHTO Bridge Specifications. Items of particular importance are (1) geometry such as minimum height of top rail and spacing between rails, (2) structural strength with respect to static loads, (3) continuity and proper offset of rails, (4) proper material selection, and (5) continuity with approach guardrail. If the installation is deficient in one or more of these items, the deficient items should be investigated for potential modifications to upgrade them for conformance with 1973 AASHTO Bridge Specifications. The upgrading requirement may consist of replacing a rail section or providing continuity in the system; this can be accomplished by local forces.

2. Identify specific installations where adverse accident experience has indicated inadequate barrier performance. These installations may or may not conform to 1973 AASHTO Bridge Specifications.

3. Classify the installation according to either Category I, II, III, or IV. In general, action to be taken includes:

   - Category I—Remove rail and replace with conforming design.
   - Category II—Either replace with conforming design or upgrade with R(II)-1 retrofit design.
   - Category III—Either replace with conforming design or upgrade with either R(IIIN)-1, R(IIIN)-2, R(IIIN)-3, or R(IIIW)-1 retrofit design.
   - Category IV—This category is adequate and does not need upgrading.

4. Examine approach guardrail for following features:

   - Acceptable design—G3 or G4W/S.
   - Proper installation—rail height, post spacing, flare geometry, and approach surface (e.g., only mountable curbs in front of installation).

TABLE 14

EXISTING BRIDGE RAIL INSTALLATION SCREENING GUIDELINES

Evaluation Guidelines	Approach Guardrail Upstream Terminal	Approach Guardrail	Approach Guardrail to Bridge Rail Transition	Bridge Rail
I. Design Guidelines	. NCHRP Report 129 . NCHRP Report 118 . NCHRP Research Digest 43 . NCHRP Report 153	. NCHRP Report 118 . Transportation Research Record 488 . NCHRP Report 153	. AASHTO 1973 Bridge Specifications . NCHRP Report 118 . NCHRP Report 115 . Transportation Research Record 488 . NCHRP Report 153	. AASHTO 1973 Bridge Specifications . NCHRP Report 149 . NCHRP Report 118 . NCHRP Report 153 . Crash Test Results . Accident Cases
II. Conforming Installations A. Preferred Design 1. Features	Sufficient anchor for approach guardrail. [May be Breakaway Cable Terminal (BCT) or rail that terminates at a natural roadside feature (e.g., side slope).]	G4S/W with Thrie Beam rail, sufficient length-of-need, and proper layout.	Structural continuity and graduated lateral stiffness between approach guardrail and bridge rail and design verified by crash tests.	Class II or Class I system with no curbs or walks in front of barrier.
2. Recommended Upgrading	none	none	none	none
B. Acceptable Design 1. Features	Sufficient anchor for approach guardrail. (May be ramped terminal or upright terminal with crash cushion.)	G4S/W (with standard flex beam), G2 and G3 systems with sufficient length-of-need and proper layout.	Structural continuity and graduated lateral stiffness transition between approach guardrail and bridge rail; however crash tests have not been performed to verify design.	Design conforms to 1973 AASHTO Bridge Specifications (i.e., geometry, static strength, continuity); however crash tests have not been performed or there are insufficient accident cases.
2. Recommended Upgrading	Upgrade to preferred design when economically practical.	Upgrade to preferred design when economically practical.	Upgrade to preferred design when economically practical.	Upgrade to preferred design when economically practical or verify design by vehicle crash tests.
III. Nonconforming Installation A. Features	Inadequate anchor for approach guardrail length-of-need. Upright terminal with unprotected rail end.	Existing installation fails to meet G2, G3 or G4 designs and/or installation is of improper length or layout geometry.	There is no approach guardrail or there is no connection between approach guardrail and bridge rail.	Does not conform to 1973 Bridge Specifications and has not been evaluated by vehicle crash tests.
B. Recommended Upgrading	Remove and replace with preferred design.	Remove and replace with preferred design.	Install preferred approach guardrail and transition design.	Remove and replace with preferred design.

- Proper length—length-of-need should be examined by procedure presented in Appendix C of NCHRP *Report 118*.

- Adequate terminal—terminal must develop strength of length-of-need approach guardrail; the terminal should not pose a spearing hazard to traffic.

- Adequate transition—approach guardrail must be securely attached to the bridge rail in such a manner to develop barrier tensile and flexural continuity in the connection.

If the approach guardrail is deficient in one or more of these items, the deficient items should be investigated for potential modification to upgrade them to acceptable performance standards. As soon as economically practical, the approach guardrail should be upgraded to the preferred design presented in Table 14.

5. Make cost studies of upgrading nonconforming bridge rail systems to conforming acceptable design and to conforming preferred design. Select degree of retrofit consistent with traffic conditions, accident experience, and funding.

6. Make installation layout drawings.

VII. CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions

1. Although recent accident statistics indicate improvement in safety performance of bridge railing systems as new designs are introduced and old installations are upgraded, as late as 1968 bridge railing systems did not perform satisfactorily with respect to today's standards in more than 68 percent of bridge railing fatal accidents. Appraisal according to 1973 AASHTO Bridge Specifications of 14 specific bridge railing designs (representing 67 percent of those surveyed) reveals that:

- Only one system conforms
- One system is considered marginal
- Twelve of the 14 designs do not conform with one or more provisions.

On the basis of reported mileage, 68 percent of the installations did not conform and another 27 percent of existing installations were determined to be marginal.

All 14 systems were designed prior to 1973 to conform to earlier AASHTO specifications, and the nonconforming deficiencies, which are minor in several instances, were expected.

2. Inadequate safety performance of the approach guardrail segment is attributed to inadequate design and/or improper layout and installation. Most states have adopted improved approach guardrail designs; however, this trend is too recent to be significantly reflected in the field.

3. Although more than 200 unique bridge rail systems are in service, these systems can be grouped into four categories, and bridge rail designs within a category are amenable to a common retrofit modification design. Categories II (parapet, no curb) and III (parapet and curb), with as many as four metal rails, represent more than 81 percent of all bridge rail systems in service.

4. Five bridge railing safety improvement modifications were developed and evaluated. In addition, preferred bridge railing designs and suggested application of the concrete safety shape in upgrading existing installations are presented.

5. Recommended approach guardrail designs, including upstream terminal and transition, that represent the latest barrier technology are presented.

B. Recommendations

1. Retrofit designs to upgrade safety performance of existing bridge railings should be implemented. These designs include R(II)-1, R(IIIN)-1, R(IIIN)-2, R(IIIN)-3, and R(IIIW)-1.

2. Highway agencies should direct their emphasis to the approach guardrail-transition to bridge railing segment of the barrier system. Designers should assure both tensile continuity and a lateral stiffness transition in the approach beam-bridge rail connection.

3. The BCT[11] should be used instead of upstream terminals presented in NCHRP *Report 118*.

REFERENCES

1. Olson, R. M., et al, "Tentative Service Requirements for Bridge Rail Systems," NCHRP *Report 86* (1970), 62 pp.

2. Hosea, H. E., "Fatal Accidents on Completed Sections of the Interstate Highway System, 1968," Public Roads (Oct 1969), pp. 217-224.

3. "Freeway Fatal Accidents—1965-1975," California Department of Transportation, Sacramento, California.

4. "A Supplement to a Guide to Standardized Highway Barrier Rail Hardware (For Bridge and Structure Mounted Barriers)," *American Road Builder's Association Technical Bulletin* No. 268-A, Washington, D.C. (1973).

5. Olson, R. M., et al, "Bridge Rail Design Factors, Trends, and Guidelines," NCHRP *Report 149* (1974), 49 pp.

6. Viner, J. G., Office of Research, Federal Highway Administration, "Bridge Railings—The Care for Full-Scale Dynamic Testing," paper presented to 1970 Regional Meetings of the AASHTO Committee on Bridges and Structures.

7. Michie, J. D. and Bronstad, M. E., "Location, Selection, and Maintenance of Highway Traffic Barriers," NCHRP *Report 118* (1971), 96 pp.

8. Bronstad, M. E. and Michie, J. D., "Recommended Procedures for Vehicle Crash Testing of Highway Appurtenances," NCHRP *Report 153,* Transportation Research Board, National Research Council, Washington, D. C. (1974).

9. Zobel, E. C., et al, Final Report, "Investigation of the Dynamic Impact of Roadside Obstacles," Federal Highway Administration and Michigan State Highway Commission, Wayne State University, Detroit, Michigan (1972).

10. DeLeys, N. J. and Segal, D. J., Calspan Corporation Final Report, "Vehicle Redirection Effectiveness of Median Berms and Curbs," Federal Highway Administration Contract No. DOT-FH-11-7913, Washington (1973).

11. "Breakaway Cable Terminals for Guardrails and Median Barriers," National Cooperative Highway Research Program, *Research Digest* 84 (March 1976).

12. Bronstad, M. E., Michie, J. D., Viner, J. G., and Behm, W. E., "Crash Test Evaluation of Thrie Beam Traffic Barriers," Transportation Research Record 488 (1974), pp. 34-44.

13. Kimball, C. E., Bronstad, M. E., Michie, J. D., Wentworth, J. A., and Viner, J. G., "Development of a Collapsing Ring Bridge Railing System," Final Report on FHWA Contract DOT-FH-11-7983, FHWA, Washington, D. C. (1976).

14. Nordlin, E. F., et al, "Dynamic Tests of the California Type 20 Bridge Rail," Res. Rep. No. M&R HRB 636459, California Div. of Highways (1971).

15. Graham, M. D., Burnett, W. C., Gibson, J. L., and Freer, R. H., "New Highway Barriers: The Practical Application of Theoretical Design," Highway Research Record 174, Highway Research Board (1967), pp.88-183.

16. Nordlin, E. F., Stoker, J. R., Hackett, R. P., and Doty, R. N., "Dynamic Tests of the California Type 15 Bridge Barrier Rail," Highway Research Record 386, Highway Research Board (1972), pp. 88-100.

17. Perrone, N., "Thick-Walled Rings for Energy-Absorbing Bridge Rail Systems," Report No. FHWA-RD-73-49 (Dec 1972).

18. Bronstad, M. E., Calcote, L. R., and Kimball, C. E., "Concrete Median Barrier Research," FHWA Contract DOT-FH-11-8130 Final Report, Washington, D. C. (June 1976).

19. Nordlin, E. F. and Field, R. N., "Dynamic Tests of the Steel Box Beam and Concrete Median Barriers," Highway Research Record 222, Highway Research Board (1968), pp. 53-88.

20. Hirsch, T. J., Post, E. R., and Hayes, G. G., "Vehicle Crash Test and Evaluation of Median Barriers for Texas Highways," Research Report 146-4, Texas Transportation Institute, Texas A&M University (1972).

APPENDIX A

DRAWINGS

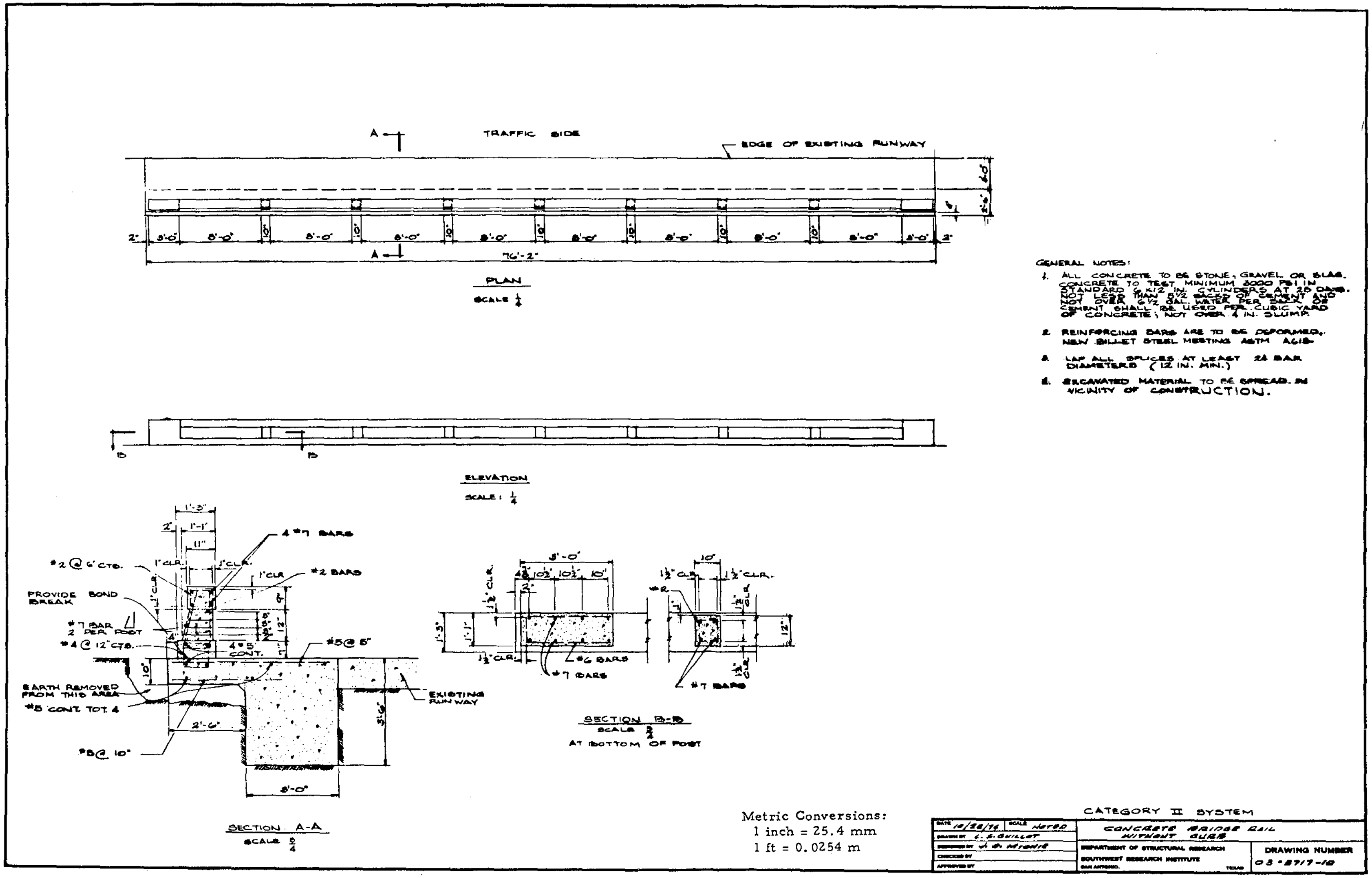


FIGURE A.1 CATEGORY II INSTALLATION DRAWING

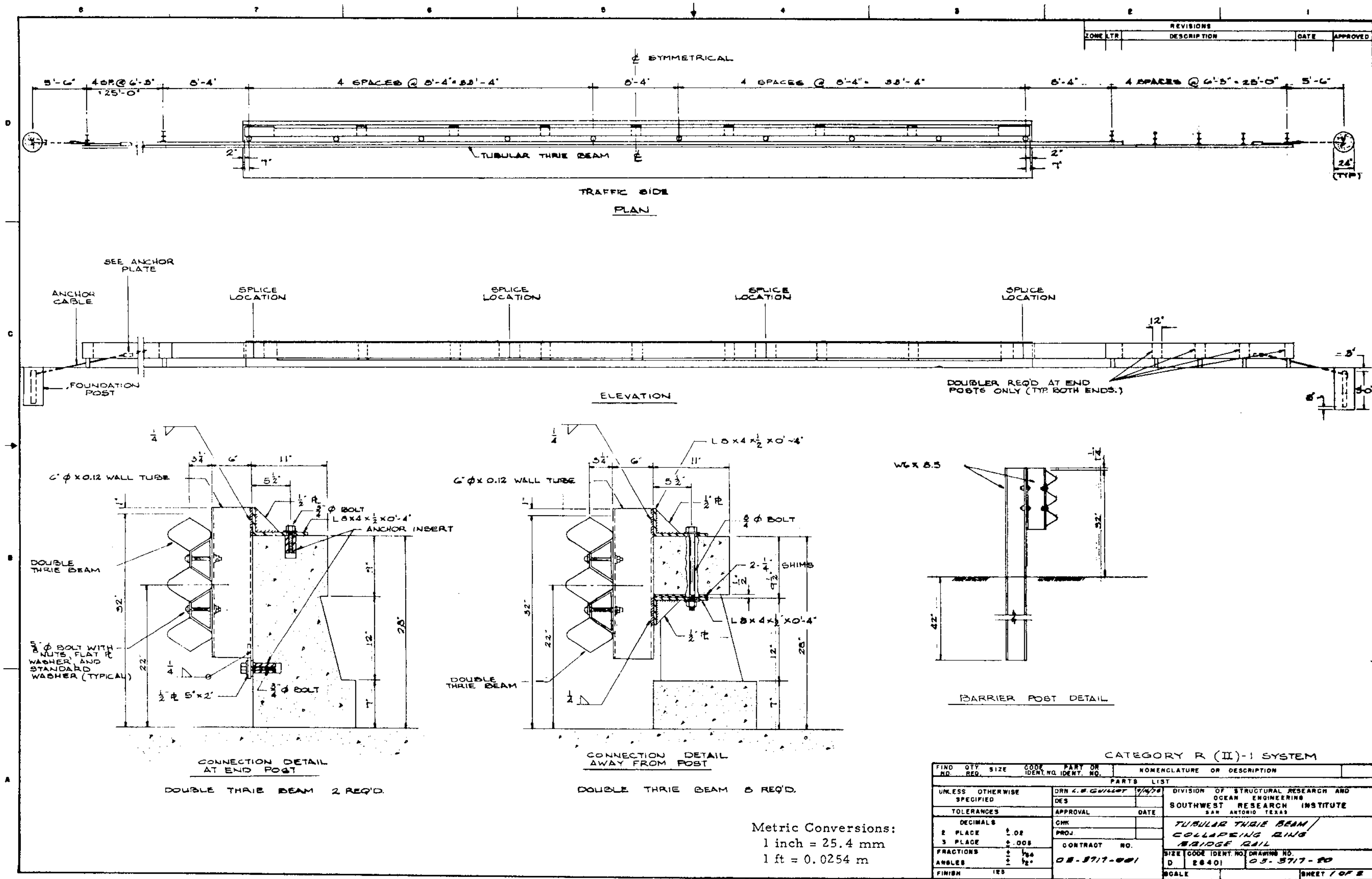


FIGURE A.2 CATEGORY R(II)-1 INSTALLATION DRAWING

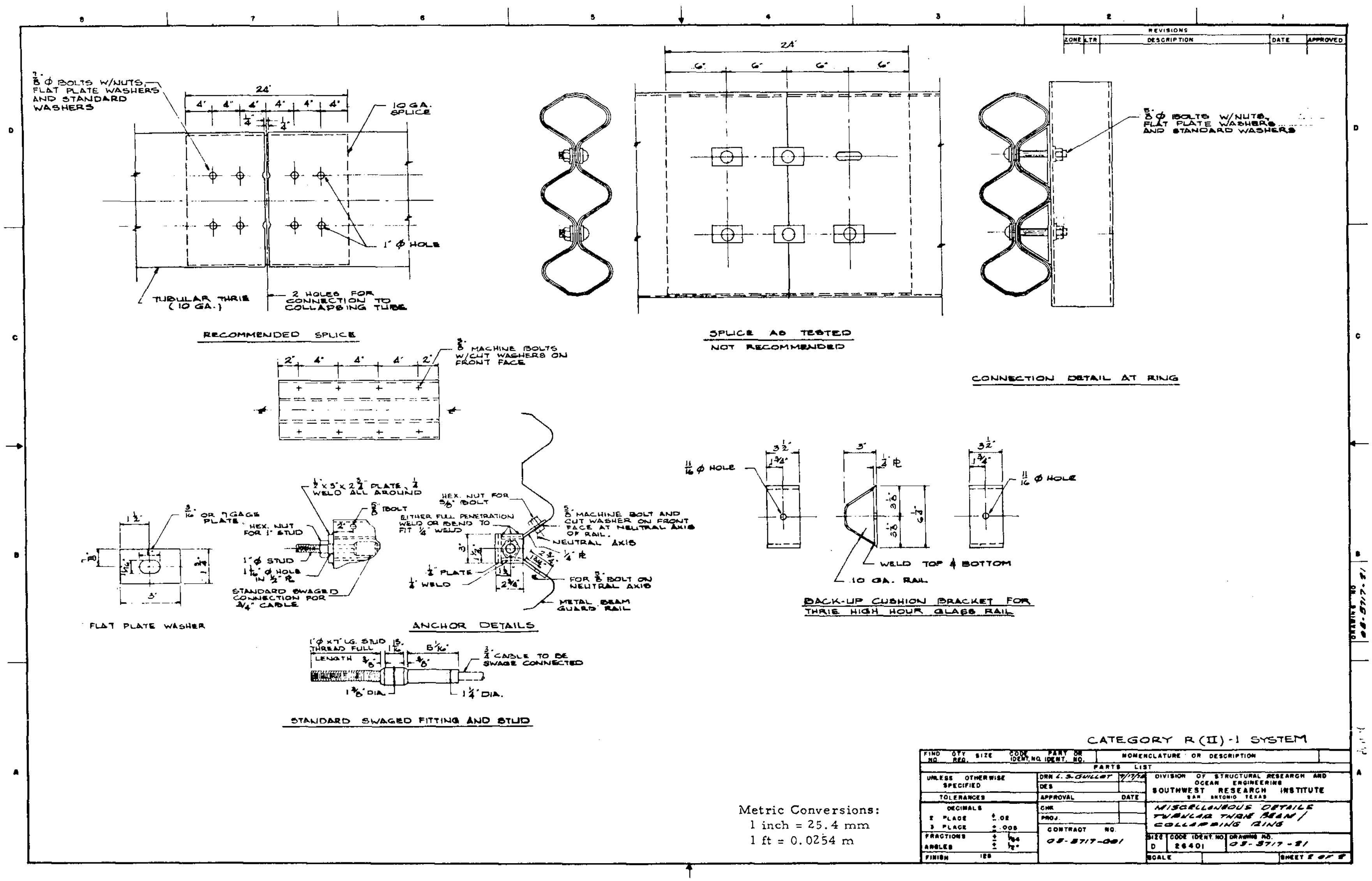


FIGURE A.3 CATEGORY R(II)-1 INSTALLATION DRAWING

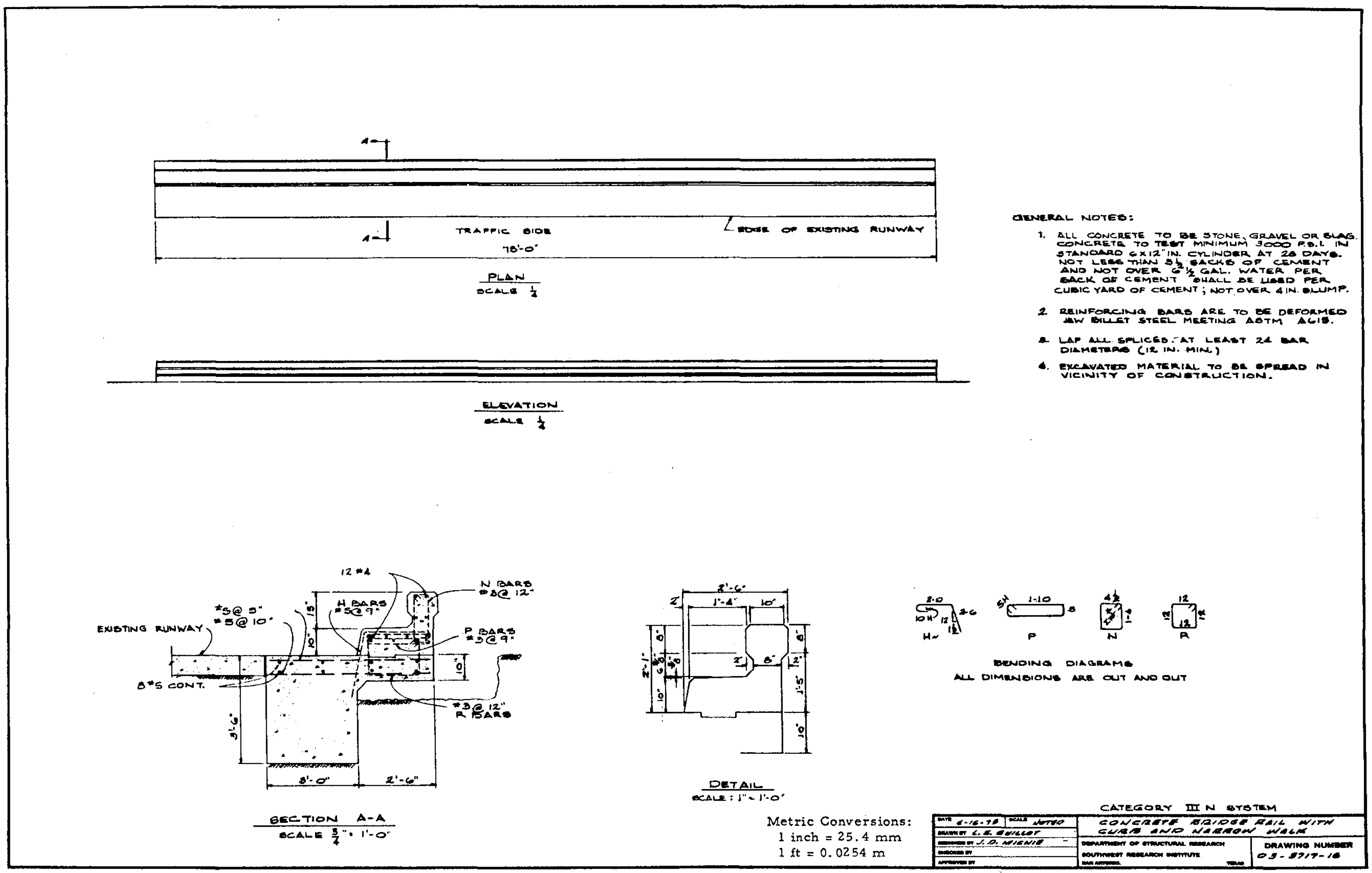


FIGURE A.4 CATEGORY IIIN INSTALLATION DRAWING

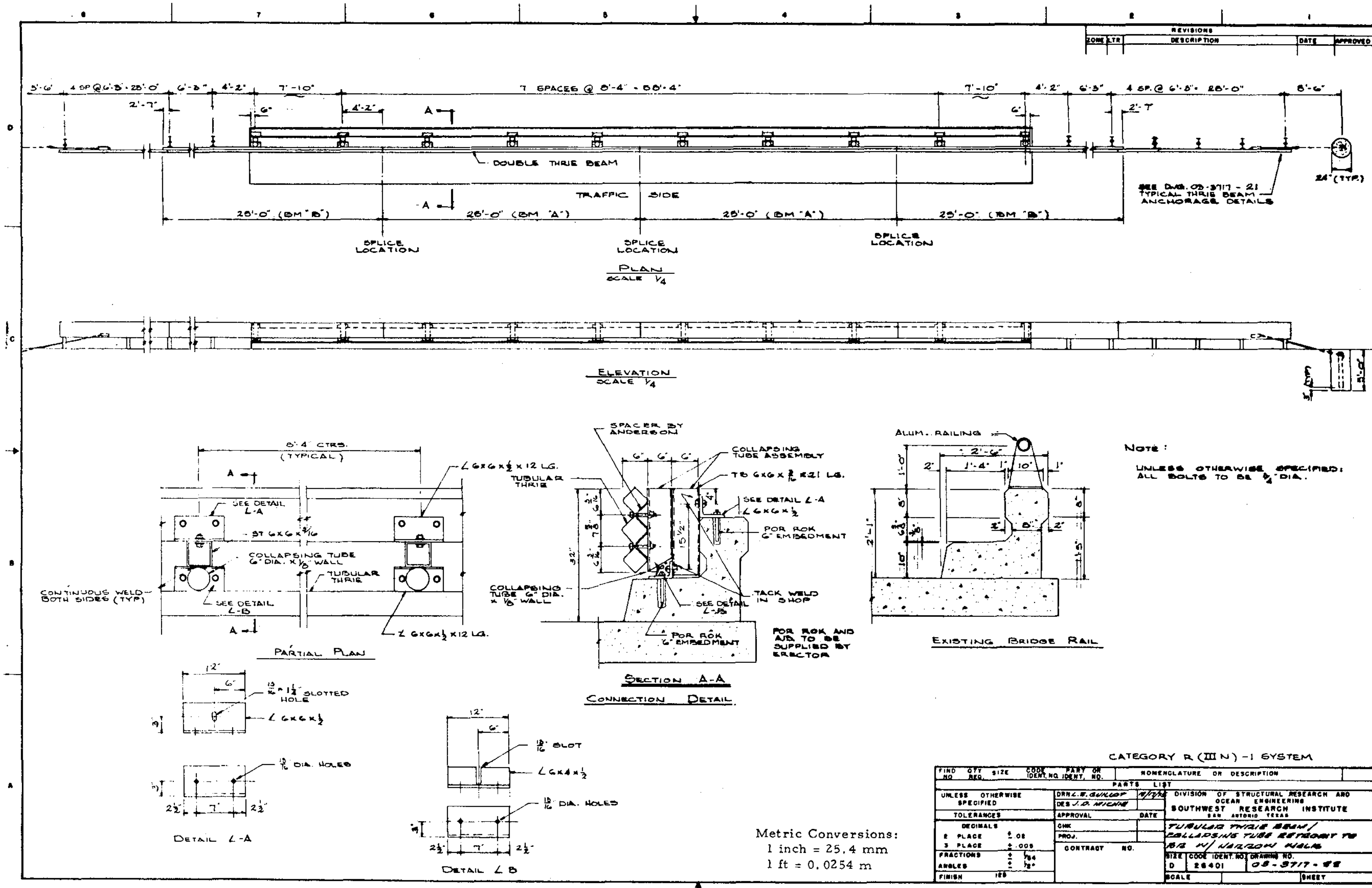


FIGURE A.5 CATEGORY R(IIIN)-1 INSTALLATION DRAWING

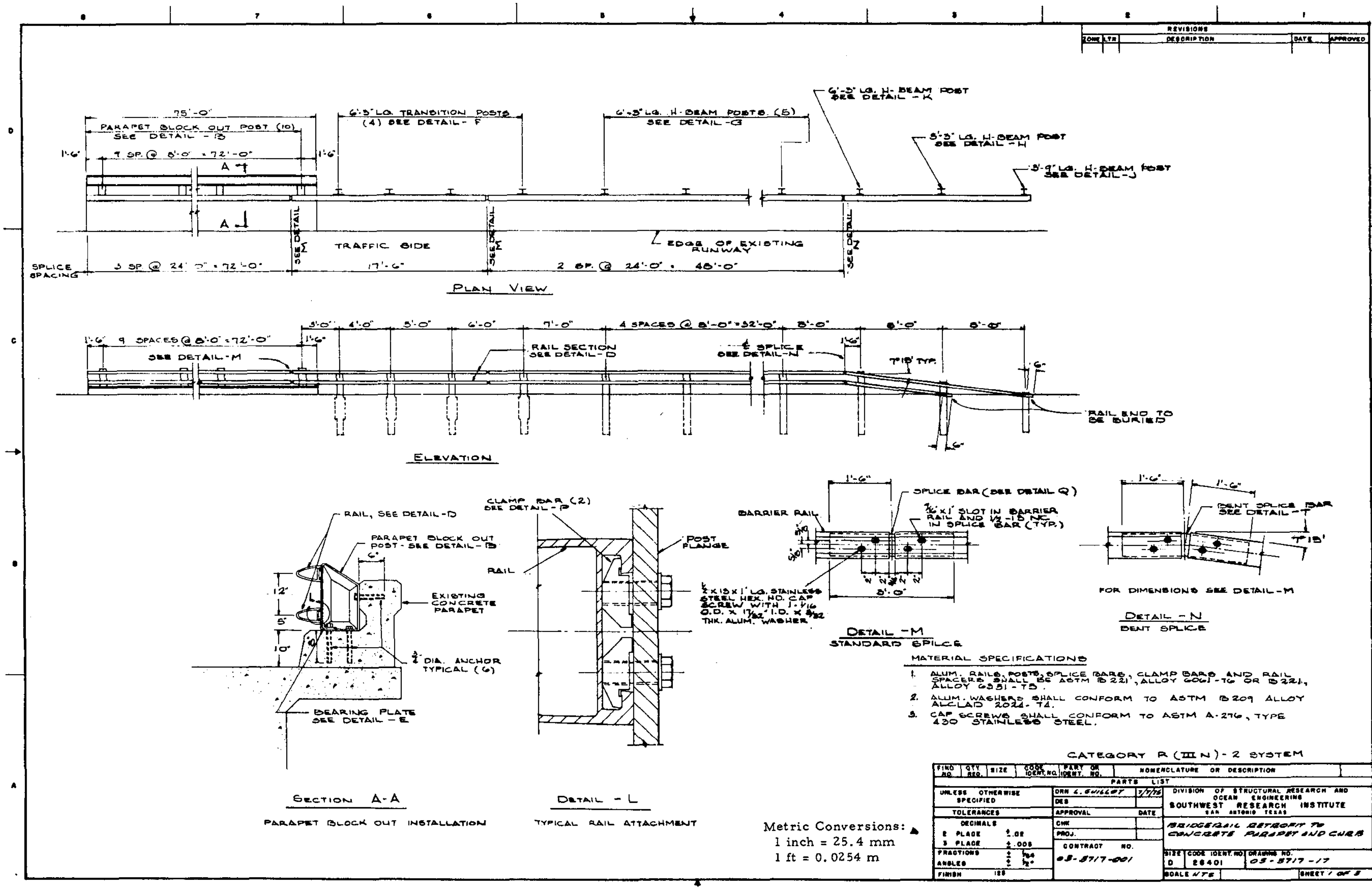


FIGURE A.6 CATEGORY R(IIIN)-2 INSTALLATION DRAWING

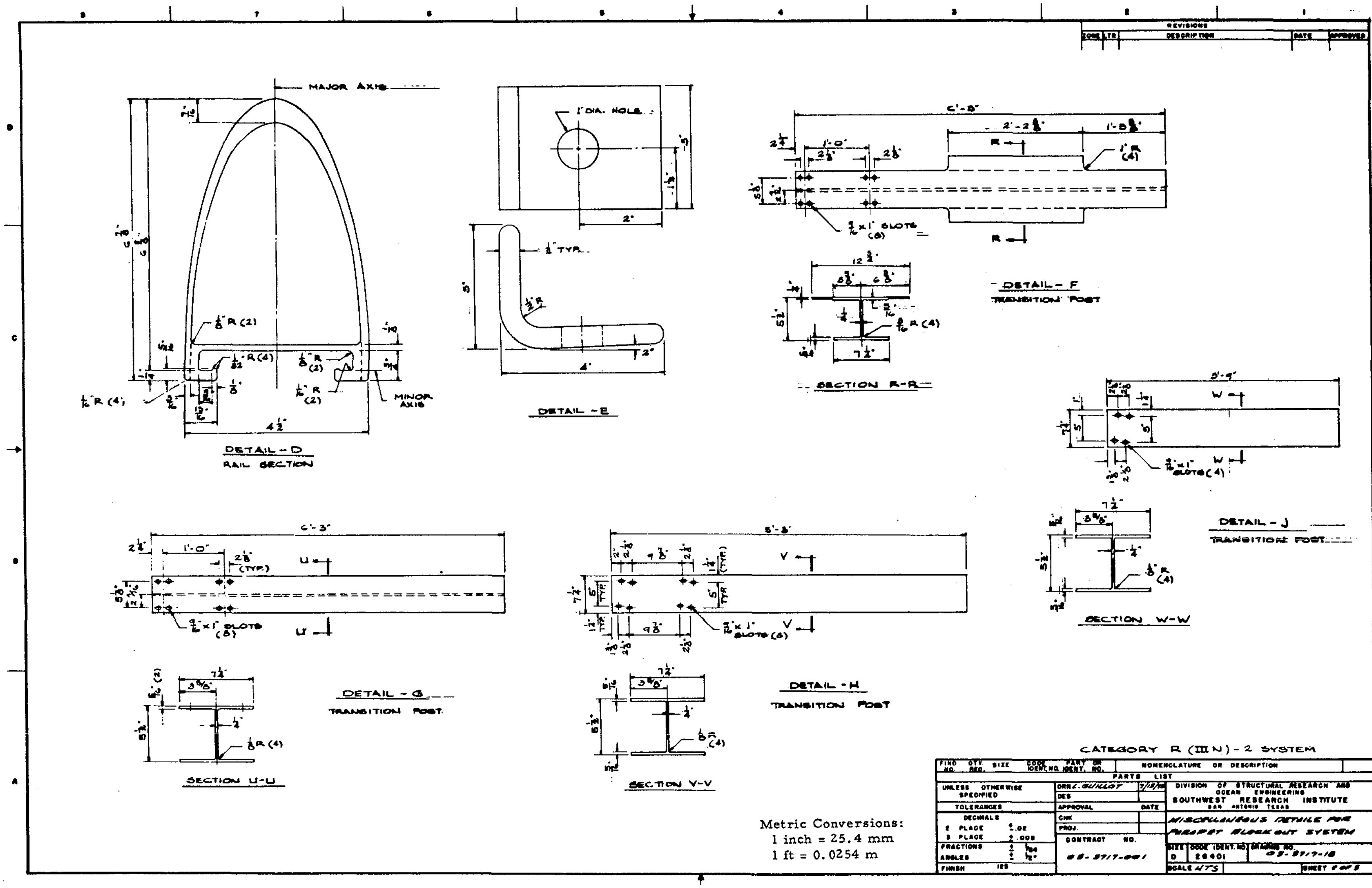


FIGURE A.7 CATEGORY R(IIIN)-2 INSTALLATION DRAWING

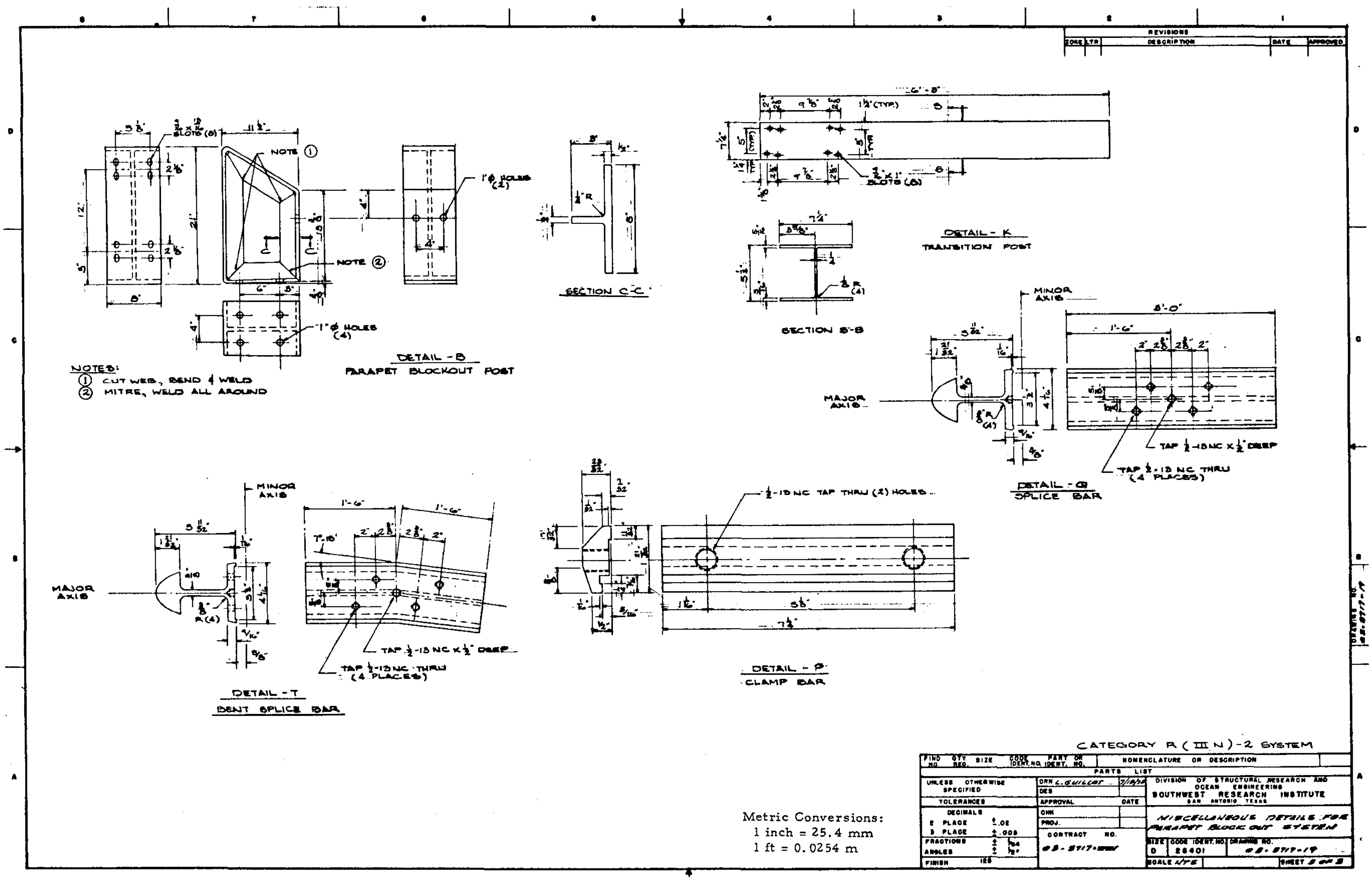


FIGURE A.8 CATEGORY R(IIIN)-2 INSTALLATION DRAWING

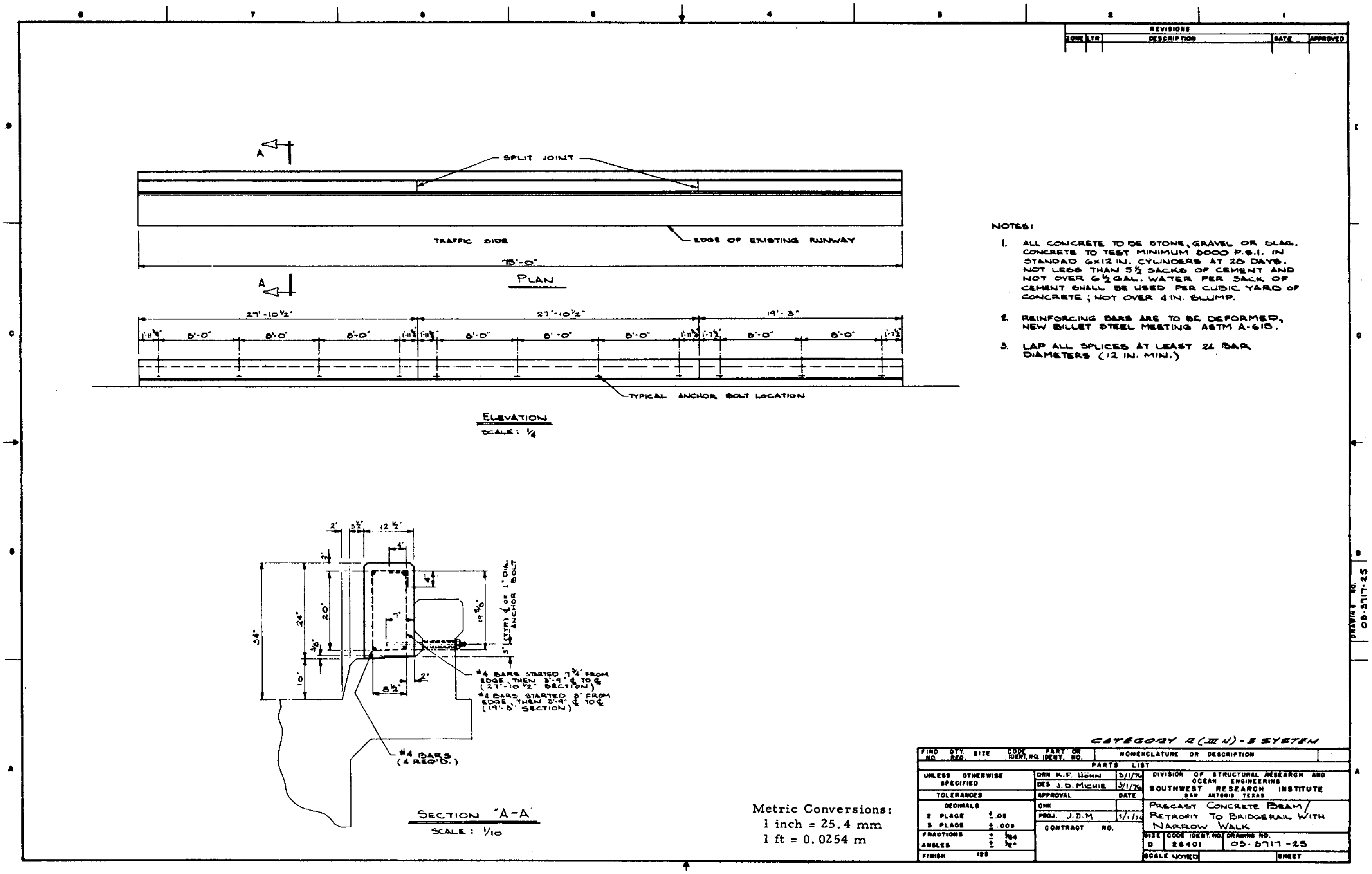


FIGURE A.9 CATEGORY R(IIIN)-3 INSTALLATION DRAWING

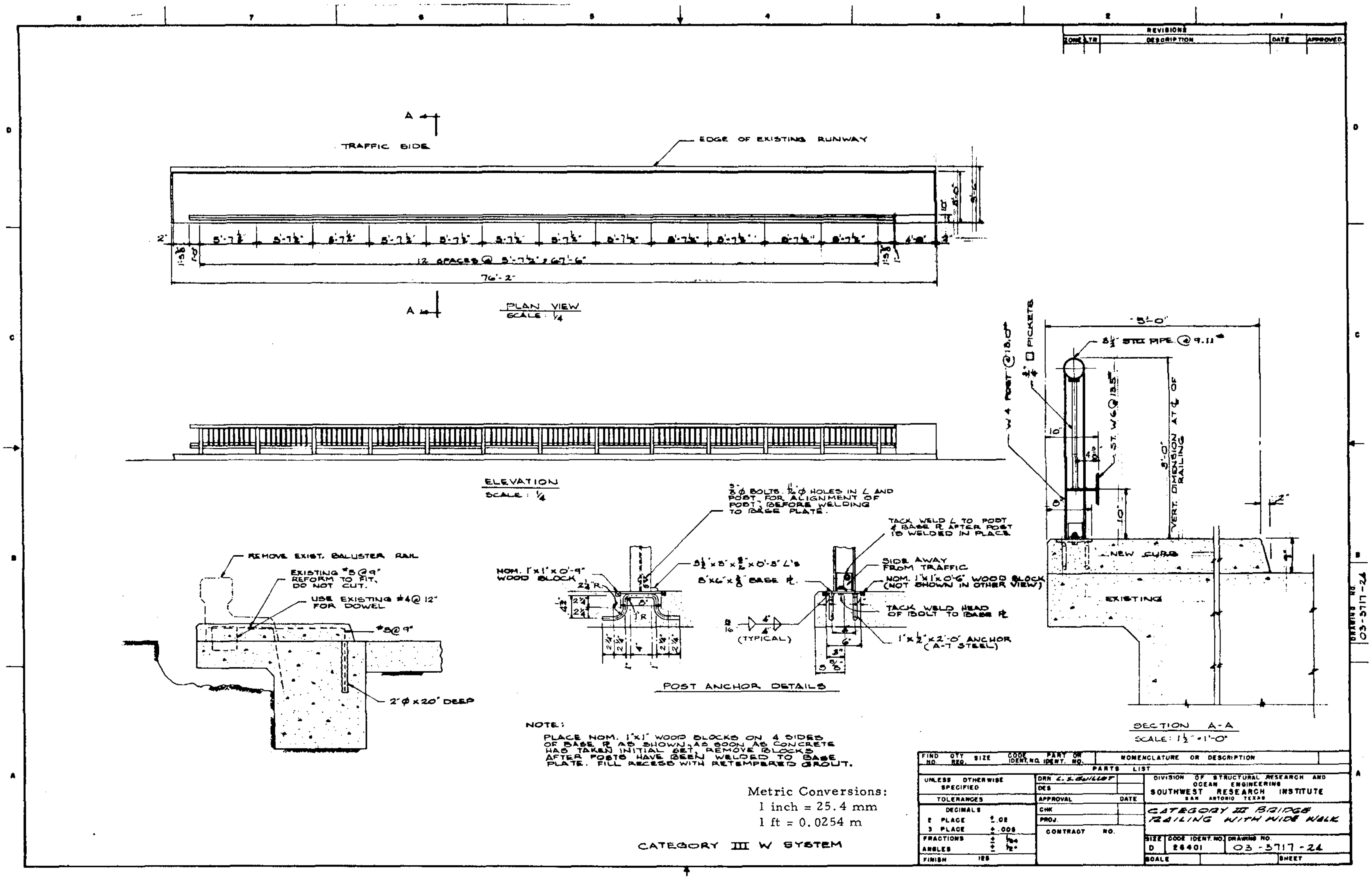


FIGURE A.10 CATEGORY IIIW INSTALLATION DRAWING

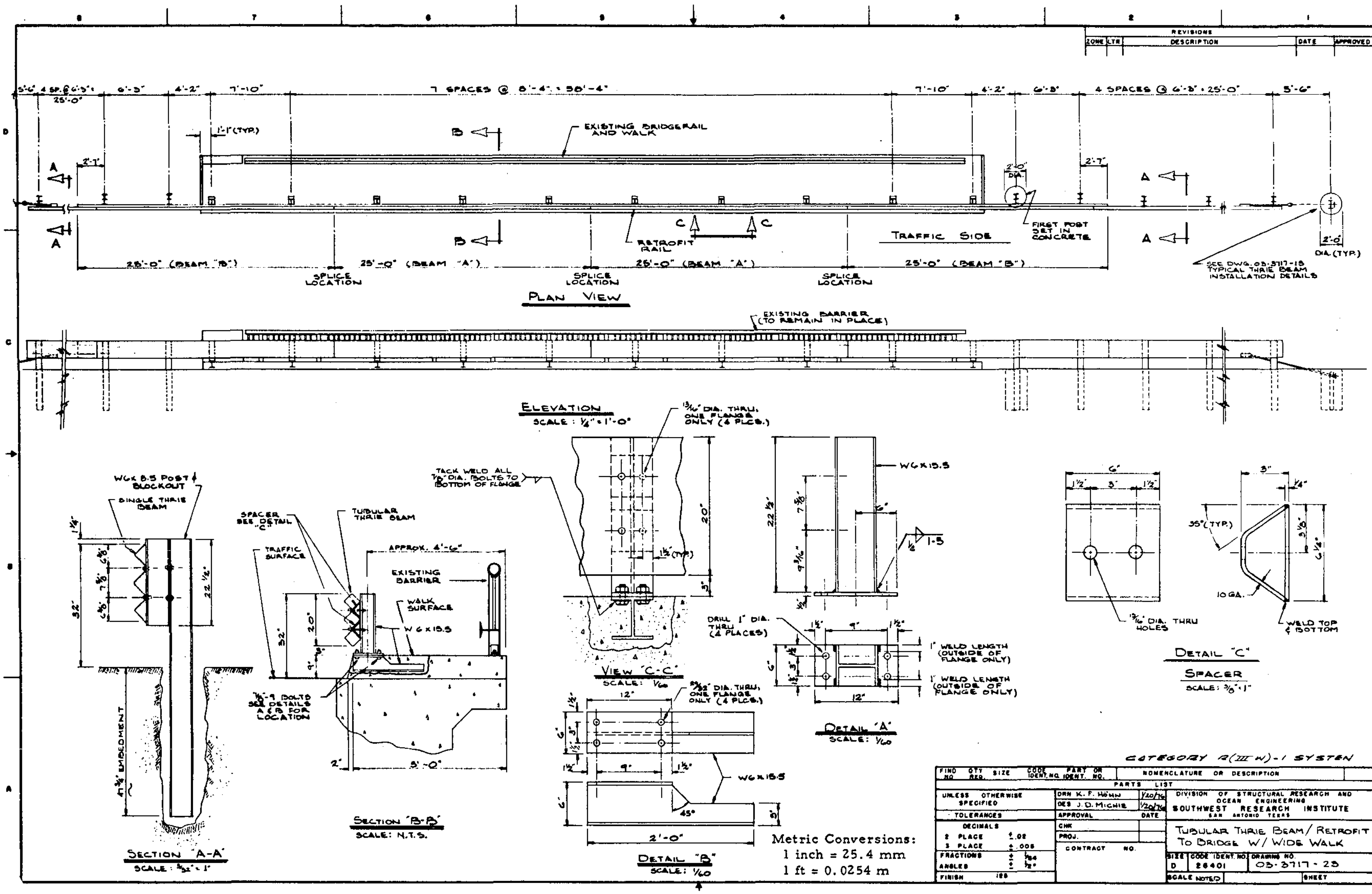


FIGURE A.11 CATEGORY R(IIIW)-1 INSTALLATION DRAWING

APPENDIX B

CRASH TEST PROCEDURES AND TEST DATA

CRASH TEST PROCEDURES AND TEST DATA

This appendix contains detailed information on vehicle crash test procedures and subsequent data reduction techniques utilized throughout the test program. Results of the data processing are presented in this appendix in tabular and graphical form.

Test Procedures

The crash tests in this program were conducted with vehicles running under their own power guided by a 1500-ft (457-m) long, 1/4-in. (6-mm) dia, steel cable pretensioned alongside the run-up area where it would not interfere with post-impact vehicle trajectory. A guide tube, attached to the front wheel, slid along the cable and provided guidance to the car. Just prior to impact, the guide bracket was sheared off. Vehicle ignition and brakes were controlled remotely from the chase vehicle through a tether line, which also carried the signals from strain gage accelerometers located in the longitudinal, lateral (or transverse), and vertical directions of the vehicle. Post-impact vehicle reaction was also monitored with a rate gyro. These transducers were mounted along or near the vehicle longitudinal centerline, and the signals were continuously recorded on high-speed magnetic tape.

A summary of the data acquisition system is presented schematically in Figure B.1, and the components are described in Table B.1. Test events were also documented by motion and still photography. High-speed and documentary 16-mm movie cameras provided extensive coverage of the test details before, during, and after the tests.

Data Processing

Data were derived from two primary sources: (1) micromotion analysis of high-speed film, and (2) accelerometers.

From the high-speed data film, readings were taken using a Vanguard motion analyzer. These readings provided input for the SwRI DATA III computer program.* Timing marks on the film edge and event markers (flash bulbs) assured frame rate accuracy and synchronization of the film data. Output from this program included vehicle lateral and longitudinal accelerations (both instantaneous and 50-millisecond averages); vehicle lateral and longitudinal velocities; vehicle heading angle; vehicle x and y coordinates; and approximate barrier forces. During the test program, a newly developed SwRI DATA IV computer program was introduced. This computer program simplified the input mode and refined film synchronization techniques developed in DATA III. Output also included a resultant for the lateral and longitudinal accelerations (50-millisecond averages).

As shown in Figure B.2, the transducer data, which was recorded on magnetic tape at 60 ips (1.5 m/sec), was replayed through filters (SAE Class 180) to an oscillograph for an immediate visual output. For analyzation, this recorded data was converted from analog to digital; once converted, it was processed through an Institute-developed computer program that provided output in tabular and graphical form. A description of each component in the data processing system is contained in Table B.2. It should be noted that this data reduction system was not developed until after the completion of the first two tests of this test program (RF-3 and RF-4). Calculations for the computer program were performed at 0.25-millisecond intervals, although

*Film analysis program developed under NCHRP Program 15-1(2).

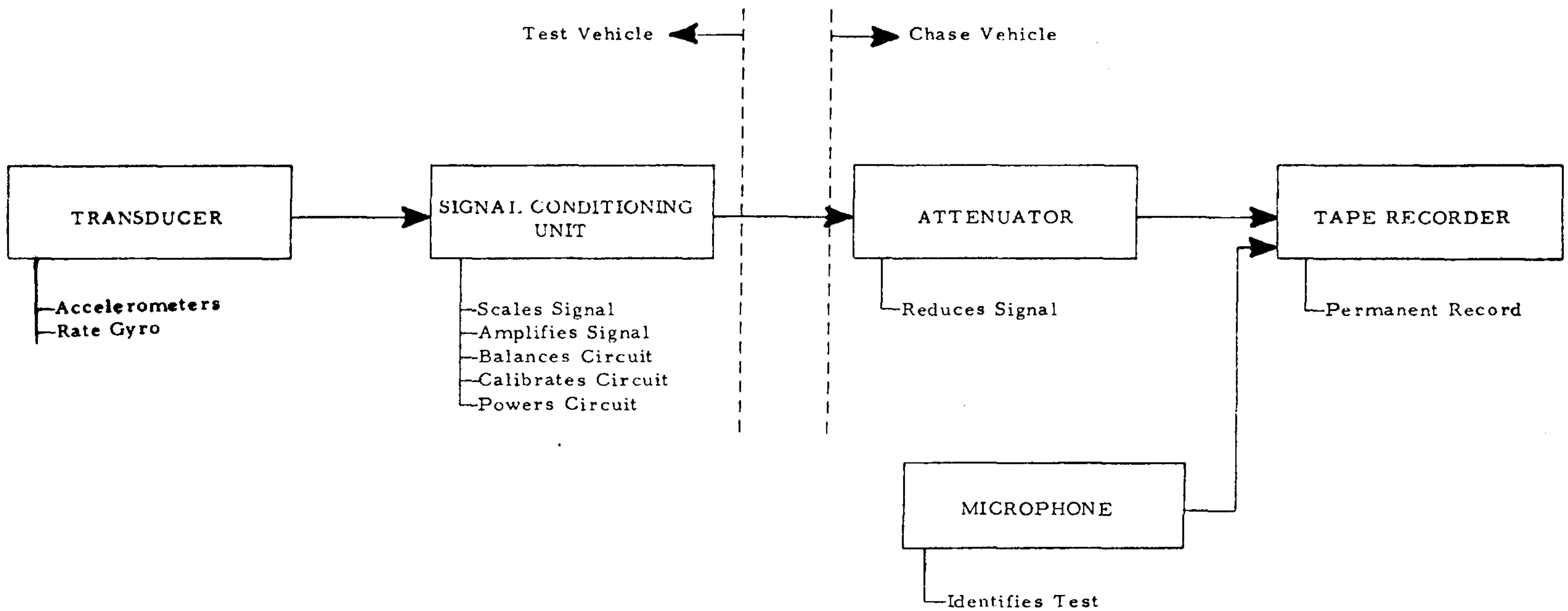


FIGURE B.1 DATA ACQUISITION SYSTEM

TABLE B.1

DATA ACQUISITION SYSTEM COMPONENTS

Component	Function	Equipment	Type	General Description
Transducer	Converts a physical phenomenon to an electric signal	Accelerometer (vehicle)	Bell & Howell Model 4-202-0001	Strain gage type, frequency response: D.C. to 1 khz
		Rate Gyro (angular)	Humphrey Model RG030 202-1	28V DC gyro; rate: $\pm$ 1000 deg/sec
Signal Conditioning Unit	Scales and amplifies transducer signal; circuit balancing, calibration, and power	Signal Conditioning Unit	SwRI design	Completes transducer circuit and amplifies signal to 1.0V for full scale response; contains calibration circuit
Attenuators	Reduces signal level for recording	Attenuator Package	SwRI design	Reduces signal by 80%
Tape Recorder	Provides permanent, high quality magnetic tape record of test date	Magnetic Tape Recorder	Leach MTR-3200	14 channel FM recorder; tape speeds: 30 to 60 ips; extended bandwidth: DC to 20 khz; signal/noise 42db; input sensitivity: 0.5 to 5V p/p; linearity: 1.0% of best straight line
			Sangamo Sabre III	14 channel FM recorder; tape speeds: 1-7/8 to 120 ips; extended bandwidth DC to 40 khz; signal/noise: 51 db; input sensitivity: 0.2 to 10V rms; linearity: 0.5% of best straight line

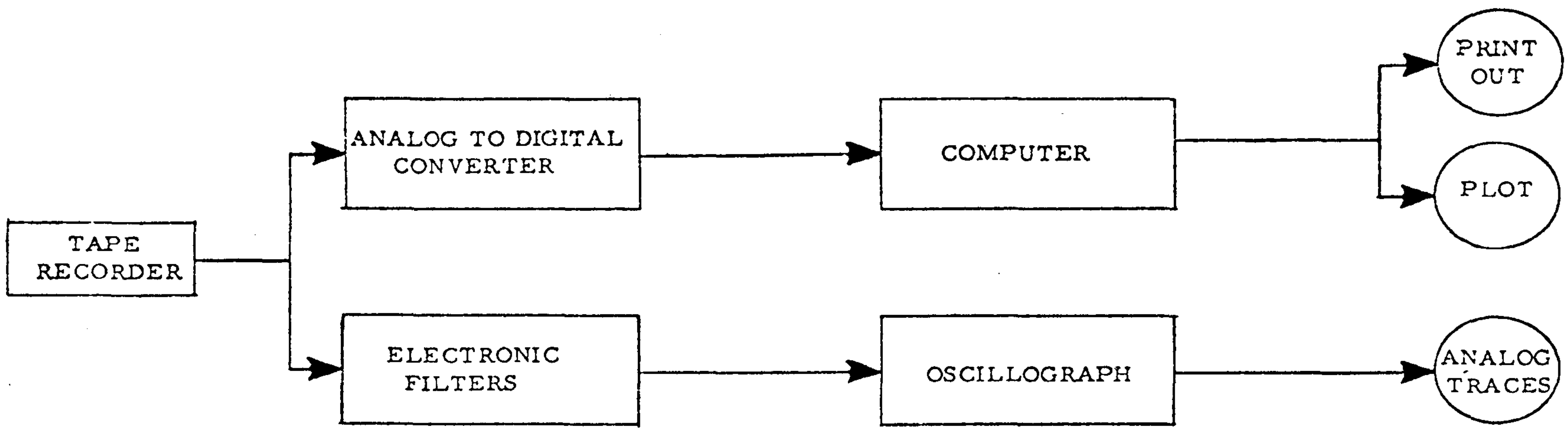


FIGURE B.2 DATA PROCESSING SYSTEM

TABLE B.2

DATA PROCESSING SYSTEM COMPONENTS

Component	Function	Type	General Description
Analog to Digital Converter	Converts analog data to digital format	Subsystem consists of a Sangamo Sabre III 3600 magnetic tape reducer, a HP-2310C, 16 channel sample and hold, 12 bit A/D converter with a HP2781A pacer, a HP-7970E magnetic 9-track tape unit for mass storage, and HP-2100S computer with the HP-91701A data communication package	Converts data on analog magnetic tapes to digital form for processing or a central computer system. The system is configured around the HP2100S digital computer. Up to 16 analog inputs are simultaneously sampled and held, then processed, by the HP 2310C high speed data acquisition subsystem. Initial mass storage is provided via the HP-7970E 9-track tape unit. The HP-91701A communication package is used to convert the 9-track digital tape to a 7-track tape to be processed on HP2100A computer
Computer	Program scales digital input, filters out high frequency responses, vectorially adds components and provides printout as a function of time. Also provides input data for plotter	Consists of a 32K 16-bit HP 2100A computer, HP-7900A moving head disk, HP2752A modified ASR33 teletype, two 7-track HP 7970B magnetic tape units, HP 2610A line printer, HP 2761B card reader and a calcomp 565 plotter	Printout and plots at desired time increments and duration of vehicle accelerometer, velocity, resultants, and 50 msec acceleration average
Plotter	Plots the desired computer data reduction results	Calcomp 565 plotter	0.01 inch increments, 300 increments/sec, x-axis, 120 inch; y-axis, 11 inch
Electronic Filters	Filters out high frequency portion of signal that is outside the interest of the experiment	SwRI design	12-channel active low pass filter; 12db/octave rolloff with cutoff tunable from 60 hz to 10 khz. Each channel is adjustable to meet one of SAE J211 data classes
Oscillograph	Provides analog traces of raw and filtered data	CEC Oscillograph 5-124A	8-channel oscillograph with independent galvanometers and galvanometer circuits. Typical galvanometers used are CEC 7-326 (within ±5% flat frequency response from 0 to 3000 hz) and CEC 7-361 (0 to 5000 hz)

results are displayed every 10 milliseconds. The output included vehicle lateral, longitudinal, resultant of lateral and longitudinal, and vertical accelerations (both instantaneous and 50-millisecond averages); vehicle lateral and longitudinal velocities; and vehicle x and y coordinates. The vehicle heading angle was computed from data taken from the rate gyro. In addition, the program was used to plot the theoretical results of the high-speed cine data superimposed with the transducer data.

It is important to note that vehicle accelerations calculated from cine data may differ from electronic accelerometer data. This difference should be anticipated for the following reasons:

- Accelerations which vary throughout the vehicle are measured at different vehicle locations. Accelerometers are mounted near the center of gravity of the vehicle while cine targets are affixed to the vehicle roof.

- Cine data processing computer program assumes vehicle remains planer during redirection. Any rolling or pitching of vehicle introduces error in the results.

- Cine data method is not responsive to the higher frequency accelerations although the maximum 50 ms averages are generally comparable.

These two independent methods provide redundancy in the data acquisition system and serve as a check on calibration of instrumentation. For instance, time-displacement information calculated from electronic accelerometer data can be compared directly with time-displacement data acquired from micromotion analysis of high-speed film. If there is a close comparison, the test engineer is assured that the accelerometers and electronic acquisition system is in proper calibration and functioning correctly. In a similar manner vehicle acceleration data are calculated from high-speed movie film and these are compared directly with electronic accelerometer readings. A close comparison provides assurance to the test engineer that the film acquisition system (i.e., camera locations, reference points, synchronization of cameras, camera frame speed, etc.) was properly set up and documented. In comparing maximum 50 ms average accelerations, the preference should be the results obtained from electronic accelerometers positioned near the vehicle center of gravity as specified in NCHRP *Report 153*.

Findings from high-speed film analysis and electronic transducer data, along with the corresponding plots, are contained in this appendix.

TABLE B.3

SUMMARY OF VEHICLE CINE DATA FOR CRASH TEST RF-1

TIME AFTER IMPACT (SEC)	VEHICLE C. G. COORDINATES (FT) X	Y	HEADING ANGLE (DEG)	VEHICLE VELOCITY (FT/SEC) LONG	LAT	VEHICLE ACCELERATION (G'S) AT TIME T LONG	LAT	AVERAGE OVER .05 SEC. LONG	LAT	RESULT	APPROX. BARRIER FORCES (KIPS) X	Y
0.000	-10.98	-5.17	16.84	93.23	-3.31	.03	.02	.02	-.09	.09	-.0	-.1
.010	-10.08	-4.93	17.08	93.04	-3.75	-1.10	-.44	-.99	-.54	1.12	2.0	1.6
.020	-9.18	-4.69	17.15	92.52	-4.10	-2.11	-1.00	-1.92	-1.07	2.20	3.7	3.4
.030	-8.29	-4.46	17.04	91.71	-4.34	-2.91	-1.63	-2.68	-1.68	3.17	4.9	5.2
.040	-7.40	-4.24	16.74	90.70	-4.50	-3.47	-2.33	-3.24	-2.35	4.00	5.7	6.9
.050	-6.53	-4.03	16.25	89.56	-4.60	-3.78	-3.06	-3.57	-3.04	4.69	5.9	8.6
.060	-5.66	-3.83	15.58	88.38	-4.66	-3.85	-3.78	-3.67	-3.73	5.23	5.8	10.0
.070	-4.80	-3.64	14.74	87.23	-4.71	-3.71	-4.46	-3.56	-4.39	5.65	5.2	11.3
.080	-3.95	-3.47	13.77	86.16	-4.78	-3.38	-5.07	-3.28	-4.97	5.95	4.4	12.3
.090	-3.10	-3.32	12.69	85.24	-4.87	-2.93	-5.56	-2.87	-5.45	6.15	3.5	13.0
.100	-2.26	-3.19	11.52	84.48	-4.99	-2.39	-5.93	-2.37	-5.80	6.27	2.5	13.4
.110	-1.43	-3.08	10.29	83.91	-5.14	-1.81	-6.15	-1.83	-6.02	6.29	1.5	13.6
.120	-.59	-3.00	9.04	83.53	-5.31	-1.25	-6.22	-1.30	-6.10	6.24	.5	13.6
.130	.24	-2.93	7.80	83.33	-5.50	-.74	-6.15	-.80	-6.04	6.10	-.2	13.3
.140	1.08	-2.88	6.60	83.29	-5.70	-.30	-5.96	-.39	-5.86	5.87	-.8	12.7
.150	1.91	-2.85	5.45	83.36	-5.90	.03	-5.65	-.06	-5.57	5.57	-1.2	12.0
.160	2.75	-2.84	4.38	83.52	-6.11	.25	-5.25	.16	-5.19	5.19	-1.4	11.2
.170	3.58	-2.84	3.41	83.73	-6.31	.35	-4.79	.27	-4.75	4.75	-1.4	10.2
.180	4.43	-2.86	2.55	83.94	-6.51	.35	-4.28	.28	-4.26	4.27	-1.2	9.1
.190	5.27	-2.90	1.81	84.12	-6.72	.25	-3.76	.20	-3.75	3.75	-.8	8.0
.200	6.11	-2.94	1.19	84.25	-6.93	.08	-3.23	.05	-3.23	3.23	-.3	6.9
.210	6.95	-3.00	.69	84.30	-7.15	-.14	-2.71	-.15	-2.73	2.73	.2	5.8
.220	7.80	-3.07	.31	84.27	-7.39	-.38	-2.21	-.37	-2.25	2.28	.8	4.7
.230	8.64	-3.14	.04	84.14	-7.63	-.63	-1.76	-.60	-1.80	1.90	1.3	3.8
.240	9.48	-3.22	-.13	83.93	-7.88	-.85	-1.34	-.81	-1.39	1.61	1.8	2.9
.250	10.32	-3.30	-.21	83.63	-8.13	-1.04	-.98	-.99	-1.03	1.43	2.2	2.1
.260	11.15	-3.38	-.22	83.28	-8.37	-1.17	-.67	-1.11	-.72	1.32	2.5	1.4
.270	11.98	-3.47	-.19	82.88	-8.60	-1.24	-.41	-1.17	-.47	1.26	2.7	.9
.280	12.81	-3.56	-.11	82.47	-8.81	-1.24	-.21	-1.17	-.26	1.20	2.7	.4
.290	13.63	-3.65	-.01	82.06	-8.99	-1.17	-.06	-1.10	-.11	1.11	2.5	.1
.300	14.45	-3.74	.09	81.69	-9.14	-1.03	.04	-.97	-.00	.97	2.2	-.1

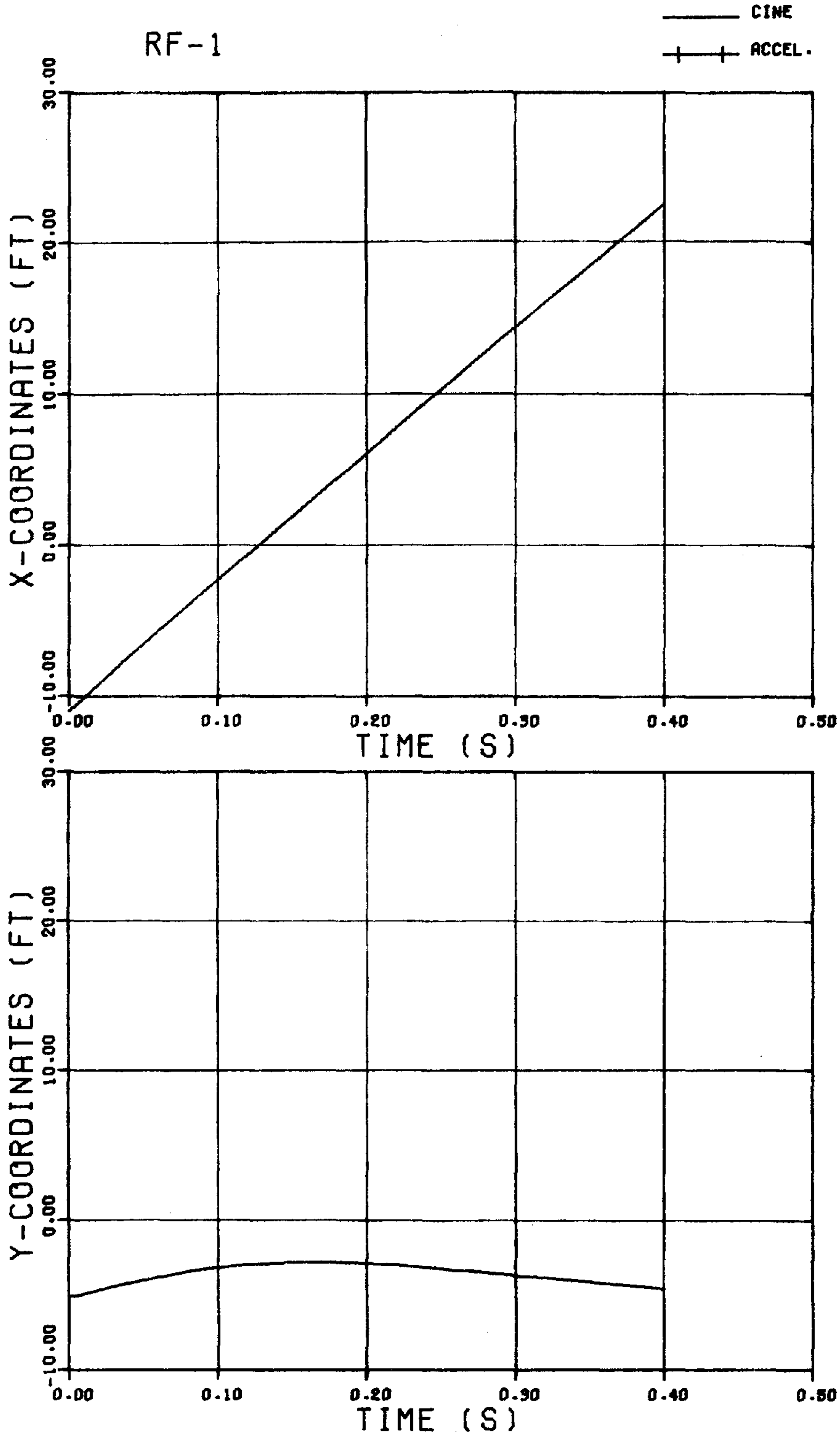


FIGURE B.3 VEHICLE X AND Y DISPLACEMENT HISTORIES FOR CRASH TEST RF-1

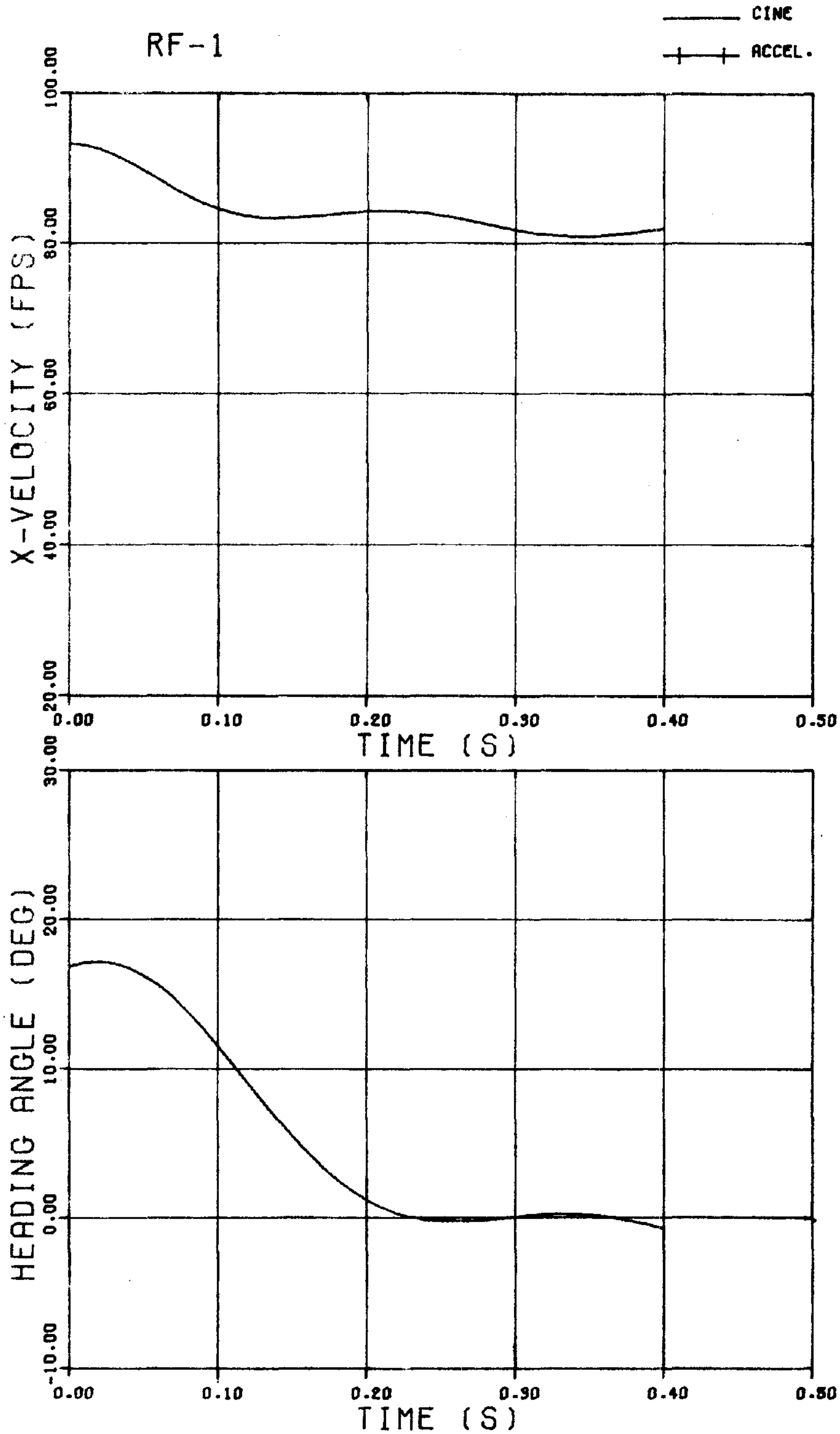


FIGURE B.4 VEHICLE X VELOCITY AND HEADING ANGLE HISTORIES FOR CRASH TEST RF-1

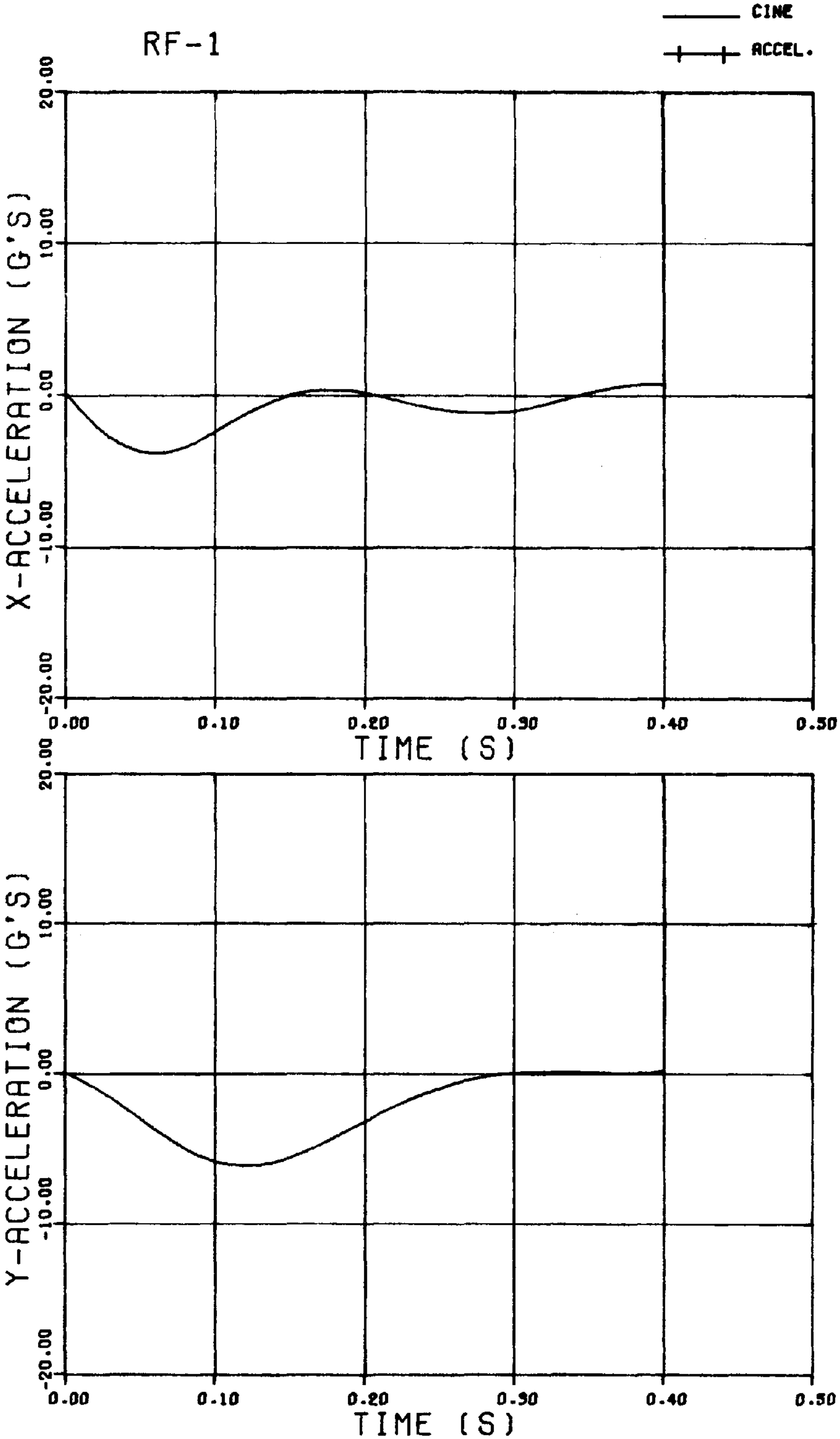


FIGURE B.5 VEHICLE X AND Y ACCELERATION HISTORIES FOR CRASH TEST RF-1

TABLE B.4

SUMMARY OF VEHICLE CINE DATA FOR CRASH TEST RF-2

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	VEHICLE ACCELERATION (G'S) AVERAGE OVER .05 SEC. RESULT	APPROX. BARRIER FORCES (KIPS) X	APPROX. BARRIER FORCES (KIPS) Y
0.000	-9.01	-6.63	23.89	97.73	-.81	.07	.01	-.22	-.30	.37	-.3	-.1
.010	-8.11	-6.24	23.73	97.53	-.67	-1.34	-.85	-1.50	-1.04	1.83	3.8	5.7
.020	-7.22	-5.86	23.51	96.85	-.75	-2.91	-1.90	-2.94	-1.98	3.54	8.2	12.5
.030	-6.33	-5.48	23.24	95.66	-1.09	-4.49	-3.04	-4.39	-3.01	5.33	12.6	19.6
.040	-5.45	-5.13	22.90	93.98	-1.68	-5.96	-4.17	-5.75	-4.06	7.04	16.6	26.5
.050	-4.59	-4.79	22.46	91.87	-2.48	-7.19	-5.21	-6.89	-5.05	8.55	20.0	32.5
.060	-3.74	-4.47	21.90	89.43	-3.43	-8.09	-6.12	-7.73	-5.94	9.75	22.5	37.4
.070	-2.90	-4.18	21.22	86.78	-4.47	-8.59	-6.88	-8.19	-6.69	10.57	23.7	41.0
.080	-2.09	-3.93	20.38	84.06	-5.55	-8.65	-7.47	-8.24	-7.29	11.00	23.7	43.1
.090	-1.29	-3.70	19.40	81.43	-6.60	-8.26	-7.89	-7.86	-7.73	11.03	22.2	43.8
.100	-.51	-3.51	18.26	79.04	-7.60	-7.43	-8.15	-7.09	-8.02	10.70	19.4	43.3
.110	.26	-3.35	16.99	77.01	-8.51	-6.24	-8.25	-5.97	-8.15	10.10	15.3	41.8
.120	1.02	-3.22	15.58	75.45	-9.29	-4.76	-8.20	-4.58	-8.13	9.33	10.2	39.5
.130	1.77	-3.12	14.07	74.44	-9.93	-3.09	-8.02	-3.02	-7.97	8.52	4.5	36.7
.140	2.51	-3.05	12.47	74.01	-10.40	-1.35	-7.70	-1.39	-7.68	7.80	-1.5	33.6
.150	3.26	-3.01	10.83	74.15	-10.70	.33	-7.28	.17	-7.27	7.27	-7.3	30.5
.160	4.01	-2.98	9.18	74.81	-10.81	1.82	-6.76	1.55	-6.77	6.94	-12.4	27.5
.170	4.77	-2.98	7.54	75.91	-10.74	3.00	-6.19	2.64	-6.20	6.74	-16.3	24.7
.180	5.54	-3.00	5.95	77.31	-10.51	3.78	-5.58	3.35	-5.58	6.51	-18.7	22.2
.190	6.33	-3.03	4.44	78.86	-10.14	4.08	-4.96	3.60	-4.95	6.13	-19.1	19.9
.200	7.13	-3.08	3.03	80.39	-9.69	3.85	-4.34	3.38	-4.33	5.49	-17.5	17.8
.210	7.94	-3.14	1.76	81.74	-9.19	3.10	-3.75	2.67	-3.72	4.58	-13.8	15.7
.220	8.77	-3.21	.63	82.73	-8.68	1.88	-3.17	1.53	-3.12	3.48	-8.2	13.6
.230	9.60	-3.29	-.35	83.23	-8.20	.27	-2.60	.07	-2.53	2.53	-1.1	11.2
.240	10.43	-3.38	-1.16	83.13	-7.76	-1.58	-2.01	-1.59	-1.92	2.49	7.0	8.5
.250	11.26	-3.48	-1.81	82.41	-7.36	-3.46	-1.37	-3.24	-1.28	3.48	15.1	5.4
.260	12.07	-3.58	-2.31	81.07	-6.97	-5.14	-.66	-4.66	-.58	4.70	22.2	1.9
.270	12.87	-3.68	-2.68	79.25	-6.55	-6.36	.12	-5.61	.16	5.62	27.3	-1.8
.280	13.65	-3.78	-2.93	77.13	-6.04	-6.83	.94	-5.85	.92	5.92	29.1	-5.5

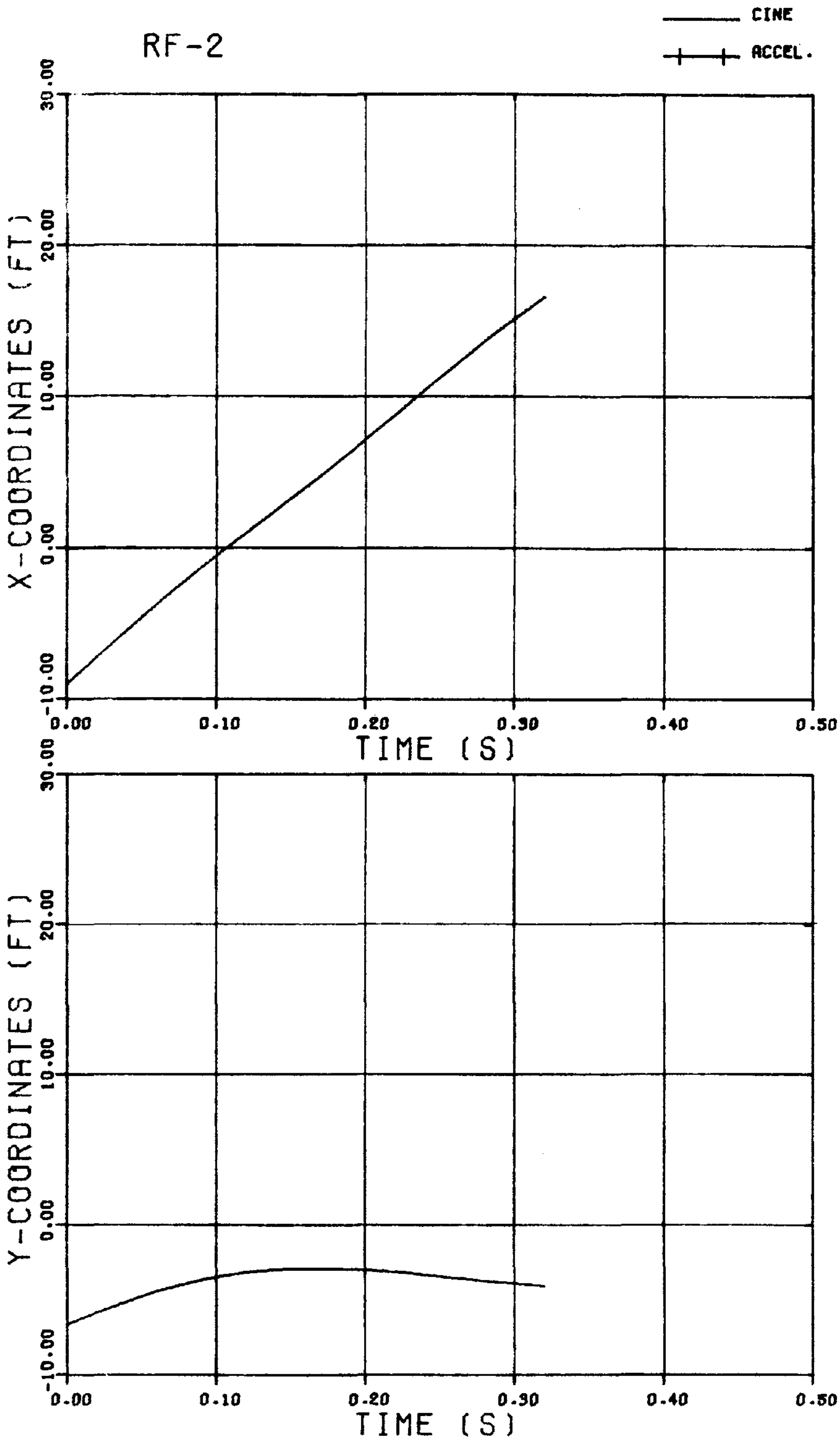


FIGURE B.6 VEHICLE X AND Y DISPLACEMENT HISTORIES FOR CRASH TEST RF-2

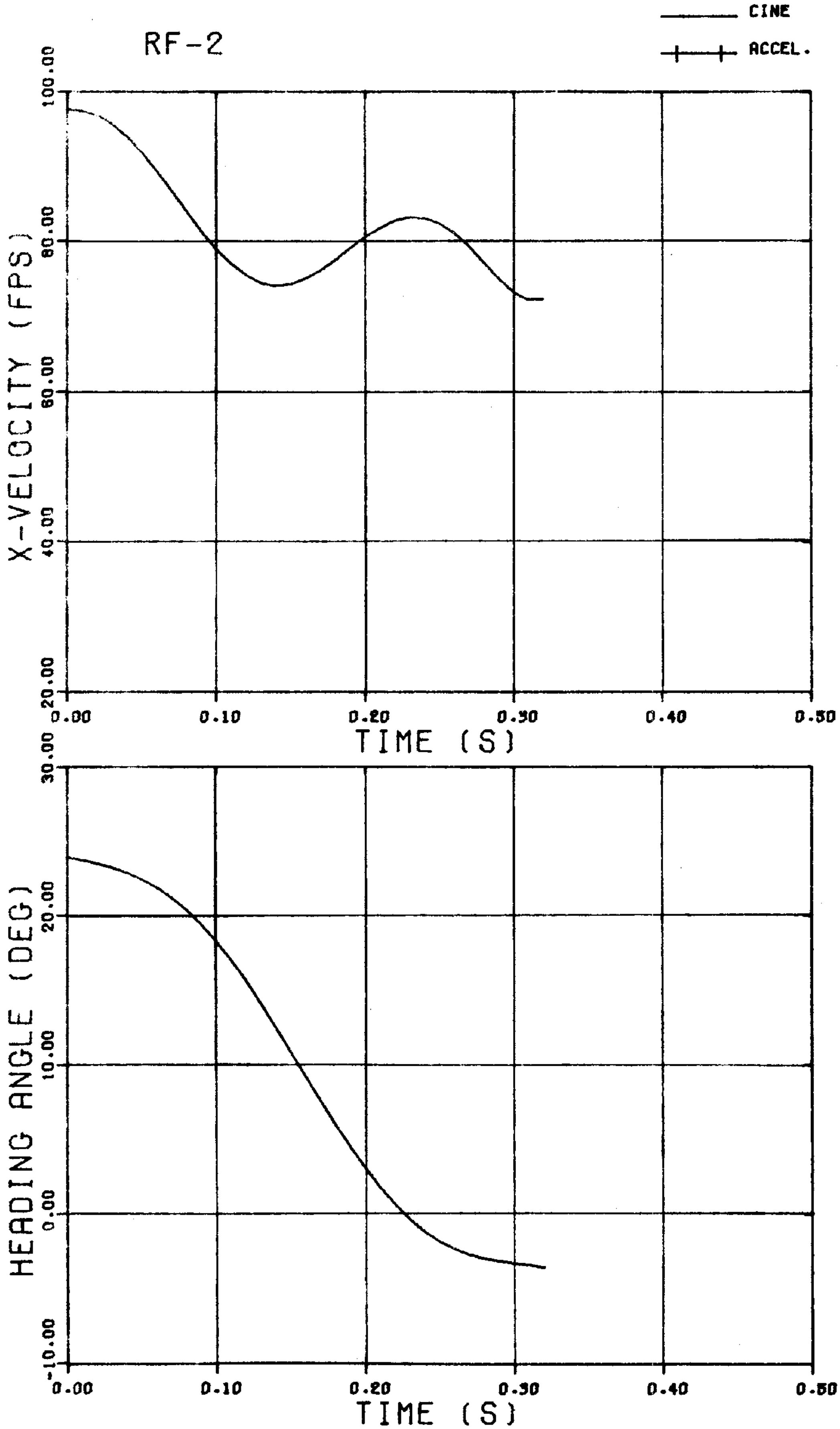


FIGURE B.7 VEHICLE X VELOCITY AND HEADING ANGLE HISTORIES FOR CRASH TEST RF-2

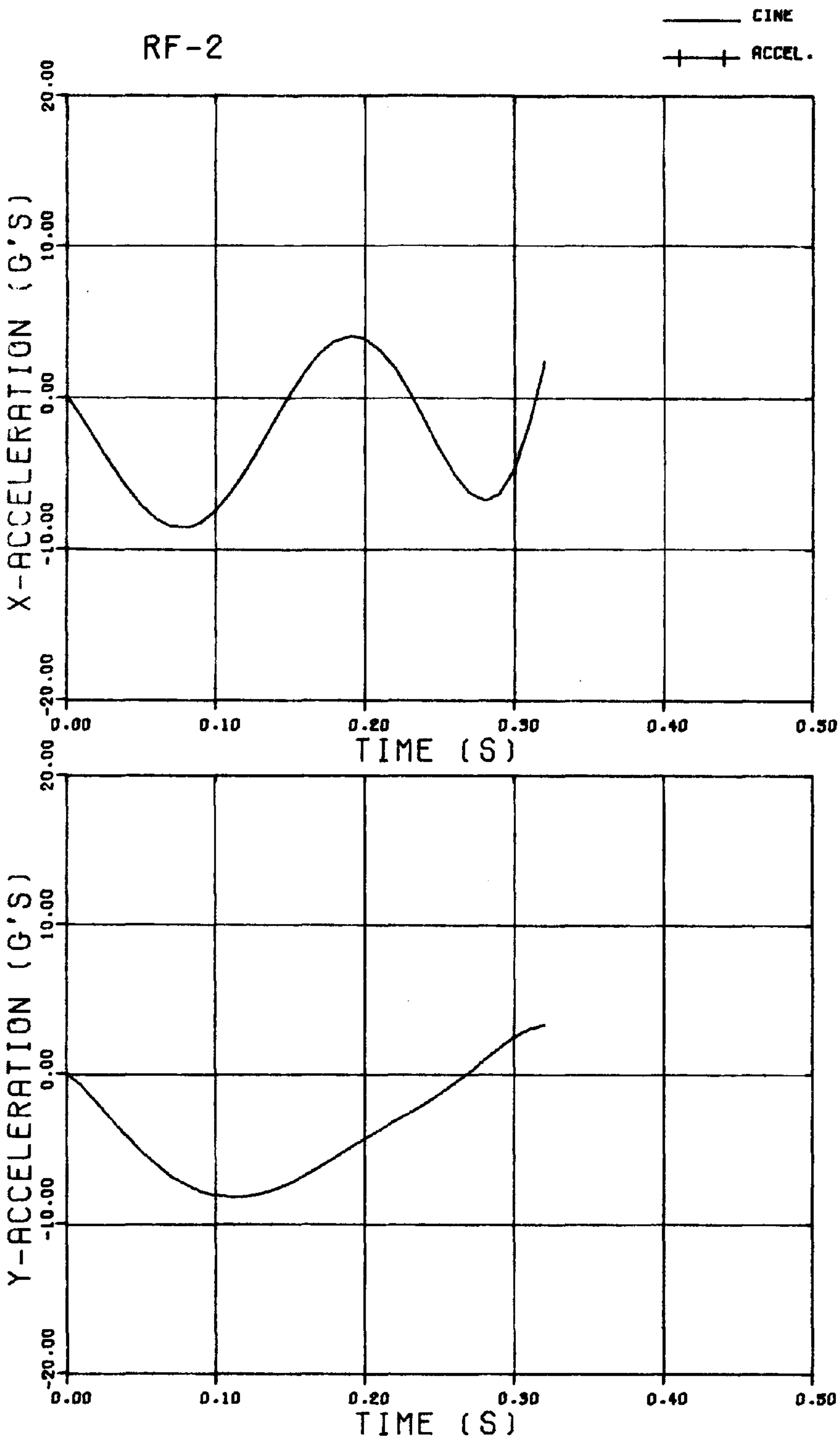


FIGURE B.8 VEHICLE X AND Y ACCELERATION HISTORIES FOR CRASH TEST RF-2

TABLE B.5

SUMMARY OF VEHICLE CINE DATA FOR CRASH TEST RF-3

TIME AFTER IMPACT(SEC)	VEHICLE C. G. COORDINATES(FT) X	Y	HEADING ANGLE (DEG)	VEHICLE VELOCITY (FT/SEC) LONG	LAT	VEHICLE ACCELERATION(G'S) AT TIME T LONG	LAT	AVERAGE OVER .05 SEC. LONG	LAT	APPROX. BARRIER FORCES(LB) X	Y
0.000	18.92	-7.35	29.96	88.51	-2.55	.79	3.75	0.00	0.00	5348	-16401
.010	19.70	-6.92	29.95	88.64	-.94	-.06	5.89	0.00	0.00	13461	-22818
.020	20.47	-6.48	30.03	88.43	.98	-1.27	6.51	-1.53	5.08	19599	-22499
.030	21.22	-6.02	30.19	87.80	2.73	-2.73	5.67	-2.87	4.47	23454	-15854
.040	21.96	-5.55	30.43	86.67	3.89	-4.34	3.61	-4.36	2.76	25089	-4123
.050	22.68	-5.08	30.72	85.03	4.16	-5.99	.72	-5.88	.28	24820	10975
.060	23.38	-4.61	31.03	82.87	3.40	-7.56	-2.59	-7.35	-2.63	23119	27534
.070	24.06	-4.17	31.33	80.22	1.61	-8.94	-5.92	-8.65	-5.59	20524	43692
.080	24.73	-3.75	31.56	77.15	-1.11	-10.05	-8.90	-9.69	-8.27	17578	57805
.090	25.39	-3.38	31.69	73.78	-4.54	-10.80	-11.24	-10.41	-10.40	14768	68572
.100	26.04	-3.06	31.67	70.24	-8.41	-11.13	-12.75	-10.74	-11.79	12489	75111
.110	26.67	-2.79	31.49	66.70	-12.41	-11.02	-13.31	-10.67	-12.34	11020	76997
.120	27.30	-2.57	31.12	63.31	-16.24	-10.53	-12.92	-10.24	-12.03	10508	74258
.130	27.92	-2.41	30.57	60.22	-19.63	-9.71	-11.64	-9.50	-10.91	10967	67341
.140	28.54	-2.30	29.86	57.52	-22.34	-8.68	-9.64	-8.55	-9.13	12286	57050
.150	29.14	-2.22	29.00	55.25	-24.20	-7.56	-7.11	-7.51	-6.87	14247	44463
.160	29.74	-2.18	28.03	53.42	-25.13	-6.47	-4.32	-6.49	-4.37	16548	30832
.170	30.32	-2.16	27.00	51.95	-25.12	-5.49	-1.56	-5.57	-1.90	18832	17473
.180	30.89	-2.15	25.94	50.77	-24.27	-4.69	.89	-4.79	.30	20725	5649
.190	31.45	-2.15	24.90	49.79	-22.75	-4.08	2.76	-4.19	1.98	21869	-3540
.200	31.99	-2.15	23.91	48.93	-20.81	-3.63	3.86	-3.72	2.97	21959	-9264
.210	32.51	-2.13	23.00	48.14	-18.74	-3.29	4.07	-3.35	3.16	20780	-11055
.220	33.02	-2.11	22.18	47.38	-16.84	-3.01	3.36	-3.03	2.54	18235	-8873
.230	33.52	-2.09	21.45	46.66	-15.38	-2.72	1.82	-2.70	1.21	14371	-3151
.240	34.00	-2.06	20.79	46.01	-14.60	-2.36	-.34	-2.31	-.65	9395	5199
.250	34.48	-2.04	20.18	45.48	-14.61	-1.90	-2.81	-1.83	-2.73	3678	14825
.260	34.96	-2.02	19.58	45.11	-15.44	-1.32	-5.20	-1.24	-4.67	-2252	24022
.270	35.44	-2.03	18.94	44.98	-16.93	-.60	-7.05	-.55	-6.08	-7739	30873
.280	35.92	-2.05	18.25	45.13	-18.82	.21	-7.90	.21	-6.55	-12041	33463
.290	36.41	-2.10	17.46	45.61	-20.70	1.04	-7.35	.94	-5.77	-14402	30162
.300	36.92	-2.17	16.57	46.39	-22.05	1.74	-5.15	1.50	-3.60	-14140	19992
.310	37.43	-2.26	15.61	47.40	-22.34	2.12	-1.30	1.72	-.16	-10775	3085
.320	37.95	-2.34	14.62	48.45	-21.13	1.95	3.80	1.39	3.99	-4181	-18761
.330	38.47	-2.42	13.67	49.29	-18.22	1.05	9.22	.36	7.23	5225	-41416
.340	38.99	-2.46	12.86	49.60	-13.83	-.67	13.29	-1.40	9.19	16247	-57636
.350	39.50	-2.46	12.25	49.13	-8.85	-3.14	13.45	-3.81	5.57	26644	-56151
.360	39.98	-2.43	11.88	47.68	-5.14	-6.19	5.99	-6.67	-7.12	32805	-20623
.370	40.45	-2.38	11.69	45.16	-5.89	-9.62	-14.25	0.00	0.00	29379	71550

TABLE B.6

SUMMARY OF VEHICLE CINE DATA FOR CRASH TEST RF-4

TIME AFTER IMPACT (SEC)	VEHICLE C. G. COORDINATES (FT) X	Y	HEADING ANGLE (DEG)	VEHICLE VELOCITY (FT/SEC) LONG	LAT	VEHICLE ACCELERATION (G'S) AT TIME T LONG	LAT	AVERAGE OVER .05 SEC. LONG	LAT	APPROX. BARRIER FORCES (LB) X	Y
0.000	5.60	-3.92	15.45	83.57	2.12	-.39	.20	0.0	0.00	920	-188
.010	6.40	-3.67	15.54	83.26	1.73	-1.54	-1.74	0.00	0.00	2162	4442
.020	7.19	-3.44	15.54	82.61	.89	-2.52	-3.53	0.00	0.00	3162	8683
.030	7.98	-3.22	15.39	81.66	-.29	-3.30	-5.04	-2.73	-3.99	3942	12209
.040	8.77	-3.01	15.05	80.51	-1.63	-3.86	-6.18	-3.39	-5.26	4521	14847
.050	9.55	-2.83	14.52	79.23	-3.01	-4.18	-6.94	-3.82	-6.22	4918	16544
.060	10.32	-2.67	13.77	77.91	-4.30	-4.29	-7.33	-4.04	-6.82	5152	17334
.070	11.08	-2.54	12.83	76.62	-5.40	-4.20	-7.38	-4.06	-7.09	5241	17312
.080	11.84	-2.44	11.71	75.41	-6.25	-3.97	-7.14	-3.91	-7.06	5201	16613
.090	12.58	-2.36	10.44	74.33	-6.83	-3.64	-6.68	-3.65	-6.77	5051	15392
.100	13.32	-2.30	9.08	73.38	-7.12	-3.25	-6.05	-3.31	-6.29	4804	13807
.110	14.06	-2.27	7.66	72.58	-7.15	-2.84	-5.31	-2.93	-5.66	4478	12012
.120	14.78	-2.25	6.25	71.91	-6.95	-2.43	-4.53	-2.54	-4.95	4086	10145
.130	15.50	-2.25	4.88	71.35	-6.57	-2.04	-3.75	-2.16	-4.20	3643	8322
.140	16.21	-2.26	3.59	70.90	-6.07	-1.68	-3.01	-1.81	-3.47	3163	6633
.150	16.92	-2.28	2.43	70.53	-5.49	-1.35	-2.36	-1.48	-2.79	2658	5141
.160	17.63	-2.31	1.41	70.24	-4.91	-1.05	-1.80	-1.18	-2.19	2141	3884
.170	18.33	-2.34	.55	70.01	-4.36	-.78	-1.34	-.90	-1.68	1624	2873
.180	19.03	-2.38	-.15	69.86	-3.87	-.52	-.99	-.65	-1.26	1118	2099
.190	19.73	-2.42	-.70	69.76	-3.47	-.29	-.72	-.41	-.94	635	1534
.200	20.42	-2.47	-1.13	69.73	-3.16	-.08	-.54	-.19	-.69	184	1139
.210	21.12	-2.51	-1.45	69.75	-2.92	.12	-.40	.00	-.51	-225	867
.220	21.82	-2.56	-1.69	69.83	-2.73	.28	-.31	.18	-.38	-581	671
.230	22.52	-2.61	-1.89	69.95	-2.57	.42	-.22	.32	-.27	-878	505
.240	23.21	-2.66	-2.08	70.11	-2.41	.52	-.14	.44	-.18	-1105	335
.250	23.92	-2.71	-2.27	70.30	-2.20	.59	-.04	.52	-.08	-1256	136
.260	24.62	-2.76	-2.48	70.50	-1.93	.62	.07	.57	.03	-1323	-97
.270	25.32	-2.81	-2.73	70.71	-1.58	.60	.20	.57	.14	-1299	-355
.280	26.03	-2.86	-3.02	70.90	-1.15	.54	.31	.53	.24	-1177	-609
.290	26.74	-2.91	-3.33	71.06	-.65	.42	.41	.44	.33	-953	-816
.300	27.45	-2.95	-3.64	71.18	-.12	.26	.45	.30	.37	-619	-922
.310	28.16	-3.00	-3.95	71.23	.40	.05	.41	.11	.35	-172	-867
.320	28.87	-3.04	-4.22	71.20	.85	-.21	.27	-.12	.24	395	-600
.330	29.58	-3.09	-4.44	71.08	1.17	-.51	.00	-.40	.03	1084	-88
.340	30.29	-3.13	-4.60	70.86	1.31	-.86	-.38	-.74	-.28	1900	667
.350	30.99	-3.17	-4.70	70.51	1.24	-1.27	-.86	-1.12	-.67	2847	1602
.360	31.69	-3.22	-4.77	70.03	.97	-1.74	-1.36	-1.56	-1.07	3927	2576
.370	32.39	-3.27	-4.83	69.39	.53	-2.27	-1.76	-2.08	-1.38	5143	3333
.380	33.08	-3.33	-4.92	68.56	.05	-2.90	-1.88	-2.68	-1.42	6498	3468
.390	33.75	-3.39	-5.09	67.51	-.31	-3.64	-1.45	-3.39	-.96	7994	2391

TABLE B.7

SUMMARY OF VEHICLE CINE DATA FOR CRASH TEST RF-5

TIME AFTER IMPACT(SEC)	VEHICLE C. G. COORDINATES(FT) X	Y	HEADING ANGLE (DEG)	VEHICLE VELOCITY (FT/SEC) LONG	LAT	VEHICLE ACCELERATION(G'S) AT TIME T LONG	LAT	AVERAGE OVER .05 SEC. LONG	LAT	APPROX. BARRIER FORCES(LB) X	Y
0.000	-5.38	-5.14	15.43	83.15	5.14	-.59	.37	-.91	.24	1436	-419
.010	-4.59	-4.87	15.70	82.89	4.76	-1.20	-.31	-1.31	-.41	2297	1335
.020	-3.81	-4.60	15.92	82.41	4.21	-1.91	-1.09	-1.88	-1.16	3296	3359
.030	-3.03	-4.33	16.01	81.69	3.60	-2.59	-1.94	-2.48	-1.98	4174	5516
.040	-2.26	-4.08	15.88	80.75	3.02	-3.13	-2.84	-2.98	-2.85	4786	7685
.050	-1.49	-3.83	15.49	79.66	2.50	-3.50	-3.77	-3.34	-3.73	5069	9768
.060	-.74	-3.61	14.80	78.48	2.09	-3.66	-4.68	-3.50	-4.61	5020	11683
.070	.01	-3.39	13.81	77.27	1.78	-3.61	-5.54	-3.48	-5.44	4679	13365
.080	.76	-3.20	12.55	76.10	1.56	-3.37	-6.32	-3.27	-6.19	4108	14766
.090	1.49	-3.03	11.05	75.04	1.39	-2.97	-6.97	-2.90	-6.82	3381	15853
.100	2.22	-2.89	9.36	74.12	1.27	-2.45	-7.46	-2.42	-7.31	2576	16606
.110	2.95	-2.77	7.54	73.39	1.16	-1.86	-7.78	-1.86	-7.62	1765	17018
.120	3.68	-2.67	5.64	72.85	1.05	-1.25	-7.90	-1.29	-7.75	1008	17093
.130	4.40	-2.60	3.73	72.51	.93	-.68	-7.84	-.73	-7.70	354	16846
.140	5.12	-2.56	1.87	72.35	.78	-.17	-7.61	-.24	-7.49	-163	16297
.150	5.85	-2.54	.11	72.34	.62	.23	-7.23	.16	-7.12	-524	15477
.160	6.57	-2.54	-1.52	72.45	.43	.52	-6.73	.45	-6.64	-726	14420
.170	7.30	-2.57	-2.99	72.63	.21	.68	-6.12	.62	-6.06	-776	13165
.180	8.02	-2.62	-4.26	72.86	-.04	.73	-5.45	.68	-5.41	-692	11754
.190	8.75	-2.68	-5.35	73.09	-.30	.68	-4.74	.64	-4.71	-502	10232
.200	9.48	-2.76	-6.24	73.30	-.57	.55	-4.00	.53	-3.99	-236	8642
.210	10.20	-2.85	-6.95	73.46	-.82	.36	-3.26	.36	-3.27	72	7028
.220	10.93	-2.95	-7.50	73.55	-1.05	.15	-2.54	.17	-2.57	388	5433
.230	11.66	-3.06	-7.91	73.57	-1.23	-.06	-1.85	-.04	-1.89	682	3896
.240	12.39	-3.18	-8.21	73.52	-1.34	-.26	-1.20	-.22	-1.26	926	2453
.250	13.11	-3.30	-8.43	73.42	-1.35	-.43	-.60	-.38	-.67	1100	1137
.260	13.83	-3.42	-8.59	73.26	-1.24	-.55	-.07	-.50	-.15	1193	-25
.270	14.56	-3.54	-8.73	73.07	-1.01	-.63	.38	-.57	.30	1198	-1011
.280	15.28	-3.66	-8.87	72.87	-.65	-.65	.75	-.60	.67	1120	-1805

TABLE B.8

SUMMARY OF VEHICLE ACCELEROMETER DATA FOR CRASH TEST RF-5

TIME (SEC)	DISPLACEMENT - FT X	DISPLACEMENT - FT Y	HEARING ANGLE (DEG)	VELOCITY - FPS X	VELOCITY - FPS Y	VEHICLE ACCELERATION G'S AT TIME T X	VEHICLE ACCELERATION G'S AT TIME T Y	VEHICLE ACCELERATION G'S AVERAGE OVER .05 SEC. X	VEHICLE ACCELERATION G'S AVERAGE OVER .05 SEC. Y
.00000	-5.41	-4.79	17.08	85.67	7.40	.69	-.74		
.01000	-4.61	-4.47	17.14	85.53	6.79	-2.39	-2.75		
.02000	-3.81	-4.16	17.10	85.52	6.43	-.04	1.94		
.03000	-3.02	-3.85	16.99	84.76	6.03	-.33	.69	-1.37	-2.15
.04000	-2.23	-3.54	16.62	84.43	6.00	-.87	-.72	-1.47	-3.78
.05000	-1.44	-3.25	16.19	83.38	5.30	.01	-12.24	-2.38	-4.82
.06000	-.65	-2.98	15.25	82.99	3.51	-3.07	-13.73	-2.56	-6.01
.07000	.14	-2.74	15.36	81.54	1.21	-3.93	1.43	-3.35	-7.32
.08000	.92	-2.52	13.63	80.48	1.23	-8.85	-10.24	-3.59	-8.38
.09000	1.69	-2.34	12.24	78.86	.44	-2.88	-6.35	-4.11	-7.85
.10000	2.46	-2.18	10.96	77.49	-.89	-3.17	-6.69	-3.38	-8.08
.11000	3.22	-2.06	9.43	76.34	-1.13	-.31	-5.81	-3.20	-7.39
.12000	3.97	-1.96	7.68	76.10	-1.25	-.97	-6.52	-2.43	-6.08
.13000	4.72	-1.88	5.65	75.38	.05	-.82	-3.26	-1.45	-4.72
.14000	5.47	-1.81	3.67	75.02	2.05	-2.17	-2.49	-.70	-3.56
.15000	6.22	-1.74	2.29	75.16	2.99	-2.05	-5.58	-.34	-2.22
.16000	6.97	-1.68	.48	75.06	4.90	2.90	.69	.50	-2.32
.17000	7.72	-1.63	-1.21	75.17	6.82	2.41	-.92	.98	-2.86
.18000	8.48	-1.59	-2.90	75.56	7.53	1.40	-2.06	1.04	-3.24
.19000	9.24	-1.56	-4.10	75.86	7.66	1.18	-4.92	.93	-3.57
.20000	10.00	-1.54	-4.10	76.16	6.16	1.28	-5.38	.71	-3.93
.21000	10.77	-1.54	-5.00	75.91	6.38	1.09	1.49	.25	-2.59
.22000	11.53	-1.55	-4.26	75.92	4.53	-.19	-.74	.21	-1.60
.23000	12.29	-1.56	-4.78	75.74	5.83	-1.19	5.38	.05	-.71
.24000	13.05	-1.56	-4.93	76.10	6.17	.30	-.43	.09	-.35
.25000	13.81	-1.56	-5.12	76.13	6.37	1.43	-3.83	-.01	-.03
.26000	14.58	-1.57	-5.87	75.98	6.98	-2.17	1.06	.02	-.59
.27000	15.34	-1.58	-6.33	75.68	7.22	.30	-1.06		
.28000	16.10	-1.59	-6.60	75.56	7.31	.40	.17		
.29000	16.86	-1.61	-6.80	75.61	7.87	.84	1.26		

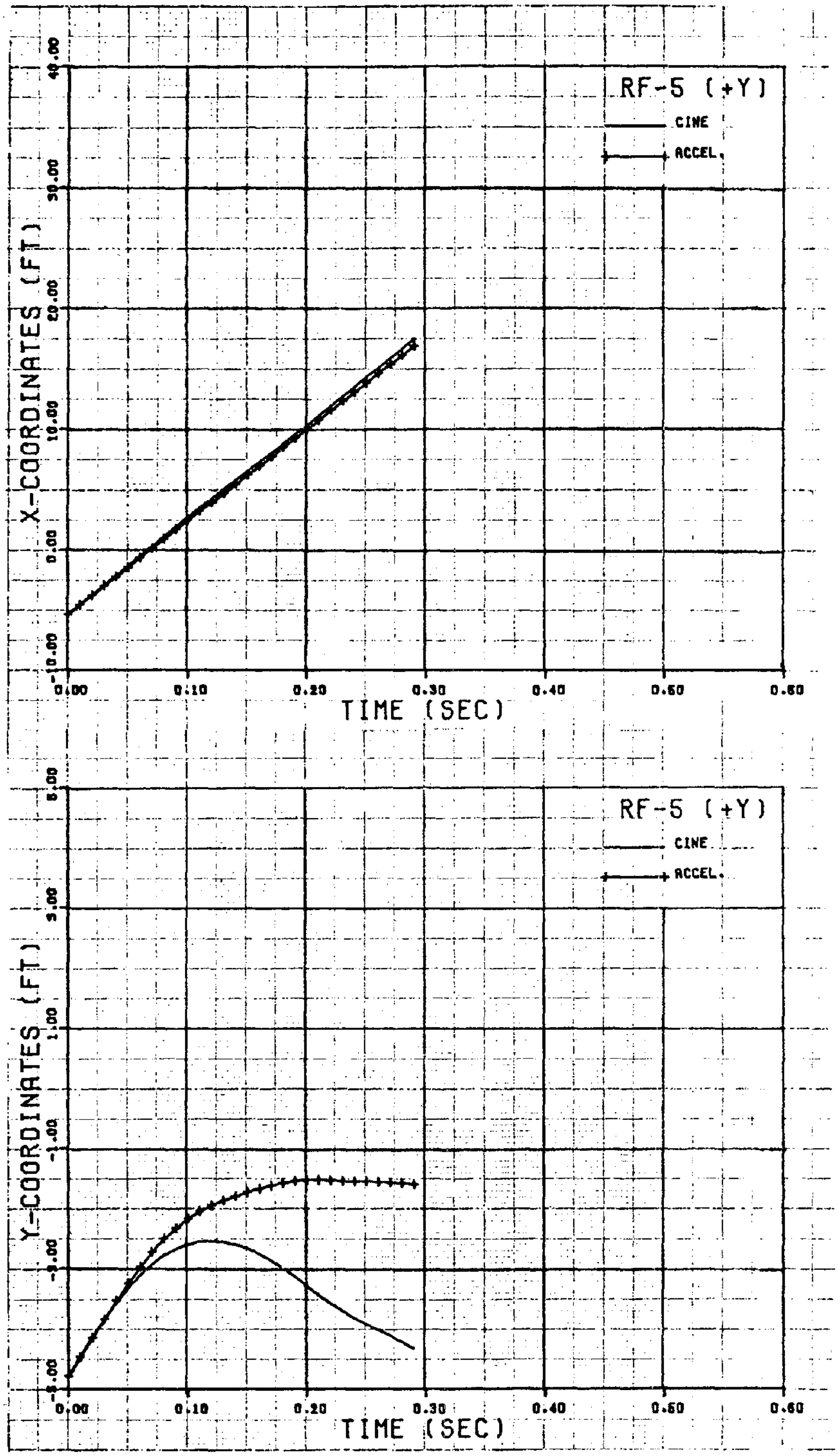


FIGURE B.9 VEHICLE X AND Y DISPLACEMENT HISTORIES FOR CRASH TEST RF-5

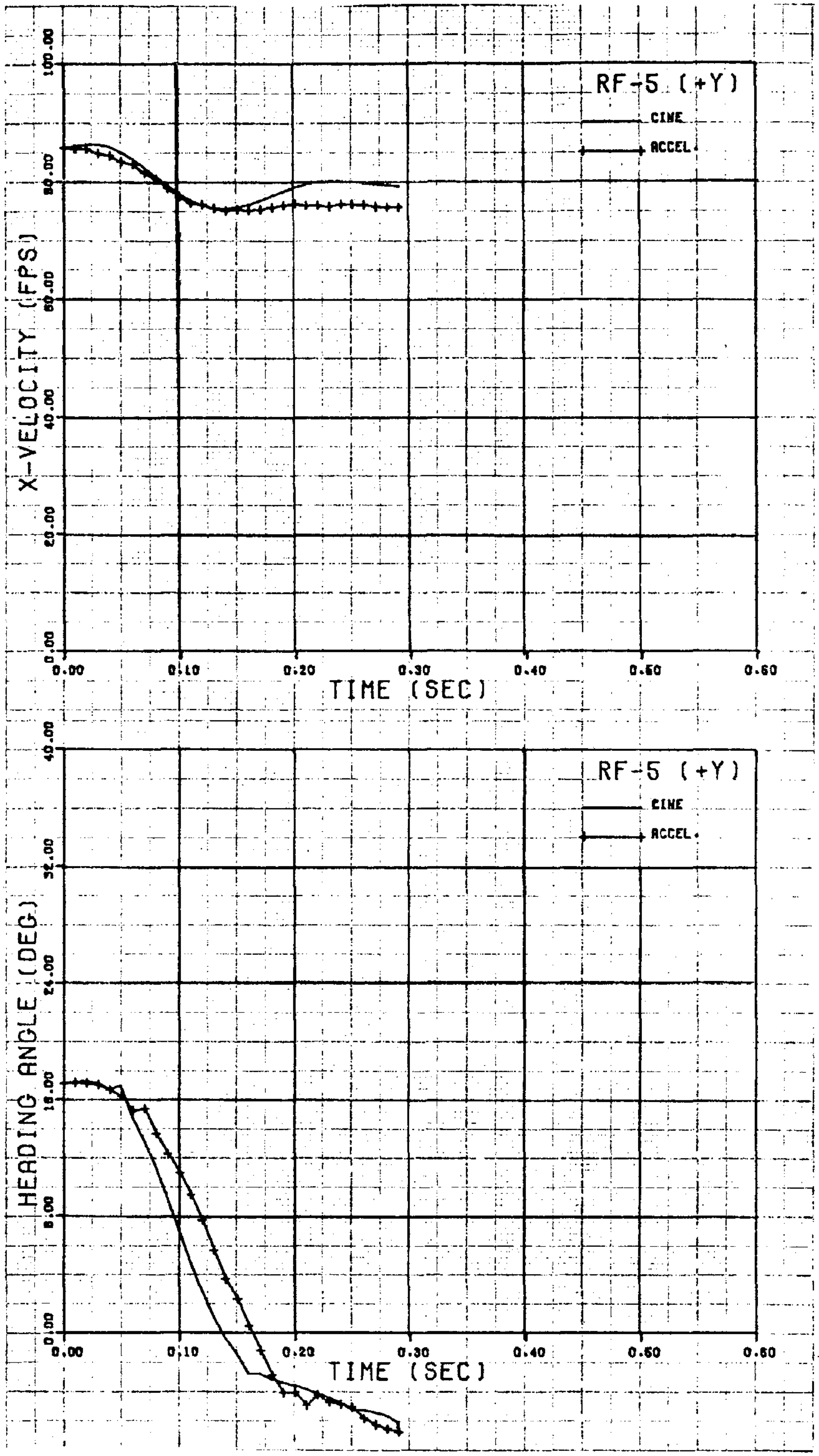


FIGURE B.10 VEHICLE X VELOCITY AND HEADING ANGLE HISTORIES FOR CRASH TEST RF-5

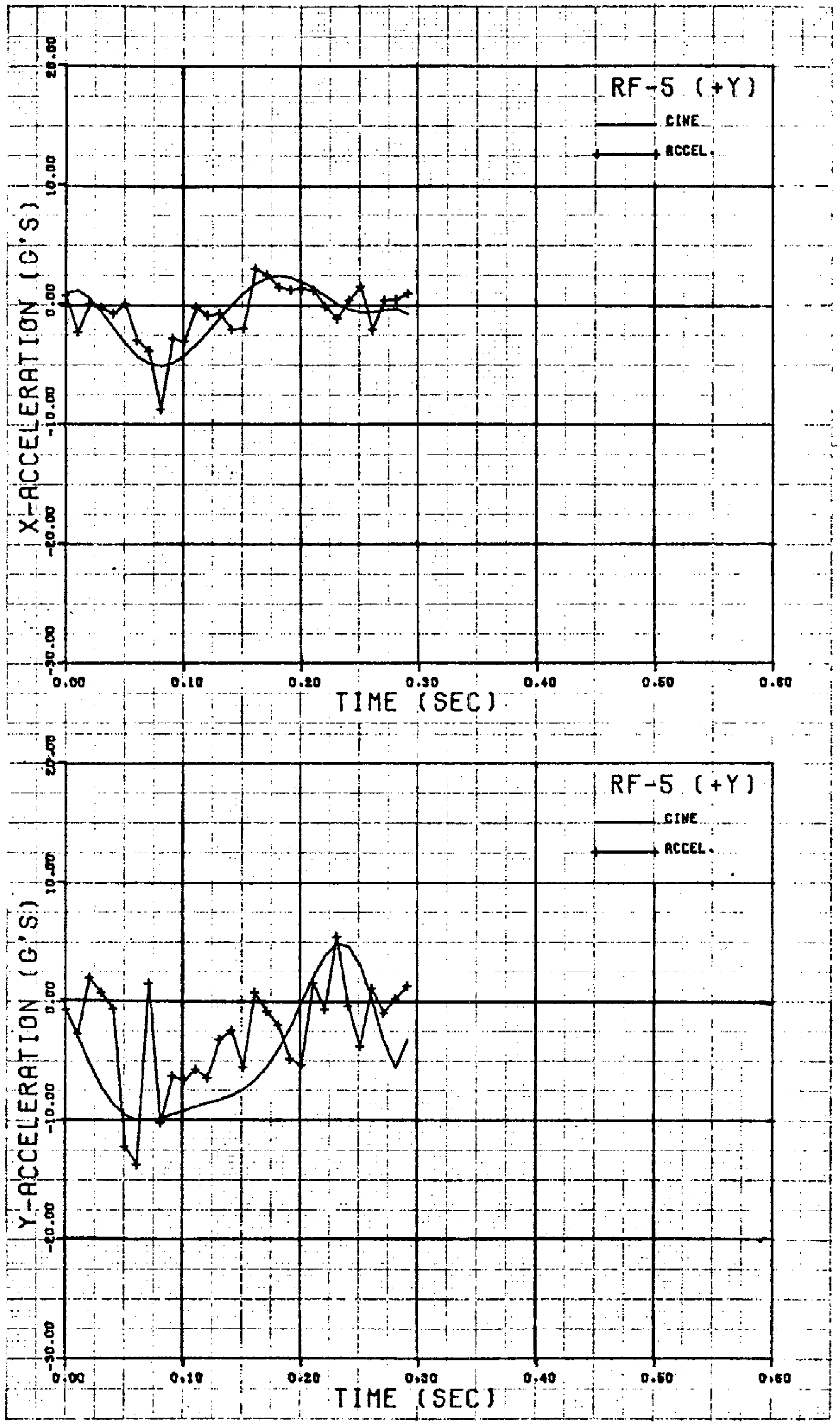


FIGURE B.11 VEHICLE X AND Y ACCELERATION HISTORIES FOR CRASH TEST RF-5

TABLE B.9

SUMMARY OF VEHICLE ACCELEROMETER DATA FOR CRASH TEST RF-6

TIME (SEC)	DISPLACEMENT - FT X	DISPLACEMENT - FT Y	HEADING ANGLE (DEG)	VELOCITY - FPS X	VELOCITY - FPS Y	VEHICLE ACCELERATION G'S AT TIME T X	VEHICLE ACCELERATION G'S AT TIME T Y	VEHICLE ACCELERATION G'S (AVERAGE OVER .05 SEC.) X	VEHICLE ACCELERATION G'S (AVERAGE OVER .05 SEC.) Y
.00000	.00	.00	25.00	88.00	.00	-1.41	-1.87		
.01000	.80	.37	24.95	87.99	.48	-3.40	2.01		
.02000	1.59	.75	24.95	87.65	.99	-3.87	-2.75		
.03000	2.38	1.12	25.31	86.50	-1.70	-.12	-4.39	-1.83	-3.27
.04000	3.17	1.47	25.40	85.94	-3.49	-3.24	-3.57	-2.89	-4.68
.05000	3.96	1.79	25.43	85.05	-5.89	-1.51	-5.42	-3.51	-6.70
.06000	4.75	2.09	25.23	83.37	-7.46	-6.74	-8.03	-3.73	-7.14
.07000	5.54	2.36	24.95	82.07	-9.81	-4.81	-9.73	-4.39	-8.45
.08000	6.32	2.60	24.38	80.68	-11.84	-5.41	-11.48	-5.22	-9.80
.09000	7.11	2.81	23.62	79.24	-14.54	-4.49	-12.64	-5.44	-11.06
.10000	7.89	2.97	22.46	77.33	-17.50	-4.34	-12.79	-5.74	-11.64
.11000	8.67	3.08	21.09	75.70	-19.57	-4.97	-12.82	-5.91	-11.72
.12000	9.44	3.15	19.42	74.49	-21.06	-8.00	-11.36	-5.47	-10.23
.13000	10.21	3.18	17.59	73.38	-21.69	.90	-6.48	-4.27	-8.19
.14000	10.98	3.18	15.38	73.28	-20.27	1.58	-2.72	-3.02	-5.86
.15000	11.74	3.18	13.23	73.70	-18.76	1.08	-.75	-1.90	-3.04
.16000	12.50	3.16	10.81	74.39	-15.77	-1.09	-.08	-.76	-.87
.17000	13.26	3.15	8.36	74.95	-11.74	-.41	1.31	.05	-.45
.18000	14.02	3.15	5.94	75.44	-8.04	1.52	1.74	.86	-.50
.19000	14.78	3.14	3.94	76.07	-6.09	1.24	-4.18	1.47	-1.61
.20000	15.54	3.13	1.79	77.26	-4.54	3.12	-3.24	2.37	-3.38
.21000	16.32	3.10	.50	78.27	-4.70	5.71	-6.21	2.04	-5.74
.22000	17.11	3.05	-.42	79.79	-5.42	1.37	-14.82	2.44	-7.03
.23000	17.91	2.97	1.24	79.07	-11.00	.74	-9.42	1.79	-7.61
.24000	18.71	2.87	3.32	79.72	-16.68	-22.81	-6.82	1.32	-6.80
.25000	19.51	2.73	4.34	79.27	-20.34	-1.98	-6.82	.54	-5.60
.26000	20.32	2.59	4.12	79.50	-20.70	-1.80	1.31	.79	-3.63
.27000	21.12	2.44	3.90	79.76	-20.45	-.15	-.17	.01	-1.91
.28000	21.93	2.29	3.68	79.79	-20.24	-.26	-.42	-.09	-.55
.29000	22.74	2.14	3.43	79.66	-19.92	-1.07	-.69	-.19	.23
.30000	23.55	1.99	3.32	79.48	-19.83	-.52	-.14	-.22	.53
.31000	24.35	1.84	3.06	79.56	-18.84	-.15	2.10	.00	.65
.32000	25.16	1.69	2.85	79.74	-18.15	1.86	1.19	.23	.58
.33000	25.97	1.55	2.74	80.11	-17.89	.84	-1.30		
.34000	26.78	1.41	2.67	80.27	-17.92	-.86	-.45		
.35000	27.58	1.27	2.58	80.06	-18.47	-.88	-2.63		

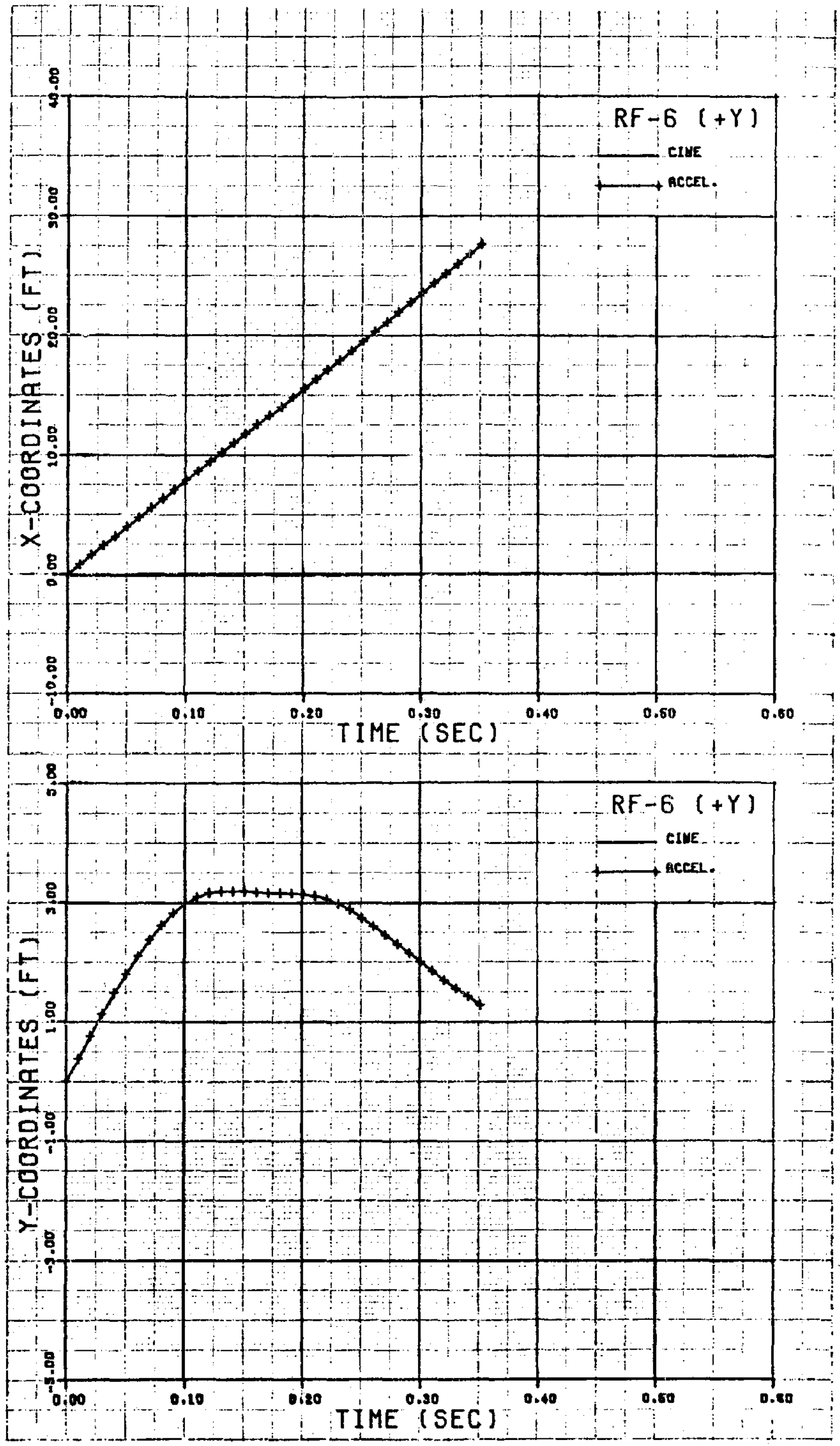


FIGURE B. 12 VEHICLE X AND Y DISPLACEMENT HISTORIES FOR CRASH TEST RF-6

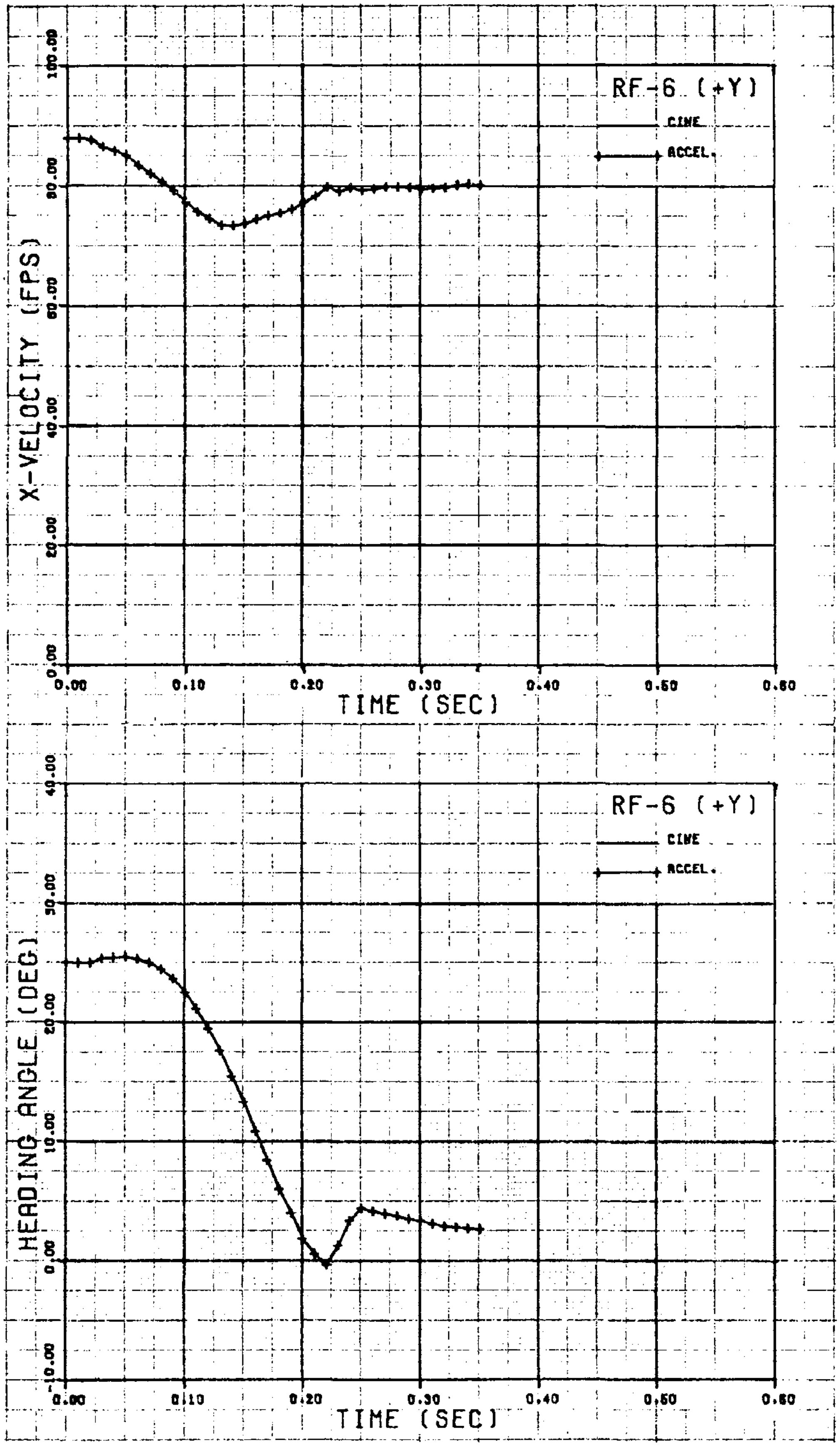


FIGURE B.13 VEHICLE X VELOCITY AND HEADING ANGLE HISTORIES FOR CRASH TEST RF-6

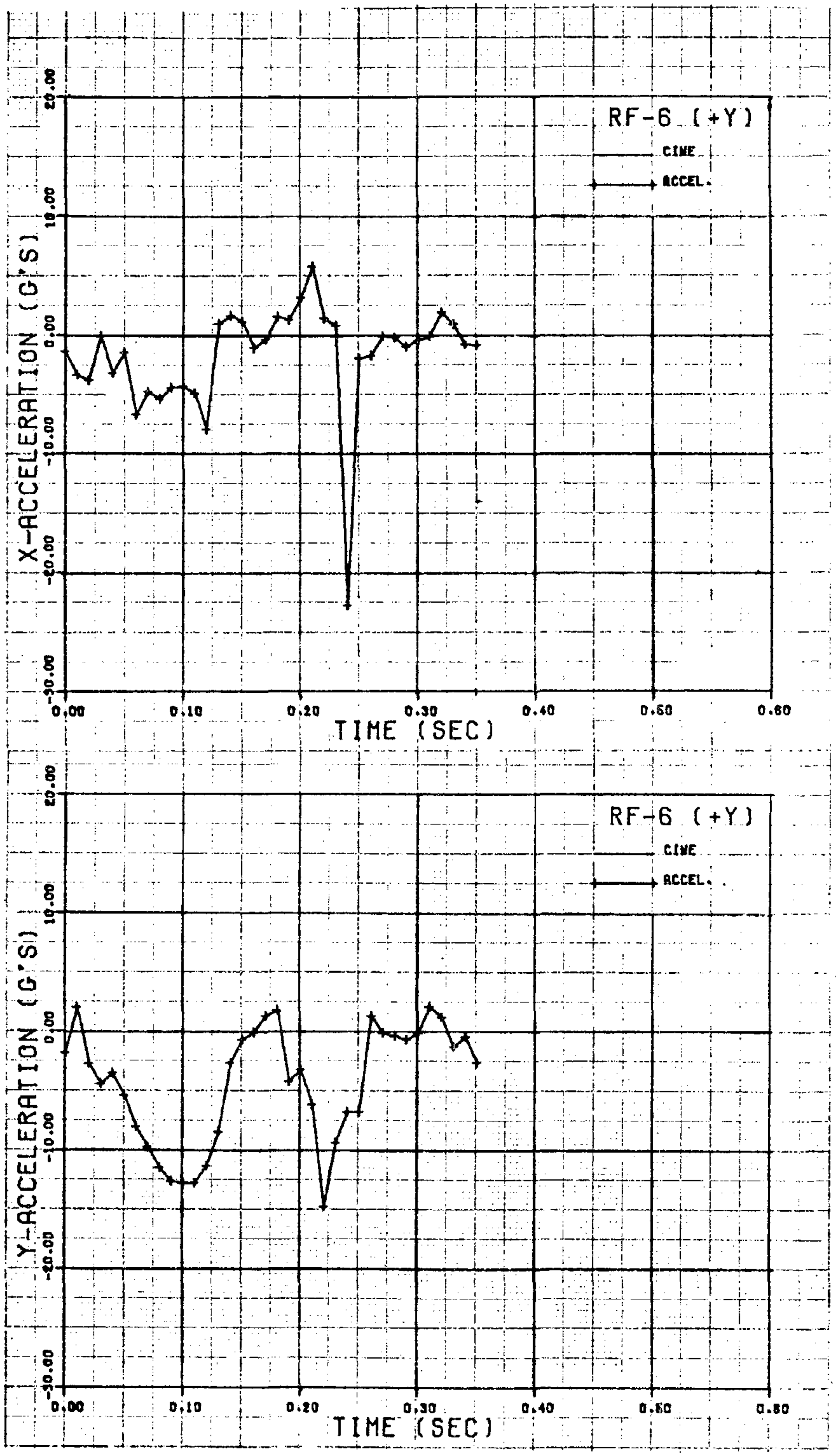


FIGURE B. 14 VEHICLE X AND Y ACCELERATION HISTORIES FOR CRASH TEST RF-6

TABLE B. 10

SUMMARY OF VEHICLE ACCELEROMETER DATA FOR CRASH TEST RF-7

TIME (SEC)	DISPLACEMENT - FT X	DISPLACEMENT - FT Y	HEADING ANGLE (DEG)	VELOCITY - FPS X	VELOCITY - FPS Y	VEHICLE ACCELERATION G'S -- AT TIME ----) X	VEHICLE ACCELERATION G'S -- AT TIME ----) Y	VEHICLE ACCELERATION G'S (--- AVERAGE OVER 0.05 SEC. --- X	VEHICLE ACCELERATION G'S (--- AVERAGE OVER 0.05 SEC. --- Y	RESULT
.00000	.00	.00	25.00	85.15	.00	-.99	-3.93			
.01000	.80	.37	24.92	87.39	-1.30	-3.47	-5.02			
.02000	1.59	.72	24.74	86.55	-1.77	.05	.21			
.03000	2.39	1.06	24.56	86.15	-1.67	-2.03	-6.38	-2.10	-2.80	3.50
.04000	3.18	1.40	24.35	85.51	-2.69	.05	-.16	-2.87	-2.61	3.88
.05000	3.96	1.73	23.86	84.80	-2.80	.12	-4.05	-3.51	-2.70	4.42
.06000	4.74	2.03	23.15	82.83	-2.88	.17	-5.04	-3.75	-3.12	4.88
.07000	5.51	2.32	22.42	81.08	-2.72	-17.73	-2.32	-3.65	-3.06	4.92
.08000	6.26	2.60	21.69	80.24	-2.57	-3.18	-2.20	-4.01	-3.35	5.23
.09000	7.02	2.87	20.88	79.49	-2.64	-3.18	-4.53	-3.15	-3.30	4.56
.10000	7.77	3.12	19.64	78.54	-2.54	-2.69	-3.97	-2.36	-3.29	4.05
.11000	8.51	3.36	18.68	77.96	-1.99	-.63	-3.80	-2.43	-3.00	3.86
.12000	9.25	3.58	17.39	77.42	-1.08	-2.90	-.79	-2.45	-2.92	3.81
.13000	9.99	3.80	16.18	76.50	.13	-2.40	-2.59	-2.45	-3.00	3.83
.14000	10.72	4.01	14.83	75.67	.85	-3.73	-4.65	-2.24	-3.15	3.87
.15000	11.45	4.20	13.38	74.65	1.28	-3.25	-4.58	-2.03	-3.75	4.26
.16000	12.17	4.38	11.74	74.31	2.14	-1.65	-5.31	-2.15	-4.70	5.17
.17000	12.90	4.54	10.01	74.00	2.60	-2.97	-7.21	-2.12	-5.12	5.54
.18000	13.62	4.69	8.13	72.80	3.05	-3.16	-7.91	-1.71	-5.52	5.78
.19000	14.33	4.81	6.02	71.90	3.97	-4.51	-7.26	-1.50	-6.96	7.12
.20000	15.04	4.91	3.60	71.41	4.61	-7.03	-6.45	-1.03	-6.84	6.92
.21000	15.75	4.99	1.77	71.28	3.58	2.86	-16.74	-.17	-6.49	6.49
.22000	16.47	5.04	-.48	71.66	4.77	-4.20	-7.69	.40	-6.77	6.78
.23000	17.18	5.08	-2.24	71.75	5.54	1.14	-.89	.77	-7.51	7.55
.24000	17.90	5.09	-3.82	71.75	5.38	-4.01	-14.77	.39	-6.00	6.01
.25000	18.62	5.08	-4.98	71.91	3.51	.90	-8.42	.17	-6.01	6.01
.26000	19.34	5.05	-6.12	71.29	3.74	-3.63	-1.74	-.83	-6.35	6.41
.27000	20.05	5.00	-6.87	71.42	3.07	-4.48	-4.29	-1.34	-6.30	6.44
.28000	20.75	4.93	-7.54	70.04	1.96	-3.07	-5.87	-1.54	-5.29	5.51
.29000	21.45	4.85	-8.04	69.34	.46	-2.22	-5.75	-1.37	-5.08	5.26
.30000	22.13	4.75	-8.38	69.28	-.81	-1.06	-3.86	-1.32	-4.27	4.46
.31000	22.81	4.64	-8.46	68.97	-1.55	1.85	-2.20	-.45	-3.23	3.26
.32000	23.50	4.52	-8.44	69.23	-1.89	.97	-.89	-.14	-2.06	2.07
.33000	24.18	4.40	-8.21	69.28	-2.45	-.47	-.72	-.13	-1.11	1.11
.34000	24.86	4.27	-7.81	69.09	-3.16	-1.51	.38	.11	-.61	.62
.35000	25.54	4.15	-7.58	69.02	-3.57	-.16	-.84	-.07	-.27	.28
.36000	26.22	4.02	-7.28	69.10	-3.96	.38	.86	.02	.10	.10
.37000	26.90	3.89	-7.02	69.04	-4.04	.90	.04	.03	.40	.40
.38000	27.58	3.77	-6.66	69.22	-4.17	.31	.91			
.39000	28.26	3.65	-6.32	69.03	-4.31	.00	.67			
.40000	28.94	3.53	-6.04	68.90	-4.59	-1.01	.55			

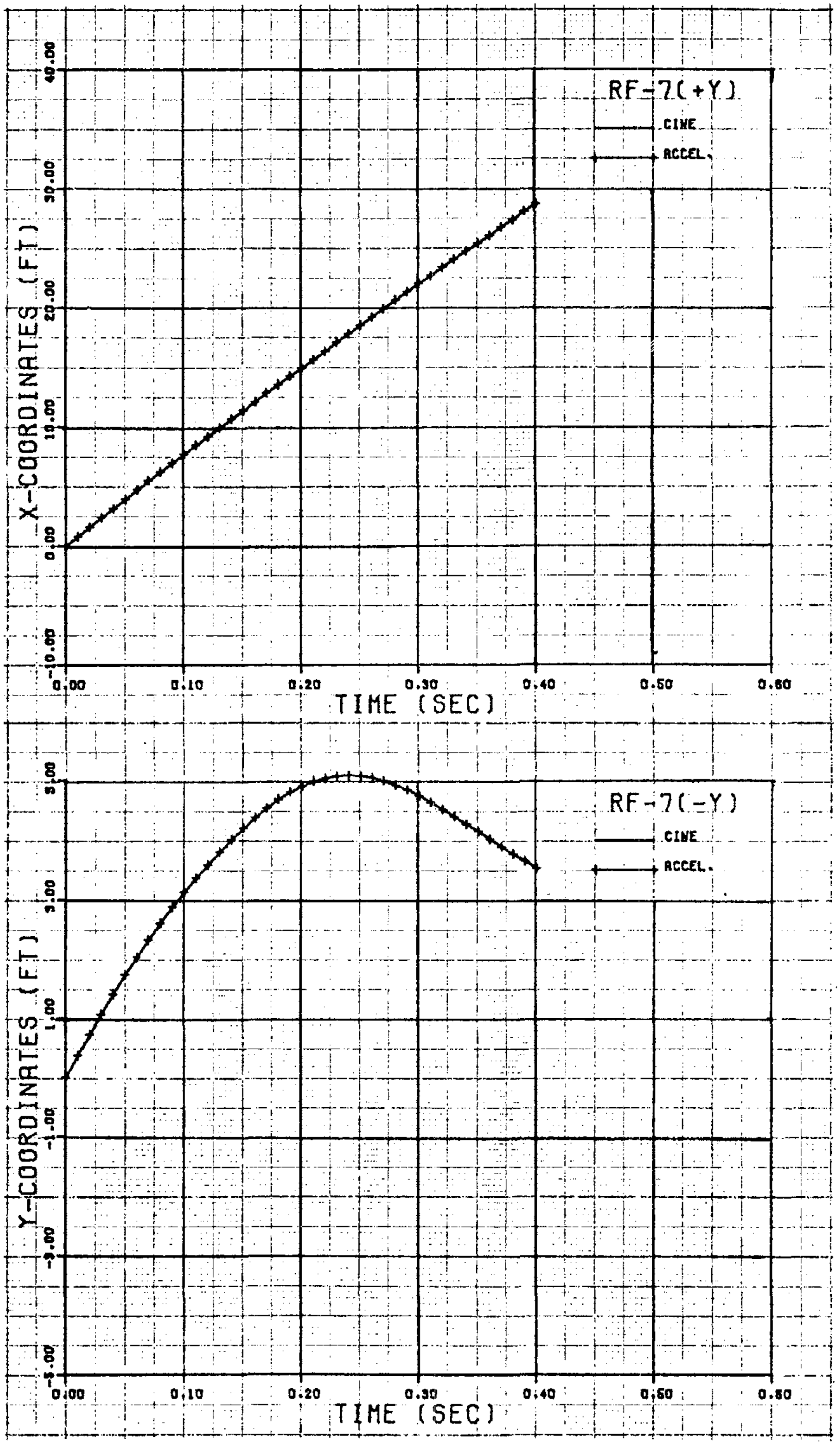


FIGURE B. 15 VEHICLE X AND Y DISPLACEMENT HISTORIES FOR CRASH TEST RF-7

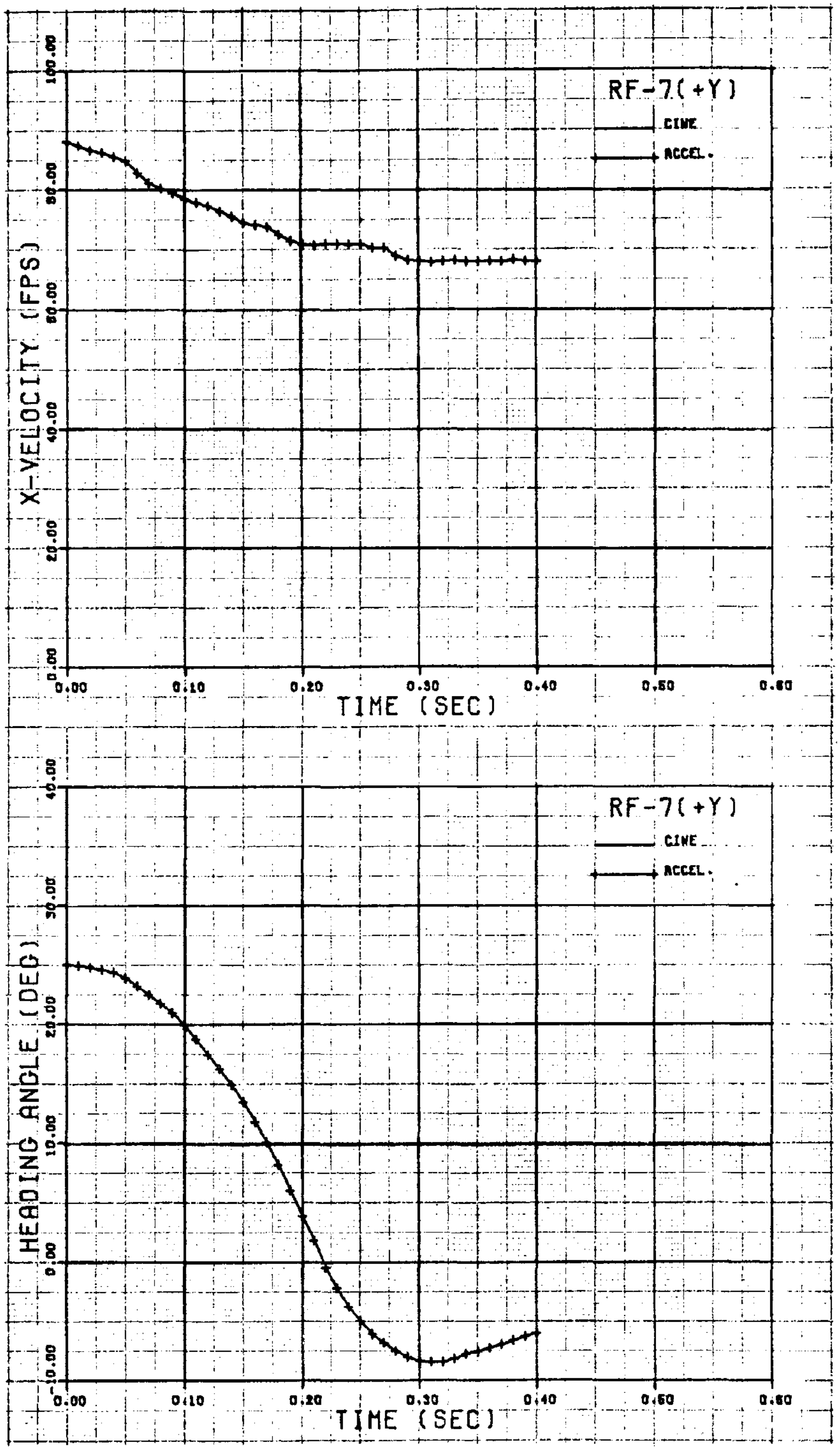


FIGURE B.16 VEHICLE X VELOCITY AND HEADING ANGLE HISTORIES FOR CRASH TEST RF-7

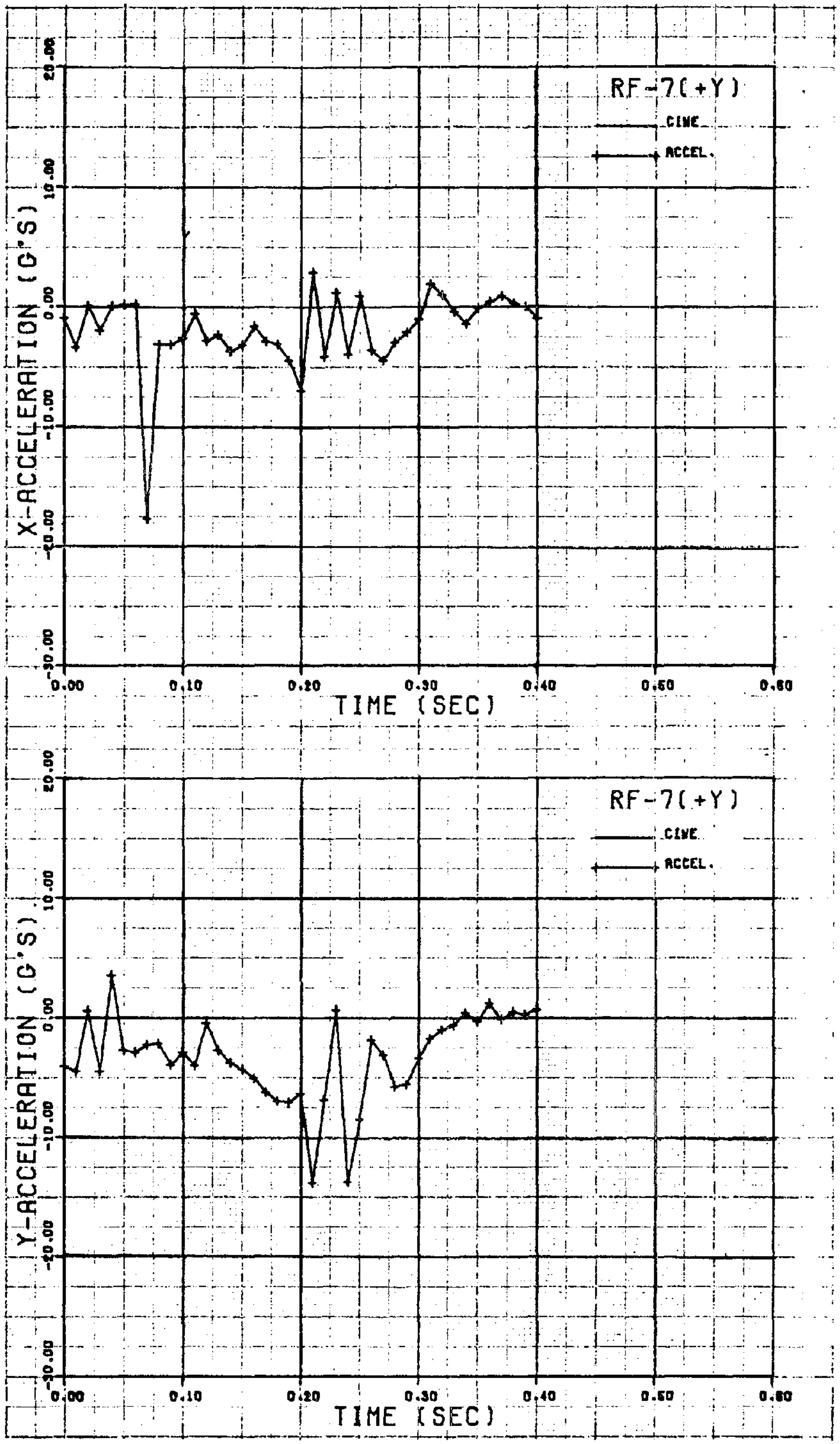


FIGURE B.17 VEHICLE X AND Y ACCELERATION HISTORIES FOR CRASH TEST RF-7

TABLE B.11

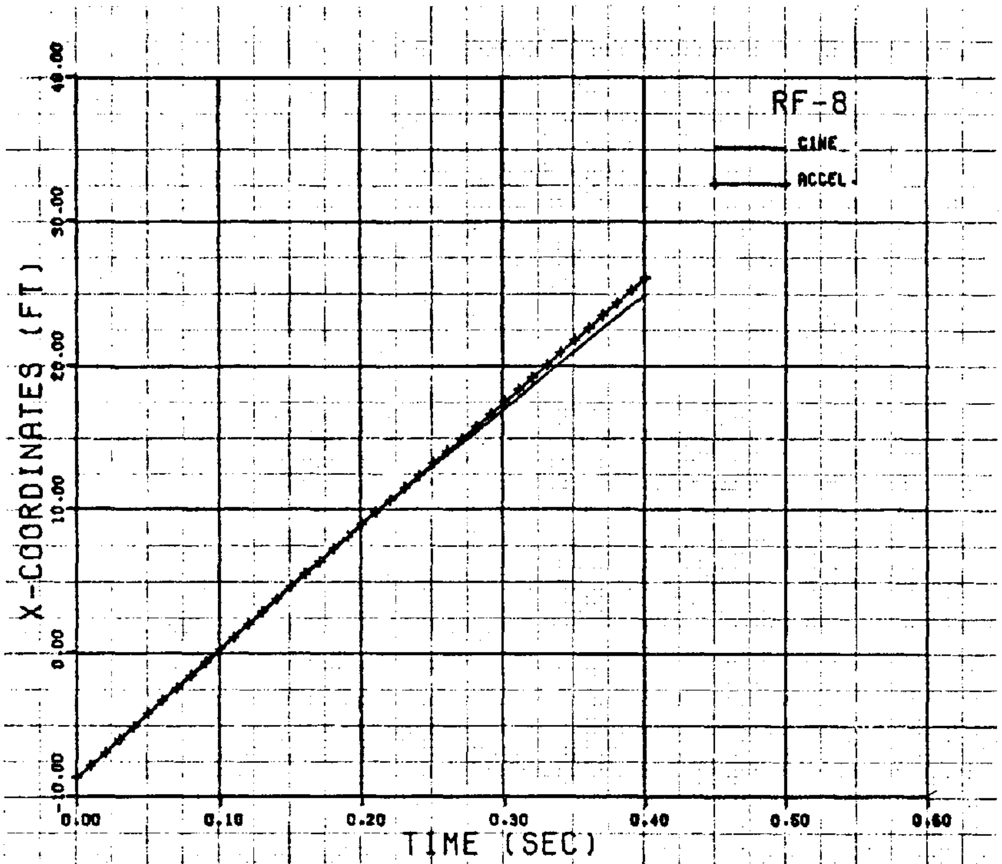
SUMMARY OF VEHICLE CINE DATA FOR CRASH TEST RF-8

TIME AFTER IMPACT (SEC)	VEHICLE C. G. COORDINATES (FT) X	Y	HEADING ANGLE (DEG)	VEHICLE VELOCITY (FT/SEC) LONG	LAT	VEHICLE ACCELERATION (G'S) AT TIME T LONG	LAT	AVERAGE OVER .05 SEC. LONG	LAT	APPROX. BARRIER FORCES (LB) X	Y
0.000	-8.72	-2.40	15.92	91.98	-2.32	.25	-.47	-1.46	-.66	-797	815
.010	-7.83	-2.17	15.87	92.18	-2.53	.75	-1.40	-.15	-1.23	-2365	2437
.020	-6.93	-1.95	15.72	92.39	-2.87	.41	-2.11	.04	-1.82	-2062	4115
.030	-6.04	-1.73	15.52	92.43	-3.30	-.26	-2.51	-.30	-2.24	-901	5327
.040	-5.14	-1.52	15.31	92.24	-3.79	-.94	-2.63	-.81	-2.45	448	5956
.050	-4.24	-1.31	15.09	91.87	-4.28	-1.46	-2.57	-1.27	-2.51	1588	6121
.060	-3.34	-1.12	14.87	91.36	-4.74	-1.78	-2.45	-1.59	-2.50	2329	6045
.070	-2.45	-.94	14.65	90.78	-5.17	-1.89	-2.39	-1.75	-2.51	2631	5967
.080	-1.56	-.76	14.43	90.20	-5.58	-1.86	-2.45	-1.78	-2.62	2553	6080
.090	-.67	-.59	14.18	89.64	-6.02	-1.75	-2.69	-1.74	-2.85	2218	6502
.100	.21	-.44	13.91	89.12	-6.52	-1.62	-3.10	-1.67	-3.22	1773	7266
.110	1.09	-.29	13.61	88.65	-7.15	-1.53	-3.63	-1.62	-3.69	1363	8320
.120	1.97	-.16	13.30	88.20	-7.92	-1.53	-4.22	-1.64	-4.20	1114	9548
.130	2.84	-.04	12.97	87.74	-8.88	-1.64	-4.79	-1.75	-4.69	1113	10785
.140	3.72	.05	12.64	87.24	-10.00	-1.85	-5.26	-1.95	-5.08	1407	11852
.150	4.59	.14	12.32	86.65	-11.26	-2.17	-5.54	-2.23	-5.30	1996	12573
.160	5.46	.21	12.02	85.96	-12.60	-2.54	-5.58	-2.56	-5.30	2832	12805
.170	6.32	.26	11.75	85.14	-13.96	-2.94	-5.33	-2.90	-5.05	3834	12453
.180	7.18	.28	11.50	84.20	-15.23	-3.31	-4.81	-3.22	-4.56	4885	11490
.190	8.03	.29	11.28	83.14	-16.33	-3.59	-4.03	-3.45	-3.84	5856	9953
.200	8.88	.29	11.07	82.02	-17.17	-3.74	-3.05	-3.57	-2.95	6610	7954
.210	9.71	.27	10.86	80.88	-17.68	-3.72	-1.98	-3.52	-1.99	7024	5663
.220	10.53	.25	10.63	79.78	-17.83	-3.50	-.91	-3.29	-1.02	6998	3294
.230	11.34	.22	10.37	78.80	-17.60	-3.07	.05	-2.87	-.17	6473	1085
.240	12.15	.19	10.07	78.00	-17.05	-2.44	.78	-2.29	.48	5440	-730
.250	12.94	.16	9.71	77.43	-16.24	-1.67	1.21	-1.57	.86	3950	-1952
.260	13.73	.13	9.32	77.15	-15.30	-.79	1.29	-.78	.93	2119	-2444
.270	14.51	.10	8.89	77.15	-14.34	.10	1.01	.01	.70	123	-2164
.280	15.30	.08	8.45	77.42	-13.51	.91	.42	.72	.23	-1803	-1183
.290	16.08	.06	8.03	77.92	-12.92	1.55	-.36	1.25	-.39	-3388	302
.300	16.88	.04	7.66	78.56	-12.67	1.89	-1.18	1.50	-1.01	-4344	1968
.310	17.68	.02	7.38	79.24	-12.78	1.84	-1.84	1.39	-1.44	-4407	3389
.320	18.48	-.01	7.21	79.80	-13.19	1.33	-2.09	.89	-1.48	-3384	4082
.330	19.29	-.04	7.16	80.09	-13.75	.36	-1.73	.01	-.99	-1215	3580
.340	20.10	-.08	7.22	79.98	-14.24	-.99	-.60	-1.12	.11	1949	1545
.350	20.91	-.12	7.36	79.39	-14.34	-2.49	1.30	-2.23	1.73	5650	-2069

TABLE B.12

SUMMARY OF VEHICLE ACCELEROMETER DATA FOR CRASH TEST RF-8

TIME (SEC)	VEHICLE ACCELERATION G'S — AT TIME X	AT TIME Y	AVERAGE OVER 0.05 SEC. X	AVERAGE OVER 0.05 SEC. Y	AVERAGE OVER 0.05 SEC. R	HEADING ANGLE (DEG),	VELOCITY - FPS X	VELOCITY - FPS Y	DISPLACEMENT - FT X	DISPLACEMENT - FT Y
.00000	.00	-.69				15.92	91.98	-2.32	-8.72	-2.40
.01000	1.06	.35				15.87	91.97	-2.41	-7.83	-2.17
.02000	.47	-2.17				15.72	91.86	-2.49	-6.94	-1.94
.03000	.95	.85	-.09	-.36	.37	15.52	91.96	-2.38	-6.05	-1.72
.04000	.16	-.22	-.06	-.23	.24	15.31	92.08	-1.86	-5.15	-1.50
.05000	-.83	-.46	-.02	-.09	.09	15.09	91.86	-1.56	-4.26	-1.27
.06000	.01	.22	-.28	-.22	.36	14.87	91.91	-1.18	-3.37	-1.05
.07000	-.79	-1.34	-.60	-.39	.72	14.65	91.86	-.93	-2.48	-.82
.08000	-1.79	-.50	-.66	-.32	.73	14.43	91.55	-.97	-1.59	-.60
.09000	-1.04	-.39	-.67	-.22	.70	14.18	91.14	-.68	-.70	-.38
.10000	.69	-.03	-.59	-.07	.59	13.91	90.81	-.19	.18	-.17
.11000	.53	.38	-.55	.13	.57	13.61	90.85	.48	1.06	.05
.12000	-.01	-.02	-.45	-.03	.45	13.30	90.91	1.10	1.95	.27
.13000	-.53	-.57	-.57	-.36	.68	12.97	90.65	1.54	2.83	.49
.14000	-.56	-1.45	-1.24	-1.01	1.60	12.64	90.40	1.71	3.71	.71
.15000	-2.20	-2.08	-1.08	-2.18	2.43	12.32	89.87	1.74	4.58	.92
.16000	-4.04	-7.32	-2.00	-2.88	3.50	12.02	88.83	1.39	5.45	1.12
.17000	-1.90	-3.87	-2.05	-3.96	4.46	11.75	89.14	.05	6.32	1.31
.18000	-1.26	-3.09	-2.03	-4.52	4.96	11.50	87.41	-.79	7.19	1.49
.19000	1.10	.88	-1.62	-4.52	4.80	11.28	87.09	-2.55	8.04	1.64
.20000	-1.30	-1.29	-2.21	-3.79	4.38	11.07	86.61	-3.60	8.90	1.78
.21000	-1.65	1.26	-1.17	-3.16	3.37	10.85	86.24	-4.13	9.76	1.91
.22000	-1.20	-.47	-.91	-2.16	2.35	10.61	85.64	-4.34	10.61	2.02
.23000	.67	-.76	-.65	-1.48	1.62	10.36	85.58	-4.15	11.46	2.14
.24000	-.11	-2.16	-.52	-1.10	1.22	10.05	85.71	-4.18	12.31	2.25
.25000	-1.22	-.39	-.28	-.72	.77	9.68	85.66	-3.92	13.16	2.35
.26000	.09	1.73	-.43	-.52	.68	9.27	85.51	-3.54	14.01	2.46
.27000	-1.52	.38	-.59	-.28	.65	8.84	85.30	-2.85	14.86	2.56
.28000	1.60	.28	-.51	.01	.51	8.39	85.00	-2.06	15.70	2.67
.29000	-3.15	1.35	.08	.20	.21	7.93	84.89	-1.50	16.55	2.77
.30000	1.15	-.25	.40	.18	.44	7.53	84.92	-.71	17.39	2.87
.31000	2.11	1.54	.78	.11	.79	7.30	85.70	-.29	18.24	2.98
.32000	2.63	.06	1.20	.21	1.21	7.03	85.97	.15	19.09	3.08
.33000	1.27	-.66	1.13	.18	1.14	7.00	86.29	.18	19.94	3.19
.34000	.38	.38	.74	.27	.78	7.03	86.81	.18	20.80	3.30
.35000	-.54	.41	.73	.36	.81	7.00	86.74	.35	21.66	3.41
.36000	2.17	.61	.60	.32	.68	7.12	86.88	.41	22.52	3.52
.37000	.78	-.19	.37	.33	.50	7.15	87.15	.55	23.39	3.63
.38000	-.45	.09				6.92	87.26	.82	24.25	3.74
.39000	-.22	-.09				6.68	87.41	1.24	25.12	3.86
.40000	-.02	-.28				6.21	87.53	1.94	25.98	3.97



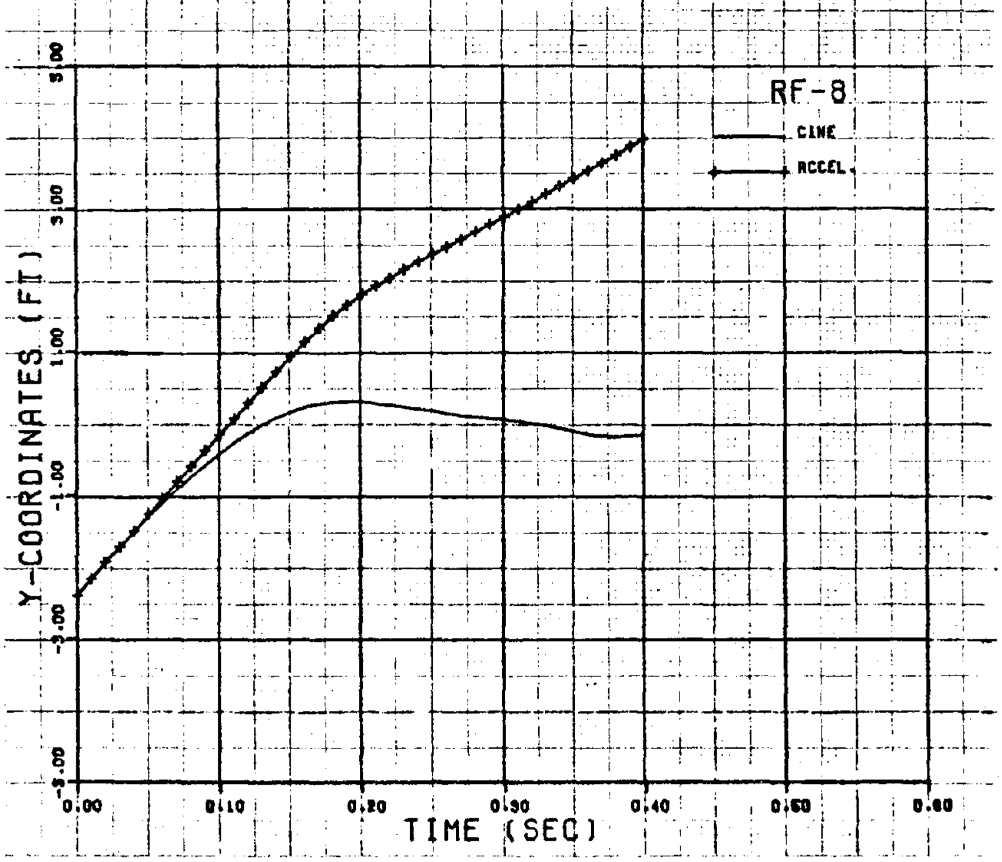


FIGURE B.18 VEHICLE X AND Y DISPLACEMENT HISTORIES FOR CRASH TEST RF-8

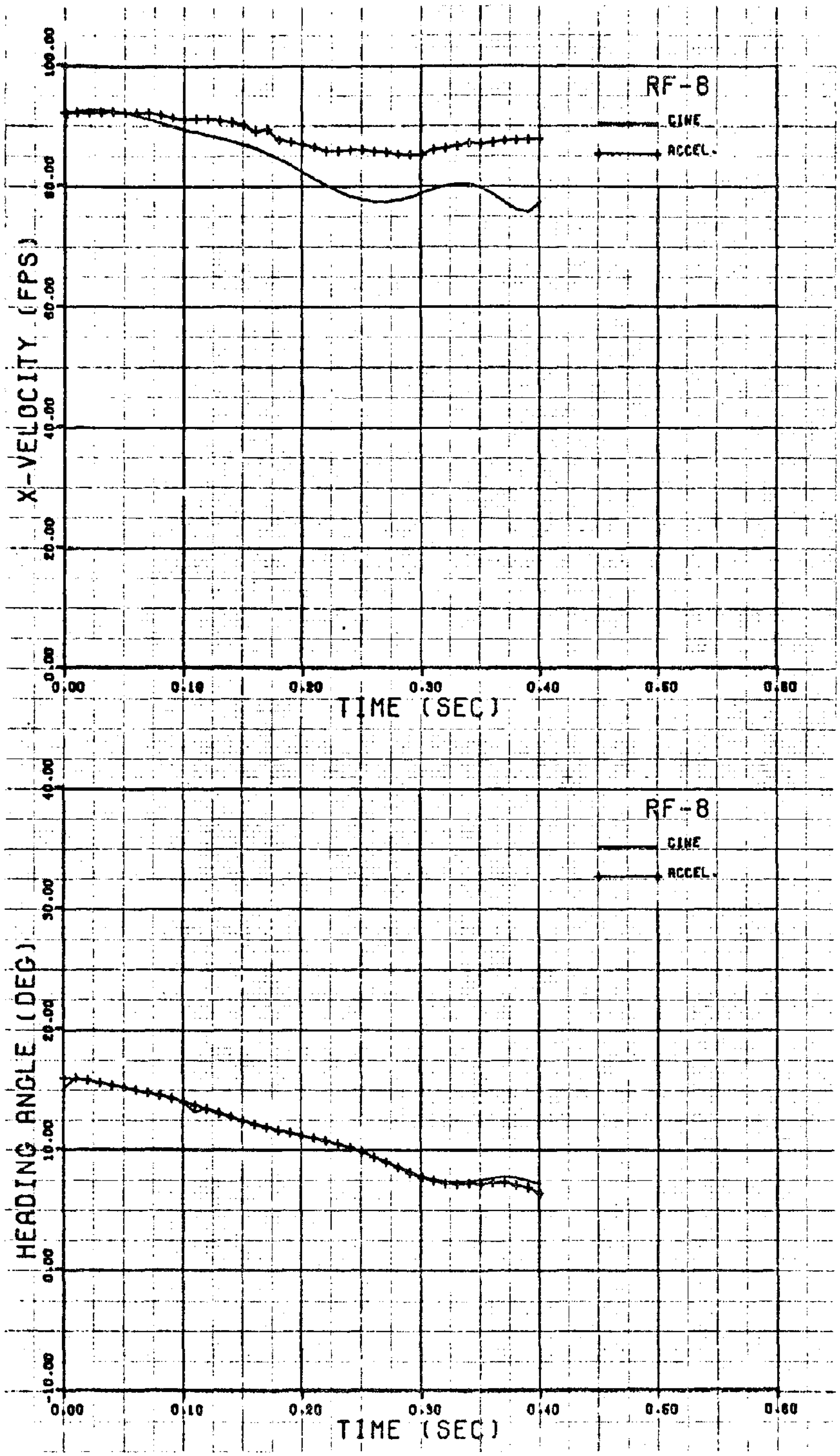


FIGURE B.19 VEHICLE X VELOCITY AND HEADING ANGLE HISTORIES FOR CRASH TEST RF-8

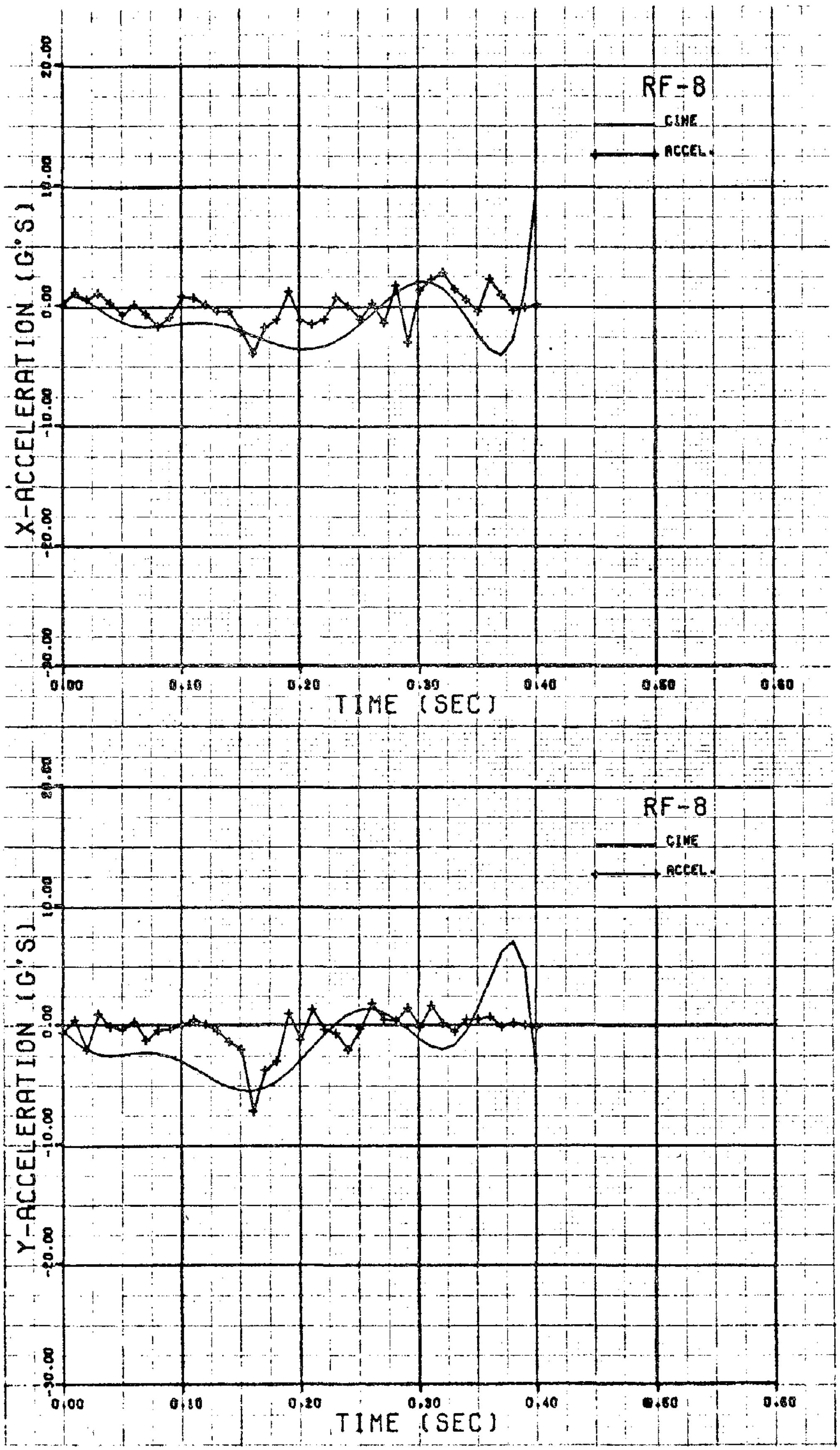


FIGURE B.20 VEHICLE X AND Y ACCELERATION HISTORIES FOR CRASH TEST RF-8

TABLE B. 13

SUMMARY OF VEHICLE CINE DATA FOR CRASH TEST RF-9

TIME AFTER IMPACT(SEC)	VEHICLE C, G, COORDINATES(FT) X	Y	HEADING ANGLE (DEG)	VEHICLE VELOCITY (FT/SEC) LONG	LAT	VEHICLE ACCELERATION(G'S) AT TIME T LONG	LAT	AVERAGE OVER ,05 SEC, LONG	LAT	APPROX, BARRIER FORCES(LB) X	Y
0.000	-,22	-4,35	29,44	85,56	-3,96	1,33	-1,43	,89	-1,70	-8790	2806
,010	,55	-3,97	29,64	85,55	-4,84	-1,29	-2,16	-1,28	-2,19	273	11860
,020	1,31	-3,59	29,93	84,69	-6,08	-3,88	-2,87	-3,58	-2,78	9120	20900
,030	2,07	-3,23	30,20	83,03	-7,50	-6,15	-3,46	-5,69	-3,30	16901	28736
,040	2,82	-2,89	30,38	80,72	-8,94	-7,94	-3,87	-7,41	-3,70	23114	34742
,050	3,55	-2,57	30,39	77,94	-10,25	-9,17	-4,12	-8,64	-3,96	27526	38703
,060	4,27	-2,28	30,20	74,91	-11,34	-9,84	-4,24	-9,35	-4,11	30106	40685
,070	4,96	-2,01	29,77	71,79	-12,16	-10,00	-4,27	-9,58	-4,17	30972	40938
,080	5,64	-1,78	29,10	68,75	-12,72	-9,71	-4,24	-9,38	-4,18	30339	39812
,090	6,29	-1,57	28,22	65,91	-13,04	-9,09	-4,18	-8,85	-4,16	28482	37692
,100	6,92	-1,38	27,14	63,37	-13,15	-8,22	-4,10	-8,07	-4,11	25704	34959
,110	7,54	-1,22	25,90	61,17	-13,11	-7,20	-4,02	-7,14	-4,05	22311	31948
,120	8,14	-1,08	24,54	59,33	-12,97	-6,13	-3,94	-6,13	-3,98	18593	28938
,130	8,73	-,96	23,10	57,86	-12,75	-5,05	-3,86	-5,11	-3,91	14809	26133
,140	9,30	-,86	21,61	56,72	-12,50	-4,05	-3,79	-4,14	-3,84	11178	23664
,150	9,87	-,78	20,11	55,89	-12,24	-3,14	-3,72	-3,25	-3,76	7873	21593
,160	10,44	-,71	18,63	55,32	-11,98	-2,35	-3,66	-2,48	-3,69	5021	19920
,170	11,00	-,65	17,18	54,97	-11,76	-1,71	-3,59	-1,84	-3,61	2700	18593
,180	11,56	-,61	15,77	54,79	-11,55	-1,20	-3,52	-1,32	-3,52	944	17526
,190	12,12	-,58	14,42	54,74	-11,37	-,82	-3,42	-,93	-3,40	-252	16611
,200	12,67	-,55	13,11	54,78	-11,21	-,56	-3,29	-,65	-3,25	-927	15732
,210	13,23	-,54	11,85	54,87	-11,03	-,40	-3,11	-,47	-3,06	-1148	14781
,220	13,79	-,54	10,63	54,99	-10,83	-,33	-2,88	-,37	-2,83	-1002	13665
,230	14,35	-,55	9,44	55,11	-10,57	-,31	-2,59	-,33	-2,54	-588	12321
,240	14,92	-,57	8,28	55,22	-10,23	-,32	-2,25	-,33	-2,19	-10	10718
,250	15,48	-,60	7,14	55,31	-9,79	-,37	-1,85	-,35	-1,80	630	8861
,260	16,04	-,63	6,01	55,37	-9,22	-,41	-1,40	-,39	-1,38	1237	6796
,270	16,60	-,66	4,89	55,41	-8,52	-,45	-,94	-,41	-,94	1731	4599
,280	17,16	-,70	3,77	55,42	-7,67	-,47	-,47	-,42	-,50	2047	2379
,290	17,71	-,74	2,67	55,40	-6,68	-,46	-,03	-,41	-,09	2146	261
,300	18,27	-,78	1,58	55,38	-5,57	-,42	,35	-,37	,28	2007	-1619
,310	18,82	-,82	,50	55,35	-4,36	-,34	,67	-,30	,56	1636	-3130
,320	19,38	-,86	-,57	55,33	-3,08	-,23	,88	-,20	,76	1062	-4157
,330	19,93	-,90	-1,62	55,32	-1,76	-,10	,98	-,08	,85	336	-4619
,340	20,48	-,93	-2,65	55,33	-,45	,06	,95	,06	,83	-474	-4481
,350	21,03	-,96	-3,67	55,37	,82	,22	,81	,21	,71	-1284	-3762
,360	21,59	-,98	-4,67	55,44	2,01	,38	,57	,34	,50	-2003	-2548
,370	22,14	-1,01	-5,67	55,54	3,11	,51	,26	,46	,23	-2533	-994
,380	22,70	-1,03	-6,65	55,66	4,09	,60	-,08	,52	-,05	-2785	683
,390	23,26	-1,06	-7,62	55,79	4,96	,62	-,39	,52	-,30	-2677	2206
,400	23,82	-1,08	-8,57	55,89	5,73	,55	-,62	,43	-,47	-2148	3266
,410	24,38	-1,11	-9,50	55,94	6,42	,37	-,70	,24	-,50	-1162	3552
,420	24,94	-1,14	-10,39	55,91	7,07	,05	-,59	-,08	-,37	283	2799
,430	25,51	-1,17	-11,21	55,75	7,72	-,41	-,26	-,53	-,04	2152	830

TABLE B.14

SUMMARY OF VEHICLE ACCELEROMETER DATA FOR CRASH TEST RF-9

TIME (SEC)	VEHICLE ACCELERATION G'S: AT TIME X	AT TIME Y	AVERAGE OVER 0.05 SEC. X	AVERAGE OVER 0.05 SEC. Y	AVERAGE OVER 0.05 SEC. R	HEADING ANGLE (DEG),	VELOCITY - FPS X	VELOCITY - FPS Y	DISPLACEMENT - FT X	DISPLACEMENT - FT Y
.00000	-.41	-.45				29.44	85.56	-3.96	-.22	-4.35
.01000	2.59	1.27				29.64	84.00	-5.01	.54	-3.97
.02000	4.72	2.38				29.93	83.56	-5.68	1.29	-3.60
.03000	-3.94	-1.72	-2.63	-2.10	3.37	30.20	81.90	-6.85	2.04	-3.24
.04000	-8.44	-4.67	-3.93	-2.76	4.80	30.38	81.58	-7.27	2.78	-2.89
.05000	8.15	-2.41	-5.67	-3.96	6.92	30.39	81.19	-8.72	3.52	-2.55
.06000	-10.57	-2.95	-6.12	-4.61	7.66	30.20	77.67	-10.24	4.25	-2.23
.07000	-14.44	-7.82	-8.77	-6.02	10.63	29.77	74.57	-11.83	4.97	-1.94
.08000	-18.71	-12.11	-10.48	-6.00	12.08	29.10	72.34	-12.82	5.67	-1.69
.09000	-14.77	-6.23	-9.41	-6.09	11.21	28.22	67.95	-14.19	6.35	-1.47
.10000	-8.01	-6.79	-8.76	-5.40	10.29	27.14	65.12	-14.34	7.00	-1.29
.11000	-7.64	-1.79	-8.52	-4.80	9.78	25.90	63.53	-14.90	7.65	-1.13
.12000	-11.49	-5.28	-5.89	-3.28	6.74	24.54	61.74	-14.46	8.28	-.99
.13000	-5.39	-2.19	-4.41	-2.55	5.09	23.10	60.06	-13.83	8.90	-.86
.14000	-.59	.46	-3.48	-1.38	3.74	21.61	60.04	-12.27	9.50	-.77
.15000	2.11	1.01	-2.79	-.93	2.94	20.11	59.64	-10.92	10.10	-.67
.16000	-.30	.45	-2.16	-.62	2.25	18.63	59.50	-9.44	10.70	-.56
.17000	-5.20	-1.36	-2.42	-1.06	2.64	17.18	58.70	-8.29	11.29	-.46
.18000	.92	1.58	-2.00	-1.18	2.33	15.77	57.87	-7.26	11.87	-.37
.19000	-4.07	-1.84	-1.88	-1.23	2.24	14.42	57.29	-6.55	12.45	-.29
.20000	-6.46	-3.23	-1.39	-1.12	1.78	13.11	57.41	-5.63	13.02	-.21
.21000	9.27	2.20	-.87	-.88	1.23	11.85	57.26	-4.54	13.59	-.14
.22000	3.28	.45	-.28	-.30	.41	10.63	57.12	-3.50	14.16	-.06
.23000	-5.92	-2.25	-.01	.14	.14	9.44	57.06	-2.30	14.73	.01
.24000	-.11	.21	.17	.30	.35	8.27	57.25	-.90	15.29	.08
.25000	3.91	2.21	.31	.46	.56	7.14	57.65	.53	15.86	.15
.26000	1.70	1.29	.43	.53	.68	6.01	57.73	1.79	16.43	.23
.27000	-3.31	-1.46	.21	.38	.44	4.88	57.68	3.02	17.01	.31
.28000	-1.75	-.61	-.15	.19	.24	3.76	57.62	4.25	17.58	.39
.29000	1.29	.90	-.24	.06	.25	2.67	57.36	5.34	18.15	.47
.30000	-.83	-.04	-.26	.06	.26	1.57	57.09	6.44	18.72	.55
.31000	-2.31	-1.54	-.37	.01	.37	.45	56.90	7.46	19.29	.63
.32000	1.17	.93	-.24	.07	.25	-.60	56.69	8.58	19.86	.71
.33000	1.48	1.19	-.35	.02	.35	-1.68	56.35	9.66	20.42	.79
.34000	-2.07	-.78	-.73	-.08	.74	-2.70	56.23	10.78	20.99	.87
.35000	-2.35	-1.00	-1.26	-.37	1.31	-3.70	55.70	11.68	21.56	.95
.36000	-2.13	-.97	-1.73	-.62	1.84	-4.70	54.81	12.38	22.12	1.03
.37000	-2.98	-1.26	-2.21	-.82	2.36	-5.73	53.69	12.98	22.67	1.11
.38000	-3.55	-1.44				-6.69	52.54	13.49	23.21	1.18
.39000	-2.52	-1.02				-7.74	51.57	14.21	23.74	1.25
.40000	-.92	-.04				-8.64	50.72	14.82	24.27	1.33

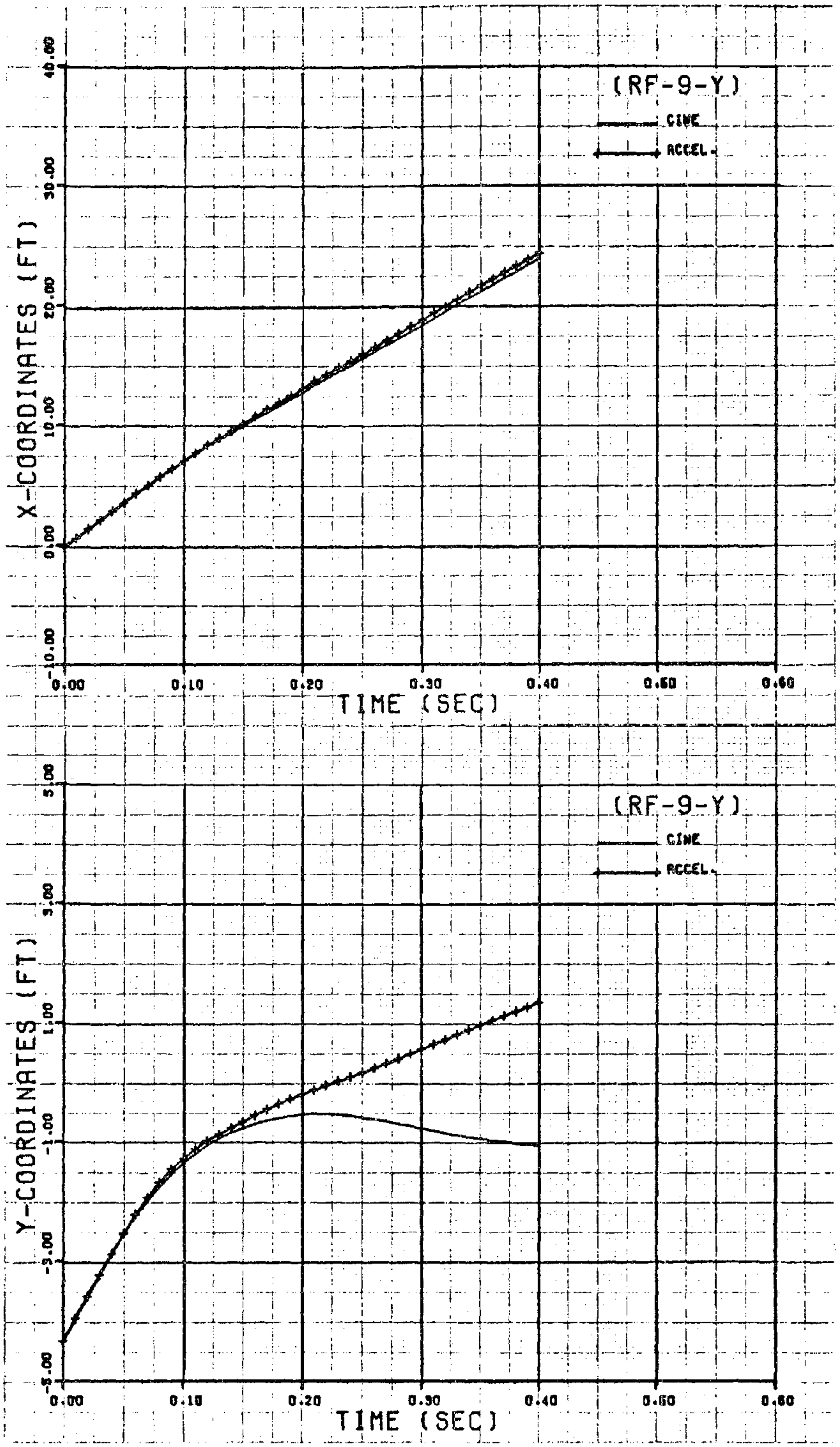


FIGURE B.21 VEHICLE X AND Y DISPLACEMENT HISTORIES FOR CRASH TEST RF-9

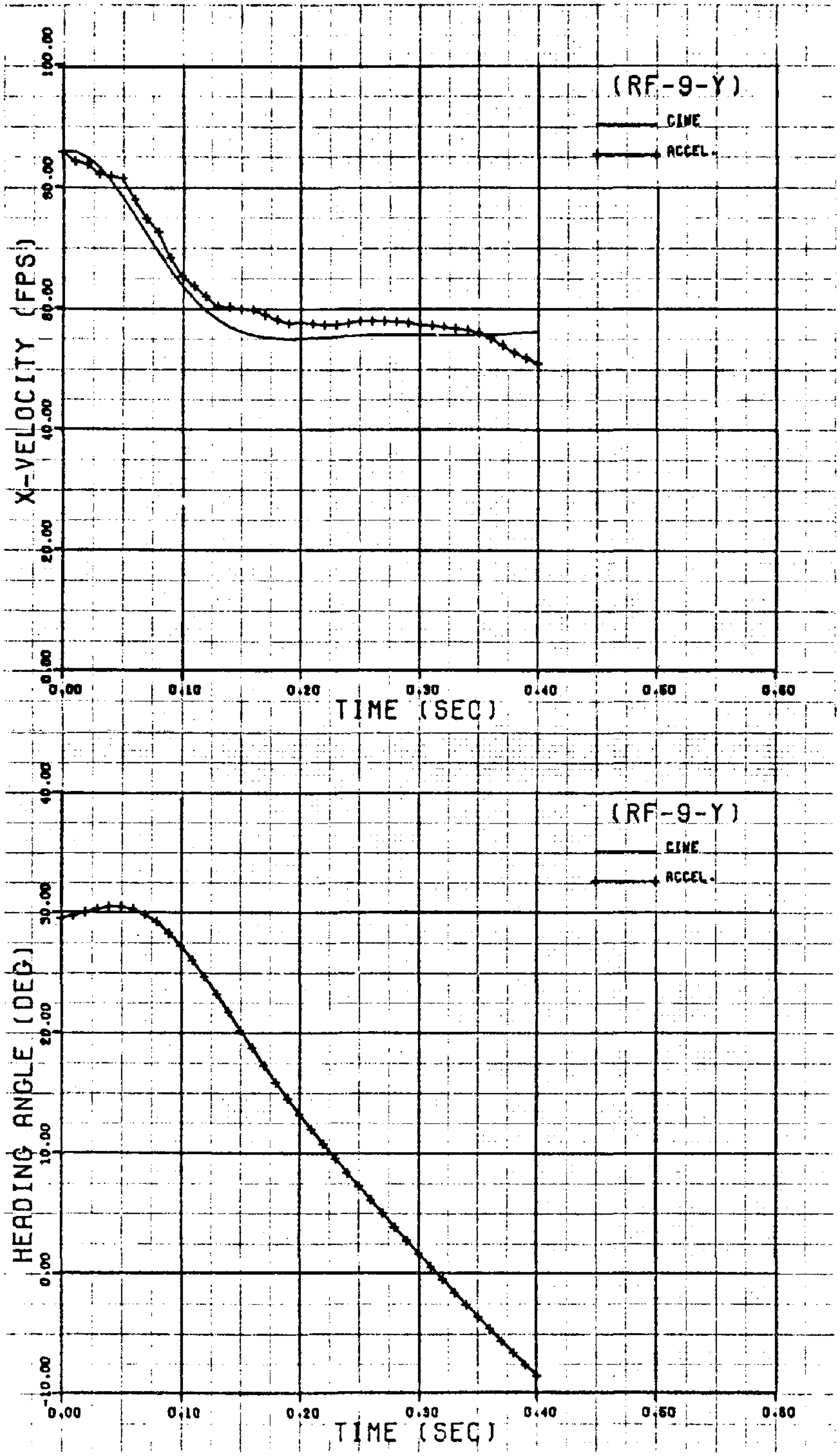
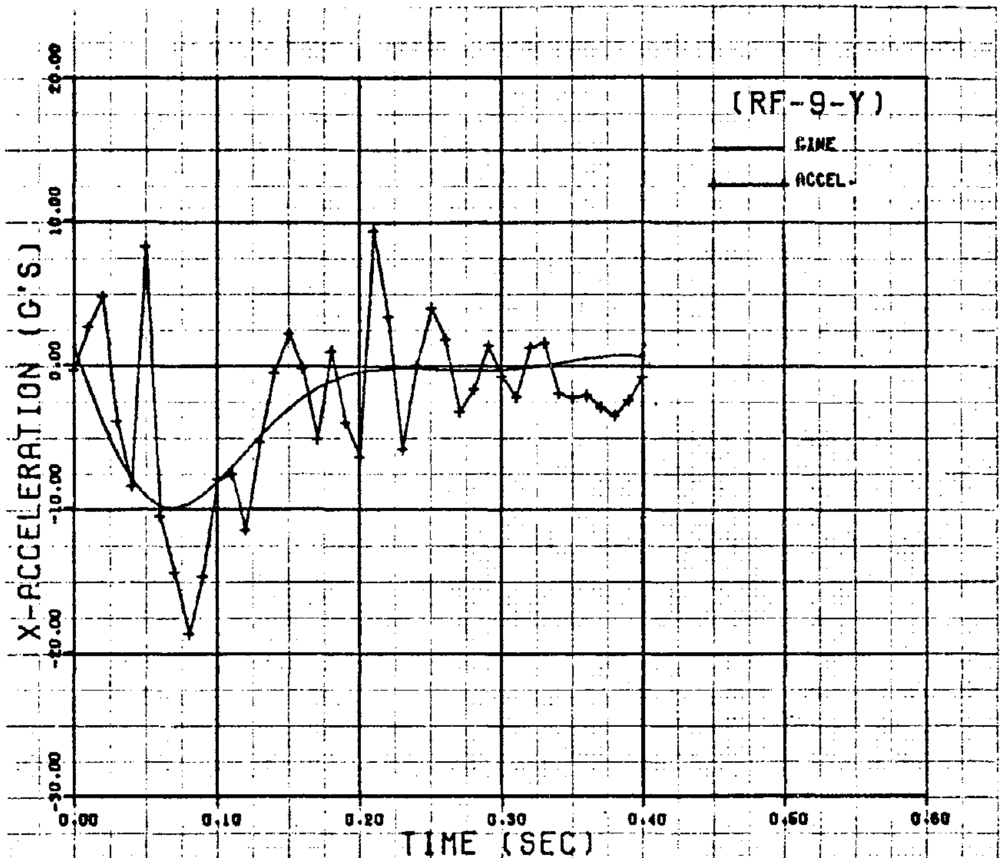


FIGURE B.22 VEHICLE X VELOCITY AND HEADING ANGLE HISTORIES FOR CRASH TEST RF-9



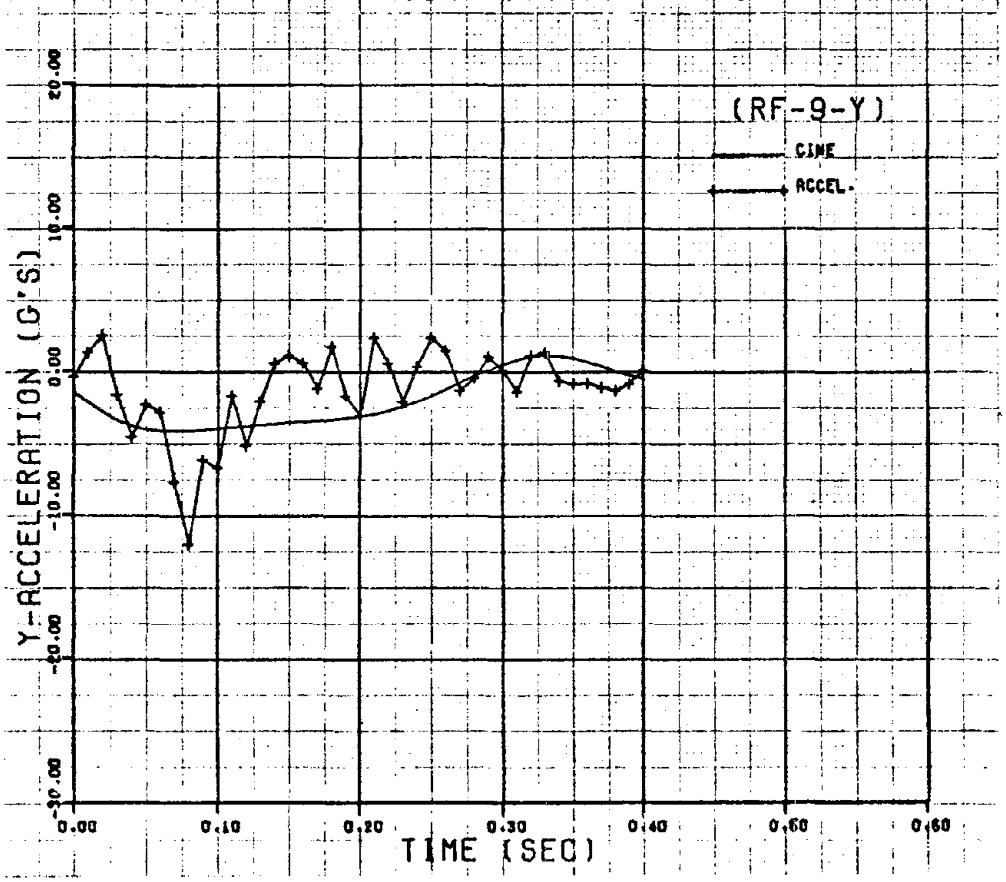


FIGURE B.23 VEHICLE X AND Y ACCELERATION HISTORIES FOR CRASH TEST RF-9

TABLE B.15

SUMMARY OF VEHICLE CINE DATA FOR CRASH TEST RF-10

TIME AFTER IMPACT(SEC)	VEHICLE C. G. COORDINATES(FT) X	Y	HEADING ANGLE (DEG)	VEHICLE VELOCITY (FT/SEC) LONG	LAT	VEHICLE ACCELERATION(G'S) AT TIME T LONG	LAT	AVERAGE OVER .05 SEC. LONG	LAT	APPROX. BARRIER FORCES(LB) X	Y
0.000	-18.80	-6.69	21.72	88.02	2.38	.70	-.08	1.03	.44	-2959	-815
.010	-17.99	-6.34	21.47	87.99	2.44	-.76	-1.88	-.97	-1.44	71	8813
.020	-17.18	-6.00	21.21	87.54	2.01	-1.91	-3.26	-1.66	-2.89	2627	16227
.030	-16.38	-5.67	20.91	86.77	1.24	-2.80	-4.28	-2.58	-3.98	4728	21762
.040	-15.57	-5.36	20.54	85.75	.29	-3.45	-5.02	-3.26	-4.76	6402	25718
.050	-14.77	-5.07	20.09	84.57	-.74	-3.90	-5.51	-3.73	-5.31	7682	28358
.060	-13.98	-4.79	19.55	83.28	-1.78	-4.16	-5.82	-4.03	-5.65	8604	29915
.070	-13.19	-4.54	18.91	81.94	-2.75	-4.28	-5.97	-4.17	-5.83	9206	30593
.080	-12.41	-4.31	18.16	80.60	-3.63	-4.27	-5.99	-4.18	-5.89	9527	30569
.090	-11.64	-4.11	17.33	79.30	-4.38	-4.16	-5.92	-4.09	-5.84	9607	29997
.100	-10.87	-3.93	16.40	78.07	-4.99	-3.97	-5.78	-3.92	-5.72	9483	29010
.110	-10.11	-3.76	15.39	76.92	-5.46	-3.73	-5.58	-3.68	-5.54	9192	27718
.120	-9.36	-3.62	14.32	75.87	-5.79	-3.44	-5.34	-3.41	-5.31	8770	26217
.130	-8.61	-3.50	13.20	74.92	-5.99	-3.14	-5.07	-3.12	-5.06	8247	24586
.140	-7.87	-3.40	12.04	74.09	-6.07	-2.82	-4.78	-2.81	-4.78	7654	22889
.150	-7.14	-3.31	10.86	73.36	-6.04	-2.50	-4.48	-2.50	-4.48	7017	21178
.160	-6.41	-3.24	9.67	72.73	-5.92	-2.19	-4.17	-2.19	-4.18	6358	19496
.170	-5.68	-3.18	8.49	72.19	-5.72	-1.90	-3.87	-1.91	-3.89	5698	17872
.180	-4.96	-3.14	7.34	71.73	-5.47	-1.63	-3.57	-1.64	-3.59	5053	16330
.190	-4.25	-3.11	6.21	71.35	-5.17	-1.38	-3.29	-1.40	-3.31	4437	14887
.200	-3.53	-3.09	5.14	71.04	-4.85	-1.16	-3.02	-1.18	-3.05	3861	13552
.210	-2.82	-3.08	4.11	70.78	-4.52	-.97	-2.77	-.98	-2.80	3332	12330
.220	-2.11	-3.07	3.16	70.57	-4.19	-.80	-2.54	-.81	-2.56	2855	11222
.230	-1.41	-3.08	2.27	70.40	-3.88	-.65	-2.33	-.67	-2.35	2434	10224
.240	-.70	-3.10	1.45	70.26	-3.60	-.53	-2.13	-.54	-2.15	2069	9331
.250	-.00	-3.12	.72	70.15	-3.35	-.43	-1.96	-.44	-1.98	1759	8535
.260	.70	-3.15	.06	70.06	-3.15	-.35	-1.80	-.36	-1.82	1502	7828
.270	1.40	-3.18	-.53	69.99	-2.99	-.28	-1.66	-.29	-1.67	1294	7199
.280	2.10	-3.22	-1.03	69.94	-2.88	-.23	-1.53	-.24	-1.54	1131	6638
.290	2.80	-3.26	-1.47	69.89	-2.82	-.19	-1.41	-.20	-1.43	1006	6134
.300	3.49	-3.31	-1.84	69.85	-2.81	-.17	-1.31	-.17	-1.32	915	5677
.310	4.19	-3.36	-2.15	69.82	-2.84	-.15	-1.21	-.15	-1.22	850	5257
.320	4.89	-3.42	-2.40	69.78	-2.91	-.14	-1.12	-.14	-1.13	807	4865
.330	5.58	-3.48	-2.61	69.75	-3.01	-.13	-1.04	-.13	-1.04	780	4494
.340	6.28	-3.54	-2.77	69.72	-3.13	-.13	-.96	-.13	-.96	763	4135
.350	6.97	-3.61	-2.90	69.68	-3.27	-.13	-.88	-.13	-.88	752	3783
.360	7.67	-3.68	-3.00	69.65	-3.42	-.13	-.80	-.13	-.80	742	3433
.370	8.36	-3.75	-3.08	69.61	-3.57	-.13	-.72	-.13	-.72	731	3081
.380	9.05	-3.82	-3.14	69.57	-3.70	-.13	-.63	-.13	-.63	716	2726
.390	9.75	-3.90	-3.20	69.53	-3.82	-.13	-.55	-.13	-.55	697	2366
.400	10.44	-3.98	-3.26	69.50	-3.92	-.13	-.47	-.13	-.47	672	2001
.410	11.13	-4.06	-3.31	69.46	-3.99	-.13	-.38	-.12	-.38	641	1633
.420	11.82	-4.14	-3.38	69.42	-4.02	-.12	-.30	-.12	-.30	606	1263
.430	12.51	-4.22	-3.45	69.39	-4.01	-.12	-.21	-.12	-.21	570	893

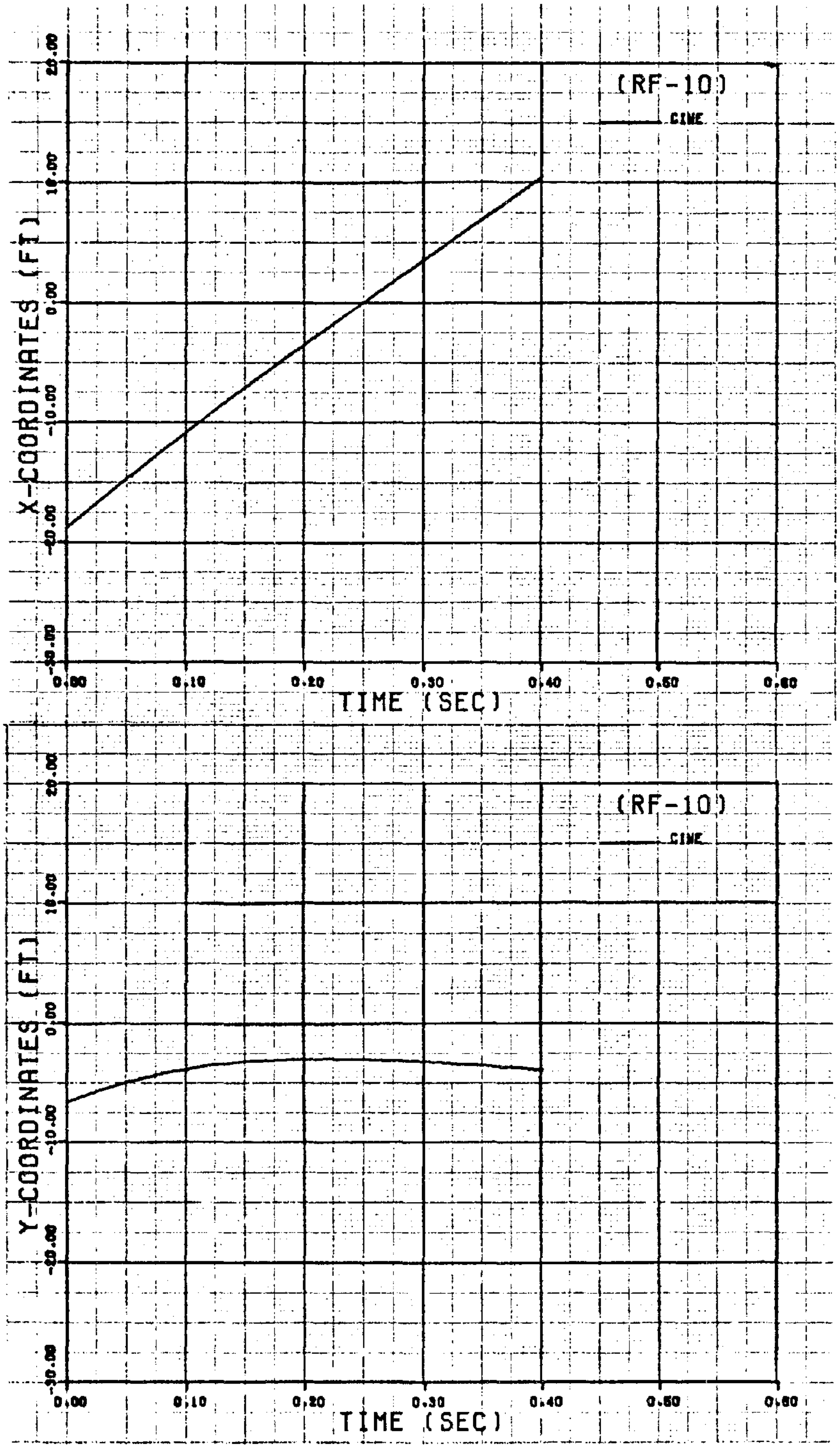
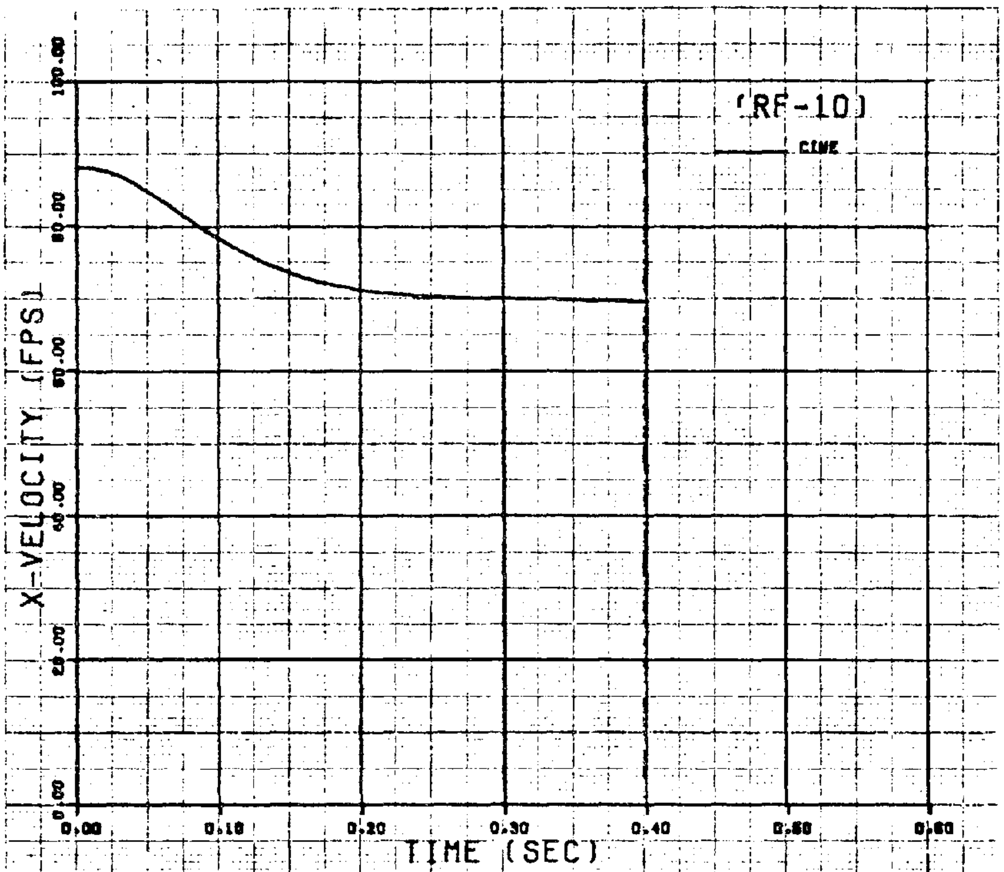


FIGURE B.24 VEHICLE X AND Y DISPLACEMENT HISTORIES FOR CRASH TEST RF-10



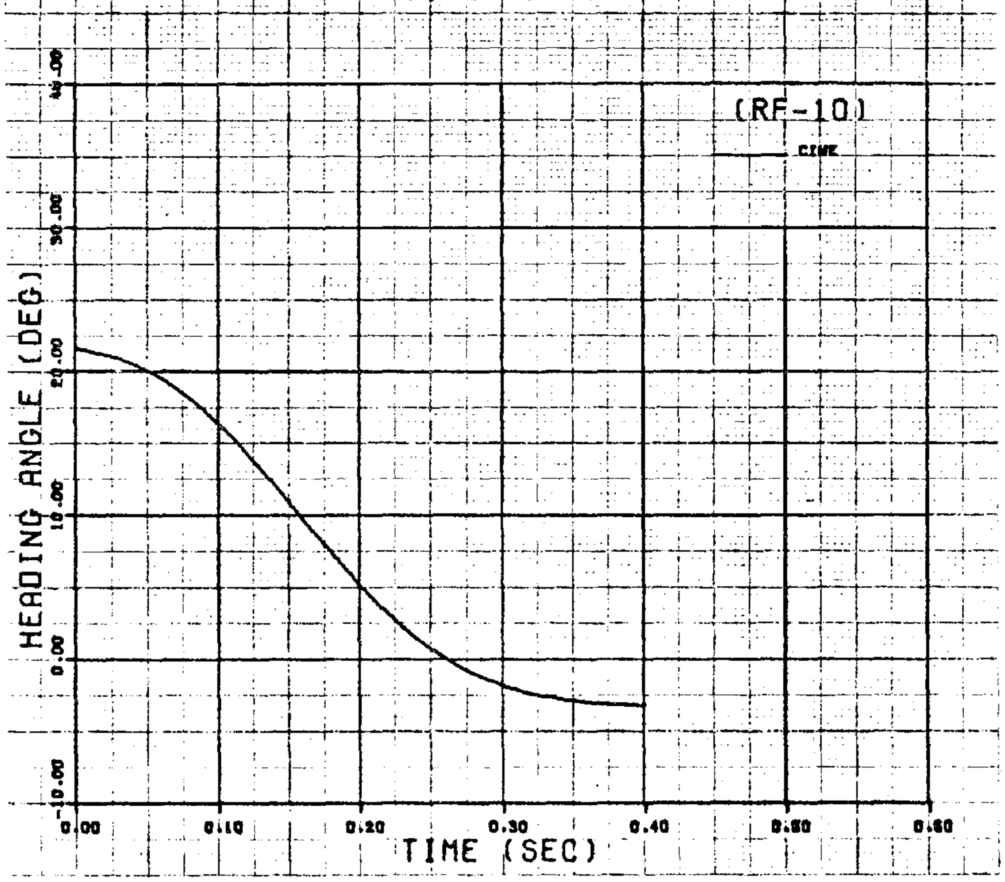


FIGURE B.25 VEHICLE X VELOCITY AND HEADING ANGLE HISTORIES FOR CRASH TEST RF-10

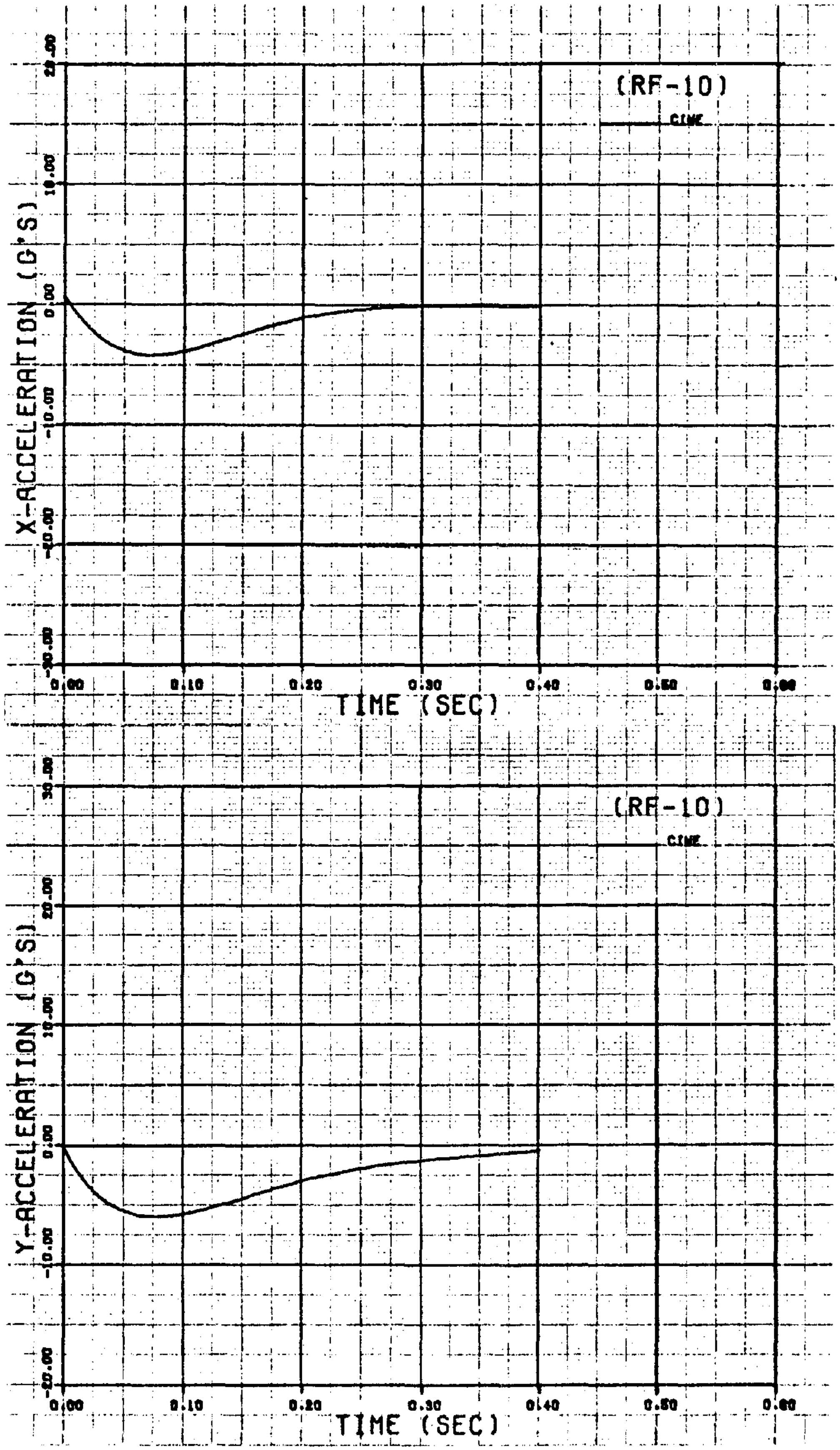


FIGURE B.26 VEHICLE X AND Y ACCELERATION HISTORIES FOR CRASH TEST RF-10

TABLE B.16

SUMMARY OF VEHICLE CINE DATA FOR CRASH TEST RF-11

TIME AFTER IMPACT (SEC)	VEHICLE C. G. COORDINATES (FT) X	Y	HEADING ANGLE (DEG)	VEHICLE VELOCITY (FT/SEC) LONG	LAT	VEHICLE ACCELERATION (G'S) AT TIME T LONG	LAT	AVERAGE OVER ,05 SEC. LONG	LAT	APPROX. BARRIER FORCES (LB) X	Y
0,000	-5,03	-4,39	15,05	94,60	-,97	-,31	,26	-,09	,02	757	-355
,010	-4,12	-4,16	15,60	94,30	-1,93	-1,44	-,62	-1,22	-,72	2505	2016
,020	-3,21	-3,93	15,99	93,67	-2,93	-2,36	-1,58	-2,15	-1,59	3760	4457
,030	-2,30	-3,70	16,15	92,78	-3,85	-3,07	-2,55	-2,86	-2,48	4589	6769
,040	-1,40	-3,48	16,01	91,72	-4,60	-3,56	-3,45	-3,37	-3,33	5059	8814
,050	-,51	-3,28	15,57	90,56	-5,14	-3,83	-4,25	-3,66	-4,10	5228	10503
,060	,37	-3,10	14,82	89,38	-5,45	-3,90	-4,92	-3,76	-4,75	5152	11791
,070	1,24	-2,93	13,80	88,24	-5,53	-3,79	-5,43	-3,67	-5,26	4881	12665
,080	2,11	-2,78	12,54	87,18	-5,42	-3,52	-5,78	-3,42	-5,62	4461	13136
,090	2,97	-2,66	11,11	86,24	-5,16	-3,13	-5,96	-3,06	-5,82	3933	13234
,100	3,82	-2,55	9,57	85,44	-4,78	-2,66	-5,98	-2,62	-5,86	3334	13005
,110	4,67	-2,47	7,98	84,79	-4,33	-2,15	-5,86	-2,13	-5,75	2698	12499
,120	5,51	-2,40	6,40	84,29	-3,84	-1,64	-5,60	-1,63	-5,52	2053	11774
,130	6,35	-2,36	4,88	83,94	-3,35	-1,14	-5,23	-1,16	-5,18	1424	10888
,140	7,19	-2,33	3,45	83,72	-2,88	-,70	-4,79	-,72	-4,77	832	9896
,150	8,03	-2,31	2,16	83,62	-2,47	-,31	-4,31	-,34	-4,30	295	8851
,160	8,87	-2,31	1,03	83,63	-2,11	,02	-3,81	-,02	-3,82	-174	7799
,170	9,70	-2,32	,05	83,71	-1,83	,27	-3,31	,23	-3,34	-564	6781
,180	10,54	-2,35	-,77	83,85	-1,63	,46	-2,84	,42	-2,88	-868	5829
,190	11,38	-2,38	-1,43	84,04	-1,49	,59	-2,41	,55	-2,46	-1083	4970
,200	12,22	-2,42	-1,96	84,26	-1,43	,66	-2,04	,62	-2,10	-1207	4220
,210	13,06	-2,46	-2,38	84,48	-1,42	,68	-1,72	,64	-1,79	-1242	3589
,220	13,91	-2,52	-2,71	84,71	-1,45	,65	-1,47	,62	-1,53	-1192	3082
,230	14,75	-2,57	-2,97	84,91	-1,50	,59	-1,29	,56	-1,34	-1065	2695
,240	15,60	-2,63	-3,19	85,09	-1,56	,49	-1,15	,46	-1,20	-868	2419
,250	16,45	-2,70	-3,39	85,24	-1,62	,36	-1,07	,34	-1,12	-612	2242
,260	17,30	-2,77	-3,59	85,34	-1,66	,22	-1,04	,20	-1,07	-309	2147
,270	18,15	-2,84	-3,80	85,39	-1,68	,06	-1,03	,05	-1,05	27	2115
,280	19,00	-2,91	-4,03	85,38	-1,68	-,11	-1,05	-,11	-1,06	383	2126
,290	19,85	-2,99	-4,28	85,33	-1,64	-,28	-1,08	-,28	-1,08	743	2158
,300	20,70	-3,07	-4,56	85,22	-1,58	-,45	-1,11	-,44	-1,10	1093	2193
,310	21,55	-3,16	-4,86	85,06	-1,49	-,60	-1,13	-,58	-1,12	1419	2211
,320	22,39	-3,25	-5,18	84,85	-1,39	-,73	-1,14	-,71	-1,12	1706	2197
,330	23,24	-3,34	-5,51	84,60	-1,27	-,84	-1,13	-,81	-1,10	1941	2137
,340	24,08	-3,44	-5,85	84,33	-1,13	-,92	-1,09	-,89	-1,05	2113	2023
,350	24,91	-3,54	-6,18	84,02	-,98	-,98	-1,01	-,94	-,98	2213	1849
,360	25,74	-3,64	-6,52	83,71	-,80	-,99	-,91	-,96	-,87	2235	1615
,370	26,57	-3,74	-6,84	83,40	-,59	-,98	-,77	-,94	-,74	2175	1324
,380	27,40	-3,85	-7,16	83,09	-,35	-,92	-,60	-,89	-,58	2035	986
,390	28,22	-3,95	-7,48	82,81	-,05	-,84	-,41	-,81	-,40	1819	612
,400	29,04	-4,06	-7,79	82,56	,29	-,73	-,21	-,71	-,20	1538	217
,410	29,86	-4,17	-8,10	82,34	,70	-,60	,00	-,58	-,00	1209	-179
,420	30,67	-4,28	-8,40	82,16	1,17	-,45	,21	-,45	,19	854	-558
,430	31,49	-4,39	-8,69	82,04	1,69	-,31	,40	-,33	,36	506	-897
,440	32,30	-4,50	-8,96	81,95	2,23	-,19	,55	-,23	,51	204	-1179

TABLE B. 17

SUMMARY OF VEHICLE ACCELEROMETER DATA FOR CRASH TEST RF-11

TIME	DISPLACEMENT - FT		HEADING	VELOCITY - FPS		VEHICLE ACCELERATION G'S						
						AT TIME T			AVERAGE OVER .05 SEC.			
(SEC)	X	Y	ANGLE (DEG).	X	Y	X	Y	Z	X	Y	R	Z
.00000	-5.03	-4.39	15.05	94.60	-.97	1.03	.24	.43				
.01000	-4.11	-4.15	15.10	94.38	-1.47	.35	-3.41	-1.16				
.02000	-3.20	-3.93	15.00	94.06	-1.56	-2.15	5.26	-2.70				
.03000	-2.29	-3.70	14.91	93.25	-2.94	-4.63	-16.51	-12.30	-3.18	-4.92	5.86	-.72
.04000	-1.38	-3.51	14.59	91.70	-5.97	-1.85	-6.55	-10.09	-4.47	-7.79	8.98	-2.66
.05000	-.49	-3.35	14.03	89.61	-7.22	-7.30	-11.74	-14.42	-5.64	-9.88	11.37	-2.51
.06000	.40	-3.23	13.17	87.44	-10.90	-5.96	-18.59	-6.96	-6.23	-10.49	12.20	-2.90
.07000	1.27	-3.16	11.98	85.47	-12.74	-6.12	-8.82	-7.91	-5.87	-9.76	11.39	-2.16
.08000	2.13	-3.12	10.66	83.99	-13.37	-2.98	-10.08	-1.30	-4.86	-8.64	9.91	-2.22
.09000	2.99	-3.11	9.20	83.34	-13.57	-1.88	-7.87	-10.73	-3.53	-5.42	6.47	.18
.10000	3.83	-3.12	7.62	83.14	-11.66	.26	-1.16	-6.00	-2.29	-3.13	3.88	.48
.11000	4.68	-3.13	5.99	83.28	-9.17	1.20	.71	-5.37	-.99	-1.50	1.80	1.07
.12000	5.52	-3.13	4.31	83.27	-6.63	2.15	-2.80	-.13	-.14	-1.15	1.16	.50
.13000	6.37	-3.14	2.62	83.77	-4.13	-1.25	1.46	10.06	.64	-2.15	2.25	.89
.14000	7.21	-3.15	.84	84.24	-3.27	1.97	-2.35	5.31	.90	-4.25	4.35	-.10
.15000	8.07	-3.18	-.49	85.03	-3.23	1.72	-12.37	-1.71	1.03	-4.96	5.07	-.06
.16000	8.93	-3.24	-1.14	85.34	-5.54	.57	-6.57	-1.06	.94	-4.79	4.88	-.14
.17000	9.79	-3.32	-1.46	85.36	-6.14	-.13	-.55	.84	.89	-3.68	3.78	.70
.18000	10.65	-3.40	-1.76	85.56	-5.39	1.40	1.48	.82	.26	-2.37	2.38	.45
.19000	11.51	-3.48	-2.06	85.87	-4.89	2.80	-3.54	-3.53	.04	-.61	.61	1.35
.20000	12.38	-3.56	-2.35	85.62	-4.31	-1.46	-2.15	.82	-.06	-.10	.12	1.83
.21000	13.24	-3.64	-2.59	85.54	-4.39	-.96	.96	4.05	-.13	-.52	.54	1.42
.22000	14.10	-3.73	-2.85	85.39	-4.22	-.73	-1.86	7.23	-.36	-.55	.66	.87
.23000	14.96	-3.82	-3.11	85.46	-4.20	1.03	.18	.88	-.23	-.64	.68	.60
.24000	15.83	-3.91	-3.43	85.42	-3.75	-1.27	1.35	-1.78	-.28	-.31	.42	.49
.25000	16.69	-4.00	-3.72	85.36	-3.32	-3.05	3.69	9.71	-.28	-.16	.33	.02
.26000	17.54	-4.09	-4.04	85.19	-2.73	-2.34	.92	3.27	-.35	.10	.37	.30
.27000	18.40	-4.17	-4.38	85.01	-2.20	.45	-1.50	.28	-.22	.04	.22	.03
.28000	19.25	-4.26	-4.62	84.97	-1.80	1.93	3.82	4.89	-.10	-.09	.13	.55
.29000	20.11	-4.35	-4.80	85.12	-1.65	-1.15	1.56	3.47	-.05	-.21	.21	.27
.30000	20.97	-4.44	-5.06	85.25	-1.45	-.90	-1.44	-2.43	.00	-.15	.15	.32
.31000	21.83	-4.53	-5.33	85.15	-1.15	-.61	.00	-.59	-.09	-.13	.16	.09
.32000	22.68	-4.62	-5.61	85.05	-.62	.17	-.30	-.64	-.31	-.16	.35	.39
.33000	23.54	-4.71	-5.86	84.85	-.15	-1.03	-1.73	-.03	-.49	-.06	.50	.51
.34000	24.39	-4.80	-6.08	84.63	.00	.04	-2.26	3.36	-.44	-.11	.45	.51
.35000	25.24	-4.89	-6.29	84.46	.25	-.17	.50	-.56	-.38	-.32	.50	.33
.36000	26.09	-4.99	-6.47	84.44	.35	-.07	.63	-4.26	-.38	-.44	.58	.20
.37000	26.94	-5.08	-6.64	84.44	.38	-1.25	.92	-.51	-.39	-.37	.54	.01
.38000	27.79	-5.18	-6.82	84.24	.56	-1.28	-1.90	-8.74				
.39000	28.63	-5.27	-7.01	84.00	.78	-.90	-.41	-3.55				
.40000	29.48	-5.37	-7.19	83.79	.85	.31	.04	1.29				

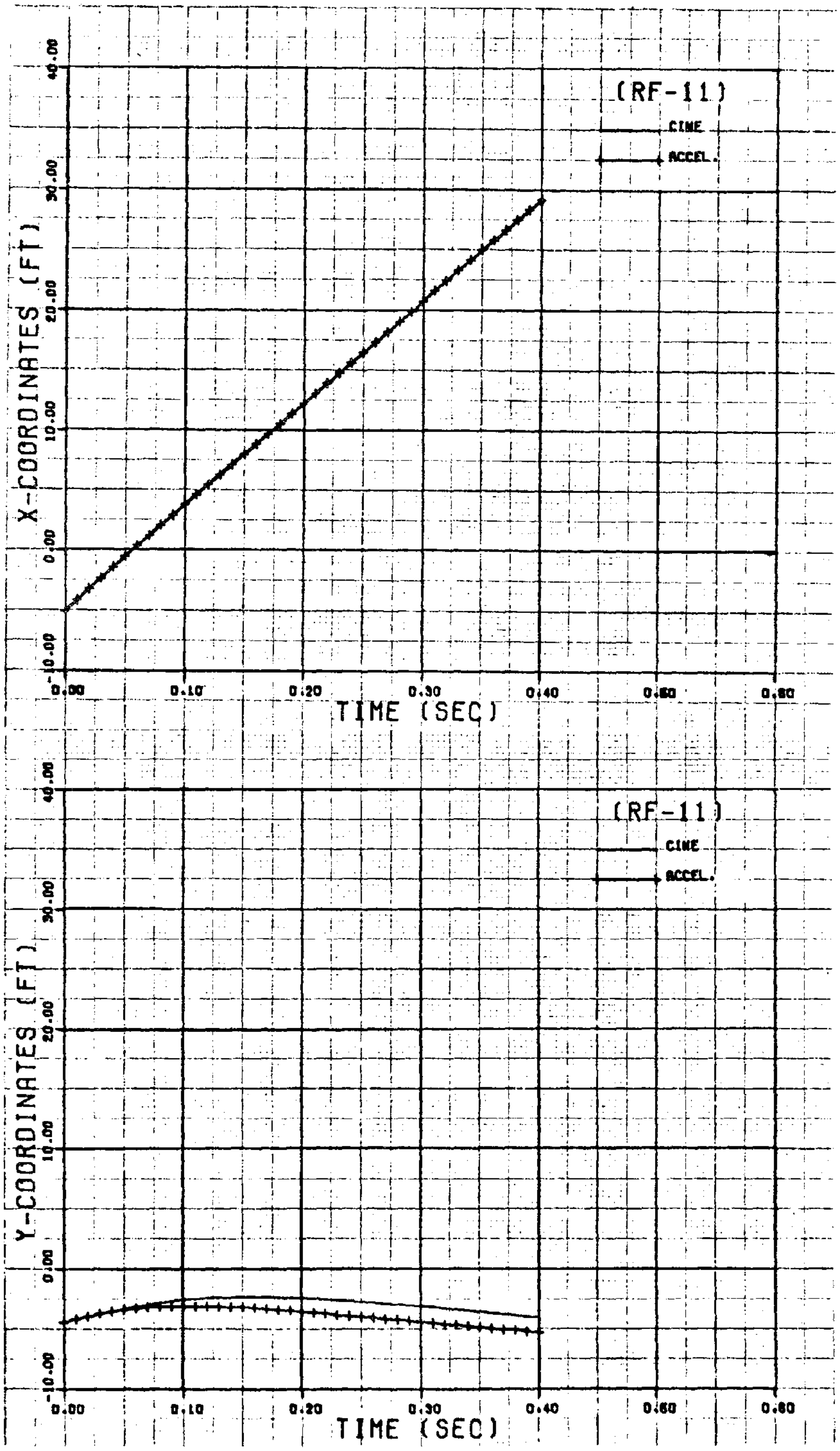
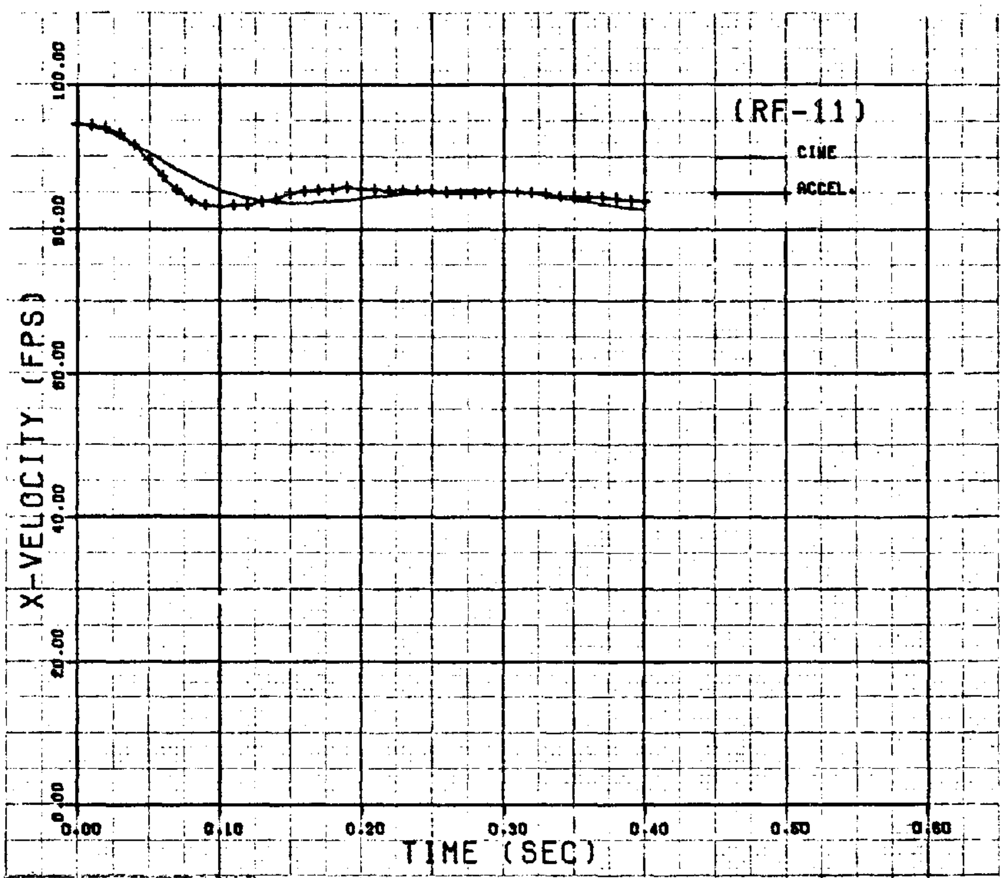


FIGURE B.27 VEHICLE X AND Y DISPLACEMENT HISTORIES FOR CRASH TEST RF-11



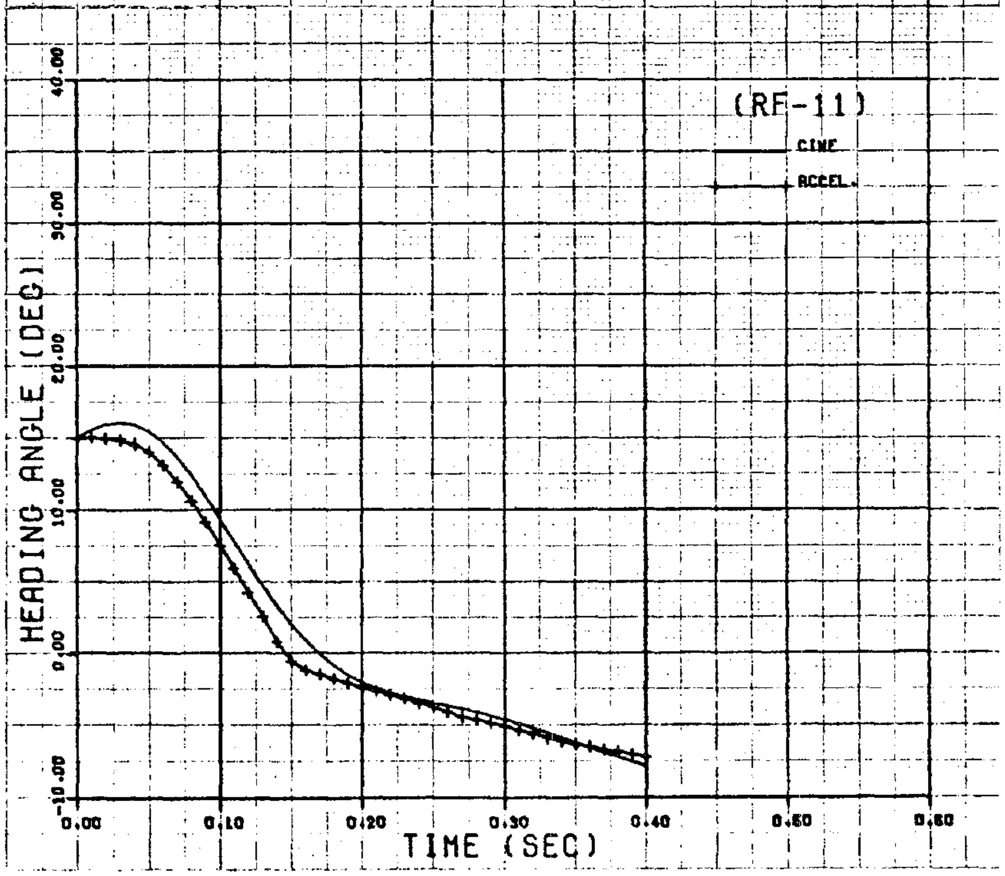


FIGURE B.28 VEHICLE X VELOCITY AND HEADING ANGLE HISTORIES FOR CRASH TEST RF-11

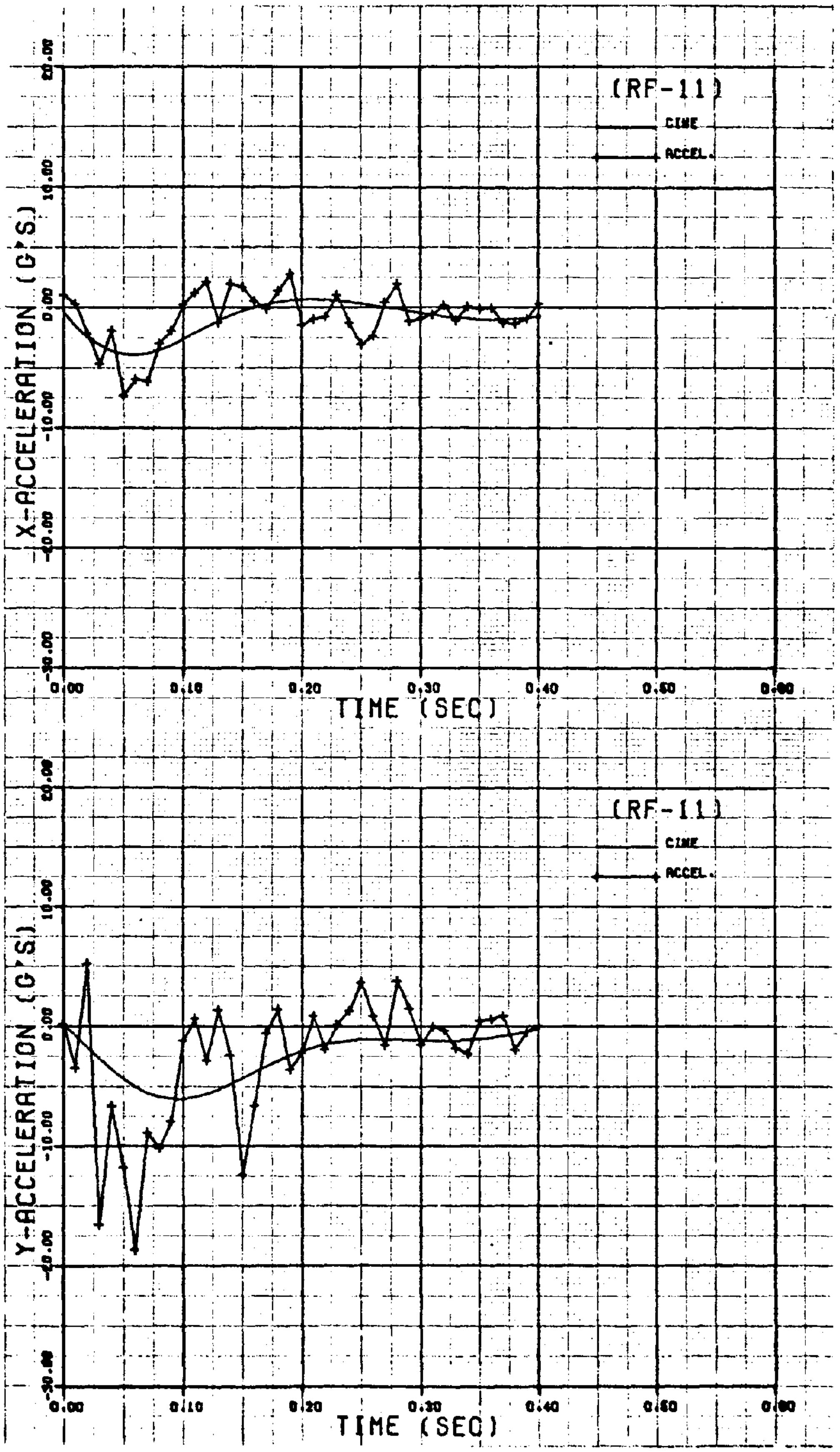


FIGURE B.29 VEHICLE X AND Y ACCELERATION HISTORIES FOR CRASH TEST RF-11

TABLE B.18

SUMMARY OF VEHICLE CINE DATA FOR CRASH TEST RF-12

TIME AFTER IMPACT(SEC)	VEHICLE C. G. COORDINATES(FT) X	Y	HEADING ANGLE (DEG)	VEHICLE VELOCITY (FT/SEC) LONG	LAT	VEHICLE ACCELERATION(G'S) AT TIME T LONG	LAT	AVERAGE OVER .05 SEC. LONG	LAT	APPROX. BARRIER FORCES(LB) X	Y
0.000	-26.17	-5.99	19.87	116.77	2.00	.59	-.40	1.20	-1.07	-3066	773
.010	-25.08	-5.58	19.76	116.73	2.08	-.71	-.57	-.28	-1.02	2114	3431
.020	-23.99	-5.17	19.76	116.35	1.82	-1.59	-1.19	-1.30	-1.47	4857	7317
.030	-22.90	-4.76	19.84	115.73	1.13	-2.19	-2.07	-2.01	-2.22	6013	11923
.040	-21.82	-4.36	19.97	114.96	.03	-2.63	-3.10	-2.52	-3.13	6233	16842
.050	-20.74	-3.97	20.12	114.05	-1.42	-2.97	-4.15	-2.92	-4.11	6002	21749
.060	-19.67	-3.60	20.22	113.05	-3.12	-3.27	-5.16	-3.26	-5.06	5675	26396
.070	-18.60	-3.25	20.23	111.95	-4.97	-3.56	-6.06	-3.57	-5.92	5490	30598
.080	-17.53	-2.92	20.13	110.76	-6.84	-3.85	-6.83	-3.88	-6.67	5595	34226
.090	-16.47	-2.62	19.87	109.51	-8.65	-4.15	-7.44	-4.17	-7.27	6064	37199
.100	-15.42	-2.34	19.44	108.20	-10.31	-4.45	-7.89	-4.47	-7.72	6917	39472
.110	-14.36	-2.09	18.83	106.84	-11.75	-4.73	-8.19	-4.75	-8.02	8127	41034
.120	-13.32	-1.88	18.03	105.45	-12.93	-5.00	-8.33	-5.01	-8.18	9638	41902
.130	-12.28	-1.69	17.04	104.02	-13.82	-5.25	-8.35	-5.24	-8.21	11374	42109
.140	-11.25	-1.53	15.89	102.58	-14.42	-5.46	-8.25	-5.44	-8.13	13247	41708
.150	-10.23	-1.40	14.60	101.13	-14.75	-5.64	-8.05	-5.60	-7.95	15164	40761
.160	-9.22	-1.31	13.18	99.65	-14.81	-5.78	-7.78	-5.73	-7.70	17035	39338
.170	-8.22	-1.24	11.67	98.16	-14.65	-5.87	-7.45	-5.81	-7.39	18773	37514
.180	-7.24	-1.20	10.09	96.66	-14.31	-5.92	-7.07	-5.85	-7.02	20305	35366
.190	-6.27	-1.18	8.48	95.15	-13.83	-5.92	-6.65	-5.85	-6.62	21566	32969
.200	-5.31	-1.19	6.87	93.63	-13.25	-5.87	-6.21	-5.79	-6.20	22507	30398
.210	-4.38	-1.22	5.29	92.11	-12.61	-5.78	-5.76	-5.69	-5.76	23094	27721
.220	-3.46	-1.27	3.76	90.60	-11.95	-5.63	-5.30	-5.54	-5.30	23308	25004
.230	-2.55	-1.34	2.30	89.12	-11.29	-5.43	-4.83	-5.35	-4.85	23142	22303
.240	-1.67	-1.42	.94	87.67	-10.67	-5.18	-4.36	-5.11	-4.39	22608	19670
.250	-.80	-.52	-.32	86.27	-10.10	-4.89	-3.90	-4.82	-3.94	21726	17150
.260	.06	-1.63	-1.46	84.95	-9.58	-4.55	-3.46	-4.49	-3.50	20528	14778
.270	.90	-1.76	-2.47	83.70	-9.14	-4.18	-3.03	-4.13	-3.07	19057	12584
.280	1.72	-1.89	-3.35	82.56	-8.76	-3.78	-2.62	-3.74	-2.67	17363	10591
.290	2.54	-2.03	-4.11	81.52	-8.46	-3.35	-2.24	-3.32	-2.29	15500	8812
.300	3.34	-2.17	-4.75	80.61	-8.22	-2.91	-1.89	-2.90	-1.94	13527	7256
.310	4.13	-2.32	-5.28	79.82	-8.03	-2.47	-1.57	-2.46	-1.62	11502	5925
.320	4.91	-2.48	-5.71	79.15	-7.90	-2.03	-1.30	-2.04	-1.35	9485	4817
.330	5.69	-2.64	-6.05	78.62	-7.81	-1.60	-1.06	-1.62	-1.11	7533	3924
.340	6.46	-2.80	-6.32	78.20	-7.75	-1.20	-.87	-1.23	-.91	5696	3232
.350	7.23	-2.96	-6.52	77.91	-7.72	-.83	-.72	-.87	-.76	4022	2727
.360	7.99	-3.13	-6.69	77.71	-7.71	-.51	-.60	-.56	-.64	2549	2390
.370	8.75	-3.30	-6.82	77.61	-7.71	-.23	-.53	-.29	-.56	1309	2200
.380	9.52	-3.47	-6.94	77.59	-7.71	-.01	-.49	-.07	-.52	323	2136
.390	10.28	-3.64	-7.05	77.63	-7.71	.15	-.48	.09	-.50	-395	2176
.400	11.04	-3.81	-7.17	77.71	-7.71	.25	-.49	.20	-.51	-843	2295
.410	11.80	-3.99	-7.31	77.82	-7.69	.30	-.53	.25	-.54	-1028	2473
.420	12.56	-4.16	-7.46	77.94	-7.65	.30	-.57	.25	-.58	-965	2687
.430	13.33	-4.34	-7.64	78.05	-7.60	.24	-.63	.20	-.64	-678	2918
.440	14.09	-4.52	-7.85	78.14	-7.53	.14	-.70	.11	-.70	-201	3147
.450	14.85	-4.70	-8.09	78.20	-7.45	.01	-.77	-.01	-.76	427	3358

TABLE B.19

SUMMARY OF VEHICLE ACCELEROMETER DATA FOR CRASH TEST RF-12

TIME (SEC)	DISPLACEMENT - FT X	DISPLACEMENT - FT Y	HEADING ANGLE (DEG).	VELOCITY - FPS X	VELOCITY - FPS Y	VEHICLE ACCELERATION G'S AT TIME X	AT TIME Y	AT TIME Z	AVERAGE OVER 0.05 SEC. X	AVERAGE Y	AVERAGE R	AVERAGE Z
.00000	-26.17	-5.99	19.87	116.77	2.00	.25	-.39	-.71				
.01000	-25.08	-5.57	19.86	116.72	1.98	-.56	-.42	-.29				
.02000	-23.99	-5.16	19.90	116.25	1.70	-2.36	-2.19	2.18				
.03000	-22.90	-4.76	19.83	115.35	.68	-1.68	-5.07	-3.89	-1.90	-2.49	3.13	-.50
.04000	-21.82	-4.36	19.70	114.90	-.37	-3.05	-4.61	-1.52	-2.47	-2.70	3.66	-.16
.05000	-20.74	-3.99	19.35	113.75	-.96	-7.18	-2.92	-.87	-3.34	-3.67	4.97	.69
.06000	-19.66	-3.62	19.20	112.78	-1.03	-7.40	-3.01	13.73	-3.91	-5.59	6.82	-.53
.07000	-18.60	-3.28	19.08	110.88	-2.57	-4.56	-5.72	-.87	-4.91	-6.83	8.41	-.53
.08000	-17.54	-2.96	18.70	109.09	-6.07	-.81	-12.43	2.33	-5.29	-7.27	8.99	-1.39
.09000	-16.50	-2.69	17.96	107.14	-8.00	-5.10	-4.28	-5.96	-6.07	-8.72	10.63	-2.51
.10000	-15.46	-2.44	17.38	105.44	-8.91	-5.03	-4.74	-7.35	-5.88	-9.07	10.81	-2.30
.11000	-14.43	-2.23	16.23	103.41	-9.54	-9.30	-3.56	13.27	-6.04	-8.04	10.05	-1.59
.12000	-13.41	-2.04	15.05	102.00	-9.71	-4.33	-16.73	-16.87	-6.62	-7.41	9.93	-1.77
.13000	-12.41	-1.89	13.58	100.21	-9.76	-8.74	-5.50	.88	-7.64	-6.96	10.34	-2.31
.14000	-11.42	-1.76	11.97	97.54	-9.30	-18.72	-.12	-11.98	-6.86	-7.58	10.22	.19
.15000	-10.47	-1.66	9.81	94.31	-6.93	3.55	-3.05	2.52	-7.26	-6.14	9.51	-2.54
.16000	-9.52	-1.59	9.03	93.45	-9.38	2.77	-1.94	-16.78	-6.61	-4.49	8.00	-2.35
.17000	-8.60	-1.54	7.03	91.52	-6.17	-7.17	-.28	-7.14	-5.19	-3.06	6.03	-1.41
.18000	-7.69	-1.49	5.71	90.60	-4.02	.55	.28	9.95	-3.98	-2.25	4.57	.30
.19000	-6.78	-1.44	4.17	89.99	-1.58	-2.68	.17	.21	-4.93	.09	4.93	-.15
.20000	-5.89	-1.39	2.41	88.51	1.21	-6.57	.60	-1.63	-5.23	.13	5.23	-.81
.21000	-5.02	-1.34	.85	85.95	3.62	-4.11	.37	4.48	-5.12	.09	5.12	-2.43
.22000	-4.17	-1.29	-.88	83.13	6.23	-16.56	-.56	-12.68	-3.79	.11	3.80	-1.87
.23000	-3.35	-1.24	-1.56	82.14	7.20	2.21	.17	-14.34	-4.07	.13	4.08	-2.51
.24000	-2.52	-1.19	-2.79	83.38	9.02	6.85	.37	-7.46	-2.47	.16	2.48	-3.86
.25000	-1.69	-1.14	-3.37	81.41	9.96	-12.43	.34	-19.37	-1.33	.23	1.35	-2.21
.26000	-.88	-1.09	-3.47	81.43	10.18	.44	.26	14.23	-1.46	.23	1.47	1.21
.27000	-.06	-1.04	-3.50	80.64	10.37	-25.58	2.59	27.19	-2.37	.15	2.38	-1.42
.28000	.74	-.98	-4.28	79.40	11.45	-10.31	-.50	-22.86	-.98	.17	1.00	-2.31
.29000	1.54	-.93	-5.29	79.07	12.78	9.60	-.14	-28.05	-1.24	.15	1.25	-2.62
.30000	2.34	-.87	-5.15	79.44	12.70	-3.83	.87	-2.09	-.41	.12	.43	-1.64
.31000	3.14	-.82	-5.80	78.94	13.64	2.83	.26	-3.25	.12	.16	.20	-2.20
.32000	3.94	-.76	-5.63	79.43	13.52	.83	.52	2.59	-.06	.22	.23	-.95
.33000	4.74	-.70	-6.06	79.16	14.17	.86	.26	2.93	-.29	.19	.35	1.65
.34000	5.54	-.64	-6.04	78.83	14.16	-.52	.06	-.22	-.08	.18	.20	2.87
.35000	6.34	-.59	-6.20	78.71	14.45	-1.18	.43	6.71	-.57	.17	.60	2.19
.36000	7.14	-.53	-6.48	78.65	14.86	-.87	.19	-.32	-.70	.18	.72	1.42
.37000	7.93	-.47	-6.68	78.25	15.24	-.62	.16	-2.58	-.54	.19	.57	1.32
.38000	8.73	-.41	-6.95	77.81	15.68	-.54	.34	.07				
.39000	9.52	-.35	-7.11	77.69	15.94	-.12	.37	-.96				
.40000	10.31	-.28	-7.37	77.49	16.40	-.07	.26	-3.78				

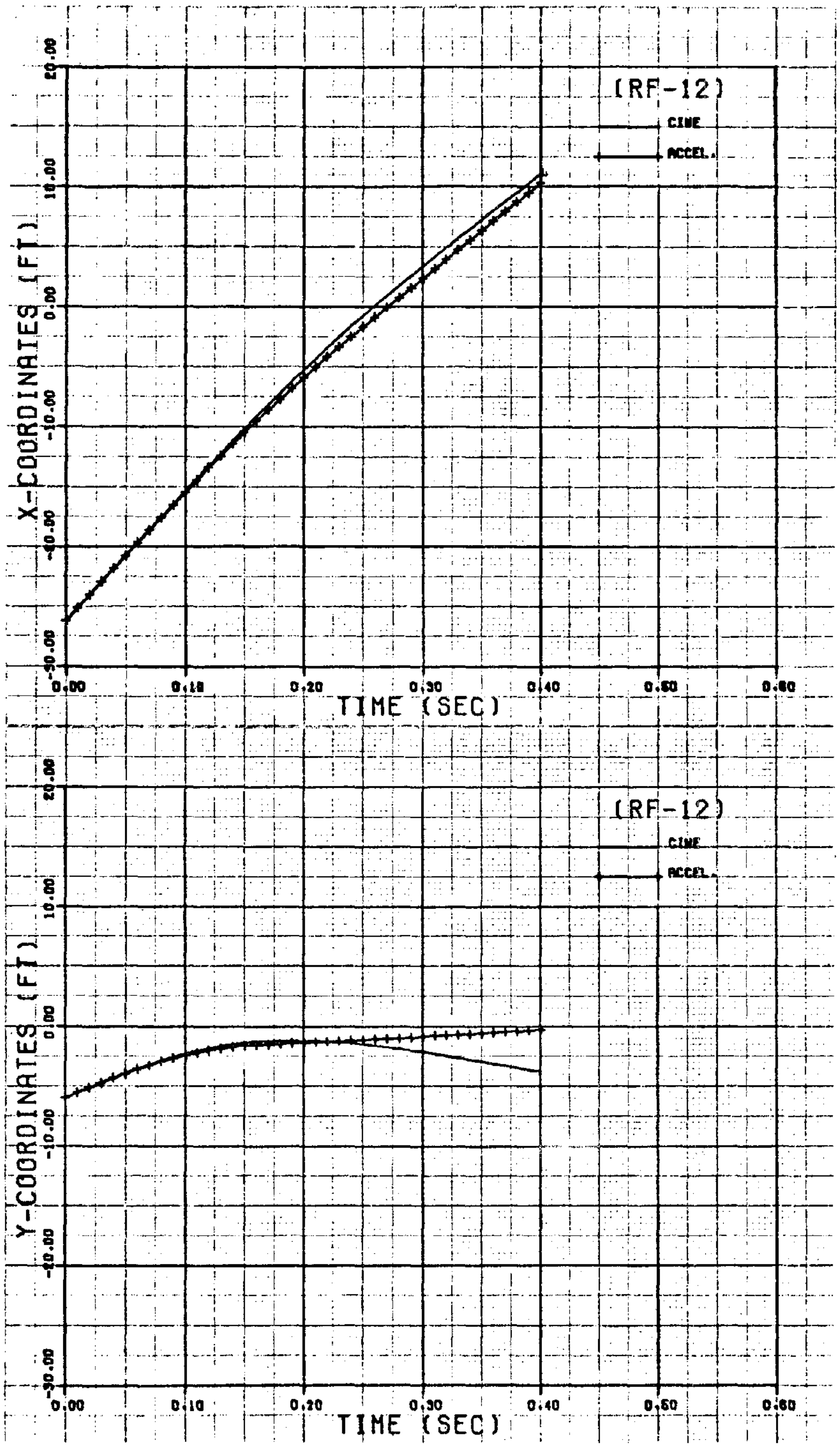


FIGURE B.30 VEHICLE X AND Y DISPLACEMENT HISTORIES FOR CRASH TEST RF-12

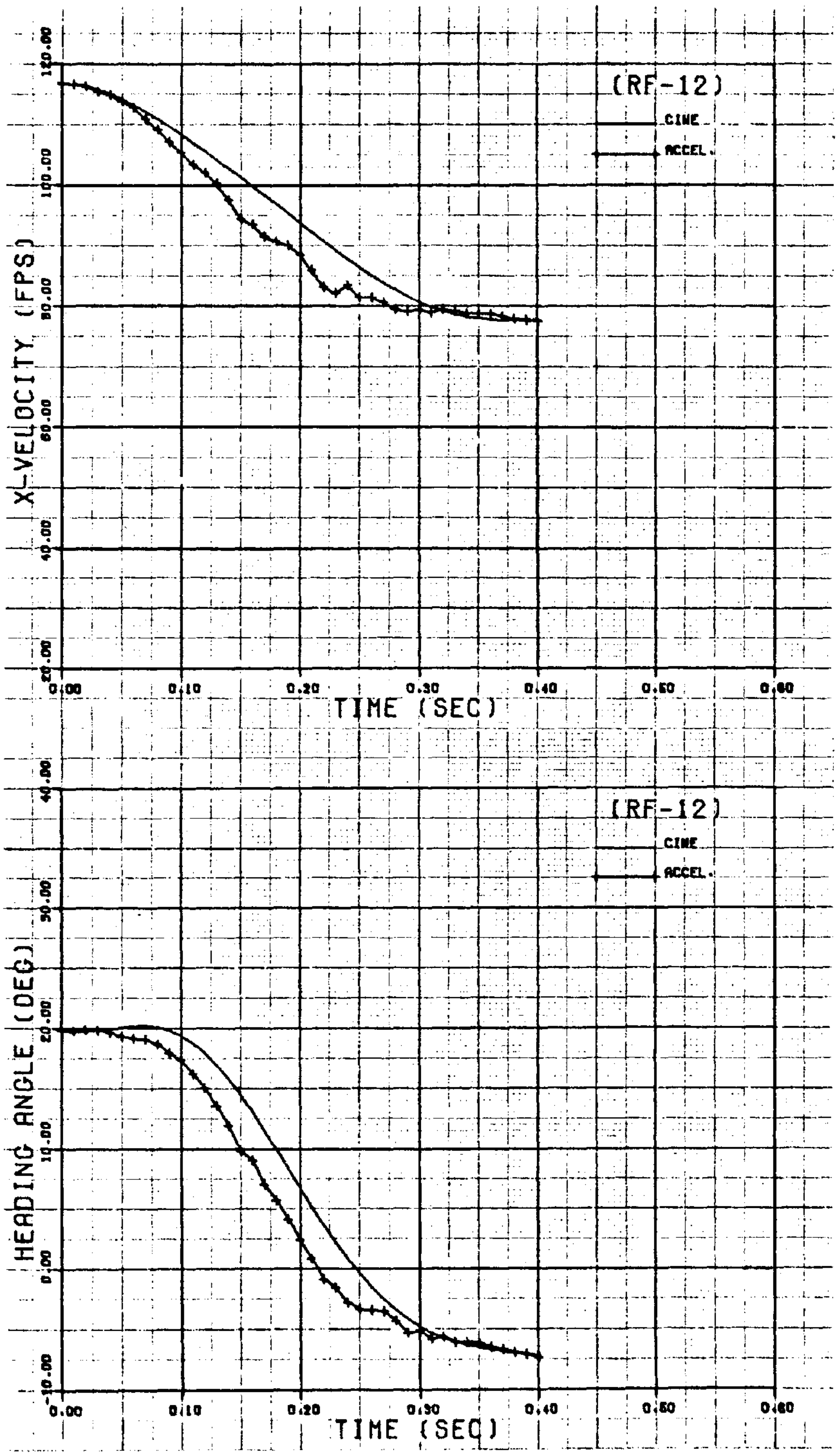


FIGURE B.31 VEHICLE X VELOCITY AND HEADING ANGLE HISTORIES FOR CRASH TEST RF-12

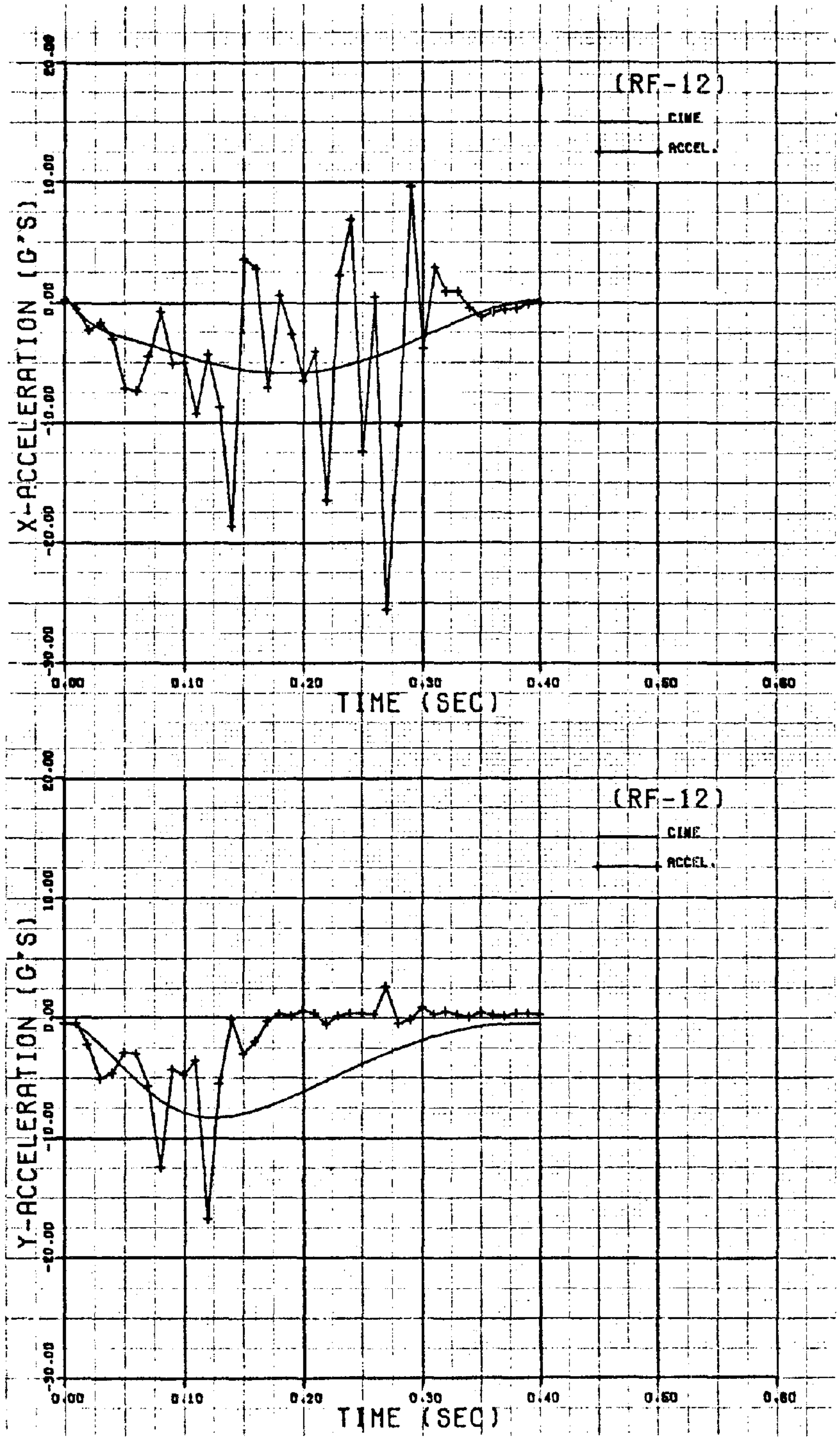


FIGURE B.32 VEHICLE X AND Y ACCELERATION HISTORIES FOR CRASH TEST RF-12

TABLE B.20

SUMMARY OF VEHICLE CINE DATA FOR CRASH TEST RF-13

TIME AFTER IMPACT(SEC)	VEHICLE C. G. COORDINATES(FT) X	Y	HEADING ANGLE (DEG)	VEHICLE VELOCITY (FT/SEC) LONG	LAT	VEHICLE ACCELERATION(G'S) AT TIME T LONG	LAT	AVERAGE OVER .05 SEC. LONG	LAT	RESULT	APPROX. BARRIER FORCES(KIPS) X	Y
0.000	-13.45	-8.30	26.14	95.45	-2.84	-.21	.14	.22	.38	.43	1.1	-.2
.010	-12.59	-8.50	25.39	95.35	-1.60	-.56	-.19	-.29	-.05	.30	1.9	1.8
.020	-11.72	-8.11	24.80	95.16	-.72	-.64	-.39	-.50	-.32	.59	1.9	2.8
.030	-10.85	-7.72	24.46	94.97	-.29	-.59	-.52	-.55	-.50	.74	1.5	3.2
.040	-9.99	-7.33	24.37	94.79	-.33	-.50	-.63	-.52	-.66	.84	.9	3.5
.050	-9.12	-6.94	24.50	94.64	-.78	-.44	-.78	-.50	-.82	.96	.4	4.0
.060	-8.26	-6.56	24.80	94.49	-1.55	-.45	-.96	-.54	-1.02	1.15	.0	4.8
.070	-7.39	-6.18	25.19	94.32	-2.54	-.55	-1.21	-.65	-1.26	1.42	-.1	6.0
.080	-6.53	-5.80	25.59	94.09	-3.62	-.76	-1.50	-.86	-1.55	1.78	.1	7.6
.090	-5.66	-5.43	25.91	93.78	-4.69	-1.07	-1.85	-1.16	-1.69	2.22	.7	9.6
.100	-4.80	-5.06	26.10	93.35	-5.65	-1.48	-2.24	-1.56	-2.26	2.75	1.5	12.0
.110	-3.94	-4.71	26.08	92.80	-6.42	-1.96	-2.66	-2.02	-2.67	3.34	2.7	14.6
.120	-3.08	-4.36	25.83	92.12	-6.94	-2.48	-3.10	-2.53	-3.09	3.99	4.0	17.4
.130	-2.22	-4.03	25.31	91.29	-7.18	-3.03	-3.55	-3.05	-3.54	4.67	5.5	20.3
.140	-1.37	-3.71	24.52	90.33	-7.13	-3.58	-4.02	-3.57	-3.99	5.36	7.1	23.2
.150	-.52	-3.41	23.44	89.23	-6.83	-4.08	-4.50	-4.06	-4.46	6.03	8.8	25.9
.160	.32	-3.13	22.11	87.99	-6.29	-4.53	-4.97	-4.49	-4.91	6.66	10.5	28.4
.170	1.16	-2.87	20.54	86.63	-5.58	-4.90	-5.43	-4.85	-5.36	7.23	12.1	30.6
.180	1.99	-2.63	18.78	85.17	-4.75	-5.17	-5.86	-5.11	-5.79	7.73	13.6	32.5
.190	2.80	-2.41	16.85	83.61	-3.86	-5.35	-6.26	-5.29	-6.18	8.13	14.9	33.9
.200	3.61	-2.22	14.81	82.00	-2.99	-5.43	-6.60	-5.36 *	-6.52	8.44	16.0	35.0
.210	4.40	-2.05	12.71	80.34	-2.19	-5.41	-6.88	-5.34	-6.79	8.64	17.0	35.6
.220	5.19	-1.91	10.60	78.68	-1.50	-5.31	-7.08	-5.24	-6.99	8.74 *	17.6	35.7
.230	5.96	-1.79	8.51	77.04	-.96	-5.14	-7.19	-5.07	-7.10	8.73	18.1	35.4
.240	6.71	-1.70	6.49	75.45	-.60	-4.90	-7.20	-4.84	-7.12 *	8.61	18.3	34.7
.250	7.46	-1.63	4.59	73.93	-.43	-4.63	-7.12	-4.57	-7.05	8.40	18.2	33.6
.260	8.19	-1.59	2.83	72.50	-.44	-4.32	-6.95	-4.27	-6.88	8.10	17.9	32.2
.270	8.90	-1.57	1.24	71.18	-.65	-4.00	-6.68	-3.95	-6.63	7.72	17.3	30.5
.280	9.61	-1.57	-.16	69.96	-1.03	-3.67	-6.35	-3.63	-6.31	7.28	16.6	28.5
.290	10.30	-1.59	-1.35	68.86	-1.56	-3.35	-5.95	-3.31	-5.92	6.78	15.7	26.4
.300	10.99	-1.63	-2.33	67.87	-2.23	-3.02	-5.50	-3.00	-5.48	6.25	14.6	24.2
.310	11.66	-1.69	-3.11	66.98	-3.01	-2.71	-5.01	-2.69	-5.01	5.68	13.4	21.9
.320	12.32	-1.76	-3.67	66.19	-3.89	-2.41	-4.51	-2.39	-4.51	5.11	12.1	19.5
.330	12.98	-1.85	-4.04	65.49	-4.83	-2.11	-4.00	-2.11	-4.01	4.53	10.8	17.3
.340	13.62	-1.95	-4.24	64.87	-5.82	-1.83	-3.50	-1.83	-3.52	3.97	9.4	15.1
.350	14.26	-2.06	-4.27	64.33	-6.83	-1.55	-3.02	-1.56	-3.05	3.42	8.0	13.0
.360	14.89	-2.18	-4.17	63.86	-7.84	-1.29	-2.57	-1.30	-2.60	2.91	6.6	11.1
.370	15.52	-2.31	-3.95	63.45	-8.84	-1.03	-2.15	-1.05	-2.19	2.43	5.3	9.3
.380	16.15	-2.45	-3.64	63.11	-9.81	-.79	-1.78	-.81	-1.82	2.00	4.1	7.8
.390	16.77	-2.59	-3.27	62.82	-10.75	-.57	-1.45	-.59	-1.50	1.61	2.9	6.4
.400	17.39	-2.73	-2.85	62.59	-11.62	-.35	-1.17	-.38	-1.21	1.27	1.9	5.2
.410	18.01	-2.88	-2.41	62.42	-12.44	-.17	-.93	-.20	-.97	.99	1.0	4.2
.420	18.63	-3.03	-1.96	62.29	-13.19	-.01	-.73	-.04	-.76	.76	.2	3.3
.430	19.25	-3.19	-1.53	62.20	-13.87	.13	-.56	.10	-.59	.59	-.5	2.5
.440	19.86	-3.34	-1.12	62.16	-14.47	.24	-.42	.21	-.44	.48	-1.0	1.9
.450	20.48	-3.50	-.74	62.16	-15.00	.32	-.30	.29	-.31	.42	-1.4	1.3

TABLE B.21

SUMMARY OF VEHICLE ACCELEROMETER DATA FOR CRASH TEST RF-13

TIME	DISPLACEMENT-(FT)		HEADING	VELOCITY-(FPS)		VEHICLE ACCELERATION-(G'S)						
						AT TIME T			AVERAGE OVER .05 SEC.			
(SEC)	LONG.	LAT.	ANGLE-(DEG)	LONG.	LAT.	LONG.	LAT.	VERT.	LONG.	LAT.	RESULT	VERT.
.0000	-13.45	-8.90	26.14	95.45	-2.84	-.73	.47	3.17	-.73	.47	.86	3.17
.0100	-12.58	-8.51	26.17	95.30	-2.94	-.44	-.47	-3.23	.00	.38	.38	-.17
.0200	-11.71	-8.11	26.21	95.33	-2.61	1.18	1.13	-.45	-.75	-1.16	1.38	.47
.0300	-10.85	-7.71	26.21	95.09	-2.55	-2.44	-4.88	9.13	-1.43	-2.08	2.53	-.13
.0400	-9.98	-7.32	26.21	94.13	-4.52	-1.30	-2.07	-6.28	-2.46	-2.28	3.35	2.61
.0500	-9.12	-6.95	26.02	93.28	-5.21	-4.16	-4.11	.20	-4.14	-3.04	5.14	3.38
.0600	-8.26	-6.60	25.84	92.29	-5.40	-5.59	-1.46	10.42	-4.67	-3.78	6.01	2.84
.0700	-7.41	-6.25	25.48	90.59	-5.90	-7.21	-2.68	3.43	-5.26	-4.78	7.11	3.15
.0800	-6.57	-5.93	25.20	89.00	-8.13	-5.11	-8.58	6.41	-5.26	-4.61	7.00	1.79
.0900	-5.74	-5.63	24.85	87.62	-8.88	-4.21	-7.09	-4.72	-5.36	-7.06	8.86	-1.73
.1000	-4.90	-5.36	24.13	86.13	-9.99	-4.21	-3.23	-6.60	-5.30	-8.00	9.60	-1.60
.1100	-4.08	-5.11	23.32	84.18	-10.92	-6.07	-13.71	-7.18	-5.19	-6.25	8.12	-2.55
.1200	-3.27	-4.89	22.43	82.69	-11.78	-6.92	-7.42	4.08	-5.66	-6.69	8.76	-2.65
.1300	-2.46	-4.70	21.24	81.54	-11.88	-4.54	.19	1.69	-6.20	-8.74 *	10.72 *	-1.08
.1400	-1.66	-4.53	19.65	80.06	-12.07	-6.54	-9.30	-5.24	-6.90	-7.51	10.20	.79
.1500	-.87	-4.39	18.11	78.33	-13.15	-6.92	-13.49	1.23	-7.10	-6.87	9.87	-1.86
.1600	-.10	-4.29	16.56	76.20	-13.80	-9.59	-7.53	2.20	-7.17	-7.52	10.39	-1.74
.1700	.66	-4.21	14.37	74.40	-12.45	-7.88	-4.22	-9.19	-7.24 *	-7.32	10.29	-2.62
.1800	1.41	-4.16	12.26	73.38	-10.55	-4.92	-3.06	2.27	-6.54	-6.74	9.39	-5.29
.1900	2.14	-4.11	10.83	72.17	-8.73	-6.88	-8.30	-9.64	-2.39	-4.25	4.88	-7.82
.2000	2.87	-4.06	8.73	71.38	-7.00	-3.44	-10.56	-12.10	-.68	-3.40	3.47	-4.90
.2100	3.57	-4.03	6.70	71.06	-6.51	11.19	4.88	-10.42	-1.82	-6.22	6.48	-3.66
.2200	4.29	-4.02	5.49	71.14	-7.86	.66	.03	5.38	-2.31	-3.08	3.85	2.58
.2300	4.99	-4.03	4.68	68.80	-6.68	-10.64	-17.13	8.48	-3.14	-4.84	5.77	1.85
.2400	5.68	-4.07	3.62	68.04	-11.46	-9.31	7.36	21.56	-6.30	-6.55	9.09	5.82
.2500	6.36	-4.15	2.63	67.41	-11.87	-7.59	-19.33	-15.73	-6.77	-6.43	9.34	7.34
.2600	7.04	-4.24	2.14	67.00	-11.83	-4.64	-3.67	9.39	-4.71	-2.92	5.54	8.84
.2700	7.71	-4.34	1.79	67.08	-12.14	-1.68	.63	13.01	-2.29	-3.69	4.34	5.48
.2800	8.38	-4.44	1.63	66.95	-12.02	-.35	.41	15.99	-.90	.47	1.01	8.02
.2900	9.06	-4.55	1.90	67.00	-13.47	2.80	3.50	4.73	.34	.06	.35	6.05
.3000	9.73	-4.66	1.98	67.31	-13.66	-.63	1.46	-3.04	.49	-.71	.87	.21
.3100	10.41	-4.77	2.26	67.03	-13.55	1.56	-5.71	-.45	.48	-.58	.76	-2.15
.3200	11.08	-4.88	2.40	66.95	-13.78	-.92	-3.23	-16.18	-.07	-1.36	1.36	-1.81
.3300	11.76	-4.99	2.66	66.57	-14.45	-.39	1.07	4.21	-.30	-.73	.79	-1.74
.3400	12.43	-5.10	3.04	66.27	-14.90	.04	-.41	6.41	-.93	.55	1.08	-1.38
.3500	13.09	-5.22	3.34	65.65	-14.92	-1.78	4.61	-2.72	-.53	-.29	.60	1.57
.3600	13.76	-5.33	3.63	65.16	-14.97	-1.58	.69	1.36	-.25	-.95	.99	.48
.3700	14.41	-5.43	4.17	64.49	-15.93	1.08	-7.42	-1.42	-.02	-.65	.65	.33
.3800	15.07	-5.55	4.38	64.52	-16.16	.99	-2.23	-1.23	.49	-1.62	1.69	-.28
.3900	15.73	-5.66	4.62	65.13	-16.67	1.18	1.13	5.63	.53	-3.00	3.04	-.11
.4000	16.39	-5.77	4.66	64.89	-15.32	.80	-.25	-5.76	.15	-1.56	1.57	-1.11
.4100	17.05	-5.87	5.22	64.94	-16.01	-1.39	-6.21	2.20	-.38	-.49	.62	1.09
.4200	17.71	-5.97	5.41	64.49	-16.24	-.82	-.25	-6.40	-.97	-.66	1.18	1.75
.4300	18.36	-6.07	5.72	64.36	-16.19	-1.68	3.12	9.78	-1.17	-.44	1.25	3.91

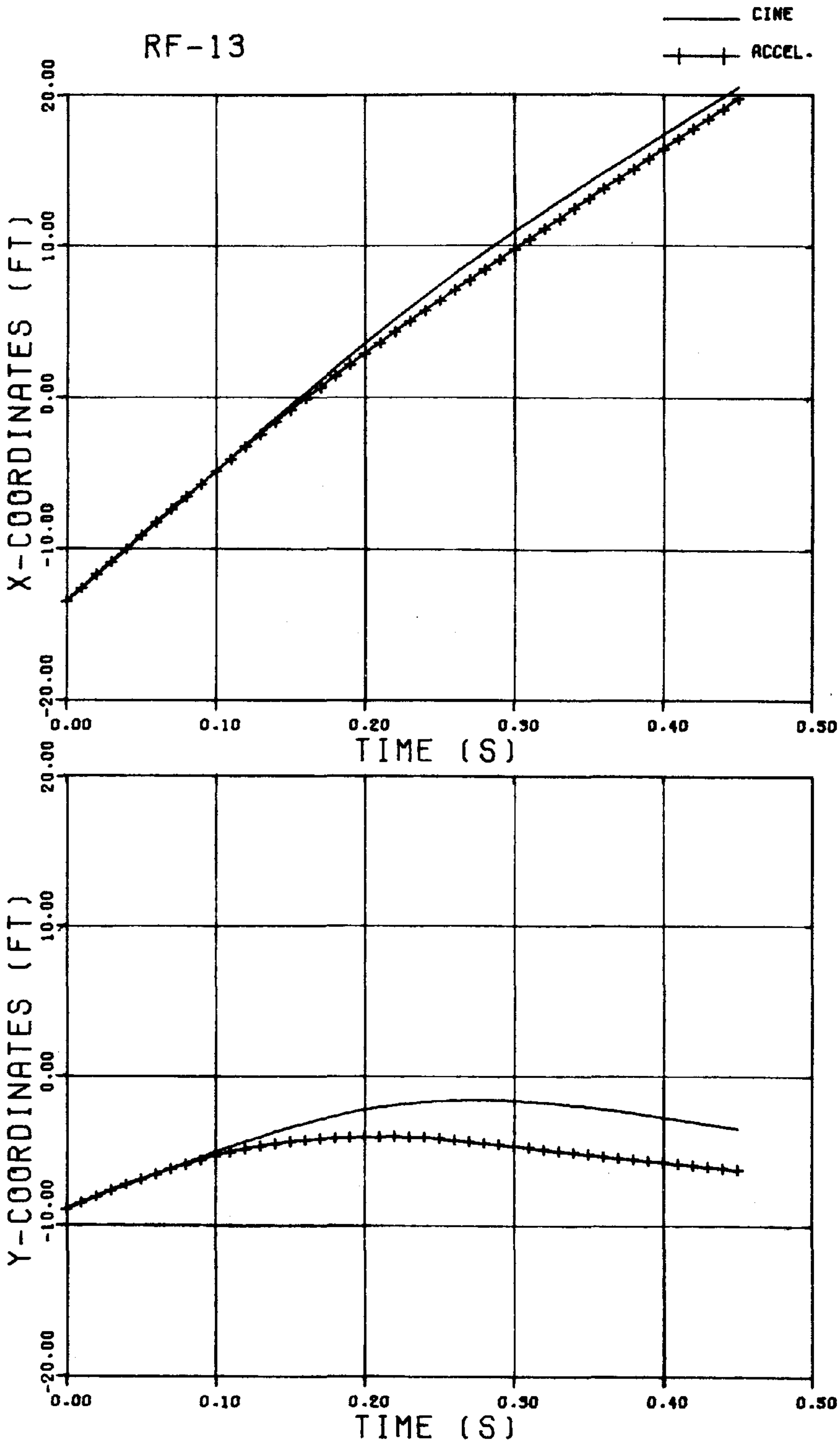


FIGURE B.33 VEHICLE X AND Y DISPLACEMENT HISTORIES FOR CRASH TEST RF-13

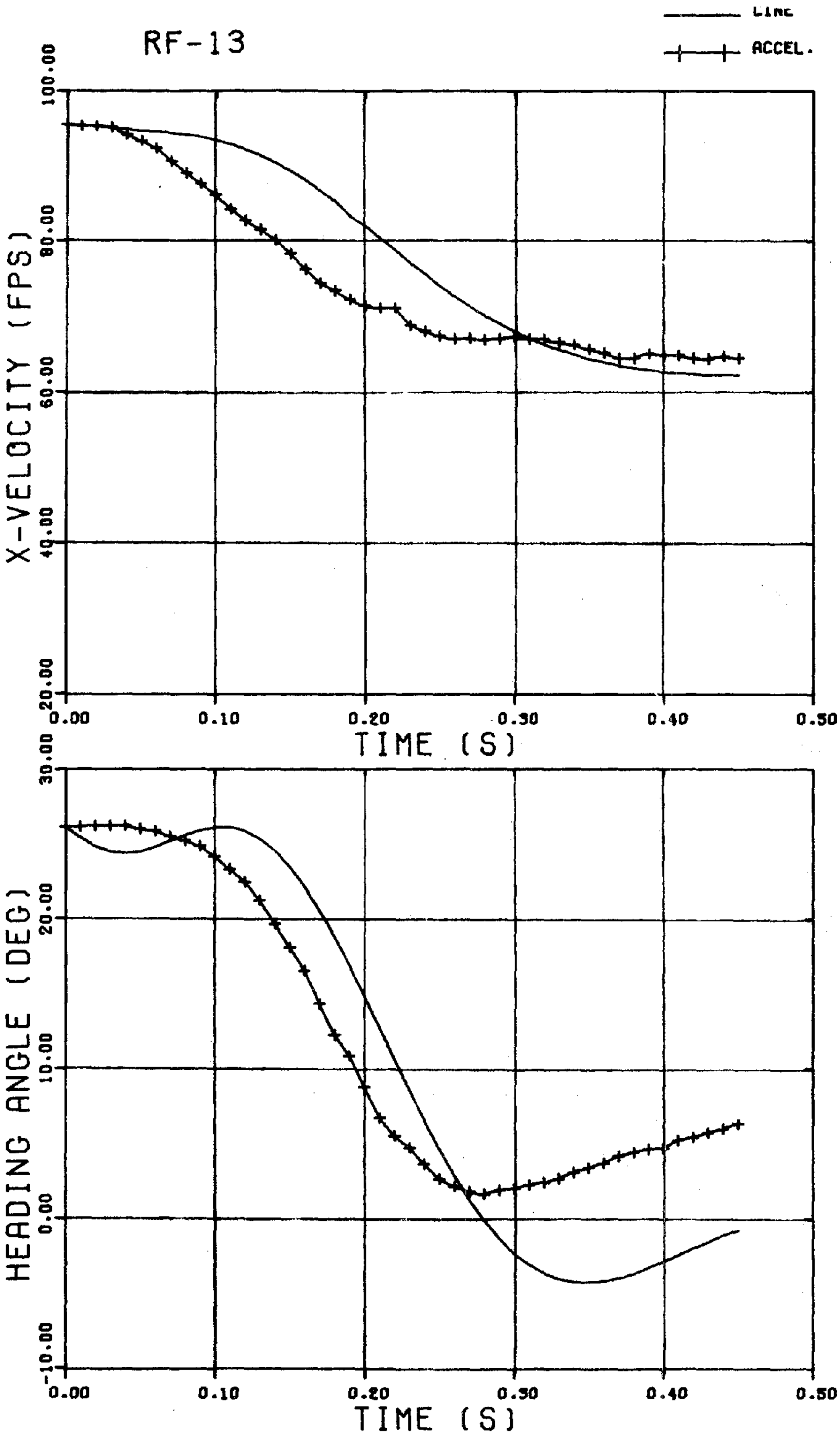


FIGURE B.34 VEHICLE X VELOCITY AND HEADING ANGLE HISTORIES FOR CRASH TEST RF-13

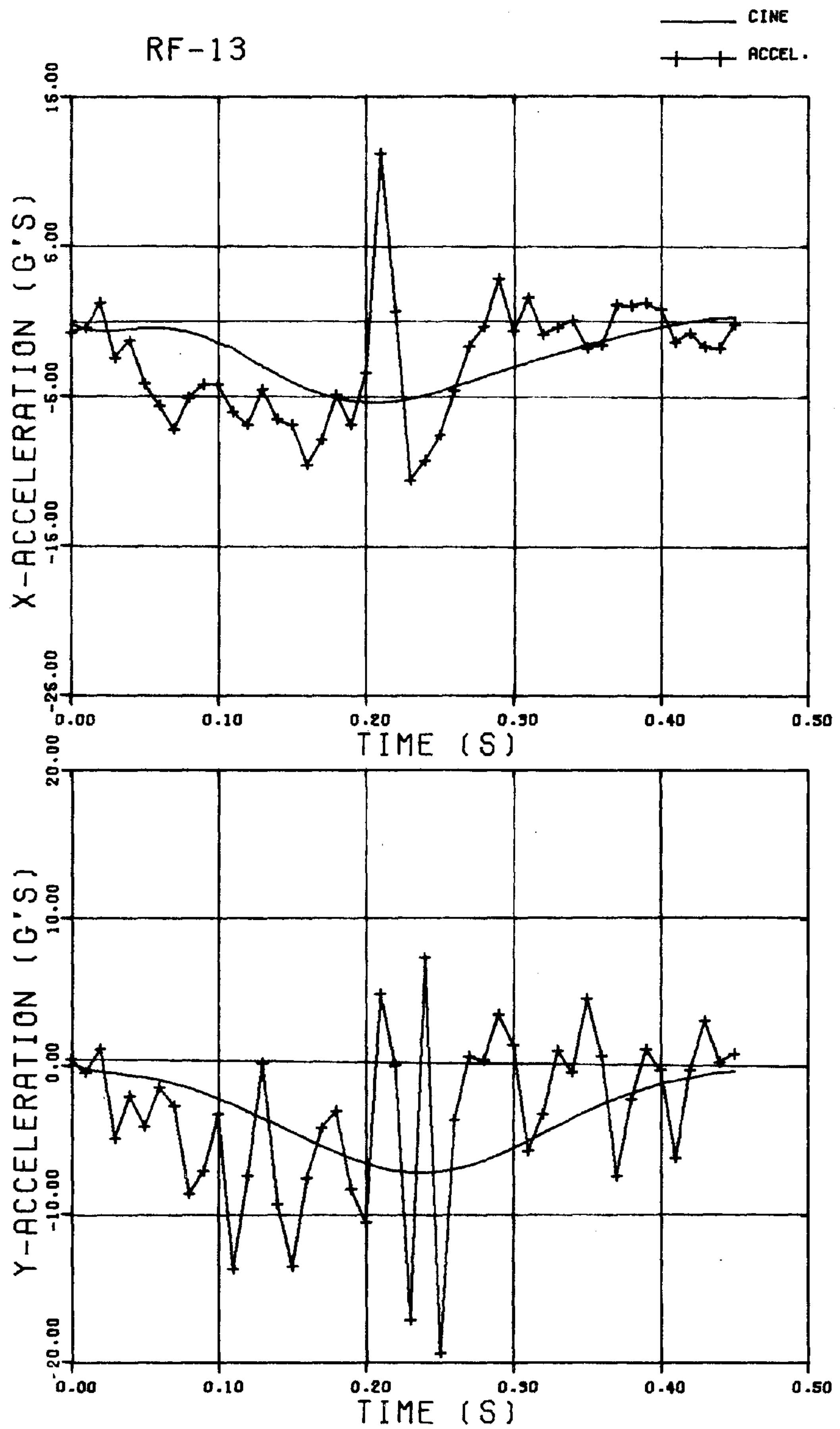


FIGURE B.35 VEHICLE X AND Y ACCELERATION HISTORIES FOR CRASH TEST RF-13

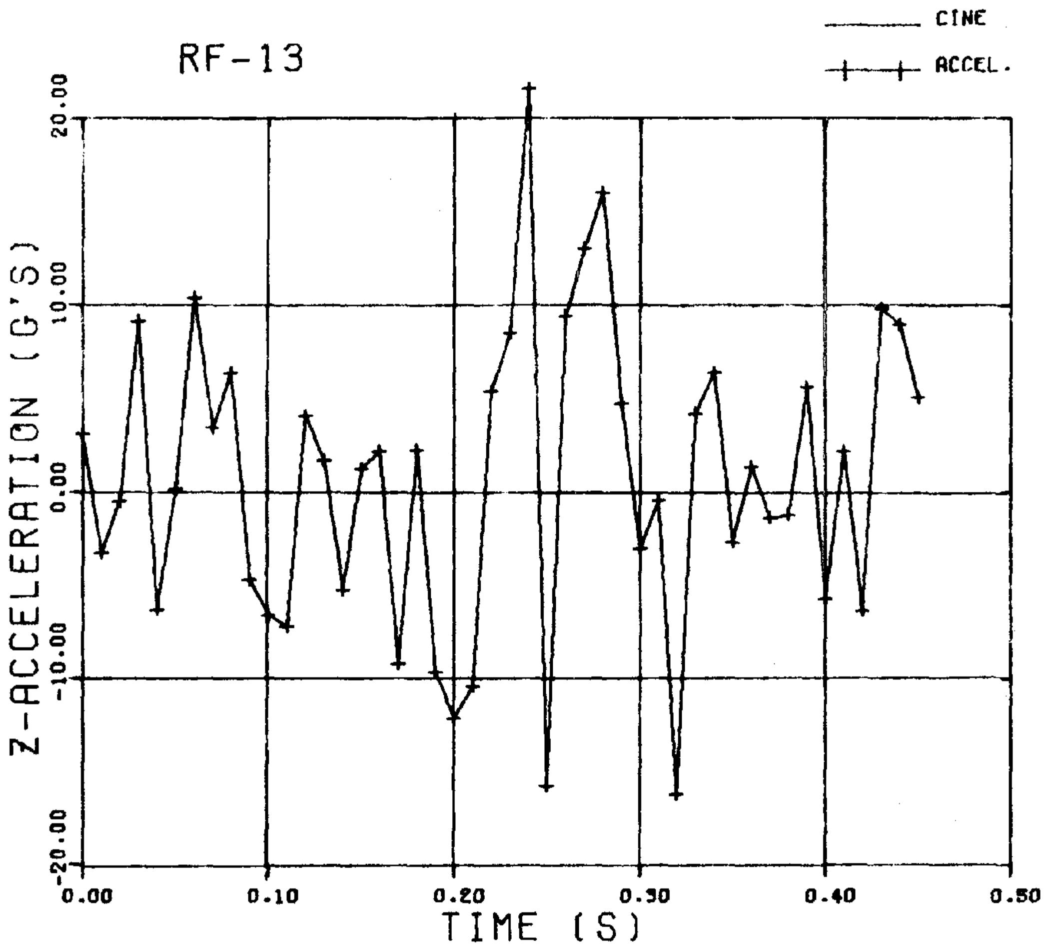


FIGURE B.36 VEHICLE Z ACCELERATION HISTORY FOR CRASH TEST RF-13

TABLE B.22

SUMMARY OF VEHICLE CINE DATA FOR CRASH TEST RF-14

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	VEHICLE ACCELERATION(G'S) AVERAGE OVER .05 SEC. RESULT	APPROX. BARRIER FORCES(KIPS) X	APPROX. BARRIER FORCES(KIPS) Y
0.000	-11.57	-11.41	25.33	90.77	-2.71	.12	.06	.13	-.06	.14	-.4	-.4
.010	-10.74	-11.04	25.51	90.75	-2.98	-.15	-.01	-.12	-.11	.16	.5	.3
.020	-9.91	-10.68	25.68	90.66	-3.27	-.39	-.17	-.36	-.24	.43	1.2	1.4
.030	-9.07	-10.32	25.83	90.49	-3.61	-.60	-.41	-.57	-.44	.72	1.6	2.7
.040	-8.25	-9.96	25.97	90.26	-3.99	-.79	-.57	-.76	-.68	1.02	1.8	4.1
.050	-7.42	-9.60	26.08	89.97	-4.43	-.95	-.94	-.94	-.92	1.31	1.9	5.4
.060	-6.59	-9.25	26.17	89.63	-4.91	-1.10	-1.19	-1.10	-1.14	1.58	2.0	6.6
.070	-5.76	-8.90	26.24	89.25	-5.43	-1.25	-1.38	-1.26	-1.31	1.82	2.2	7.7
.080	-4.94	-8.55	26.29	88.81	-5.98	-1.41	-1.51	-1.42	-1.43	2.01	2.5	8.5
.090	-4.12	-8.22	26.32	88.33	-6.52	-1.57	-1.55	-1.59	-1.47	2.17	3.1	9.0
.100	-3.30	-7.89	26.33	87.79	-7.04	-1.75	-1.52	-1.77	-1.44	2.28	3.8	9.2
.110	-2.48	-7.57	26.34	87.20	-7.52	-1.95	-1.41	-1.97	-1.34	2.38	4.8	9.1
.120	-1.67	-7.25	26.33	86.54	-7.94	-2.17	-1.22	-2.19	-1.17	2.48	6.0	8.8
.130	-.86	-6.94	26.31	85.80	-8.26	-2.41	-.98	-2.42	-.94	2.60	7.4	8.3
.140	-.06	-6.64	26.28	84.99	-8.49	-2.66	-.70	-2.67	-.68	2.75	8.9	7.7
.150	.74	-6.34	26.23	84.10	-8.60	-2.92	-.41	-2.92	-.41	2.95	10.4	7.1
.160	1.53	-6.05	26.17	83.13	-8.60	-3.18	-.11	-3.17	-.13	3.17	12.0	6.4
.170	2.30	-5.76	26.10	82.08	-8.48	-3.43	.17	-3.42	.13	3.42	13.5	5.8
.180	3.07	-5.48	26.01	80.94	-8.26	-3.68	.40	-3.66	.34	3.67	14.9	5.4
.190	3.83	-5.20	25.91	79.74	-7.96	-3.90	.57	-3.88	.50	3.91	16.1	5.1
.200	4.58	-4.92	25.79	78.46	-7.59	-4.10	.66	-4.07	.58	4.11	17.1	5.1
.210	5.31	-4.65	25.65	77.13	-7.19	-4.26	.67	-4.22	.58	4.26	17.7	5.3
.220	6.03	-4.39	25.51	75.76	-6.79	-4.39	.59	-4.34	.50	4.37	18.1	5.8
.230	6.74	-4.12	25.35	74.35	-6.43	-4.47	.41	-4.42	.33	4.44	18.1	6.6
.240	7.43	-3.87	25.20	72.92	-6.13	-4.50	.15	-4.46	.07	4.46	17.7	7.6
.250	8.11	-3.61	25.05	71.49	-5.95	-4.49	-.19	-4.45	-.25	4.46	17.1	8.9
.260	8.77	-3.37	24.91	70.06	-5.90	-4.44	-.59	-4.40	-.69	4.45	16.2	10.3
.270	9.43	-3.13	24.79	68.66	-6.02	-4.35	-1.04	-4.32	-1.06	4.45	15.1	11.9
.280	10.07	-2.90	24.70	67.28	-6.32	-4.23	-1.51	-4.20	-1.51	4.47	13.8	13.4
.290	10.70	-2.68	24.65	65.95	-6.83	-4.08	-1.98	-4.07	-1.96	4.51	12.4	15.0
.300	11.33	-2.48	24.65	64.66	-7.53	-3.92	-2.42	-3.92	-2.38	4.58	10.9	16.4
.310	11.94	-2.28	24.70	63.42	-8.44	-3.76	-2.82	-3.76	-2.75	4.66	9.6	17.7
.320	12.55	-2.10	24.82	62.21	-9.53	-3.60	-3.13	-3.61	-3.04	4.72	8.4	18.7
.330	13.15	-1.93	25.00	61.04	-10.77	-3.46	-3.35	-3.48	-3.25	4.76	7.4	19.3
.340	13.75	-1.78	25.26	59.90	-12.14	-3.35	-3.46	-3.37	-3.34	4.75	6.6	19.5
.350	14.34	-1.64	25.59	58.76	-13.60	-3.26	-3.45	-3.28	-3.32	4.67	6.2	19.3
.360	14.93	-1.52	25.99	57.62	-15.10	-3.19	-3.30	-3.21	-3.17	4.52	6.1	18.7
.370	15.51	-1.41	26.46	56.47	-16.59	-3.15	-3.02	-3.17	-2.90	4.30	6.3	17.6
.380	16.09	-1.31	27.00	55.30	-18.02	-3.13	-2.62	-3.14	-2.52	4.03	6.8	16.1
.390	16.66	-1.23	27.59	54.10	-19.35	-3.11	-2.12	-3.11	-2.05	3.73	7.6	14.2
.400	17.22	-1.15	28.22	52.88	-20.54	-3.09	-1.55	-3.08	-1.51	3.43	8.5	12.1
.410	17.78	-1.09	28.89	51.65	-21.54	-3.04	-.93	-3.02	-.94	3.16	9.5	9.8
.420	18.34	-1.03	29.58	50.42	-22.36	-2.96	-.32	-2.92	-.37	2.94	10.3	7.5
.430	18.88	-.98	30.29	49.20	-22.93	-2.82	.24	-2.77	.14	2.78	11.0	5.2
.440	19.42	-.93	31.00	48.03	-23.44	-2.63	.69	-2.56	.55	2.62	11.2	3.3
.450	19.95	-.88	31.72	46.94	-23.75	-2.36	.99	-2.29	.81	2.42	10.8	1.7
.460	20.47	-.84	32.42	45.94	-23.98	-2.01	1.10	-1.93	.88	2.13	9.8	.6
.470	20.98	-.80	33.13	45.06	-24.21	-1.59	.98	-1.51	.75	1.69	8.0	.2
.480	21.49	-.75	33.84	44.32	-24.50	-1.09	.61	-1.03	.42	1.11	5.4	.4
.490	21.99	-.71	34.57	43.74	-24.95	-.54	.04	-.49	-.09	.50	2.0	1.2

TABLE B.23

SUMMARY OF VEHICLE ACCELEROMETER DATA FOR CRASH TEST RF-14

TIME (SEC)	DISPLACEMENT-(FT) LONG.	DISPLACEMENT-(FT) LAT.	HEADING ANGLE-(DEG)	VELOCITY-(FPS) LONG.	VELOCITY-(FPS) LAT.	VEHICLE ACCELERATION-(G'S) AT TIME T LONG.	AT TIME T LAT.	AT TIME T VERT.	AVERAGE OVER .05 SEC. LONG.	AVERAGE OVER .05 SEC. LAT.	AVERAGE OVER .05 SEC. RESULT	AVERAGE OVER .05 SEC. VERT.
.0000	-11.57	-11.41	25.33	90.77	-2.71	-4.14	-1.28	1.22	-4.14	-1.28	4.33	1.22
.0100	-10.74	-11.05	25.49	90.11	-3.11	-9.32	-1.81	13.12	-5.14	-.65	5.18	5.63
.0200	-9.91	-10.69	26.16	90.32	-3.50	-1.96	1.13	2.54	-5.83	-1.24	5.96	4.23
.0300	-9.08	-10.32	25.47	90.40	-3.03	-5.50	3.99	10.21	-7.23	-2.80	7.76	10.81
.0400	-8.26	-9.96	25.43	88.92	-3.12	-8.23	-8.21	-5.92	-8.19	1.01	8.25	8.27
.0500	-7.44	-9.60	26.67	90.36	-4.06	-11.16	-9.12	34.09	-9.04	-1.25	9.13	10.61
.0600	-6.62	-9.24	25.31	87.98	-3.44	-14.09	17.25	.43	-6.30	-.20	6.31	5.34
.0700	-5.81	-8.89	25.81	88.22	-3.19	-6.25	-10.17	14.26	-4.78	-.54	4.81	8.80
.0800	-5.00	-8.54	25.95	88.10	-3.29	8.20	9.27	-16.14	-2.12	2.23	3.08	2.31
.0900	-4.19	-8.18	26.36	88.19	-4.54	-.59	-9.95	11.35	.36	-2.29	2.32	3.86
.1000	-3.38	-7.83	25.93	88.66	-3.25	2.13	4.75	1.66	1.03	-.60	1.19	-1.51
.1100	-2.57	-7.48	25.95	87.86	-3.80	-1.68	-5.35	8.18	-.55	-5.85	5.87	-.24
.1200	-1.76	-7.12	26.56	87.47	-4.00	-2.91	-1.73	-12.61	-3.65	-2.91	4.66	-5.81
.1300	-.97	-6.79	25.46	84.70	-7.20	.29	-16.96	-9.79	-3.43	-3.38	4.81	-5.42
.1400	-.18	-6.51	25.80	81.74	-9.07	-16.06	4.75	-16.49	-2.75	-2.08	3.45	-3.20
.1500	.59	-6.25	26.49	80.65	-11.45	3.22	2.41	3.60	-4.29	-2.65	5.04	1.06
.1600	1.36	-5.99	27.02	79.70	-12.89	1.72	1.13	19.28	-4.35	2.08	4.83	2.51
.1700	2.13	-5.75	26.54	79.20	-12.03	-10.61	-4.60	8.71	-1.21	3.07	3.30	18.16
.1800	2.90	-5.51	26.65	78.56	-14.12	-.05	6.71	-2.57	-4.18	4.28	5.98	26.21
.1900	3.66	-5.28	26.49	78.53	-12.64	-.32	9.72	61.75	-4.91	3.03	5.77	25.72
.2000	4.41	-5.06	27.36	76.91	-13.98	-11.63	8.44	43.87	-3.67	2.33	4.35	24.20
.2100	5.15	-4.84	26.80	75.63	-14.45	-1.96	-5.13	16.82	-4.55	3.36	5.65	25.47
.2200	5.89	-4.64	27.27	73.55	-16.40	-4.41	-8.06	1.13	-4.49	2.24	5.02	18.17
.2300	6.61	-4.45	27.32	72.27	-15.85	-4.41	11.83	3.78	-2.98	-3.35	4.48	1.06
.2400	7.32	-4.28	27.95	70.64	-17.18	-.05	4.14	25.28	-1.62	-1.64	2.30	-4.51
.2500	8.02	-4.10	27.98	68.81	-18.46	-4.07	-19.52	-41.69	.76	6.98	7.02	-3.73
.2600	8.71	-3.94	27.82	68.59	-17.25	4.86	3.39	-11.03	-.70	5.29	5.33	8.22
.2700	9.40	-3.77	27.75	68.33	-16.37	7.45	35.04	5.01	-4.08	4.44	6.03	-2.87
.2800	10.07	-3.59	27.77	68.35	-14.80	-11.70	3.39	63.52	-4.61	6.80	8.21	4.82
.2900	10.73	-3.42	27.43	64.91	-14.03	-16.95	-.08	-30.15	-8.62	5.94	10.47	1.61
.3000	11.36	-3.23	28.13	63.74	-12.77	-6.73	-7.76	-3.27	-14.37	-1.99	14.51	13.35
.3100	11.98	-3.04	28.46	63.36	-12.68	-15.18	-.91	-27.06	-10.35	-1.88	10.52	9.33
.3200	12.58	-2.85	29.10	61.43	-9.67	-21.31	-4.60	63.69	-4.95	-1.92	5.31	6.84
.3300	13.15	-2.65	29.57	60.11	-10.52	8.40	3.92	43.43	-3.54	-2.59	4.39	9.22
.3400	13.71	-2.45	30.29	58.46	-9.74	10.04	-.23	-42.57	-1.93	-6.27	6.56	15.58
.3500	14.26	-2.25	31.76	56.78	-12.07	.36	-11.15	8.62	4.18	-7.05	8.20	25.03
.3600	14.80	-2.05	32.82	56.45	-13.20	-7.14	-19.29	4.75	4.26	-6.54	7.81	17.29
.3700	15.35	-1.87	33.76	54.50	-15.19	9.22	-8.52	110.92	2.20	-5.91	6.31	25.29
.3800	15.88	-1.70	35.02	52.78	-16.40	8.81	6.48	4.75	3.07	-2.37	3.88	17.49
.3900	16.40	-1.53	35.96	51.75	-17.02	-.25	2.94	-2.57	3.70	2.71	4.59	17.50
.4000	16.93	-1.37	37.08	51.34	-19.51	4.72	6.55	-30.41	2.83	4.70	5.49	-8.19
.4100	17.45	-1.22	37.61	49.17	-18.66	-4.00	6.10	4.83	2.66	4.90	5.57	-3.70
.4200	17.95	-1.07	38.02	48.81	-17.47	4.86	1.43	-17.55	2.38	6.92	7.31	4.06
.4300	18.43	-.90	39.00	47.97	-16.15	7.99	7.46	27.21	-.36	5.30	5.32	12.13
.4400	18.91	-.72	40.22	47.70	-16.87	-1.68	13.03	36.20	-1.18	4.37	4.53	12.52
.4500	19.37	-.54	41.60	46.17	-16.53	-8.98	-1.51	9.94	-3.09	5.65	6.44	21.29
.4600	19.83	-.35	42.01	45.61	-16.09	-8.09	1.43	6.77	-5.79	5.35	7.88	19.74
.4700	20.27	-.17	43.04	44.82	-16.52	-4.68	7.84	26.33	-5.46	3.84	6.68	15.05

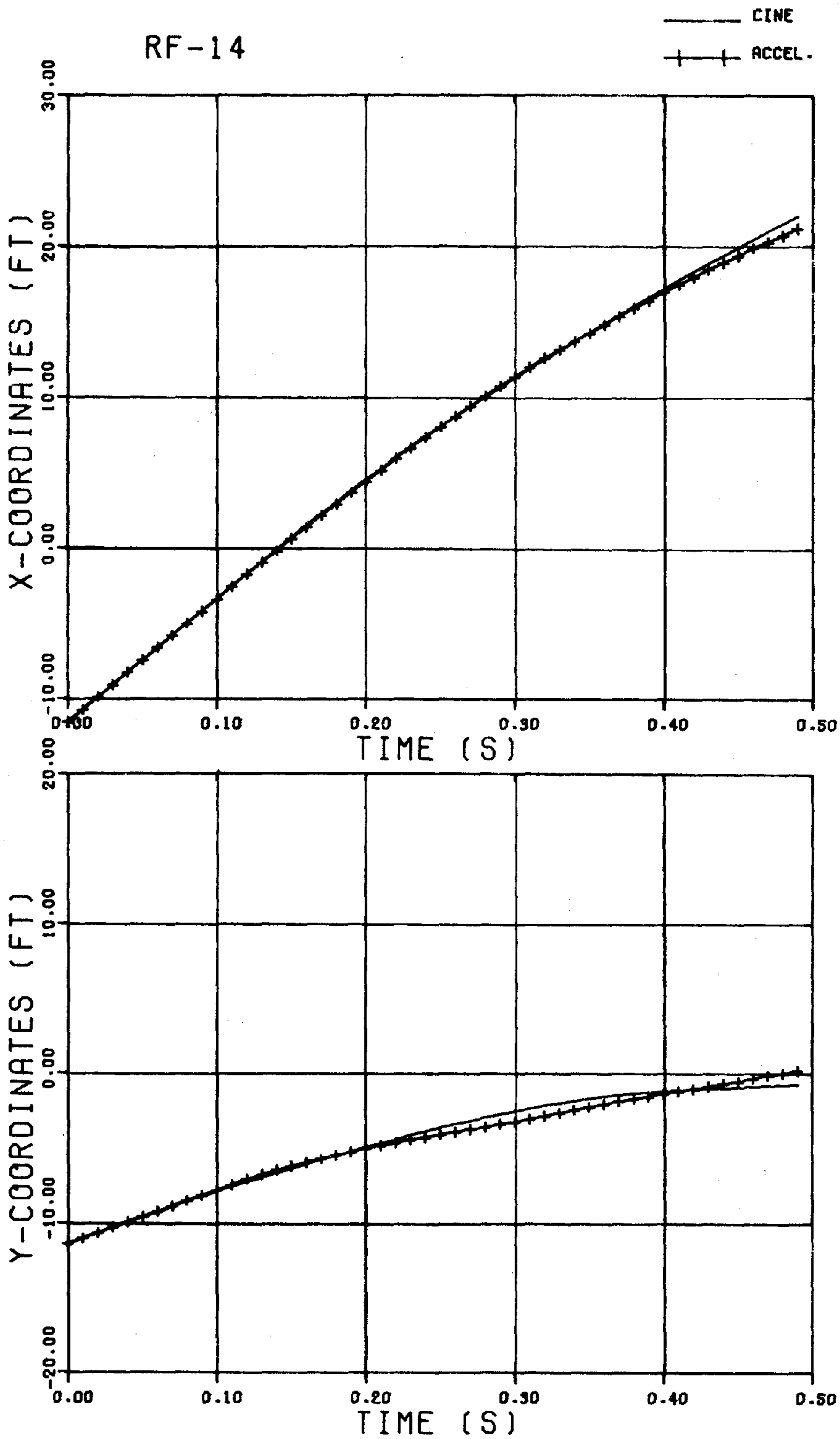


FIGURE B.37 VEHICLE X AND Y DISPLACEMENT HISTORIES FOR CRASH TEST RF-14

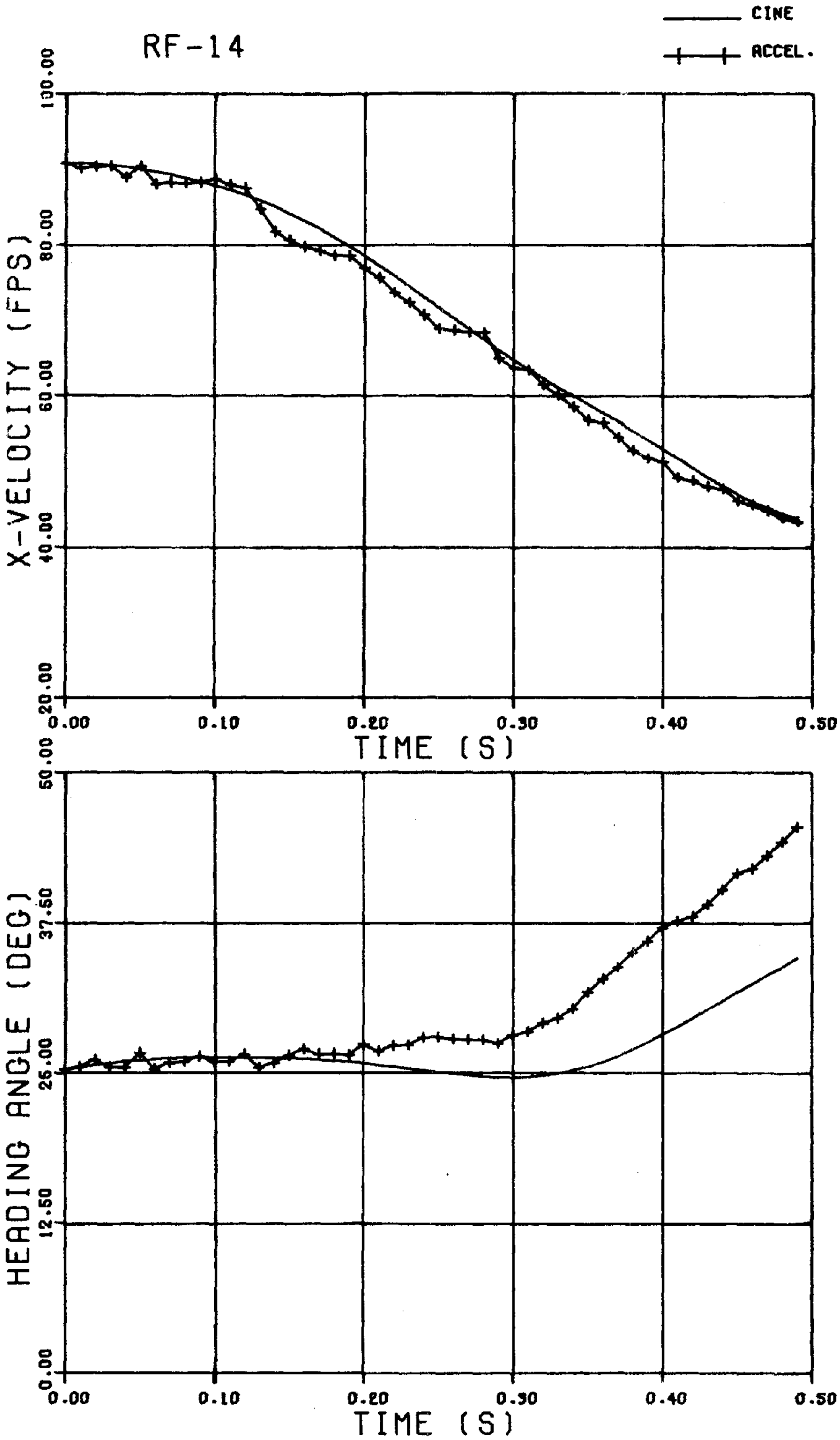


FIGURE B.38 VEHICLE X VELOCITY AND HEADING ANGLE HISTORIES FOR CRASH TEST RF-14

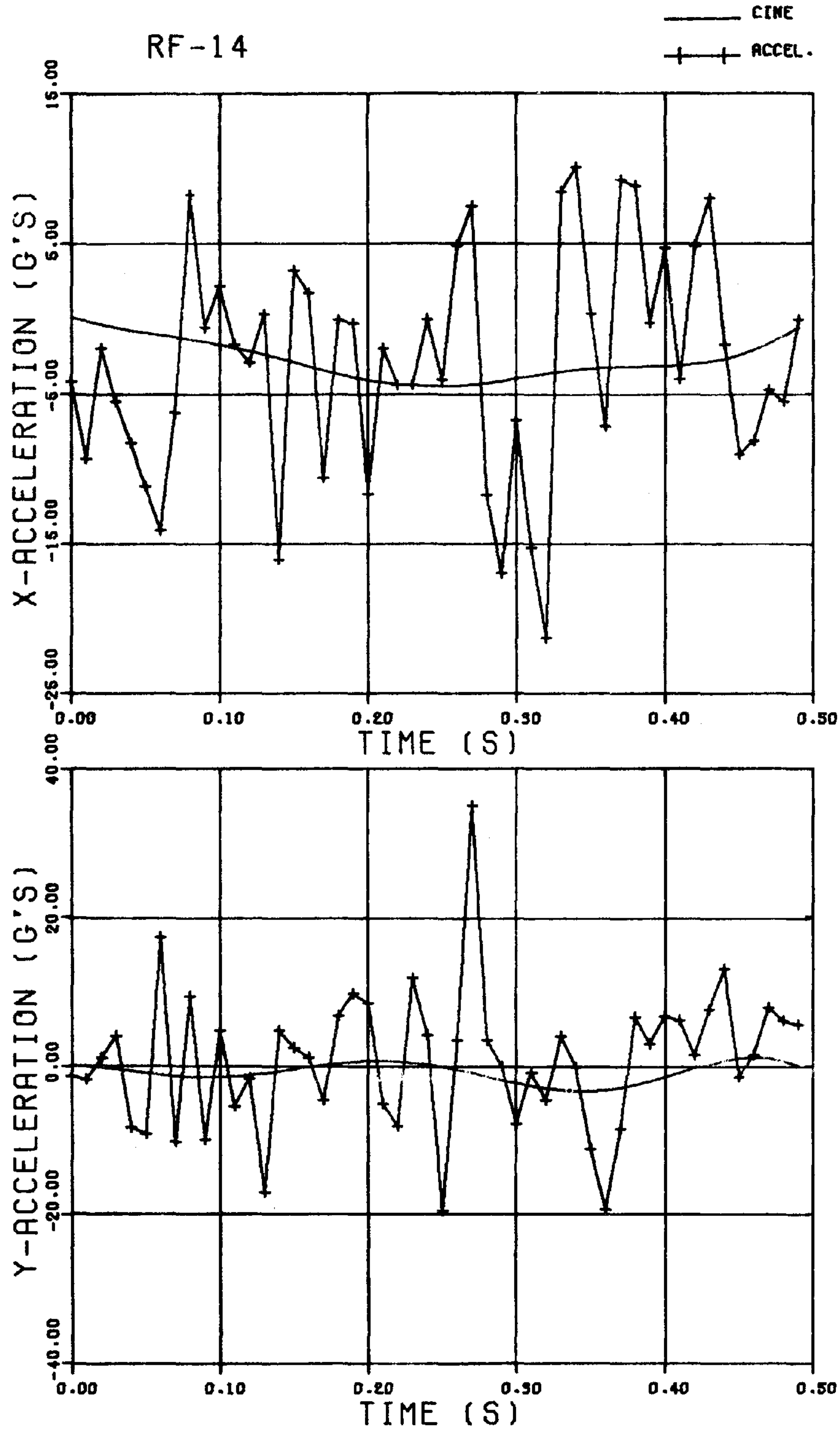


FIGURE B.39 VEHICLE X AND Y ACCELERATION HISTORIES FOR CRASH TEST RF-14

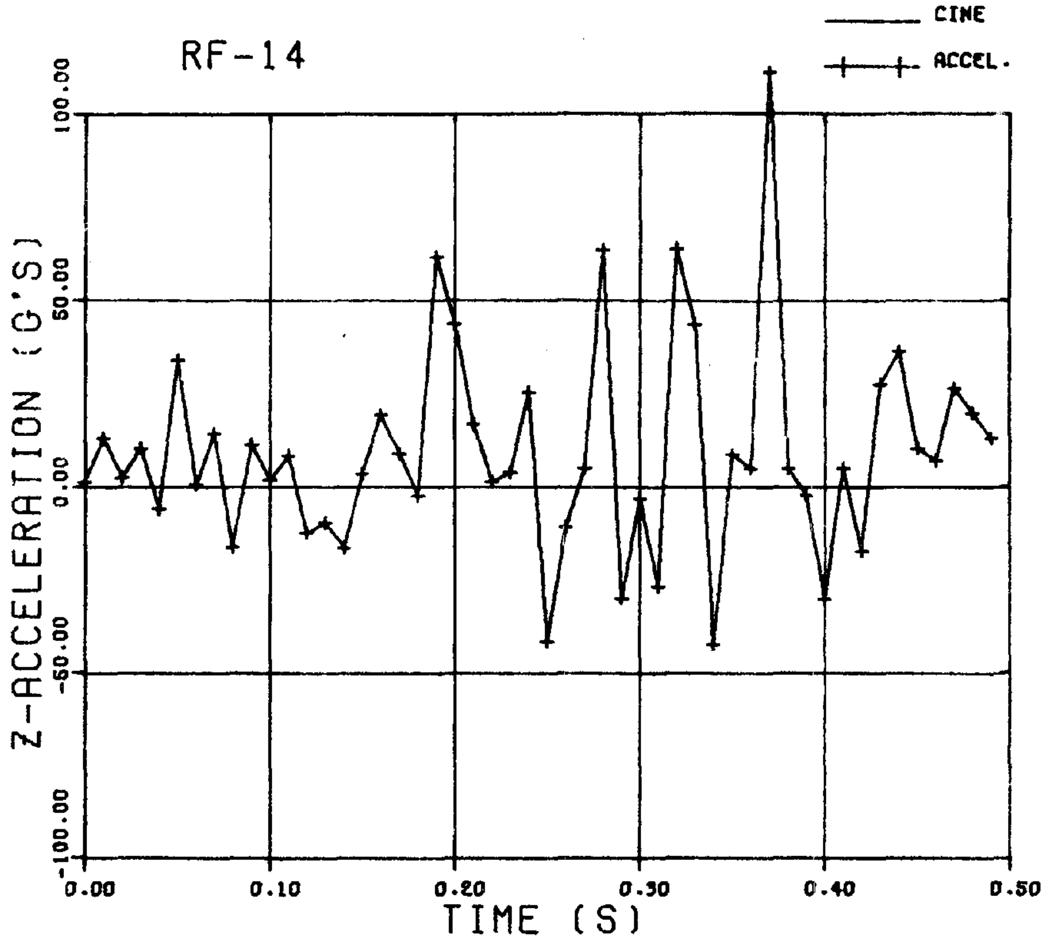


FIGURE B.40 VEHICLE Z ACCELERATION HISTORY
FOR CRASH TEST RF-14

TABLE B.24

SUMMARY OF VEHICLE CINE DATA FOR CRASH TEST RF-15

TIME AFTER IMPACT(SEC)	VEHICLE C. G. COORDINATES(FT) X	Y	HEADING ANGLE (DEG)	VEHICLE VELOCITY (FT/SEC) LONG	LAT	VEHICLE ACCELERATION(G'S) AT TIME T LONG	LAT	AVERAGE OVER .05 SEC. LONG	LAT	RESULT	APPROX. BARRIER FORCES(KIPS) X	Y
0.000	-15.20	-4.94	13.52	91.90	-.84	-.14	.24	-.21	.16	.27	.4	-.4
.010	-14.30	-4.74	13.66	91.83	-1.10	-.30	-.39	-.35	-.44	.56	.4	1.0
.020	-13.41	-4.53	13.71	91.70	-1.41	-.50	-1.08	-.54	-1.10	1.23	.5	2.5
.030	-12.52	-4.33	13.64	91.50	-1.77	-.74	-1.79	-.76	-1.78	1.94	.6	4.0
.040	-11.62	-4.14	13.45	91.23	-2.14	-1.00	-2.49	-1.00	-2.46	2.66	.8	5.6
.050	-10.73	-3.95	13.11	90.88	-2.53	-1.24	-3.17	-1.23	-3.11	3.34	1.0	7.1
.060	-9.84	-3.77	12.63	90.47	-2.89	-1.45	-3.79	-1.43	-3.71	3.98	1.2	8.5
.070	-8.95	-3.61	12.02	90.01	-3.23	-1.63	-4.34	-1.59	-4.25	4.54	1.4	9.7
.080	-8.07	-3.46	11.27	89.51	-3.53	-1.74	-4.81	-1.70	-4.71	5.01	1.6	10.7
.090	-7.18	-3.33	10.39	88.99	-3.78	-1.80	-5.18	-1.76	-5.07	5.37	1.8	11.4
.100	-6.30	-3.22	9.41	88.48	-3.98	-1.79	-5.45	-1.75	-5.34	5.62	1.9	12.0
.110	-5.42	-3.12	8.34	87.99	-4.11	-1.73	-5.61	-1.69	-5.49	5.75	1.9	12.2
.120	-4.55	-3.04	7.20	87.53	-4.17	-1.62	-5.65	-1.59	-5.54	5.77	1.9	12.3
.130	-3.68	-2.98	6.01	87.12	-4.17	-1.47	-5.59	-1.44	-5.49	5.67	1.9	12.1
.140	-2.81	-2.94	4.79	86.76	-4.11	-1.29	-5.42	-1.27	-5.33	5.48	1.8	11.6
.150	-1.94	-2.92	3.58	86.46	-3.97	-1.10	-5.15	-1.08	-5.07	5.19	1.6	11.0
.160	-1.08	-2.91	2.38	86.22	-3.77	-.90	-4.80	-.89	-4.74	4.82	1.5	10.2
.170	-.22	-2.92	1.22	86.03	-3.52	-.72	-4.38	-.71	-4.33	4.39	1.3	9.3
.180	.64	-2.95	.13	85.89	-3.20	-.55	-3.90	-.55	-3.87	3.91	1.1	8.2
.190	1.50	-2.98	-.90	85.79	-2.84	-.40	-3.39	-.41	-3.38	3.40	1.0	7.1
.200	2.36	-3.03	-1.84	85.72	-2.45	-.29	-2.86	-.30	-2.87	2.88	.8	6.0
.210	3.21	-3.09	-2.68	85.68	-2.02	-.20	-2.34	-.21	-2.36	2.37	.7	4.9
.220	4.07	-3.15	-3.42	85.65	-1.58	-.14	-1.83	-.15	-1.86	1.87	.5	3.8
.230	4.92	-3.22	-4.07	85.62	-1.13	-.11	-1.35	-.12	-1.40	1.40	.4	2.8
.240	5.78	-3.29	-4.61	85.60	-.68	-.10	-.92	-.11	-.98	.98	.4	1.9
.250	6.63	-3.37	-5.06	85.57	-.25	-.12	-.55	-.13	-.61	.62	.3	1.1
.260	7.48	-3.45	-5.42	85.53	.17	-.15	-.24	-.15	-.31	.35	.4	.5
.270	8.33	-3.53	-5.72	85.47	.57	-.19	-.00	-.19	-.08	.21	.4	-.0
.280	9.18	-3.61	-5.95	85.40	.95	-.23	.16	-.24	.08	.25	.5	-.4
.290	10.03	-3.69	-6.14	85.31	1.29	-.29	.25	-.29	.17	.33	.5	-.6
.300	10.88	-3.77	-6.30	85.21	1.62	-.34	.26	-.33	.19	.39	.6	-.6
.310	11.73	-3.84	-6.45	85.09	1.91	-.38	.21	-.38	.15	.41	.8	-.5
.320	12.58	-3.92	-6.60	84.95	2.19	-.42	.10	-.41	.05	.41	.9	-.3
.330	13.42	-3.99	-6.77	84.80	2.46	-.45	-.06	-.44	-.10	.45	1.0	.0

TABLE B.25

SUMMARY OF VEHICLE ACCELEROMETER DATA FOR CRASH TEST RF-15

TIME (SEC)	DISPLACEMENT-(FT) LONG.	DISPLACEMENT-(FT) LAT.	HEADING ANGLE-(DEG)	VELOCITY-(FPS) LONG.	VELOCITY-(FPS) LAT.	VEHICLE ACCELERATION-(G'S) AT TIME T LONG.	AT TIME T LAT.	AT TIME T VERT.	AVERAGE OVER .05 SEC. LONG.	AVERAGE OVER .05 SEC. LAT.	AVERAGE OVER .05 SEC. RESULT	AVERAGE OVER .05 SEC. VERT.
.0000	-15.20	-4.94	13.52	91.90	-.84	-1.01	-1.42	-1.20	-1.01	-1.42	1.74	-1.20
.0100	-14.31	-4.73	13.47	91.37	-.80	2.57	.39	-.53	-.14	-.74	.75	-.49
.0200	-13.42	-4.53	13.43	91.51	-.69	-1.96	-1.18	.26	-.12	-.03	.13	-.60
.0300	-12.53	-4.32	13.52	91.51	-.59	.47	-.38	.39	-.50	.14	.52	.97
.0400	-11.63	-4.12	13.55	91.56	-.76	-.68	2.43	-1.91	-.70	-.49	.85	.19
.0500	-10.74	-3.91	13.62	91.25	-.56	-2.91	-.55	6.66	-.50	-1.20	1.30	-.09
.0600	-9.86	-3.70	13.77	90.49	-1.34	1.55	-2.75	-4.46	-1.15	-2.35	2.61	.53
.0700	-8.98	-3.50	13.84	89.79	-2.75	-.95	-4.76	-1.12	-.77	-3.68	3.76	-.98
.0800	-8.11	-3.32	13.74	88.51	-4.02	-2.77	-6.10	3.48	-1.18	-6.90	7.00	-3.13
.0900	-7.24	-3.16	13.40	87.68	-5.53	1.22	-4.26	-9.44	-3.47	-7.19	7.99	-.25
.1000	-6.38	-3.02	12.84	86.70	-6.63	-4.94	-16.61	-4.13	-4.49	-9.82	10.79	2.56
.1100	-5.52	-2.91	12.15	84.76	-8.74	-9.94	-4.23	9.97	-2.54	-7.91	8.31	-3.15
.1200	-4.69	-2.84	11.20	82.34	-11.11	-6.02	-17.88	12.90	-4.15	-7.14	8.26	1.94
.1300	-3.86	-2.81	9.81	82.31	-11.15	6.96	3.40	-25.05	-3.77	-5.02	6.28	3.43
.1400	-3.03	-2.78	8.44	81.96	-10.22	-6.83	-.38	16.03	-1.07	-4.59	4.72	-.96
.1500	-2.20	-2.76	7.03	81.48	-9.24	-3.04	-6.03	3.32	-.37	-1.70	1.74	-2.04
.1600	-1.39	-2.76	5.67	81.20	-8.75	3.58	-2.08	-12.00	-1.89	-3.19	3.71	2.76
.1700	-.57	-2.77	4.43	81.22	-7.54	-2.50	-3.42	7.50	-.43	-4.07	4.09	-.11
.1800	.25	-2.79	3.11	81.47	-7.67	-.68	-4.03	-1.03	.04	-3.40	3.40	-1.17
.1900	1.06	-2.83	1.97	81.61	-7.72	.47	-4.76	1.64	-1.04	-3.72	3.86	1.43
.2000	1.89	-2.89	1.01	82.09	-7.21	-.68	-2.69	-1.95	-.93	-3.70	3.82	.15
.2100	2.71	-2.95	.33	81.92	-7.47	-1.83	-3.69	.97	-.81	-3.44	3.53	.30
.2200	3.53	-3.03	-.14	81.78	-8.03	-1.96	-3.36	1.10	-1.27	-2.43	2.74	-.71
.2300	4.34	-3.11	-.51	81.51	-8.21	-.07	-2.69	-.28	-1.05	-1.91	2.18	-.47
.2400	5.15	-3.21	-.79	81.30	-8.17	-1.83	.26	-3.38	-.95	-1.16	1.50	-.57
.2500	5.97	-3.30	-1.08	81.35	-7.79	.41	-.08	-.74	-1.38	-.29	1.41	-.64
.2600	6.78	-3.39	-1.41	81.34	-7.02	-1.28	.06	.47	-1.33	-.31	1.36	-.96
.2700	7.59	-3.48	-1.71	80.67	-6.29	-4.12	.99	.72	-1.03	-.55	1.17	-.42
.2800	8.39	-3.57	-2.10	80.29	-6.07	.20	-2.79	-1.87	-1.04	-.85	1.34	.07
.2900	9.19	-3.66	-2.44	80.11	-5.88	-.34	-.95	-.70	-.80	-1.17	1.42	-.37
.3000	9.99	-3.76	-2.79	80.11	-5.86	.34	-1.55	1.73	.15	-1.15	1.16	-.69
.3100	10.78	-3.86	-3.09	80.17	-5.95	-.07	-1.58	-1.75	-.07	-.73	.74	.08

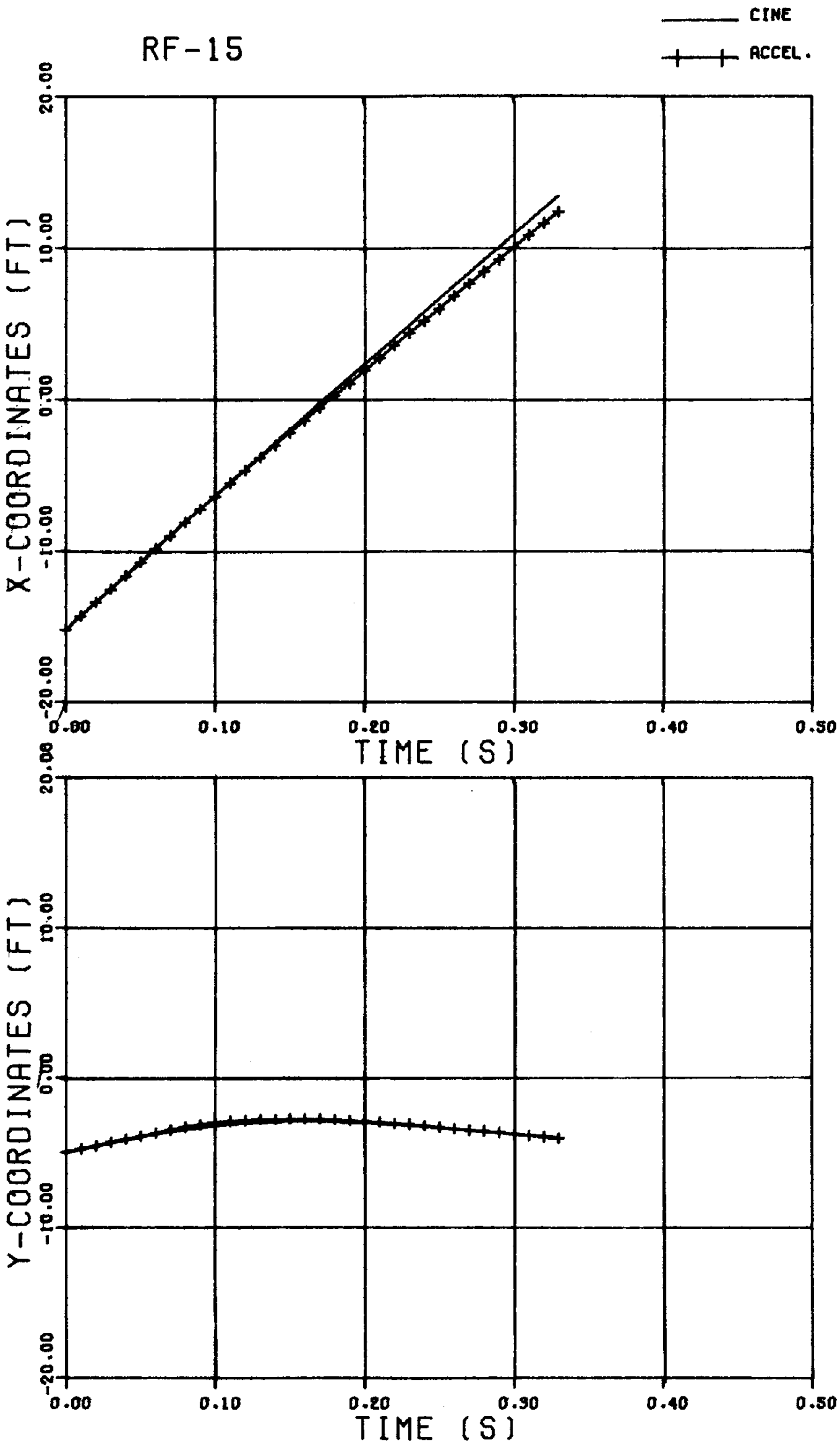


FIGURE B.41 VEHICLE X AND Y DISPLACEMENT HISTORIES FOR CRASH TEST RF-15

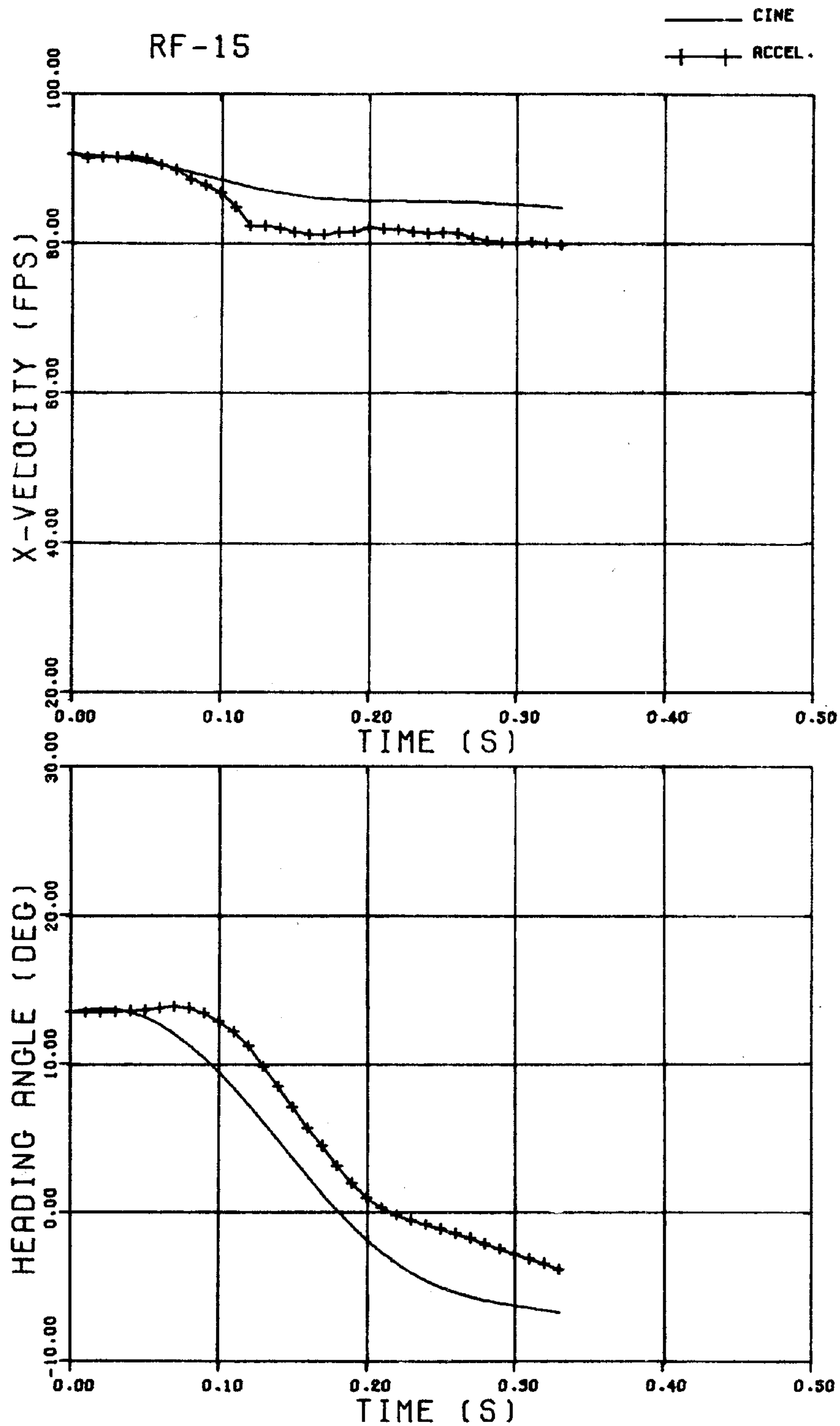


FIGURE B.42 VEHICLE X VELOCITY AND HEADING ANGLE HISTORIES FOR CRASH TEST RF-15

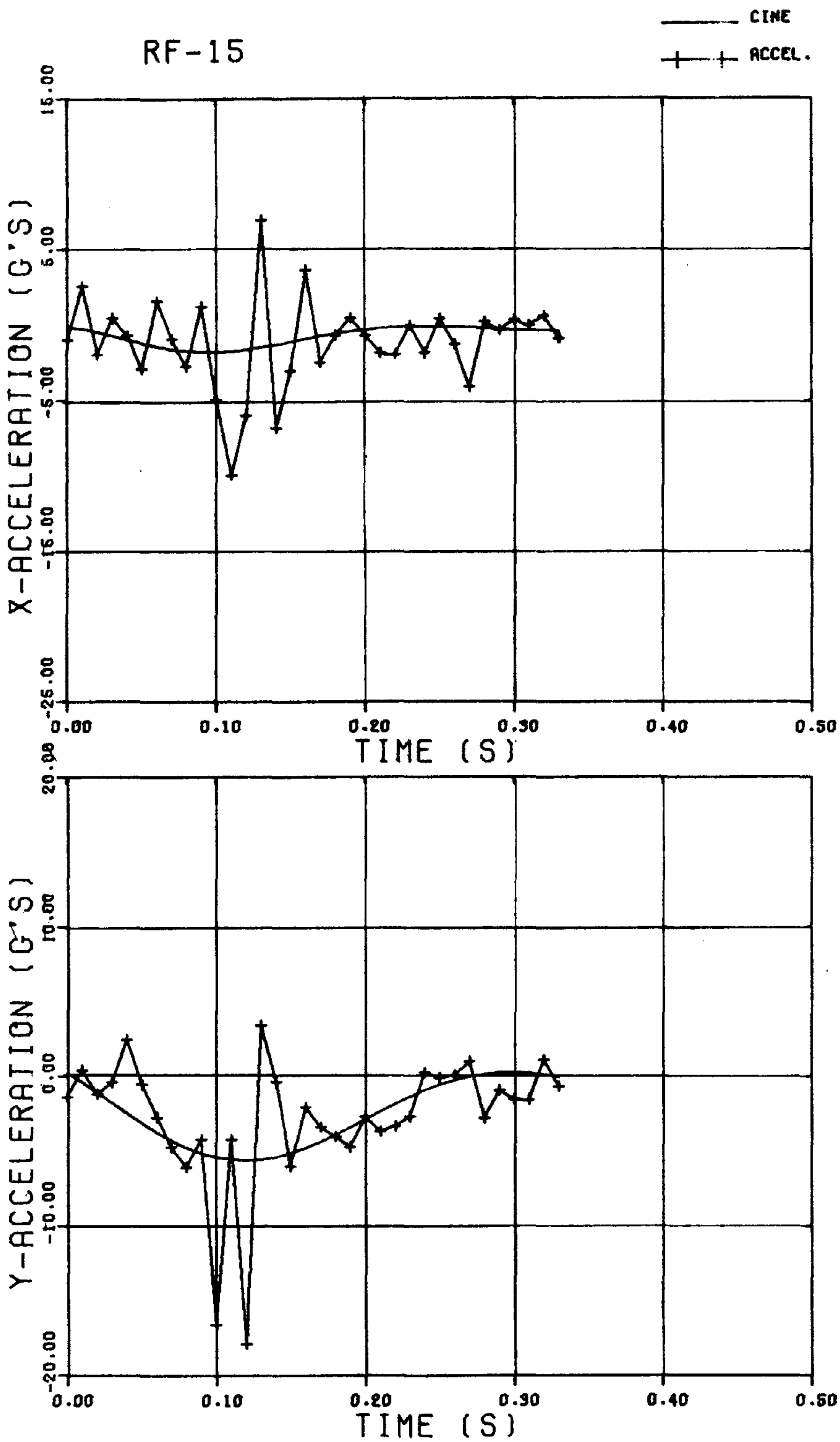


FIGURE B. 43 VEHICLE X AND Y ACCELERATION HISTORIES FOR CRASH TEST RF-15

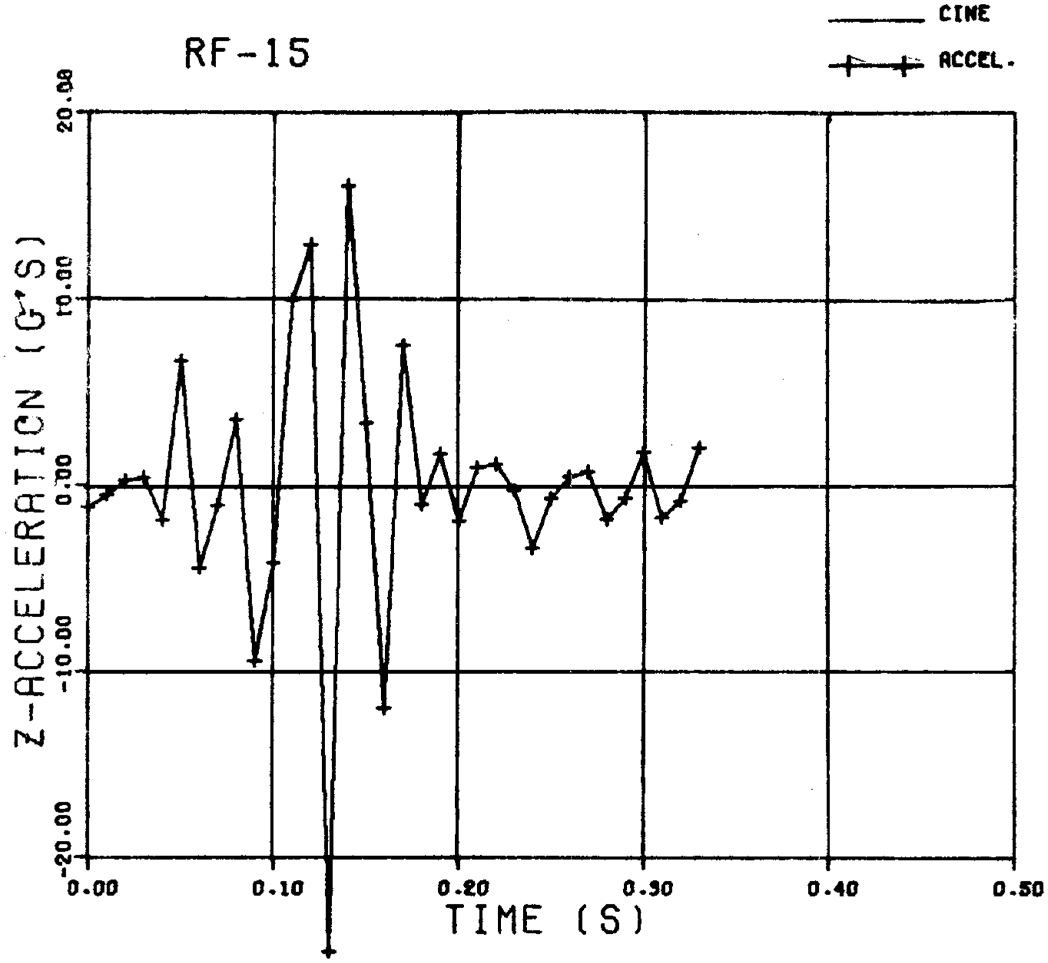


FIGURE B.44 VEHICLE Z ACCELERATION HISTORY FOR CRASH TEST RF-15

TABLE B.26

SUMMARY OF VEHICLE CINE DATA FOR CRASH TEST RF-16

TIME AFTER IMPACT(SEC)	VEHICLE C. G. COORDINATES(FT) X	Y	HEADING ANGLE (DEG)	VEHICLE VELOCITY (FT/SEC) LONG	LAT	VEHICLE ACCELERATION(G'S) AT TIME T LONG	LAT	AVERAGE OVER .05 SEC. LONG	LAT	RESULT	APPROX. BARRIER FORCES(KIPS) X	Y
0.000	-7.34	-9.54	25.75	91.98	.50	.14	.56	.10	.60	.60	.5	-2.5
.010	-6.51	-7.18	25.78	91.88	.35	-.76	-1.19	-.74	-1.02	1.26	.7	6.1
.020	-5.69	-6.79	25.80	91.49	-.32	-1.65	-2.76	-1.58	-2.51	2.97	1.2	13.9
.030	-4.86	-6.40	25.79	90.83	-1.41	-2.46	-4.08	-2.36	-3.79	4.46	1.9	20.6
.040	-4.04	-6.02	25.72	89.92	-2.79	-3.17	-5.11	-3.05	-4.80	5.69	2.8	25.9
.050	-3.22	-5.67	25.56	88.82	-4.32	-3.74	-5.83	-3.60	-5.54	6.61	3.7	29.8
.060	-2.40	-5.33	25.30	87.56	-5.87	-4.16	-6.27	-4.02	-6.00	7.22	4.7	32.3
.070	-1.58	-5.03	24.92	86.22	-7.35	-4.42	-6.45	-4.28	-6.21	7.54	5.6	33.4
.080	-.77	-4.74	24.42	84.85	-8.67	-4.53	-6.40	-4.40	-6.20	7.60	6.4	33.4
.090	.03	-4.48	23.77	83.50	-9.75	-4.49	-6.16	-4.38	-6.01	7.43	7.1	32.3
.100	.83	-4.25	23.00	82.21	-10.56	-4.34	-5.78	-4.23	-5.67	7.08	7.5	30.4
.110	1.63	-4.03	22.10	81.02	-11.06	-4.08	-5.29	-3.99	-5.22	6.57	7.7	27.9
.120	2.42	-3.84	21.08	79.96	-11.24	-3.74	-4.74	-3.67	-4.71	5.97	7.7	25.0
.130	3.20	-3.67	19.96	79.04	-11.12	-3.35	-4.15	-3.29	-4.16	5.31	7.5	21.9
.140	3.98	-3.51	18.75	78.26	-10.70	-2.92	-3.57	-2.88	-3.60	4.61	7.0	18.7
.150	4.75	-3.37	17.47	77.62	-10.02	-2.48	-3.00	-2.46	-3.06	3.93	6.3	15.7
.160	5.52	-3.23	16.15	77.12	-9.12	-2.04	-2.49	-2.03	-2.57	3.27	5.5	12.8
.170	6.29	-3.11	14.79	76.73	-8.03	-1.61	-2.03	-1.62	-2.13	2.67	4.5	10.3
.180	7.05	-3.00	13.43	76.46	-6.80	-1.21	-1.66	-1.23	-1.76	2.14	3.4	8.2
.190	7.80	-2.89	12.08	76.27	-5.48	-.85	-1.36	-.87	-1.47	1.70	2.3	6.5
.200	8.56	-2.78	10.75	76.16	-4.12	-.51	-1.16	-.55	-1.26	1.37	1.3	5.3
.210	9.32	-2.68	9.47	76.12	-2.77	-.23	-1.04	-.27	-1.13	1.16	.2	4.6
.220	10.07	-2.59	8.25	76.14	-1.47	.02	-1.00	-.03	-1.09	1.09	-.7	4.3
.230	10.83	-2.49	7.09	76.19	-.26	.22	-1.05	.17	-1.12	1.13	-1.5	4.4
.240	11.58	-2.41	6.02	76.28	.82	.37	-1.16	.32	-1.22	1.26	-2.1	4.8
.250	12.34	-2.32	5.02	76.40	1.75	.47	-1.32	.42	-1.37	1.43	-2.5	5.5
.260	13.10	-2.24	4.11	76.52	2.51	.52	-1.53	.47	-1.56	1.63	-2.7	6.5
.270	13.87	-2.16	3.28	76.65	3.08	.53	-1.77	.48	-1.78	1.85	-2.7	7.5
.280	14.63	-2.09	2.54	76.78	3.46	.49	-2.02	.44	-2.02	2.07	-2.5	8.7
.290	15.40	-2.02	1.88	76.88	3.65	.40	-2.28	.36	-2.26	2.29	-2.1	9.8
.300	16.17	-1.96	1.30	76.95	3.66	.28	-2.52	.24	-2.49	2.50	-1.4	10.9
.310	16.93	-1.91	.78	76.98	3.51	.12	-2.73	.09	-2.70	2.70	-.7	11.8
.320	17.70	-1.87	.32	76.97	3.22	-.06	-2.92	-.08	-2.87	2.87	.2	12.6
.330	18.47	-1.84	-.08	76.89	2.80	-.26	-3.06	-.27	-3.01	3.02	1.2	13.3
.340	19.24	-1.82	-.45	76.76	2.29	-.47	-3.15	-.46	-3.10	3.13	2.1	13.6
.350	20.01	-1.81	-.78	76.56	1.71	-.67	-3.19	-.65	-3.14	3.21	3.1	13.8
.360	20.77	-1.81	-1.09	76.31	1.09	-.85	-3.19	-.83	-3.14	3.25	4.0	13.7
.370	21.53	-1.82	-1.37	76.01	.45	-1.01	-3.13	-.97	-3.09	3.24	4.7	13.5
.380	22.29	-1.83	-1.65	75.66	-.18	-1.13	-3.04	-1.09	-3.00	3.20	5.3	13.0
.390	23.05	-1.86	-1.92	75.28	-.78	-1.21	-2.91	-1.16	-2.88	3.11	5.7	12.4
.400	23.80	-1.90	-2.19	74.89	-1.34	-1.24	-2.75	-1.18	-2.74	2.98	5.8	11.7

TABLE B.26 (Cont'd)

SUMMARY OF VEHICLE CINE DATA FOR CRASH TEST RF-16

.410	24.54	-1.95	-2.46	74.50	-1.85	-1.21	-2.58	-1.15	-2.57	2.82	5.7	11.0
.420	25.28	-2.00	-2.72	74.14	-2.31	-1.12	-2.40	-1.07	-2.40	2.63	5.4	10.2
.430	26.02	-2.06	-2.98	73.81	-2.72	-.96	-2.22	-.93	-2.23	2.42	4.8	9.4
.440	26.76	-2.13	-3.24	73.53	-3.08	-.79	-2.05	-.75	-2.08	2.21	3.9	8.7
.450	27.49	-2.21	-3.48	73.33	-3.40	-.56	-1.91	-.52	-1.94	2.01	2.9	8.1
.460	28.22	-2.29	-3.71	73.21	-3.70	-.29	-1.79	-.28	-1.82	1.84	1.8	7.7
.470	28.94	-2.38	-3.92	73.17	-3.99	-.01	-1.70	-.01	-1.73	1.73	.6	7.3
.480	29.67	-2.47	-4.11	73.23	-4.29	.26	-1.64	.24	-1.67	1.69	-.6	7.2
.490	30.40	-2.57	-4.26	73.36	-4.62	.52	-1.62	.48	-1.64	1.71	-1.7	7.2
.500	31.13	-2.67	-4.38	73.58	-4.99	.73	-1.62	.67	-1.63	1.77	-2.6	7.2
.510	31.86	-2.78	-4.46	73.85	-5.41	.88	-1.64	.80	-1.64	1.83	-3.3	7.4
.520	32.59	-2.89	-4.49	74.15	-5.90	.95	-1.66	.85	-1.65	1.86	-3.5	7.5
.530	33.33	-3.01	-4.49	74.45	-6.44	.91	-1.68	.81	-1.64	1.83	-3.4	7.6
.540	34.07	-3.14	-4.45	74.72	-7.03	.78	-1.66	.68	-1.61	1.74	-2.8	7.4
.550	34.81	-3.27	-4.36	74.92	-7.64	.54	-1.59	.46	-1.52	1.59	-1.8	7.1
.560	35.55	-3.40	-4.29	75.04	-8.25	.22	-1.45	.18	-1.35	1.36	-.5	6.3
.570	36.29	-3.54	-4.19	75.03	-8.82	-.14	-1.21	-.12	-1.10	1.10	1.0	5.2
.580	37.03	-3.69	-4.08	74.91	-9.29	-.49	-.85	-.38	-.73	.83	2.4	3.5
.590	37.77	-3.84	-3.99	74.69	-9.62	-.74	-.37	-.50	-.25	.56	3.3	1.4
.600	38.51	-3.98	-3.92	74.43	-9.74	-.76	.23	-.35	.34	.49	3.2	-1.2

TABLE B.27

SUMMARY OF VEHICLE ACCELEROMETER DATA FOR CRASH TEST RF-16

TIME (SEC)	DISPLACEMENT-(FT) LONG.	DISPLACEMENT-(FT) LAT.	HEADING ANGLE-(DEG)	VELOCITY-(FPS) LONG.	VELOCITY-(FPS) LAT.	VEHICLE ACCELERATION-(G'S) AT TIME T LONG.	AT TIME T LAT.	AT TIME T VERT.	AVERAGE OVER .05 SEC. LONG.	AVERAGE OVER .05 SEC. LAT.	AVERAGE OVER .05 SEC. RESULT	AVERAGE OVER .05 SEC. VERT.
.0000	-7.34	-7.59	25.75	91.98	.50	1.40	-.33	-.57	1.40	-.33	1.44	-.57
.0100	-6.52	-7.19	25.73	89.46	.56	-8.81	-9.58	10.97	-1.86	-6.15	6.43	2.93
.0200	-5.71	-6.80	25.64	89.48	-1.64	1.84	-8.54	-1.59	-1.90	-3.30	3.80	.22
.0300	-4.89	-6.44	25.48	88.87	-2.45	1.40	-2.90	-8.12	-4.66	-4.41	6.42	1.34
.0400	-4.08	-6.08	25.25	88.22	-2.39	-5.29	4.88	.40	-3.73	-3.43	5.07	.31
.0500	-3.28	-5.73	24.97	86.50	-2.82	-12.42	-5.90	5.02	-6.40	-4.50	7.83	1.11
.0600	-2.48	-5.40	24.73	84.80	-4.33	-4.15	-4.69	5.87	-9.46	-6.85	11.67	4.84
.0700	-1.70	-5.10	24.24	82.86	-5.94	-11.54	-13.90	2.36	-10.08	-11.03	14.94	1.37
.0800	-.92	-4.84	23.60	79.93	-8.19	-13.87	-14.61	10.53	-10.05	-11.21	15.06	.68
.0900	-.16	-4.62	22.75	77.67	-10.80	-8.42	-16.04	-16.91	-11.03	-12.07	16.35	-.74
.1000	.59	-4.45	21.87	74.37	-13.65	-12.25	-6.83	1.56	-10.37	-10.84	15.00	-1.14
.1100	1.33	-4.32	20.81	72.38	-15.37	-9.08	-8.97	-1.24	-7.21	-6.43	9.66	-2.74
.1200	2.05	-4.22	19.50	70.67	-16.04	-8.24	-7.76	.36	-6.01	-2.02	6.34	-1.07
.1300	2.77	-4.14	18.25	70.44	-14.97	1.92	7.45	2.54	-3.40	-1.08	3.57	-.06
.1400	3.48	-4.06	16.84	70.46	-11.85	-2.39	6.02	-8.57	-2.29	.51	2.35	-1.17
.1500	4.19	-3.96	15.53	70.55	-9.92	.78	-2.16	6.62	-.75	1.90	2.04	.08
.1600	4.89	-3.87	14.22	70.36	-8.66	-3.53	-.98	-6.79	-.79	.90	1.20	-1.89
.1700	5.60	-3.79	12.97	70.14	-7.09	-.54	-.83	6.58	.16	-.14	.22	1.27
.1800	6.29	-3.70	11.76	70.00	-5.58	1.75	2.45	-7.28	-1.26	-.68	1.44	-1.44
.1900	6.99	-3.61	10.57	70.61	-3.97	2.37	.81	7.24	-.72	-1.00	1.23	-.91
.2000	7.69	-3.52	9.43	69.89	-2.76	-6.35	-4.87	-6.97	-1.06	-1.69	2.00	-4.63
.2100	8.39	-3.43	8.59	70.28	-2.31	-.80	-2.55	-4.13	-.97	-1.06	1.44	.07
.2200	9.08	-3.36	7.64	70.04	-2.00	-2.26	-4.30	-12.03	-1.05	-1.69	1.99	-2.58
.2300	9.78	-3.28	6.65	70.42	-.67	2.19	5.59	16.21	1.78	.59	1.88	.58
.2400	10.48	-3.21	5.85	69.53	.27	1.97	-2.33	-5.99	4.18	-1.31	4.38	-4.00
.2500	11.18	-3.13	5.18	70.67	.87	7.82	6.52	8.84	4.57	-.75	4.64	2.24
.2600	11.88	-3.06	4.21	70.23	.38	11.17	-12.04	-27.04	5.02	-2.39	5.56	-3.66
.2700	12.58	-3.01	3.42	70.02	.35	-.28	-1.48	19.19	3.85	-1.01	3.98	1.39
.2800	13.28	-2.97	2.86	70.14	.39	4.43	-2.62	-13.27	2.50	-2.55	3.57	-1.59
.2900	13.98	-2.93	2.50	69.28	1.04	-3.88	4.59	19.23	.75	.35	.83	6.42
.3000	14.67	-2.88	2.08	69.47	2.26	1.04	-1.19	-6.08	.33	-.30	.45	-.84
.3100	15.37	-2.83	1.80	70.02	2.83	2.45	2.45	13.01	-.41	.33	.52	4.54
.3200	16.07	-2.78	1.60	70.38	2.62	-2.39	-4.73	-17.09	.07	-1.33	1.34	-1.30
.3300	16.77	-2.74	1.54	70.21	1.78	.74	.52	13.64	-.07	-1.52	1.52	1.73
.3400	17.47	-2.70	1.30	69.89	1.56	-1.51	-3.73	-9.99	-1.06	-2.43	2.65	-1.95
.3500	18.17	-2.68	1.07	69.27	.72	.34	-2.12	9.06	-.75	-1.69	1.85	3.22
.3600	18.86	-2.66	.87	68.94	.37	-2.48	-2.12	-5.37	-.95	-2.43	2.61	-.87
.3700	19.54	-2.65	.71	68.29	.10	-.85	-1.01	8.75	-.78	-1.83	1.99	1.69
.3800	20.23	-2.64	.52	68.00	-.27	-.28	-3.19	-6.79	-.63	-1.81	1.92	-.80
.3900	20.90	-2.65	.28	67.54	-.88	-.63	-.69	2.80	-.03	-2.14	2.14	-.07
.4000	21.58	-2.65	.03	67.39	-.86	1.09	-2.05	-3.42	.26	-2.66	2.67	-1.33
.4100	22.25	-2.66	-.21	67.33	-1.42	.52	-3.76	-1.68	.58	-3.06	3.12	-1.15
.4200	22.93	-2.69	-.37	67.35	-2.10	.60	-3.62	2.45	.64	-3.38	3.44	-1.32
.4300	23.60	-2.72	-.48	67.36	-3.32	1.31	-5.19	-5.90	.28	-3.26	3.27	-1.23
.4400	24.27	-2.76	-.56	67.03	-4.11	-.32	-2.26	1.96	-.27	-2.52	2.53	-.10
.4500	24.94	-2.81	-.61	66.77	-4.81	-.72	-1.48	-2.97	-.56	-2.11	2.18	-1.31
.4600	25.60	-2.87	-.79	66.40	-4.67	-2.21	-.05	3.96	-.94	-1.36	1.66	1.43
.4700	26.27	-2.93	-.86	66.08	-5.11	-.85	-1.55	-3.59	-.69	-.85	1.09	-.44

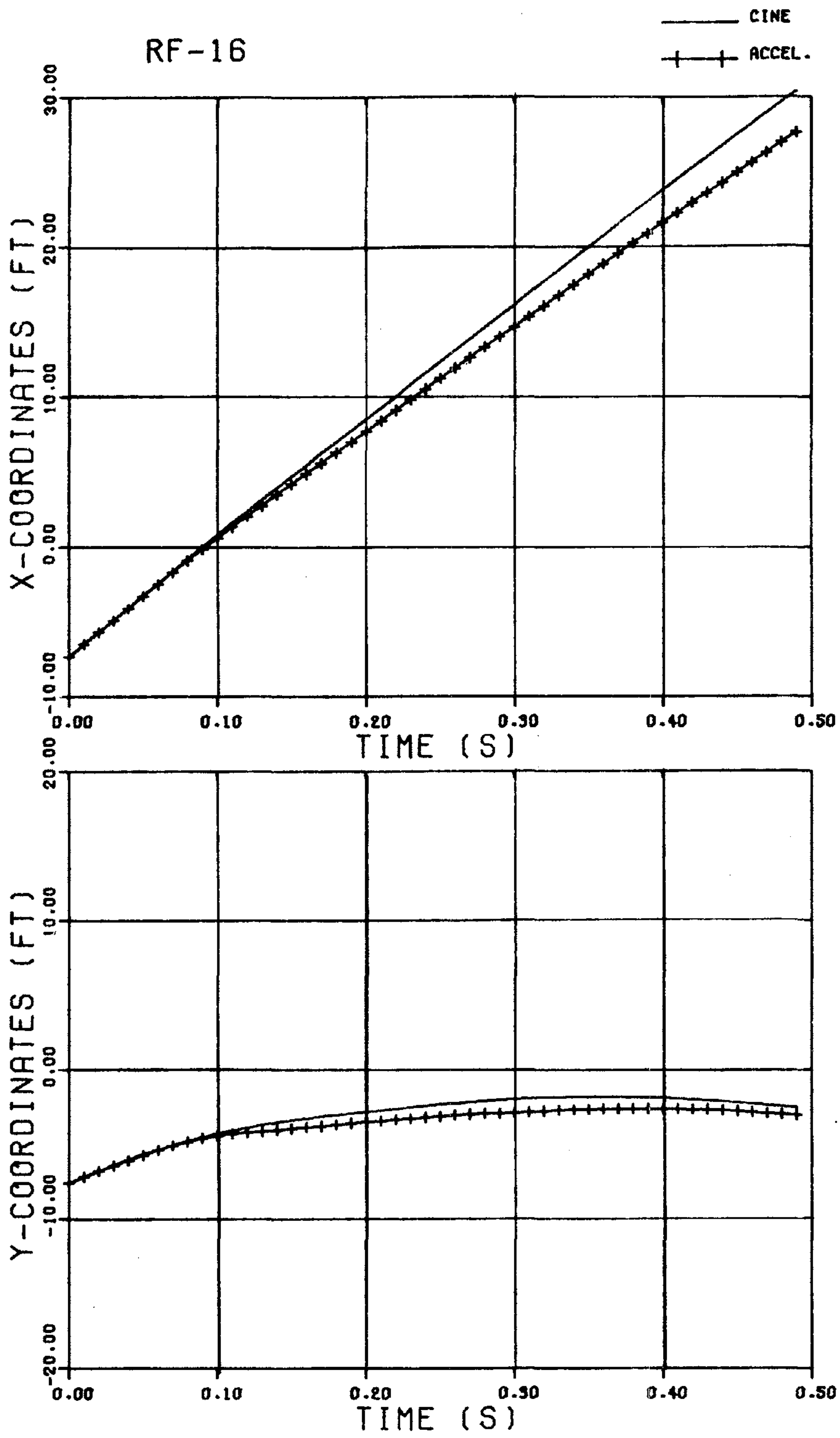


FIGURE B. 45 VEHICLE X AND Y DISPLACEMENT HISTORIES FOR CRASH TEST RF-16

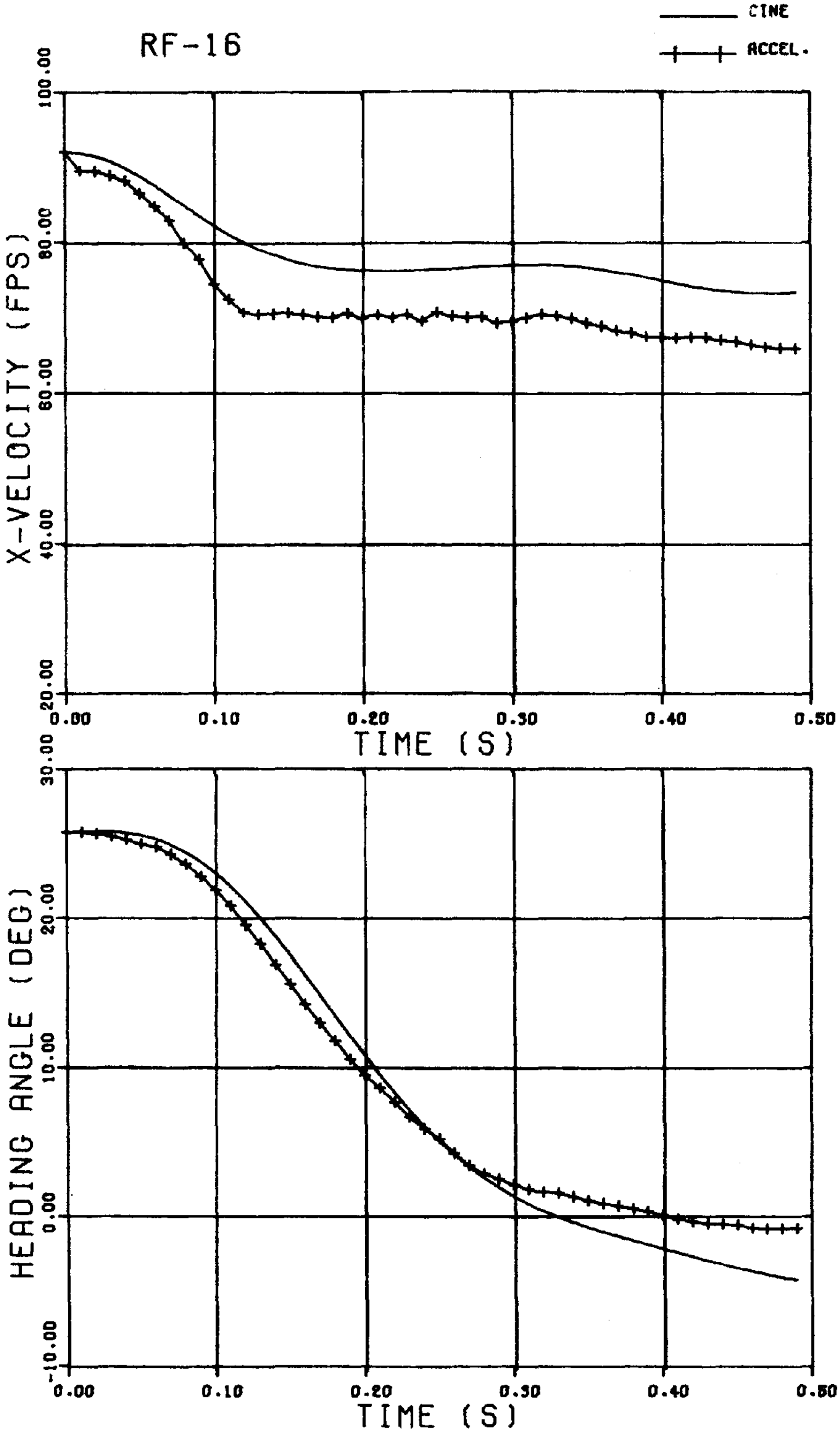


FIGURE B.46 VEHICLE X VELOCITY AND HEADING ANGLE HISTORIES FOR CRASH TEST RF-16

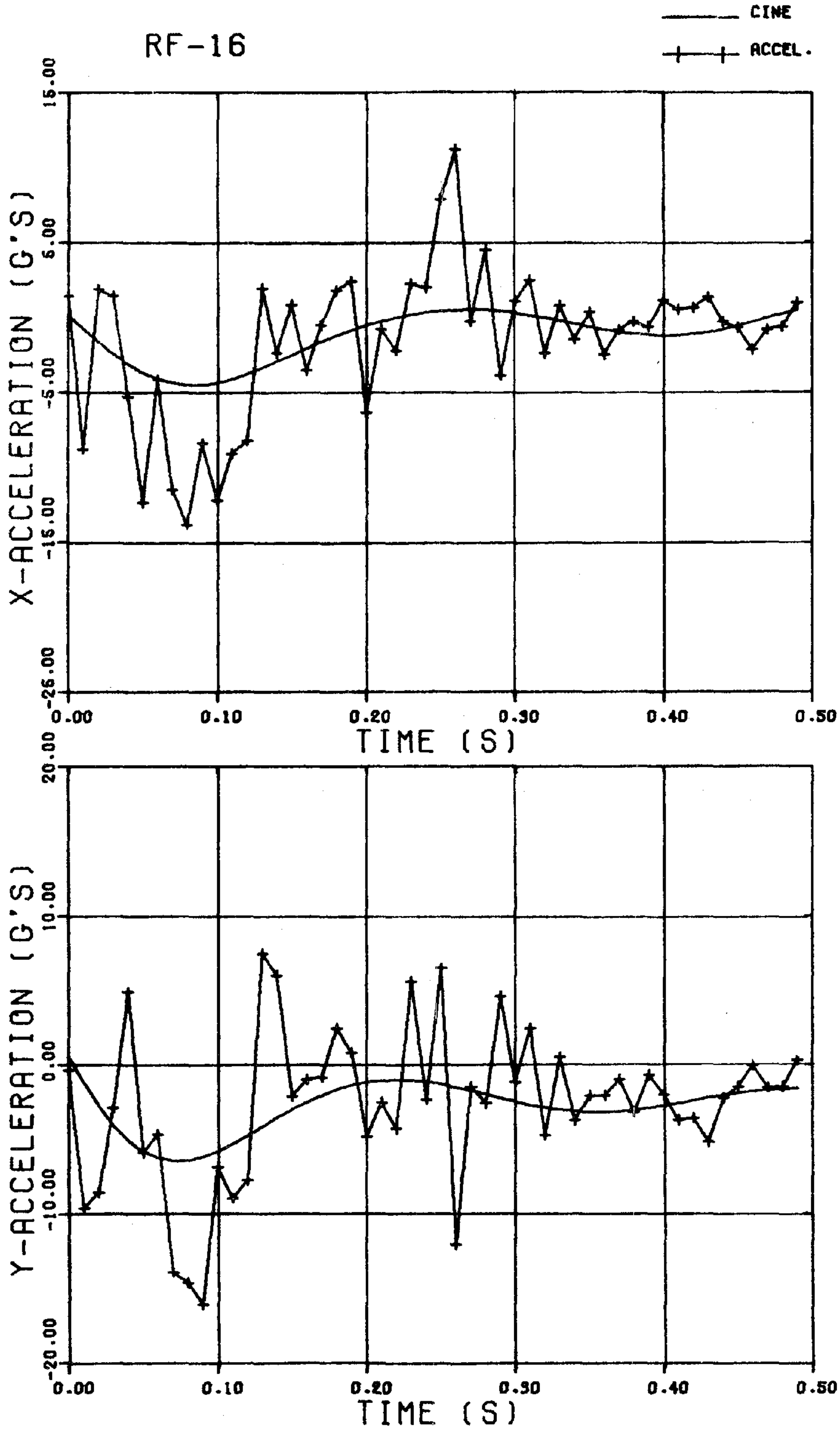


FIGURE B.47 VEHICLE X AND Y ACCELERATION HISTORIES FOR CRASH TEST RF-16

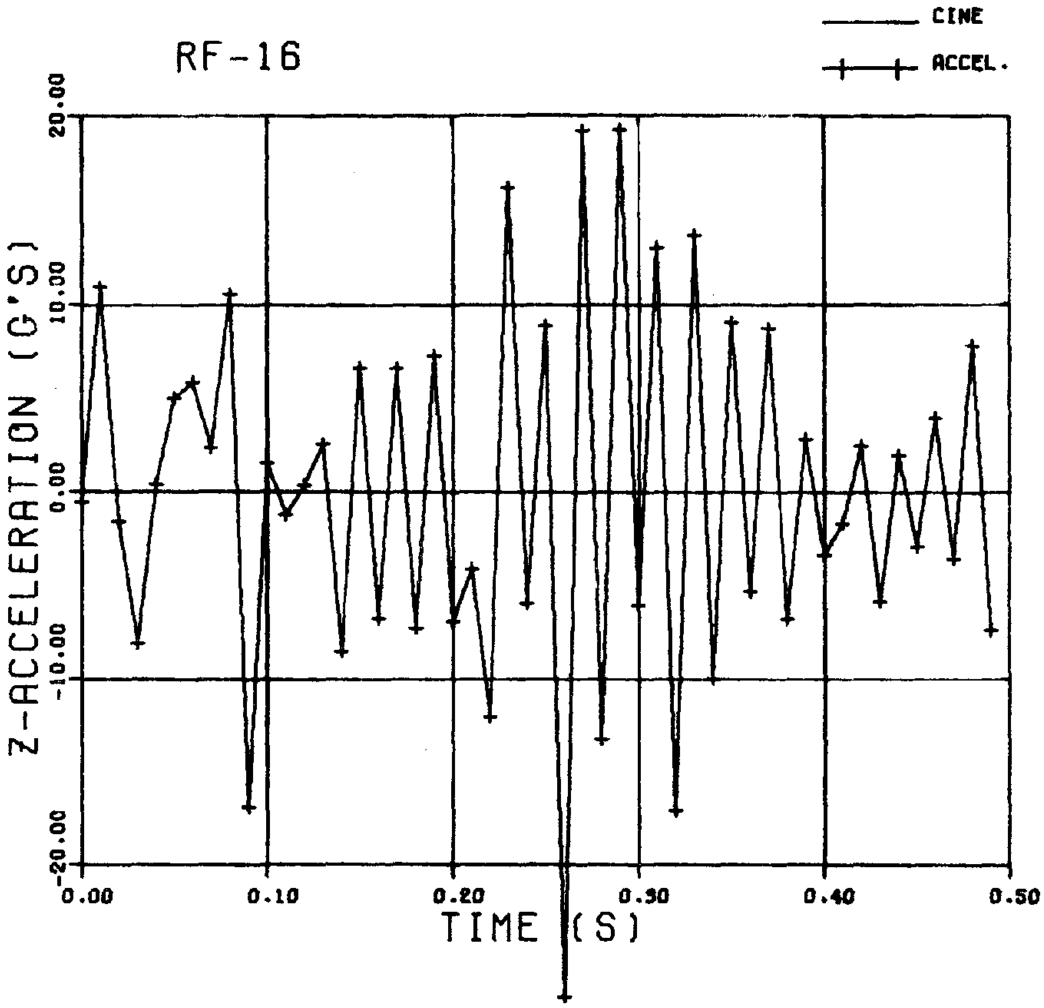


FIGURE B.48 VEHICLE Z ACCELERATION HISTORY FOR CRASH TEST RF-16

TABLE B.28

SUMMARY OF VEHICLE CINE DATA FOR CRASH TEST RF-17

TIME AFTER IMPACT(SEC)	VEHICLE C. G. COORDINATES(FT) X	Y	HEADING ANGLE (DEG)	VEHICLE VELOCITY (FT/SEC) LONG	LAT	VEHICLE ACCELERATION(G'S) AT TIME T LONG	LAT	AVERAGE OVER .05 SEC. LONG	LAT	RESULT	APPROX. BARRIER FORCES(KIPS) X	Y
0.000	-3.05	-6.62	28.60	70.40	-1.65	-.23	.56	-.27	.46	.53	2.1	-1.7
.010	-2.43	-6.30	28.91	70.21	-1.98	-.93	-.25	-.93	-.27	.97	3.1	3.0
.020	-1.80	-5.98	29.24	69.78	-2.60	-1.64	-1.06	-1.60	-1.03	1.90	4.1	7.7
.030	-1.18	-5.66	29.56	69.13	-3.45	-2.31	-1.83	-2.25	-1.76	2.86	4.9	12.2
.040	-.57	-5.36	29.83	68.26	-4.40	-2.93	-2.52	-2.86	-2.43	3.75	5.7	16.3
.050	.05	-5.06	30.02	67.21	-5.62	-3.48	-3.12	-3.39	-3.00	4.53	6.5	19.8
.060	.65	-4.78	30.10	66.01	-6.79	-3.93	-3.60	-3.84	-3.47	5.18	7.1	22.6
.070	1.26	-4.52	30.03	64.69	-7.93	-4.28	-3.96	-4.19	-3.84	5.68	7.7	24.8
.080	1.85	-4.27	29.80	63.30	-9.00	-4.53	-4.21	-4.44	-4.10	6.04	8.2	26.3
.090	2.44	-4.05	29.40	61.88	-9.94	-4.67	-4.36	-4.59	-4.25	6.26	8.6	27.2
.100	3.03	-3.84	28.81	60.48	-10.73	-4.71	-4.42	-4.64	-4.32	6.34	8.9	27.4
.110	3.61	-3.65	28.03	59.12	-11.33	-4.67	-4.39	-4.60	-4.31	6.30	9.1	27.0
.120	4.18	-3.48	27.06	57.83	-11.75	-4.54	-4.30	-4.49	-4.23	6.17	9.3	26.3
.130	4.74	-3.33	25.92	56.63	-11.97	-4.36	-4.14	-4.32	-4.09	5.95	9.4	25.1
.140	5.30	-3.20	24.60	55.54	-11.99	-4.13	-3.94	-4.10	-3.91	5.66	9.4	23.6
.150	5.85	-3.09	23.14	54.55	-11.81	-3.87	-3.71	-3.85	-3.69	5.33	9.4	22.0
.160	6.40	-2.99	21.54	53.68	-11.46	-3.59	-3.46	-3.58	-3.45	4.97	9.2	20.2
.170	6.94	-2.91	19.84	52.90	-10.94	-3.31	-3.19	-3.30	-3.20	4.60	9.1	18.4
.180	7.47	-2.84	18.04	52.21	-10.28	-3.04	-2.93	-3.03	-2.95	4.23	8.8	16.6
.190	7.99	-2.78	16.19	51.59	-9.51	-2.77	-2.68	-2.77	-2.71	3.87	8.5	14.9
.200	8.51	-2.73	14.30	51.04	-8.64	-2.53	-2.44	-2.53	-2.48	3.54	8.2	13.3
.210	9.03	-2.69	12.40	50.54	-7.71	-2.30	-2.24	-2.30	-2.28	3.24	7.8	11.9
.220	9.53	-2.66	10.52	50.07	-6.75	-2.08	-2.06	-2.09	-2.11	2.97	7.5	10.7
.230	10.03	-2.64	8.67	49.63	-5.78	-1.89	-1.92	-1.89	-1.97	2.73	7.0	9.7
.240	10.53	-2.63	6.89	49.22	-4.85	-1.71	-1.82	-1.71	-1.87	2.53	6.6	9.0
.250	11.02	-2.62	5.19	48.82	-3.96	-1.54	-1.75	-1.54	-1.80	2.37	6.1	8.4
.260	11.51	-2.62	3.58	48.45	-3.16	-1.38	-1.72	-1.38	-1.75	2.23	5.7	8.0
.270	11.99	-2.62	2.09	48.11	-2.45	-1.23	-1.71	-1.23	-1.74	2.13	5.2	7.8
.280	12.47	-2.63	.72	47.79	-1.86	-1.09	-1.72	-1.09	-1.74	2.06	4.7	7.7
.290	12.95	-2.65	-.51	47.49	-1.39	-.95	-1.75	-.95	-1.76	2.00	4.3	7.8
.300	13.42	-2.67	-1.60	47.23	-1.06	-.81	-1.78	-.82	-1.79	1.97	3.8	7.8
.310	13.89	-2.70	-2.55	47.01	-.86	-.69	-1.82	-.70	-1.81	1.94	3.4	7.9
.320	14.36	-2.73	-3.36	46.81	-.79	-.58	-1.84	-.58	-1.83	1.92	3.0	8.0
.330	14.83	-2.77	-4.02	46.65	-.84	-.47	-1.85	-.48	-1.83	1.89	2.7	8.1
.340	15.29	-2.81	-4.55	46.53	-1.00	-.38	-1.84	-.39	-1.81	1.85	2.4	8.0
.350	15.75	-2.86	-4.96	46.42	-1.26	-.31	-1.80	-.32	-1.77	1.80	2.1	7.9
.360	16.22	-2.92	-5.25	46.34	-1.59	-.25	-1.72	-.26	-1.69	1.71	1.8	7.5
.370	16.67	-2.98	-5.43	46.27	-1.98	-.21	-1.62	-.22	-1.58	1.60	1.6	7.1
.380	17.13	-3.04	-5.52	46.21	-2.41	-.18	-1.48	-.20	-1.44	1.46	1.4	6.5
.390	17.59	-3.11	-5.54	46.16	-2.85	-.17	-1.30	-.19	-1.27	1.29	1.3	5.7
.400	18.05	-3.19	-5.49	46.10	-3.27	-.18	-1.10	-.19	-1.07	1.09	1.3	4.8
.410	18.50	-3.27	-5.39	46.03	-3.67	-.20	-.87	-.21	-.85	.88	1.2	3.8
.420	18.96	-3.35	-5.25	45.95	-4.02	-.23	-.63	-.24	-.62	.66	1.3	2.7
.430	19.41	-3.43	-5.10	45.85	-4.30	-.26	-.37	-.27	-.38	.47	1.3	1.6
.440	19.86	-3.51	-4.94	45.76	-4.51	-.31	-.13	-.31	-.15	.35	1.4	.4
.450	20.31	-3.60	-4.78	45.64	-4.64	-.36	.10	-.36	.07	.37	1.5	-.6

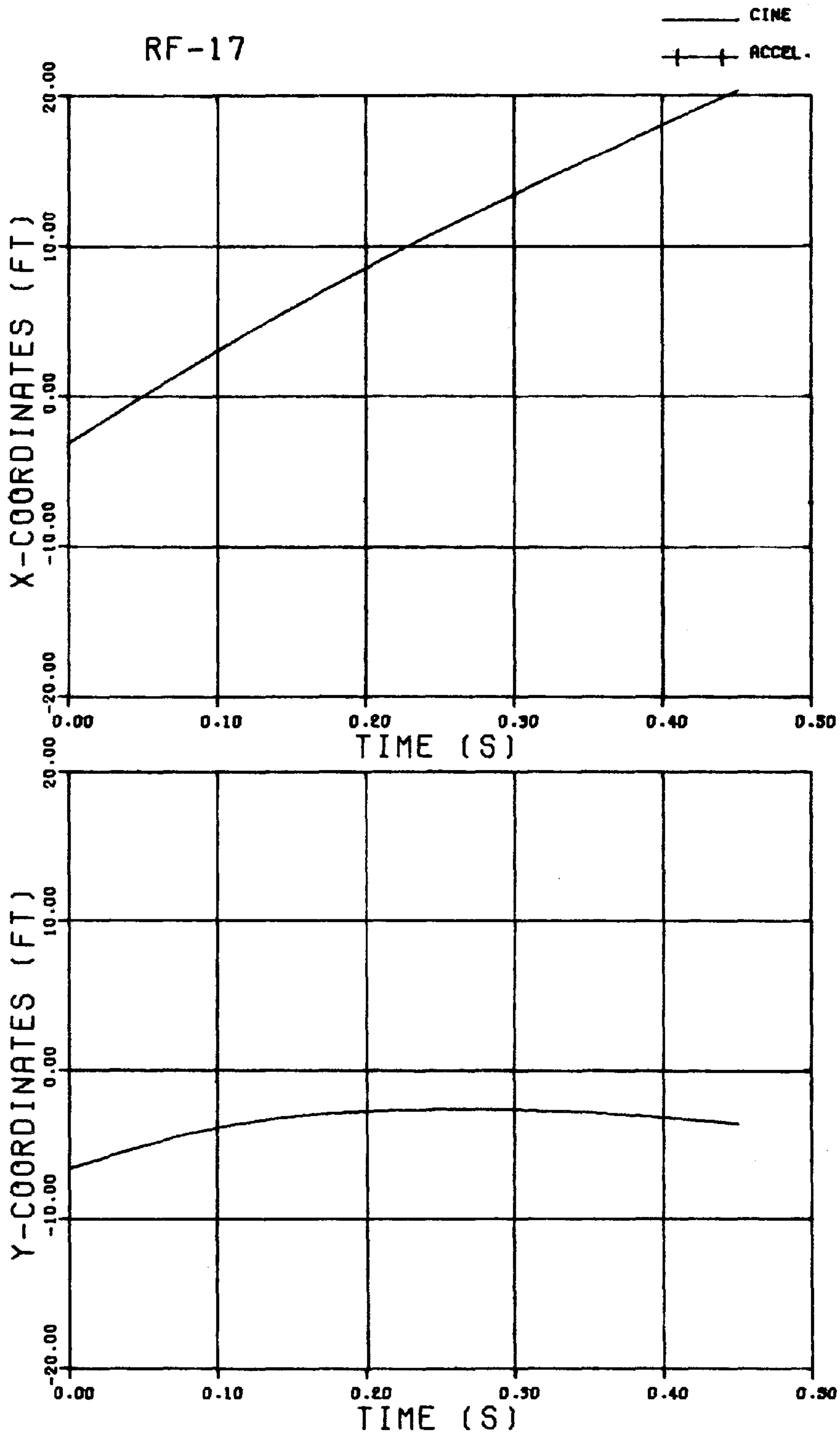


FIGURE B.49 VEHICLE X AND Y DISPLACEMENT HISTORIES FOR CRASH TEST RF-17

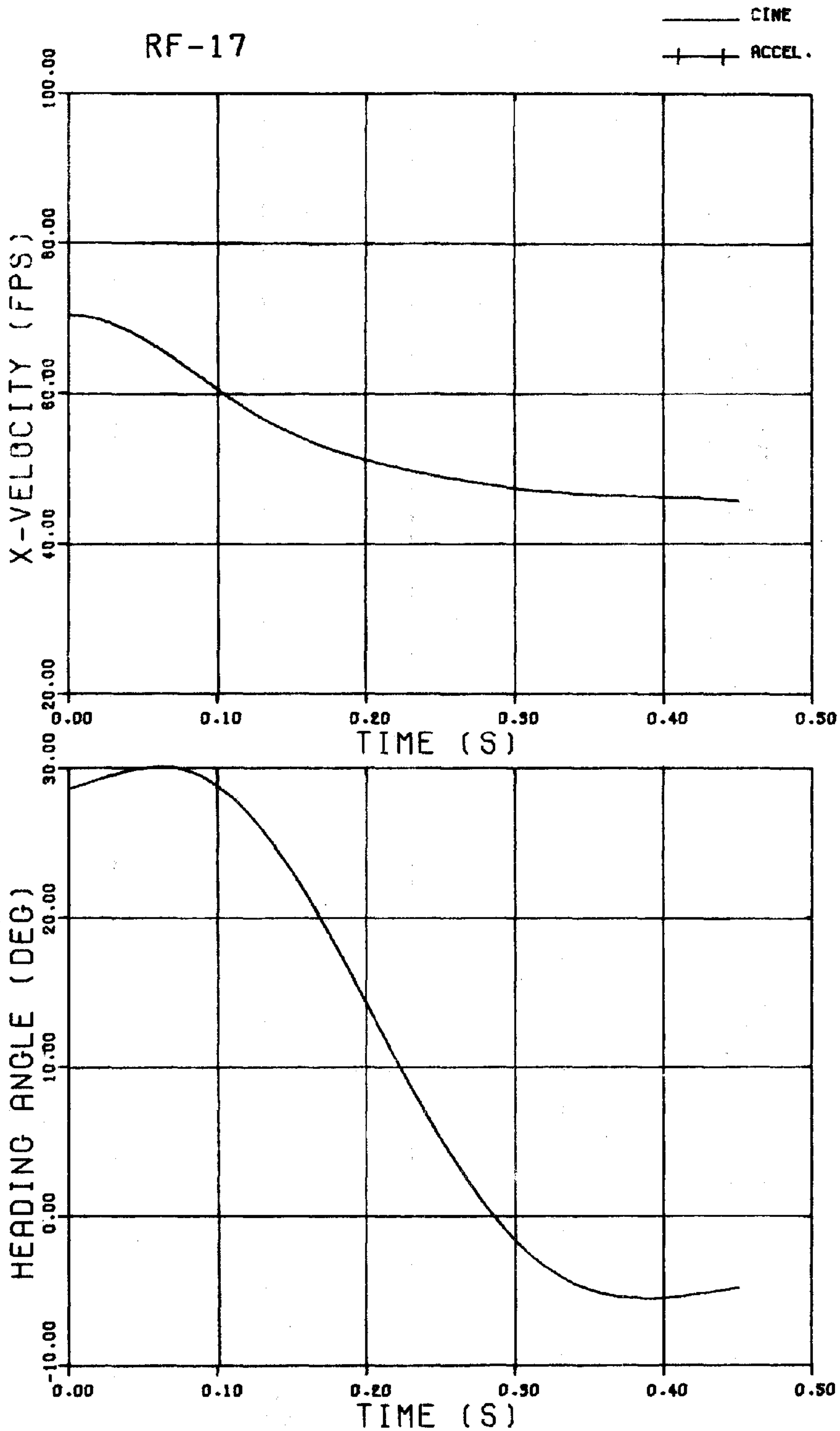


FIGURE B.50 VEHICLE X VELOCITY AND HEADING ANGLE HISTORIES FOR CRASH TEST RF-17

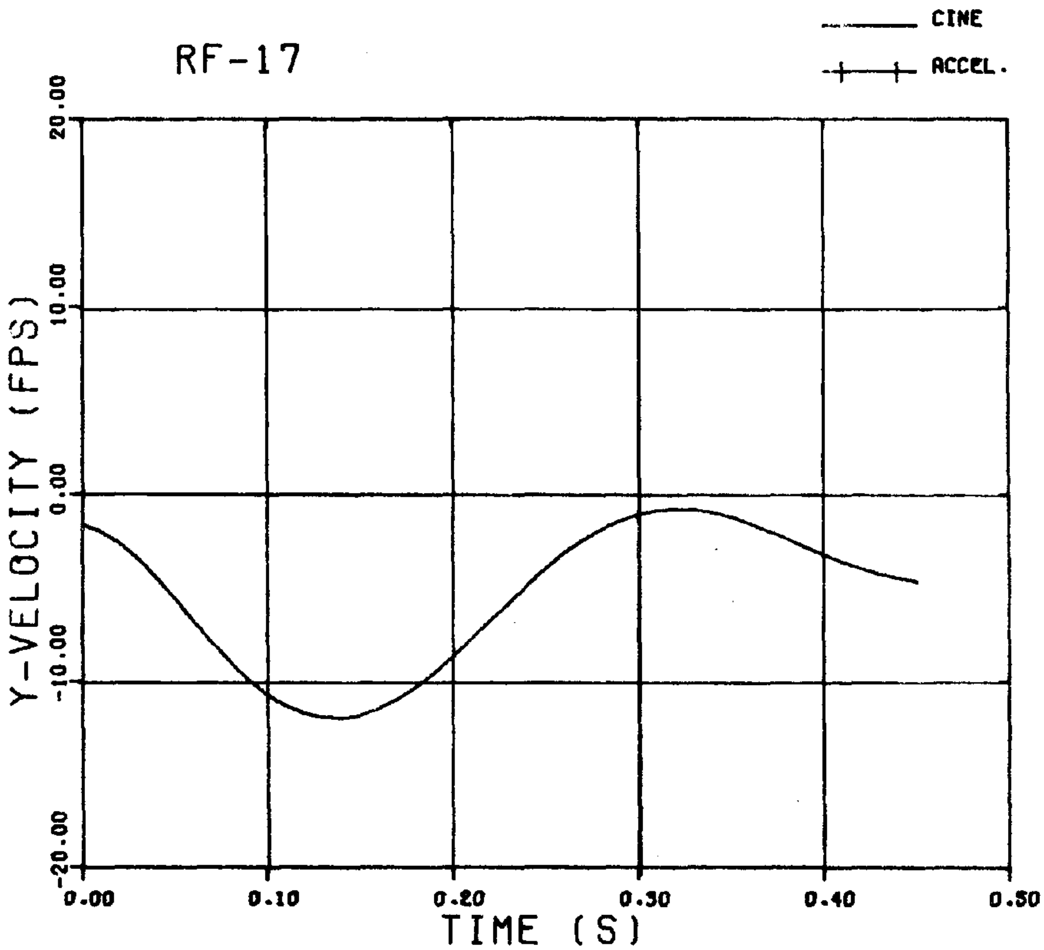


FIGURE B.51 VEHICLE Y VELOCITY HISTORY
FOR CRASH TEST RF-17

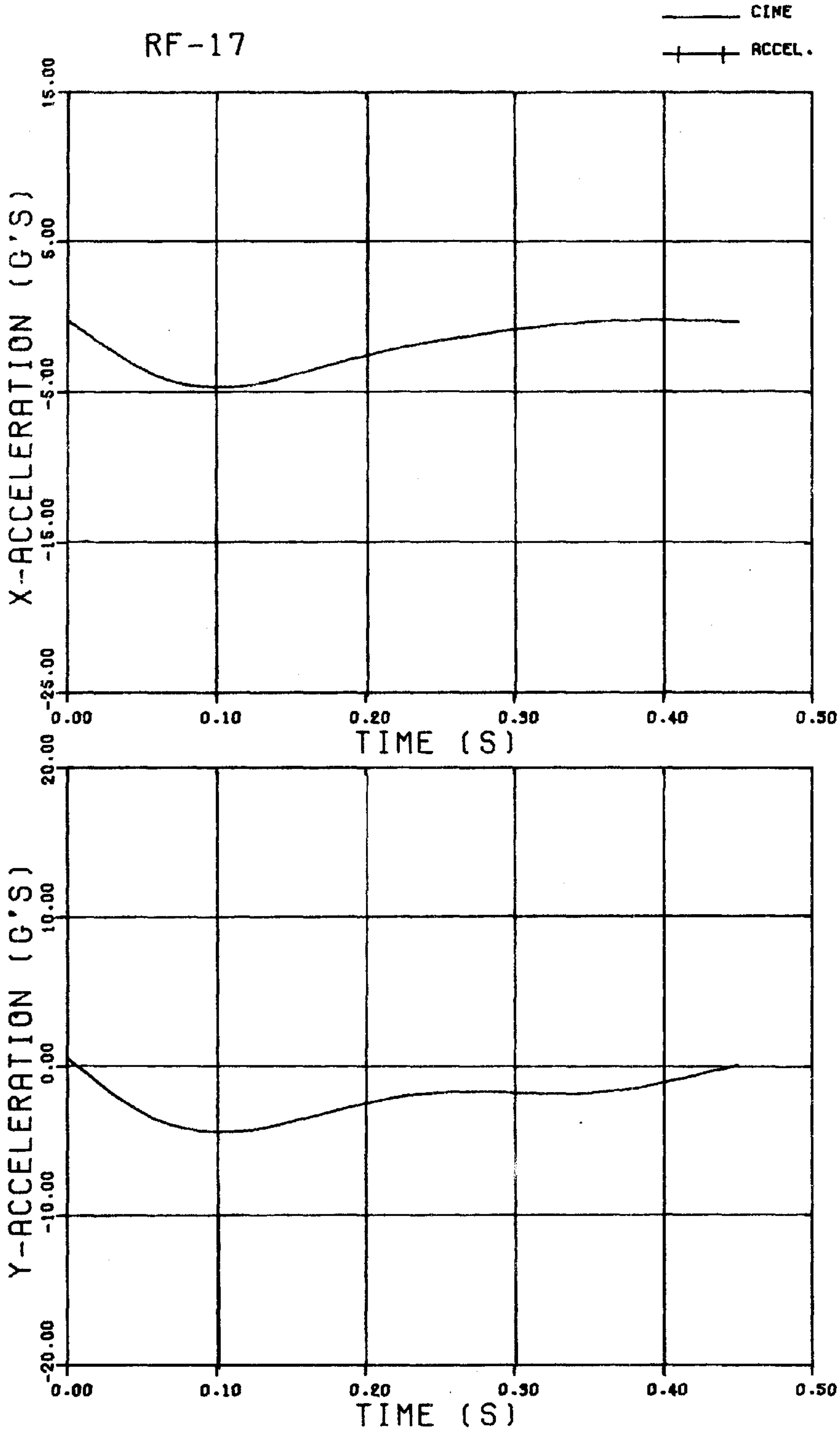


FIGURE B. 52 VEHICLE X AND Y ACCELERATION HISTORIES FOR CRASH TEST RF-17

TABLE B.29

SUMMARY OF VEHICLE CINE DATA FOR CRASH TEST RF-18

TIME AFTER IMPACT(SEC)	VEHICLE C. G. COORDINATES(FT) X	Y	HEADING ANGLE (DEG)	VEHICLE VELOCITY (FT/SEC) LONG	LAT	VEHICLE ACCELERATION(G'S) AT TIME T LONG	LAT	AVERAGE OVER .05 SEC. LONG	LAT	RESULT	APPROX. BARRIER FORCES(KIPS) X	Y
.010	33.16	-3.76	6.68	95.53	4.14	-2.09	-1.16	-1.73	-1.42	2.24	8.6	6.2
.020	34.10	-3.61	6.01	94.39	4.52	-4.54	-3.37	-3.67	-3.08	4.79	18.4	16.9
.030	35.02	-3.48	5.73	92.64	3.58	-6.04	-5.27	-5.00	-4.54	6.75	24.2	25.9
.040	35.93	-3.36	5.75	90.61	1.64	-6.44	-6.36	-5.59	-5.42	7.79	25.5	30.9
.050	36.82	-3.26	5.74	88.60	-.45	-5.92	-6.46	-5.58	-5.55	7.87	23.2	31.1
.060	37.70	-3.19	5.40	86.85	-1.89	-5.00	-5.64	-5.33	-5.00	7.30	19.6	26.9
.070	38.56	-3.14	4.70	85.38	-2.42	-4.41	-4.15	-5.30	-3.97	6.63	17.9	19.9
.080	39.40	-3.10	3.99	83.95	-2.44	-4.85	-2.47	-5.80	-2.84	6.46	20.6	12.4
.090	40.23	-3.07	3.79	82.16	-2.71	-6.48	-1.14	-6.49	-2.03	6.80	28.3	6.9
.100	41.04	-3.04	4.17	79.72	-3.51	-8.45	-.66	-5.89	-1.94	6.20	37.1	5.6
.110	41.83	-3.02	4.26	76.91	-3.95	-8.33	-1.53	-.79	-3.02	3.12	36.2	9.5
.120	42.59	-3.01	2.75	75.18	-2.80	-1.22	-3.98	0.00	0.00	0.00	4.5	17.8
.130	43.35	-3.01	1.17	77.89	-2.45	21.04	-6.75	0.00	0.00	0.00	-93.6	27.9

TABLE B.30

SUMMARY OF VEHICLE ACCELEROMETER DATA FOR CRASH TEST RF-18

TIME (SEC)	DISPLACEMENT-(FT) LONG.	LAT.	HEADING ANGLE-(DEG)	VELOCITY-(FPS) LONG.	LAT.	VEHICLE ACCELERATION-(G'S) AT TIME T LONG.	LAT.	VERT.	AVERAGE OVER .05 SEC. LONG.	LAT.	RESULT	VERT.
.0000	32.21	-3.92	7.51	95.79	2.79	.08	-.50	.91	.08	-.50	.50	.91
.0100	33.16	-3.77	7.49	95.71	2.88	-.74	.05	.26	-.85	-2.05	2.22	-.20
.0200	34.10	-3.61	7.46	95.40	2.66	-1.88	-5.71	-1.76	-1.66	-2.63	3.11	-.66
.0300	35.04	-3.47	7.44	94.53	.90	-2.63	-5.21	1.97	-2.29	-4.00	4.61	.43
.0400	35.97	-3.35	7.23	94.00	.07	-3.13	-1.76	-4.65	-2.38	-4.53	5.12	-.82
.0500	36.90	-3.23	6.94	93.02	-.33	-3.06	-7.39	6.31	-2.58	-3.66	4.48	-.56
.0600	37.82	-3.13	6.60	92.53	-1.72	-1.21	-2.60	-5.95	-2.20	-2.67	3.46	-.50
.0700	38.74	-3.05	6.26	92.01	-1.36	-2.85	-1.34	-.47	-1.64	-2.26	2.80	.63
.0800	39.66	-2.96	[illegible]	91.63	-1.35	-.74	-.24	2.28	-1.03	-.90	1.37	.01
.0900	40.57	-2.89	5.39	91.33	-.90	-.35	.26	.98	-.76	-.65	1.00	1.24
.1000	41.46	-2.81	4.75	91.21	-.38	-.03	-.58	3.19	-.46	-.68	.82	.90

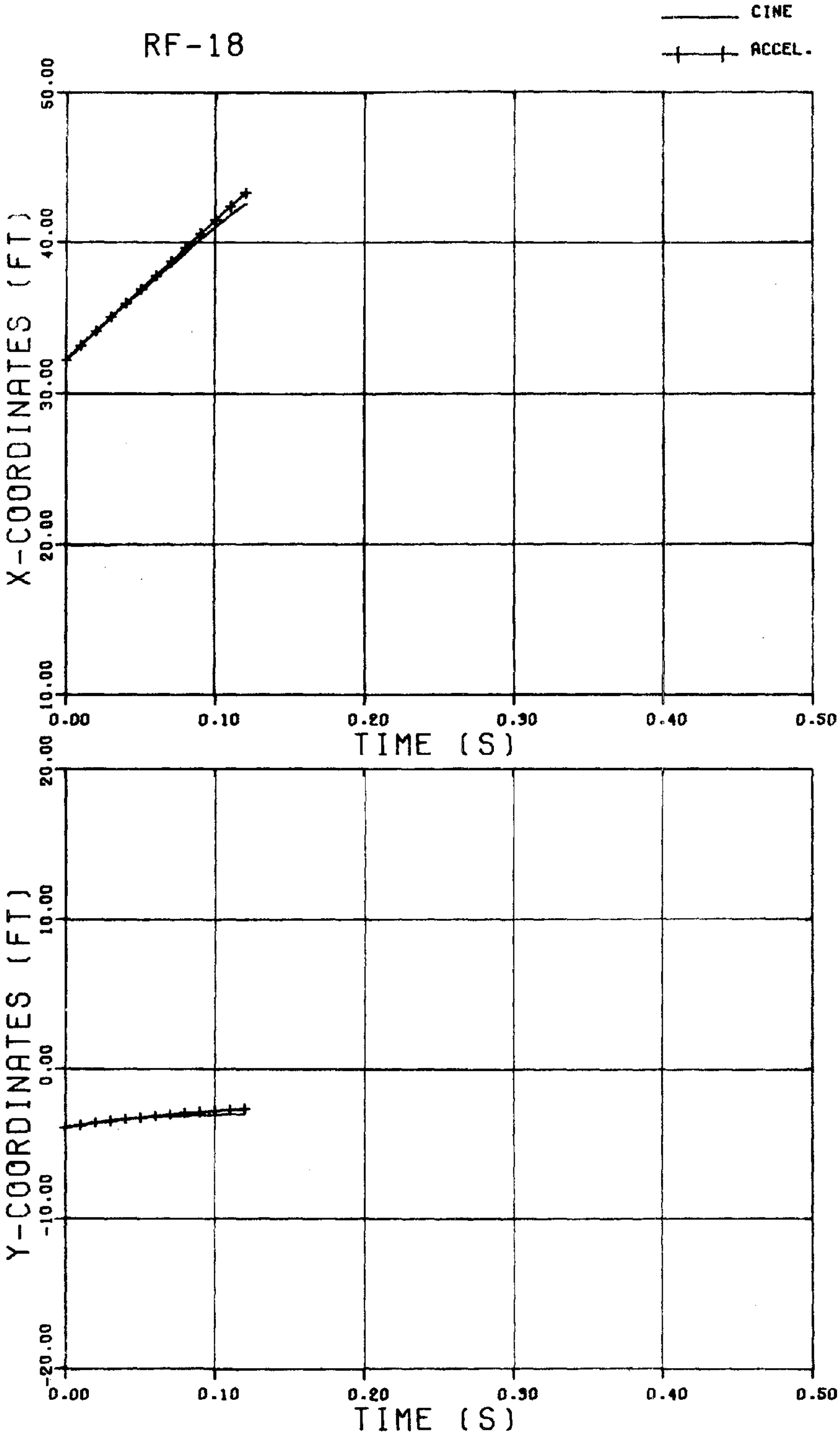


FIGURE B.53 VEHICLE X AND Y DISPLACEMENT HISTORIES FOR CRASH TEST RF-18

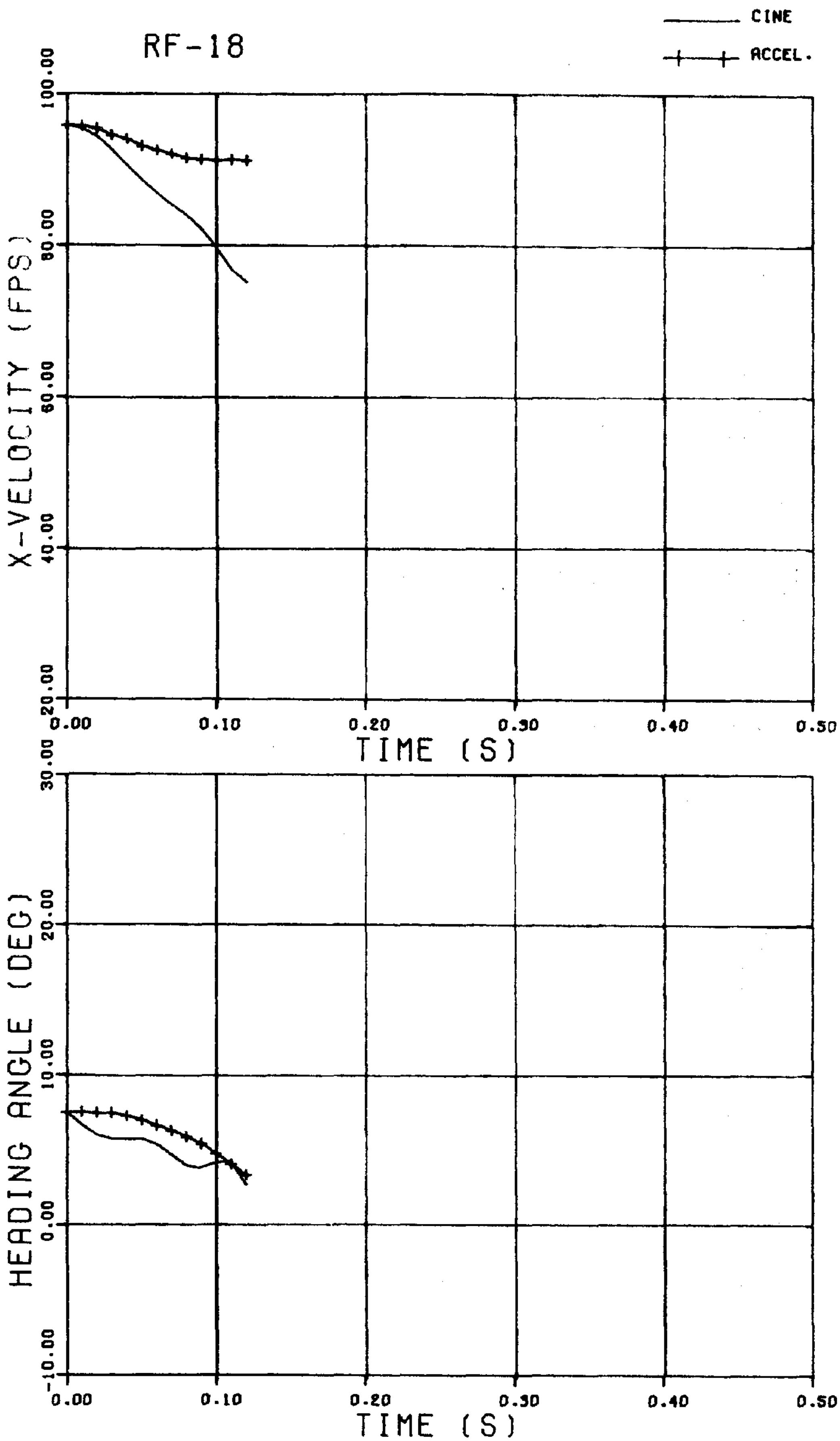


FIGURE B.54 VEHICLE X VELOCITY AND HEADING ANGLE HISTORIES FOR CRASH TEST RF-18

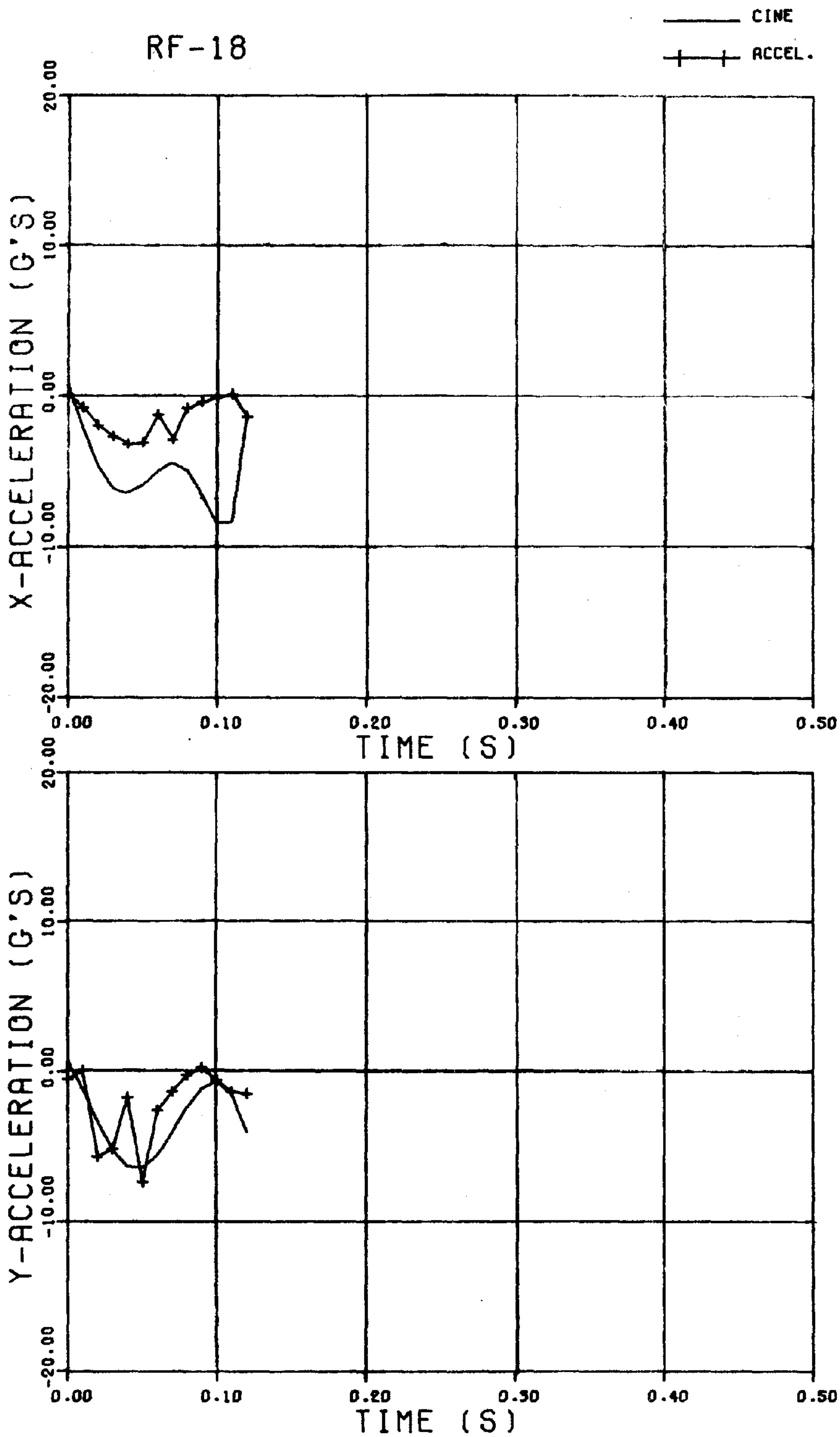


FIGURE B.55 VEHICLE X AND Y ACCELERATION HISTORIES
FOR CRASH TEST RF-18

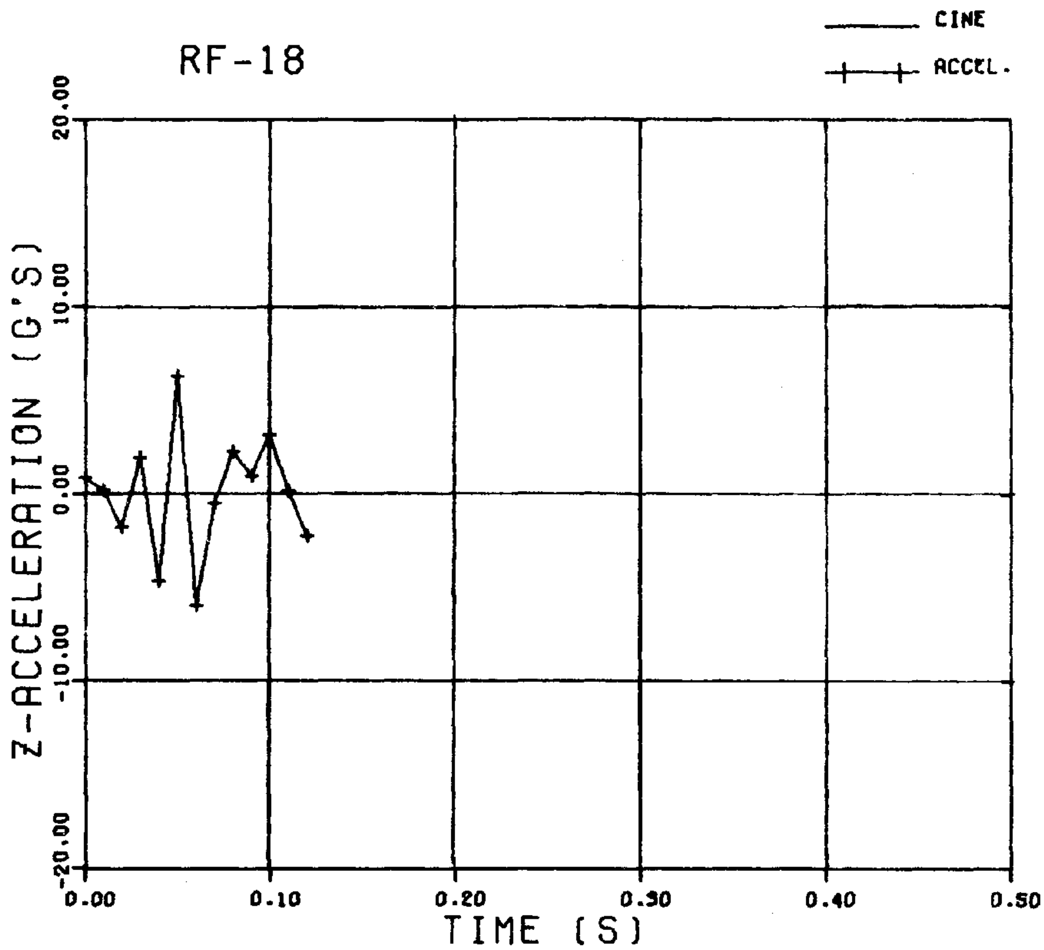


FIGURE B.56 VEHICLE Z ACCELERATION HISTORY
FOR CRASH TEST RF-18

TABLE B.31

SUMMARY OF VEHICLE CINE DATA FOR CRASH TEST RF-19

TIME AFTER IMPACT(SEC)	VEHICLE C. G. COORDINATES(FT) X	Y	HEADING ANGLE (DEG)	VEHICLE VELOCITY (FT/SEC) LONG	LAT	VEHICLE ACCELERATION(G'S) AT TIME T LONG	LAT	AVERAGE OVER .05 SEC. LONG	LAT	RESULT	APPROX. BARRIER FORCES(KIPS) X	Y
0.000	44.04	-5.29	11.49	88.83	3.70	.54	.80	.38	.15	.41	-1.6	-3.9
.010	44.91	-5.07	11.30	88.63	3.90	-1.68	-1.51	-1.52	-1.67	2.26	6.0	8.0
.020	45.76	-4.87	11.11	87.74	3.30	-3.71	-3.98	-3.31	-3.69	4.96	12.7	20.4
.030	46.61	-4.67	10.91	86.27	1.95	-5.30	-6.14	-4.78	-5.52	7.31	17.9	31.1
.040	47.45	-4.50	10.71	84.37	.01	-6.34	-7.66	-5.79	-6.86	8.98	21.3	38.5
.050	48.27	-4.36	10.48	82.24	-2.25	-6.81	-8.36	-6.28	-7.52	9.80	22.9	41.8
.060	49.08	-4.25	10.20	80.07	-4.55	-6.73	-8.19	-6.26	-7.46	9.74	22.9	40.9
.070	49.86	-4.17	9.87	78.01	-6.60	-6.17	-7.28	-5.77	-6.75	8.88	21.4	36.4
.080	50.64	-4.11	9.48	76.22	-8.20	-5.21	-5.82	-4.88	-5.57	7.41	18.5	29.2
.090	51.40	-4.08	9.04	74.80	-9.21	-3.94	-4.11	-3.69	-4.15	5.56	14.4	20.7
.100	52.14	-4.06	8.54	73.85	-9.61	-2.44	-2.42	-2.27	-2.74	3.56	9.1	12.2
.110	52.89	-4.04	8.00	73.42	-9.47	-.79	-1.05	-.72	-1.57	1.73	2.8	5.1
.120	53.63	-4.04	7.43	73.53	-8.91	.92	-.18	.85	-.81	1.18	-4.2	.3
.130	54.37	-4.03	6.83	74.19	-8.14	2.56	.06	2.30	-.57	2.37	-11.2	-1.6
.140	55.12	-4.02	6.21	75.33	-7.36	3.95	-.32	3.45	-.85	3.55	-17.5	-.5
.150	55.88	-4.01	5.57	76.84	-6.75	4.86	-1.23	4.11	-1.54	4.39	-21.9	3.3
.160	56.66	-4.01	4.92	78.53	-6.45	5.03	-2.45	4.09	-2.49	4.78	-23.1	8.9
.170	57.46	-4.01	4.26	80.13	-6.54	4.25	-3.72	3.30	-3.47	4.79	-20.0	15.0
.180	58.27	-4.02	3.62	81.31	-7.01	2.47	-4.77	1.90	-4.26	4.66	-12.2	20.4
.190	59.09	-4.05	3.03	81.79	-7.82	-.00	-5.33	.48	-4.67	4.69	-1.2	23.5
.200	59.91	-4.09	2.56	81.48	-8.86	-2.22	-5.23	.42	-4.60	4.62	8.8	23.6

TABLE B.32

SUMMARY OF VEHICLE ACCELEROMETER DATA FOR CRASH TEST RF-19

TIME (SEC)	DISPLACEMENT-(FT) LONG.	LAT.	HEADING ANGLE-(DEG)	VELOCITY-(FPS) LONG.	LAT.	VEHICLE ACCELERATION-(G'S) AT TIME T LONG.	LAT.	VERT.	AVERAGE OVER .05 SEC. LONG.	LAT.	RESULT	VERT.
.0000	44.04	-5.29	11.49	88.83	3.70	-.35	-.77	.62	-.35	-.77	.84	.62
.0100	44.90	-5.08	11.44	88.85	3.90	-.91	-.10	.97	-.94	-.26	.97	.06
.0200	45.77	-4.86	11.45	88.72	3.96	-1.55	.09	-1.42	-2.13	-2.41	3.22	1.64
.0300	46.62	-4.65	11.42	87.37	2.37	-1.57	-7.99	3.09	-3.10	-3.38	4.59	1.39
.0400	47.47	-4.47	11.17	85.63	.28	-6.29	-3.23	4.94	-3.14	-3.19	4.47	.84
.0500	48.30	-4.31	10.89	84.33	-1.25	-5.21	-5.61	-.64	-4.36	-4.34	6.15	2.21
.0600	49.13	-4.17	10.58	83.50	-1.64	-1.06	.84	-1.76	-4.39	-4.57	6.34	1.72
.0700	49.95	-4.04	10.06	82.52	-2.76	-7.68	-5.65	5.43	-3.52	-4.93	6.06	1.84
.0800	50.76	-3.93	9.30	80.79	-3.12	-1.69	-9.17	.63	-3.09	-3.89	4.97	2.16
.0900	51.56	-3.84	8.43	80.20	-3.32	-1.94	-5.09	5.52	-2.37	-3.97	4.62	1.14
.1000	52.36	-3.76	7.26	80.12	-2.44	-3.09	-.40	.99	-1.18	-3.64	3.83	.11
.1100	53.16	-3.69	6.11	80.14	-.94	2.56	.47	-6.87	-.87	-2.13	2.30	-.15
.1200	53.96	-3.61	4.88	80.32	.61	-1.72	-4.03	.26	-.63	-1.78	1.89	-1.42
.1300	54.76	-3.54	3.65	80.34	1.91	-.16	-1.59	-.64	-.35	-2.08	2.11	-1.24
.1400	55.56	-3.47	2.44	80.28	3.33	-.72	-3.36	-.84	-.53	-4.91	4.94	-.95
.1500	56.36	-3.40	1.18	79.87	4.30	-1.73	-1.87	1.86	.61	-4.66	4.70	2.42
.1600	57.15	-3.35	-.00	79.66	4.29	1.67	-13.69	-5.39	2.38	-4.86	5.41	.12
.1700	57.95	-3.32	-.82	80.07	2.14	4.00	-2.78	17.09	2.48	-4.59	5.22	-.03
.1800	58.76	-3.32	-1.30	80.88	1.41	4.68	-2.58	-12.14	3.28	-4.57	5.63	-.12
.1900	59.57	-3.33	-1.63	81.00	.80	-.24	-2.04	-1.55	2.47	-1.97	3.15	2.39
.2000	60.38	-3.35	-1.73	80.87	.24	2.31	-1.75	1.38	1.72	-1.52	2.30	-1.93

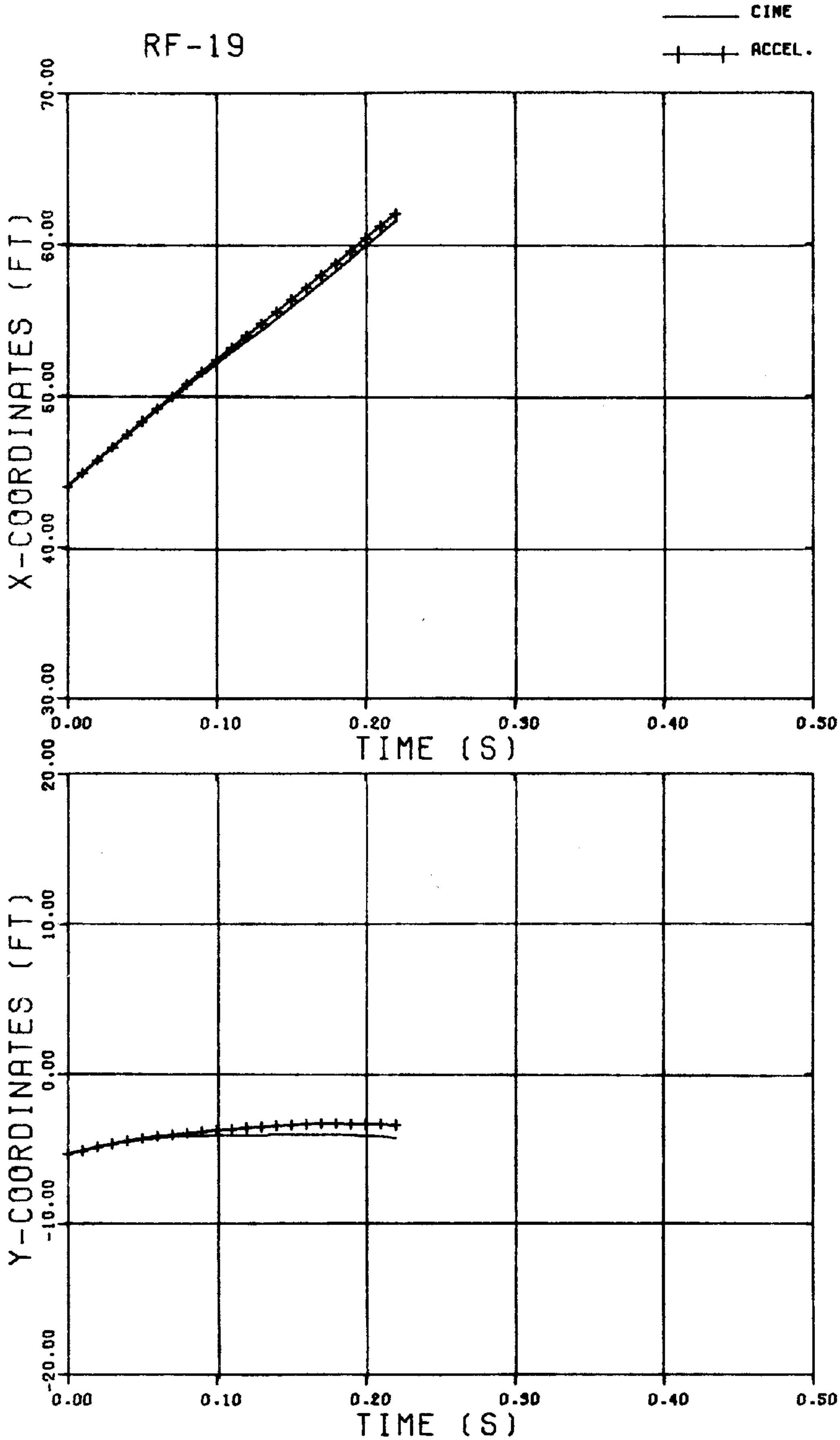


FIGURE B.57 VEHICLE X AND Y DISPLACEMENT HISTORIES FOR CRASH TEST RF-19

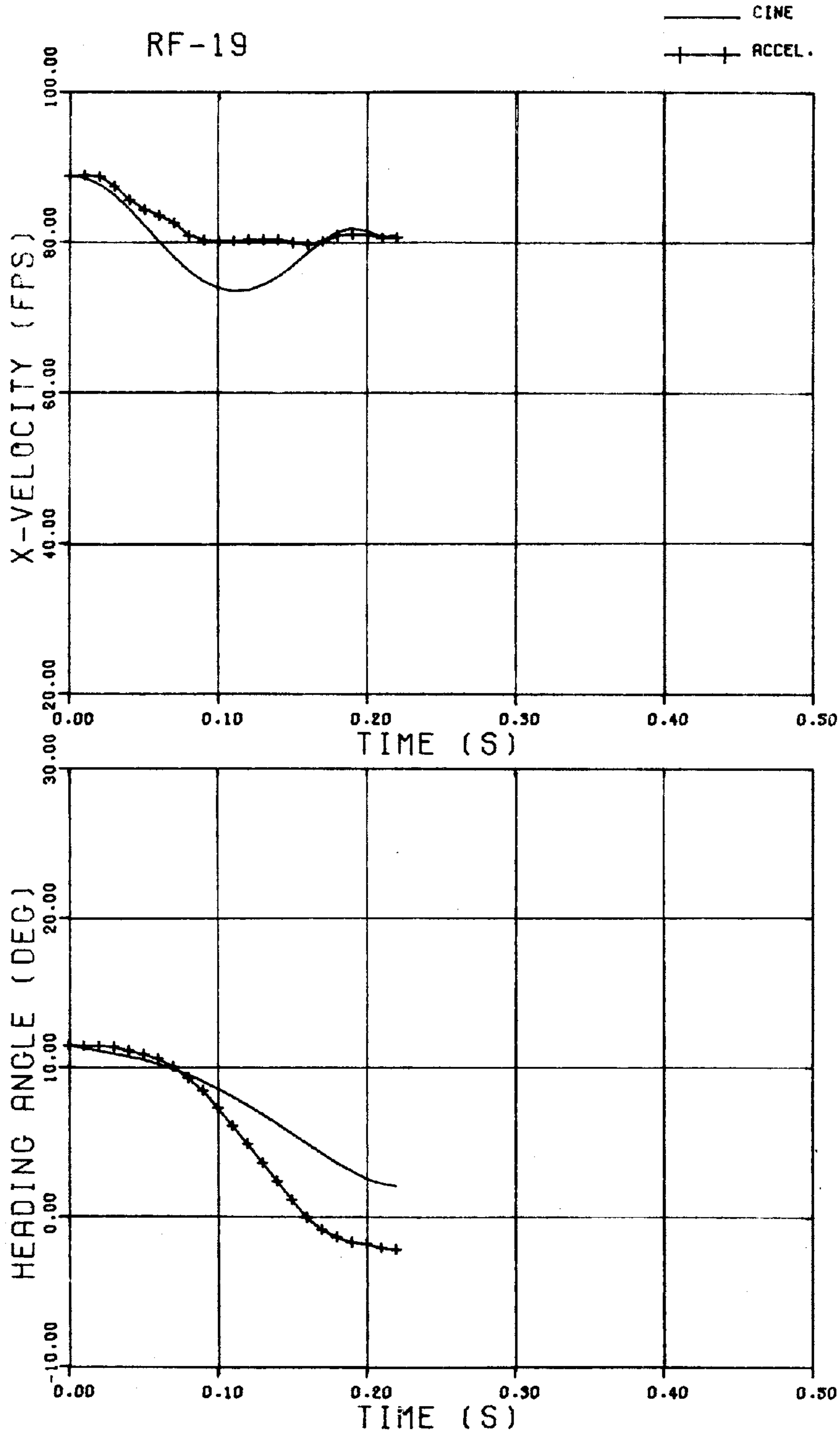


FIGURE B.58 VEHICLE X VELOCITY AND HEADING ANGLE HISTORIES FOR CRASH TEST RF-19

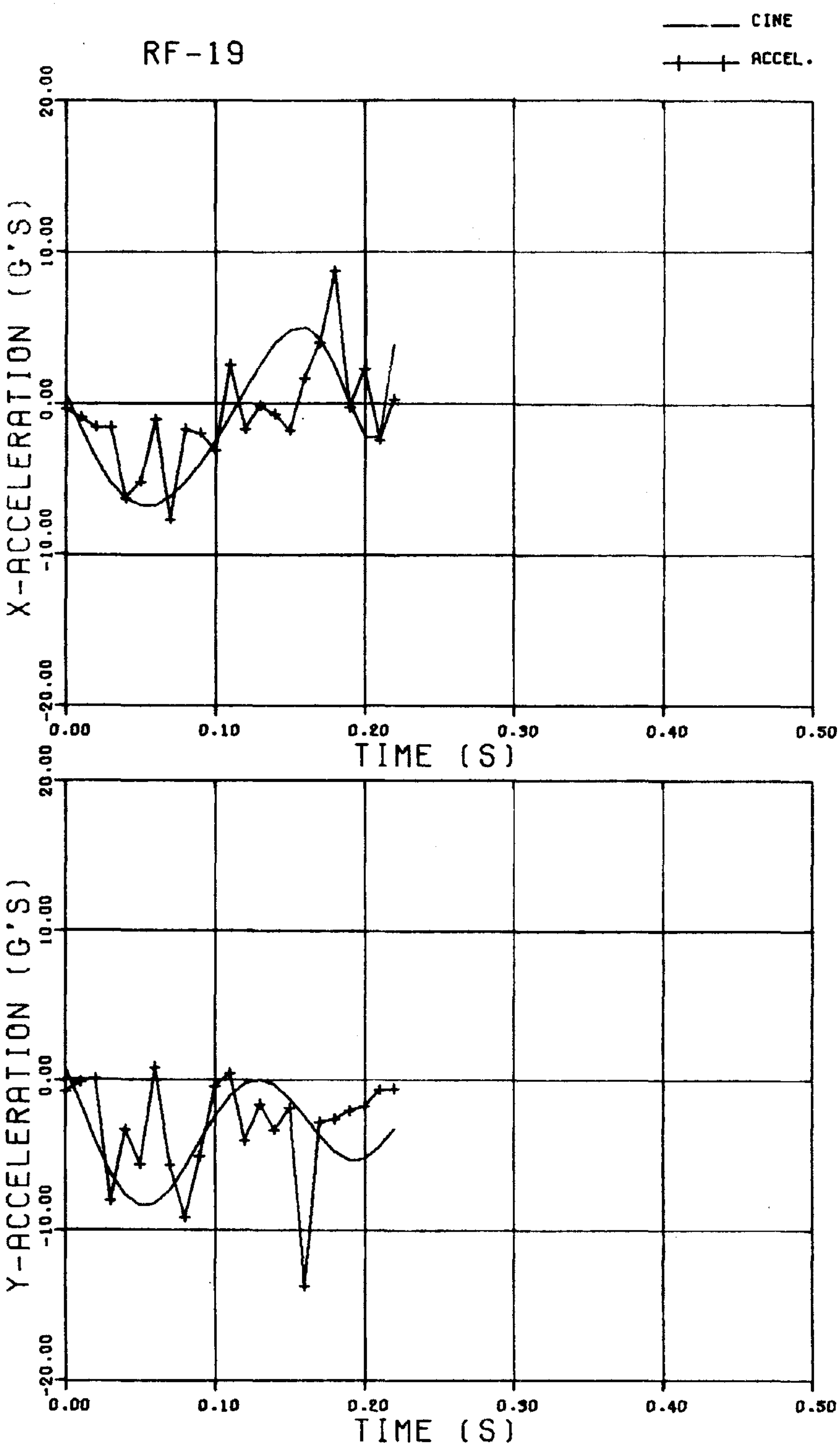


FIGURE B.59 VEHICLE X AND Y ACCELERATION HISTORIES FOR CRASH TEST RF-19

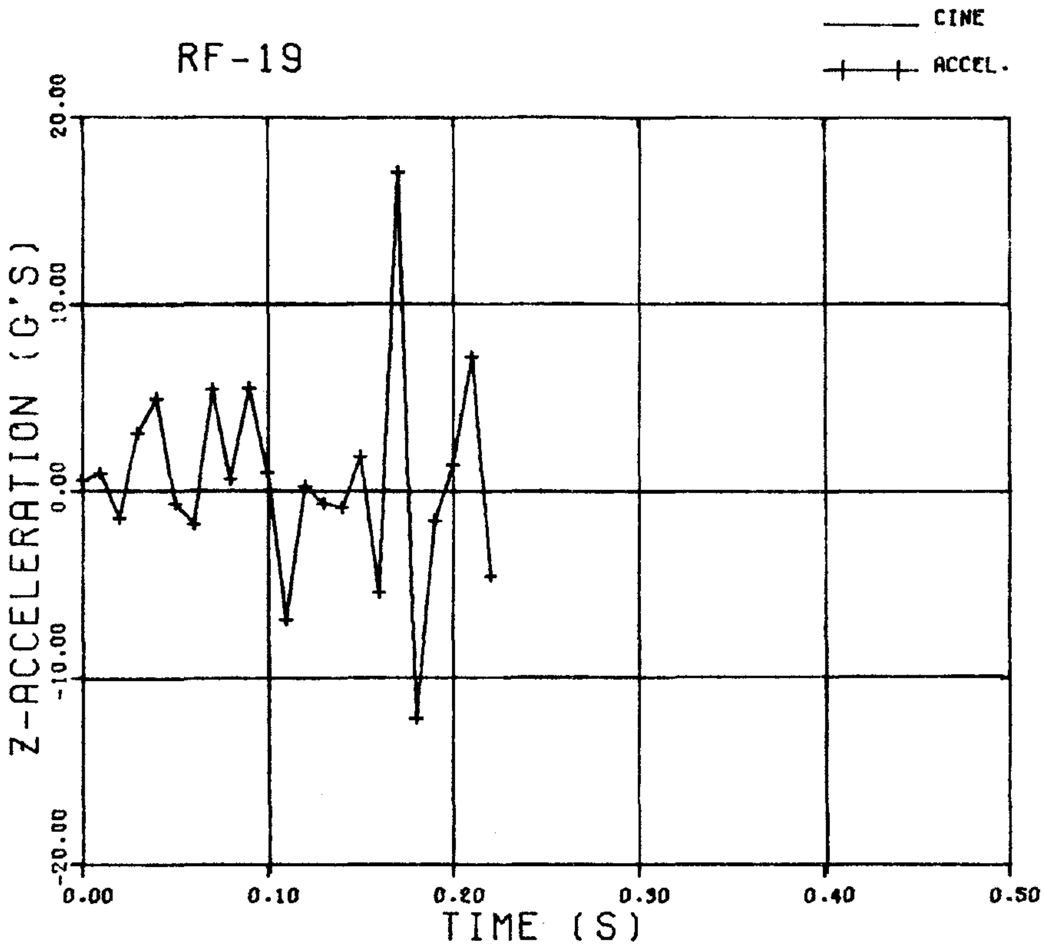


FIGURE B.60 VEHICLE Z ACCELERATION HISTORY FOR CRASH TEST RF-19

TABLE B.33

SUMMARY OF VEHICLE CINE DATA FOR CRASH TEST RF-20

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	VEHICLE ACCELERATION (G'S) AVERAGE OVER .05 SEC. RESULT	APPROX. BARRIER FORCES (KIPS) X	APPROX. BARRIER FORCES (KIPS) Y
0.000	-6.54	-5.15	9.17	79.93	-1.80	-.20	-.04	-.21	-.05	.22	.4	.1
.010	-5.75	-5.04	9.46	79.82	-2.25	-.40	-.24	-.41	-.24	.47	.8	.6
.020	-4.96	-4.93	9.78	79.65	-2.81	-.61	-.44	-.61	-.44	.75	1.1	1.1
.030	-4.17	-4.82	10.12	79.40	-3.46	-.82	-.64	-.81	-.63	1.03	1.5	1.7
.040	-3.38	-4.72	10.47	79.08	-4.17	-1.02	-.83	-1.01	-.82	1.30	1.8	2.1
.050	-2.60	-4.62	10.81	78.69	-4.94	-1.22	-1.01	-1.20	-.99	1.56	2.2	2.6
.060	-1.82	-4.52	11.13	78.24	-5.73	-1.40	-1.17	-1.39	-1.15	1.80	2.5	3.0
.070	-1.04	-4.43	11.42	77.73	-6.52	-1.57	-1.31	-1.55	-1.29	2.02	2.7	3.4
.080	-.27	-4.34	11.66	77.17	-7.29	-1.72	-1.43	-1.70	-1.41	2.20	3.0	3.7
.090	.50	-4.26	11.84	76.57	-8.01	-1.84	-1.52	-1.82	-1.50	2.36	3.2	4.0
.100	1.26	-4.19	11.96	75.94	-8.67	-1.95	-1.60	-1.92	-1.57	2.48	3.4	4.2
.110	2.02	-4.12	11.99	75.30	-9.23	-2.03	-1.64	-2.00	-1.61	2.57	3.5	4.3
.120	2.77	-4.05	11.94	74.64	-9.70	-2.08	-1.66	-2.05	-1.64	2.63	3.6	4.4
.130	3.52	-4.00	11.80	73.99	-10.05	-2.10	-1.66	-2.08	-1.64	2.65	3.7	4.4
.140	4.26	-3.95	11.56	73.36	-10.27	-2.10	-1.64	-2.08	-1.61	2.63	3.7	4.3
.150	5.00	-3.90	11.22	72.75	-10.36	-2.08	-1.59	-2.05	-1.57	2.59	3.7	4.2
.160	5.73	-3.87	10.79	72.16	-10.32	-2.03	-1.53	-2.01	-1.51	2.51	3.7	4.0
.170	6.46	-3.84	10.26	71.62	-10.14	-1.96	-1.44	-1.94	-1.43	2.41	3.6	3.8
.180	7.18	-3.81	9.65	71.11	-9.82	-1.87	-1.35	-1.86	-1.33	2.28	3.5	3.5
.190	7.89	-3.79	8.95	70.64	-9.37	-1.77	-1.23	-1.76	-1.22	2.14	3.3	3.2
.200	8.60	-3.78	8.18	70.21	-8.80	-1.65	-1.11	-1.64	-1.10	1.98	3.2	2.8
.210	9.31	-3.77	7.35	69.82	-8.12	-1.53	-.97	-1.52	-.97	1.80	3.0	2.5
.220	10.01	-3.76	6.46	69.46	-7.33	-1.40	-.83	-1.39	-.83	1.62	2.8	2.1
.230	10.70	-3.76	5.53	69.15	-6.46	-1.27	-.68	-1.26	-.68	1.43	2.6	1.7
.240	11.40	-3.75	4.56	68.86	-5.50	-1.13	-.53	-1.13	-.54	1.25	2.3	1.3
.250	12.08	-3.75	3.61	68.60	-4.49	-1.00	-.39	-1.00	-.39	1.07	2.1	1.0
.260	12.77	-3.76	2.64	68.37	-3.43	-.87	-.24	-.87	-.25	.90	1.8	.6
.270	13.45	-3.76	1.68	68.16	-2.34	-.74	-.10	-.74	-.12	.75	1.6	.3
.280	14.13	-3.76	.75	67.97	-1.24	-.62	.02	-.62	.01	.62	1.3	-.0
.290	14.81	-3.77	-.16	67.80	-.15	-.51	.14	-.51	.12	.52	1.1	-.3
.300	15.49	-3.77	-1.01	67.65	.93	-.40	.24	-.40	.22	.46	.8	-.5
.310	16.17	-3.77	-1.82	67.51	1.96	-.30	.32	-.30	.30	.42	.6	-.7
.320	16.84	-3.77	-2.56	67.40	2.95	-.20	.38	-.21	.36	.42	.4	-.8
.330	17.52	-3.77	-3.24	67.31	3.88	-.12	.42	-.13	.40	.42	.2	-.9
.340	18.19	-3.77	-3.85	67.24	4.73	-.04	.45	-.05	.42	.43	.0	-1.0
.350	18.86	-3.77	-4.36	67.19	5.50	.03	.45	.02	.42	.42	-.1	-.9
.360	19.54	-3.77	-4.84	67.16	6.18	.09	.42	.08	.40	.41	-.3	-.9
.370	20.21	-3.76	-5.23	67.16	6.77	.15	.38	.14	.36	.38	-.4	-.8
.380	20.89	-3.75	-5.54	67.17	7.25	.19	.31	.18	.29	.35	-.5	-.6

TABLE B.34

SUMMARY OF VEHICLE ACCELEROMETER DATA FOR CRASH TEST RF-20

TIME (SEC)	DISPLACEMENT-(FT) LONG.	DISPLACEMENT-(FT) LAT.	HEADING ANGLE-(DEG)	VELOCITY-(FPS) LONG.	VELOCITY-(FPS) LAT.	VEHICLE ACCELERATION-(G'S) AT TIME T LONG.	AT TIME T LAT.	AT TIME T VERT.	AVERAGE OVER .05 SEC. LONG.	AVERAGE OVER .05 SEC. LAT.	AVERAGE OVER .05 SEC. RESULT	AVERAGE OVER .05 SEC. VERT.
.0000	-6.54	-5.15	9.17	79.93	-1.80	.14	.59	-1.42	.14	.59	.61	-1.42
.0100	-5.75	-5.04	9.24	79.79	-1.82	-.67	.83	-.17	-.35	-.05	.35	-.28
.0200	-4.96	-4.93	9.37	79.64	-1.64	-.53	-1.57	.76	-1.47	-1.33	1.99	-1.66
.0300	-4.17	-4.81	9.49	79.44	-1.84	-.44	.23	-1.30	-1.92	-2.77	3.37	-.94
.0400	-3.39	-4.70	9.45	78.62	-2.39	-5.37	-6.75	-6.17	-1.25	-2.11	2.45	.54
.0500	-2.61	-4.60	9.19	77.55	-2.45	-2.07	-6.62	2.19	-1.16	-4.12	4.28	2.27
.0600	-1.85	-4.51	9.33	76.42	-3.67	2.66	4.16	7.20	-1.98	-6.55	6.84	3.62
.0700	-1.09	-4.42	9.21	76.37	-4.07	-.12	-11.63	9.40	-1.88	-5.91	6.21	3.75
.0800	-.33	-4.35	9.00	75.05	-5.31	-5.00	-11.91	5.48	-2.63	-5.99	6.54	4.83
.0900	.41	-4.29	8.57	73.83	-5.96	-4.91	-3.58	-5.50	-4.22	-8.34	9.35	5.00
.1000	1.15	-4.25	7.95	72.47	-7.49	-5.79	-6.98	7.57	-4.27	-6.17	7.50	1.46
.1100	1.87	-4.23	7.18	71.76	-7.33	-5.28	-7.63	8.06	-3.52	-4.59	5.78	-.26
.1200	2.59	-4.22	6.41	70.92	-7.42	-.38	-.75	-8.29	-2.91	-3.95	4.91	.72
.1300	3.30	-4.22	5.51	70.38	-7.08	-1.23	-3.99	-3.15	-2.05	-2.48	3.22	-1.56
.1400	4.00	-4.23	4.54	70.12	-6.46	-1.88	-.40	-.59	-1.14	-1.31	1.74	-3.01
.1500	4.71	-4.24	3.53	69.85	-5.33	-1.50	.37	-3.85	-1.31	-1.67	2.12	-1.60
.1600	5.40	-4.25	2.64	69.61	-4.74	-.73	-1.77	.85	-1.02	-.79	1.29	-1.66
.1700	6.10	-4.27	1.79	69.36	-4.34	-1.21	-2.58	-1.25	-.60	-.87	1.06	-2.40
.1800	6.79	-4.29	.90	69.25	-3.71	.23	.43	-3.47	-.36	-.98	1.05	-2.05
.1900	7.49	-4.32	.01	69.29	-2.92	.21	-.81	-4.27	-.32	-.50	.60	-2.68
.2000	8.18	-4.35	-.96	69.14	-2.11	-.29	-.19	-2.13	-.13	.15	.20	-2.58
.2100	8.87	-4.38	-1.92	69.05	-.97	-.55	.63	-2.28	-.22	-.27	.35	-2.24
.2200	9.56	-4.42	-2.89	69.00	.24	-.26	.67	-.77	-.25	.69	.73	-1.31
.2300	10.25	-4.45	-3.84	68.84	1.04	-.19	-1.67	-1.76	-.28	.12	.31	-1.03
.2400	10.93	-4.49	-4.74	68.70	1.51	.03	4.00	.36	-.05	-.68	.69	-.51
.2500	11.62	-4.53	-5.69	68.55	2.37	-.44	-3.03	-.70	-.04	-1.10	1.10	-.05
.2600	12.30	-4.58	-6.54	68.53	2.73	.60	-3.39	.32	-.01	-.60	.60	.39
.2700	12.99	-4.63	-7.36	68.50	2.92	-.20	-1.40	1.54	.07	-1.62	1.62	.26
.2800	13.67	-4.69	-8.13	68.39	3.72	-.02	.84	.45	.27	-1.18	1.21	.78
.2900	14.35	-4.75	-8.70	68.40	4.49	.40	-1.11	-.31	.17	-.81	.83	1.01
.3000	15.03	-4.81	-9.36	68.65	5.13	.57	-.83	1.86	.20	-.78	.80	.77
.3100	15.72	-4.87	-9.83	68.84	5.58	.12	-1.57	1.48	.08	-1.05	1.06	.64
.3200	16.41	-4.94	-10.25	68.73	5.79	-.05	-1.23	.37	.04	-1.26	1.26	.89
.3300	17.10	-5.00	-10.58	68.66	5.85	-.62	-.55	-.19	.04	-1.30	1.30	.61
.3400	17.78	-5.07	-10.87	68.56	5.91	.20	-2.12	.91	.01	-.96	.96	.53
.3500	18.46	-5.15	-11.10	68.57	5.79	.53	-1.03	.47	.03	-.52	.52	.41
.3600	19.15	-5.22	-11.41	68.62	6.04	-.03	.13	1.08	.20	-.20	.28	.37
.3700	19.83	-5.30	-11.71	68.55	6.72	.06	.97	-.19	.20	.33	.39	.41
.3800	20.52	-5.37	-11.98	68.49	7.23	.24	1.07	-.42	.16	.48	.51	.46

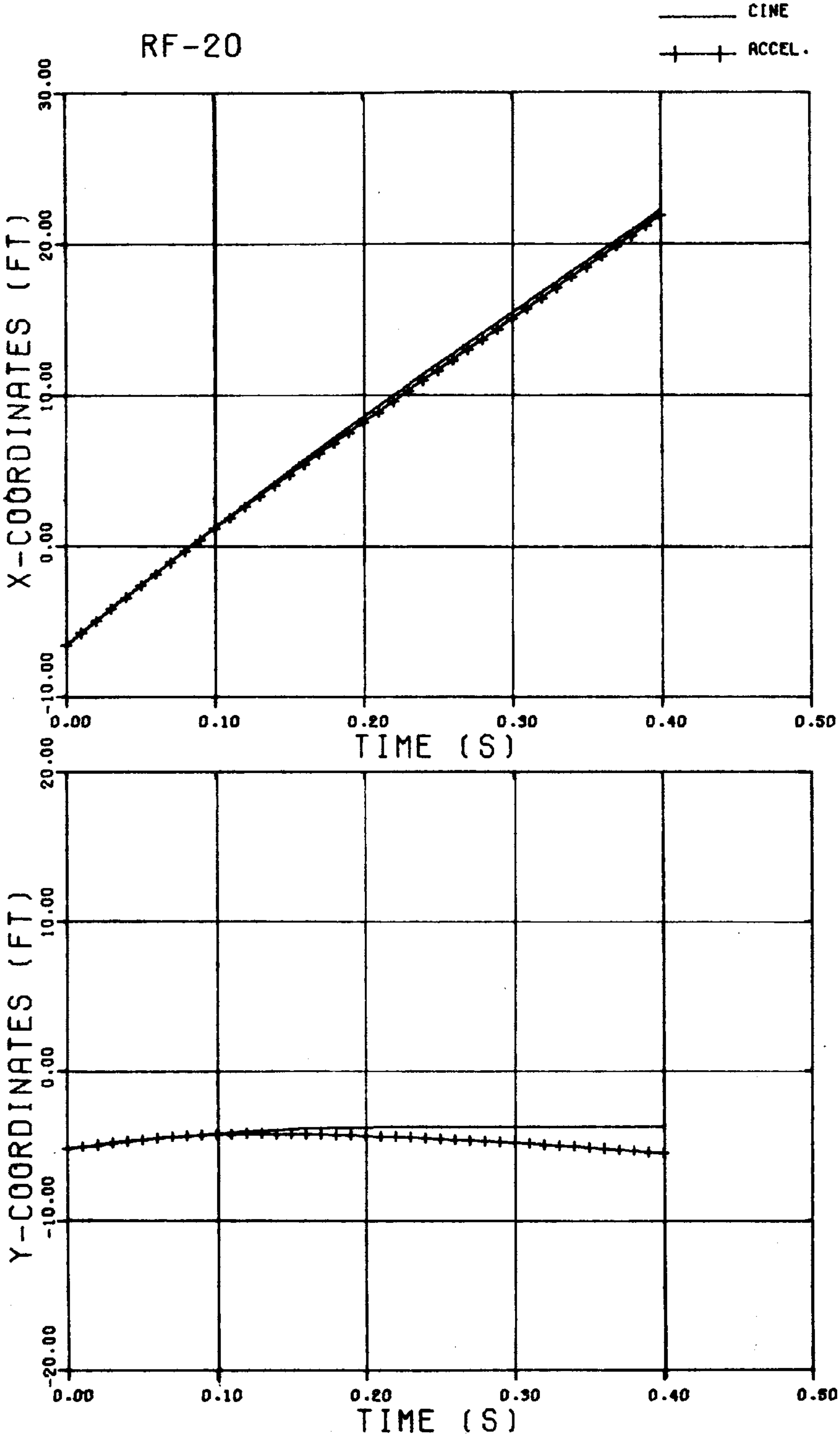


FIGURE B.61 VEHICLE X AND Y DISPLACEMENT HISTORIES FOR CRASH TEST RF-20

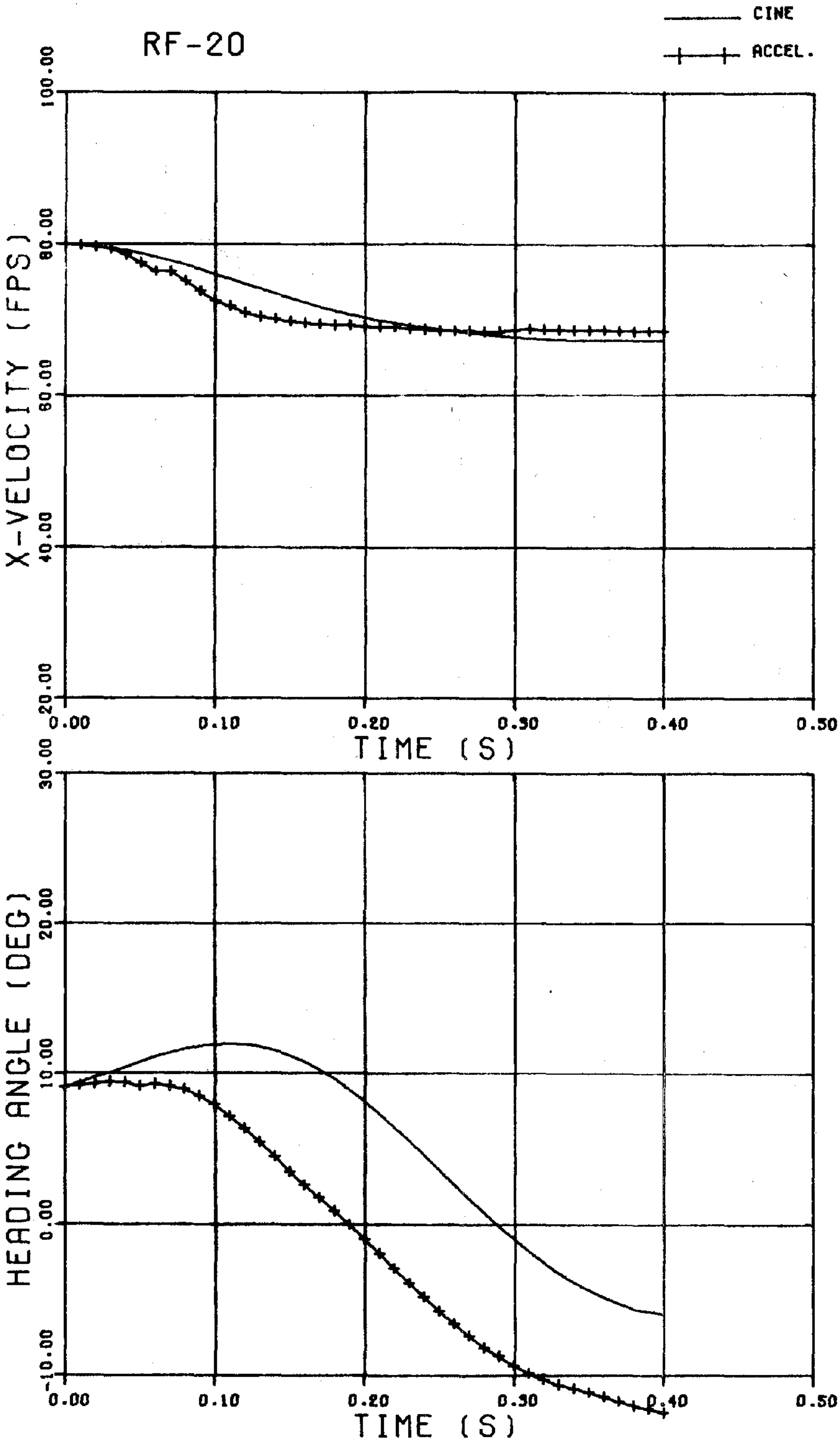


FIGURE B.62 VEHICLE X VELOCITY AND HEADING ANGLE HISTORIES FOR CRASH TEST RF-20

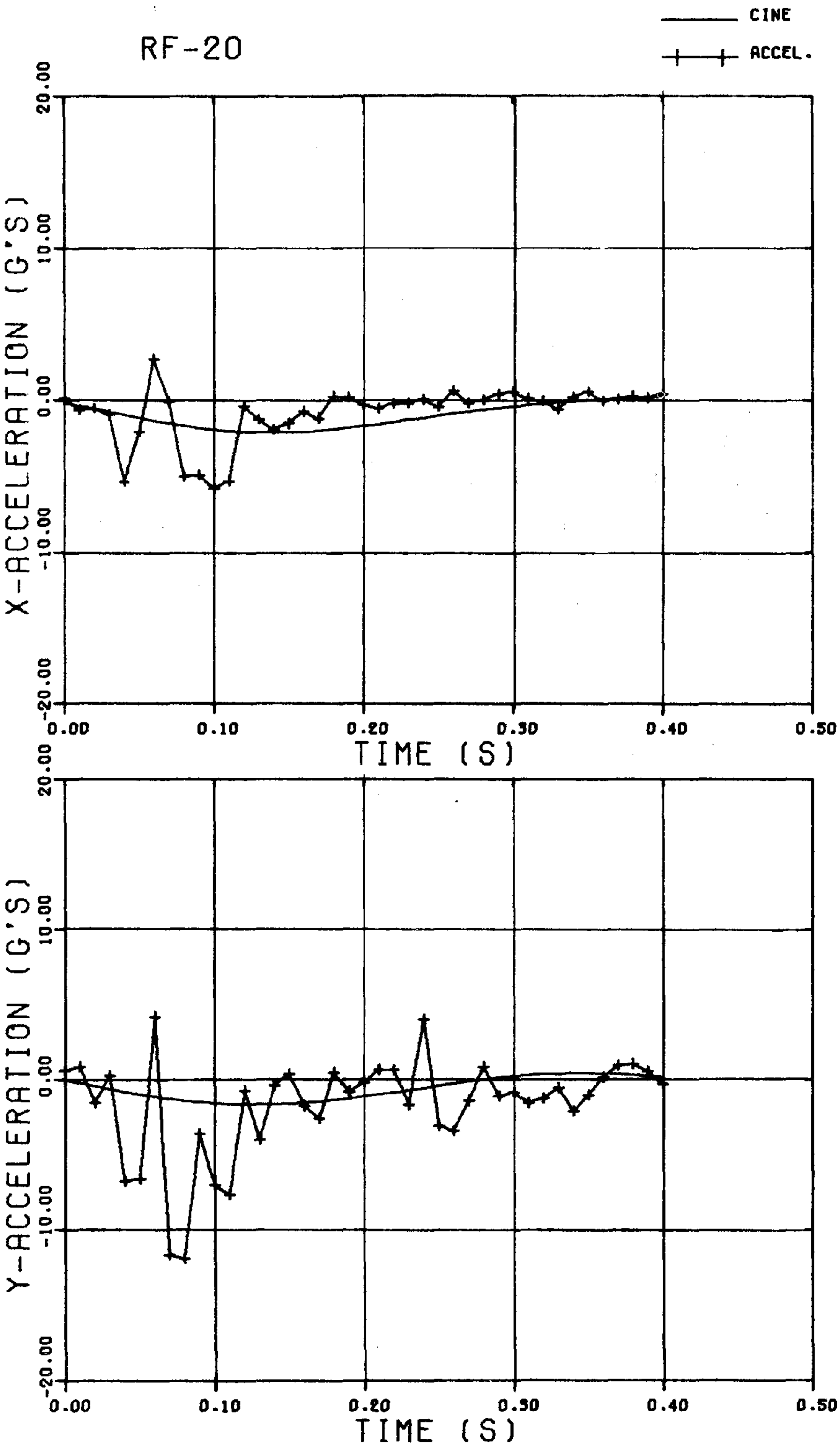


FIGURE B.63 VEHICLE X AND Y ACCELERATION HISTORIES FOR CRASH TEST RF-20

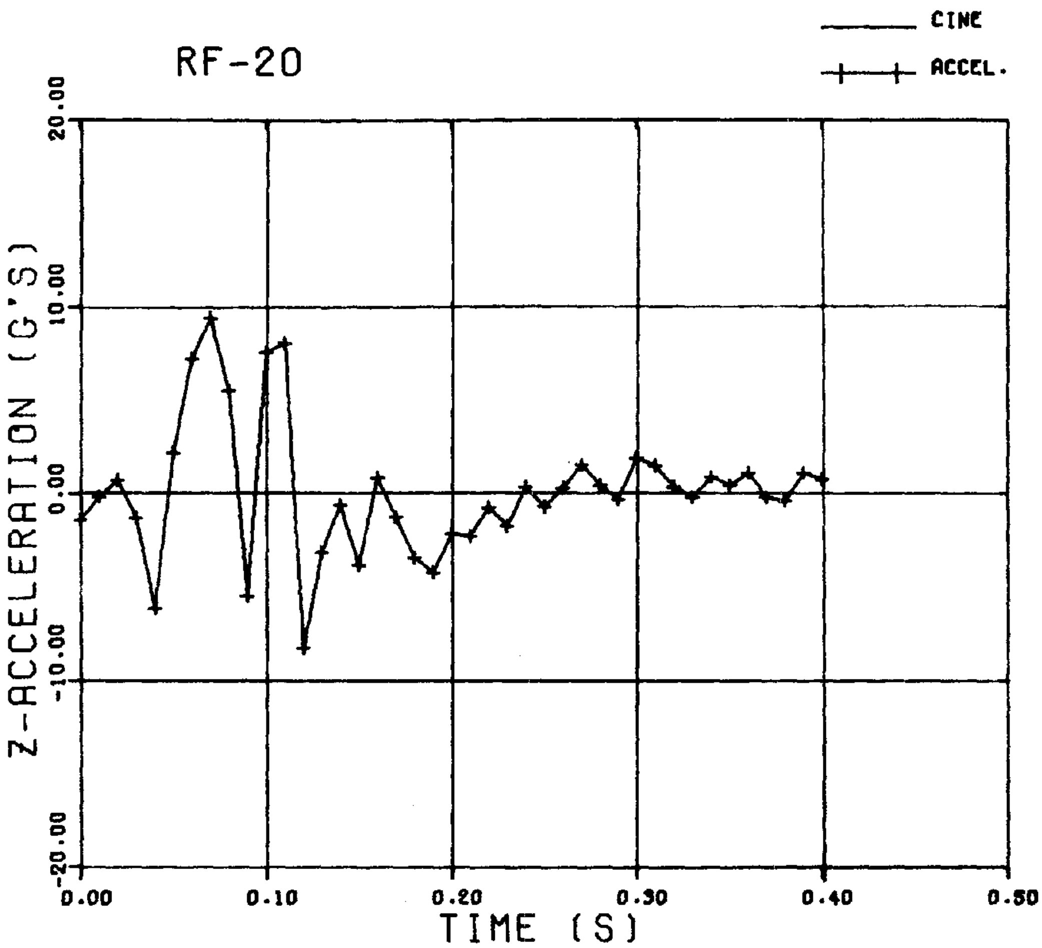


FIGURE B.64 VEHICLE Z ACCELERATION HISTORY FOR CRASH TEST RF-20

TABLE B.35

SUMMARY OF VEHICLE CINE DATA FOR CRASH TEST RF-21

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	VEHICLE ACCELERATION (G'S) AVERAGE OVER .05 SEC. RESULT	APPROX. BARRIER FORCES (KIPS) X	APPROX. BARRIER FORCES (KIPS) Y
0.000	-2.39	-4.86	16.20	64.73	.34	.72	.19	.52	.25	.58	-1.4	-.8
.010	-1.76	-4.68	16.18	64.82	.22	-.13	-1.06	-.18	-.91	.93	-.4	2.3
.020	-1.14	-4.50	16.24	64.64	-.37	-1.02	-2.15	-.98	-1.95	2.18	.8	5.0
.030	-.52	-4.32	16.34	64.17	-1.32	-1.87	-3.03	-1.76	-2.80	3.31	2.0	7.4
.040	.10	-4.16	16.43	63.44	-2.51	-2.60	-3.68	-2.44	-3.44	4.22	3.1	9.1
.050	.71	-4.01	16.46	62.51	-3.80	-3.17	-4.08	-2.99	-3.86	4.88	4.0	10.3
.060	1.32	-3.88	16.40	61.43	-5.08	-3.55	-4.27	-3.37	-4.07	5.29	4.7	10.9
.070	1.92	-3.77	16.20	60.27	-6.25	-3.74	-4.27	-3.57	-4.10	5.44	5.1	11.0
.080	2.51	-3.67	15.84	59.10	-7.23	-3.75	-4.11	-3.60	-3.98	5.36	5.3	10.6
.090	3.09	-3.58	15.32	57.99	-7.98	-3.60	-3.83	-3.47	-3.73	5.10	5.3	9.9
.100	3.67	-3.51	14.63	56.97	-8.47	-3.32	-3.45	-3.22	-3.39	4.66	5.0	8.9
.110	4.24	-3.46	13.79	56.08	-8.68	-2.95	-3.02	-2.88	-2.99	4.15	4.6	7.8
.120	4.80	-3.41	12.81	55.35	-8.62	-2.52	-2.56	-2.47	-2.56	3.56	4.0	6.5
.130	5.36	-3.38	11.71	54.78	-8.31	-2.05	-2.09	-2.04	-2.12	2.94	3.4	5.3
.140	5.91	-3.35	10.53	54.36	-7.79	-1.59	-1.63	-1.60	-1.69	2.32	2.7	4.1
.150	6.45	-3.33	9.29	54.08	-7.07	-1.15	-1.22	-1.17	-1.29	1.74	2.0	3.0
.160	7.00	-3.32	8.02	53.92	-6.21	-.75	-.85	-.78	-.93	1.22	1.3	2.0
.170	7.54	-3.31	6.76	53.86	-5.25	-.39	-.55	-.44	-.64	.77	.7	1.3
.180	8.08	-3.29	5.53	53.89	-4.23	-.09	-.33	-.14	-.42	.44	.1	.7
.190	8.62	-3.29	4.37	53.98	-3.21	.15	-.18	.10	-.27	.29	-.3	.4
.200	9.16	-3.28	3.28	54.11	-2.24	.34	-.12	.28	-.20	.34	-.7	.2
.210	9.70	-3.27	2.30	54.27	-1.34	.47	-.12	.42	-.19	.46	-1.0	.2
.220	10.25	-3.26	1.42	54.45	-.56	.55	-.20	.51	-.26	.57	-1.2	.4
.230	10.79	-3.25	.66	54.64	.08	.59	-.33	.55	-.37	.67	-1.3	.7
.240	11.34	-3.25	.02	54.83	.55	.60	-.51	.56	-.53	.77	-1.3	1.1
.250	11.89	-3.24	-.50	55.01	.86	.56	-.70	.54	-.71	.89	-1.2	1.5
.260	12.44	-3.24	-.91	55.18	.99	.51	-.91	.48	-.90	1.02	-1.1	2.0
.270	12.99	-3.24	-1.21	55.32	.96	.42	-1.11	.41	-1.08	1.16	-.9	2.4
.280	13.55	-3.24	-1.43	55.44	.78	.33	-1.28	.32	-1.24	1.28	-.6	2.8
.290	14.10	-3.25	-1.57	55.52	.48	.22	-1.42	.22	-1.37	1.39	-.4	3.0
.300	14.66	-3.26	-1.64	55.58	.08	.11	-1.50	.11	-1.45	1.45	-.1	3.2
.310	15.21	-3.28	-1.67	55.59	-.38	.00	-1.53	.01	-1.47	1.47	.1	3.3
.320	15.77	-3.30	-1.67	55.58	-.87	-.10	-1.50	-.08	-1.44	1.44	.3	3.2
.330	16.32	-3.33	-1.65	55.54	-1.36	-.18	-1.40	-.16	-1.34	1.35	.5	3.0
.340	16.88	-3.36	-1.62	55.46	-1.81	-.24	-1.24	-.22	-1.19	1.21	.6	2.6
.350	17.43	-3.40	-1.60	55.38	-2.20	-.28	-1.03	-.26	-.98	1.02	.7	2.2
.360	17.98	-3.44	-1.59	55.28	-2.51	-.30	-.77	-.28	-.73	.78	.7	1.6
.370	18.54	-3.48	-1.59	55.19	-2.70	-.30	-.47	-.28	-.45	.53	.7	1.0
.380	19.09	-3.52	-1.62	55.10	-2.78	-.27	-.16	-.26	-.16	.30	.6	.3

TABLE B.36

SUMMARY OF VEHICLE ACCELEROMETER DATA FOR CRASH TEST RF-21

TIME (SEC)	DISPLACEMENT-(FT) LONG.	DISPLACEMENT-(FT) LAT.	HEADING ANGLE-(DEG)	VELOCITY-(FPS) LONG.	VELOCITY-(FPS) LAT.	VEHICLE ACCELERATION-(G'S) AT TIME T LONG.	AT TIME T LAT.	AT TIME T VERT.	AVERAGE OVER .05 SEC. LONG.	AVERAGE OVER .05 SEC. LAT.	AVERAGE OVER .05 SEC. RESULT	AVERAGE OVER .05 SEC. VERT.
.0000	-2.39	-4.86	16.20	64.73	.34	-2.04	1.30	2.27	-2.04	1.30	2.42	2.27
.0100	-1.77	-4.68	16.17	63.88	-.27	-5.18	-7.45	-1.50	-4.39	-6.26	7.64	-.60
.0200	-1.16	-4.52	15.83	62.24	-3.21	-5.94	-12.62	-2.57	-3.50	-2.96	4.58	1.24
.0300	-.56	-4.38	15.68	61.42	-1.76	-1.24	10.19	4.80	-4.38	-5.96	7.40	1.84
.0400	.04	-4.22	15.77	61.35	-1.14	-3.10	-6.21	3.23	-4.94	-4.93	6.98	3.32
.0500	.63	-4.09	17.05	59.51	-6.21	-6.46	-13.70	5.27	-4.25	-2.74	5.06	3.79
.0600	1.21	-3.99	17.20	58.09	-8.16	-7.96	-2.31	5.89	-4.97	-6.16	7.91	2.86
.0700	1.79	-3.90	16.54	57.05	-8.48	-2.51	-1.68	-.26	-5.19	-6.18	8.07	2.25
.0800	2.35	-3.83	15.66	56.02	-9.49	-4.82	-6.89	.19	-4.30	-3.70	5.67	.49
.0900	2.91	-3.77	14.54	55.17	-9.42	-4.22	-6.33	.17	-2.71	-3.90	4.75	-.72
.1000	3.47	-3.74	13.52	54.70	-9.84	-1.96	-1.31	-3.52	-2.52	-3.98	4.70	-1.34
.1100	4.03	-3.71	12.32	54.81	-9.37	-.03	-3.29	-.21	-1.67	-2.60	3.09	-2.20
.1200	4.58	-3.59	11.15	54.90	-8.89	-1.55	-2.06	-3.34	-.77	-1.19	1.42	-2.64
.1300	5.14	-3.67	9.83	55.02	-7.67	-.57	-.04	-4.09	-.43	-1.10	1.18	-2.22
.1400	5.69	-3.65	8.61	54.94	-6.90	.26	.75	-2.06	-.29	-.60	.66	-2.30
.1500	6.24	-3.64	7.51	54.95	-5.82	-.27	-.87	-1.42	-.25	-.70	.75	-1.32
.1600	6.80	-3.63	6.36	54.91	-5.32	.70	-.78	-.58	-.31	-1.56	1.59	-.90
.1700	7.35	-3.62	5.17	54.82	-4.79	-1.38	-2.58	1.54	-.15	-2.26	2.26	-.65
.1800	7.90	-3.63	4.15	54.58	-5.03	-.86	-4.31	-1.96	.27	-2.59	2.60	-.66
.1900	8.45	-3.64	3.27	54.91	-5.27	1.06	-2.77	-.84	-.27	-2.93	2.94	-.40
.2000	9.00	-3.67	2.88	55.75	-5.92	1.81	-2.51	-1.46	.00	-2.78	2.78	-.43
.2100	9.56	-3.71	2.38	55.61	-6.45	-1.98	-2.49	.73	.40	-1.87	1.91	.16
.2200	10.12	-3.76	2.14	55.02	-6.94	-.01	-1.86	1.39	.13	-1.01	1.02	.88
.2300	10.67	-3.80	1.76	54.92	-6.56	1.15	.27	.98	-.50	-.89	1.02	1.15
.2400	11.22	-3.85	1.61	55.17	-6.14	-.29	1.51	2.78	-.24	-.24	.34	.94
.2500	11.77	-3.90	1.34	55.12	-6.09	-1.36	-1.90	-.12	-.52	.46	.70	.65
.2600	12.32	-3.94	1.13	54.58	-5.76	-.69	.79	-.33	-.48	1.05	1.15	1.09
.2700	12.87	-3.99	.99	54.65	-5.07	-1.40	1.65	-.07	-.29	.55	.63	1.05
.2800	13.42	-4.03	1.07	54.41	-4.87	1.36	3.13	3.18	-.06	1.08	1.08	2.02
.2900	13.96	-4.06	.98	54.45	-4.54	.62	-.96	2.56	.08	.78	.78	2.14
.3000	14.51	-4.10	.91	54.51	-4.48	-.19	.73	4.77	.45	.43	.62	2.81
.3100	15.06	-4.14	.70	54.55	-4.33	.03	-.71	.22	.11	-.40	.41	2.25
.3200	15.60	-4.17	.63	54.76	-4.23	.42	-.10	3.31	-.15	-.05	.16	2.22
.3300	16.15	-4.21	.57	54.61	-4.32	-.31	-.95	.38	-.09	.01	.09	1.28
.3400	16.70	-4.25	[illegible]	54.60	-4.46	-.70	.77	2.42	.03	.10	.10	1.23
.3500	17.24	-4.29	.56	54.48	-4.38	.11	1.06	.08	-.13	.10	.17	.76
.3600	17.79	-4.33	.44	54.64	-4.34	.63	-.31	-.05	-.12	.38	.40	.74
.3700	18.34	-4.37	.21	54.68	-4.19	-.39	-.06	.96	.09	.18	.20	.41
.3800	[illegible]	-4.45	.17	54.63	-4.09	-.25	.43	.28	-.01	-.24	.24	.69

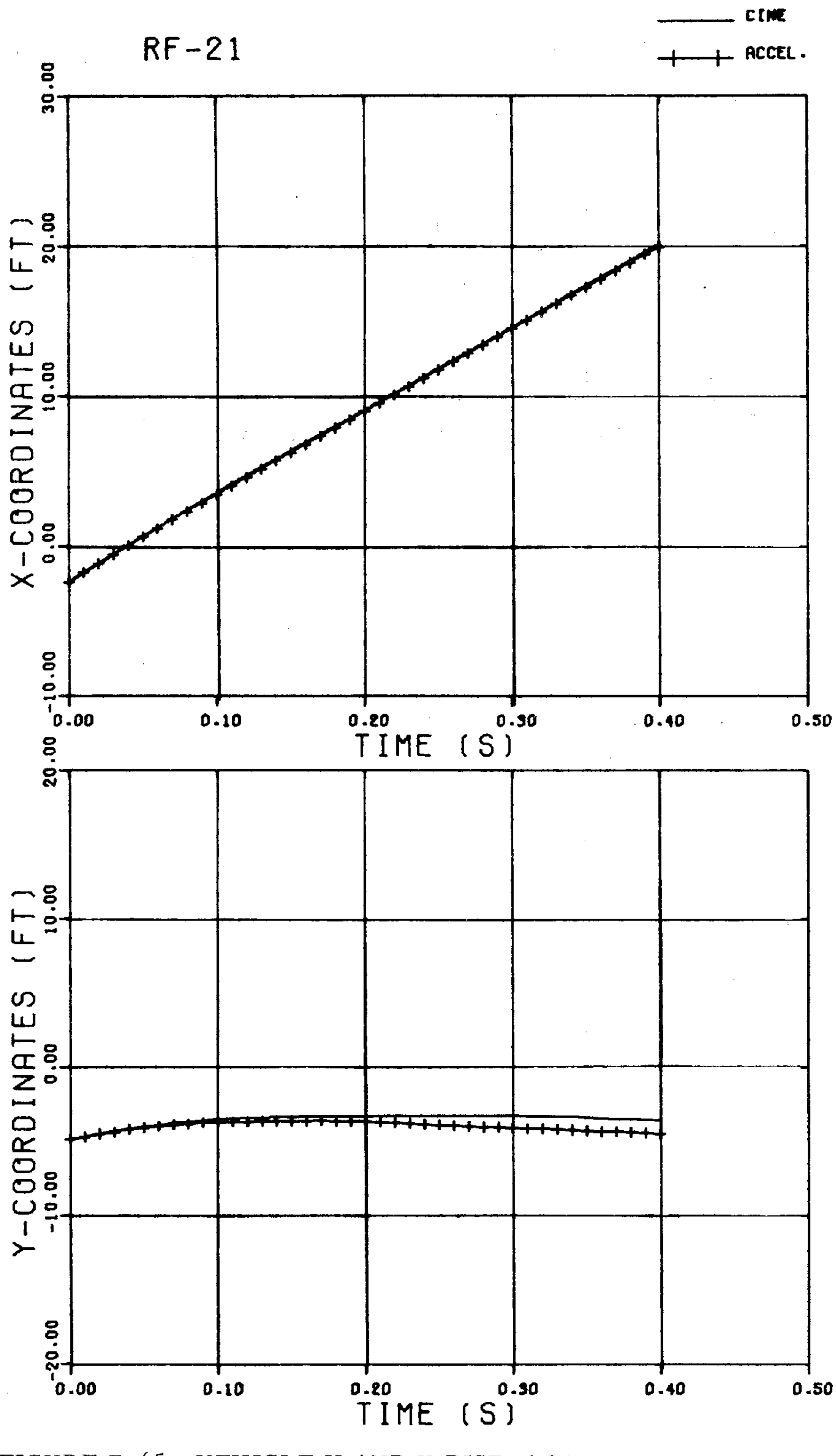


FIGURE B.65 VEHICLE X AND Y DISPLACEMENT HISTORIES FOR CRASH TEST RF-21

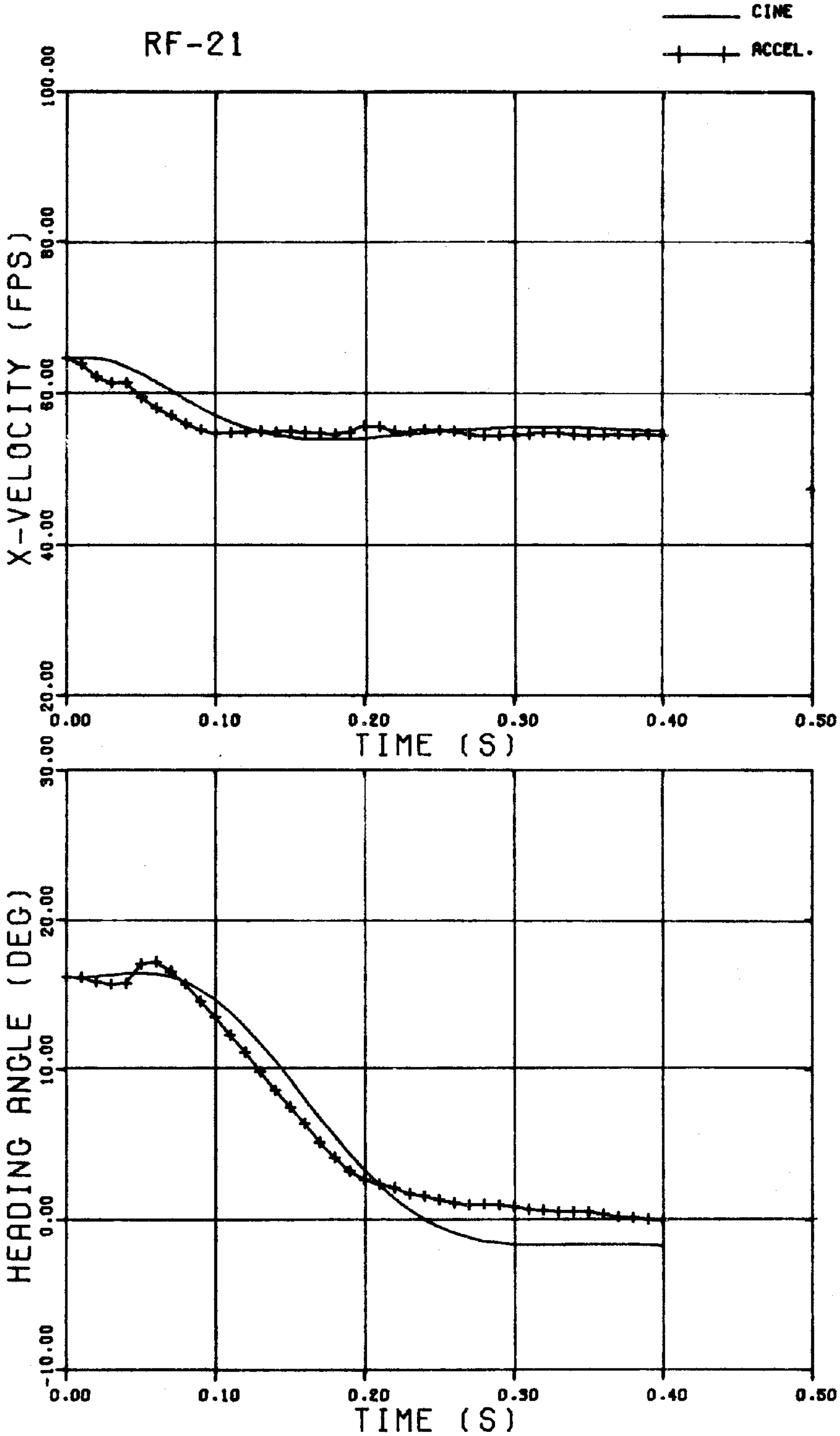


FIGURE B.66 VEHICLE X VELOCITY AND HEADING ANGLE HISTORIES FOR CRASH TEST RF-21

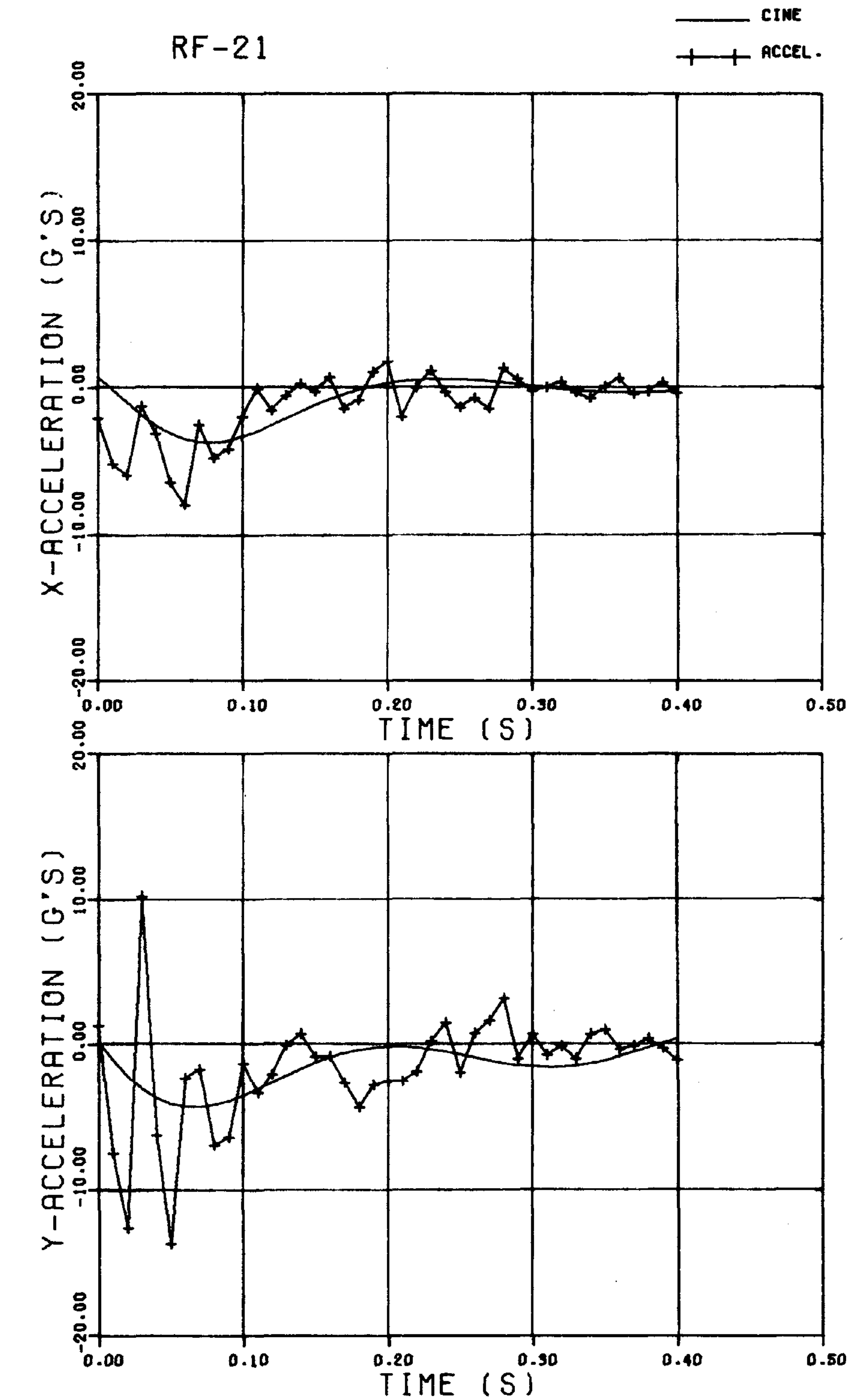


FIGURE B.67 VEHICLE X AND Y ACCELERATION HISTORIES FOR CRASH TEST RF-21

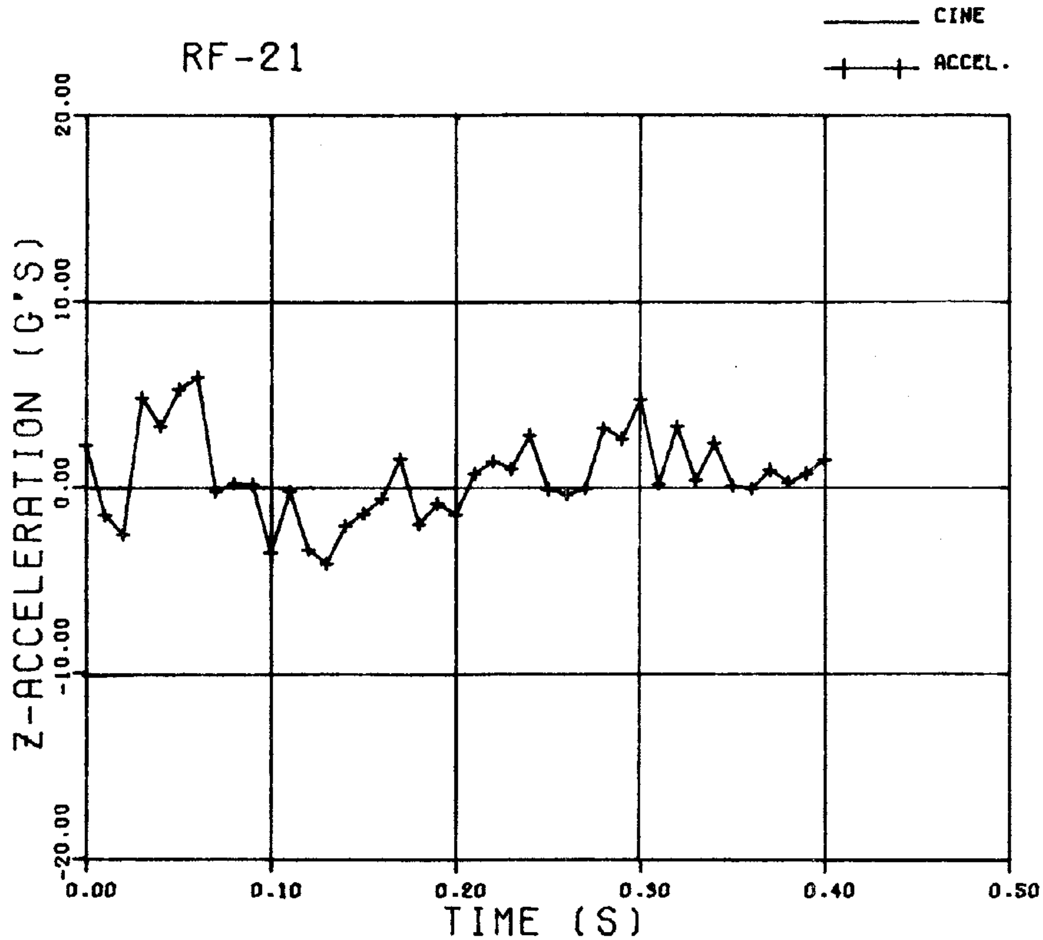


FIGURE B.68 VEHICLE Z ACCELERATION HISTORY FOR CRASH TEST RF-21

TABLE B.37

SUMMARY OF VEHICLE ACCELERATION DATA FOR CRASH TEST RF-22

TIME (SEC)	DISPLACEMENT-(FT) LONG.	DISPLACEMENT-(FT) LAT.	HEADING ANGLE-(DEG)	VELOCITY-(FPS) LONG.	VELOCITY-(FPS) LAT.	VEHICLE ACCELERATION-(G'S) AT TIME T LONG.	AT TIME T LAT.	AT TIME T VERT.	AVERAGE OVER .05 SEC. LONG.	AVERAGE OVER .05 SEC. LAT.	AVERAGE OVER .05 SEC. RESULT	AVERAGE OVER .05 SEC. VERT.
.0000	.00	.00	18.30	90.79	.00	.04	-1.74	-2.59	.04	-1.74	1.74	-2.59
.0100	.86	.28	18.30	90.86	-.01	.44	1.94	-1.56	.38	-.18	.42	-.73
.0200	1.72	.57	18.39	90.86	-.20	.64	-.74	1.97	-1.44	-3.05	3.37	-1.21
.0300	2.59	.86	18.46	90.81	-.18	.40	.46	-.99	-2.71	.10	2.71	-.51
.0400	3.45	1.13	18.46	89.29	-1.51	-8.71	-15.16	-2.90	-2.68	-2.55	3.69	-2.20
.0500	4.30	1.38	17.78	88.17	-3.01	-6.32	14.00	.94	-4.60	-6.80	8.21	-.12
.0600	5.14	1.63	18.05	87.25	-1.68	.60	-11.29	-10.00	-7.36	-10.22	12.60	-.55
.0700	5.97	1.87	18.60	86.61	-5.71	-8.99	-22.03	12.36	-7.10	-10.83	12.95	-1.92
.0800	6.81	2.06	21.56	82.43	-15.12	-13.40	-16.62	-3.15	-7.26	-16.09	17.65	-3.84
.0900	7.62	2.19	20.37	79.50	-18.45	-7.37	-18.19	-9.74	-8.21	-15.57	17.60	1.02
.1000	8.43	2.26	19.44	77.53	-21.86	-7.12	-12.31	-8.66	-7.01	-10.28	12.45	-.03
.1100	9.23	2.29	17.21	77.10	-22.46	-4.17	-8.68	14.29	-4.01	-7.80	8.77	.95
.1200	10.03	2.29	15.58	76.98	-21.29	-3.00	4.40	7.14	-1.95	-4.14	4.57	1.77
.1300	10.83	2.30	13.89	77.80	-18.85	1.64	-4.24	1.73	-.62	-3.39	3.44	1.77
.1400	11.63	2.30	12.36	78.58	-16.18	2.91	.14	-5.65	.20	-2.32	2.33	-1.98
.1500	12.44	2.31	10.81	79.28	-14.42	-.45	-8.56	-8.66	.54	-2.63	2.68	-3.87
.1600	13.25	2.31	9.51	79.31	-15.17	-.11	-3.33	-4.44	-.76	-1.37	1.56	-3.42
.1700	14.06	2.28	8.40	80.01	-14.59	-1.27	2.87	-2.33	-2.00	-1.77	2.67	-2.35
.1800	14.87	2.25	7.12	79.74	-13.31	-4.85	2.04	4.00	-1.45	-.45	1.52	-1.73
.1900	15.67	2.21	6.00	79.24	-13.00	-3.30	-1.85	-.32	-1.52	.40	1.58	-2.34
.2000	16.47	2.16	5.15	79.62	-13.22	2.27	-1.99	-5.55	-1.13	-.45	1.21	-1.95
.2100	17.28	2.10	4.39	80.18	-12.24	-.47	.95	-7.48	-.06	-.87	.87	-1.82
.2200	18.09	2.04	4.16	80.37	-12.56	.72	-1.39	-.43	.47	-.31	.56	-1.92
.2300	18.90	1.97	3.78	80.45	-11.97	.48	-.05	4.67	-.18	-.06	.19	-.57
.2400	19.71	1.91	3.56	80.44	-11.40	-.63	.95	-.81	-.15	-.14	.21	.91
.2500	20.52	1.84	3.25	80.37	-11.13	-1.01	-.74	1.22	-.39	.62	.73	.97
.2600	21.33	1.77	2.84	80.31	-10.77	-.29	.51	-.12	-.56	.75	.93	-.05
.2700	22.13	1.71	2.43	80.16	-9.96	-.47	2.43	-.09	-.38	.37	.53	-.06
.2800	22.94	1.64	2.07	80.01	-9.18	-.37	.60	-.43	.13	.66	.67	.46
.2900	23.74	1.58	1.80	80.03	-8.95	.26	-.97	-.89	.42	.56	.70	1.18
.3000	24.54	1.51	1.57	80.20	-8.98	1.52	.72	3.84	.52	.16	.54	.73
.3100	25.35	1.45	1.27	80.57	-8.59	1.16	.02	3.48	.32	.18	.37	.75
.3200	26.16	1.38	.97	80.68	-8.27	.04	.42	-2.38	.20	.48	.52	1.47
.3300	26.96	1.31	.70	80.47	-7.88	-1.39	.74	-.32	-.21	.28	.35	.70

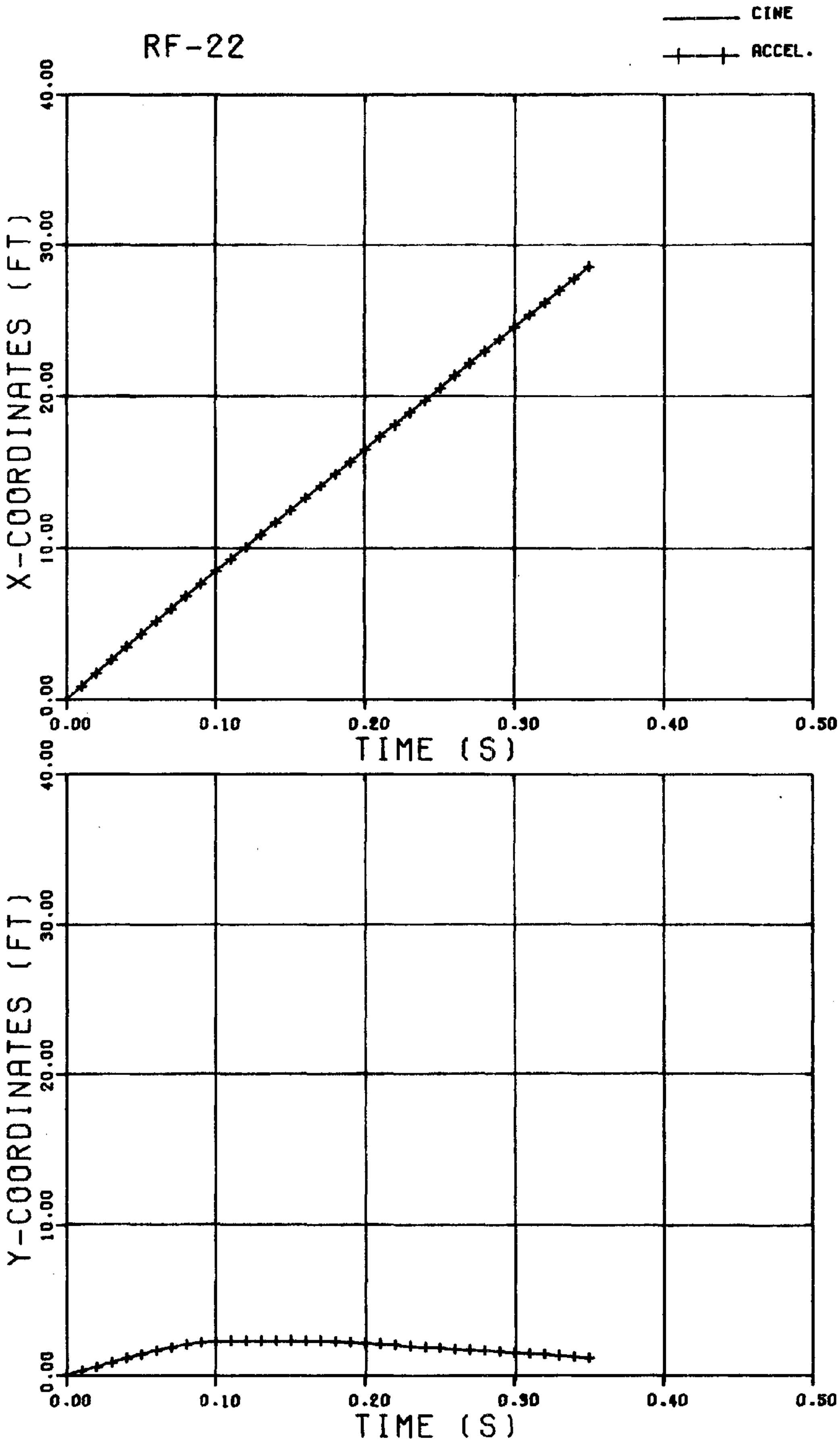


FIGURE B.69 VEHICLE X AND Y DISPLACEMENT HISTORIES FOR CRASH TEST RF-22

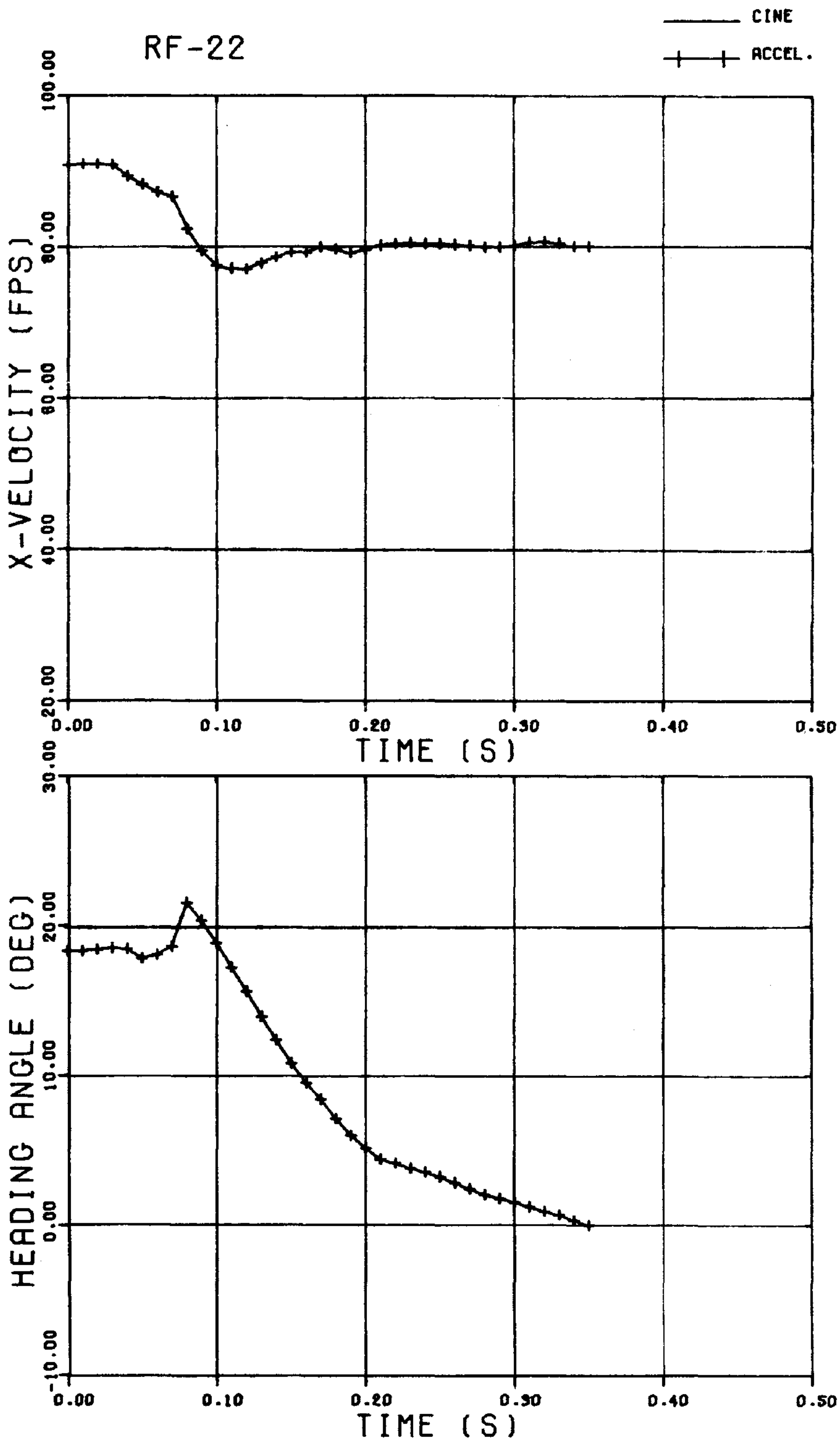


FIGURE B.70 VEHICLE X VELOCITY AND HEADING ANGLE HISTORIES FOR CRASH TEST RF-22

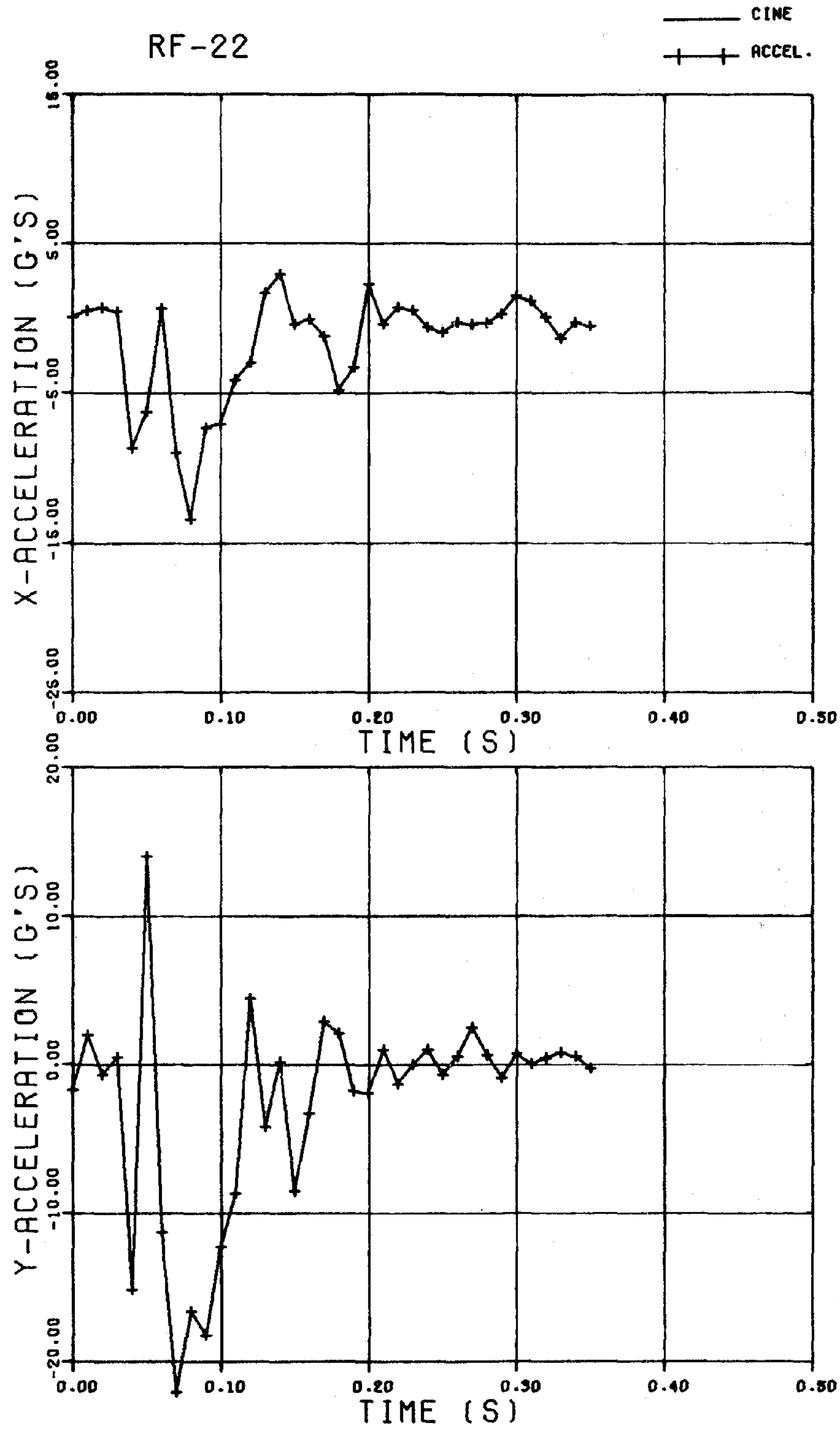


FIGURE B.71 VEHICLE X AND Y ACCELERATION HISTORIES FOR CRASH TEST RF-22

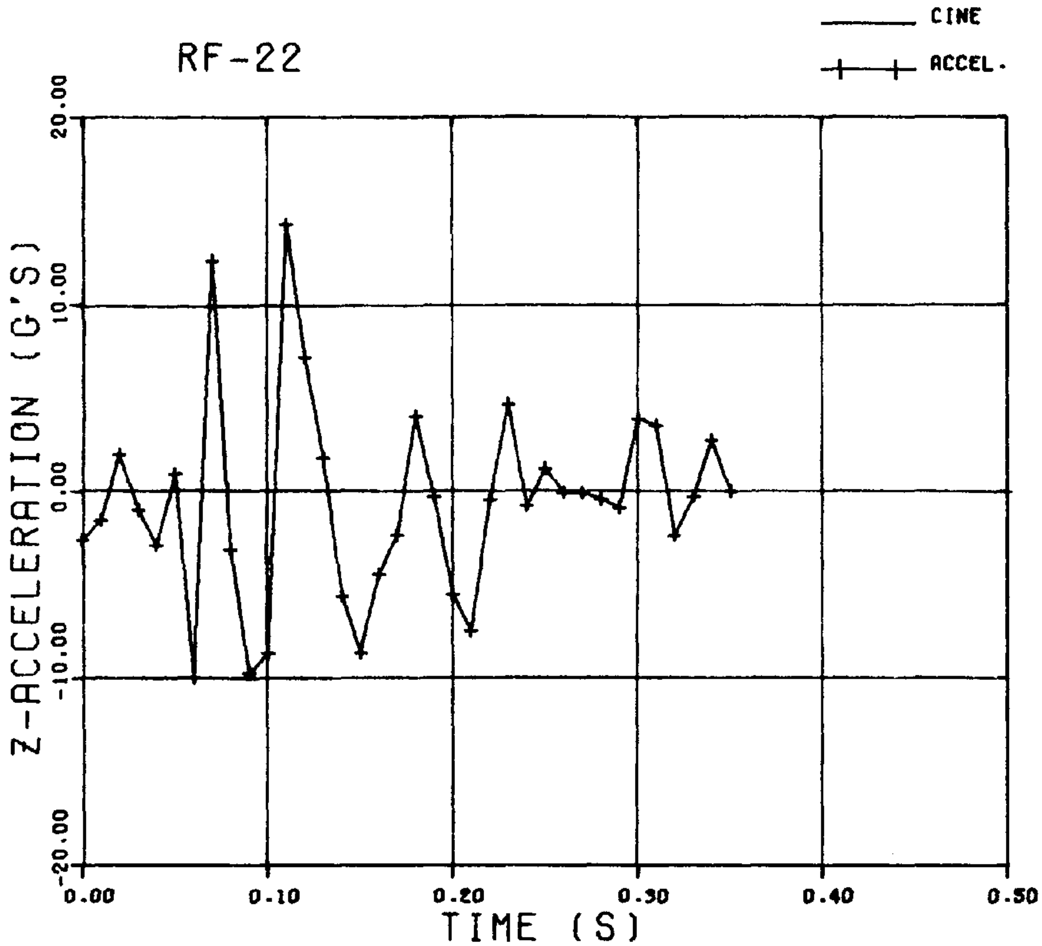


FIGURE B.72 VEHICLE Z ACCELERATION HISTORY FOR CRASH TEST RF-22

APPENDIX C

SIMULATION STUDIES: EFFECTS OF CURB GEOMETRY ON VEHICLE REDIRECTION

SIMULATION STUDIES: EFFECTS OF CURB GEOMETRY ON VEHICLE REDIRECTION

The influence of bridge railing curb and walk geometry was investigated by conducting HVOSM computer simulation of the vehicle-barrier interaction. It is recognized that the wheel-tire analog of the HVOSM program was developed primarily for vehicle handling studies, and it cannot accommodate side forces introduced by a curb in shallow angle impacts. However, the HVOSM program is judged to represent the best technology for this application. It was felt that this theoretical study would provide insight into the vehicle-curb interaction.

A case matrix was formulated to examine curb geometry and walk width. An approach angle of 15 degrees, in accord with Zobel's recommendation, was selected as a prime test condition. The vehicle characteristics as shown in Table C.1 and approach speed of 60 mph (26.8 m/s) were held constant during these runs, and only the curb geometry was changed. The test matrix comprised the following cases:

No.	Approach Angle (deg)	Curb Dimensions (in.)*			Other
		Height	Batter	Walk Width	
1	15	9	1	0	
2	15	9	1	12	
3	15	9	1	24	
4	15	9	1	36	
5	15	9	1	48	
13	15				Gen. Motors Shape
14	15				NJ Shape
15	15	9	9	12	
16	15	9	9	48	

Three additional cases were run to examine effect of vehicle approach angle:

No.	Approach Angle (deg)	Curb Dimensions (in.)*		
		Height	Batter	Walk Width
6	5	9	1	0
7	10	9	1	0
10	25	9	1	0

Typical input information for the HVOSM is presented in Table C.2. Output of HVOSM is a number of vehicle dynamic and kinematic properties as a function of time. Ultimately, vehicle redirection severity is based on occupant hazard. Unfortunately, there is no simple or complex interrelationship between vehicle dynamics and occupant hazard presently available. With other factors being equal, it is known that an occupant is more vulnerable to lateral impact with an adjacent door than a longitudinal impact with the dash; this is due to the physiological construction of the human body and to the lack of padding on the door. In viewing the computer results, it is found that vehicle longitudinal and vertical accelerations do not vary significantly among the cases. Accordingly, it was decided to use vehicle lateral accelerations during impact and redirection as an index to severity.

Vehicle lateral accelerations are shown for three curb widths in Figure C.1: 0, 1, and 2 feet (0, 0.3 and 0.6 m); results of 3- and 4-ft (0.9 and 1.2 m) wide curbs are similar to those of the 2-ft

*Metric conversion: multiply in. by 25.4 to obtain mm.

TABLE C.1

HVOSM VEHICLE PROPERTIES

Vehicle Property	1963 Plymouth*
A - Dist. CG to Front Wheel, in.	58.58
B - Dist. CG to Rear Wheel, in.	57.42
TF - Tread at Front, in.	60.00
TR - Tread at Rear, in.	60.00
ZF - Dist. CG Sprung & CG Unsprung Front, in.	10.00
ZR - Dist. CG Sprung & CG Unsprung Rear, in.	12.00
RHO - Dist. CG Rear Axle & Rear Axle Roll Center, in.	-2.00
RW - Undeflected Wheel Radius, in.	14.00
MS - Sprung Mass, $lb\text{-}s^2/in.$	8.90
MUF - Front Unsprung Mass, $lb\text{-}s^2/in.$	0.600
MUR - Rear Unsprung Mass, $lb\text{-}s^2/in.$	0.900
I_x - Moment of Inertia - X Axis, $lb\text{-}s^2\text{-}in.$	4500
I_y - Moment of Inertia - Y Axis, $lb\text{-}s^2\text{-}in.$	25000
I_z - Moment of Inertia - Z Axis, $lb\text{-}s^2\text{-}in.$	39000
I_{xz} - Product of Inertia, $lb\text{-}s^2\text{-}in.$	0.0
IR - Rear Unsprung I About Line Thru Its CG and Parallel to X Axis, $lb\text{-}s^2\text{-}in.$	600
XVF - Dist. From CG to Front of Vehicle, in.	90.58
XVR - Dist. From CG to Rear of Vehicle, in.	-112.42
YV - Dist. From CG to Either Side, in.	37
ZVT - Dist. From CG to Top, in.	-14.00
ZVB - Dist. From CG to Bottom, in.	10.00

*Data obtained from Texas Transportation Institute.

Metric Conversions:

Multiply in. by 0.0254 to obtain m.

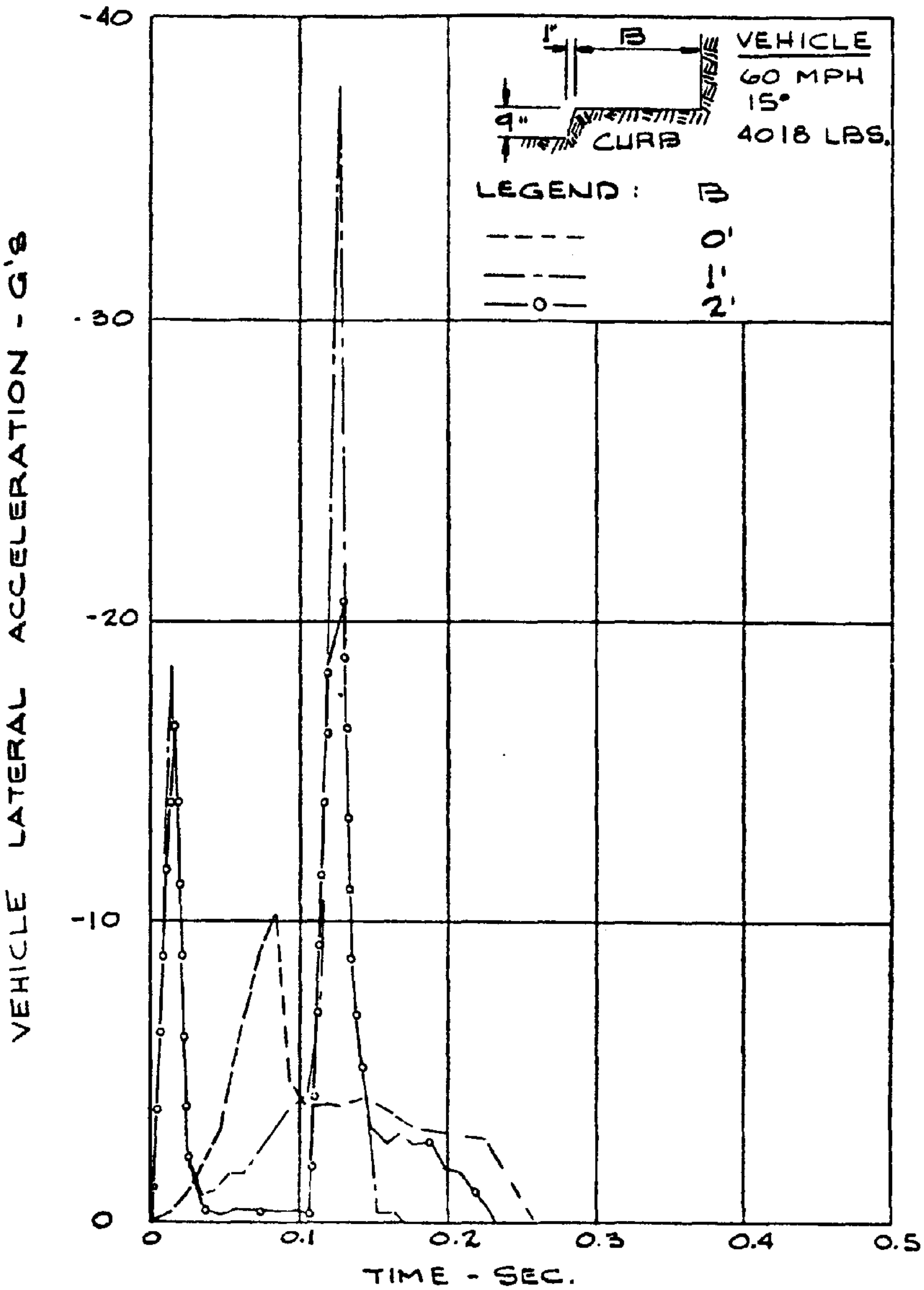
Multiply $lb\text{-}s^2/in.$ by 17.86 to obtain $kg\text{-}s^2/m$.

Multiply $lb\text{-}s^2\text{-}in.$ by 0.012 to obtain $kg\text{-}s^2\text{-}m$.

TABLE C.2

TYPICAL HVOSM INPUT

```
                                              INITIAL CONDITIONS                                                              ACCELEROMETER POSITIONS

PHIO   =    0.0     DEGREES    XCO'   = 240.000INCHES      PO      =     0.0    DEG/SEC     UO      =1056.000 IN/SEC             X1    = -32.670 INCHES
THETAO=     0.0       ''       YCO'   =1208.000  ''        QO      =     0.0      ''        VO      =    0.0     ''              Y1    = -18.750   ''
PSIO   =    7.000     ''       ZCO'   = -24.000  ''        RO      =     0.0      ''        WO      =    0.0     ''              Z1    =   8.000   ''
PHIRO =     0.0       ''       DELTA1=    0.0    ''   D(PHIR)/DT=    0.0      ''   D(DEL1)/DT=      0.0     ''              X2    = -32.670   ''
PSIFIO=     0.0       ''       DELTA2=    0.0    ''   D(PSIF)/DT=    0.0   RAD/SC D(DEL2)/DT=      0.0     ''              Y2    =  18.750   ''
                               DELTA3=    0.0    ''                                  D(DEL3)/DT=   0.0     ''              Z2    =   8.000   ''


                                                            DRIVER CONTROL TABLES

   T      PSIF     TQF     TQR      T      PSIF     TQF     TQR      T      PSIF     TQF     TQR      T      PSIF     TQF     TQR
  SEC      DEG    LB/FT   LB/FT    SEC      DEG    LB/FT   LB/FT    SEC      DEG    LB/FT   LB/FT    SEC      DEG    LB/FT   LB/FT

  0.0      0.0     0.0     0.0

                                                                                                        FRONT WHEEL CAMBER
     TIRE DATA              TERRAIN TABLE ARGUMENTS                    PROGRAM CONTROL DATA                      VS
                                                                                                       SUSPENSION DEFLECTION
KT          1098.000 LB/IN                                START TIME              =   0.0   SEC
SIGMAT  =      3.000                                      END TIME                =   0.500                      DELTAF    PHIC
LAMBDAT =     10.000                                      INCR FOR INTEGRATION =      0.0050 ''                  INCHES    DEGREES
A0       =4400.000        SOIL DAMPING= 0.001 SPI         PRINT INTERVAL          =   0.010  ''
A1       =     3.276      SOIL FRICT. = 0.250             THETA MAX (TO SWITCH)=  70.000 DEG                    -5.000    -3.550
A2       =2900.000        SSTIFF    =    4000. LB/IN      UVWMIN(STOP)            =   0.0
A3       =     1.780      NO.X TEMPS. =  2                PQRMIN(STOP)            =   0.0
A4       =3900.000        NO.Y TEMPS. =  2                INDCRB                  =   1  (=0.NO CURB,=1 CURB,=-1 STEER DEG.OF FREEDOM)
AMU      =     0.800      NO. VAR AMU =  0                MODE OF INTEGRATION     =   1  (=0 VAR.ADAMS-MOULT.,=1 RUNGE-KUTTA,=2FIX.AM)
OMEGT    =     1.000      TABLES                          DTCMP1                  =  0.  (=1.0 SUPPLY INITIAL POSITION)
                                                                                          (=0.0 CAR RESTS ON TERRAIN)
                                             STRUCTURAL HARDPOINTS RELATIVE TO C. G.
                                                          X        Y         Z    STIFFNESS                 WHEEL RADIUS-RADIAL SPRING FOR TABLE
                                                              (INCHES)             LB/IN                    RWHJB(BEGIN)    =    0.0    INCHES
COEFF. OF TIRE FRICTION                      POINT   1  67.000  30.000  17.000   2500.000                  RWHJE(END)      =    8.000    ''
          VS.                                POINT   2 -57.420  30.000  20.000   2500.000                  DRWHJ(INCRE.)   =    0.250    ''
(SPEED AND  LOAD) DATA                       POINT   3  77.000  18.000   0.0     2500.000
ALPHA= 0.0          1/(LB-MPH)

ANTI-PITCH TABLES FOR CIRCUMFERENTIAL TIRE FORCE
APF=     0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
         0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
APR=     0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0
         0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0       0.0

      CURB IMPACT DATA                                                      SPRUNG MASS-BARRIER IMPACT DATA
                                                    BARRIER DIMENSIONS                                                   BARRIER LOAD DEFLECT.
YC1'             =1273.000 INCHES            (YB')0 =1280.000 INCHES      KV          =    2.000 LB/IN**3         SIGMAR 0  =     0.0
YC2'             =1273.260   ''              DELYB' =    0.500   ''       SET         =    0.001 DEFL.RATIO       SIGMAR 1  =     0.0
ZC2'             =   -3.000  ''              ZBT'   =  -32.000   ''       CONS        =    1.000 ENERGY RATIO     SIGMAR 2  =     0.0
DELTC            =    0.0020 SEC(INTEG.INCR.)  ZBB'  =    0.0    ''       MUB         =    0.300                  SIGMAR 3  =     0.0
PHIC1            = -85.000 DEGREES             VEHICLE DIMENSIONS          EPSILON V=      1.000 IN/SEC           SIGMAR 4  =     0.0
PHIC2            = -55.000   ''              XVF    =   90.580 INCHES     EPSILON B= 500.000 LB                   SIGMAR 5  =     0.0
MUC              =    0.500                  XVR    =-112.420   ''        DELTB       =    0.0020 SEC             SIGMAR 6  =     0.0
                                             YV     =   37.000   ''                        (INTEG.INCR)          SIGMAR 7  =     0.0
IPSI             = 492.000 LB-SEC**2-IN      ZVT    =  -14.000   ''                                               SIGMAR 8  =     0.0
CPSI'            = 600.000 LB-IN             ZVB    =   10.000   ''                                               SIGMAR 9  =     0.0
OMEGA PSI        =    0.400 RAD              INDB =   1 (=1 RIGID BARRIER, FINITE VERT. DIM.)                     SIGMAR10  =     0.0
KPSI             =5000.000 LB-IN/RAD                  =2  ''       ''    INFINITE  ''    ''  )
EPSILON PSI      =    0.075 RAD/SEC                   =3 DEFORM.BARRIER,FINITE  ''    ''  )
TRAIL,FRONT(PT)=     1.500 INCHES                     =4  ''       ''    INFINITE  ''    ''  )
                                                                              XKVTH= 0.0          1/MPH
VEHICLE-CURB FRICTION COEFFICIENT (AMUC) = 0.500                              XKL=   0.0          1/LB
                    FIXED SPACE PHI-COORDINATES (DEGREES)

                                                                                    VEHICLE MONITOR POINTS
PHIC1          PHIC2          PHIC3          PHIC4          PHIC5          PHIC6
                                                                                       X         Y         Z
-85.000        -55.000                                                               (IN.)     (IN.)     (IN.)
                    FIXED SPACE Y-COORDINATES (INCHES)
                                                                              POINT 1   81.517   39.500   12.138
                                                                              POINT 2   81.517  -39.500   12.138
  YC1P           YC2P           YC3P           YC4P           YC5P           YC6P     POINT 3-117.483   39.000    8.138
                                                                              POINT 4-117.483  -39.000    8.138
1273.000       1273.260
                    FIXED SPACE Z-COORDINATES (INCHES)


               ZC2P           ZC3P           ZC4P           ZC5P           ZC6P

               -3.000
```



Metric Conversions:
Multiply mph by 0.447 to obtain m/s.
Multiply lbs by 0.454 to obtain kg.
Multiply in. by 25.4 to obtain mm.
Multiply ft by 0.305 to obtain m.

FIGURE C.1 EFFECT OF CURB WIDTH ON VEHICLE LATERAL ACCELERATION

(0.6 m) wide curb. For the 0-ft wide curb (vertical wall), there is only one peak at about 10 g's, and this represents the vehicle front crushing into the wall. For both the 1- and 2-ft (0.3 and 0.6 m) wide curbs (and 3- and 4-ft [0.9 and 1.2 m] wide curbs), there is an initial peak of about 18 g's which occurs as the vehicle front wheel "mounts" the curb. The second peak occurs when the rear wheel mounts the curb; for the narrow 1-ft (0.3 m) wide curb, the front wheel and front quarter panel impact the vertical wall simultaneously.

Two cases (Nos. 15 and 16) were performed to study influence of a 45-deg batter or ramp on the curb; although this design would not be expected to be used in service, the represented wheel would more easily mount the curb. Results of these cases are shown in Figure C.2, along with the vertical wall case that serves as a reference. As expected, vehicle lateral accelerations are greatly diminished from those shown in Figure C.1, with the peak values corresponding to vehicle crush into the vertical wall.

Lateral acceleration time history as a function of impact angle into a vertical wall is presented in Figure C.3. Peak values range from a high of 19 g's for a 25-deg impact to a low of 2.5 g's for a 5-deg impact.

Somewhat surprising findings are shown in Figure C.4, where vehicle impacts into a vertical wall and New Jersey shape are compared. Longitudinal acceleration peak is less for the NJ shape; however, the lateral peaks (primary and secondary) are larger for the NJ shape.

Two model inputs, vehicle deformation crush constant K of 2.0 pci (5.4×10^5 N/m^3) and hardpoint stiffness of 2,500 lb/in. (4.4×10^5 N/m) were suspected of being improper. Accordingly, a series of parametric cases was performed in which these two inputs were varied independently over a reasonable range.

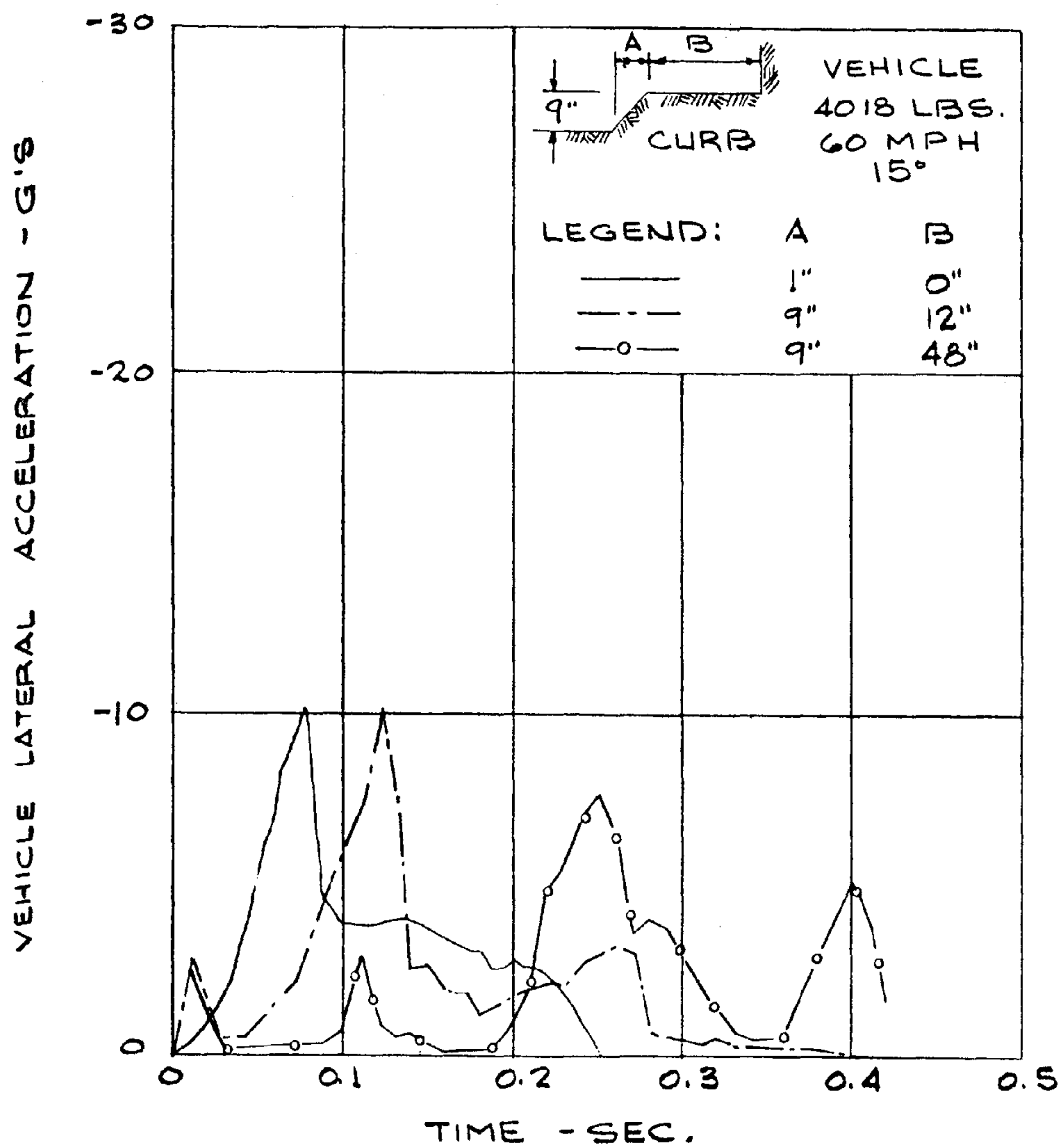
Three additional values of K_V were investigated: 1.0, 3.0, and 6.0 pci (2.7×10^5, 8.1×10^5, and 1.6×10^6 N/m^3). Results from the computer runs are summarized in Table C.3. Lateral acceleration peaks are approximately equivalent for the eight cases. Vehicle crush, normal and friction force on the barrier vary in proportion to the deformation constant.

Stiffness of the vehicle hardpoints was varied over the range of 2,500 to 25,000 lb/in. (4.4×10^5 to 4.4×10^6 N/m). Findings from these computer runs are summarized in Table C.4 in terms of vehicle accelerations, speed change, exit angle, deformation and friction work. As noted in the table, vehicle acceleration peaks are only moderately affected by stiffness through the range of impact angles. As might be expected, the greatest variation occurs with the vertical wall and at the 15-deg impact. In the vehicle/GM barrier interaction, the hardpoint stiffness is even less significant. Vehicle peak accelerations are generally higher for the vertical wall than the GM barrier shape.

A comparison of vehicle speed change during barrier contact is shown in Figure C.5 for the two barrier shapes. The vertical wall will effect about twice the speed change of a GM barrier and, hence, subject vehicle occupants to a much greater hazard during impact.

The vehicle kinetic energy dissipated because of friction work as the vehicle slides along the barrier is illustrated in Figure C.6. Friction work for the vertical barrier is more than twice that of the GM barrier and may imply greater vehicle interaction and damage caused by the vertical surface.

Vehicle exit angle is plotted as a function of impact angle for the two barriers in Figure C.7; the exit angle was determined at the instant the vehicle lost contact with the barrier, even though the vehicle exhibited a significant yaw velocity at that time. The vehicle left the vertical wall at more than twice the exit angle of the GM barrier. A low exit angle is, of course, preferable as it tends to minimize involvement of the rebounding vehicle with adjacent traffic.



Metric Conversions:
Multiply lbs by 0.454 to obtain kg.
Multiply mph by 0.447 to obtain m/s.
Multiply in. by 0.0254 to obtain m.

FIGURE C.2 EFFECT OF CURB BATTER ON VEHCLE LATERAL ACCELERATION

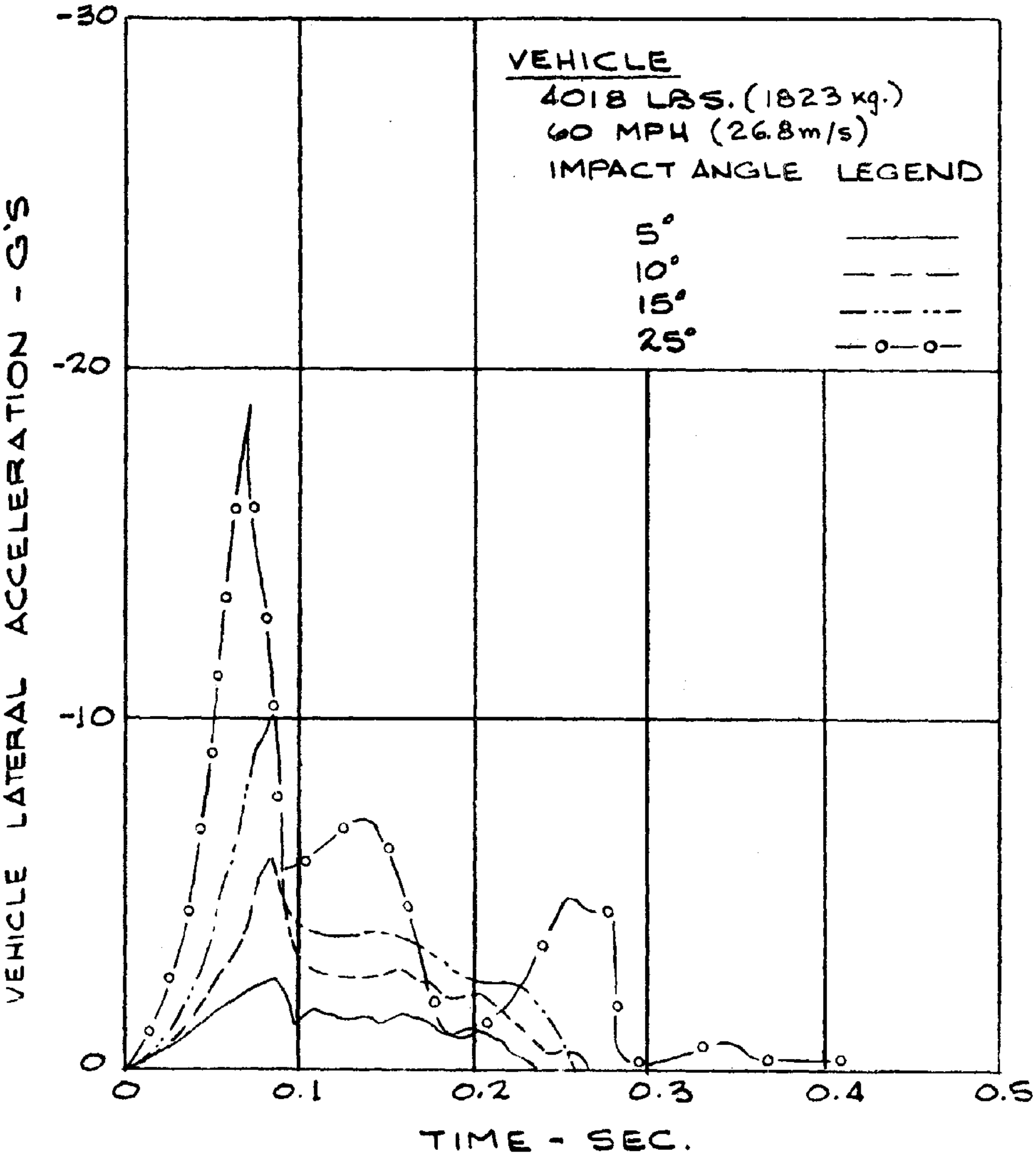


FIGURE C.3 EFFECT OF IMPACT ANGLE INTO VERTICAL WALL ON VEHICLE LATERAL ACCELERATIONS

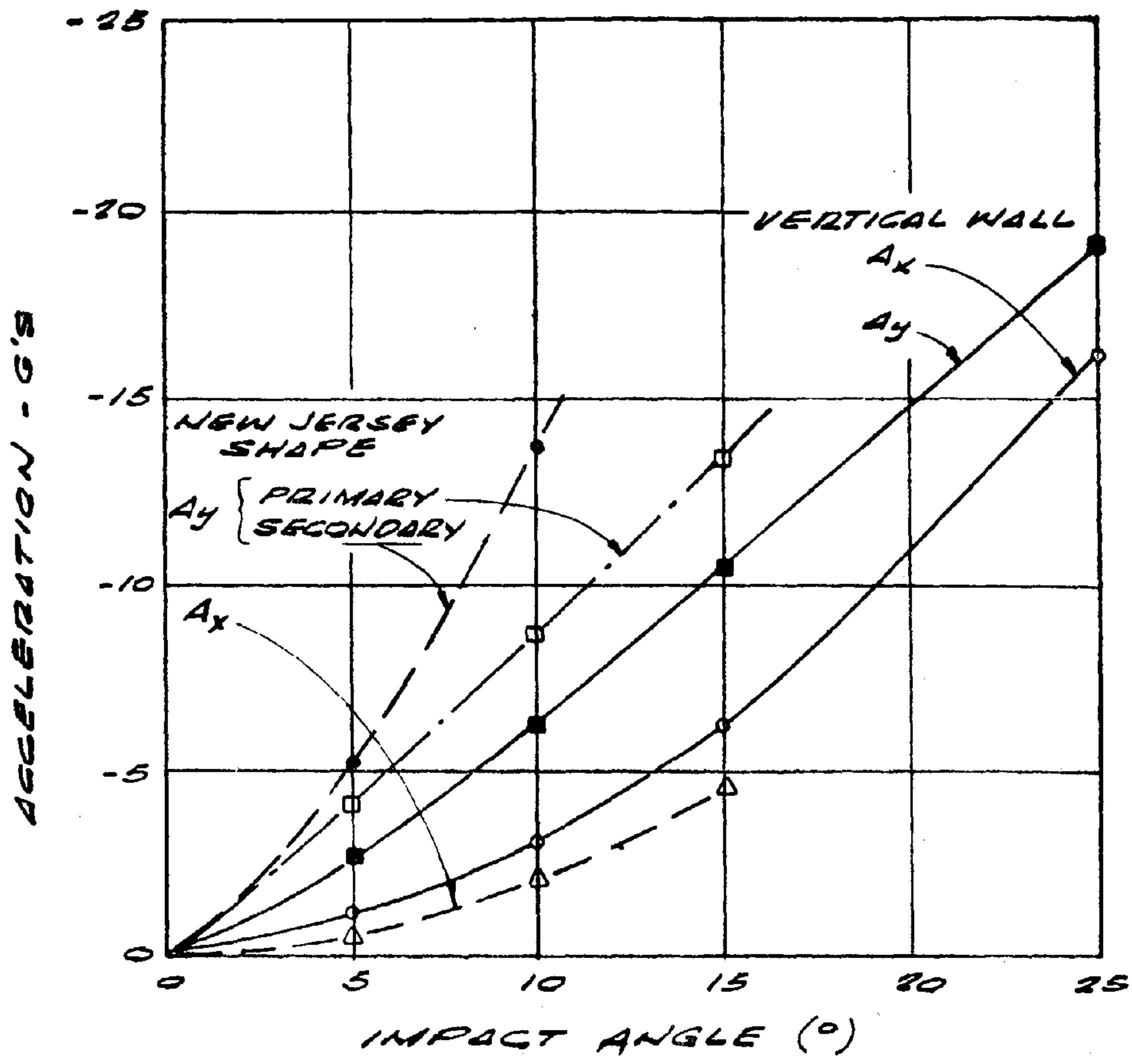


FIGURE C.4 COMPARISON OF VEHICLE PEAK ACCELERATIONS FOR VERTICAL WALL AND NEW JERSEY IMPACTS

TABLE C.3

EFFECT OF VEHICLE DEFORMATION CHARACTERISTIC ON REDIRECTION DYNAMICS*

Deformation Constant, K_V (lb/in.^{3})	New Jersey Shape				Vertical Wall			
	1.0	2.0	3.0	6.0	1.0	2.0	3.0	6.0
Peak Acceleration (g's)								
Vertical	14.1	13.7	12.1	9.4	0.1	0.1	0.2	0.9
Longitudinal	-2.3	-2.7	-4.1	-5.5	-5.9	-6.1	-6.2	-6.6
Lateral								
First peak	-10.0	-10.8	-11.9	-12.6	-9.9	-10.4	-10.5	-11.6
Second peak	-7.3	-7.9	-7.9	-7.2	-	-	-4.4	-7.4
Crush (in.)	15.8	13.6	13.2	11.7	22.5	19.1	17.2	14.0
Max. Force (kips)								
Normal	12.8	16.6	20.5	31.0	20.6	30.0	35.0	46.5
Friction	3.8	5.0	6.1	9.3	6.2	9.0	10.5	13.9

*4000-lb (1814-kg) car, 60 mph (26.8 m/s) and 15-deg impact.

Metric Conversions:
Multiply lb/in.^{3} by 2.71 x 10^5 to obtain N/m^3.
Multiply in. by 0.0254 to obtain m.
Multiply kips by 4448.2 to obtain N.

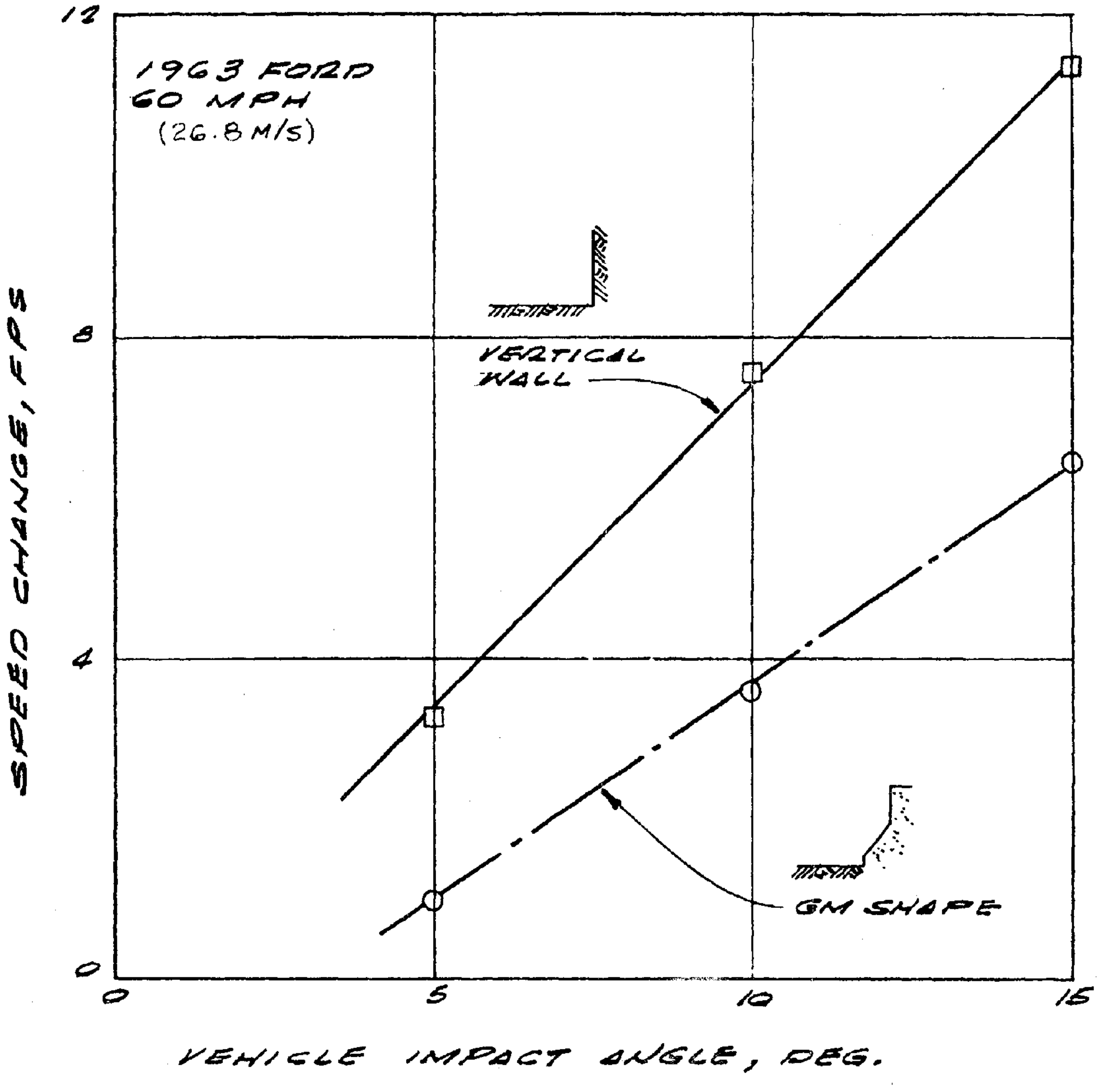
TABLE C.4

APPRAISAL OF EXISTING BRIDGE RAILING SYSTEMS*

Barrier	Impact Angle (deg)	Hard Point Stiffness (lb/in.)	Peak Vehicle Accelerations (g's)					Speed Change (fps)	Exit Angle* (deg)	Max. Vehicle Deformation (in.)	Friction Work (ft-lb)
			X	Y1	Y2	Z1	Z2				
Vertical Wall	5	2,500	-1.157	-3.048	-3.209	-0.212	-	3.29	-2.70	5.34	38,057
		25,000	-1.157	-3.048	-3.209	-0.212	-	3.29	-2.49	5.32	38,057
	10	2,500	-2.979	-6.349	-5.663	-0.550	-	7.46	-6.28	10.56	79,367
		25,000	-2.912	-6.066	-4.063	-0.534	-	7.57	-6.32	10.70	79,804
	15	2,500	-5.017	-10.409	-6.630	-0.711	-	11.81	-8.40	14.19	109,065
		5,000	-6.632	-11.335	-7.901	-0.748	-	11.68	-8.10	14.16	104,890
		25,000	-8.228	-14.488	-8.619	-0.227	-	11.40	-7.95	15.04	87,936
GM Barrier	5	2,500	-0.574	-2.755	-3.070	-1.815	-1.866	1.01	-1.01	2.97	9,414
		25,000	-0.574	-2.755	-3.070	-1.815	-1.866	1.01	-0.95	2.97	9,414
	10	2,500	-2.094	-7.116	-5.112	-5.238	-3.317	3.54	-2.60	7.11	31,624
		25,000	-2.115	-6.281	-5.395	-6.281	-5.395	3.60	-2.52	7.15	32,538
	15	2,500	-5.203	-13.776	-9.175	-7.328	-9.399	6.46	-4.58	11.47	50,209
		25,000	-5.203	-13.776	-6.121	-7.328	-9.399	6.46	-4.58	11.47	50,209

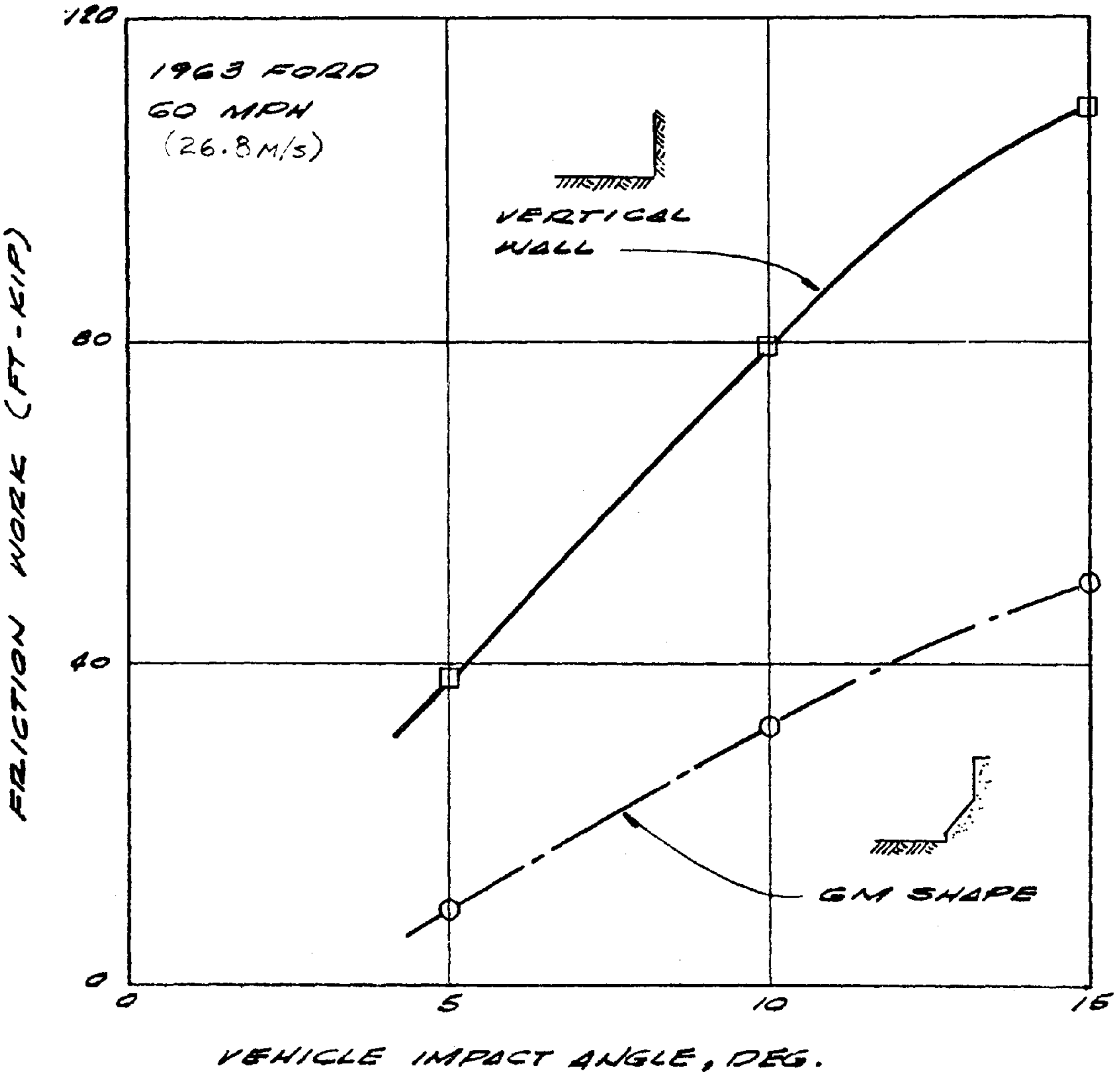
***At time of loss of contact with barrier**

Metric Conversions:
Multiply lb/in. by 175.1 to obtain N/m.
Multiply fps by 0.305 to obtain m/s.
Multiply in. by 0.0254 to obtain m.
Multiply ft-lb by 1.36 to obtain N-m.



Metric Conversion:
Multiply fps by 0.305 to obtain mps.

FIGURE C.5 CHANGE IN VEHICLE SPEED DURING BARRIER CONTACT



Metric Conversion:
Multiply ft-kip by 1.36×10^{-3} to obtain N-m.

FIGURE C.6 ENERGY DISSIPATED BY FRICTION AT VEHICLE/BARRIER CONTACT

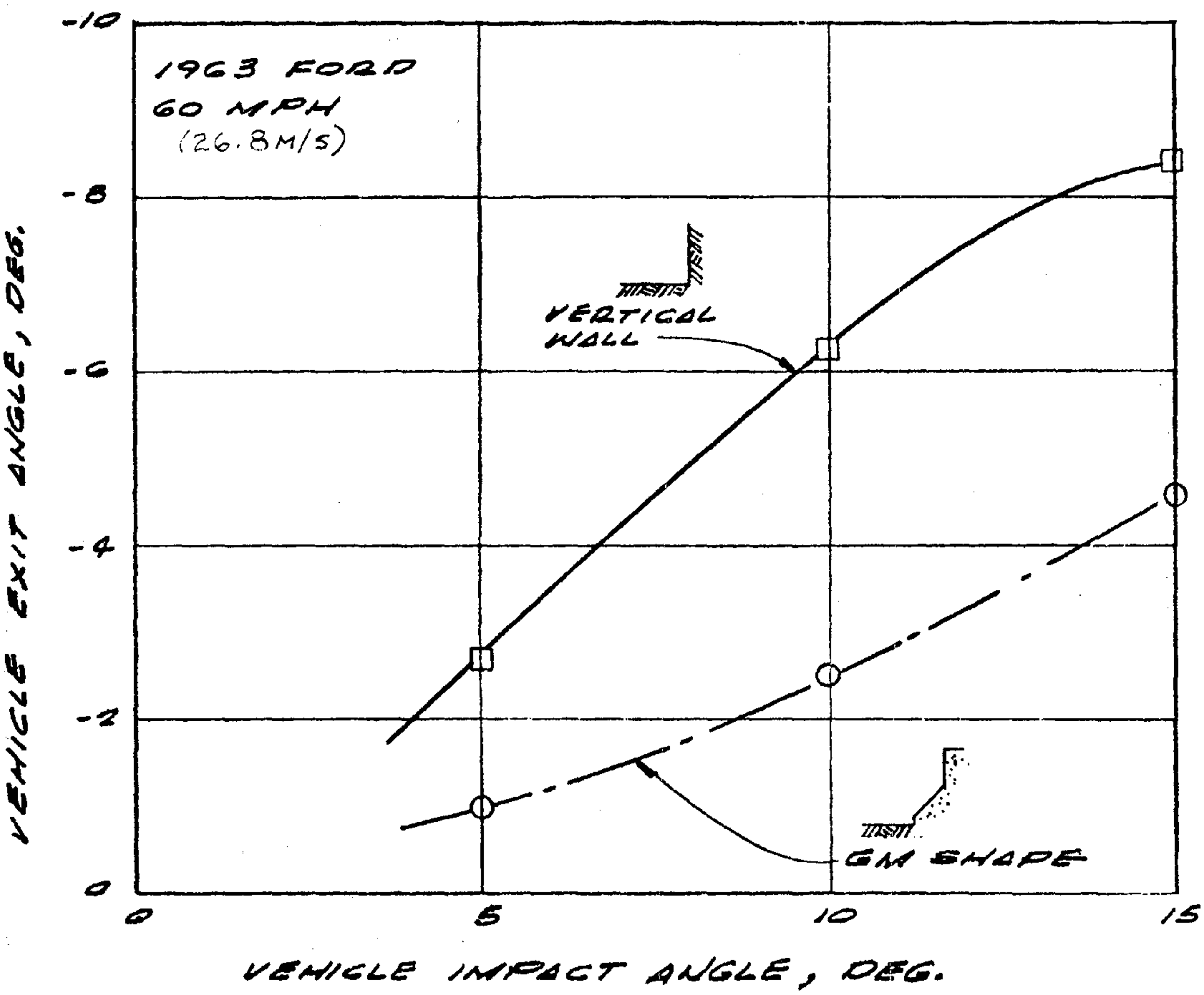


FIGURE C.7 VEHICLE EXIT ANGLE AT LOSS OF CONTACT WITH BARRIER

U. S. DEPARTMENT OF TRANSPORTATION

FEDERAL HIGHWAY ADMINISTRATION

SUBJECT "Upgrading Safety Performance in Retrofitting Traffic Railing Systems" FHWA-RD-77-40	FHWA BULLETIN May 31, 1978

Distributed with this bulletin is the subject report that summarizes research results and design details for several promising bridge rail retrofit concepts. These concepts were developed and tested in accordance with guidelines stated in NCHRP Report 153, on Crash Testing of Highway Appurtenances. The evaluation was limited to passenger vehicles only. Heavy vehicle impact consideration was beyond the scope of this study. The report contains material that can be implemented immediately by those responsible for the provision of safe bridge rails and transitions. The plans and descriptions in the report provide sufficient detail to allow field personnel to adapt the new concepts at existing bridge rail sites. Additional technical material such as specific detail designs, construction procedures, and installation costs are needed. It is planned that these will be developed through actual installation experiences.

The comprehensive research program included:

1. An in-depth survey of bridge rail systems in use. Based on the analysis of 14 specific railing designs, an estimated assessment of the performance of bridge rails on a national scale is presented. The data indicate that a significant percentage of existing railings may be below currently attainable performance standards. Bridge rail designs in this survey were grouped into four categories according to profile geometry and features that are amenable to a common retrofit design.

2. Development of five bridge rail retrofit designs for upgrading safety performance. These designs were evaluated by a program of 22 crash tests.

DISTRIBUTION: Headquarters
Special: Regions
Divisions

OPI: HRS-12
HNG-30
HHS-12
HDV-21

Requests for additional copies of this report should be directed to Mr. Charles F. Galambos, Chief, Structures and Applied Mechanics Division, Federal Highway Administration, HRS-10, Washington, D.C. 20590 (see attached Report Request Form).

Sufficient copies of the report are being distributed to provide five copies for each regional office, five copies for each division office, and ten copies for each State highway agency. Direct distribution is being made to the division offices.

for H. A. Lindberg
Associate Administrator for
Engineering and Traffic Operations

James L. Foley, Jr.
for H. L. Anderson
Associate Administrator for Safety

Attachment

Report FHWA-RD-77-40,
"Upgrading Safety Performance in Retrofitting
Traffic Railing Systems"

Abstract and Report Request Form

The purpose of this research project was to develop a series of hardware modifications that will upgrade sub-standard bridge rails and bridge rail/guardrail transitions to currently acceptable structural and safety performance levels. The project included an in-depth survey of bridge rail systems in use. Those designs that were deficient with regard to safety and most predominant in actual use were identified and considered for retrofit development. Several bridge rail retrofit concepts were developed and tested under full scale passenger vehicle impacts. Evaluation of these concepts for application to heavy vehicles was beyond the scope of this effort. A new type of rail element was developed and extensively utilized in these new concepts (Tubular Thrie Beam). The new rail element is potentially applicable to many other roadside barrier concepts.

To obtain additional copies of this report, please send in the request form below.

REPORT REQUEST FORM

Please send __________ copies of Report FHWA-RD-77-40, "Upgrading Safety Performance in Retrofitting Traffic Railing Systems."

Name ______________________________

Agency ______________________________

Street ______________________________

City ______________________________

State ____________________ Zip __________

* USGPO 734-333 1302/563

B33

FHWA

R&D