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RETROFIT RAILINGS FOR NARROW THROUGH TRUSS AND OTHER OBSOLETE BRIDGE STRUCTURES

U.S. Department of Transportation
Federal Highway Administration

Research, Development and Technology
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
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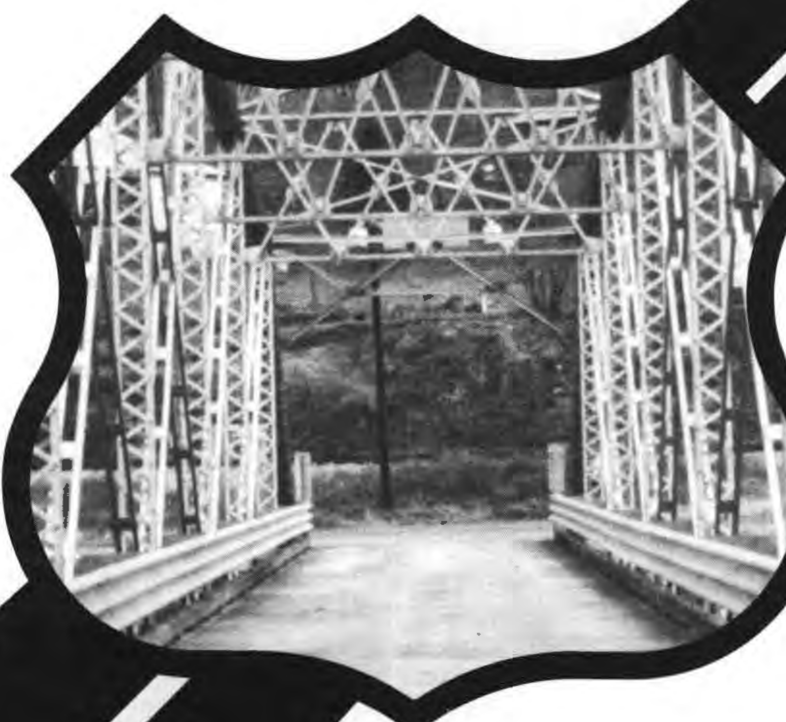

FOREWORD

This report, "Retrofit Railings for Narrow Through Truss and Other Obsolete Bridge Structures," presents the results of research conducted by the Southwest Research Institute for the Federal Highway Administration (FHWA), Office of Safety and Traffic Operations Research and Development, under Contract Number DOT-FH-11-9418. This work was conducted as part of Project 1T, "Roadside Safety Hardware," and is intended for engineers concerned with roadside safety hardware. This research has developed two retrofit bridge rail designs for upgrading through truss bridges.

A series of full-scale tests were performed on both retrofit systems. Test vehicles ranged from 1,800-lb (820 Kg) to 20,000-lb (9,000 Kg) for the higher performance system and ranged from 1,800-lb (820 Kg) to 4,500-lb (2,000 Kg) for the lower performance retrofit system. Most of the tests on both systems were conducted at 15 degree impact angles and at speeds of 55 mph (90 Kmph) to 60 mph (96 Kmph).

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Lyle Saxton for
Stanley R. Byington
Director, Office of Safety and
Traffic Operations R&D
Federal Highway Administration

NOTICE

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16. Abstract

Through truss structures are unique in that the superstructure of the bridge is exposed to impacts from errant vehicles. Effective bridge railings must not only exclude these vehicles from contacting the critical truss members by limiting system deflection, but must also prevent heavy vehicles from rolling over the barrier and contacting a truss member. Complete collapse of truss structures has resulted from automobile impacts as well as heavy vehicle impacts.

Two bridge railing retrofit systems were systematically designed and developed in this project. The high performance system is designed to contain and limit vehicle roll of 20,000-lb (9000-kg) buses impacting at 55 mph (90 kmph) and a 15-deg angle. The low service retrofit system contains and redirects a 4500-lb (2000-kg) car impacting at 60 mph (95 kmph) and a 15-deg angle without endangering the truss members behind the retrofit system.

Crash tests with vehicles ranging from the bus to an 1800-lb (800-kg) minicompact vehicle were used in the development and evaluation. Design drawings of the bridge rails, bridge attachment detail and approach rail are included in the report.

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November 1986

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Federal Highway Adm., Offices of Research and Development, U.S. Department of Transportation
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CHAPTER ONE

INTRODUCTION AND RESEARCH APPROACH

According to a recent General Accounting Office (GAO) report,[1] four out of every ten bridges in the country - at least 200,000 - are deficient. About half of this total are structurally inadequate and the others are functionally obsolete because they are narrow, have inadequate underclearances, have insufficient load-carrying capacity, or are poorly aligned with the roadway and can no longer safely serve today's traffic.

Even with this rather grim picture of our nation's bridges, the failure of a bridge is a rather infrequent event which generally is widely publicized. The focus of this project is on a particular type of bridge which has unique problems. The through truss structures are unique because the superstructure of the bridge is mostly above the bridge deck, thus exposing critical structural members to contact with out-of-control vehicles. Furthermore, since many of the older through truss structures are narrow, the clearances for bridge railing protection of the truss members are restrictive with little space for barriers and barrier deflection under impact.

Catastrophic failures of these through truss structures occur each year with some gaining nationwide attention such as the Yadkin River Bridge in North Carolina. As shown in Figure 1, the complete bridge span dropped into the river as a result of a relatively moderate impact resulting in passenger car penetration of the bridge railing with subsequent collision with a critical truss member. Thus, in the case of the Yadkin River Bridge and others such as described in Figure 2, structurally adequate bridges can collapse due to inadequate bridge railing protection. Many of these older through truss structures have relatively long spans and would require large expenditures to replace them with more modern structures. For this reason, the development of protective bridge railing systems for these unique structures is seen as a cost-effective way of keeping these otherwise structurally sound bridges in service, and minimize the potential for catastrophic events as pictured in Figures 1 and 2.

A. Objective

The objectives of the research effort were to identify typical characteristics of through truss structures, and to develop retrofit designs to protect vital structural members from impact by out-of-control vehicles.

B. Scope

This project involved background studies, structural analysis, laboratory experiments, computer simulation, and full-scale crash testing.

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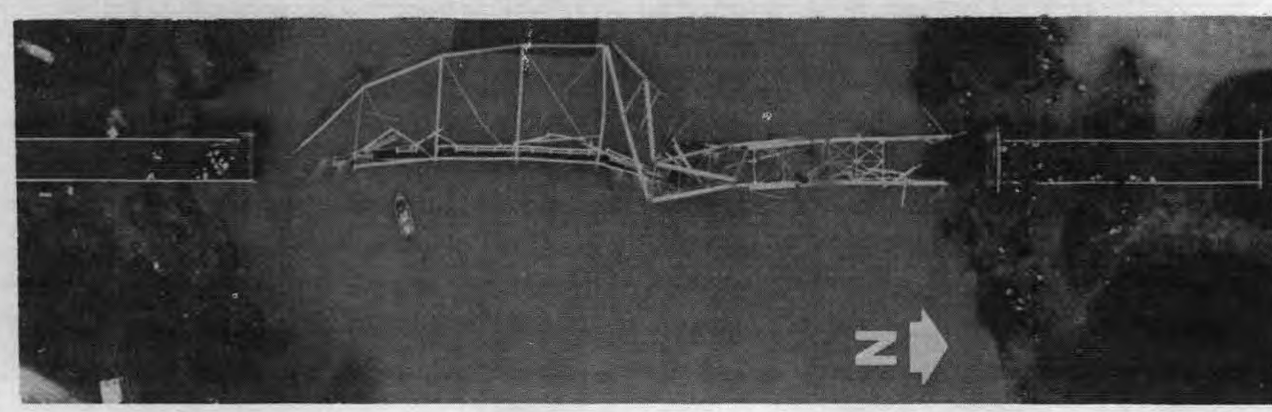
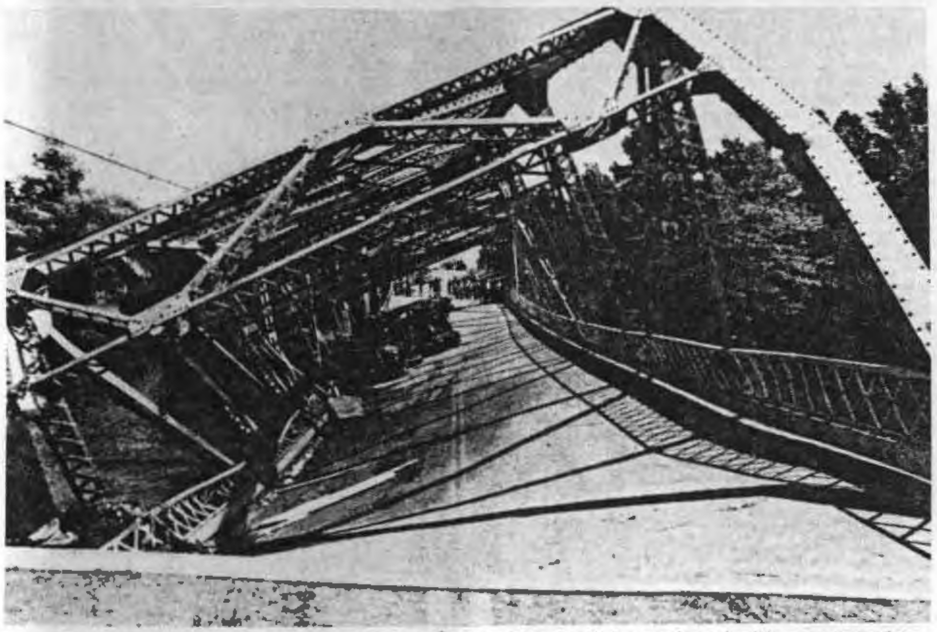


FIGURE 1. YADKIN RIVER BRIDGE COLLAPSE

(a) Truck Collision in West Virginia

Truck ramming downs bridge

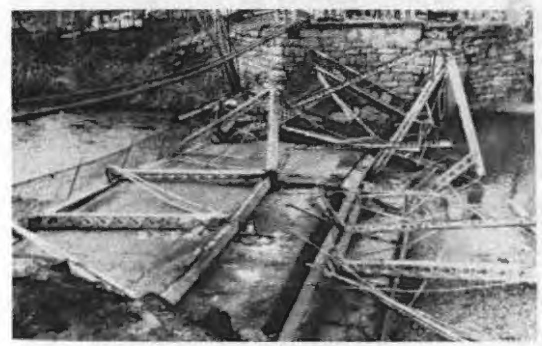


Truss bridge damaged beyond repair by truck accident will be replaced with new crossing.

(b) Truck Collision in Wisconsin

Automobile drops truss span into river

A 100-ft steel truss bridge collapsed into the Lackawanna River in Scranton, Pa., after an automobile struck one of its vertical members. The 75-year-old structure had been posted for 5 tons.



(c) Car Collision in Pennsylvania

FIGURE 2. THROUGH TRUSS FAILURES

Vehicles used in the crash tests ranged from 1800-lb (800-kg) mini cars to 20,000-lb (9000-kg) school buses.

Design drawings are presented for bridge railings according to two levels of service. The higher level of service railing was designed to contain and redirect a 20,000-lb (9000-kg) bus impacting at 55 mph (90 kmph) and a 15-deg angle without subsequent damage to a truss member behind the barrier. The lower service level railing was designed to contain and redirect a 4500-lb (2000-kg) sedan impacting at 60 mph (95 kmph) and a 15-deg impact angle.

Application of these railing systems is discussed and example retrofit details are presented.

CHAPTER TWO

FINDINGS

A. Background Study

A background study was initially undertaken to define the problems associated with retrofitting the bridge railing systems of these older bridges. Brief discussions of these problems follow.

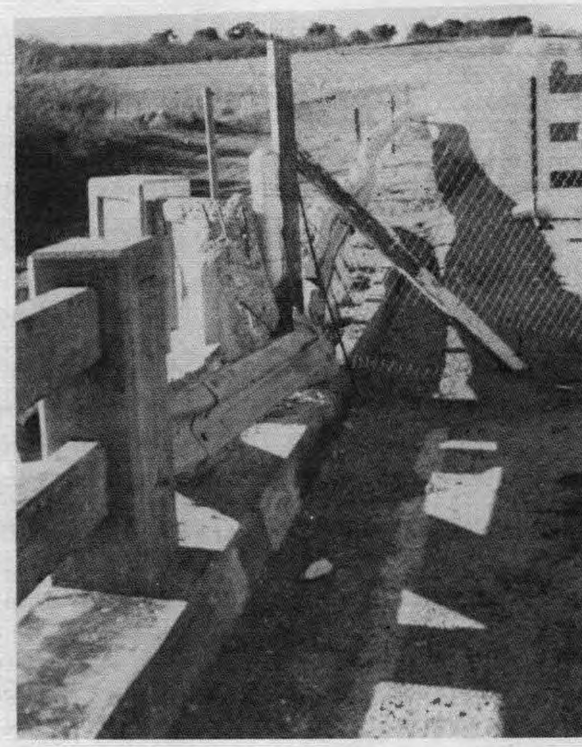
Limited Space. The clear horizontal widths on most of these bridges are substandard. For example, Figures 3, 4, and 5 show the Beaver Creek Bridge in Texas and the Yadkin River Bridge in North Carolina, both of which were irreparably damaged by vehicle impacts. Flanges of the steel channel bridge rails of Figures 3 and 4 were notched and meshed with the truss end posts and hangers for attachment. With a clear width of only 11'-2"(3.4m), the wooden railings in Figure 3 were actually butted up against the end posts for attachment.

This critical limitation of space complicates the retrofit problem. Placing any retrofit railing system on the bridge will further decrease the roadway width and could consequently increase the number of accidents. This limitation of available space between the rail and truss members suggests retrofits of rigid systems with as little dynamic deflection as possible.

Weight. Many of the through truss bridges are operating at or over their design capacity. Since adding a retrofit system will increase the load on the bridge, it should be as lightweight as possible. This will restrict the use of such systems as the rigid concrete safety shape, which weighs approximately 300 lb/ft.

Cost. Lightweight, rigid retrofits will probably be expensive. The costs of a system could be weighed against the probable reduction in accident damage and occupant injury costs that will be gained by installation of the system.

Alignment, Geometry, Operating Speed, Other Roadway Features, and Vehicle Size. The alignment and geometry of the bridge and approach roadway can affect both the frequency and severity of impacts. It would be expected that bridges with curved approaches would be more likely to have impacts and with greater impact angles. A point mass model was applied to gain some insight into the maximum probable angle of impact. The assumption was that the vehicle was in the wrong lane of a 2-lane bridge approach, traveling on a left-bending curve, and turned into the bridge rail on the right with a minimum radius of turn (coefficient of friction of unity). Results for two 12-foot (3.7m) lanes are shown in Figure 6 and for two 10-foot (30.5m) lanes in Figure 7. It was concluded from these results that the controlling criterion for a school bus should



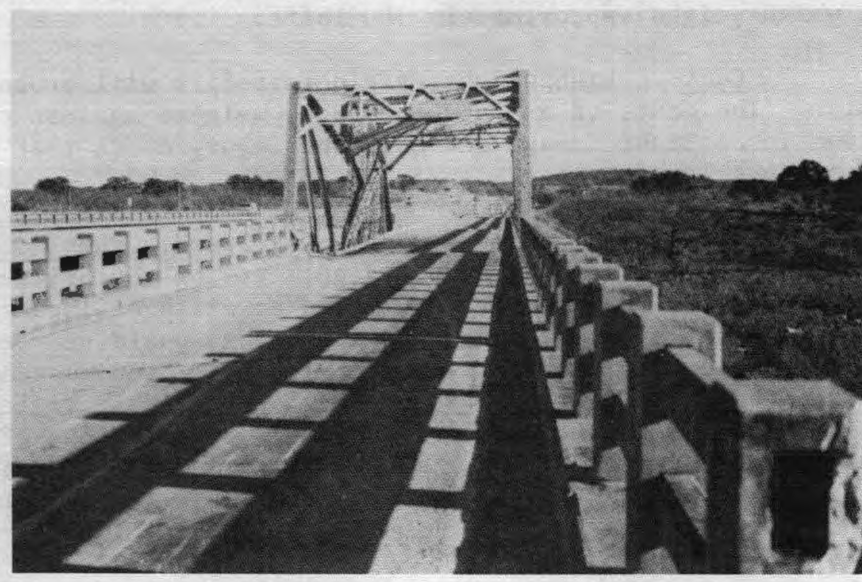


FIGURE 3. BEAVER CREEK BRIDGE (TX)

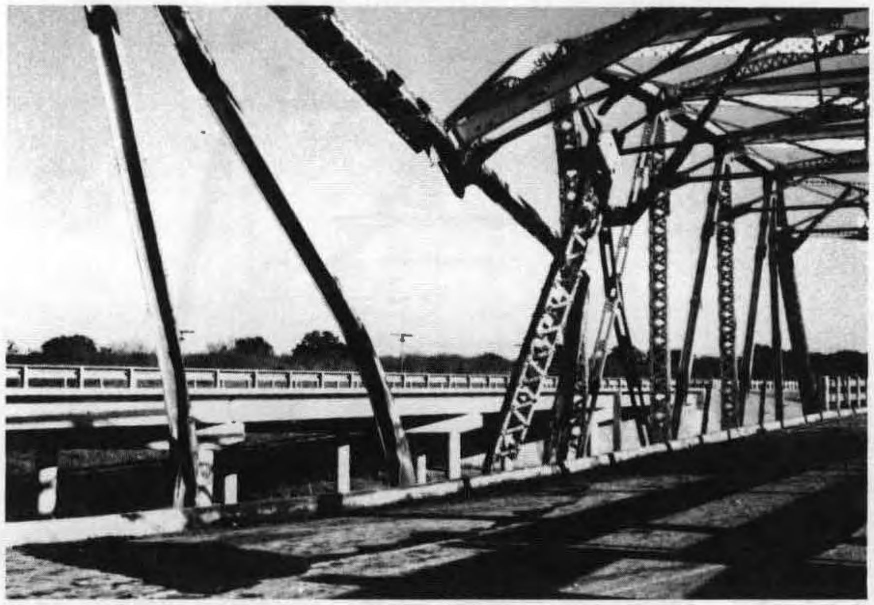


FIGURE 4. BEAVER CREEK BRIDGE (TX)

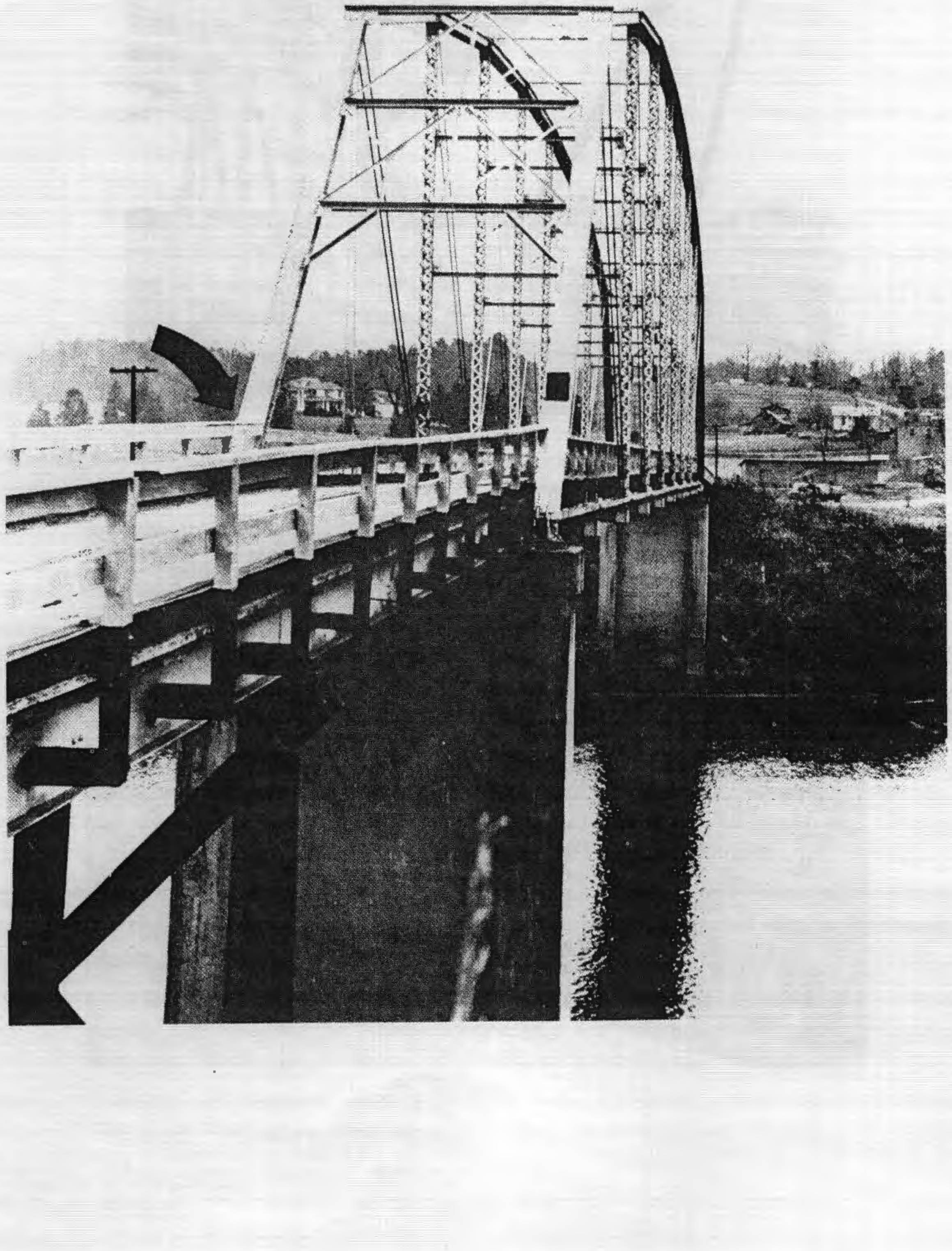


FIGURE 5. YADKIN RIVER BRIDGE (NC)

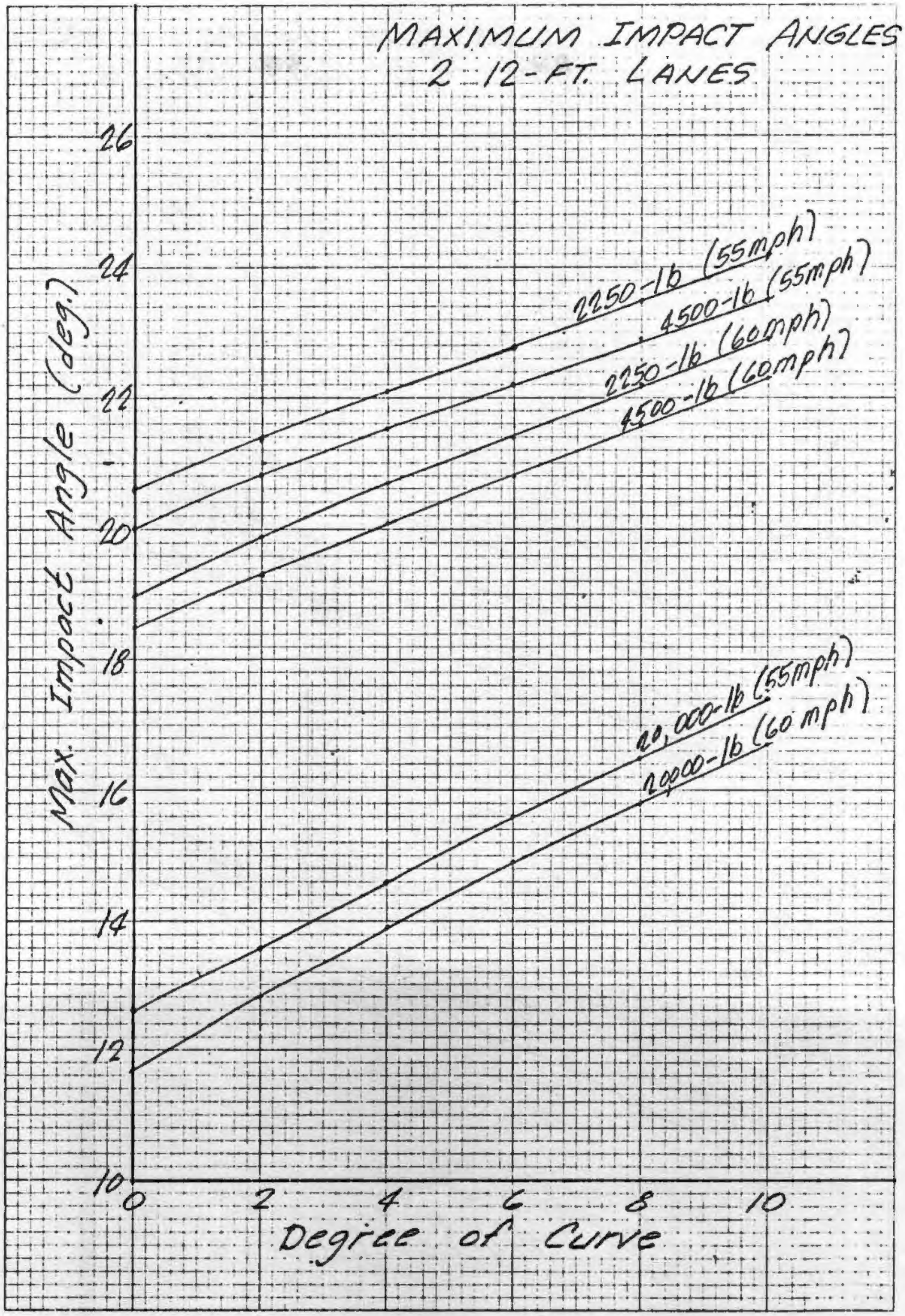


FIGURE 6. MAXIMUM IMPACT ANGLES WITH 12-FT LANES

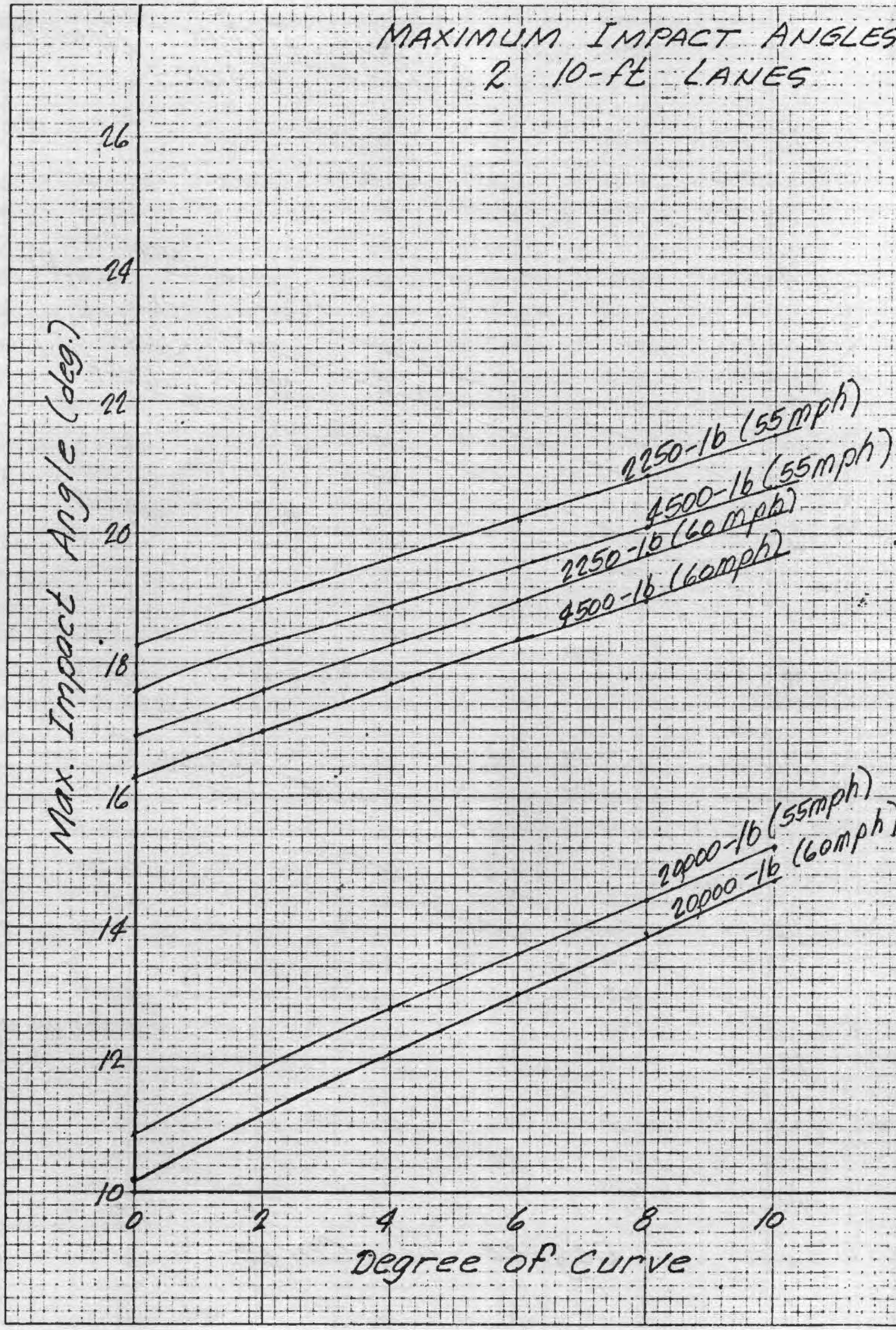


FIGURE 7. MAXIMUM IMPACT ANGLES WITH 10-FT LANES

be a 20,000-lb (9100-kg) bus traveling at 55 mph (90 kmph) and impacting the rail at 15 deg. For a more narrow bridge (i.e., one lane) or for lower operating speeds, a lower cost system was also identified for restraining a 4500-lb (2040-kg) car at 60 mph (95 kmph) and a 15-deg angle.

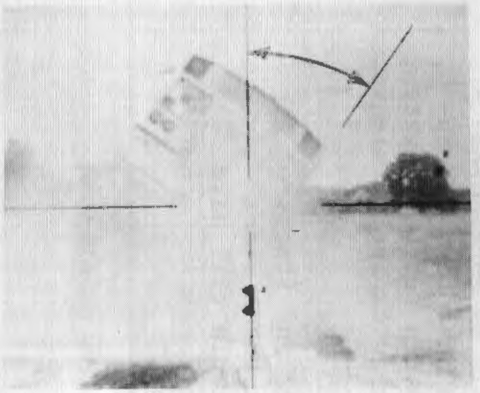
Since a retrofit system will further reduce the roadway width to some extent, channeling of vehicles from approach to bridge becomes a problem. This is compounded by the necessity for extending the railing system beyond the bridge ends to develop full railing strength anchorages.

Operating speed will affect the probability and severity of impacts. If speeds can be reduced, reduction of both of these factors should follow. Along with speed, bridge and retrofit railing geometry will affect the problem of rebounding and post-impact vehicle trajectory. By installing two retrofit rails, one above the other, the problem of vehicle contact with the truss members, either by wheel snagging or rolling over the railing, will also be reduced. The effects of wide truck or bus loads that may be higher than normal railings, thus permitting truss member contact above the railing, can also be lessened by this arrangement.

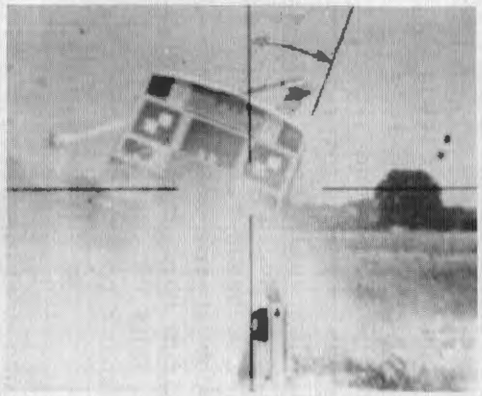
Movies of school bus tests conducted at Texas Transportation Institute (Contract No. DOT-FH-11-9181) were reviewed to evaluate this problem of vehicle roll. Sequential photographs taken from these tests, as shown in Figure 8(a) and (b), depict the maximum roll of the vehicle during the nominal 60 mph (95 kmph), 15-deg angle tests. It can be seen that the rigid 27-in. (0.7-m) railing produced roll that could not be tolerated in this project (i.e., the truss members would be struck). Even with a yielding barrier, such as the collapsing ring bridge rail shown in Figure 8(c), the maximum roll angle would be sufficient to involve the truss members. Thus, it was concluded that an upper railing element would be necessary to prevent such contact.

Bridge thermal expansion must be taken into consideration when designing the bridge rail retrofit systems. It is considered essential that the low service level retrofit beam have tensile continuity between end anchors. For the high performance retrofit system, the beam should have no clear breaks, but may have an expansion sleeve to allow movement at the joint.

Since there are various bridge geometries and stages of structural deterioration, retrofitting railings on these older bridges will require that general designs and criteria will have to be adjusted to fit the individual situations.



(a) TTI Test 1

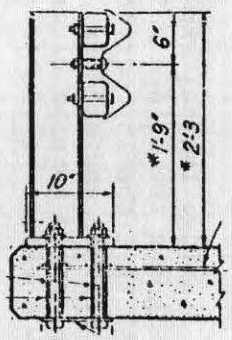


(b) TTI Test 2

Texas T101 Bridge Railing
Railing height - 27 in.
Dynamic deflection - nil

(c) Collapsing ring bridge railing

Railing heights (Test BR-8)
lower - 27 in.
upper - 59 in.
Max. dynamic deflection - 20.6 in.



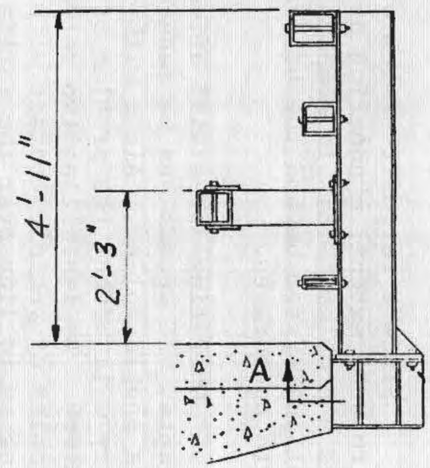


FIGURE 8. SCHOOL BUS TESTS, NOMINAL 60 MPH, 15-DEG ANGLE TESTS

B. Design Criteria

Design criteria were formulated for both the high performance retrofit and the lower service retrofit bridge railings.

High Performance Retrofit. Based on considerations in the preceding section, this barrier was to be essentially a rigid railing for a 55-mph (90-kmph), 15-deg angle impact with a 20,000-lb (9000-kg) school bus. In addition, the roll of the vehicle is limited in order to keep the bus out of the truss member zone immediately behind the retrofit.

Low Service Retrofit. This retrofit is for use on bridges which by virtue of geometry, vehicle mix, or other considerations would not require the protection of the high performance railing system. Selection of the structural adequacy test for this system was based, in part, on a recently completed NCHRP research project at SwRI.(2) This project developed a multiple service level technology for bridge railing placement based on need. The lowest service level from this project had a strength test requirement characterized by a 4500-lb (2000-kg) car impact at 60 mph (95 kmph) and a 15-deg angle.

A current SwRI project(3) involves the study of environment and accident data at bridge sites in five participating states. Table 1 shows the distribution of the data file bridges by bridge narrowness stratification and state. It can be seen from the table that the first significant number of bridges falls in the 18- to 20-ft (5.5- to 6.1-m) width category. Thus, a maximum bridge width of 20 ft (6.1 m) is assumed for establishing the design impact angle.

The assumed initial position of the impacting vehicle is shown in Figure 9(a). The 16-ft (4.9-m) lateral distance is equivalent to half a 12-ft (3.7-m) lane plus a 10-ft (3.0-m) shoulder. On assuming a vehicle speed of 60 mph (95 kmph), it can be seen from Figure 9(b) that the maximum impact angle is about 17° for a 4000-lb (1800-kg) vehicle. Note that this is the maximum impact angle for the vehicle size and that it would be less for a heavier vehicle.

Finally, a full-size 4500-lb (2000-kg) vehicle is assumed. To keep the bridge rail from deflecting into the superstructure, the maximum rail deflection (beyond the rear post line) should not exceed 3 in. (75 mm).

A summary of the design criteria for the two bridge railing systems is presented in Table 2.

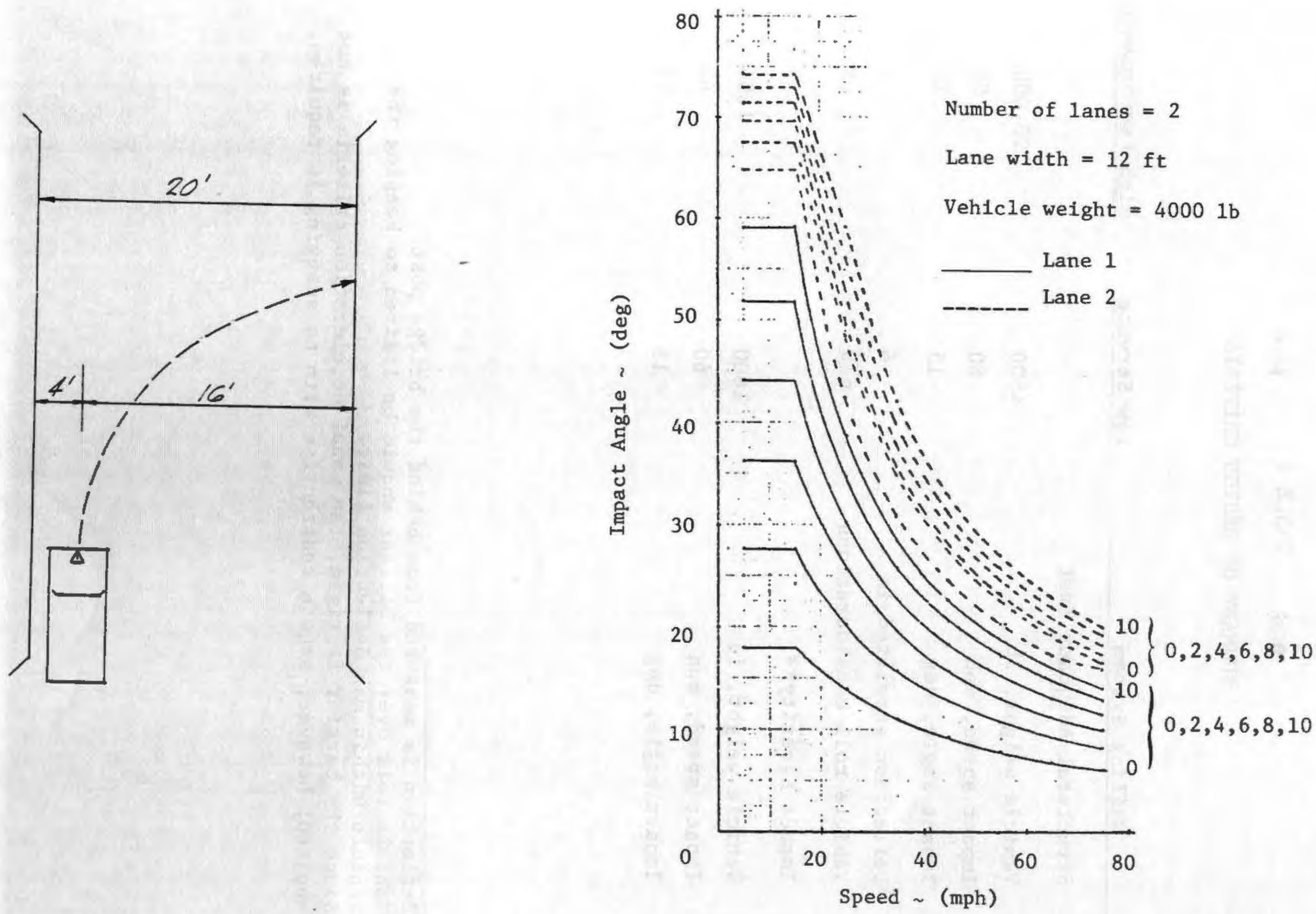
C. Preliminary Designs and Analyses

During the early months of this contract, a number of retrofit concepts were conceived and evaluated. Since the initial emphasis of this study was on the high performance system, and since only one

TABLE 1

DISTRIBUTION OF BRIDGES BY BRIDGE NARROWNESS STRATIFICATION AND STATE (Reference 1)

		Bridge Narrowness Strata			Arizona		Michigan		Montana		Texas		Washington		All Five States	
		No. Lanes	Bridge Width	Shoulder Reduction	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Single Structures	Undivided	1	≤18'	–	7	1.3	2	0.2	51	3.0	12	0.2	3	0.2	75	0.6
			>18'	–	1	0.2	0	0.0	7	0.4	2	0.0	3	0.2	13	0.1
		2	≤18', <Approach	–	1	0.2	4	0.4	10	0.6	52	0.7	10	0.8	77	0.6
			≤18', ≥Approach	–	2	0.4	0	0.0	3	0.2	12	0.2	0	0.0	17	0.1
			18'-20', <Approach	–	4	0.8	8	0.7	49	2.9	579	8.0	60	4.6	700	5.9
			18'-20', ≥Approach	–	1	0.2	0	0.0	12	0.7	273	3.8	0	0.0	286	2.4
			20'-22', <Approach	–	0	0.0	4	0.4	92	5.5	270	3.7	20	1.5	386	3.2
			20'-22', ≥Approach	–	3	3.6	1	0.1	13	0.8	117	1.6	1	0.1	135	1.1
			22'-24', <Approach	–	21	4.0	25	2.3	212	12.6	1206	16.6	231	17.5	1695	14.3
			22'-24', ≥Approach	–	16	3.0	1	0.1	195	11.6	672	9.3	19	1.4	903	7.6
			>24'	>50%	32	6.0	139	12.6	61	3.6	761	10.5	282	21.4	1275	10.7
			>24'	1-50%	55	10.4	300	27.2	173	10.3	719	9.9	152	11.5	1399	11.8
			>24'	None	234	44.2	157	14.2	527	31.3	1654	22.8	256	19.4	2828	23.8
		4	n/a	>50%	1	0.2	21	1.9	0	0.0	28	0.4	5	0.4	55	0.5
				1-50%	2	0.4	5	0.5	1	0.1	21	0.3	2	0.2	31	0.3
				None	11	2.1	44	4.0	4	0.2	120	1.7	9	0.7	188	1.6
	Divided	4	n/a	>50%	4	0.8	17	1.5	4	0.2	46	0.6	10	0.8	81	0.7
				1-50%	0	0.0	7	0.6	19	1.1	34	0.5	5	0.4	65	0.5
				None	0	0.0	2	0.2	2	0.1	16	0.2	8	0.6	28	0.2
		Other	n/a	>50%	0	0.0	8	0.7	0	0.0	15	0.2	4	0.3	27	0.2
				1-50%	0	0.0	9	0.8	1	0.1	7	0.1	3	0.2	20	0.2
				None	1	0.2	17	1.5	0	0.0	23	0.3	7	0.5	48	0.4
Twin Structures	Divided	2	≤24'	–	1	0.2	0	0.0	0	0.0	30	0.4	2	0.2	33	0.3
			>24'	>50%	34	6.4	18	1.6	49	2.9	139	1.9	71	5.4	311	2.6
			>24'	1-50%	79	14.9	27	2.5	27	1.6	63	0.9	32	2.4	228	1.9
			>24'	None	19	3.6	253	23.0	170	10.1	349	4.8	77	5.8	868	7.3
		Other	n/a	>50%	0	0.0	2	0.2	1	0.1	3	0.0	10	0.8	16	0.1
				1-50%	0	0.0	6	0.5	0	0.0	3	0.0	7	0.5	16	0.1
				None	0	0.0	25	2.3	0	0.0	22	0.3	29	2.2	76	0.6
				TOTAL	529	100.0	1102	100.0	1683	100.0	7248	100.0	1318	100.0	11,880	100.0



(a) Assumed initial position of vehicle

(b) Impact angle vs speed for different shoulder widths

FIGURE 9. VEHICLE IMPACT ANGLE CONSIDERATIONS

TABLE 2

SUMMARY OF DESIGN CRITERIA

Railing System	Low Service	High Performance
1. Structural Adequacy Test		
Vehicle weight, lb	4500	20,000
Impact speed, mph	60	55
Impact angle, deg	15	15
*Deflection permitted, in	6	3
Vehicle roll considerations	n/a	+
2. Impact Severity**		
Vehicle weight, lb	1800	1800
Impact speed, mph	60	60
Impact angle, deg	15	15

*Deflection is measured from behind the bridge post.

+Vehicle roll over the barrier should be limited to keeping the vehicle within max deflection limit.

**Since the barrier is rigid, the usual acceleration criteria is not applied; however, smooth redirection with no snagging is required.

concept could be selected for full-scale testing and development, the other concepts were eliminated from further consideration. These other concepts are shown in Appendix C.

High Performance Retrofit. As discussed in Section A of this chapter, a rigid system with minimal deflection is needed to satisfy the design criteria of this barrier. In addition, an upper railing member of lesser strength (to minimize loading of the posts) is required to prevent roll of the bus into the truss members. Accordingly, several concepts were conceived to meet the design objectives. Figure 10(a) is the concept that was selected for analysis and design. The main structural beam is a tubular thrie beam which is currently used as a strong beam for bridge rail retrofits. The upper beam has the same cross section as a currently used guardrail post (commonly called the Charley post or C post). This low cost flexural beam element showed promise of satisfying the functional requirements of the upper beam.

A series of computer cases were conducted using the BARRIER VII[(4)] computer program, and the structural adequacy impact conditions of Table 2. A number of post size and spacing combinations were evaluated. Based on the evaluation, the prototype concept of Figure 10(b) was selected for crash test evaluation.

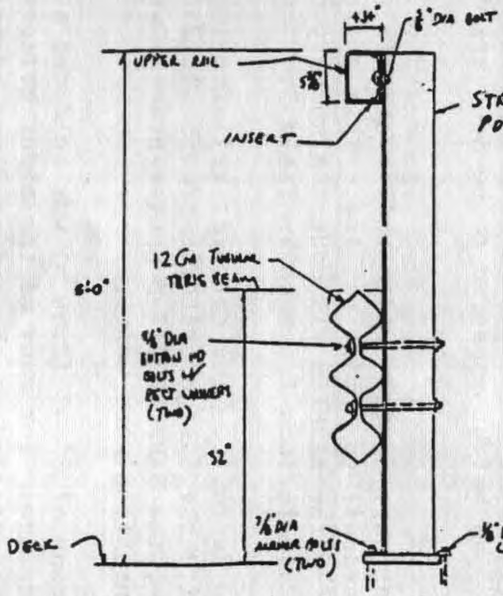
The 5-ft (1.5-m) spacing is particularly amenable with the typical 15-20-ft (4.6-6.1-m) floor beam spacing that is common among known through truss structures.

As a check, the 5-ft (1.5-m) high barrier was also modeled using the HVOSM[(5)] computer code for predicting vehicle stability. A summary of this investigation is shown in Figure 11; based on the results, the 5 ft (1.5 m) height appeared to be adequate for achieving desired goals.

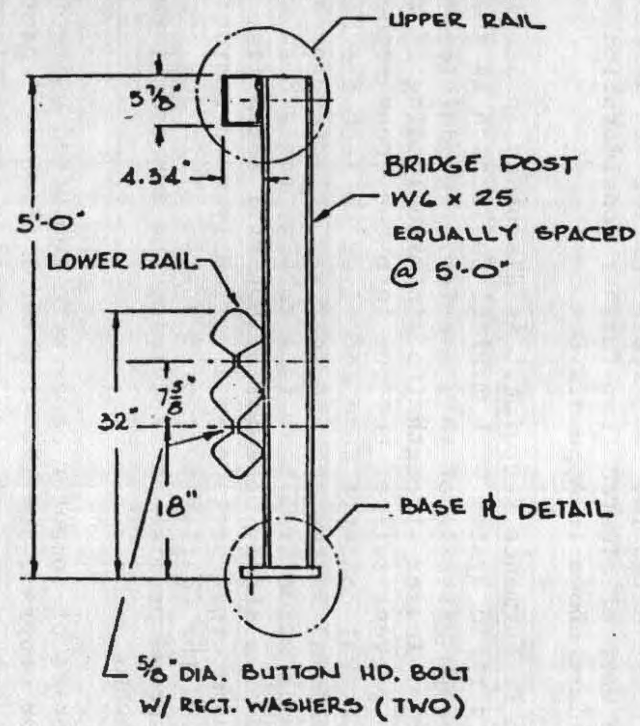
An important part of the bridge rail system is the transition from the approach guardrail to bridge railing. This approach railing was also designed using the BARRIER VII code. A summary of the results of the final simulations is shown in Table 3.

Low Service Retrofit. The retrofit rail for low service was designed to satsify the design criteria previously discussed. For analysis purposes, the BARRIER VII computer program was used. Several trial configurations were made.

A post spacing of 8'-4" (2.54 m) was selected as desirable for the preliminary design. For many of the older bridges, this would mean that posts can be attached to the bridge floor beams and only one intermediate post will be necessary between the floor beams. A single thrie beam was selected for the railing so that expensive back-up plates (or tubular configurations) would not be necessary. To keep the deflections below the target maximum of 3 in. (80 mm),

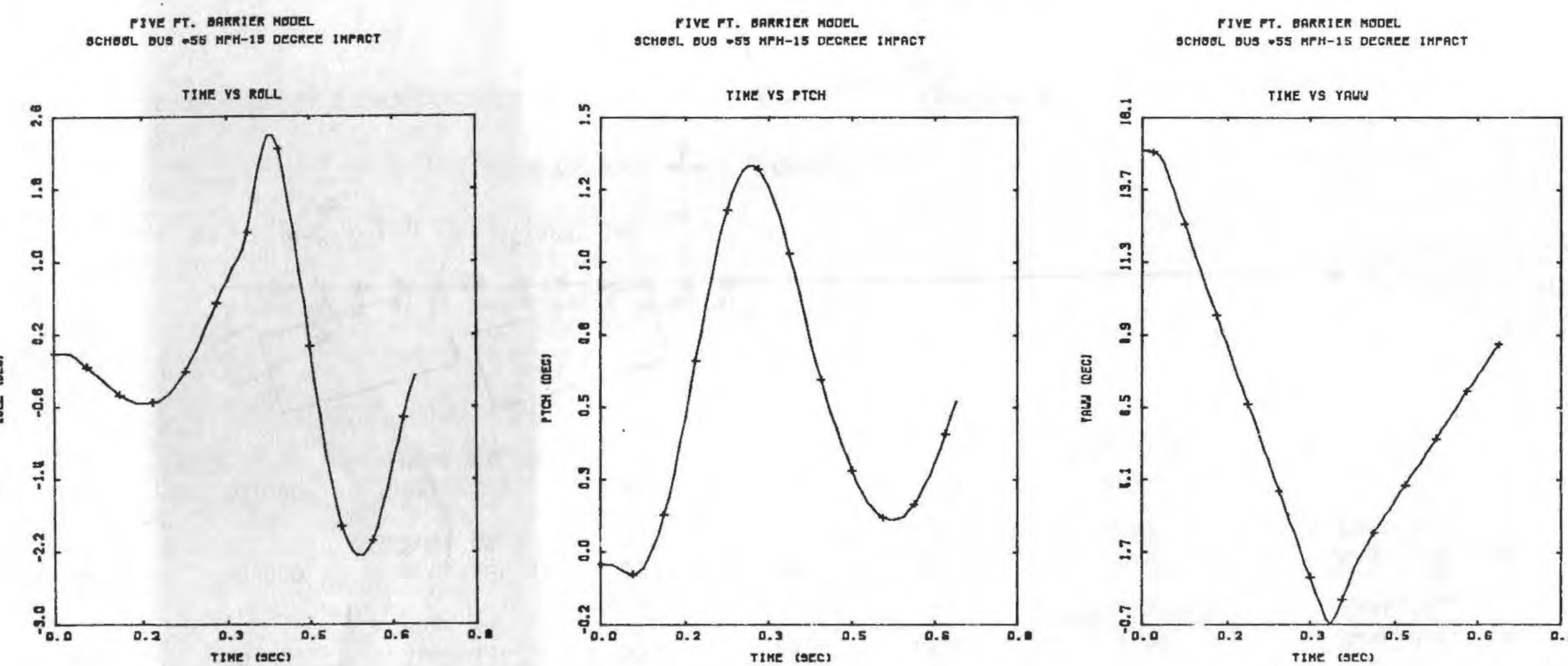


(a) Preliminary



(b) Final Prototype

FIGURE 10. PROTOTYPE DESIGN - HIGH PERFORMANCE RETROFIT



(a) Roll Angle

(b) Pitch Angle

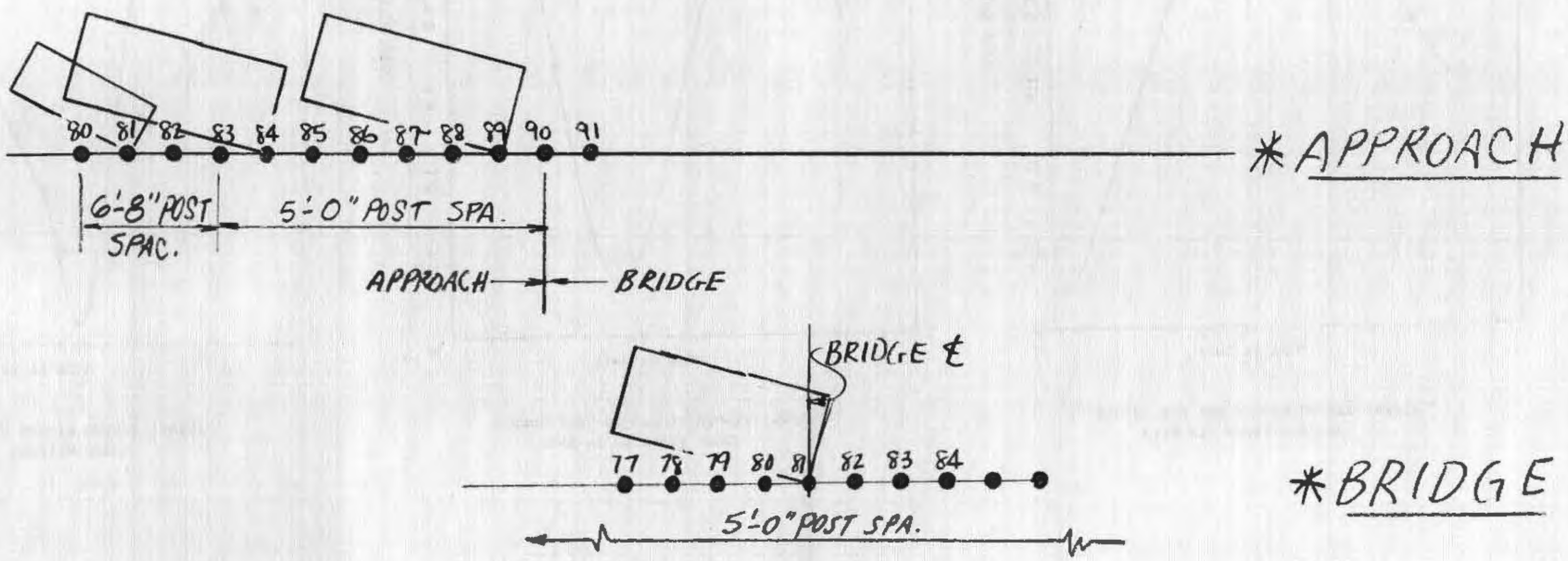
(c) Yaw Angle

FIGURE 11. SCHOOL BUS IMPACT - HVOSM SIMULATION - VEHICLE ANGLES

TABLE 3

SUMMARY OF BARRIER VII SIMULATIONS

Vehicle	Vehicle Weight (lb)	Impact Location *	Impact Speed (mph)	Impact Angle (deg)	Max. Defl. (in.)	No. of Failed Posts	Remarks
Car	4,500	Approach Post 81	60	25	22.5	Four (80,81,82,83)	Max. defl. at Post 82
Bus	20,000	Approach Post 84	55	15	18.1	Four (82,83,84,85)	Max. defl. at Post 83
Bus	20,000	Approach Post 89	55	15	7.0	One (88)	Max. defl. at Post 90
Bus	20,000	Bridge Post 81	55	15	6.7	Three (78,79,80)	Max. defl. at Post 82



an 8 x 8-in. (200 x 200-mm) wood curb was added that can easily be attached to the deck, particularly to the older wood decks. Many of the old through truss structures have wooden curbs which could be utilized. The cross-section of the prototype barrier configuration for the initial test is shown in Figure 12.

Since the maximum deflection predicted by BARRIER VII of 3.2 in. (80 mm) was only slightly above the 3-in. target, this barrier configuration was recommended for full-scale test. The wood curb could be either a notched 8"x8" timber or a 6"x8" timber with a 2"x8" facing, as illustrated in Figure 12.

D. Prototype Barrier Crash Test Evaluations

Prototype barrier installations for both systems were installed and evaluated for performance using the structural adequacy test. Details of all crash tests are in Appendix A.

High Performance Retrofit. Test TTR-1 was conducted on the prototype installation described in Figures 13 and 14. As shown in Figure 15, the bus impacted the barrier with a speed of 55.2 mph (88.9 kmph) and an angle of impact of 13.7 deg. The bus was redirected with a maximum roll angle of 20 deg while in barrier contact. After losing contact with the barrier, the bus swerved to the left due to front suspension and steering linkage failure from the force of the impact, and rolled on the right side, sliding to a stop 225 ft (68.6 m) beyond the end of the test barrier. Post-test examination revealed that the rivets which attach the front spring hanger brackets to the frame were sheared on both sides. This allowed the front axle and springs to rotate (about a vertical axis) as the right front wheel was pushed rearward by the lower rail. This in turn caused the steering pitman arm/wheel link connection to fail and the bus front wheels to be turned and locked into a hard left turn position.

Failure of the concrete support slab also contributed to the roll of the vehicle. This was not considered to be significant due to the overall test results, but the deck was additionally reinforced when repairs were made to the test installation. Photographs after test are in Figure 16.

Low Service Retrofit. Test TTR-11 was conducted on the system described in Figures 12 and 17. As shown in Figure 18, the 4588-lb (2081-kg) sedan impacted the installation at 61.7 mph (99.3 kmph) and an 18.4-deg angle. Overall deflections of the system were greater than anticipated for several reasons.

- the curb was not as effective in restraining the vehicle as predicted. This was due to tire climb which is not within the BARRIER VII model capability;
- the anchor bolts of the posts pulled from the installed holes;

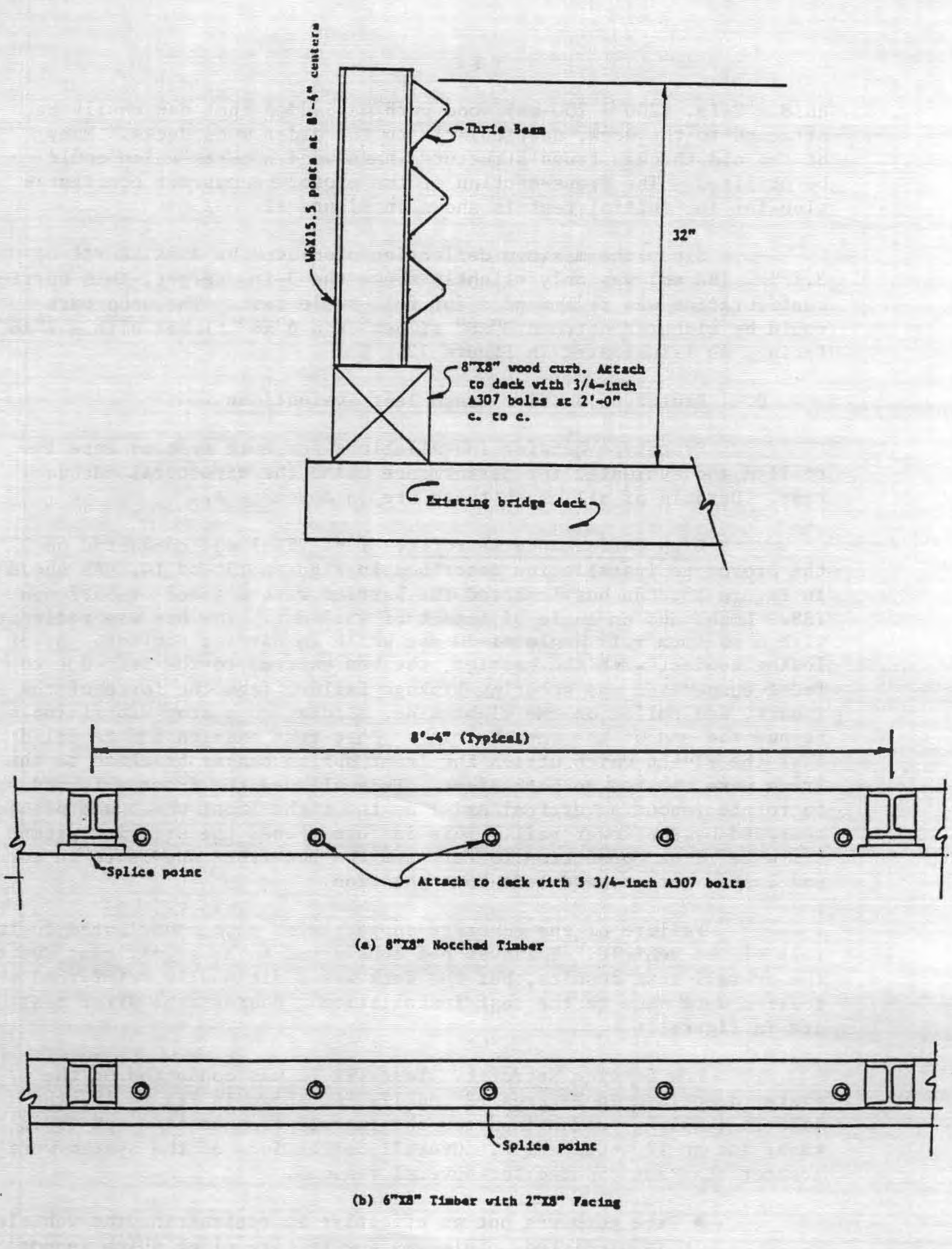


FIGURE 12. PROTOTYPE LOW SERVICE RETROFIT DRAWING

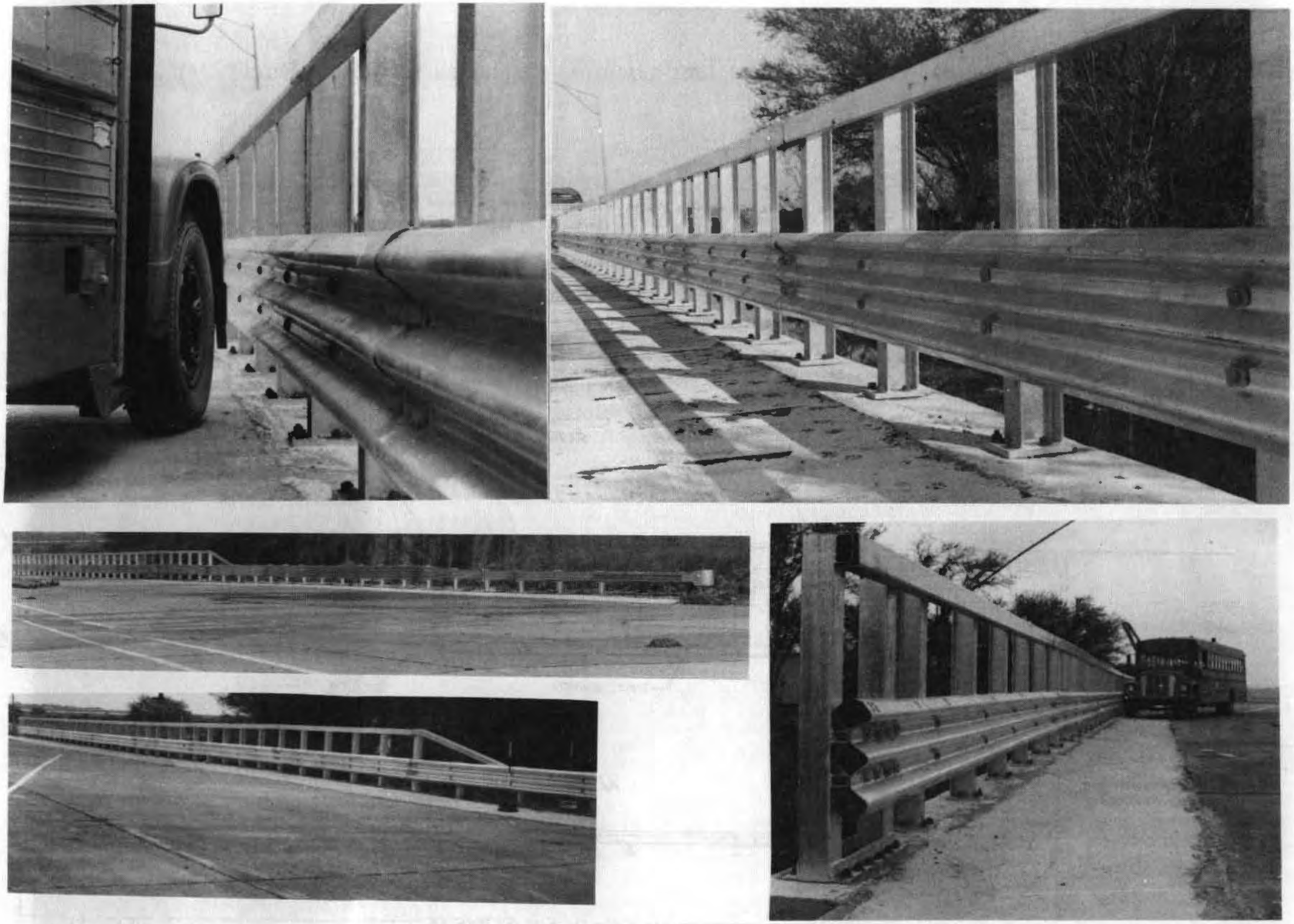
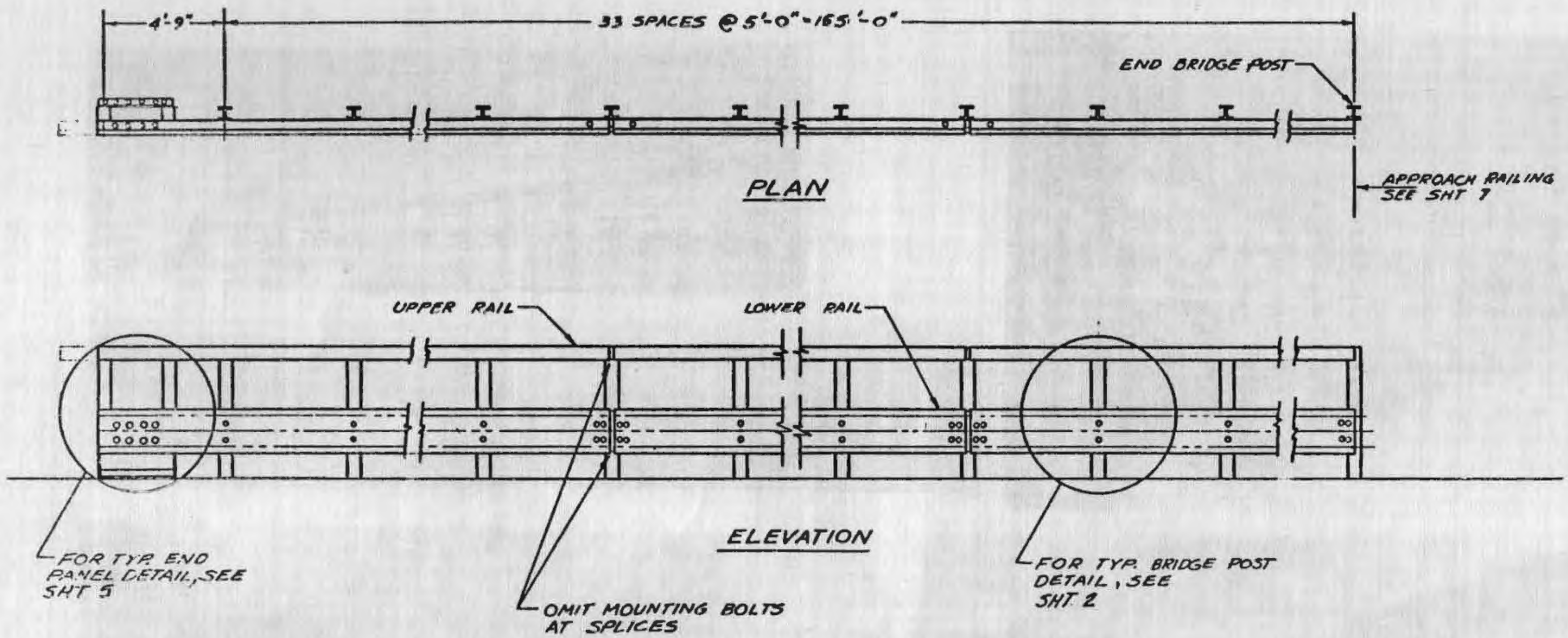


FIGURE 13. HIGH PERFORMANCE RETROFIT INSTALLATION PHOTOGRAPHS



Notes:

1. The lower rail and splices are made of tubular Thrie beam made of two continuous welded Thrie beam elements. Since no firm dimensional tolerances have been established for this beam, the manufacturer should assure compatibility of beams and splices. Thrie beam material shall conform to AASHTO M180-74 or latest revision.
2. The upper beam shall conform to ASTM A570 with mechanical properties equal to ASTM A36 and shall be galvanized in accordance with ASTM A123.
3. Posts shall conform to the requirements of ASTM A500, Grade B or ASTM A501 and shall be galvanized in accordance with the requirements of ASTM A123.
4. Bolts shall conform to requirements of ASTM A307 and nuts to requirements of ASTM A563, Grade A or better, and be galvanized in accordance with ASTM A153 except when specified otherwise. Bolts and nuts shall be of the hex or heavy hex types. Washers shall be made of steel and be galvanized in accordance with the requirements of ASTM A153.
5. Steel plate shall conform to ASTM A36 and shall be galvanized in accordance with ASTM A123.
6. Welding shall conform to the requirements of the current "Specifications for Welded Highway and Railing Bridges" of the American Welding Society, AWSD 2.0.

Thru Truss Retrofit #1
DOT FH-11-9418
Sheet #1 of 7

FIGURE 14. HIGH PERFORMANCE RETROFIT - PROTOTYPE TEST BARRIER INSTALLATION DRAWINGS

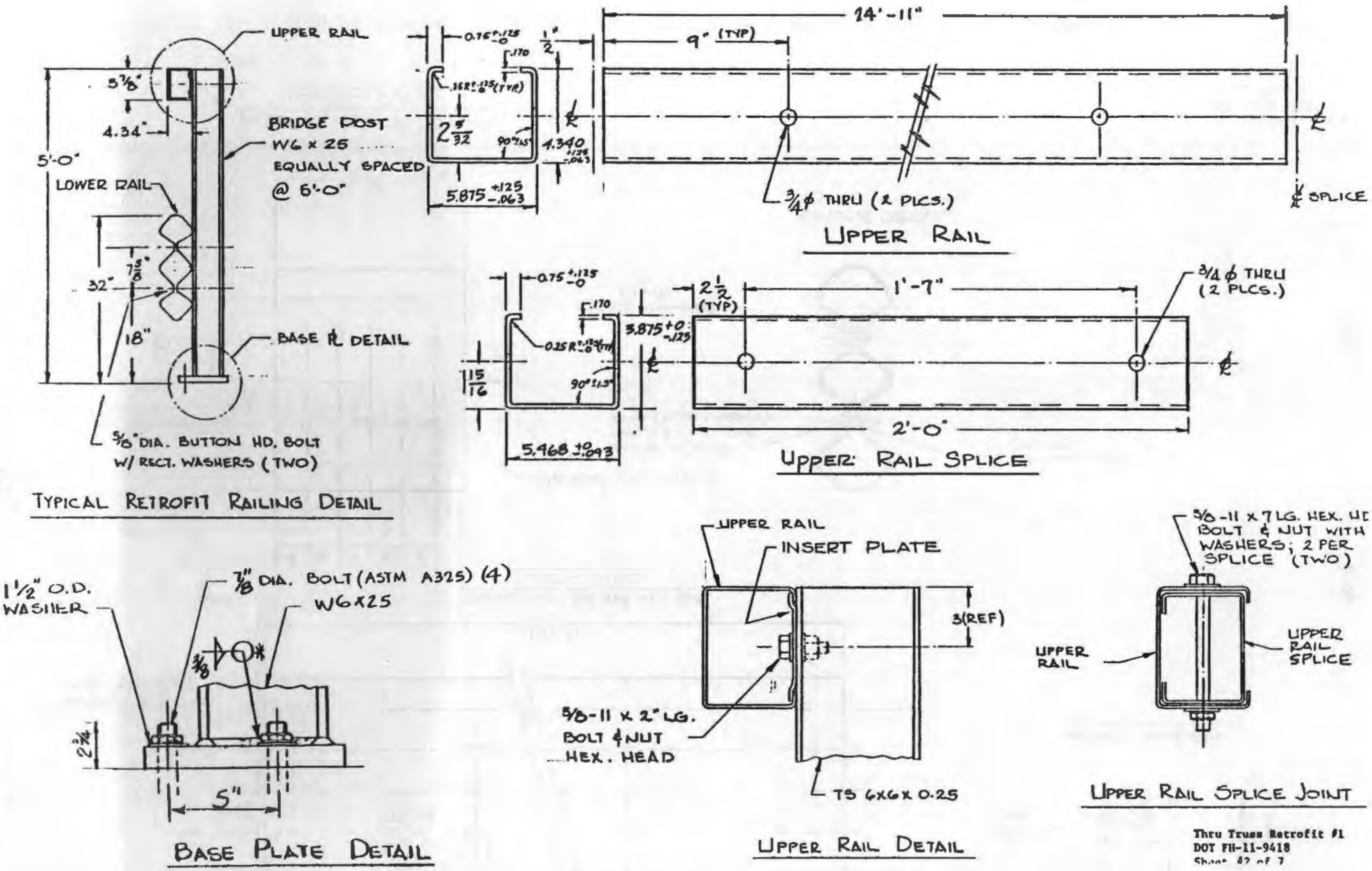
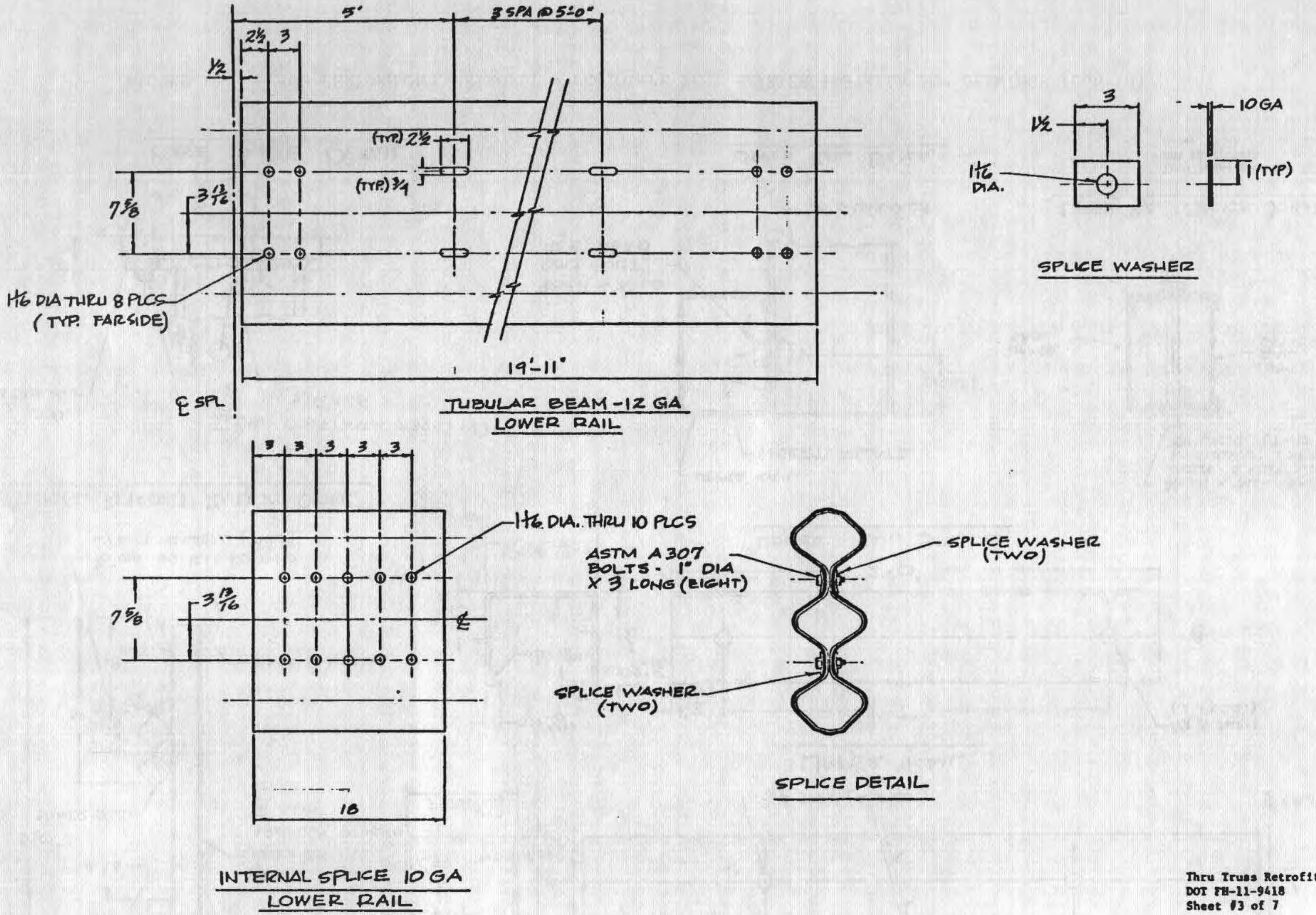


FIGURE 14. HIGH PERFORMANCE RETROFIT - PROTOTYPE TEST BARRIER INSTALLATION DRAWINGS (Cont'd)



Thru Truss Retrofit #1
DOT FH-11-9418
Sheet #3 of 7

FIGURE 14. HIGH PERFORMANCE RETROFIT - PROTOTYPE TEST BARRIER INSTALLATION DRAWINGS (Cont'd)

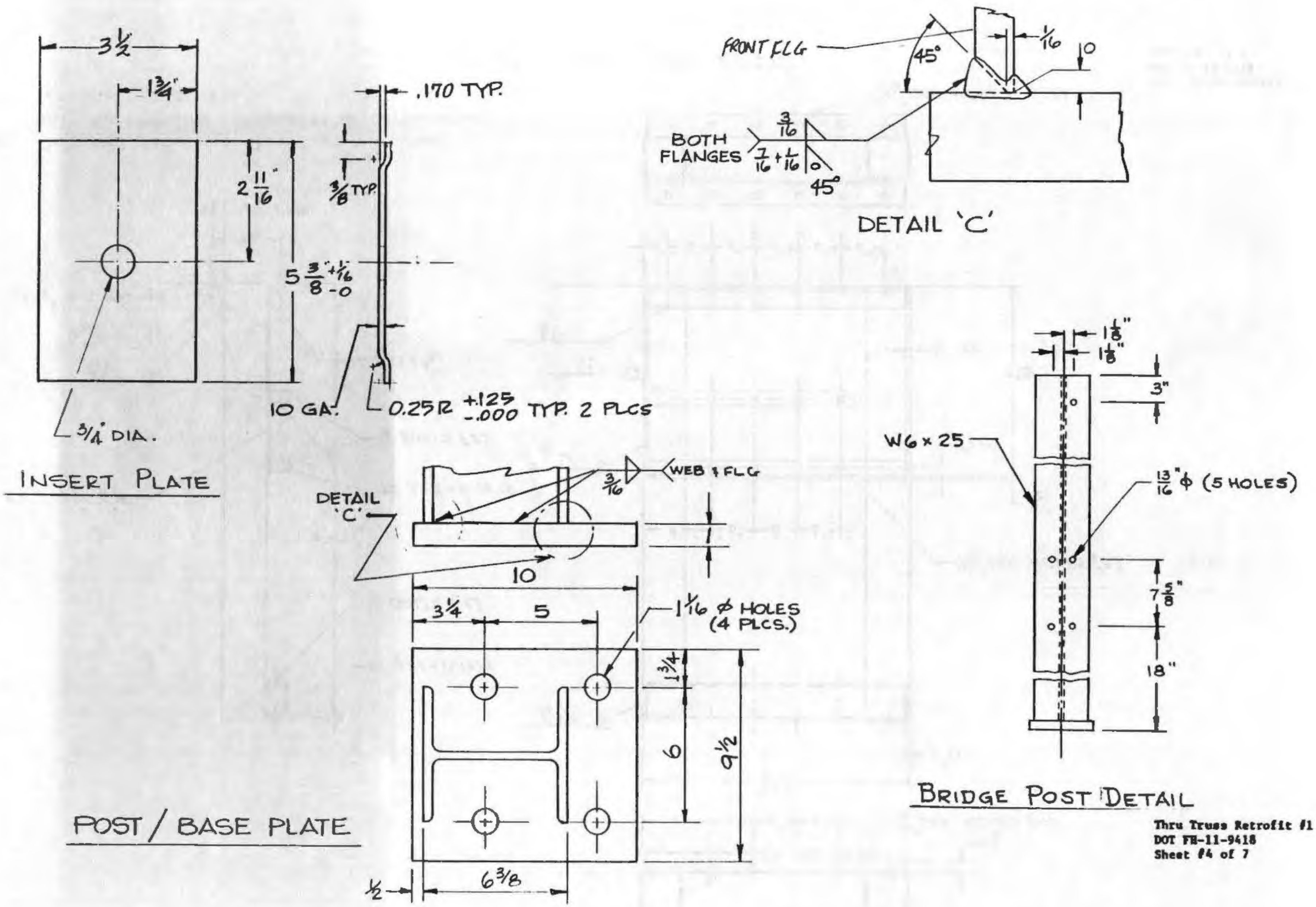
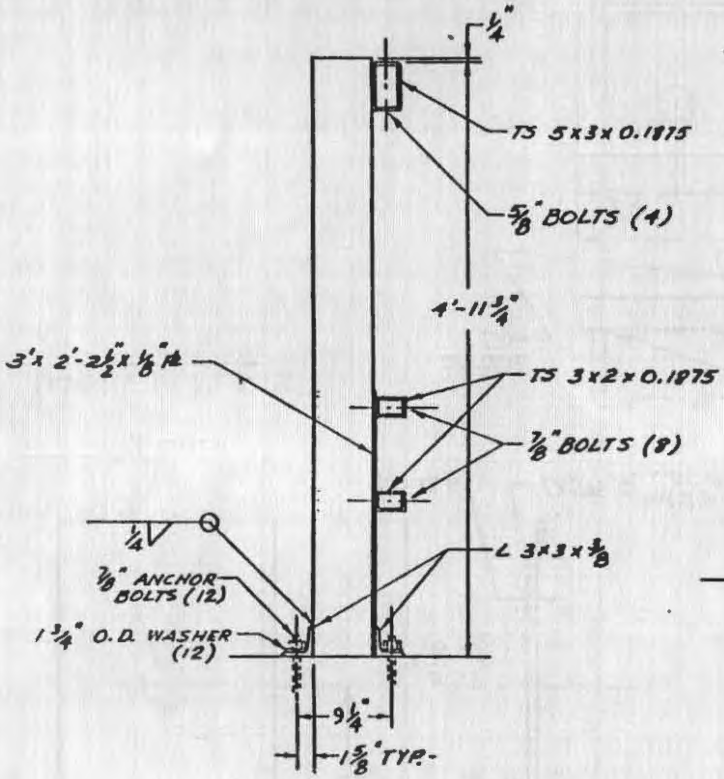
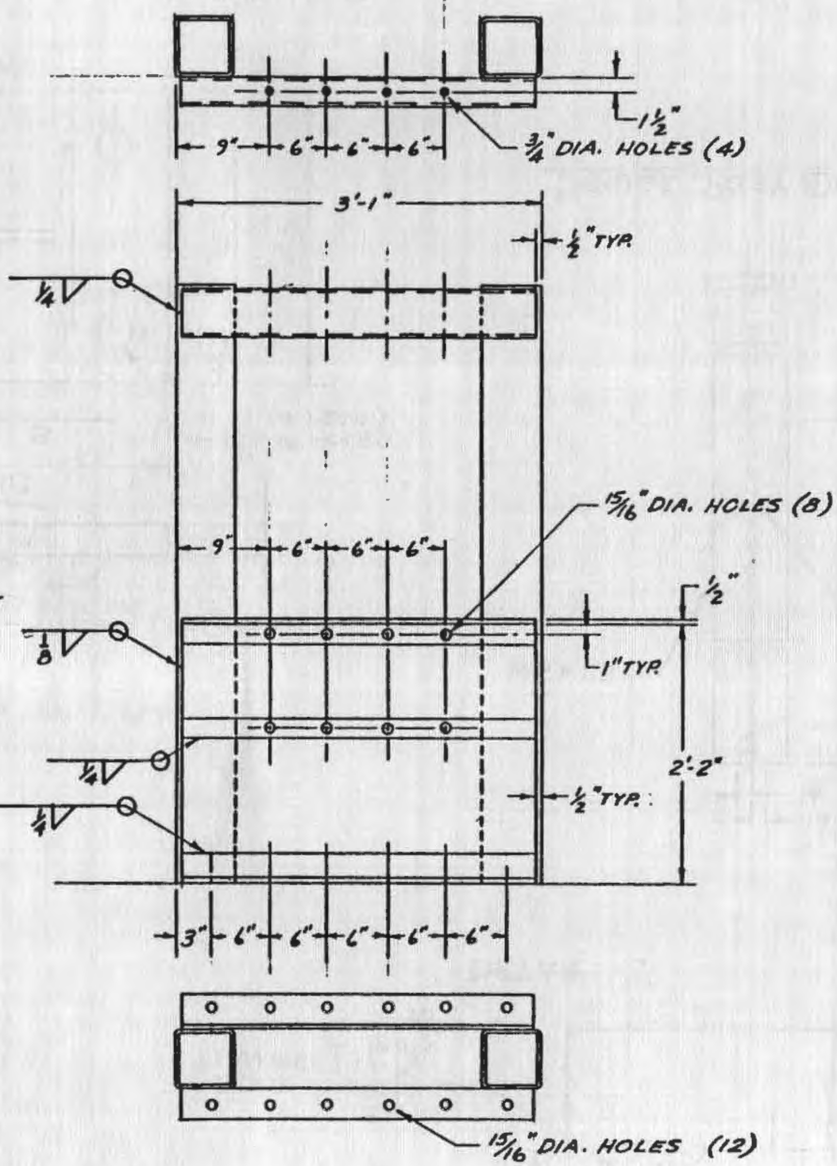


FIGURE 14. HIGH PERFORMANCE RETROFIT - PROTOTYPE TEST BARRIER INSTALLATION DRAWINGS (Cont'd)



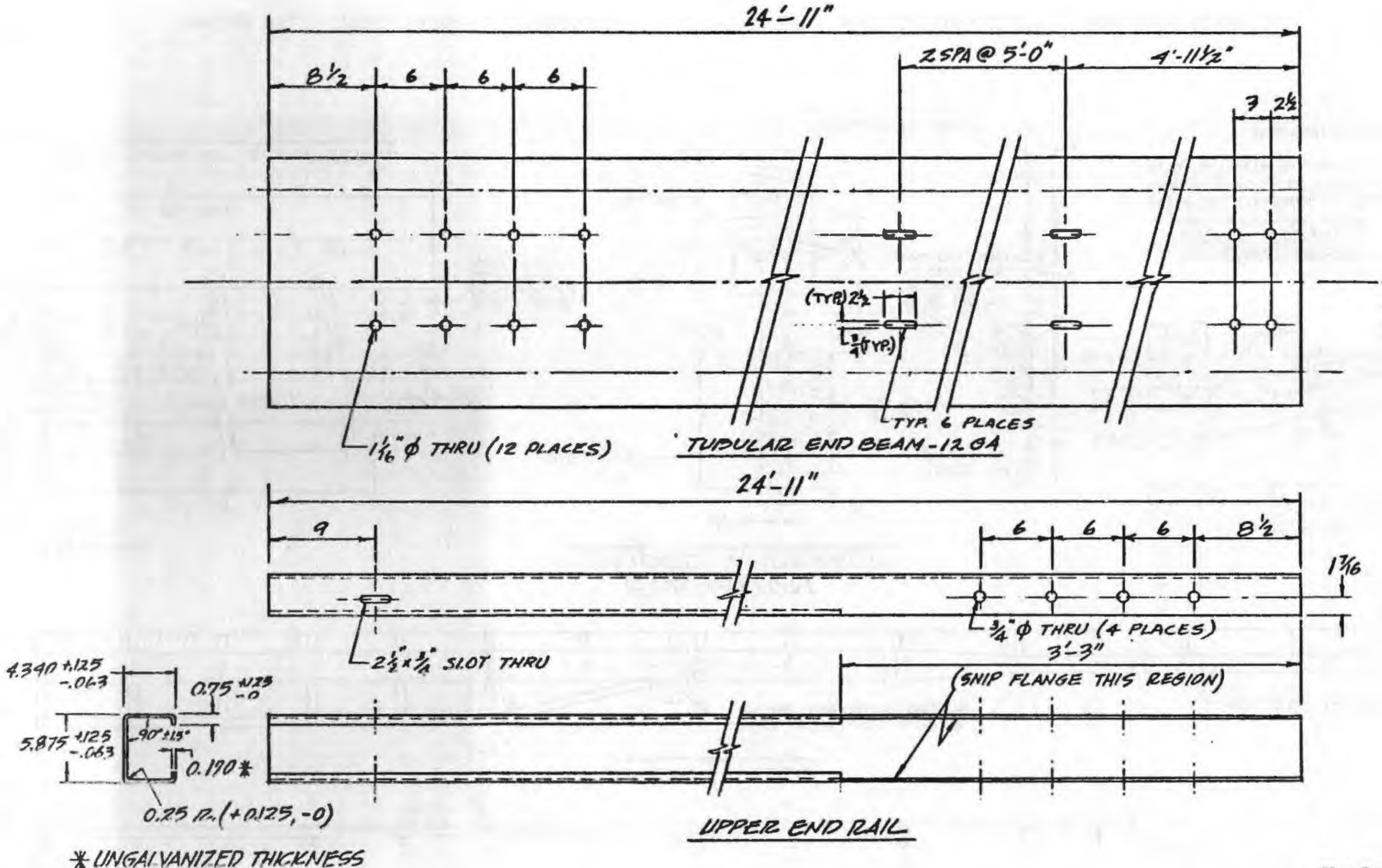


Note: This end panel was for test purposes only to provide a downstream termination for the bridge rail.

END PANEL (ONE REQ'D)

Thru Truss Retrofit #1
DOT FH-11-9418
Sheet #5 of 7

FIGURE 14. HIGH PERFORMANCE RETROFIT - PROTOTYPE TEST BARRIER INSTALLATION DRAWINGS (Cont'd)



Thru Truss Retrofit #1
DOT FH-11-9418
Sheet #6 of 7

FIGURE 14. HIGH PERFORMANCE RETROFIT - PROTOTYPE TEST BARRIER INSTALLATION DRAWINGS (Cont'd)

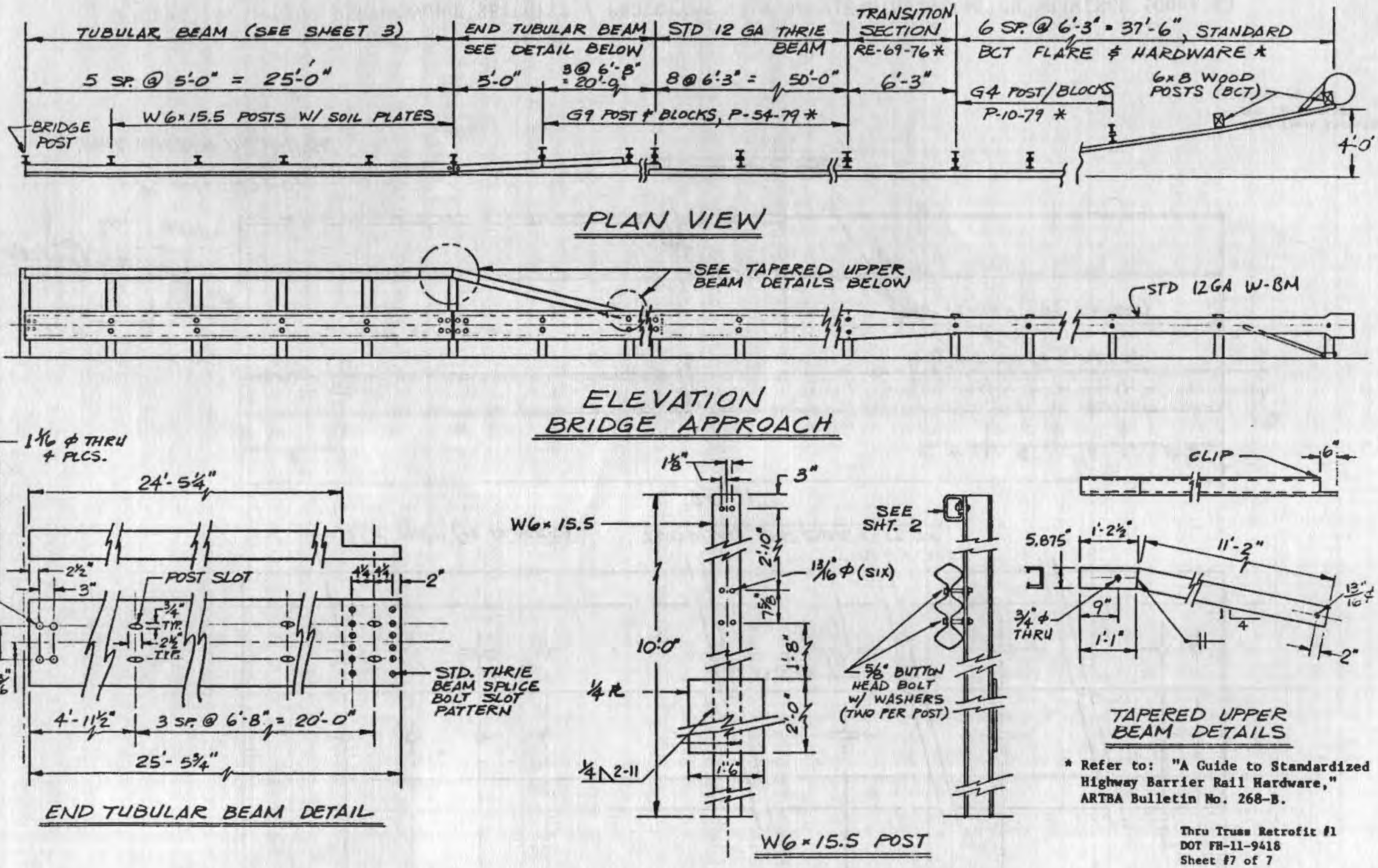


FIGURE 14. HIGH PERFORMANCE RETROFIT - PROTOTYPE TEST BARRIER INSTALLATION DRAWINGS (Cont'd)

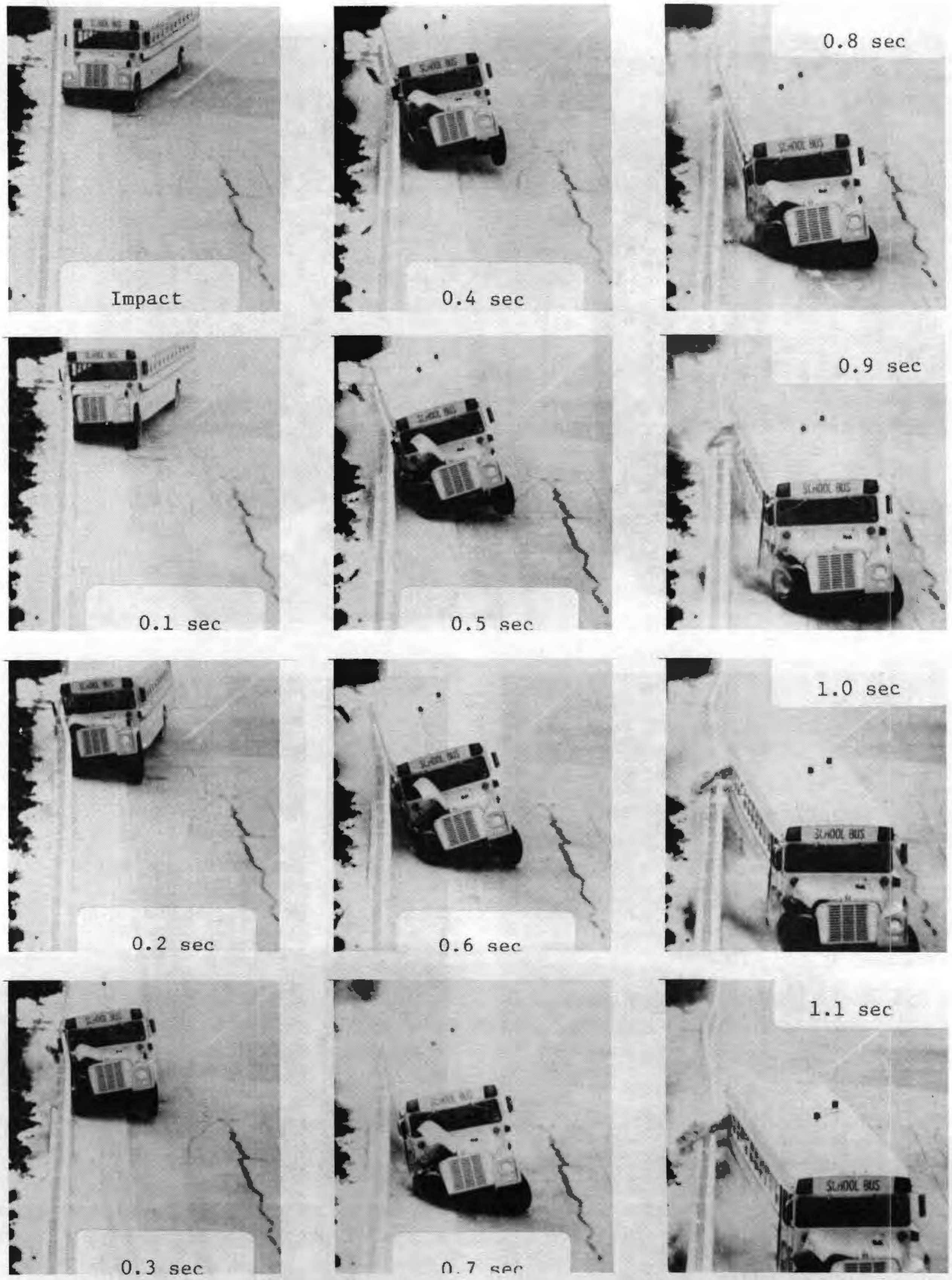


FIGURE 15. TEST TTR-1 IMPACT SEQUENCE

FIGURE 16. PHOTOGRAPHS AFTER TEST TTR-1

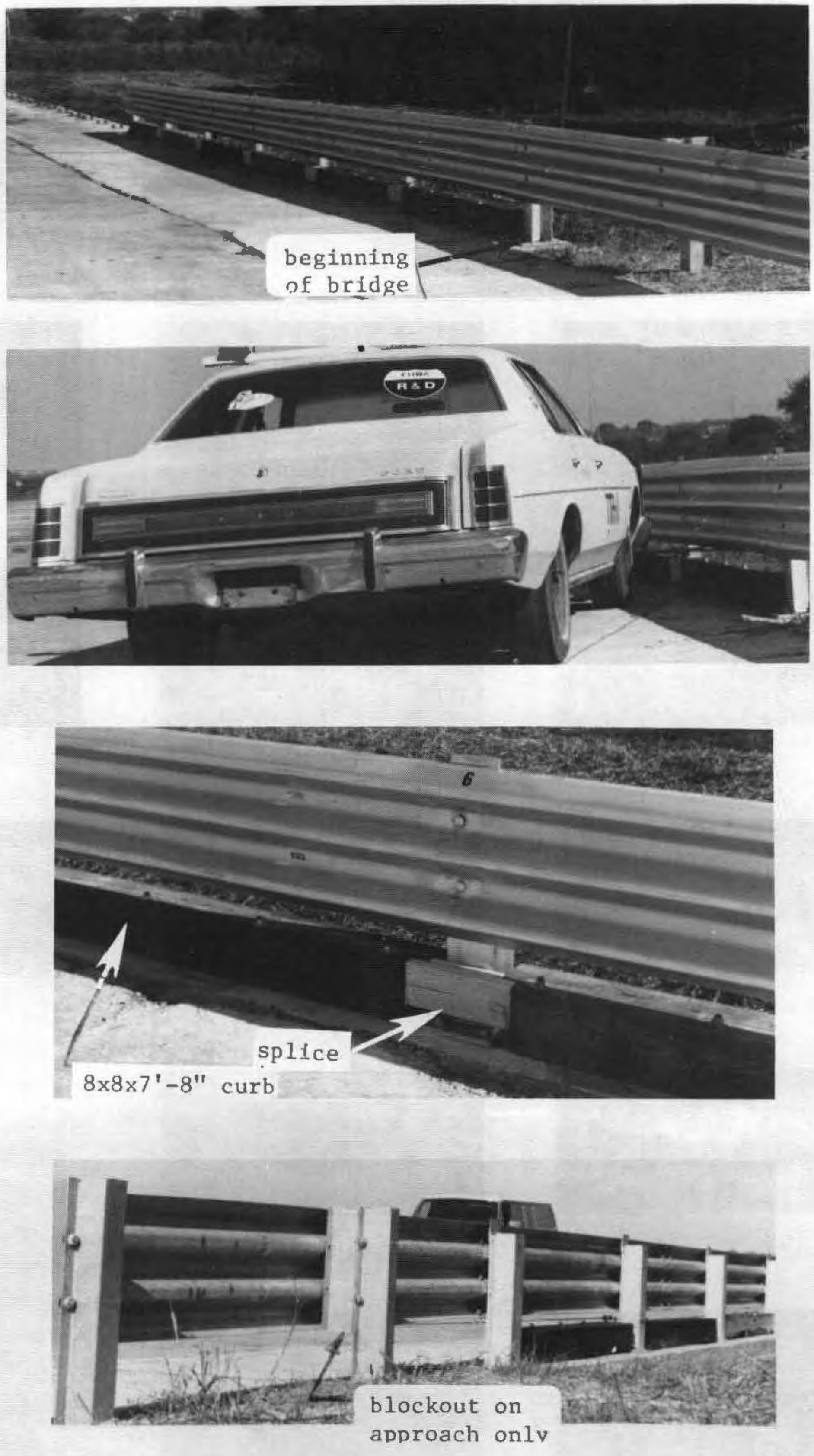


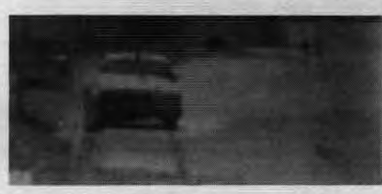
FIGURE 17.   TEST TTR-11 INSTALLATION PHOTOGRAPHS

Impact

0.05 sec

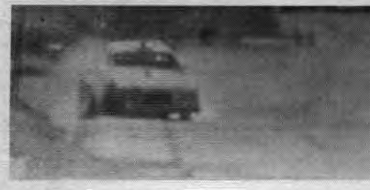
0.10 sec

0.15 sec



0.20 sec

0.25 sec



0.30 sec

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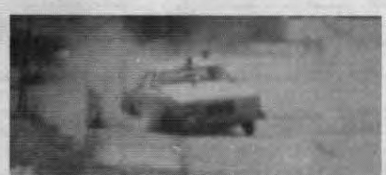
0.50 sec



0.60 sec

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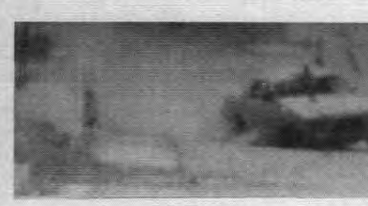
0.90 sec

1.00 sec



1.20 sec

FIGURE 18. TEST TTR-11 IMPACT SEQUENCE

- the ineffectiveness of the curb placed more of the load on the beam and posts resulting in greater deflection.

Figure 19 contains photographs after Test TTR-11.

E. Barrier Development

Based on prototype barrier crash test results, the two concepts were modified for subsequent crash test evaluation. The high performance barrier was modified three times during the development in the finalized design configuration. The low service retrofit was modified once.

1. High Performance Retrofit. Results of Test TTR-1 were compared to two tests with similar impact conditions as summarized in Table 4 and Figures 20 and 21. The two tests at TTI both resulted in the bus remaining upright, after collisions with rigid, but lower barriers than TTR-1. The difference in performance among the three tests is vehicle related, and it was concluded that a more forgiving initial impact to reduce frontal damage would be desirable.

Notched Post Concept. Concepts were conceived to provide a "cushion" without compromising the deck space used. One such concept as described in Figure 22 was subjected to a series of static tests as described in Figure 23. Load-deformation data from the finalized notch design is shown in Figure 24.

Test TTR-2. Notched posts as described in Figure 25 were installed in the impact area for this test; all other details were the same as TTR-1. The 20,000-lb (9070-kg), 72-passenger bus impacted the installation at 56.1 mph (90.3 kmph) and a 17.8-deg angle. As shown in Figure 26, the bus rolled toward the barrier after impact as it was redirected with a maximum roll angle of 12.5 deg. After losing contact with the barrier, the bus began a hard steer to the left due to suspension and linkage failure. The steer angle was too great for the speed and the bus subsequently rolled on the right side.

Post-test examination revealed that the rivets which attach the front spring hanger brackets to the frame were sheared on both sides. This allowed the front axle and springs to rotate (about a vertical axis) as the right front wheel was pushed rearward by the lower rail. This, in turn, caused the steering pitman arm/wheel link connection to fail and the bus front wheels to be turned and locked into a hard left turn position.

Results of the test were considered unsatisfactory for the following reasons:

- the bus left the barrier with a severe steer angle - resulting in rollover. On an actual through truss structure, this hard steer could have represented a very severe impact on the opposite railing

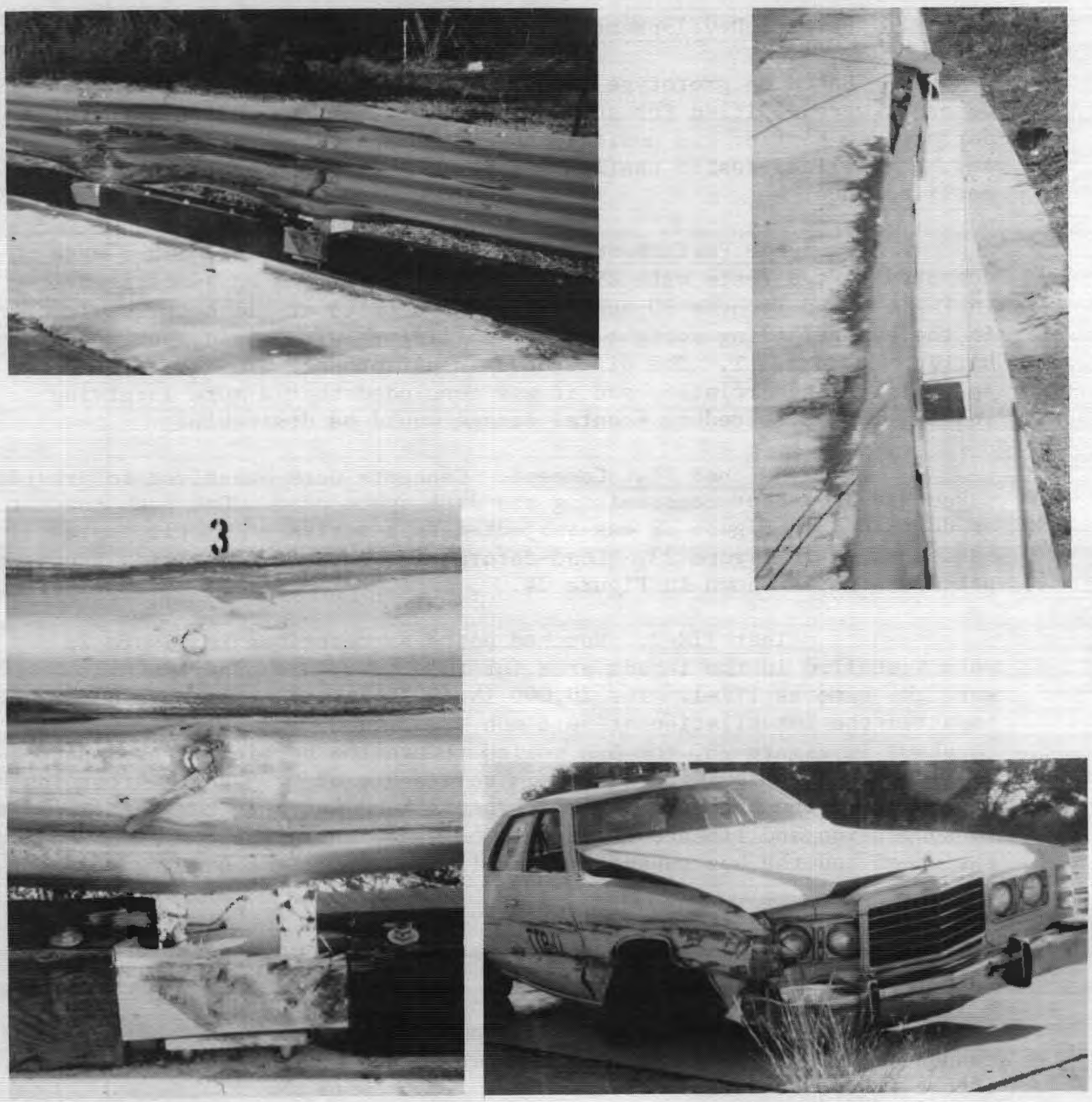


FIGURE 19. PHOTØGRAPHS AFTER TEST TTR-11

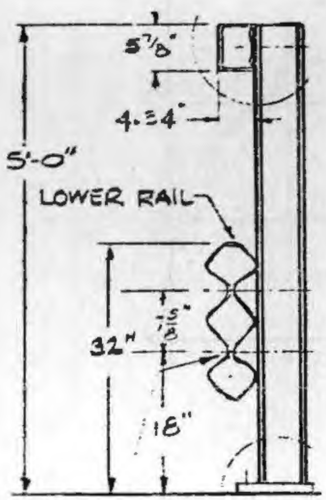
TABLE 4

SUMMARY OF SCHOOL BUS TESTS

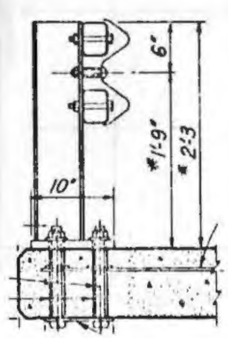
Test	Vehicle	Vehicle Weight (lbs)	Barrier*	Impact Speed (mph)	Impact Angle (deg)	Results
TTR-1 (SwRI)	72-passenger Wayne body, 1966 IH chassis	20,000	A	55	15	Vehicle rolled on side after hard steer to left; substantial damage to front suspension
RF3451-9(3) (TTI)	66-passenger Ford	20,000	B	60	15	Vehicle remained upright; front axle completely displaced from bus
2230-3 (TTI)	66-passenger Ford	20,000	C	60	15	Front wheels are locked (straight ahead) on impact due to wedging of impact-wheel against wheel well

*Barrier code:

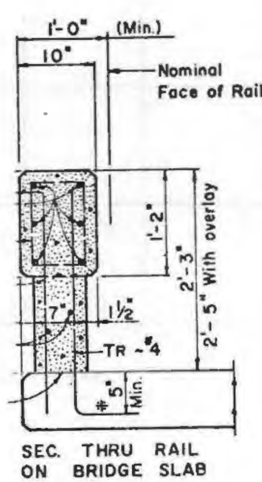
A



B



C



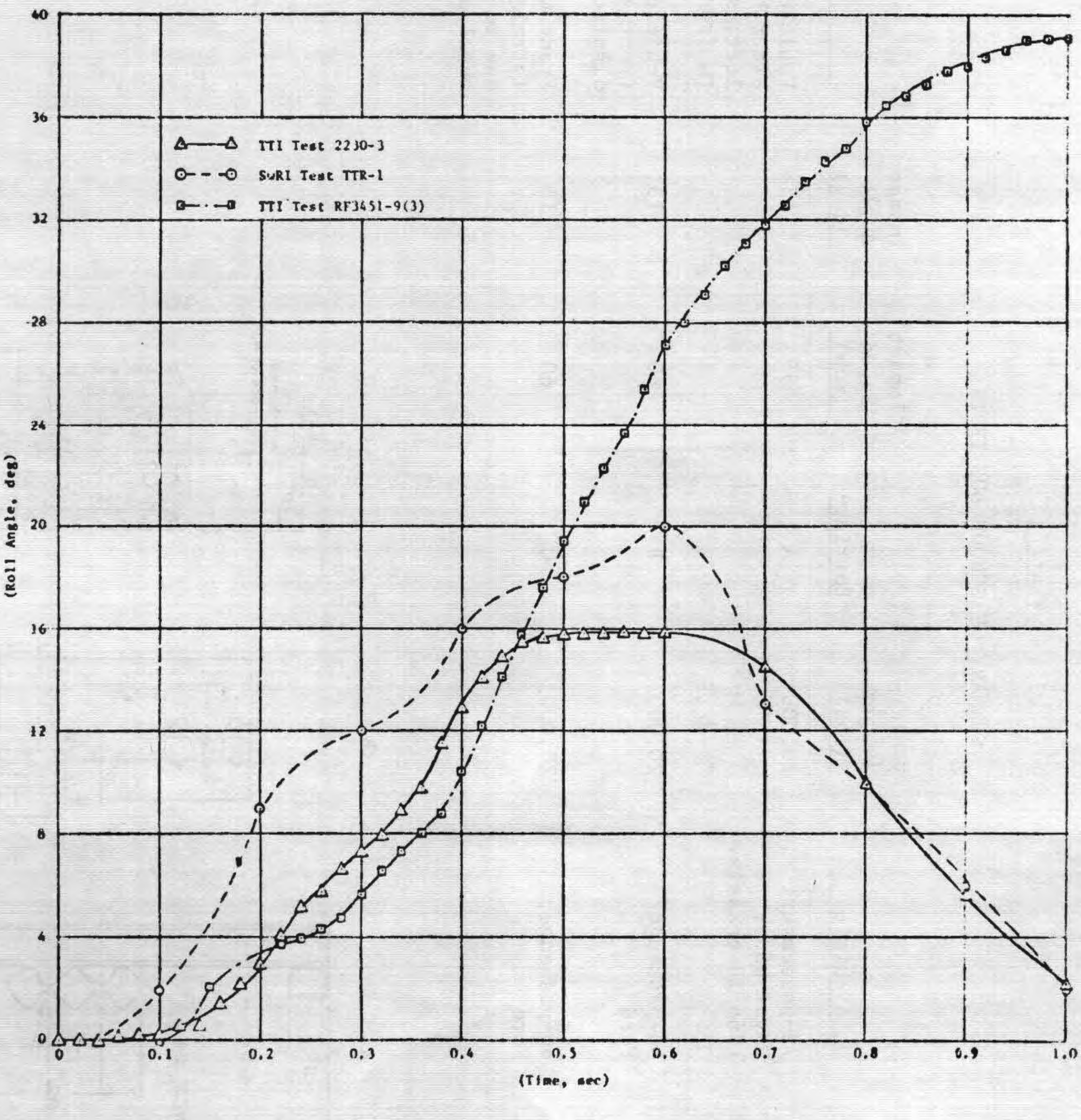


FIGURE 20. ROLL ANGLE VS TIME, SCHOOL BUS/BRIDGE RAIL IMPACTS

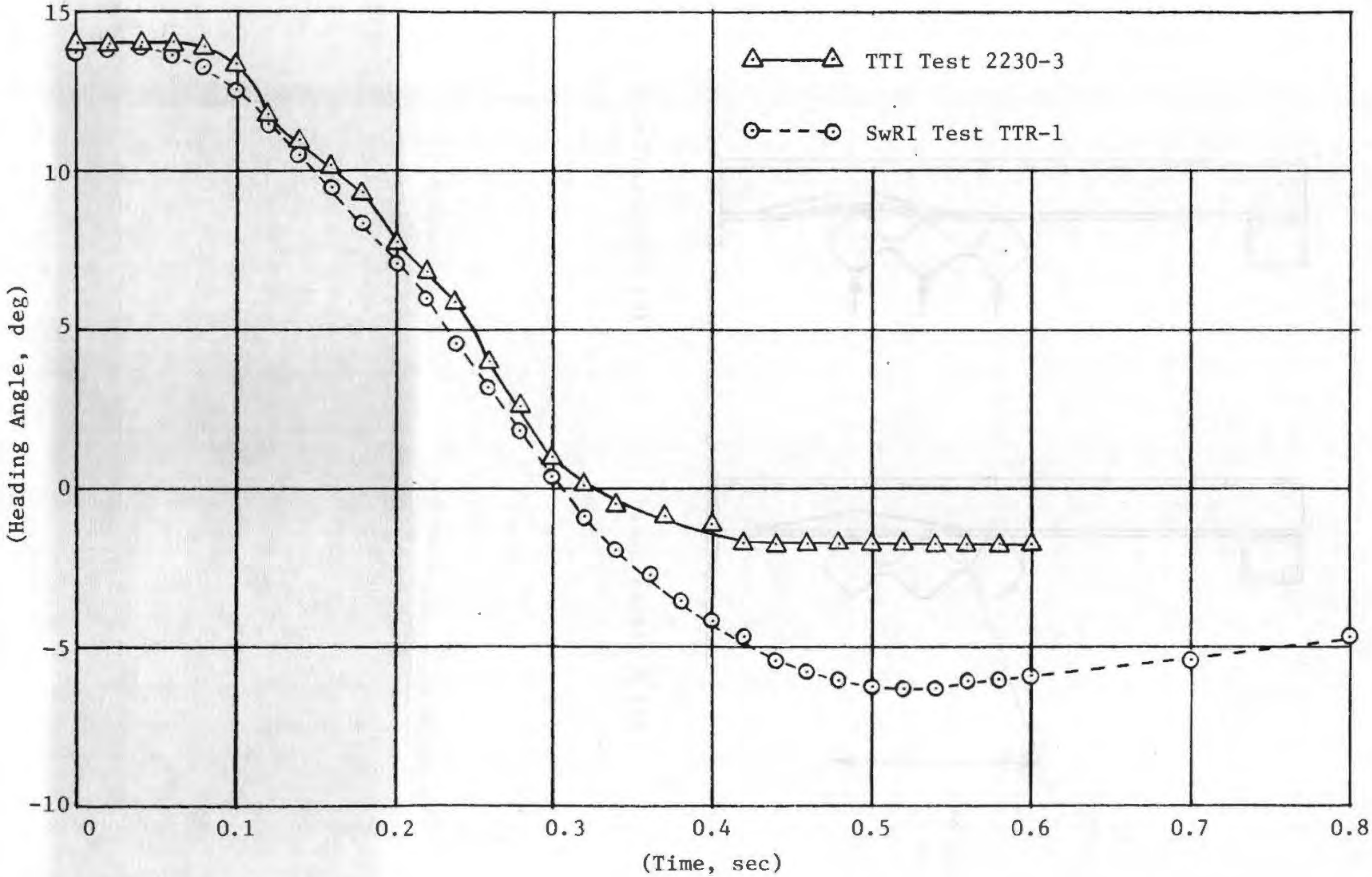


FIGURE 21. HEADING ANGLE VS TIME, SCHOOL BUS/BRIDGE RAIL IMPACTS

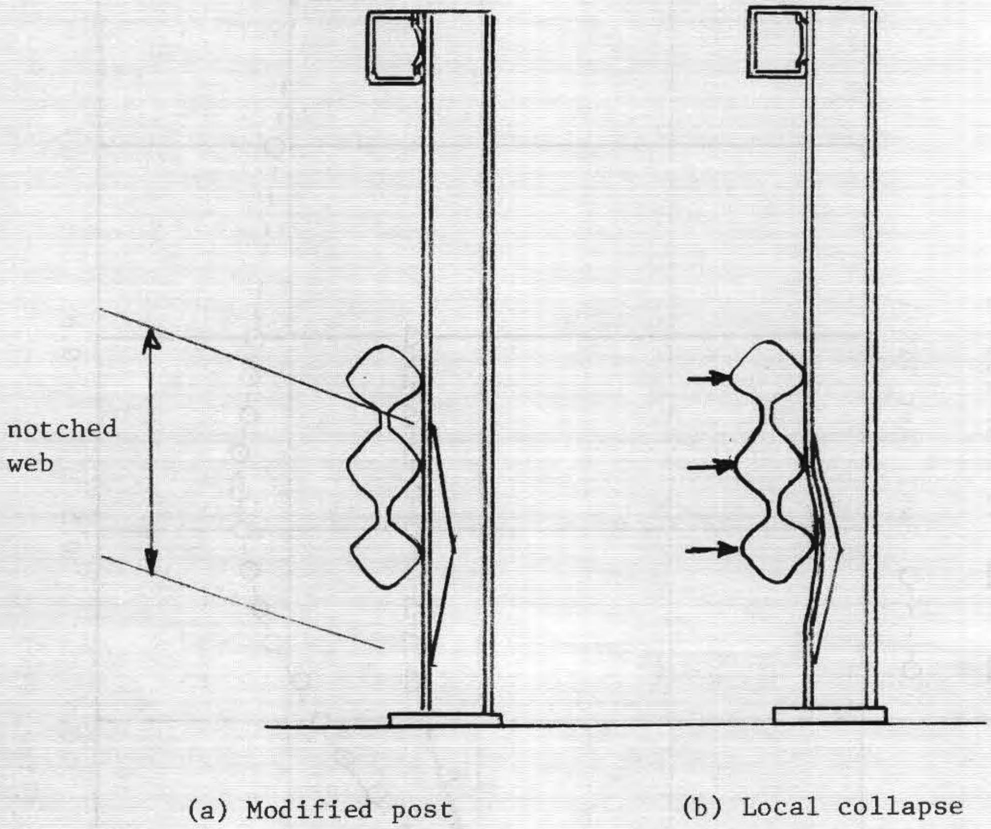


FIGURE 22. MODIFIED POST CONCEPT

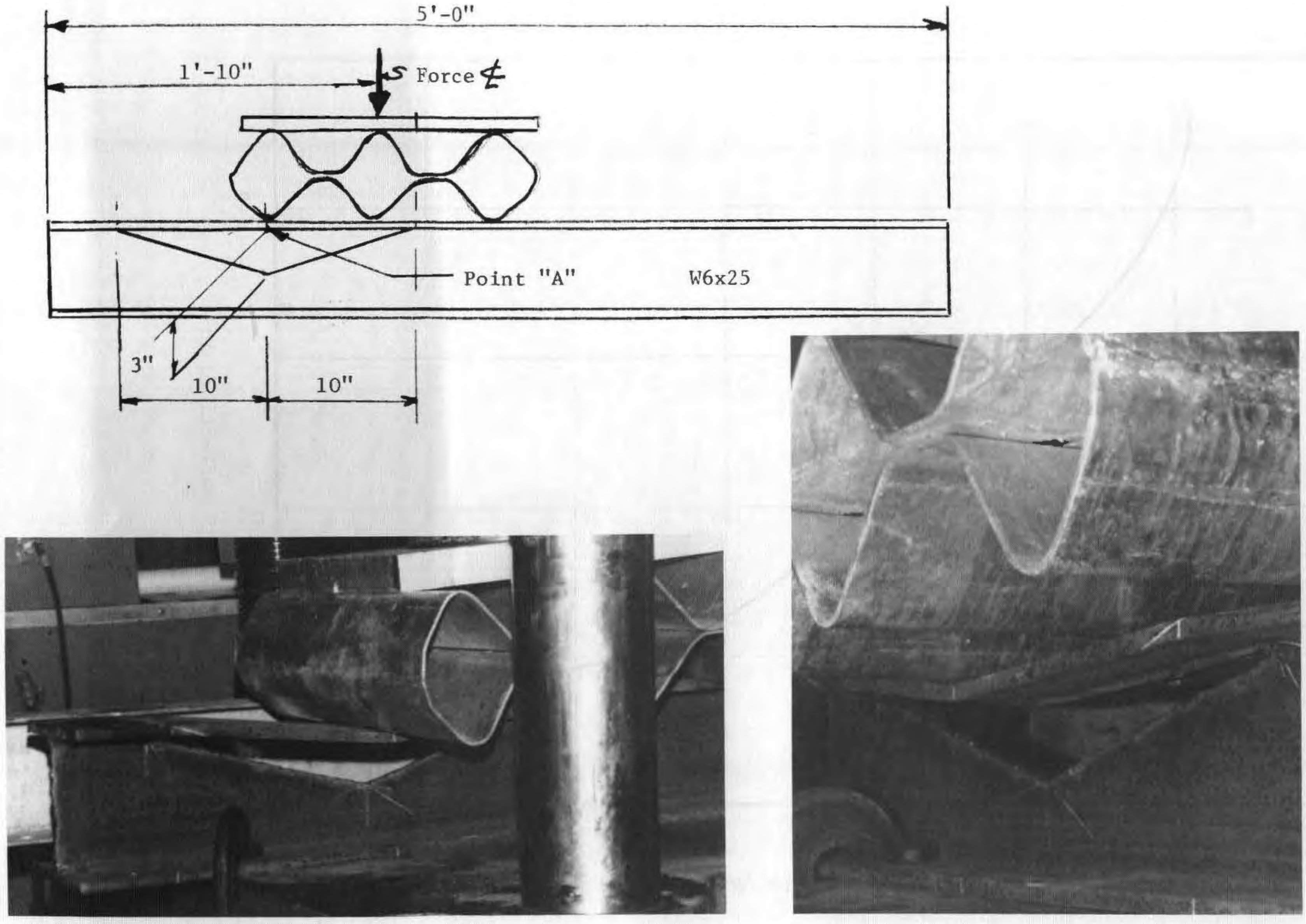


FIGURE 23. EXPERIMENTAL NOTCHED POST

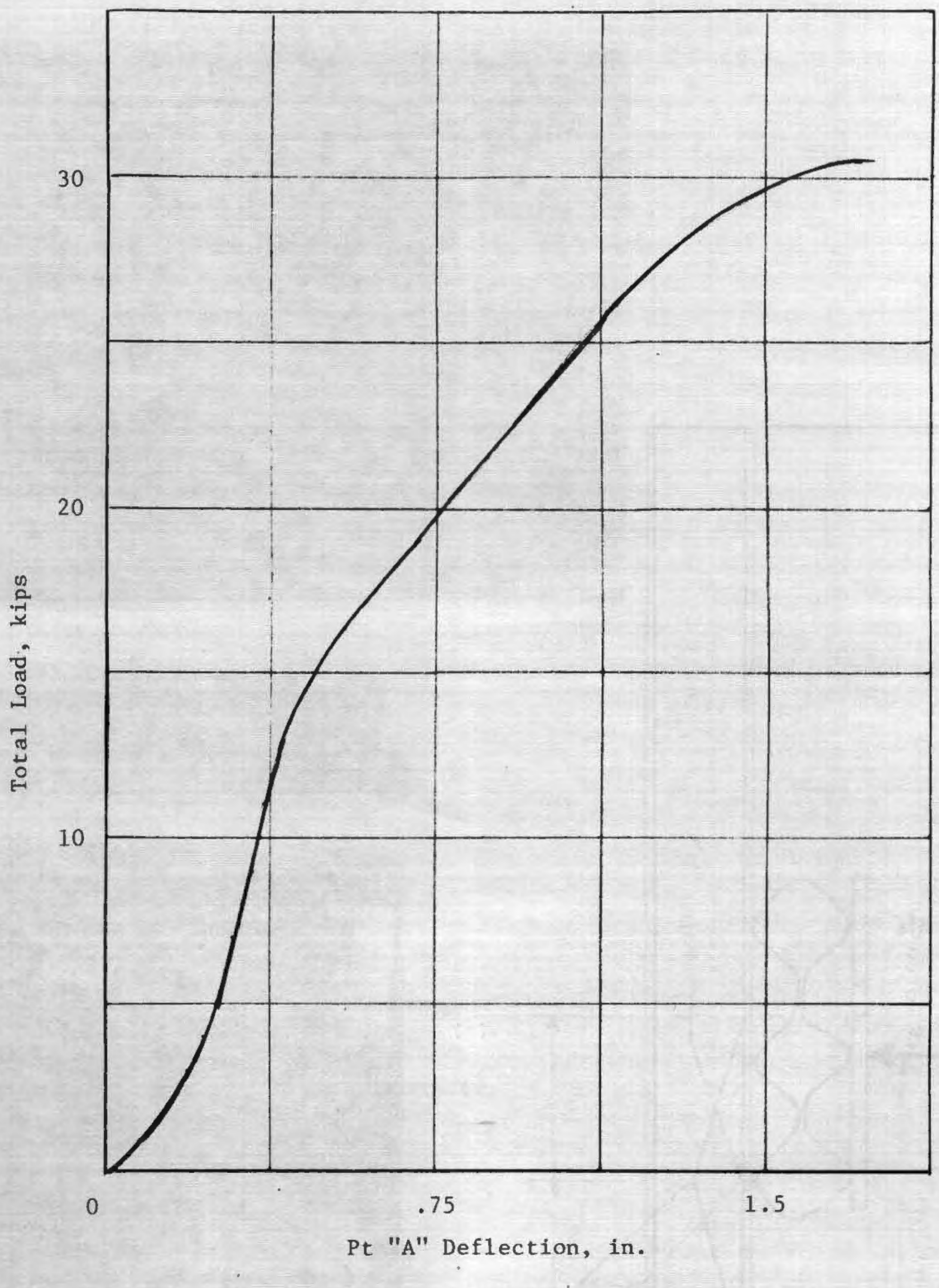


FIGURE 24. LOAD VS DEFLECTION (POINT A)

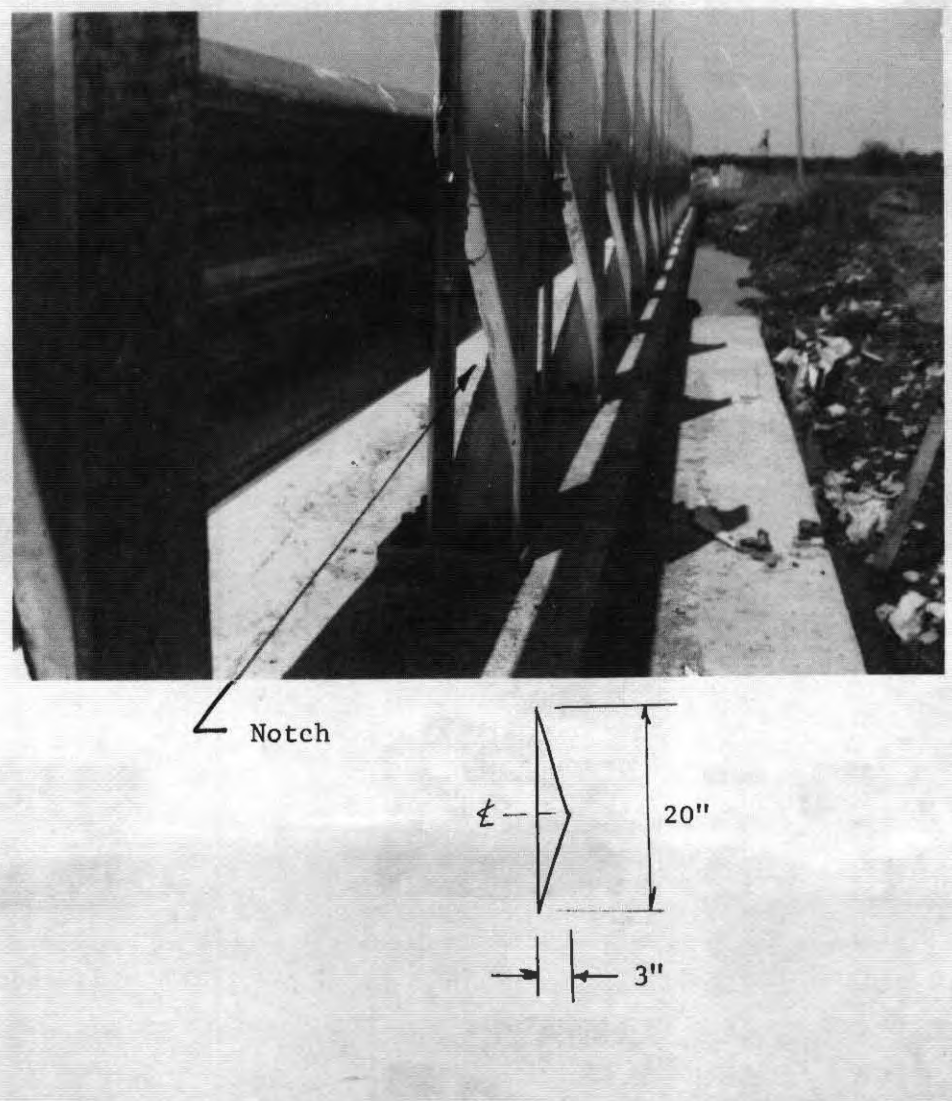


FIGURE 25. NOTCHED POST

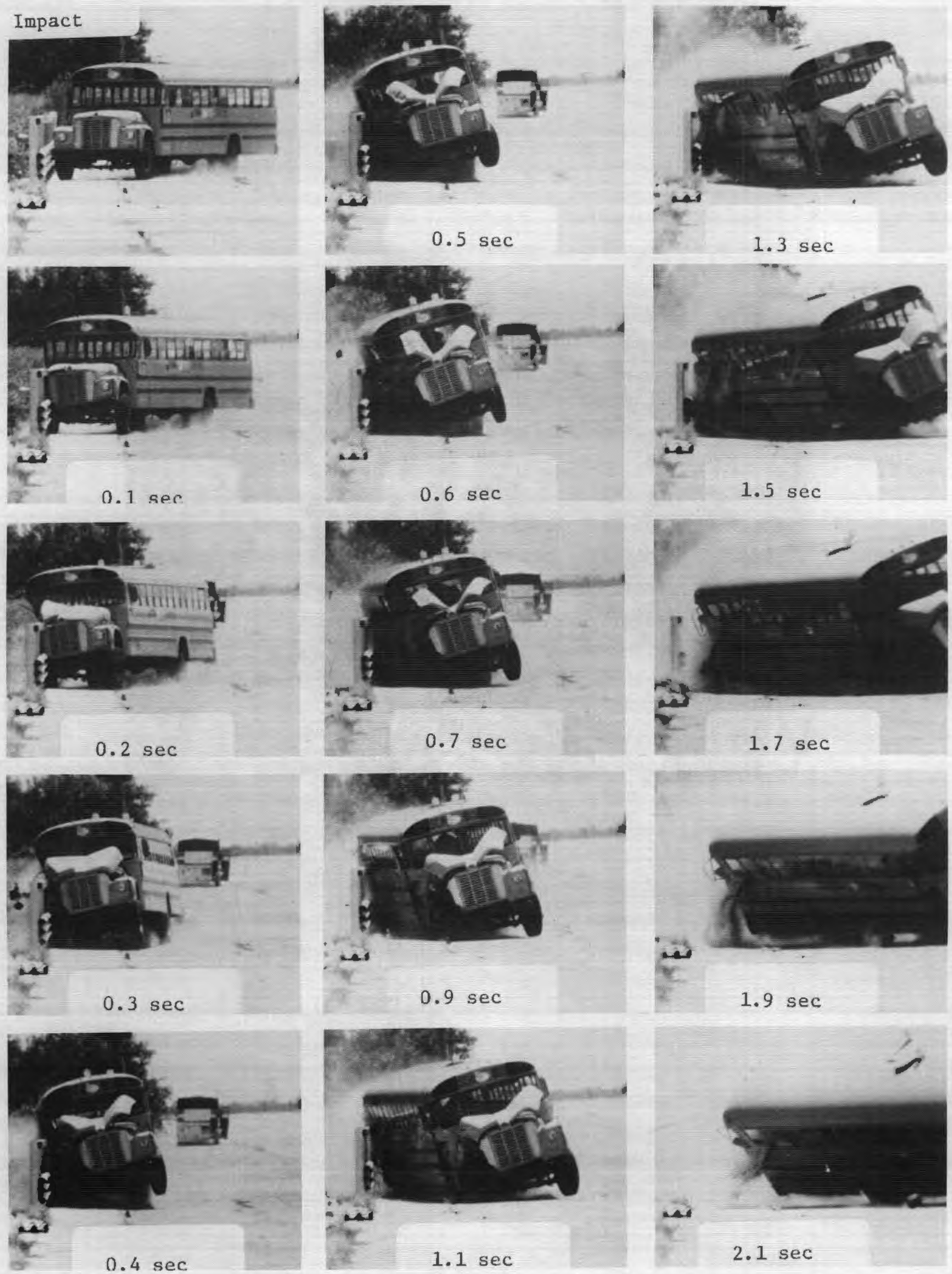


FIGURE 26. TEST TTR-2 IMPACT SEQUENCE

- the maximum post deflection exceeded the 3-in. (75-mm) design goal. This was partially attributed to weakening of the posts at the notch.

Photographs taken after the tests are shown in Figure 27. The strain gage readings indicated a maximum force of 8.5 kips (3.4 kN) at the upper rail/post interface.

Self-Restoring Concept. Based on results of TTR-2, it was deemed desirable to abandon the notched post concept and to incorporate a self-restoring 3-in. (75-mm) stroke into the lower beam mounting detail as described in Figure 28. The pivot bar is used on intermittent posts to minimize costs as shown in Figure 56.

Test TTR-3. For the test, the self-restoring beam/post detail described in Figure 28 was incorporated into the installation; all other details were essentially the same as previous tests as shown in Figure 29. A 66-passenger bus was selected for this test as being a more representative vehicle. The Chevrolet chassis of the test vehicle was also considered more crashworthy than buses previously used in TTR-1 and -2.

The test vehicle impacted the barrier at 53.9 mph (86.7 kmph) and a 15.3-deg angle. As shown in Figure 30, the bus rolled a maximum of 10.7 deg toward the barrier as it was redirected. During the impact, the right front wheel was pushed rearward by the lower rail, causing suspension failure, and forced the entire front axle to rotate. After losing contact with the barrier, the vehicle dropped at the right front onto the now horizontal front right wheel and slid upright to a stop essentially parallel to the barrier as shown in Figure 31. The maximum deflections were such that the 3-in. (75-mm) encroachment goal beyond the rear post line were met. The roll of the vehicle and the exit conditions were also considered favorable. There was some sheet metal snagging on posts at the opening between upper and lower rails as shown in Figure 31. This was sufficient to cause one post weld to separate due to flexure about the minor axis as shown in Figure 31.

TTR-4. Based on the favorable results of the preceding test, a 60-mph (95-kmph), 15-deg angle test with an 1800-lb (800-kg) class Honda Civic was scheduled. The purpose of this test was to evaluate the barrier performance for minicompact collisions.

The 1840-lb (835-kg) vehicle impacted the barrier at 59.8 mph (96.2 kmph) and a 14.8-deg angle. As shown in Figure 32, the beam displaced up and back during the collision, and then returned to the original position. Maximum 50-msec average accelerations measured from high-speed film analysis/accelerometers were 7.8 g/ 8.1 g (lateral) and -3.0 g/-2.1 g (longitudinal). There was no discernible damage to the barrier system; damage to the vehicle was moderate as shown in Figure 33.

Bridge Approach Design. The basic bridge railing approach and terminal treatment is described in Figures 14 (sheet #7)

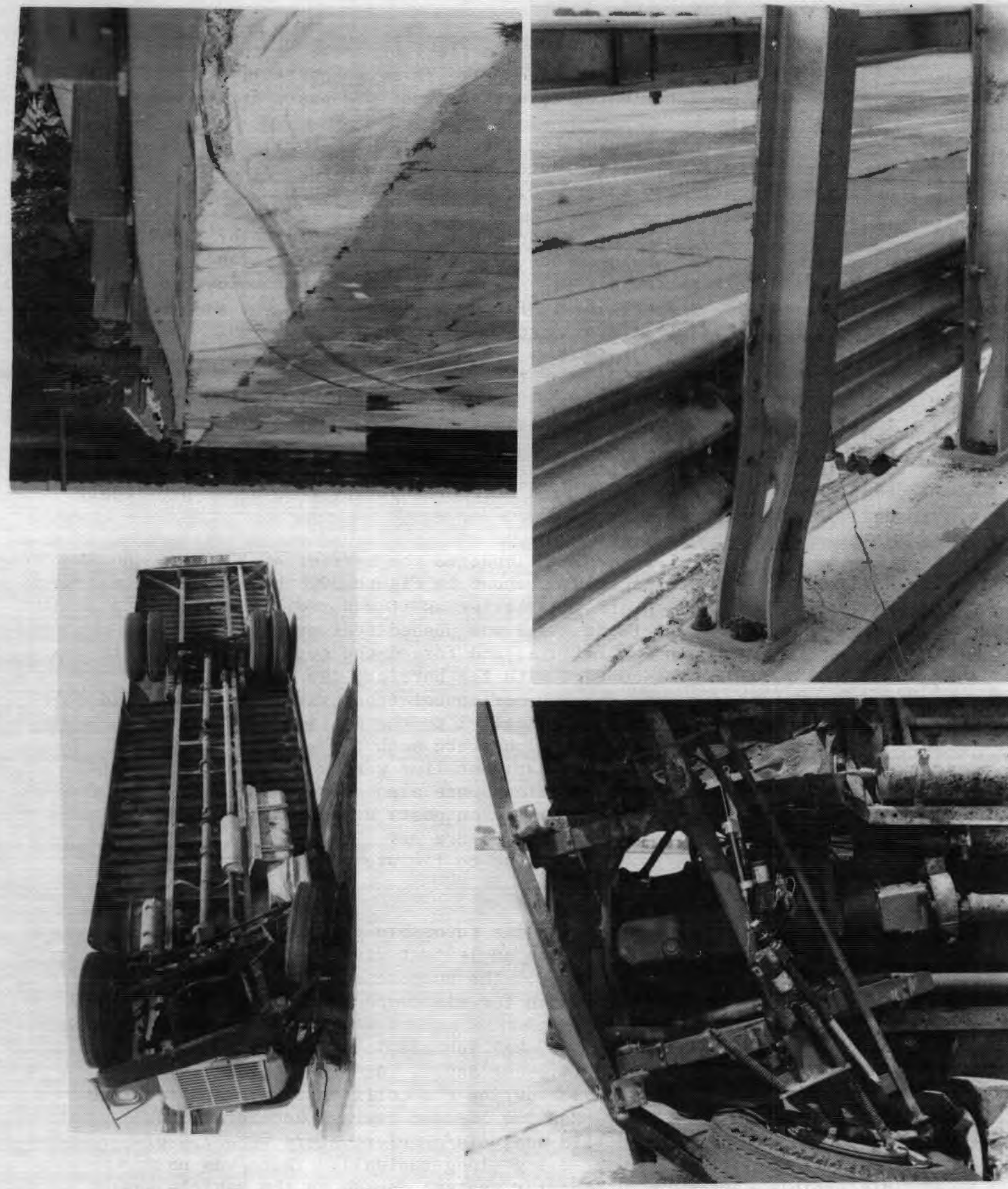


FIGURE 27. PHOTOGRAPHS AFTER TEST TTR-2

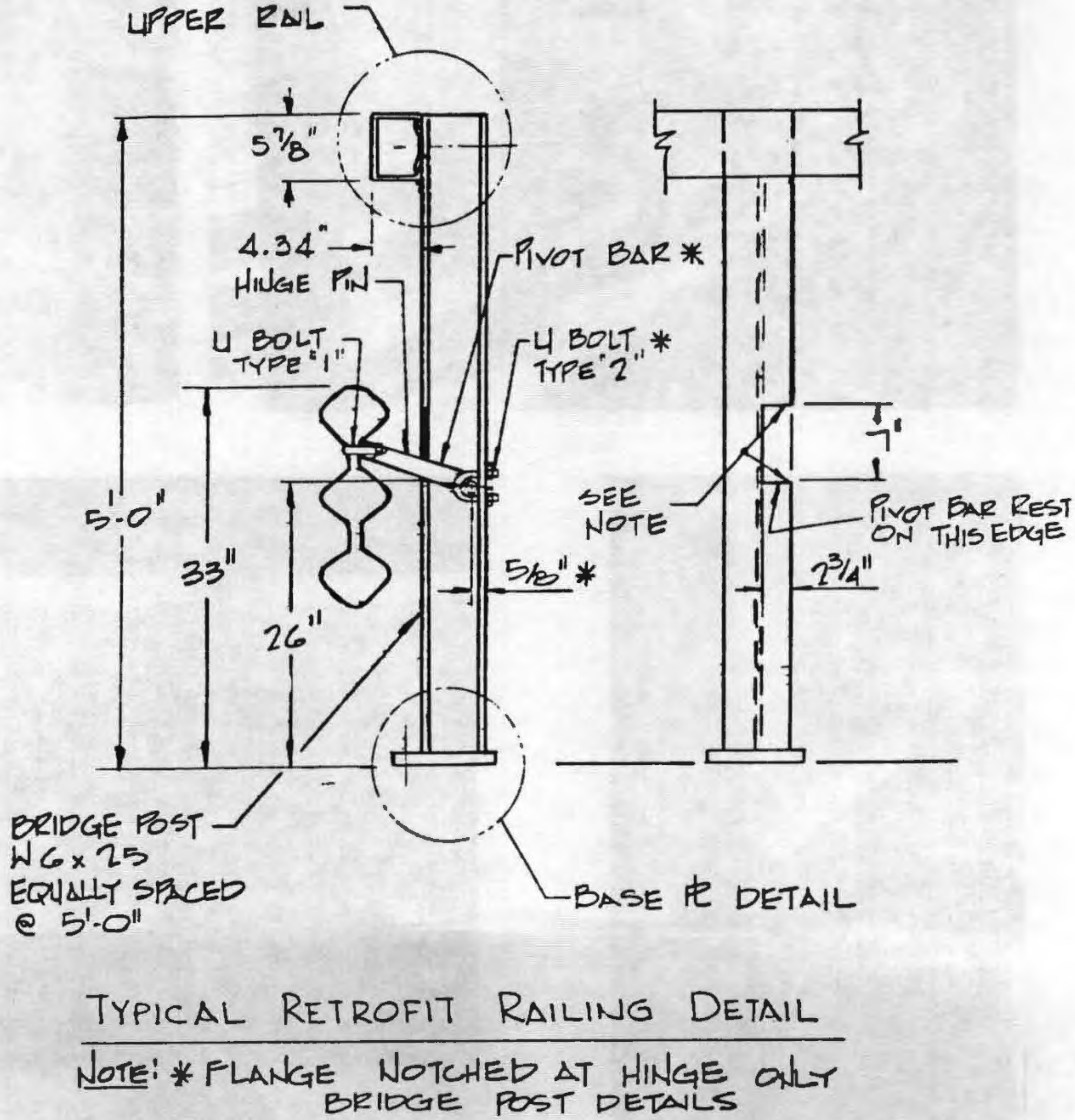


FIGURE 28. MODIFIED SELF-RESTORING THROUGH TRUSS RETROFIT

FIGURE 29. SELF-RESTORING HIGH PERFORMANCE RETROFIT

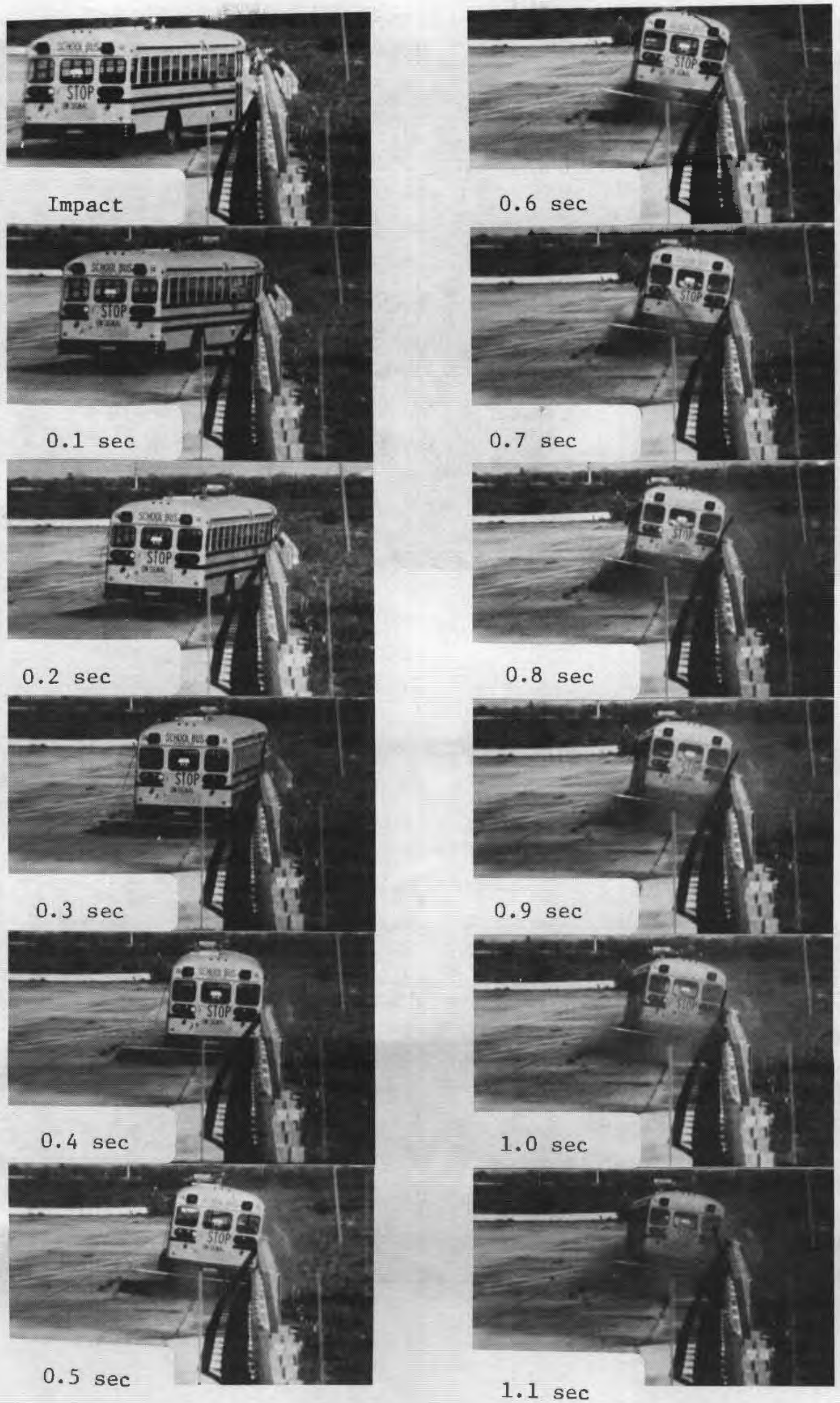


FIGURE 30. TTR-3 IMPACT SEQUENCE

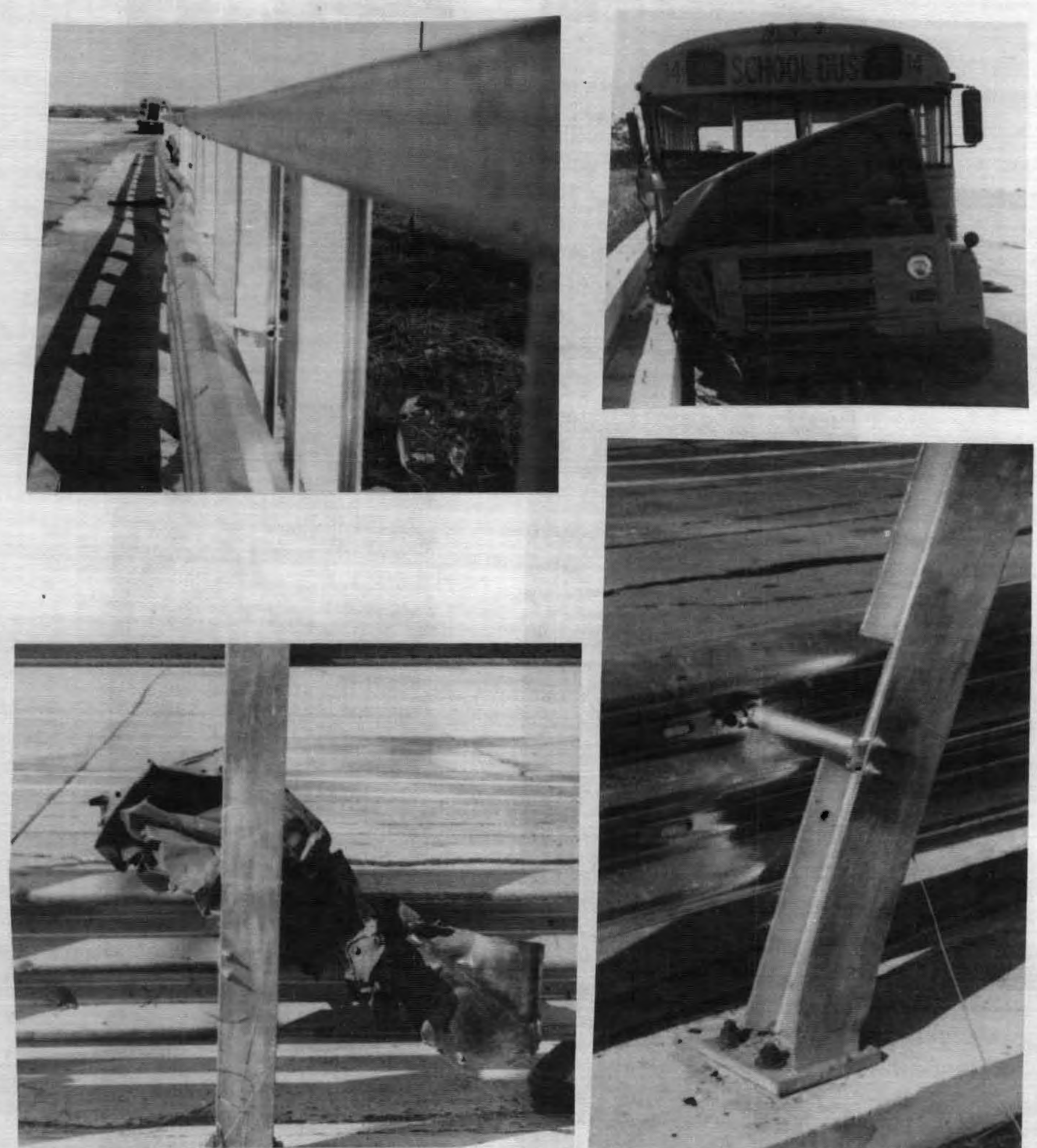
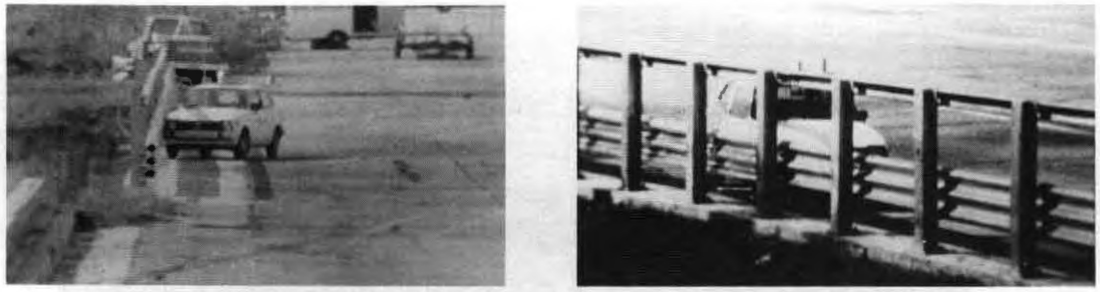
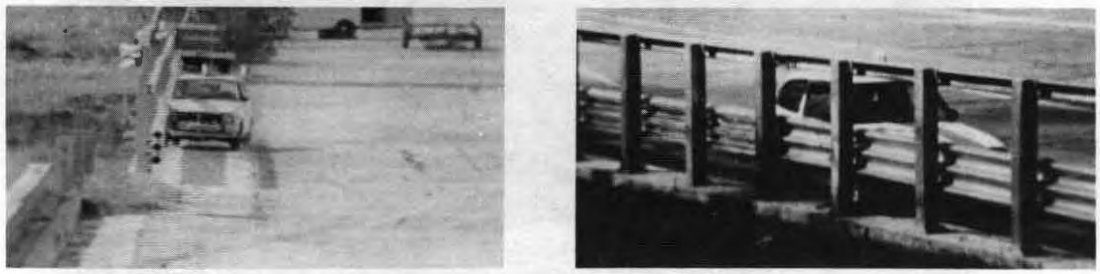


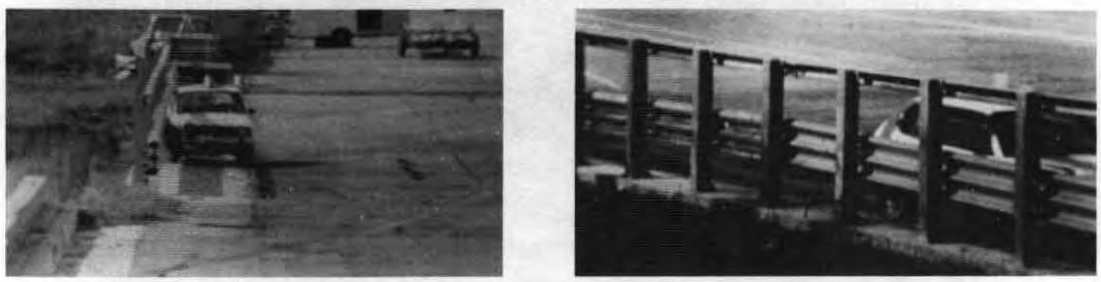
FIGURE 31. PHOTOGRAPHS AFTER TEST TTR-3



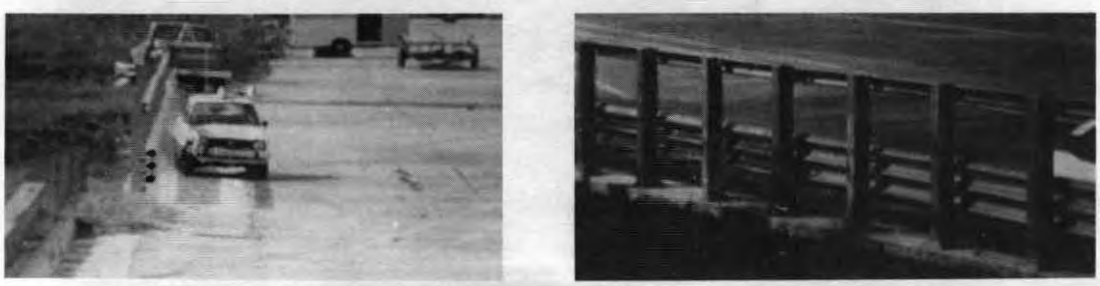
Impact



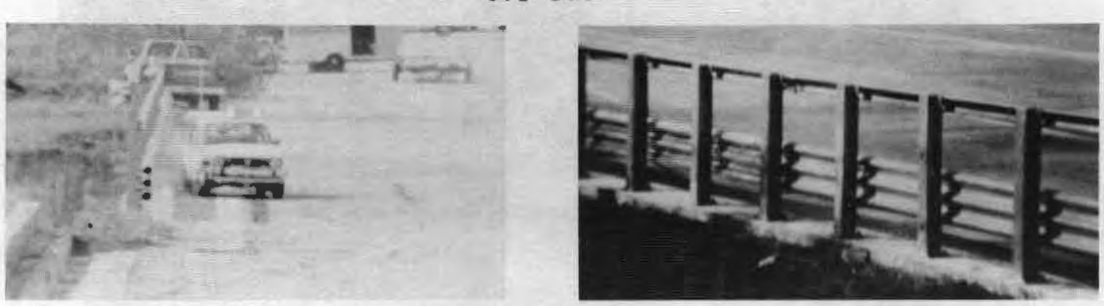
0.1 sec



0.2 sec



0.3 sec



0.4 sec

FIGURE 32. TEST TTR-4 IMPACT SEQUENCE

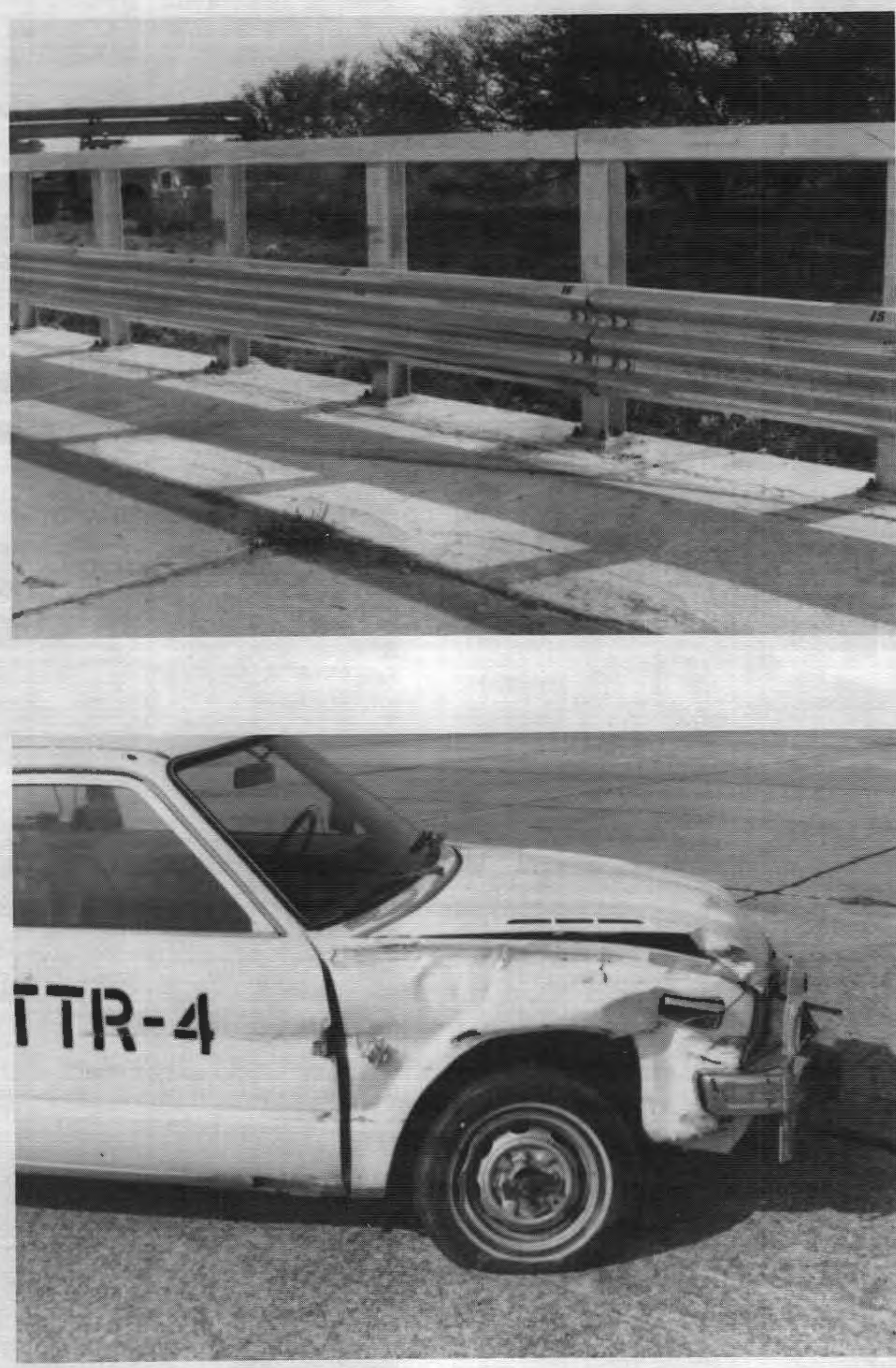


FIGURE 33. PHOTOGRAPHS AFTER TEST TTR-4

and 34. The upper railing was carried full height beyond the structure for five post spans and tapered down and back behind the lower railing as shown. The self-restoring hinges were installed on intermittent W6x15.5 posts; otherwise details were the same as described on Sheet #7 of Figure 14.

Test TTR-5. Based on the computer simulations summarized in Table 4, the critical impact location was determined to be 10 to 15 ft (2.5 m to 4.6 m) upstream of the end bridge post. This is based on the barrier deflection and possible involvement of the bus with the leading through truss member.

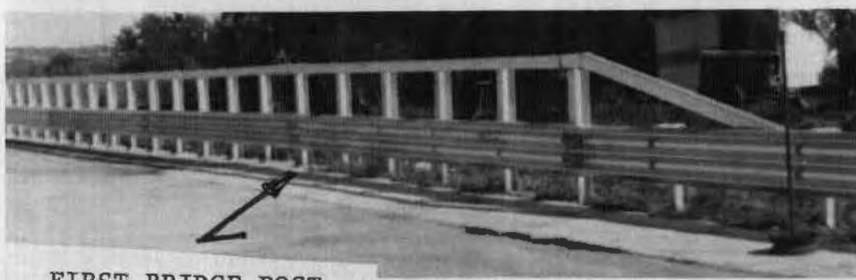
The 20,000-lb (9070-kg) bus impacted the transition at the third post from the bridge deck 15 ft (4.6 m) upstream of the bridge end at 59.6 mph (95.9 kmph) and a 15.9-deg angle. As shown in Figure 35, the bus pitched upward as it rolled toward the barrier (maximum roll angle - 15 deg) while being redirected, and then returned to an upright position. During the impact the right front wheel was pushed rearward by the lower rail, causing suspension failure, and forced the entire front axle to rotate about a vertical axis. As the bus lost barrier contact, the front dropped down onto the right front wheel similar to Test TTR-3 and slid 90 ft (27 m) past the end of the installation. A secondary collision with another barrier downstream caused additional front end damage.

Damage to the barrier consisted of two upper and lower beam sections and two bridge posts. There was some concrete fracturing at the two bridge posts. The soil-mounted posts were displaced in the soil, but were essentially undamaged. The bus sustained front suspension and steering linkage damage sufficient to totally dislodge the front axle from its mounting. The barrier deflection was significant, but in an acceptable range regarding intrusion into a leading truss member location. Photographs after the test are shown in Figure 36.

Test TTR-6. The purpose of this test was to evaluate the typical bridge rail performance with a 2250-lb (1020-kg) compact at 60 mph (95 kmph) and 15 deg which was the standard impact severity test according to TRB Circular 191.(6)

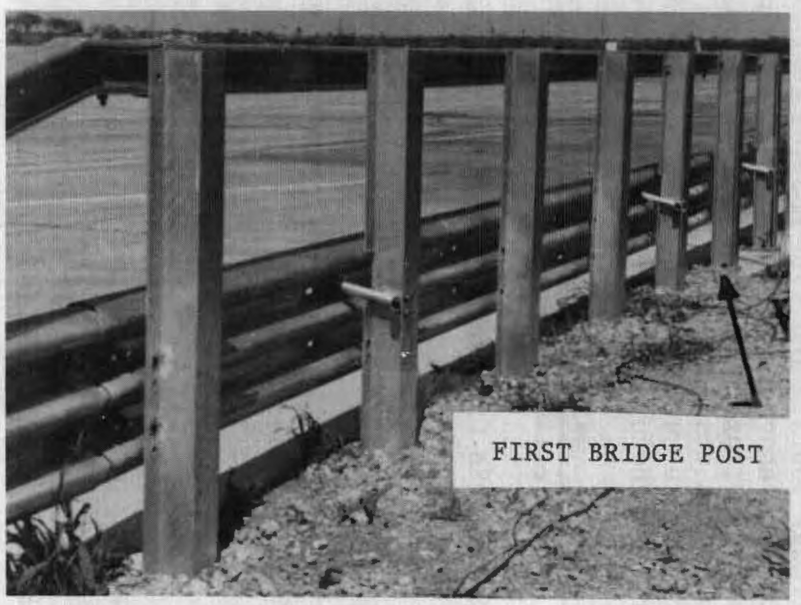
The 2250-lb (1020-kg) vehicle impacted the barrier at 58.8 mph (94.7 kmph) and an angle of 15.4 deg. As shown in Figure 37, the vehicle was smoothly redirected with maximum 50-msec average accelerations of -2.5 (film) and -4.1 g's (accelerometer) in longitudinal direction and 6.1 (film) and 4.2 g's (accelerometer) in the lateral direction. Damage to the barrier was negligible and the vehicle sustained only moderate damage as shown in Figure 38.

Test TTR-7. The purpose of this test was to evaluate the self-restoring retrofit for the structural adequacy test criteria of TRB Circular 191. The 4441-lb (2014-kg) vehicle impacted the barrier at 58.3 mph (93.9 kmph) and a 27.1-deg angle. The vehicle was being redirected smoothly until the undeformed hood slid over the top of the lower beam and snagged on a post as shown in Figure 39. A portion of the hood penetrated through the windshield prior to the complete severing of the hood from the hinges.



(a) Approach Guardrail and Bridge Rail

(b) Thrie Beam/W Beam Transition



(c) Approach Guardrail

(d) Upper Beam Termination

FIGURE 34. HIGH PERFORMANCE RETROFIT APPROACH GUARDRAIL

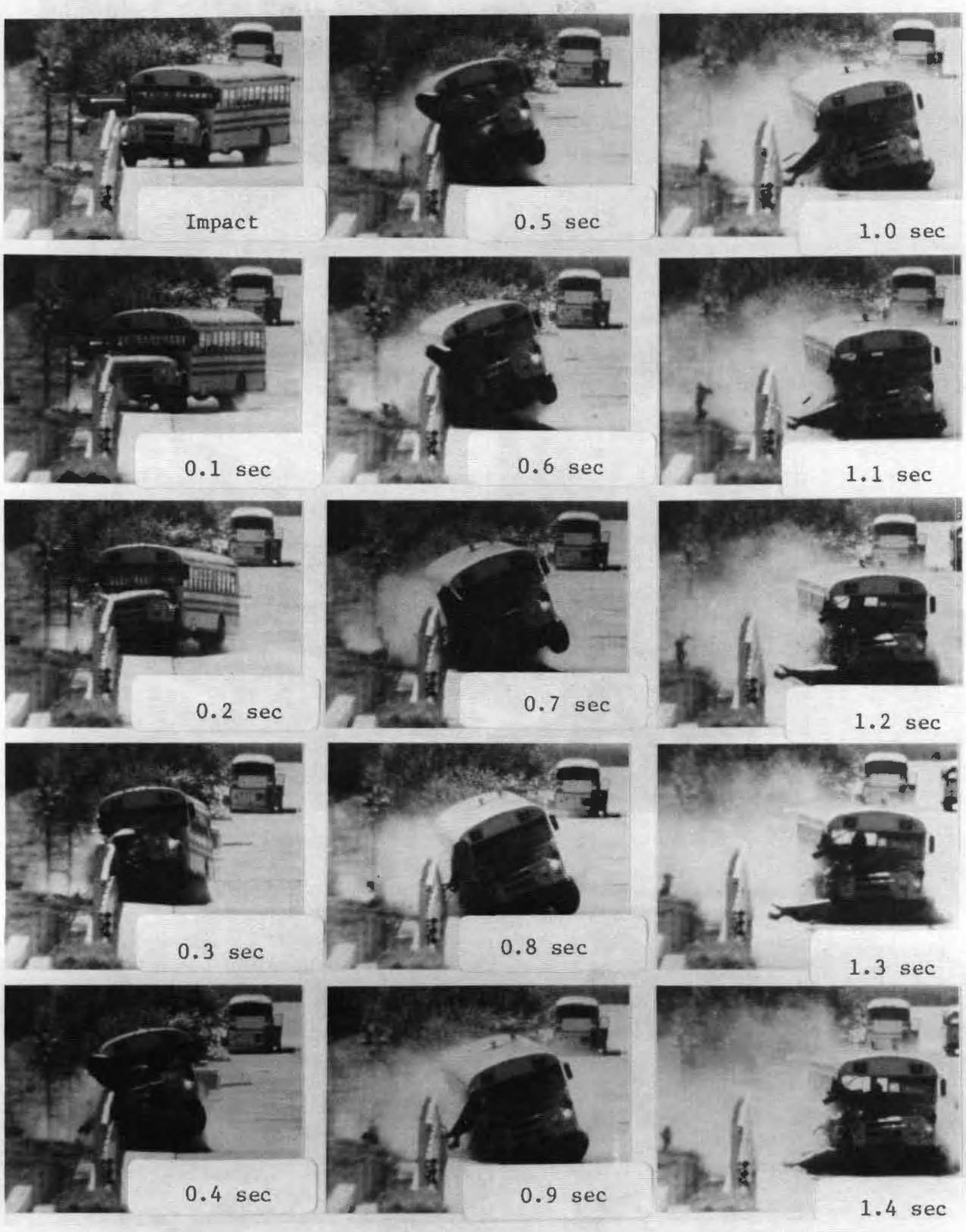


FIGURE 35. TEST TTR-5 IMPACT SEQUENCE

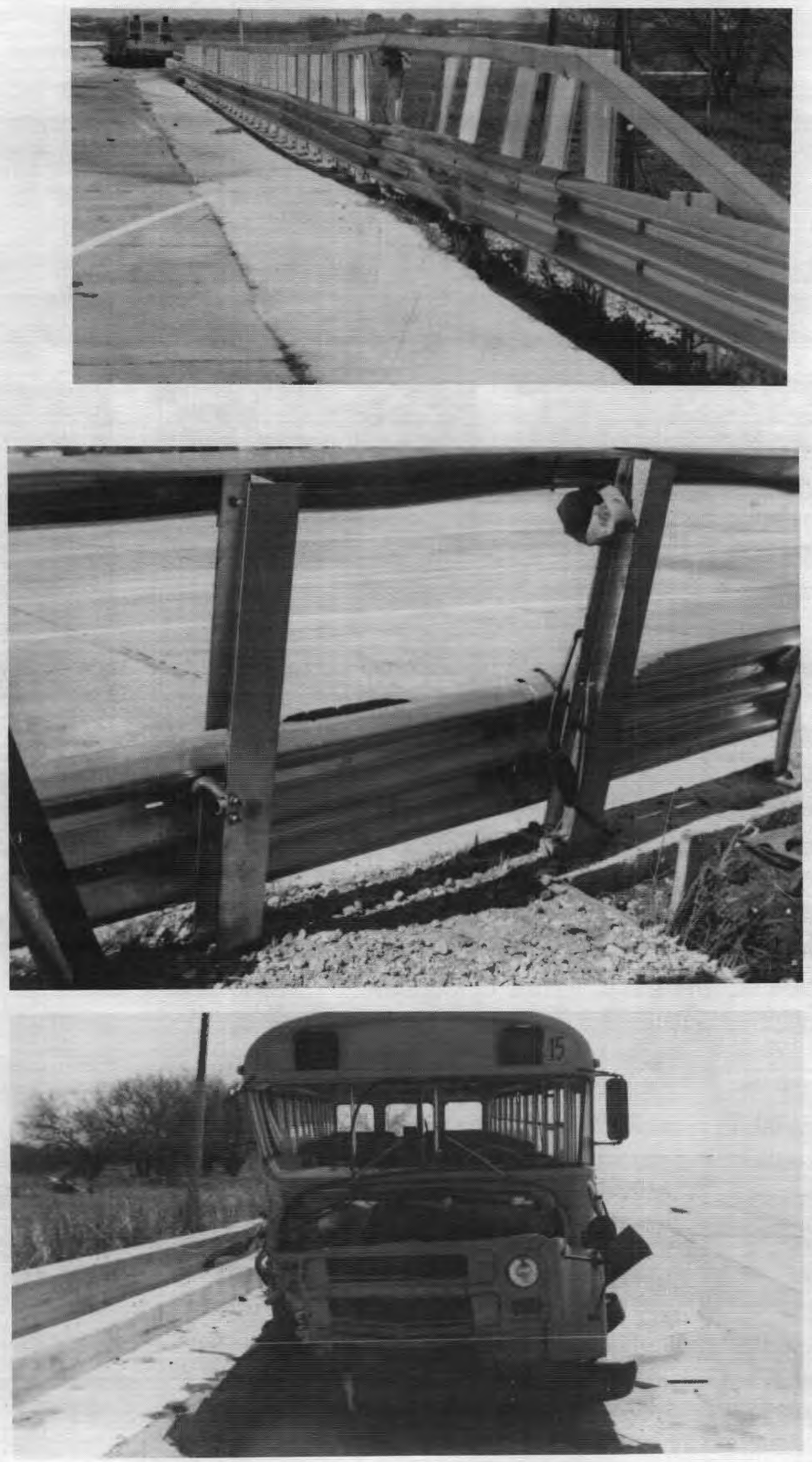
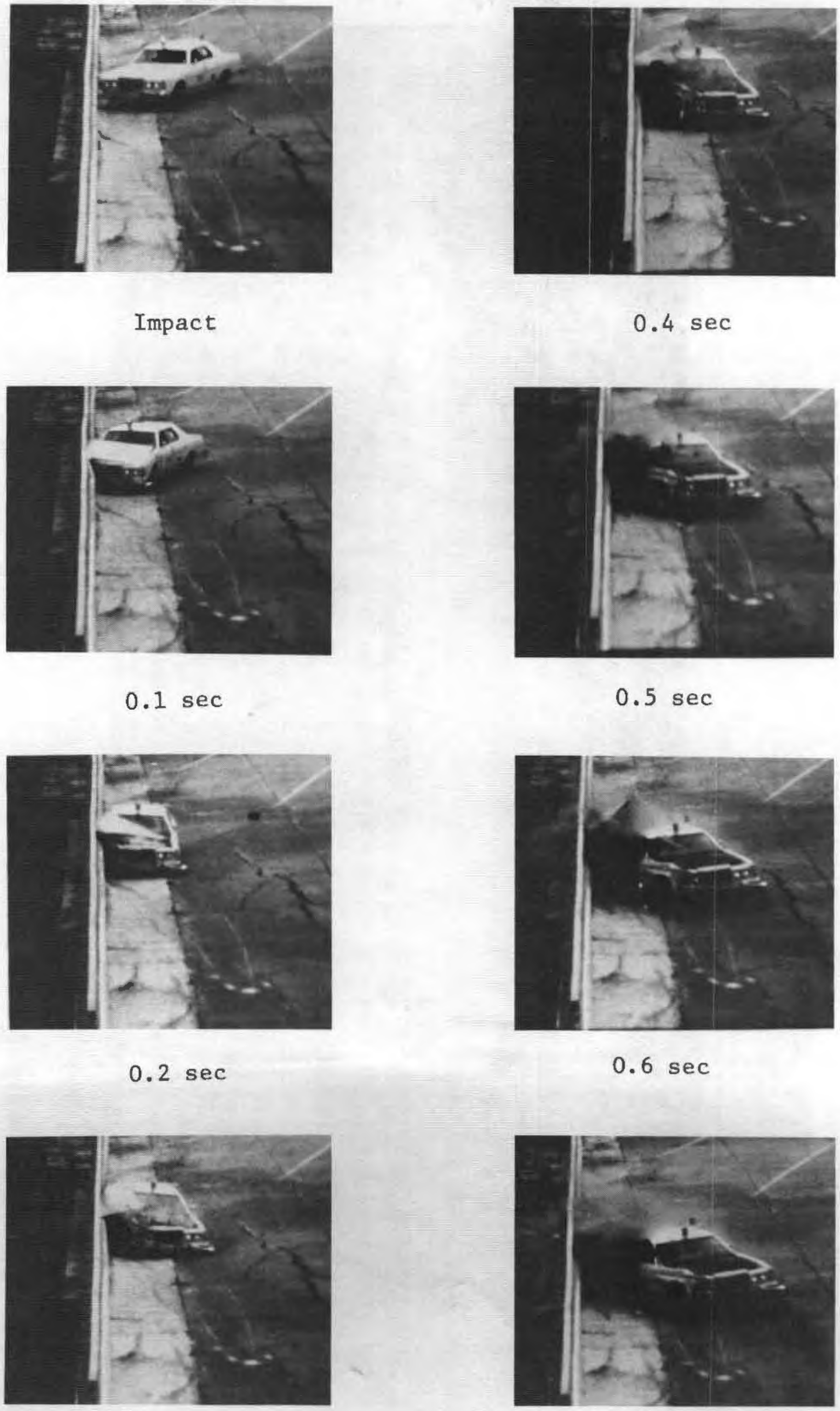


FIGURE 36. PHOTOGRAPHS AFTER TTR-5



Impact

0.4 sec

0.1 sec

0.5 sec

0.2 sec

0.6 sec

0.3 sec

0.7 sec

FIGURE 37. TEST TTR-6 SEQUENTIAL PHOTOGRAPHS

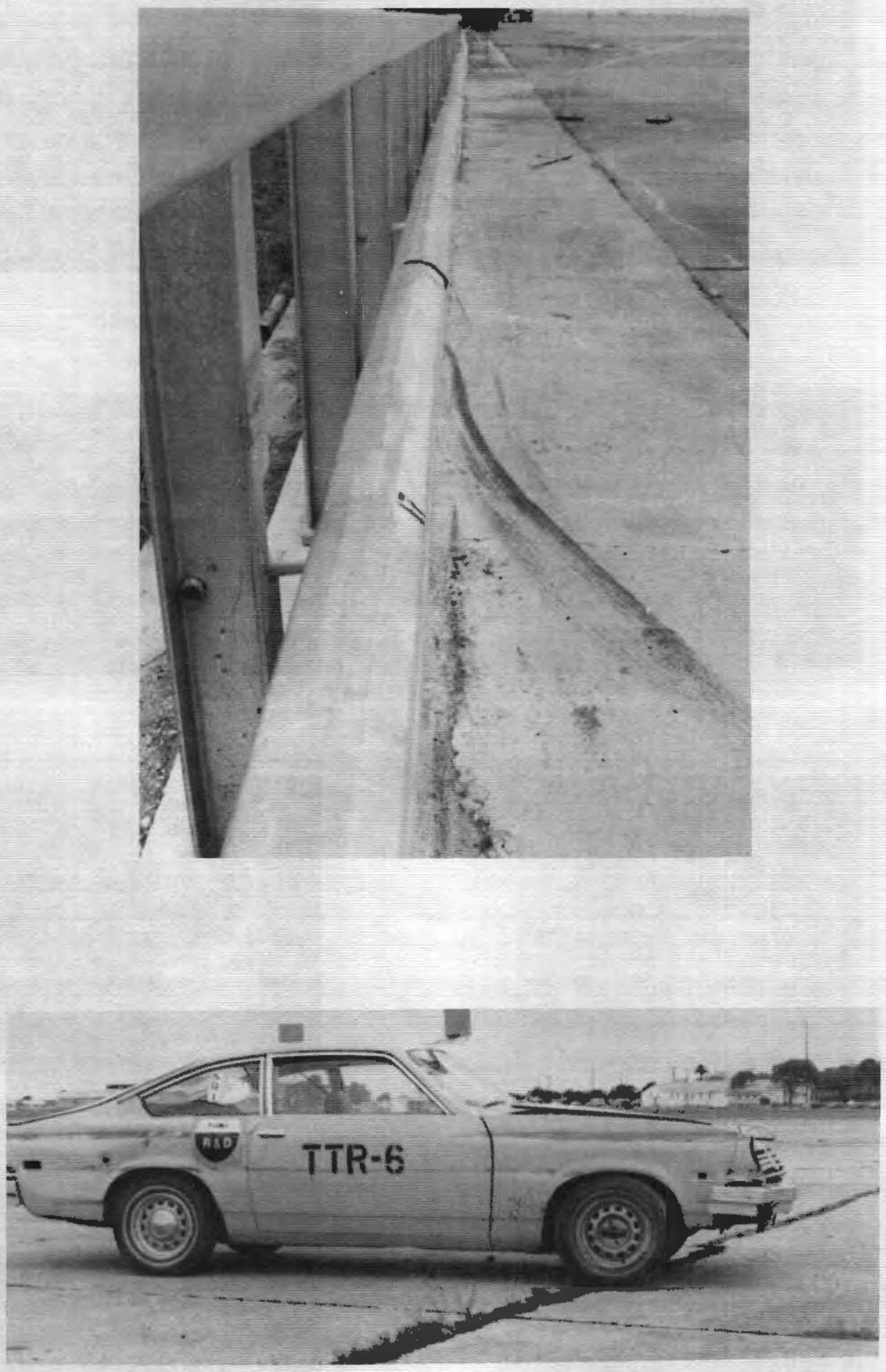


FIGURE 38. PHOTOGRAPHS AFTER TTR-6

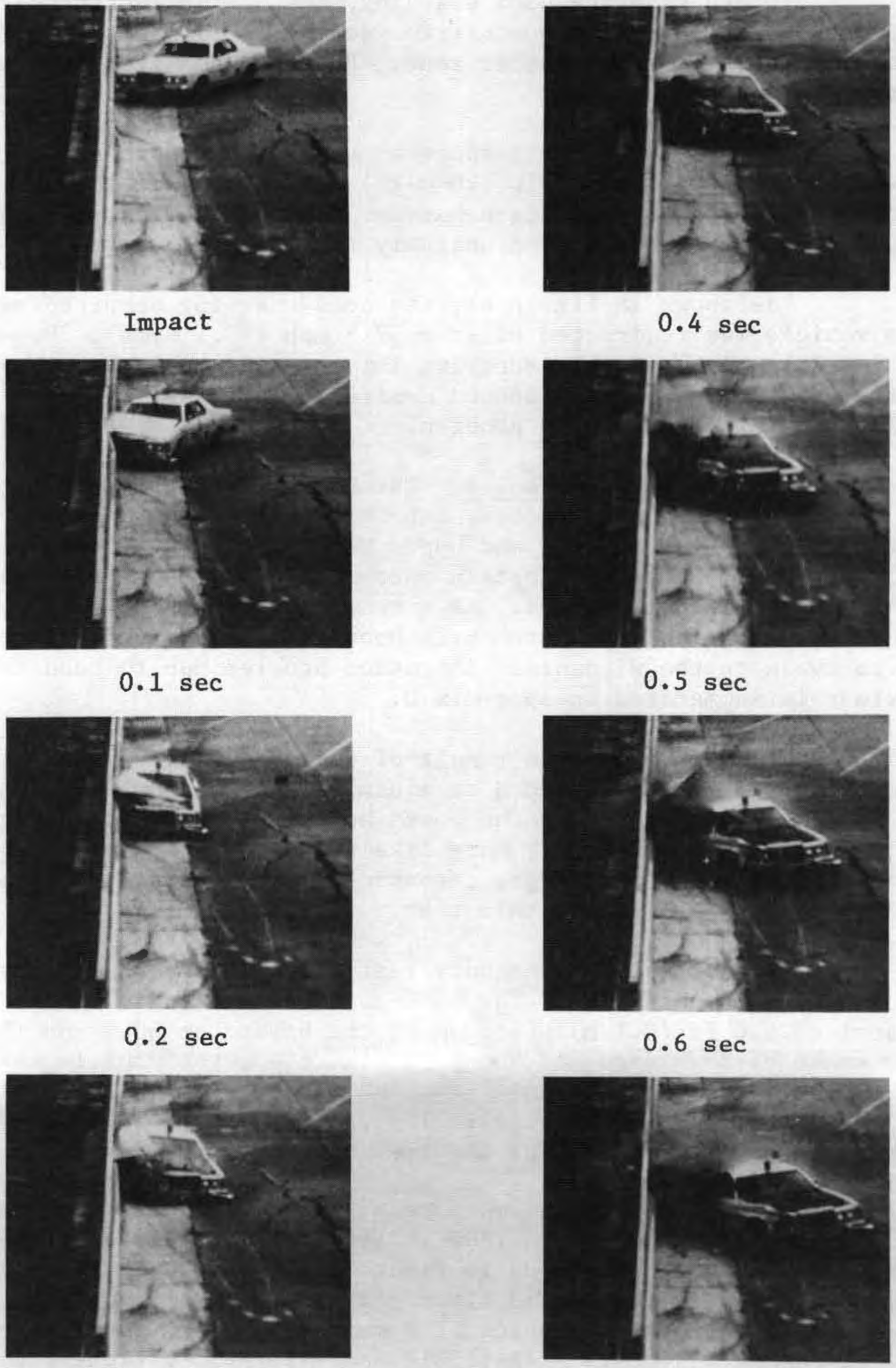


FIGURE 39. TEST TTR-7 SEQUENTIAL PHOTOGRAPHS

Other than the hood snagging, the barrier performed in an acceptable manner. The maximum barrier deflection was not sufficient to encroach into the truss member zone. Photographs after the test are shown in Figure 40.

Test TTR-8. The purpose of this test was to evaluate the bridge approach for the 4500-lb (2040-kg) car structural adequacy test. Due to the more flexible approach barrier characteristics, the hood snagging problem was considered unlikely to reoccur.

As shown in Figure 41, the hood snagging occurred again as the vehicle was redirected after a 57.8 mph (93.1 kmph), 29.6-deg angle impact. Although the excessive impact angle could have been a contributing cause, it was deemed desirable to investigate the hood snagging/windshield intrusion problem.

Hood Snagging Problem. The hood snagging occurrence in Tests TTR-7 and -8 was unexpected, but it is noteworthy because of the significant gap between lower and upper beams, thereby allowing sheet metal portions of buses and certain automobile hoods to snag on the post segment between the beams. As a result of this happening, a limited investigation into automobile hood designs was undertaken in order to evaluate the windshield intrusion problem due to hood contact. This study is summarized in Appendix D.

Test TTR-9. As a result of the hood snagging occurrences previously noted, it was decided to minimize this potential by installing 6-in. (0.2-m) spacers between the posts and beams as shown in Figure 42. Since a 25-deg angle impact is more likely to occur in a wider approach section than on a narrow bridge, the spacers were installed in the approach railing segment for this test.

The structural adequacy test of the approach railing system was repeated with this test. The 4500-lb (2040-kg) vehicle impacted the barrier 26.6 ft (8.1 m) upstream of the bridge at 60.2 mph (96.9 kmph) and an angle of 25.9 deg. As shown in Figure 43, the vehicle was smoothly redirected with no hood snagging evident. The same vehicle, a 1978 Ford LTD, was used in Tests TTR-7, -8, and -9 to insure valid comparisons. Photographs after the test are shown in Figure 44.

Test TTR-10. The purpose of this test was to evaluate the bridge approach design with an 1800-lb (800-kg) minicompact at 60 mph (95 kmph) and 15 deg. As shown in Figure 45, the 1658-lb (752-kg) vehicle was smoothly redirected after striking the barrier at 61.3 mph (98.6 kmph) and a 20.9-deg angle. The maximum 50 msec average vehicle accelerations were 9.4/9.5 g (lateral) and -4.0/-3.4 g (longitudinal) as measured from cine/electronic data.

The self-restoring stage deflected a maximum of 3.5 in. (89 mm) before returning, undamaged, to the original position after the vehicle was redirected. Photographs of the barrier and vehicle after the test are shown in Figure 46.

FIGURE 40. PHOTOGRAPHS AFTER TTR-7

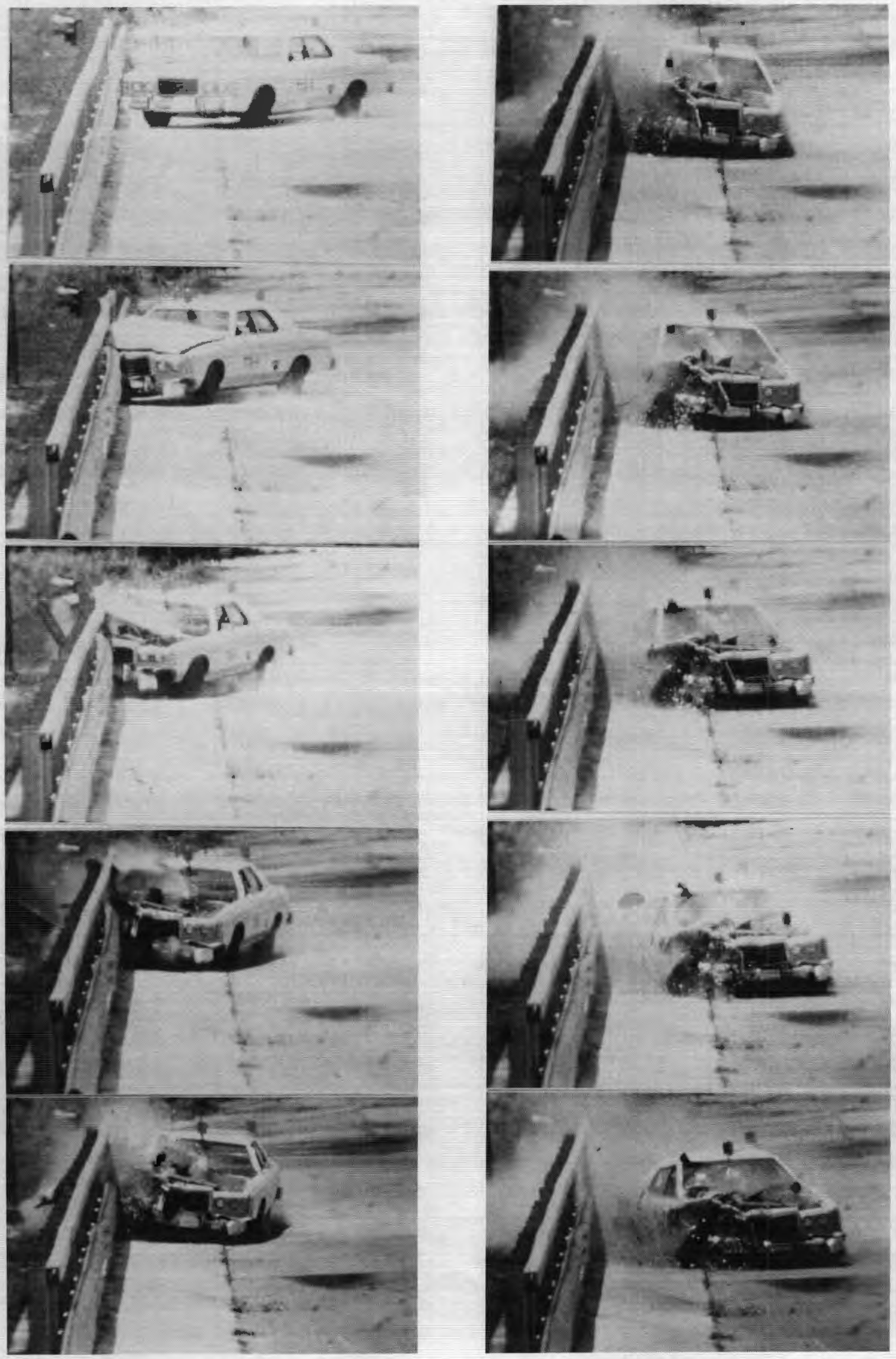


FIGURE 41. TEST TTR-8 SEQUENTIAL PHOTOGRAPHS

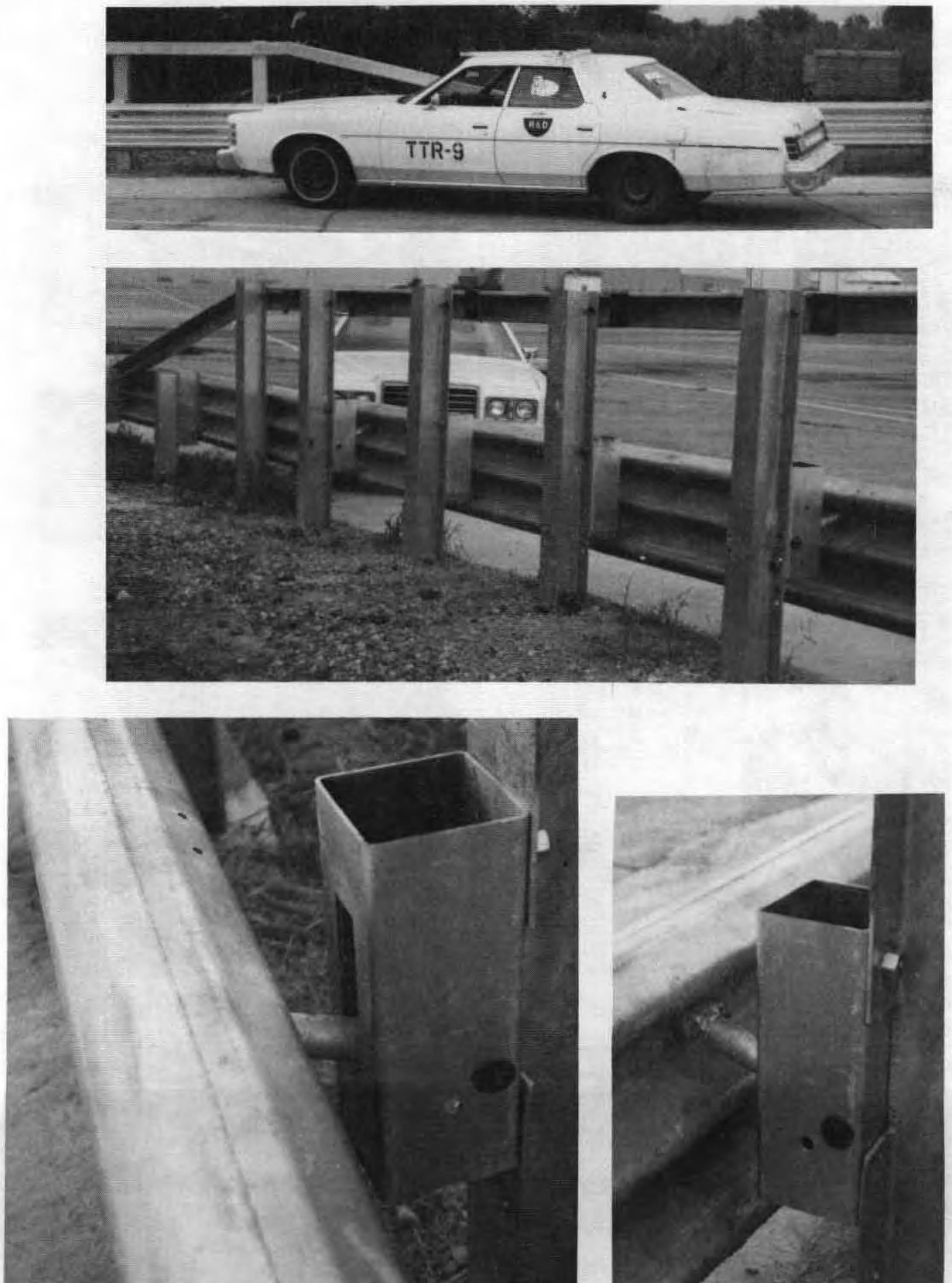


FIGURE 42. MODIFIED APPROACH GUARDRAIL TEST INSTALLATION PHOTOGRAPHS

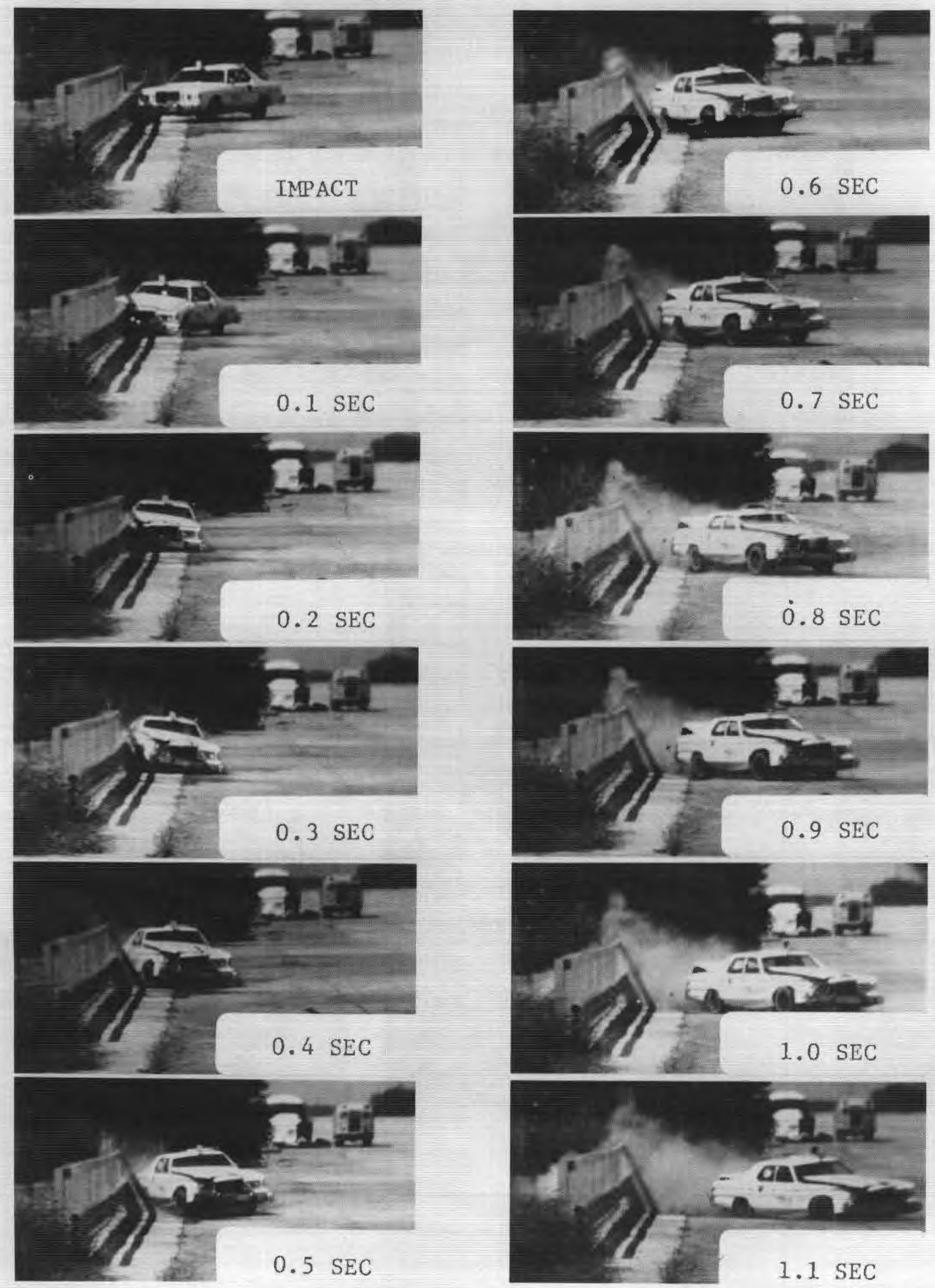


FIGURE 43. TEST TTR-9 IMPACT SEQUENCE

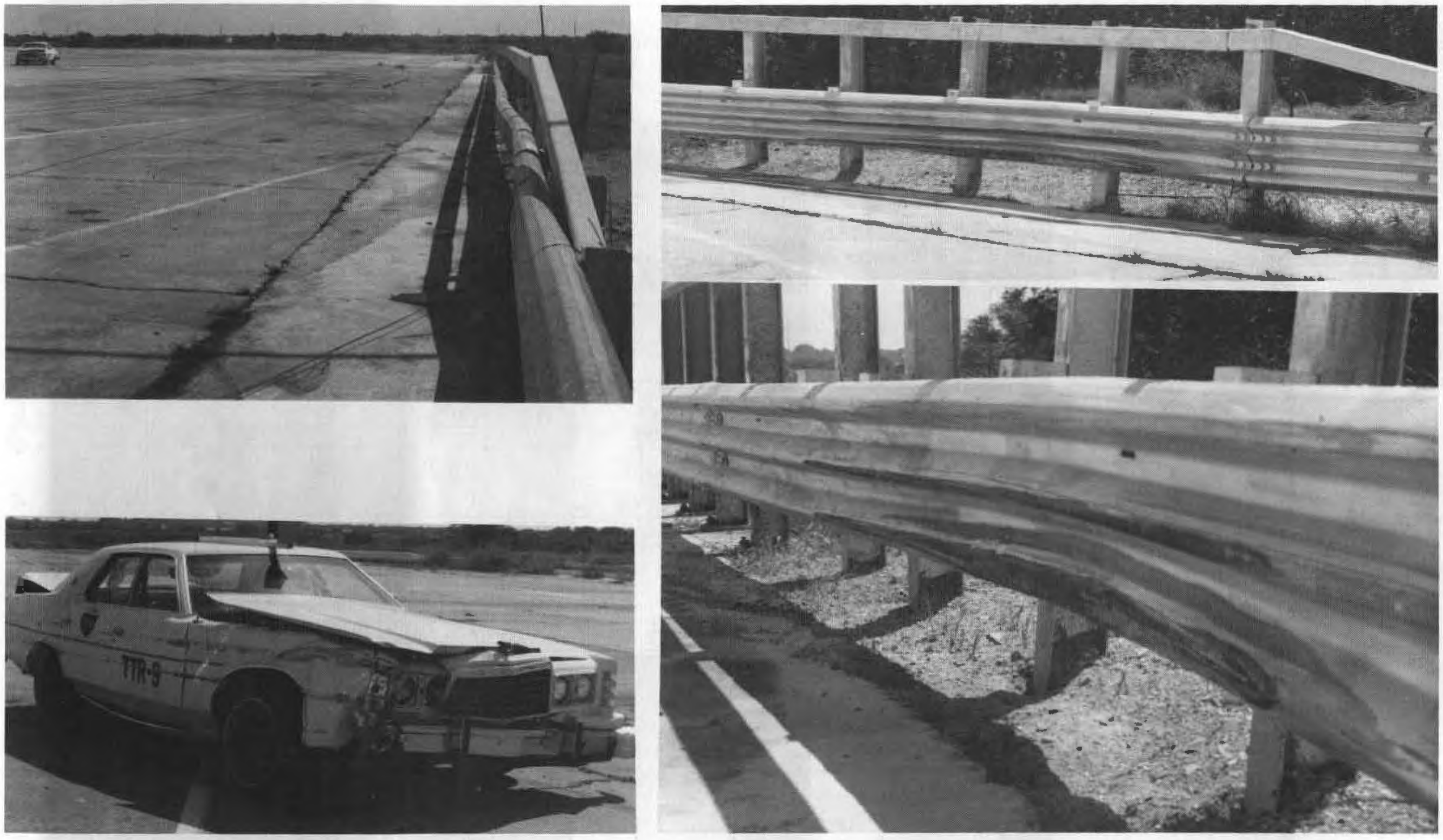


FIGURE 44. PHOTOGRAPHS AFTER TTR-9

IMPACT

0.10 SEC

0.20 SEC

0.30 SEC

0.40 SEC

0.50 SEC

0.60 SEC

0.70 SEC

0.80 SEC

0.90 SEC

FIGURE 45. TEST TTR-10 IMPACT SEQUENCE

FIGURE 46. PHOTOGRAPHS AFTER TTR-10

2. Low Service Retrofit. The wood curb did not perform as desired in Test TTR-11 and since the 8 ft-4 in. (2.5-m) beam span for the single thrie was too large for the impact condition, it was decided to develop a lower service retrofit without a curb. Accordingly, a series of BARRIER VII cases were conducted using a single thrie beam mounted on different combinations of post size and spacing. Based on these results, a design described in Figure 47 was selected for crash test evaluation.

As part of the installation, a readily installed anchor bolt detail was employed. This consisted of drilling into the bridge deck and driving commercially available anchor studs into the holes as shown in Figure 48.

Test TTR-12. The purpose of this test was to evaluate the low service retrofit shown in Figure 49 for the structural adequacy requirements. Due to a malfunction, the test vehicle impacted the barrier at only 49 mph (79 kmph) and a 15-deg angle. Damage to the barrier and vehicle is shown in Figure 50. There was negligible intrusion into the zone behind the posts.

Test TTR-13. This test was a repeat of Test TTR-12. The 4466-lb (2026-kg) vehicle impacted the barrier at 59.3 mph (95.4 kmph) and a 19.1-deg angle. As shown in Figure 51, the vehicle was smoothly redirected, and continued until contacting another barrier installation in-line with the test installation 150 ft (45 m) downstream of the impact. The design goals of the barrier were met; i.e., the maximum deflection beyond the rear post line was 3 in. (75 mm). This maximum deflection at one post was attributed to local buckling due to impact and the pulling of the anchor bolts from the slab for a distance of 0.5 in. (13 mm). A more substantial anchorage (e.g., bolts through the slab) would have prevented much of this deformation.

Damage to the barrier consisted of two rail sections and three posts; vehicle and barrier damage is shown in Figure 52.

Test TTR-14. The purpose of this test was to evaluate the low service retrofit shown in Figure 49 for the occupant risk impact conditions of NCHRP Report 230. The 1751-lb (794-kg) vehicle impacted the barrier at 60.9 mph (98.0 kmph) and a 19.9-deg angle as shown in Figure 53. The force of the impact on the right front wheel caused wheel rotation about an axis parallel to the roll axis. This allowed the wheel to intrude under the rail sufficient to snag on two of the posts. The bumper behavior of the 1979 Honda was different than observed with previous tests. Vehicle and barrier damage are shown in Figure 54.

Test TTR-15. Test TTR-15 was conducted to achieve an impact angle closer to the target 15-deg angle. The wheel snagging observed in TTR-14 was attributed to the near 20-deg angle and the difference in bumper design beginning in 1978 with the Honda Civic.

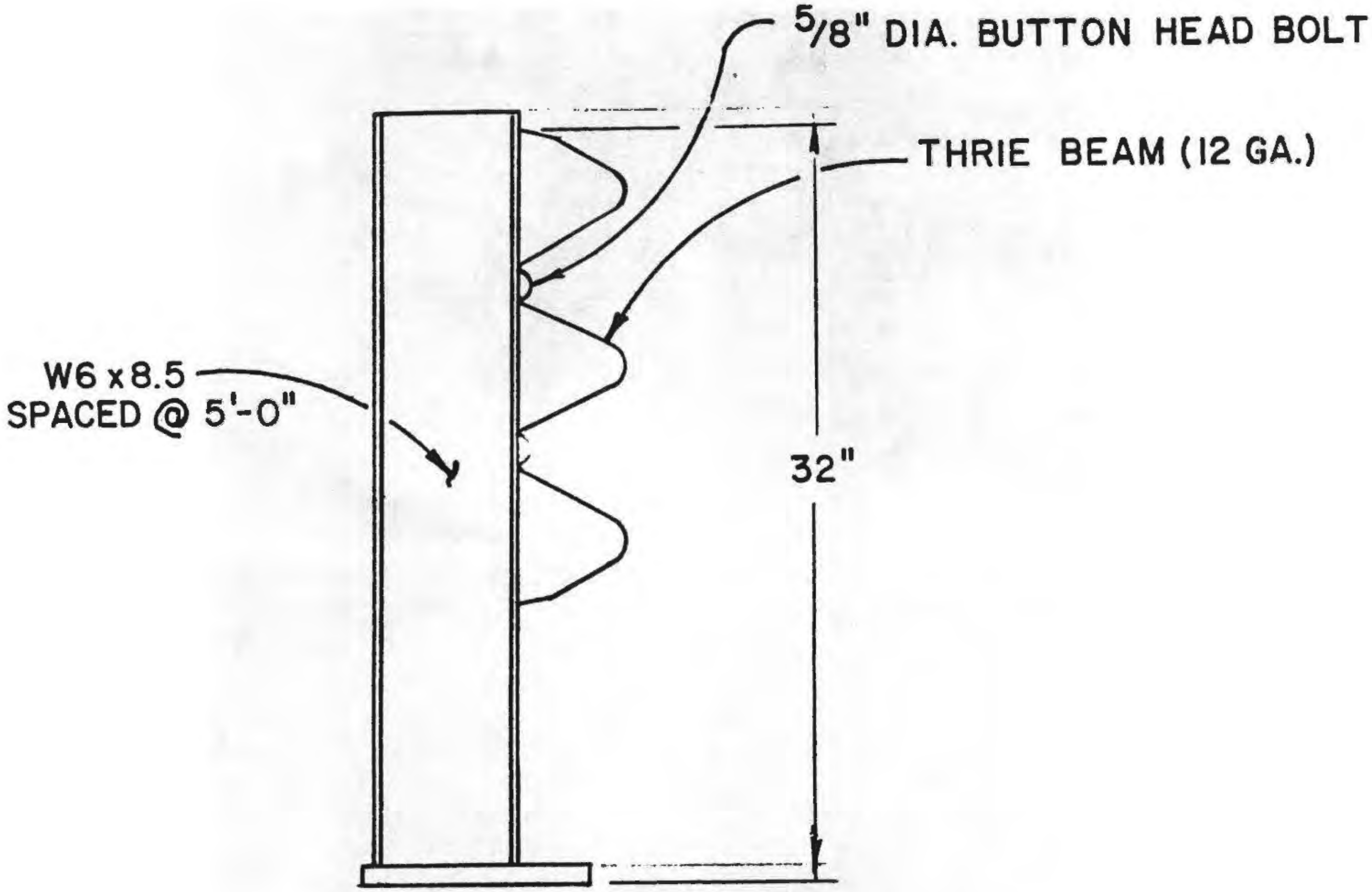
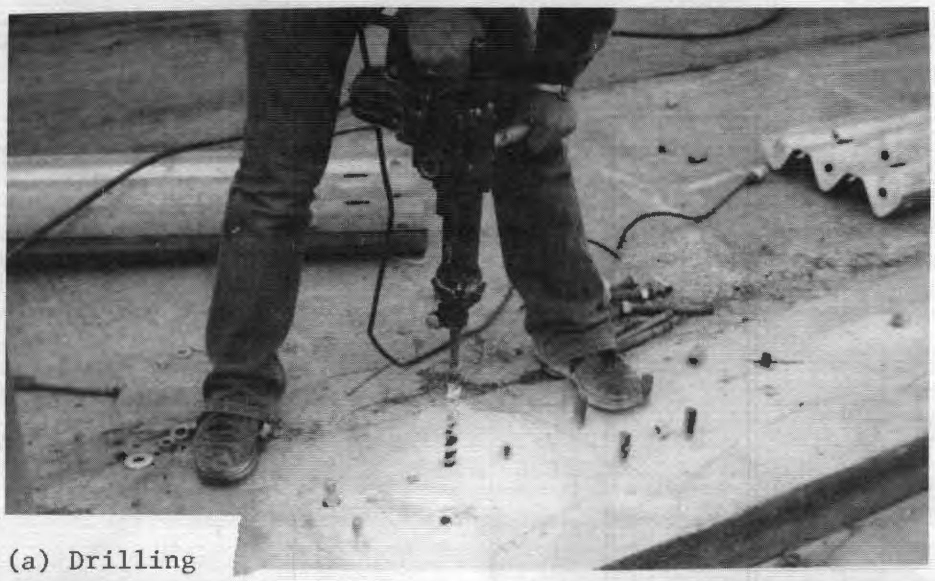
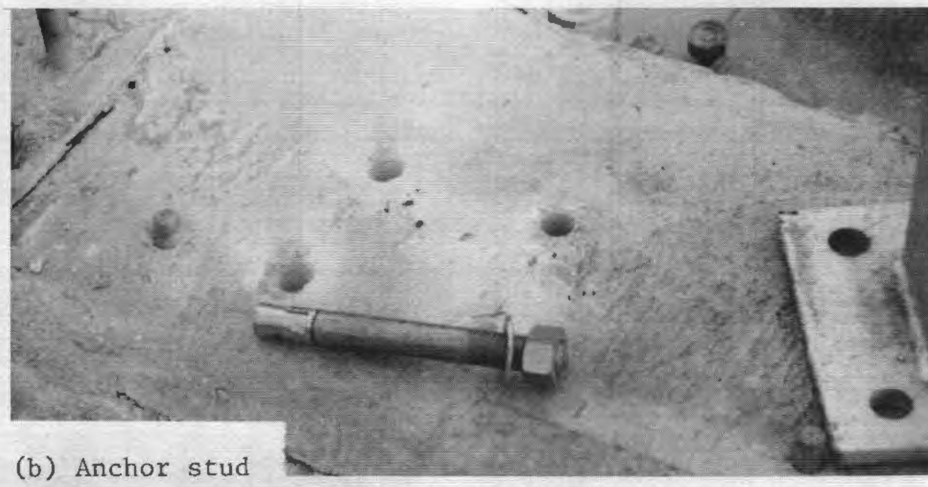


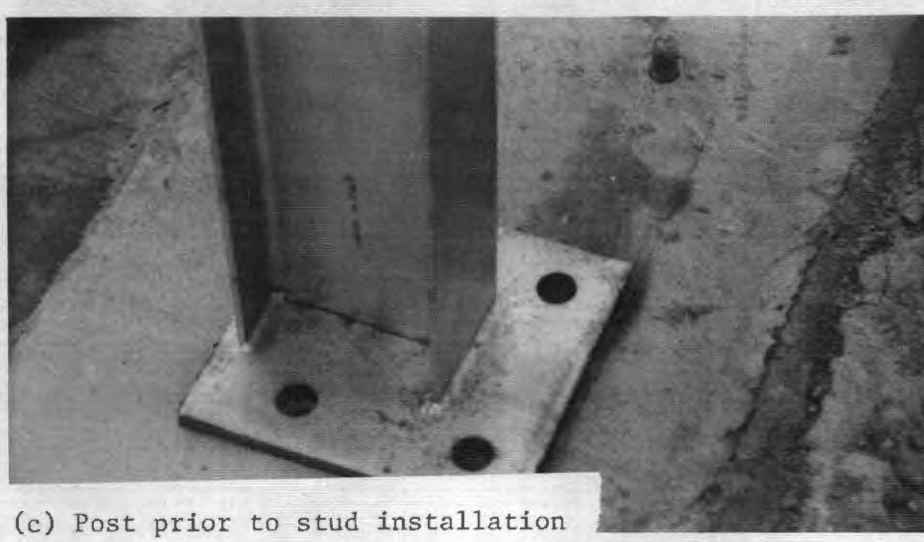
FIGURE 47. MODIFIED LOW SERVICE RETROFIT



(a) Drilling



(b) Anchor stud



(c) Post prior to stud installation

FIGURE 48. ANCHOR STUD INSTALLATION

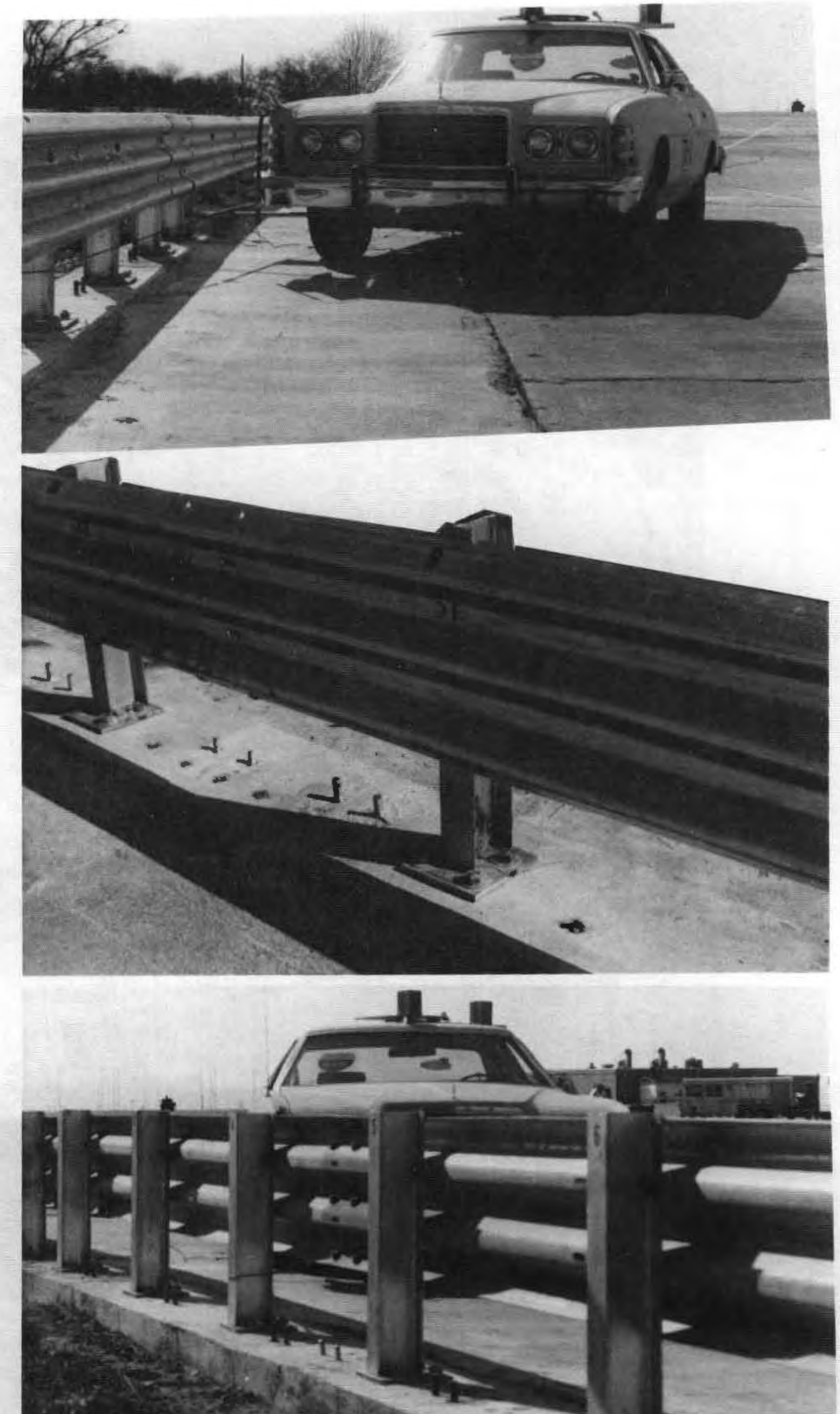


FIGURE 49. LOW SERVICE RETROFIT TEST INSTALLATION PHOTOGRAPHS

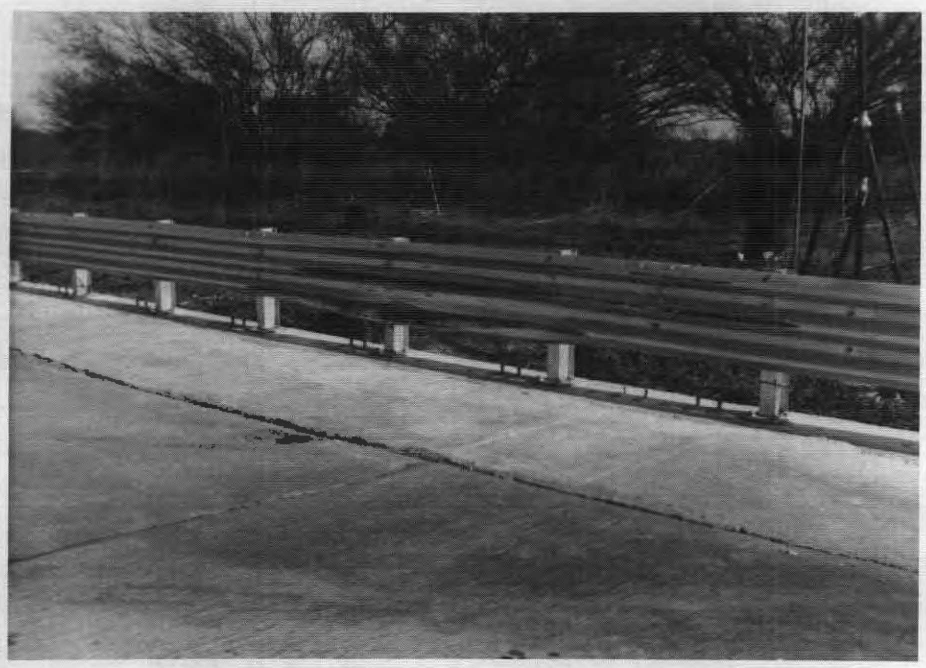


FIGURE 50. PHOTOGRAPHS AFTER TTR-12

Impact

0.05 sec

0.10 sec

0.15 sec

0.20 sec

0.25 sec

0.30 sec

0.35 sec

0.40 sec

0.50 sec

0.60 sec

0.70 sec

FIGURE 51. TEST TTR-13 IMPACT SEQUENCE

FIGURE 52. PHOTOGRAPHS AFTER TEST TTR-13

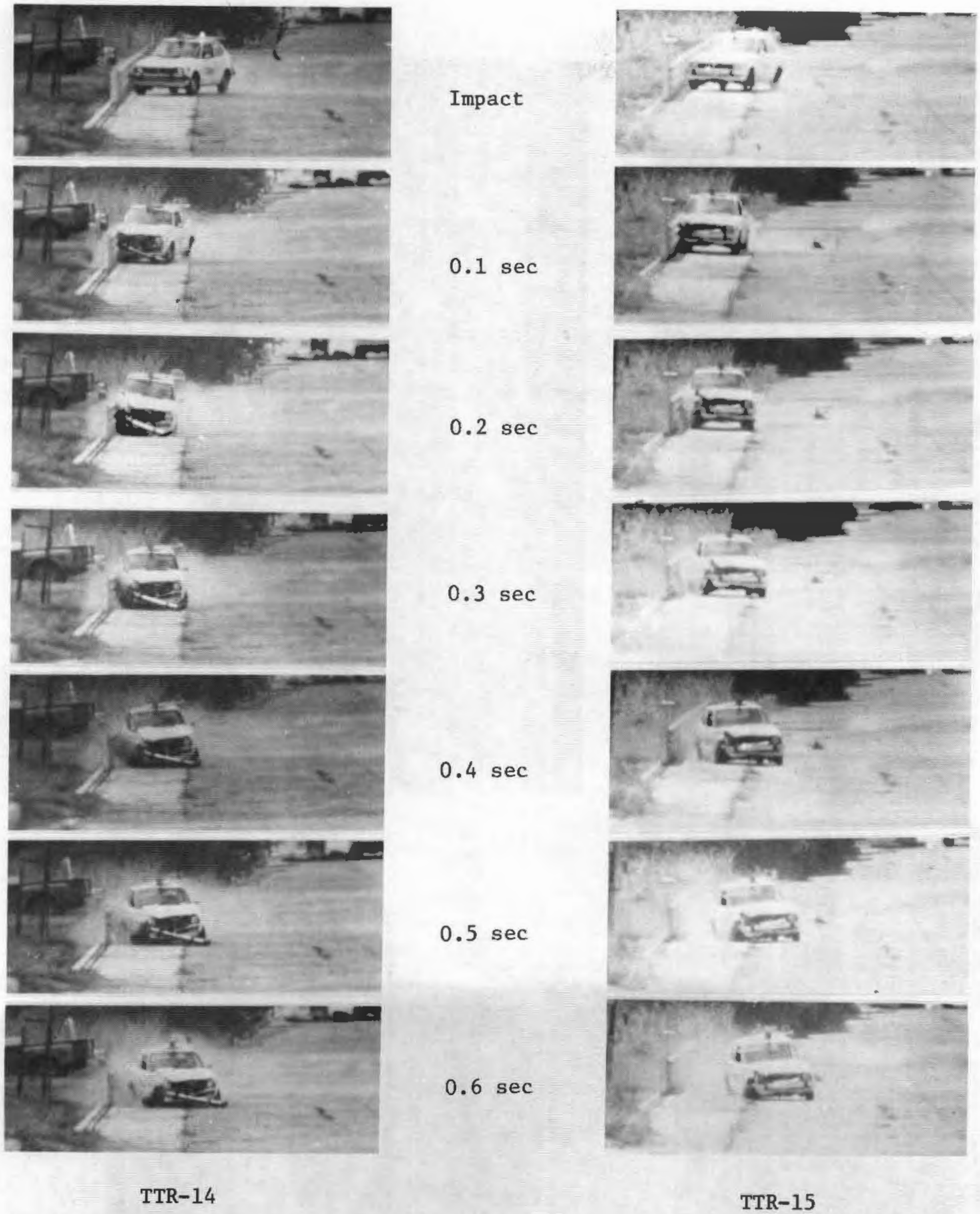
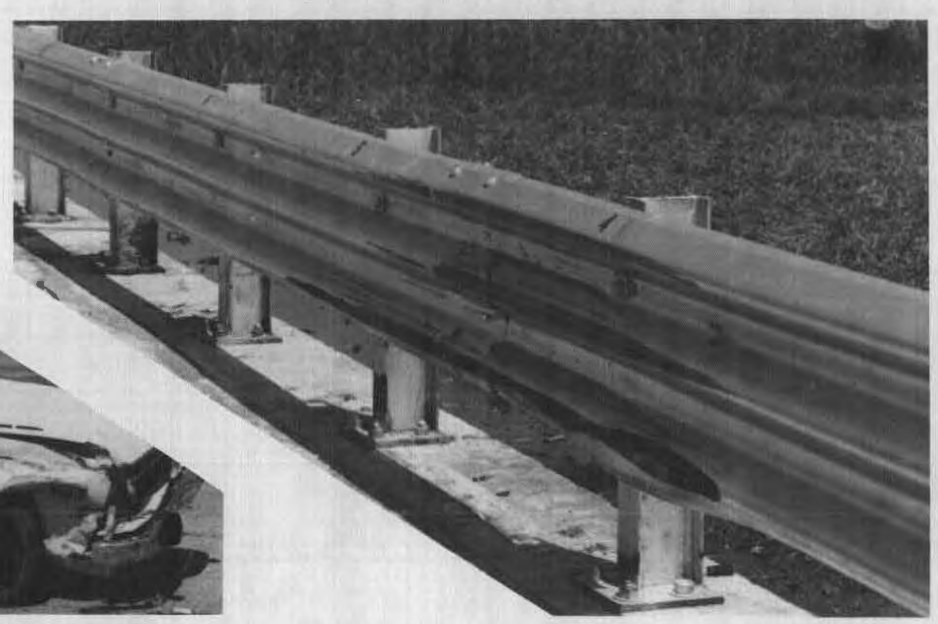


FIGURE 53. TEST TTR-14 AND TTR-15 SEQUENTIAL PHOTOGRAPHS

(a) Post 5, TTR-14

(b) TTR-14 test vehicle

(c) TTR-15 test vehicle



(d) Impact area, Test TTR-15

FIGURE 54. PHOTOGRAPHS AFTER TESTS TTR-14 AND TTR-15

The 1750-lb (794-kg) test vehicle impacted the installation at 57.9 mph (93.2 kmph) and an angle of 16.9 deg as shown in Figure 53. Redirection of the vehicle was smooth with dynamic deflection of less than 1 in. (25 mm). The damage sustained by the system was so minor that it did not have to be repaired.

CHAPTER THREE

DISCUSSION AND APPLICATION OF FINDINGS

A. Discussion

The findings of the project included the systematic design and development of two unique bridge rail retrofit systems for narrow through truss applications. Design criteria were developed according to the rationale described in the previous chapter; the systems were evaluated according to these criteria. The two different levels of service provide potential users with alternative designs and expenditures to match site requirements. Cost estimates are given in the next section. Throughout the design and development effort of this project, certain problem areas were evident. These are discussed in item 2 below.

1. Retrofit Systems Evaluation. A summary of the crash tests conducted in the project is presented in Table 5. Although the rigid requirements of these barriers may preclude conformance with impact severity criteria, comparisons to the TRB Circular 191 criteria are made. The new NCHRP Report 230[7] criteria was not in effect during much of the project, and thus the reduced data format is not amenable to such comparisons. With the multiple service level approach, the structural adequacy test differs from TRB Circular 191. For the high performance retrofit, this test condition specified a 20,000-lb (9000-kg) bus impacting at 55 mph (90 kmph) and a 15-deg angle. In addition, both deflection and vehicle roll requirements were part of the acceptance criteria due to the uniqueness of the through truss. For the lower service retrofit, the structural adequacy test condition was specified by a 4500-lb (2000-kg) car impacting at 60 mph (96.6 kmph) and a 15-deg angle. Again, deflection into the truss member zone was the critical evaluation criteria; roll of the barrier over the thrie beam rail of this system is not a problem with passenger cars.

Based upon the results of the project, both finalized retrofit designs meet the design criteria of this project.

2. Problem Areas. Due to the uniqueness of the barriers developed in this project, there were several problem areas observed including certain vehicle factor problems relating to the opening between upper and lower rails, and bridge rail post anchorage problems.

Vehicle Factors. Crashworthiness of school bus suspension and steering assemblies are considered deficient for the severity of impacts in this project. The rigid railing criteria made the destruction of these assemblies during the 55 mph (90 kmph), 15-deg angle impacts inevitable.

The particular 4500-lb (2000-kg) sedan selected for crash testing in this project had a unique hood design that made snagging of posts more probable than other designs as illustrated in Figure 55.

TABLE 5

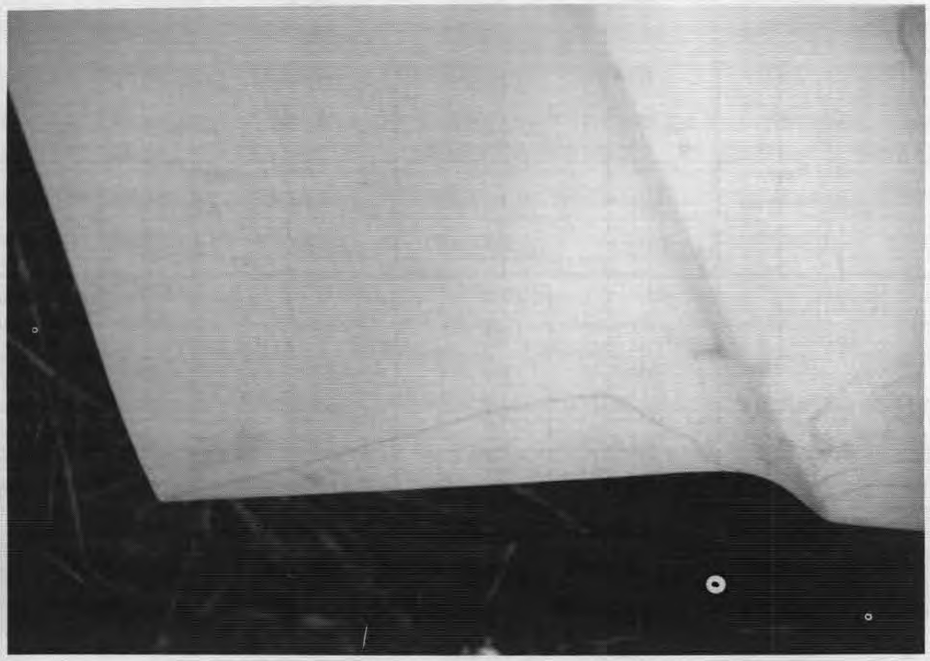
SUMMARY OF VEHICLE CRASH TESTS

Test No.	Barrier Description*	Vehicle	Vehicle Weight Including Ballast (lb)	Ballast Added (lb)	Impact Speed (mph)	Impact Angle (deg)	Vehicle Accelerations Cine/Electronic 50msec avg Lat(g's)	Long(g's)	Max Roll Angle+ (deg)	Max Dynamic Defl (in.)	Max Encroachment++ (in.)	Remarks
TTR-1	HP#1	1966 IH/ Wayne 72-pass.	20,000	6,200	55.2	13.7	3.0/-	-1.3/-	20/90	24.7	20.0	Extensive vehicle front end damage - vehicle rolled on side after losing rail contact; concrete deck failure contributed to defl.
TTR-2	HP#2	1966 IH/ Superior 72-pass.	20,000	6,600	56.1	17.8	3.3/4.0	-3.0/-1.5	12.5/90	8.6	6.2	Extensive front end damage - vehicle rolled on side after losing barrier contact.
TTR-3	HP#3	1969 Chevy/ Bluebird 66-pass.	20,000	6,000	53.9	15.3	2.3/3.5	-1.9/1.3	10.7/10.7	7.8	6.0	Extensive vehicle damage, but design goals met with smooth redirection at shallow exit angle.
TTR-4	HP#3	1976 Honda Civic	1,840	**	59.8	14.8	7.8/8.1	-3.0/-2.1	n/m	3.0	0	Smooth redirection.
TTR-5	HPAR	1969 Chevy/ Bluebird 66-pass.	20,000	6,000	59.6	15.9	1.7/5.6	-2.5/-3.8	15/15	27.8	5.0	Vehicle redirected with some sheet metal snagging at opening between rails.
TTR-6	HP#3	1974 Chevy Vega	2,250	**	58.8	15.4	6.1/4.2	-2.5/-4.1	n/m	5.1	0	Vehicle smoothly redirected.
TTR-7	HP#3	1978 Ford LTD	4,441	**	58.3	27.1	8.1/10.4	-5.1/-9.5	n/m	6.0	0	Vehicle redirected, but hood snagging on post between rail opening caused windshield penetration.
TTR-8	HPAR	1978 Ford LTD	4,500	**	57.8	29.6	6.2/-	-9.3/-	n/m	10.4	10.0	Vehicle hood snagged as in Test TTR-7.
TTR-9	HPAR(B.O.)	1978 Ford LTD	4,500	**	60.2	25.9	7.8/9.0	-4.8/-4.2	n/m	6.0	2.0	Blocked out rail effective in preventing hood snagging.
TTR-10	HPAR(B.O.)	1975 Honda Civic	1,658	**	61.3	20.9	9.4/9.5	-4.0/-3.4	n/m	3.5	0	Smooth redirection
TTR-11	LS#1	1975 Ford LTD	4,588	**	61.7	18.4	6.0/11.0	-3.5/-3.5	n/m	9.0	5.5	Excessive deformation between posts and at one post.
TTR-12	LS#2	1978 Ford LTD	4,466	**	49.0	15.0	-	-	n/m	-	-	Inadequate test speed.
TTR-13	LS#2	1978 Ford LTD	4,466	**	59.3	19.1	7.2/6.6	-4.1/4.1	n/m	3.6	3.0	Vehicle smoothly redirected; design goals met.
TTR-14	LS#2	1979 Honda Civic	1,751	**	60.9	19.9	8.7/10.9	-6.5/-5.6	n/m	1.0	0.5	Front wheel snagged on posts; otherwise redirected.
TTR-15	LS#2	1976 Honda Civic	1,750	**	57.9	16.9	8.3/16.7	-2.9/-2.7	n/m	1.0	0.5	Smooth redirection with no wheel snagging.

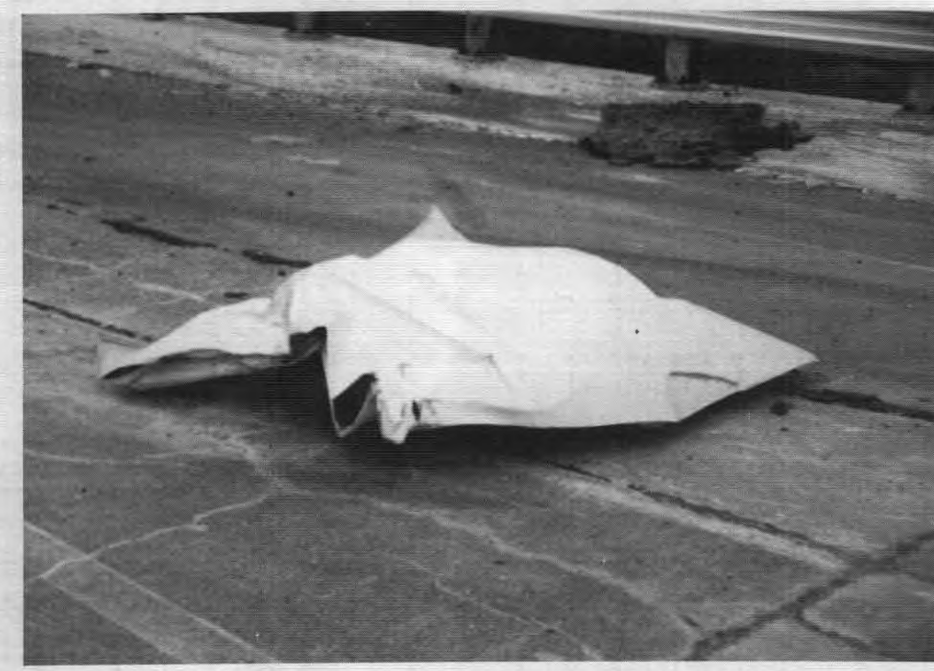
*Barrier code:
HP#1 - High Performance Retrofit Prototype #1, see Figures 13 and 14.
HP#2 - High Performance Retrofit Prototype #1, notched post, see Figures 14 and 25.
HP#3 - Self-Restoring High Performance Retrofit, see Figures 28 and 56.
HPAR - Bridge Approach Rail, see Figure 34.
HPAR(B.O.) - Approach Rail-Blocked Out Rails, see Figures 42 and 56.
LS#1 - Low Service Retrofit Bridge Railing, see Figures 11 and 17.
LS#2 - Low Service Retrofit Bridge Railing, see Figures 49 and 62.

**Test instrumentation only - some original equipment removed from vehicle.
+Roll angle: Maximum while in rail contact/maximum overall.
++Distance measured behind original bridge post line (rear flange).

Note: It should be pointed out that film analysis gives the acceleration values at the roof target. Therefore, vehicle accelerations computed from film analysis may differ from the accelerations measured by the triaxial accelerometers mounted at the center of gravity of the vehicle.



(a) Front quadrant



(b) After crash test TTR-7

FIGURE 55. 1978 FORD HOOD

This problem of hood snagging is discussed in more detail in the next section and in Appendix D.

A difference in performance between Tests TTR-14 and TTR-15 was attributed partially to the difference of bumper design for pre-1978 models and 1978 and later models with the 5-mph (8-kmph) bumper. The strength for oblique impacts of the later model bumper appears to be below that of pre-1978 models.

Openings Between Rails. The opening between the upper and lower railings after the lower beam bottoms on the posts is 18 in. (0.5 m) wide. This opening permitted sheet metal portions of the bus and the hood of the 4500-lb (2000-kg) car to snag on the exposed post flange edges. For wider bridges which will accommodate the 6-in. (150-mm) spacer block, it is recommended that the upper and lower beams be blocked out accordingly. The higher impact angle probabilities associated with the snagging problem increase with the width of the bridge; thus the more narrow bridges which cannot accommodate the spacer do not have the need of the wider ones that can tolerate the additional 6 in. (150 mm) per side encroachment.

Post Anchorage. Anchor bolt failures occurred in some of the tests. This was, in some cases, attributed to the simulated bridge deck used in the tests. In the case of the low service retrofit, driven anchor studs slipped 0.5 in. (13 mm) during the structural adequacy test although the overall results of the test were favorable.

Since each bridge to be retrofitted is a unique structure, careful attention to the post anchorage requirements should be given by the designer. Recommendations for post anchorage strength details are given in the design drawings, and some typical details for existing through truss structures are given in the next section.

B. Application of Findings

Based on the findings of this project, both the high performance retrofit and the lower service system are recommended for immediate implementation. Estimated material costs for the two systems are given in Table 6.

1. High Performance Retrofit. Design drawings for this system are given in Figure 56. This system is recommended for use where significant heavy vehicle traffic is present, and at sites where impacts with these heavy vehicles has some probability. For bridges with accommodating width, the installation of the blockout spacers between the railings and posts is recommended for minimizing vehicle snagging potential.

Design details for adapting example structures in developing the required post strength are discussed. Use of the recommended anchorage strength on the drawings should aid the designer in retrofit details for each unique bridge considered. If a through truss member is considered structurally adequate to develop the strength capacity of the W6x25 post without buckling, the upper rail member could be attached to it.

TABLE 6

THROUGH TRUSS RETROFIT RAILING ESTIMATED MATERIAL COSTS

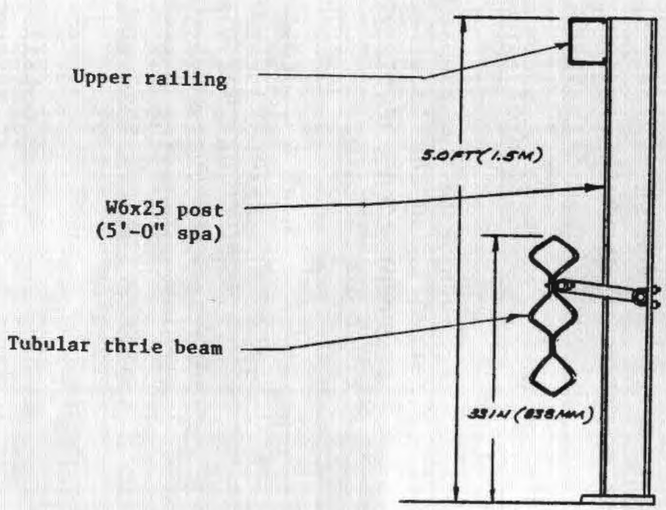
High Performance Retrofit

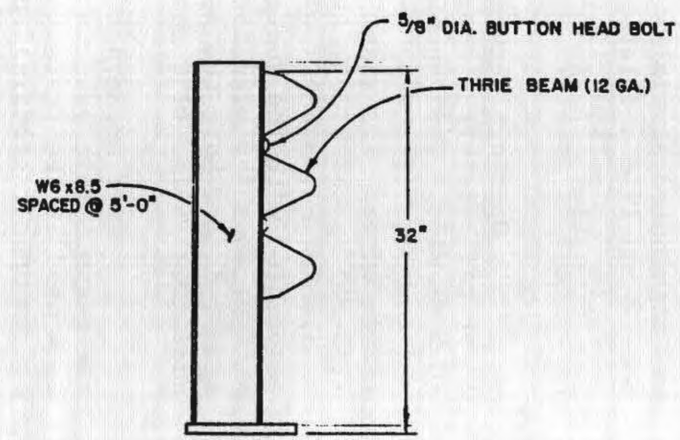
Item	Est. Cost* ($/lin. ft.)
1. Post - $100 ea.	20.70
2. Upper railing and hardware	4.00
3. Tubular thrie beam and hardware	19.00
4. Miscellaneous hardware	1.00
Total estimated cost	$44.70+

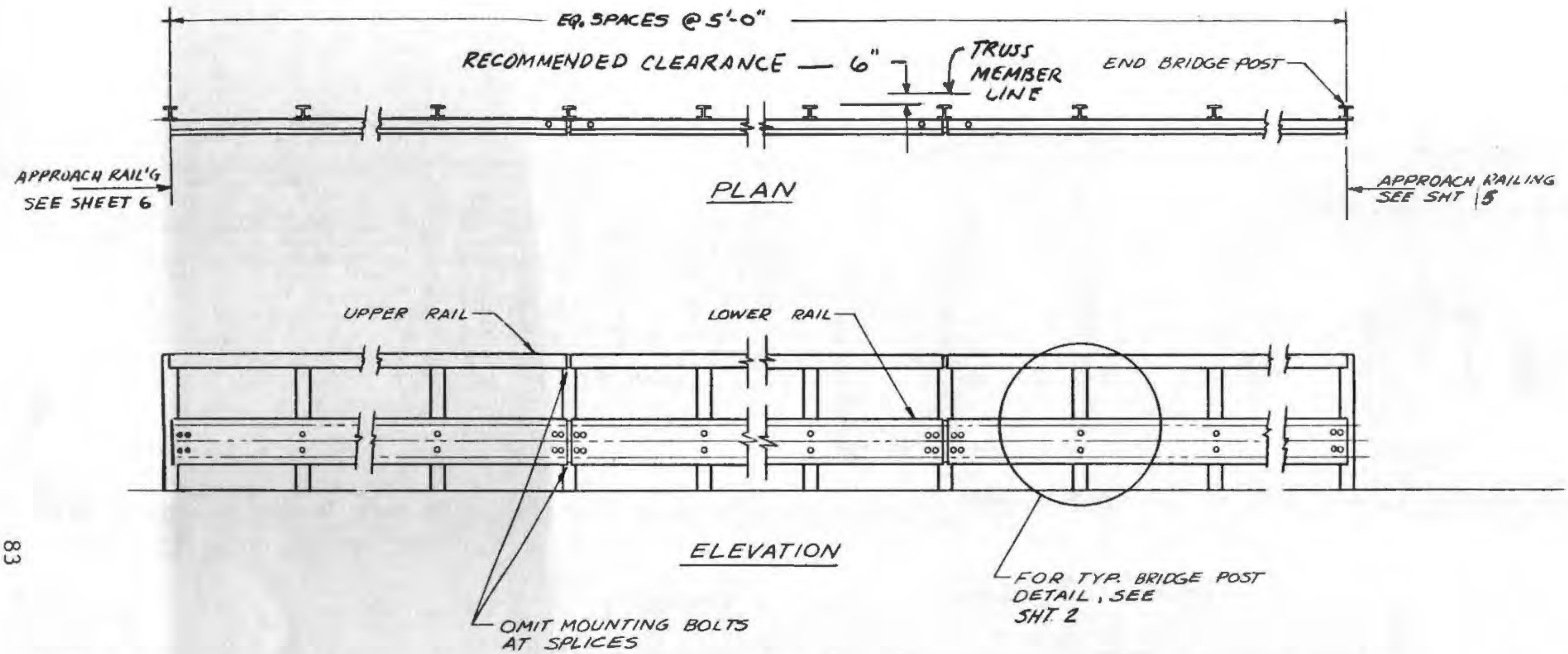
Low Service Retrofit

Item	Est. Cost* ($/lin. ft.)
1. Post - $25 ea.	5.00
2. Beam - 12 ga thrie & hardware	5.00
Total estimated cost	$10.00+

*Anderson Safeway Guard Rail Corp., Flint, MI.
+Does not include installation and post anchorage costs.







Notes:

1. The lower rail and splices are made of tubular Thrie beam made of two continuous welded Thrie beam elements. Since no firm dimensional tolerances have been established for this beam, the manufacturer should assure compatibility of beams and splices. Thrie beam material shall conform to AASHTO M180-74 or latest revision.
2. The upper beam shall conform to ASTM A570 with mechanical properties equal to ASTM A36 and shall be galvanized in accordance with ASTM A123.
3. Posts shall conform to the requirements of ASTM A36 and shall be galvanized in accordance with the requirements of ASTM A123.
4. Bolts shall conform to requirements of ASTM A307 and nuts to requirements of ASTM A563, Grade A or better, and be galvanized in accordance with ASTM A153 except when specified otherwise. Bolts and nuts shall be of the hex or heavy hex types. Washers shall be made of steel and be galvanized in accordance with the requirements of ASTM A153.
5. Steel plate shall conform to ASTM A36 and shall be galvanized in accordance with ASTM A123.
6. Welding shall conform to the requirements of the current "Specifications for Welded Highway and Railing Bridges" of the American Welding Society, AWSD 2.0.
7. Spacers. For bridges where space is available, the installation of Spacers A and B on bridge rail posts as well as the approach rail posts is recommended as shown on Sheets #5 and #6.

Thru Truss Retrofit #1
DOT FH-11-9418
Sheet 1 of 6

FIGURE 56. HIGH PERFORMANCE INSTALLATION DRAWINGS

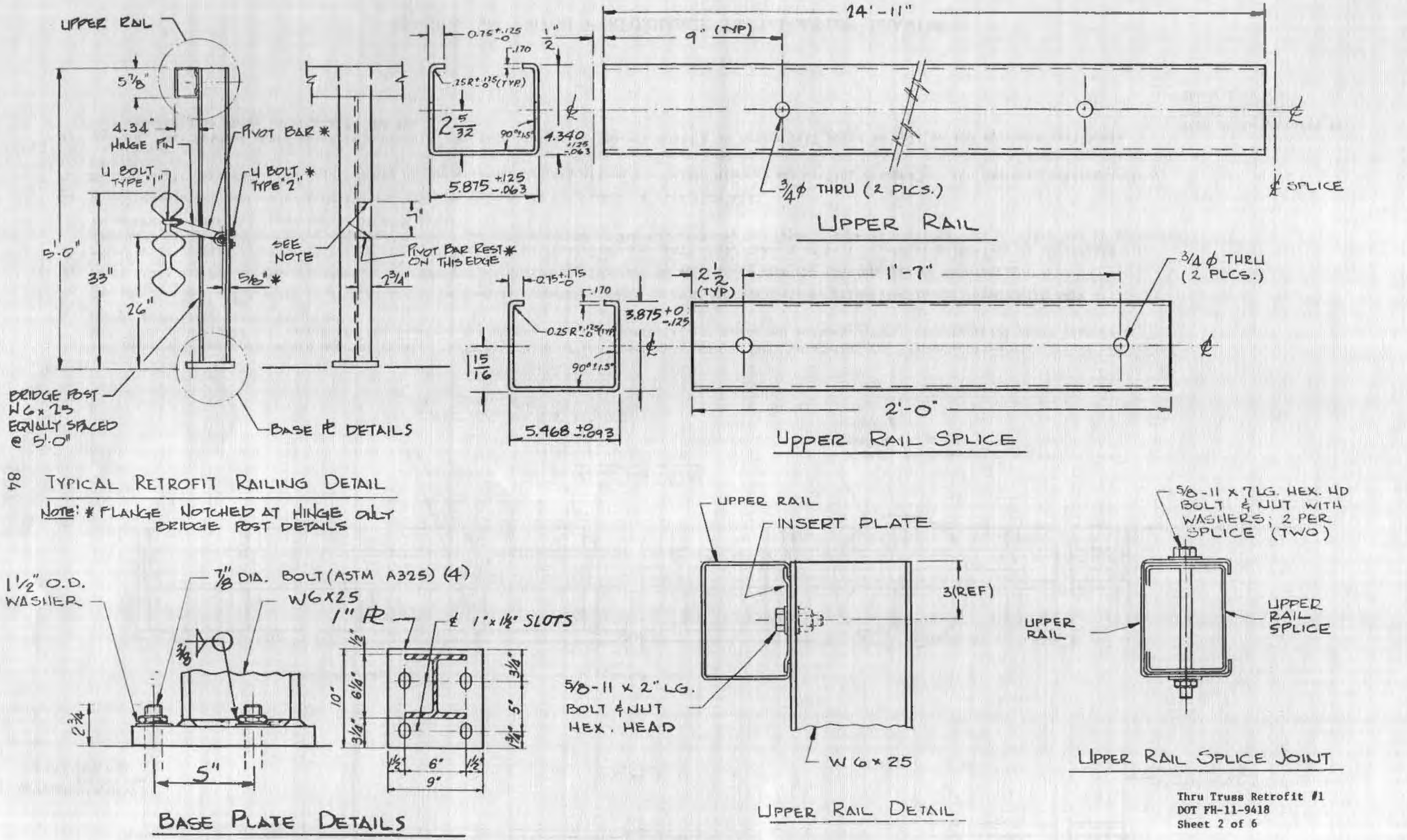
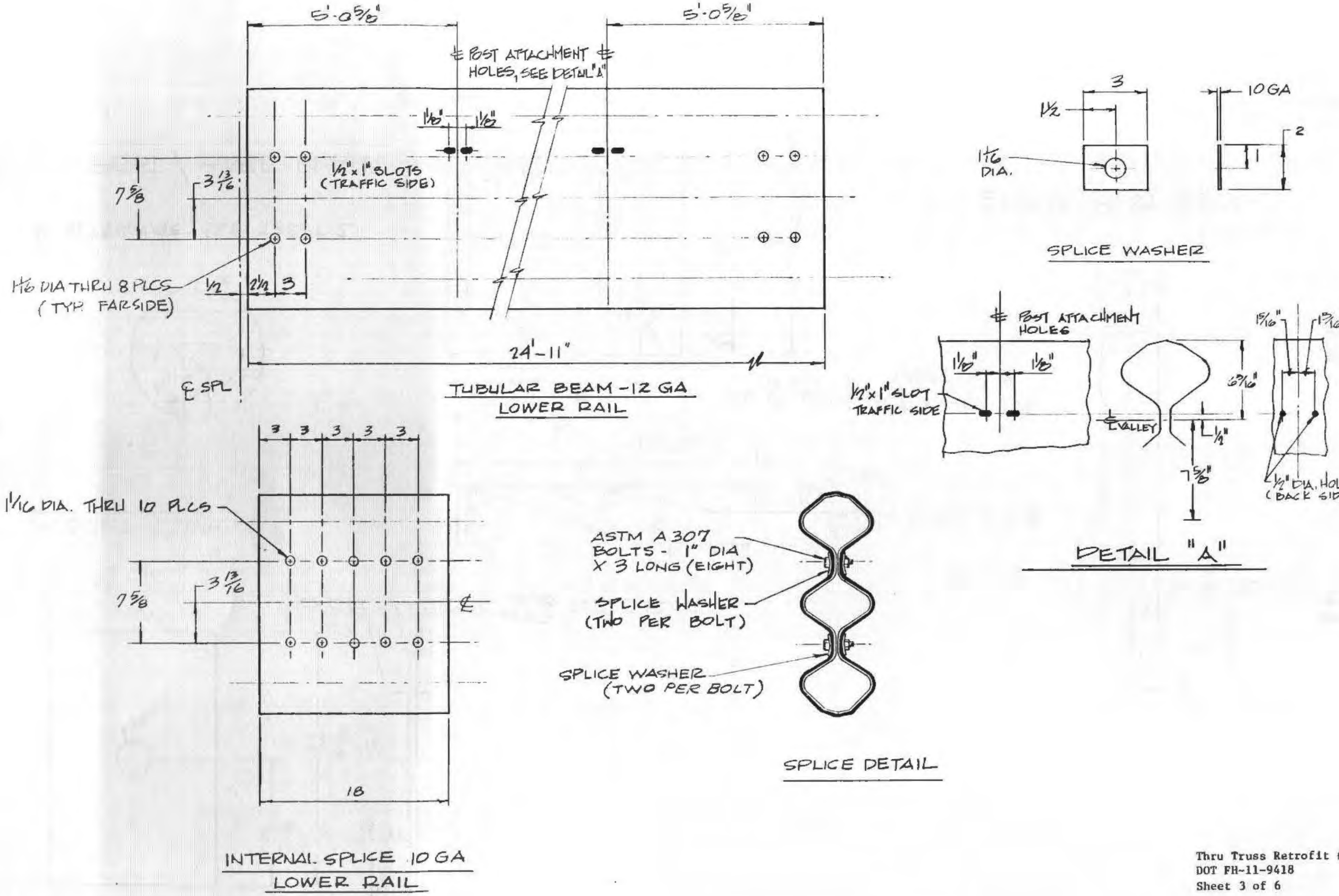
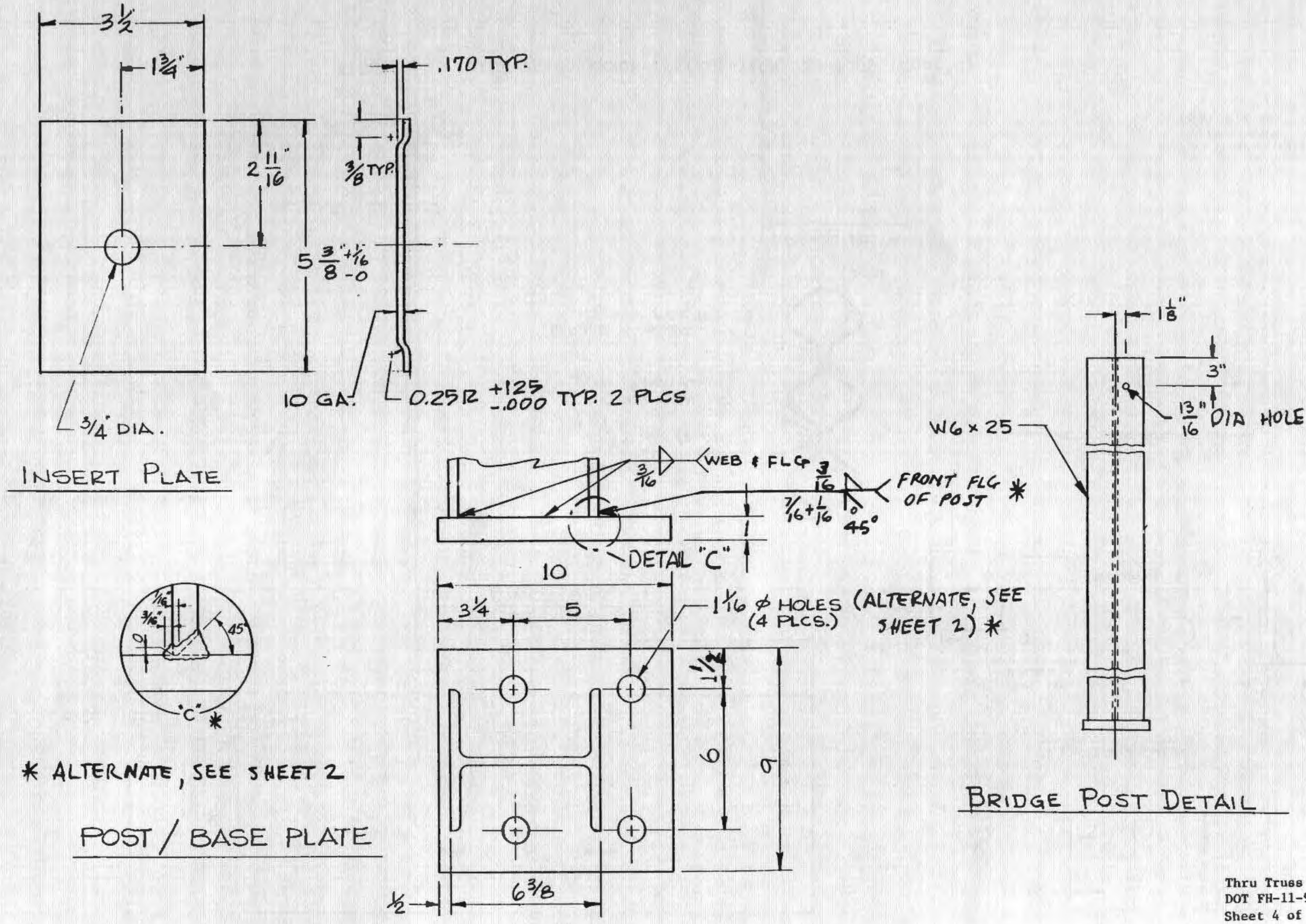


FIGURE 56. HIGH PERFORMANCE INSTALLATION DRAWINGS (Cont'd)



Thru Truss Retrofit #1
DOT FH-11-9418
Sheet 3 of 6

FIGURE 56. HIGH PERFORMANCE INSTALLATION DRAWINGS (Cont'd)



Thru Truss Retrofit #1
DOT FH-11-9418
Sheet 4 of 6

FIGURE 56. HIGH PERFORMANCE INSTALLATION DRAWINGS (Cont'd)

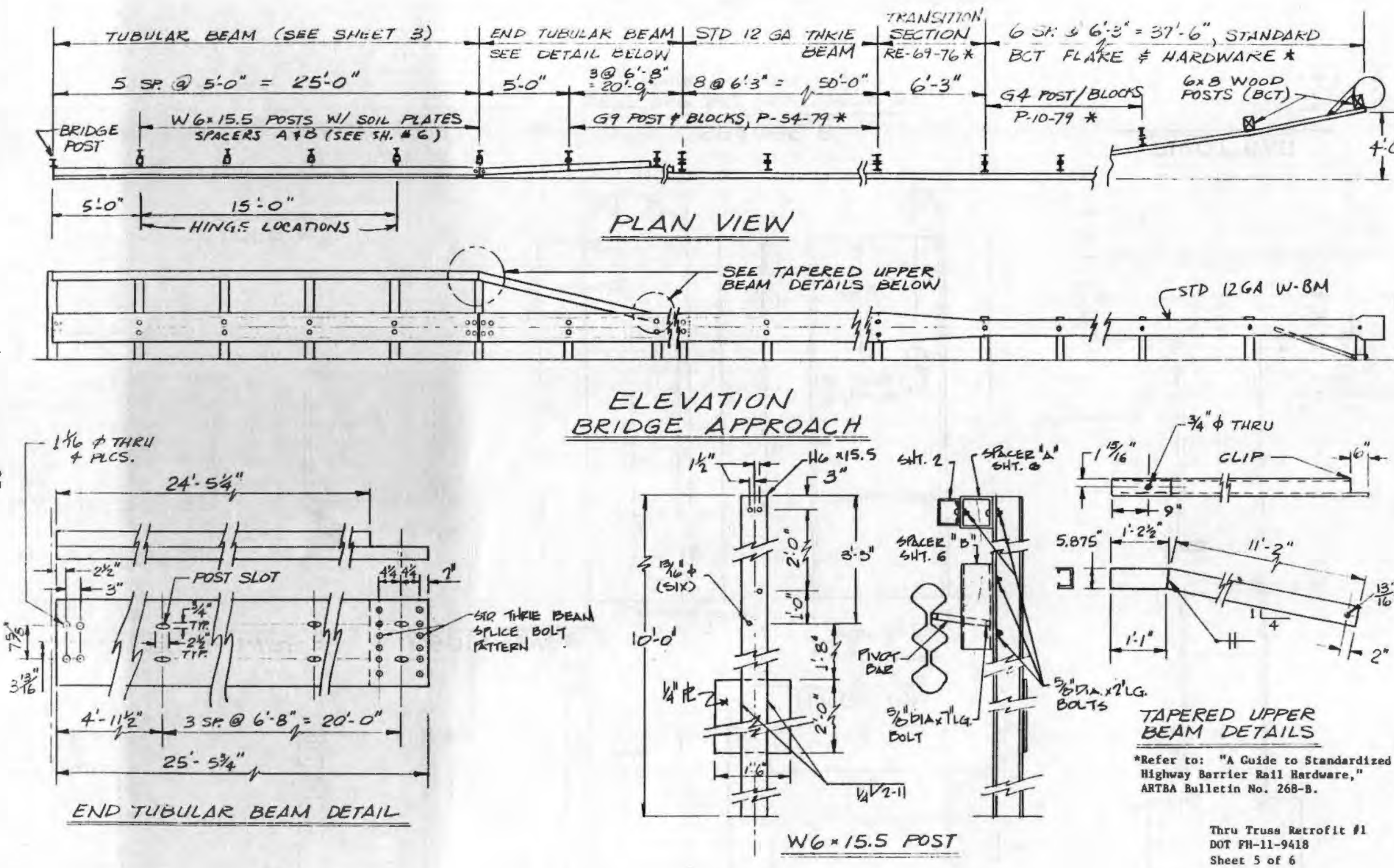


FIGURE 56. HIGH PERFORMANCE INSTALLATION DRAWINGS (Cont'd)

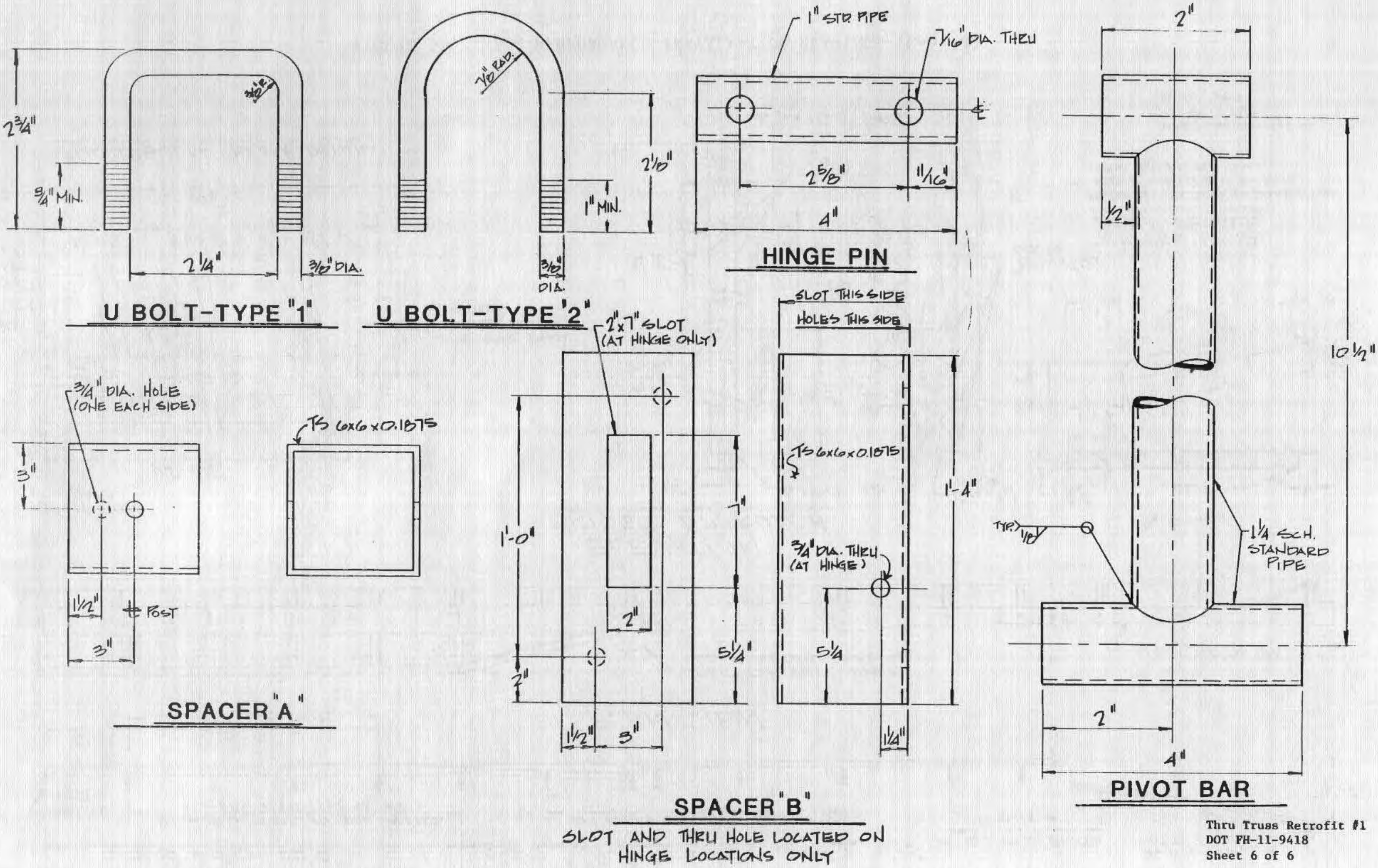


FIGURE 56. HIGH PERFORMANCE INSTALLATION DRAWINGS (Cont'd)

The design requirement is to develop the full plastic moment of the W6x25 post. For A36 steel and a plastic modulus of 18.9 in.^{3} (0.1 m^3), this corresponds to a moment of M = 36 (18.9) = 680.4 in.-kips (1.6 m-kN). Because of the inability of most through truss bridge decks to resist this large moment, earlier concepts of attaching the standard base plate to the bridge deck were largely discarded. Rather, it was decided necessary to run the posts through the deck and develop a couple to resist the moment.

The largest members of through truss bridges are invariably the floor beams at panel points on the bottom chords. The spacing of these beams ranges from about 15 ft (4.6 m) to slightly over 20 ft (6.1 m). Because of the size of these beams, it is strongly recommended that posts be placed at these locations. Figure 57 shows a suggested attachment with a standard base plate placed at the top of the concrete deck. Figure 58 shows a preferred attachment in which the standard base plate is bolted directly to the floor beam. This concept could also be used on the bridges with wood decks. With either the Figure 57 or Figure 58 concept, the 3/8-inch stiffener plates should be installed to strengthen the floor beam resistance.

Intermediate posts should be equally spaced between floor beams to approximate the desired 5-ft (1.5-m) spacing. Figure 59 is an attachment concept for a concrete deck. Suggested analysis checks are shown in Figure 59(a).

Figure 60 shows an alternate intermediate post attachment in which a truss configuration is used to transfer the lower load to the floor beams. Details of the analysis checks for a 20-ft (6.1-m) span are shown in Figure 60(a). Note that a truss weight of 665 lb (302 kg) or 33 lb/ft (0.5 kg/m) results.

For wood decks, the truss attachment of Figure 60 is probably the most feasible. A possible alternative, similar to Figure 59, is shown in Figure 61. Note that the outside stringers in these older wood deck bridges can be a problem in passing the posts through the deck. The better solution might be to move these stringers inboard as shown. To help transfer the knee brace load to the deck, the bolts should be snugged against the stringers and the space above the plate should be filled with the block shown. The block should be securely nailed or bolted to the stringers and deck.

For all of these concepts, any existing railing attached to the truss probably should be removed prior to installing the new railing. If horizontal clearance is not a problem, the new posts might be placed against the old railing, and possibly attached to it. By this addition of the old rails, a redundancy can be gained in the flexural strength of the new railing system. However, the available space for railing deflection without contacting the truss will obviously be eliminated.

2. Low Service Retrofit. Design drawings for this system are given in Figure 62. This system is recommended for use on the following bridges:

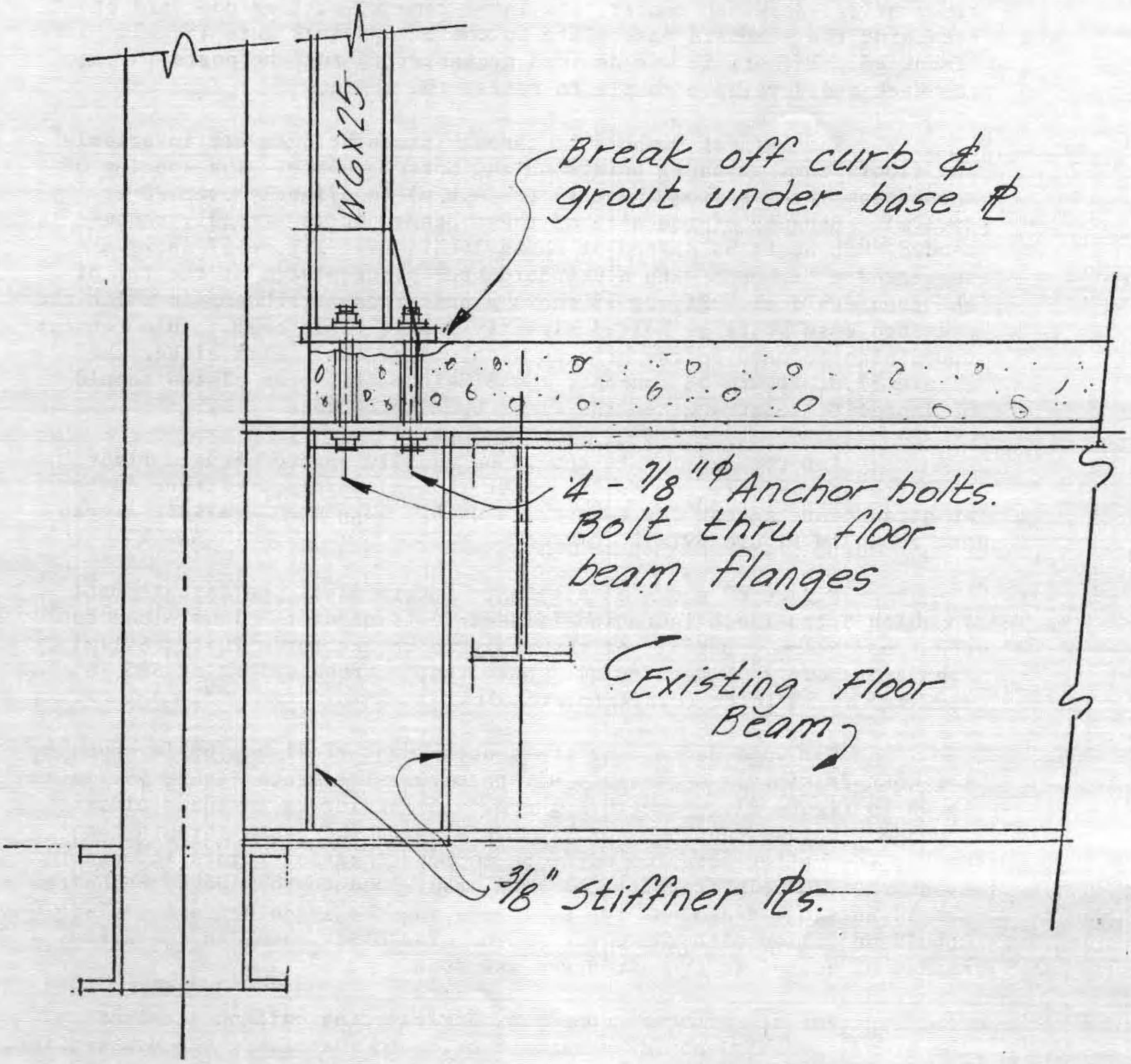


FIGURE 57. POST ATTACHMENT AT FLOOR BEAM

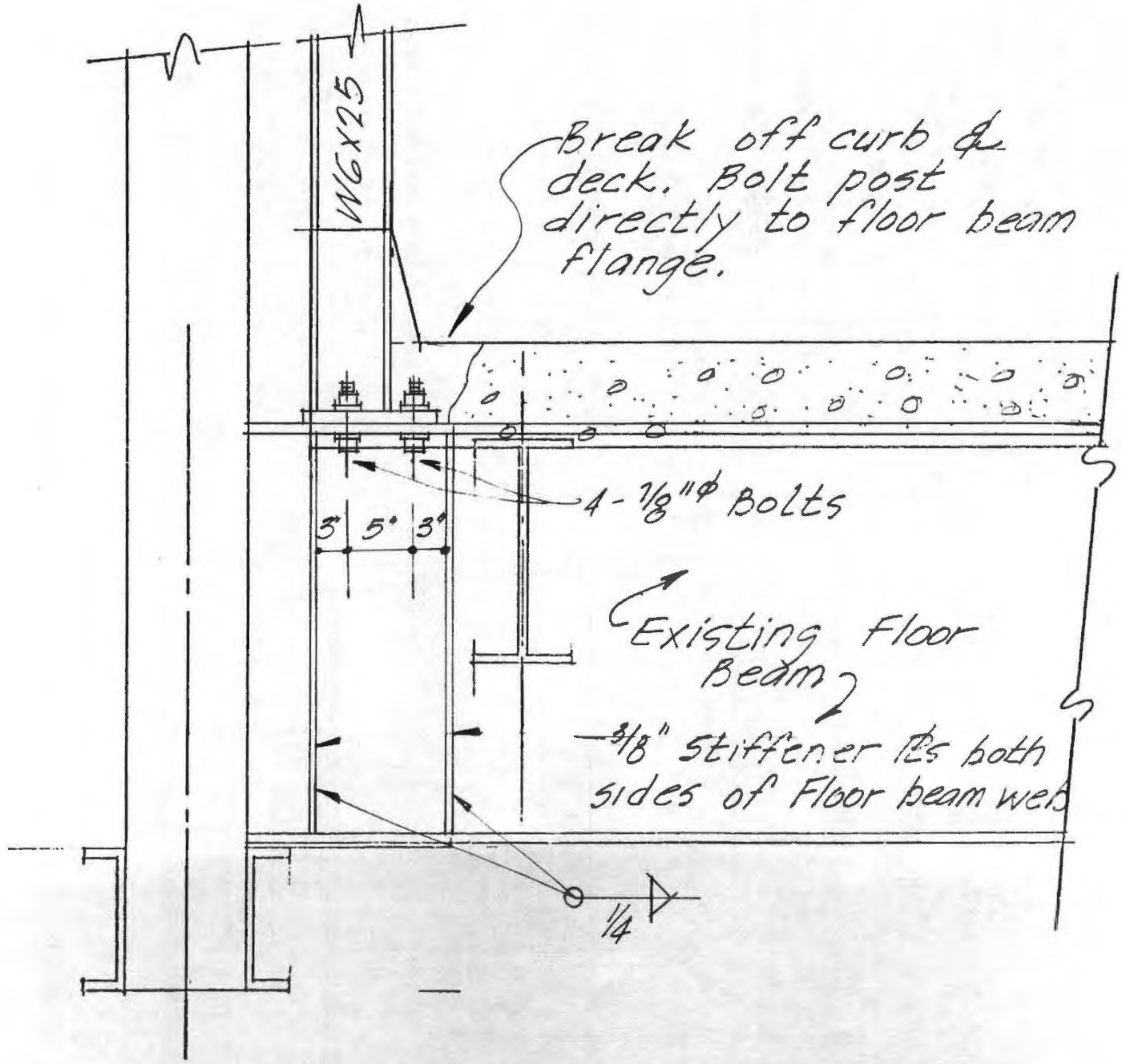
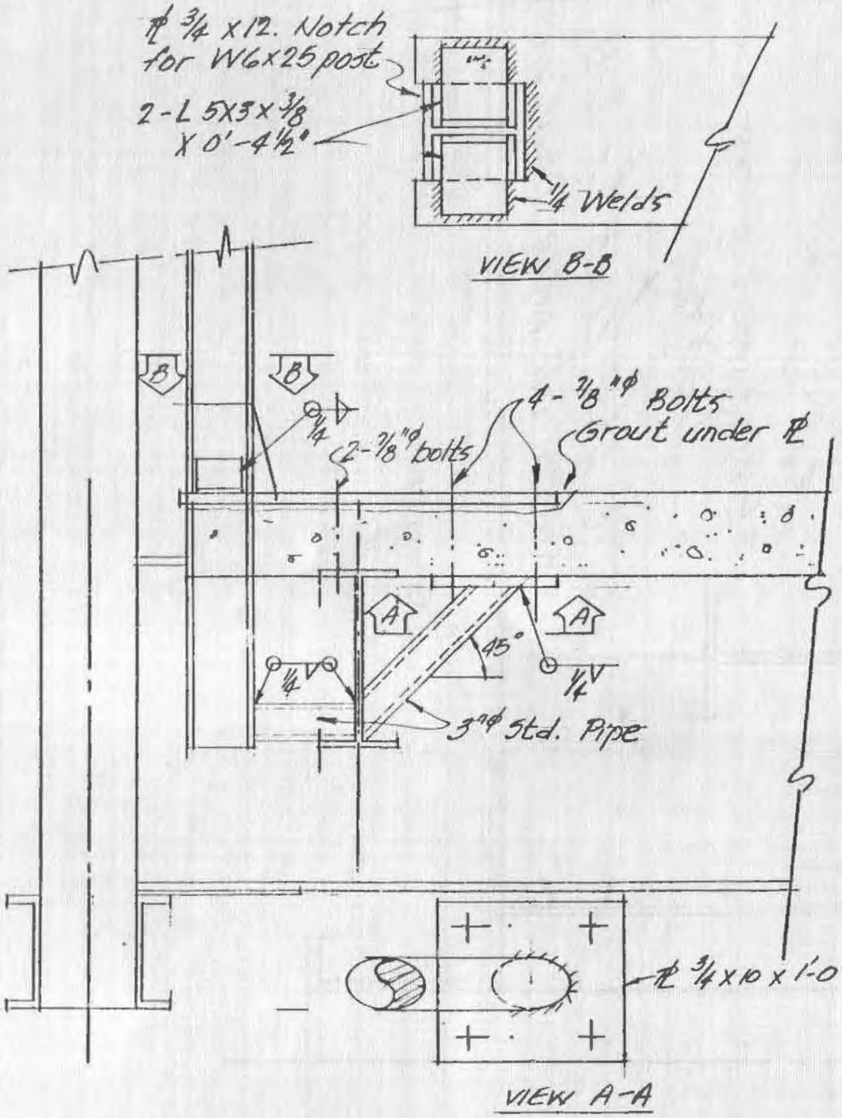


FIGURE 58. PREFERRED POST ATTACHMENT AT FLOOR BEAM



Design moment = 680.4 in-kips

Distance from top ℄ to lower strut = 21 in.

Force F in lower strut = $\frac{680.4}{21}$ = 32.4 kips

Knee Brace

Force in knee brace = $\frac{32.4}{\cos 45°}$ = 45.8^k

ℓ = 18" ±

Try 3" Std. pipe A = 2.23 r = 1.16

$\frac{\ell}{r} = \frac{18}{1.16} = 16$

F_a = 20.83 ksi (AISC Table 1-36)

Reqd. A = $\frac{45.8}{20.83}$ = 2.20 < 2.23 o.k.

Check weld

1/4" weld = 0.177 (21,000)
= 3720 lb/in.

(t = 0.177, 1/4")

Pipe circumference = π(3.50) = 11.0 in.

11.0 x 3720 = 40.9^k > 32.4^k o.k.

Use 1/4" weld all around.

Top Plate

Try 3/4" ℄

Net area = (12 - 6.125) 3/4 = 4.41 in.^{2} (6⅛", 12")

P_{ALL} = 4.41 (22.0) = 97.0^k > 32.4^k o.k.

Weld length reqd. = $\frac{32.4}{3.72}$ = 8.71 in.

Use 2-L5x3x3/8 x 0'-4½" on post web.

Bolt bearing:

P_{ALL} = 4(7/8)(3/4)(48.6) = 127.6^k > 32.4 o.k.

PC-4

(a) Analysis

FIGURE 59. SUGGESTED INTERMEDIATE POST ATTACHMENT (CONCRETE DECK)

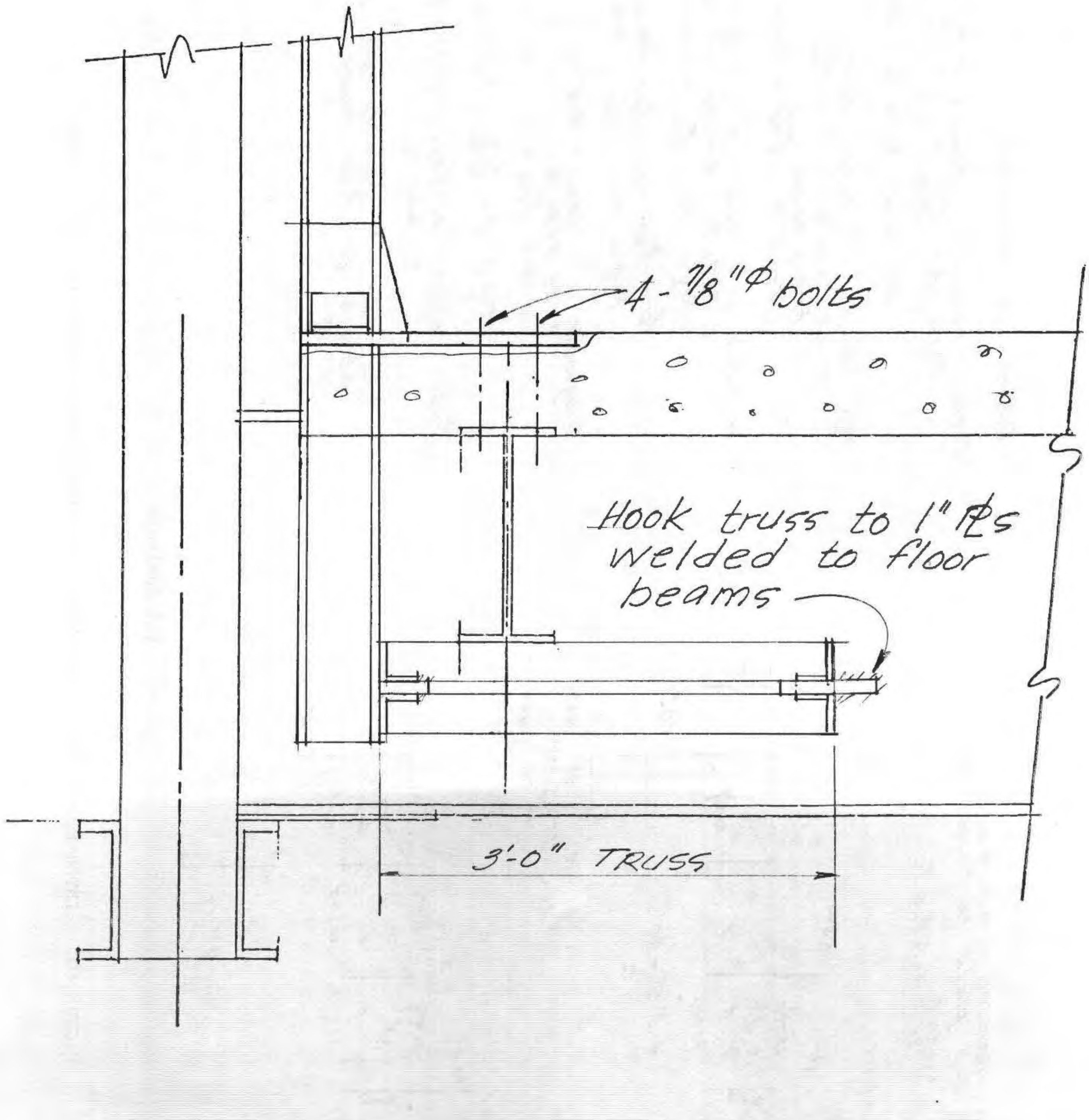


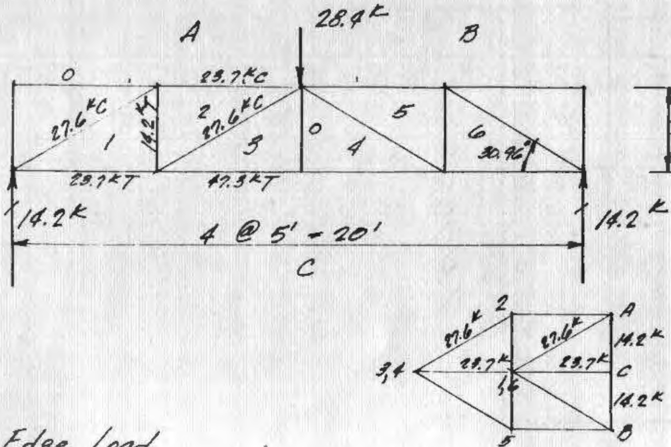
FIGURE 60. INTERMEDIATE POST ATTACHMENT WITH LOWER TRUSS CONFIGURATION

Design moment = 680.4 in-k

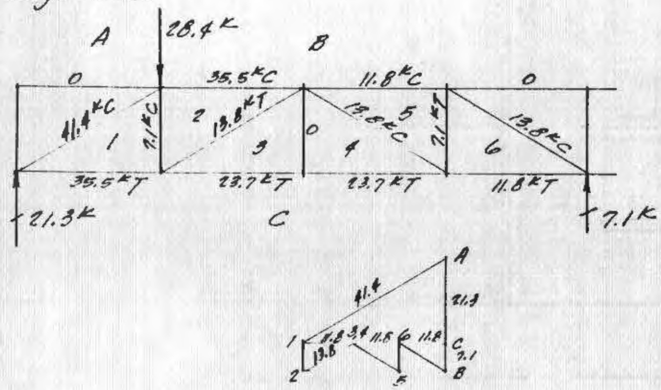
Distance top plate to truss = 24 in.

$F = \frac{680.4}{24} = 28.4^k$

Center Load



Edge Load



DESIGN OF MEMBERS

Bottom chord Load = 47.3^kT

Req'd. $A = \frac{47.3}{22.0} = 2.15$ in.^{2}

Use 2-Ls 3x3x¼ A = 2.88 Wt = 9.8 lb/ft

Top chord Load = 35.5^kC

2-Ls 3x3x¼ $\frac{\ell}{r} = \frac{60}{0.930} = 65$

$F_A = 16.94$ ksi

Req'd. $A = \frac{35.5}{16.94} = 2.10 < 2.88$ o.k.

Verticals Load = 14.2^kT & 7.1^kC

L 3x3x¼ A = 1.44 r = 0.592

Req'd. $A_T = \frac{14.2}{22.0} = 0.65 < 1.44$ o.k.

$\frac{\ell}{r} = \frac{36}{0.592} = 61$ $F_A = 17.33$ ksi

Req'd. $A_C = \frac{7.1}{17.33} = 0.41 < 1.44$ o.k.

Diagonals Load = 41.4^kC

2-Ls 3x3x¼

$\frac{\ell}{r} = \frac{70}{0.930} = 75$ $F_A = 15.90$ ksi

Req'd. $A = \frac{41.4}{15.90} = 2.60 < 2.88$ o.k.

Truss weight = 20(9.8) + 20(9.8) + 9(4.9) + 5.83(4)(9.8)
= 665 lb.

Space Ls 1" back to back & attach to floor beams with 1" PL

(a) Analysis

FIGURE 60. INTERMEDIATE POST ATTACHMENT WITH LOWER TRUSS CONFIGURATION (Cont'd)

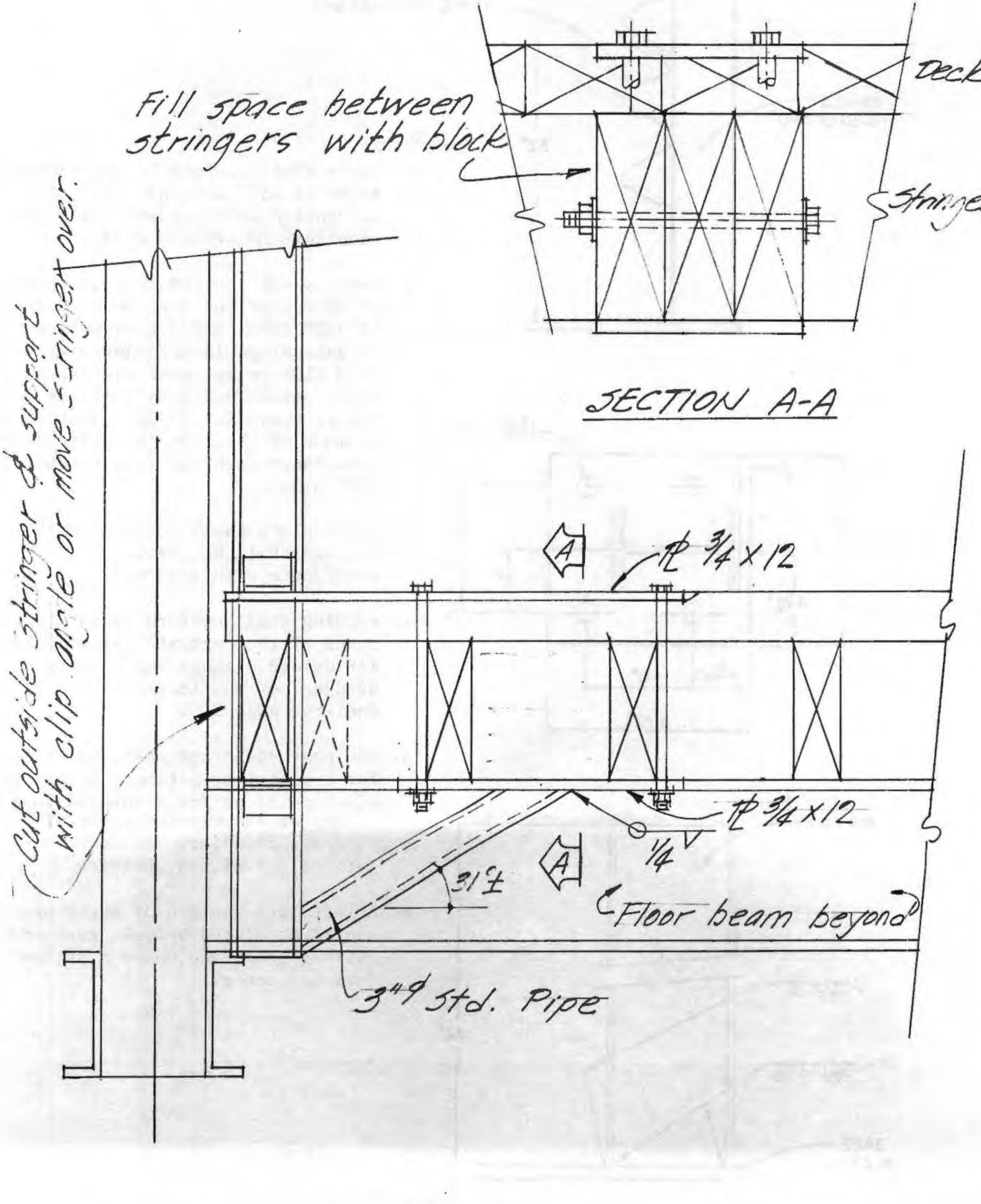
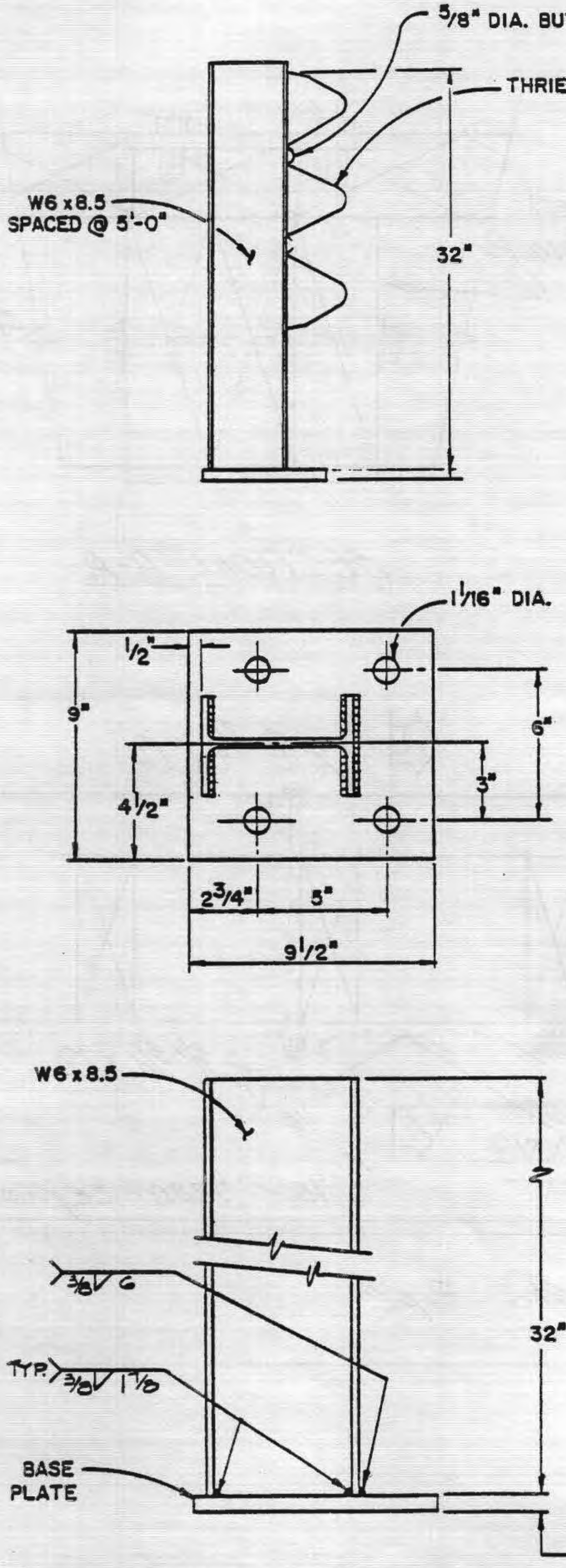


FIGURE 61. ALTERNATE INTERMEDIATE POST ATTACHMENT FOR WOOD DECKS



Notes:

1. Posts shall conform to the requirements of ASTM A36 and shall be galvanized in accordance with the requirements of ASTM A123.

2. Bolts shall conform to requirements of ASTM A307 and nuts to requirements of ASTM A563, Grade A or better, and be galvanized in accordance with ASTM A153 except when specified otherwise. Bolts and nuts shall be of the hex or heavy hex types. Washers shall be made of steel and be galvanized in accordance with the requirements of ASTM A153.

3. Steel plate shall conform to ASTM A36 and shall be galvanized in accordance with ASTM A123.

4. Welding shall conform to the requirements of the current "Specifications for Welded Highway and Railing Bridges" of the American Welding Society, AWSD 2.0.

5. The post anchorage shall be designed for a resisting ultimate moment of 420 kip-in. or for a working load moment of 140 kip-in. using allowable stresses of AASHTO "Standard Specifications for Highway Bridges".

6. A 1-ft long section of thrie beam should be placed between post and rail at locations where a splice does not occur.

FIGURE 62. LOW SERVICE RETROFIT INSTALLATION DRAWING

- one-lane structures
- narrow, 20-ft (6-m) wide 2-lane structures
- bridges with automobile traffic only
- bridges with posted speed of 35 mph (55 kmph) or less that carry truck/bus traffic

Recommended post anchorage strength values are shown in Figure 62. This anchorage can be more effectively developed by bolting through the bridge deck although 1-in. (25-mm) diameter driven anchor studs provided marginal capacity in the crash test series.

REFERENCES

1. Report to the Honorable James R. Sasser, United States Senate, "Better Targeting of Federal Funds Needed to Eliminate Unsafe Bridges," Report CED-81-126 by the Comptroller General of the United States, August 1981.

2. Bronstad, M. E. and Michie, J. D., "Multiple Service Level Highway Bridge Railing Selection Procedures," NCHRP Report 239 (March 1982).

3. "Evaluation of the Effectiveness of Meaures for Reducing Accidents and Accident Severity at Highway Narrow Bridge Sites," FHWA Contract No. DOT-FH-11-9285, SwRI Project 06-4941, in progress.

4. Powell, G. H., "BARRIER VII: A Computer Program for Evaluation of Automobile Barrier Systems," Report No. FHWA-RD-73-51 (April 1973).

5. McHenry, R. and Deleys, N. J., "Highway Vehicle Object Simulation Model (HVOSM), Vehicle Dynamics in Single-Vehicle Accidents," Report Nos. FHWA-RD-76-162, 163, 164 and 165.

6. "Recommended Procedures for Vehicle Crash Testing of Highway Appurtenances," TRB Circular 191 (Feb. 1978).

7. Michie, Jarvis D., "Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances," NCHRP Report 230 (March 1981).

APPENDIX A

CRASH TEST RESULTS

TEST TTR-1

Purpose: Purpose of this test was to evaluate the performance of the thru-truss retrofit bridgerail system when impacted by a 20,000-lb (9,072-kg) school bus at 55 mph (88.5 kmph) and a 15-deg angle.

Test Installation: The thru-truss retrofit system was installed on a 152-ft (46-m) long concrete foundation which simulated a bridge deck. The retrofit consisted of a 5-ft (1.5-m) high channel upper rail and a 32-in. (0.8-m) high tubular thrie beam lower rail attached to W6x25 posts spaced at 5-ft (1.5-m) intervals. Each post was attached to the foundation with four 7/8-in. (22-mm) dia high strength anchor bolts. The tubular thrie beam lower rail was transitioned upstream into a single thrie beam and then finally into standard G4 approach guardrail with breakaway cable terminal end treatment. Photographs of the test installation are shown in Figure 63.

Test Vehicle: A 1966 International chassis with a 72-passenger Wayne school bus body was the test vehicle. To achieve the desired weight and simulate passenger loading, 6,200 lb (2812 kg) of ballast was placed in the seats. Sandbags were not secured.

Performance: Impact conditions for the bus were 55.2 mph (88.8 kmph) and a 13.7-deg angle. Initial contact with the lower rail occurred 9 in. (0.2 m) downstream of Post 10. As shown in the sequential photos of Figure 64, the bus impacted the barrier, rolled toward it as it was redirected (maximum roll angle 20 deg) and then returned to an upright position. As the bus continued after losing contact with the installation, it began a hard swerve to the left due to front suspension and steering linkage failure inflicted during the impact, and rolled onto its right side, sliding to a stop 225 ft (68.6 m) past the barrier. Post-test examination revealed that the rivets which attach the front spring hanger brackets to the frame were sheared on both sides. This allowed the front axle and springs to rotate (in a yaw direction) as the right front wheel was pushed rearward by the lower rail. This in turn caused the steering pitman arm/wheel link connection to fail and the bus front wheels to be turned and locked into a hard left turn position.

Maximum 50 msec average accelerations measured from high-speed film were 3.0 g (lateral) and -1.3 g (longitudinal). A summary of test results is shown in Figure 64. Results of high-speed film analysis are summarized in Table 7 and accelerometer data are shown in Figure 65.

Barrier Damage: Damage to the barrier itself was relatively minor - only two upper and two lower rail sections required replace-

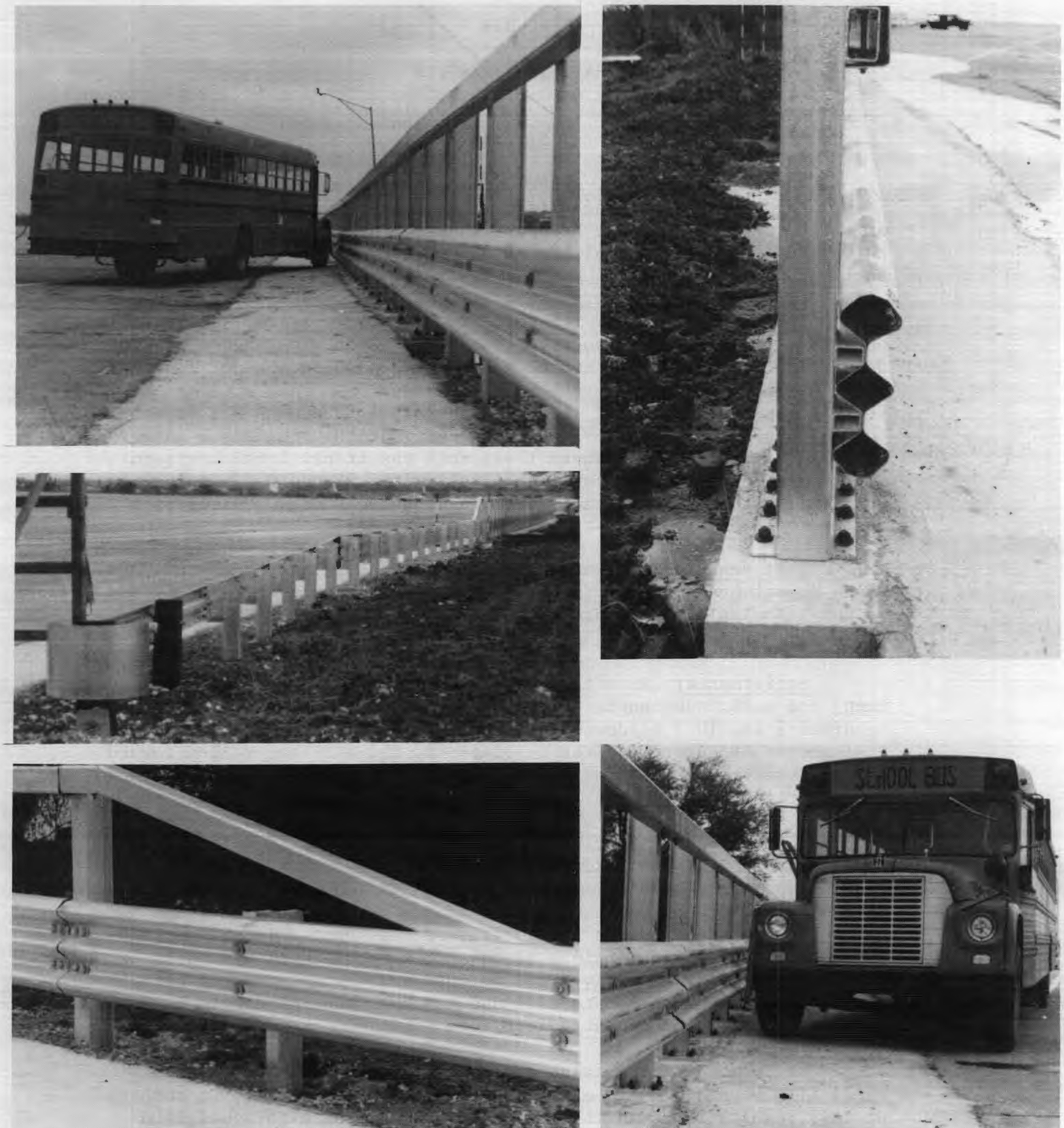
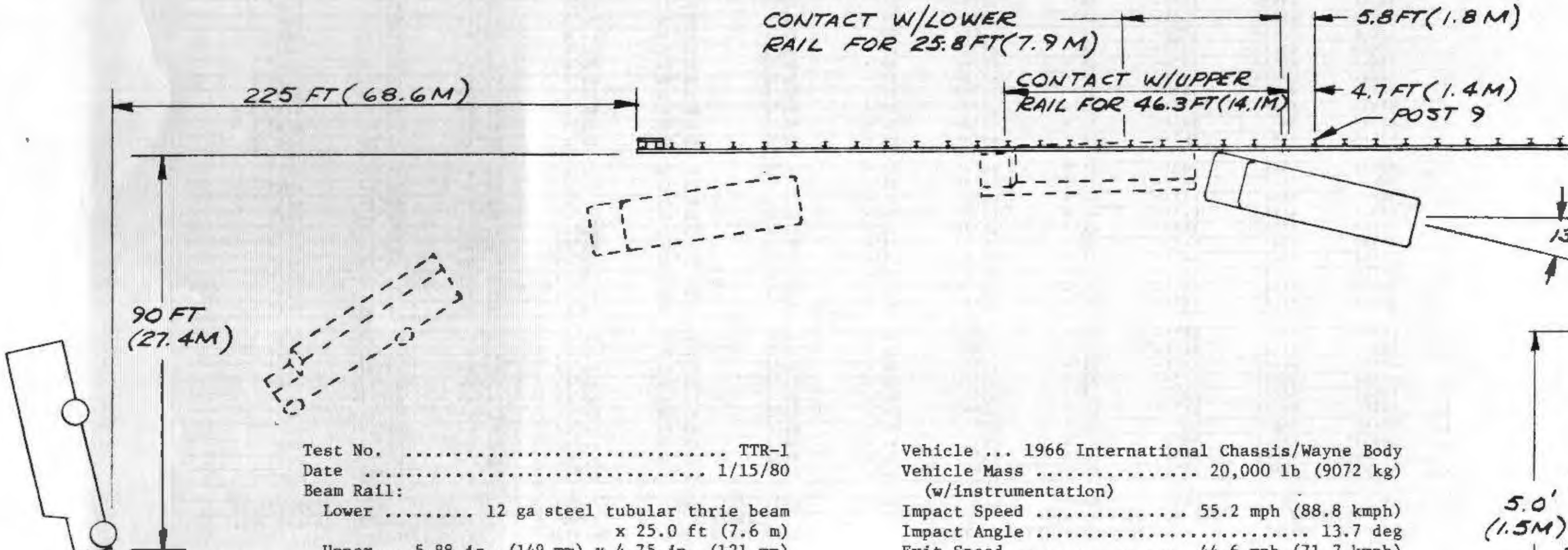
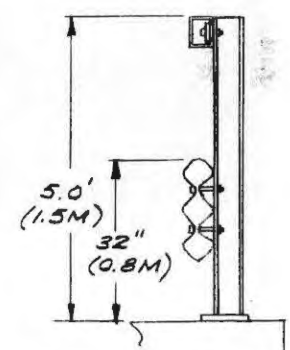


FIGURE 63. THRU-TRUSS RETROFIT TEST INSTALLATION



Test No.	TTR-1
Date	1/15/80
Beam Rail:	
Lower	12 ga steel tubular thrie beam x 25.0 ft (7.6 m)
Upper	5.88 in. (149 mm) x 4.75 in. (121 mm) x 0.17 in. thk (4.3 mm) x 25 ft (7.6 m) long steel channel
Post	W6x25 steel x 5 ft (1.5 m)
Post Spacing	5 ft (1.5 m)
Length of Installation	145 ft (44.2 m)
Upper Beam Rail Deflection:	
Max Dynamic	24.7 in. (627 mm)
Max Permanent	10.3 in. (262 mm)

Vehicle	1966 International Chassis/Wayne Body
Vehicle Mass (w/instrumentation)	20,000 lb (9072 kg)
Impact Speed	55.2 mph (88.8 kmph)
Impact Angle	13.7 deg
Exit Speed	44.6 mph (71.7 kmph)
Exit Angle	-4.7 deg
Maximum Roll Angle (during impact sequence)	20 deg
Vehicle Acceleration (max 50 ms avg):	
Lateral	3.0 g
Longitudinal	-1.3 g



Barrier Cross-Section

FIGURE 64. SUMMARY OF RESULTS, TEST TTR-1

TABLE 7

FILM ANALYSIS DATA - TEST TTR-1

SUMMARY OF VEHICLE KINEMATIC AND DYNAMIC DATA . THROUGH-TRUSS BRIDGERAIL TEST TTR-1 1/15/80

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 AVER .05 SEC. LONG	LAT	APPROX. BARRIER FORCES(LB) X	Y
0.000	-21.66	-7.75	13.72	80.97	1.82	-.47	.88	0.00	0.00	13355	-19916
.010	-20.88	-7.54	13.78	80.83	2.06	-.42	1.07	0.00	0.00	13279	-18799
.020	-20.10	-7.32	13.84	80.69	2.30	-.44	.93	0.00	0.00	13067	-15890
.030	-19.32	-7.11	13.88	80.54	2.48	-.52	.53	-.52	.55	12736	-7808
.040	-18.55	-6.89	13.89	80.35	2.56	-.63	-.00	-.59	.14	12300	3123
.050	-17.78	-6.67	13.85	80.13	2.52	-.75	-.56	-.68	-.27	11773	19521
.060	-17.00	-6.46	13.74	79.87	2.41	-.83	-1.06	-.77	-.73	11169	24505
.070	-16.24	-6.25	13.56	79.58	2.26	-.88	-1.43	-.83	-1.12	10499	31886
.080	-15.47	-6.04	13.30	79.29	2.12	-.89	-1.65	-.85	-1.41	9777	36216
.090	-14.70	-5.84	12.97	78.99	2.03	-.86	-1.73	-.85	-1.58	9015	37677
.100	-13.94	-5.65	12.57	78.71	2.02	-.80	-1.71	-.81	-1.65	8222	36902
.110	-13.17	-5.46	12.12	78.45	2.10	-.73	-1.62	-.75	-1.63	7410	34760
.120	-12.41	-5.28	11.63	78.21	2.27	-.65	-1.51	-.68	-1.56	6580	32162
.130	-11.65	-5.10	11.11	77.99	2.50	-.57	-1.41	-.61	-1.49	5765	29907
.140	-10.89	-4.93	10.58	77.79	2.78	-.51	-1.36	-.54	-1.43	4951	28572
.150	-10.13	-4.76	10.04	77.61	3.07	-.45	-1.37	-.48	-1.42	4153	28469
.160	-9.37	-4.60	9.50	77.44	3.36	-.41	-1.43	-.44	-1.45	3379	29690
.170	-8.62	-4.44	8.94	77.28	3.63	-.38	-1.56	-.40	-1.59	2636	31099
.180	-7.86	-4.28	8.38	77.13	3.86	-.35	-1.71	-.36	-1.66	1931	34899
.190	-7.10	-4.14	7.81	76.99	4.05	-.32	-1.88	-.33	-1.80	1269	38186
.200	-6.34	-4.00	7.22	76.84	4.22	-.29	-2.05	-.30	-1.94	655	41321
.210	-5.59	-3.86	6.60	76.70	4.36	-.26	-2.18	-.26	-2.08	96	43898
.220	-4.83	-3.73	5.96	76.58	4.50	-.22	-2.27	-.22	-2.18	-406	45615
.230	-4.07	-3.61	5.29	76.46	4.65	-.17	-2.31	-.18	-2.24	-845	46301
.240	-3.32	-3.50	4.60	76.36	4.82	-.12	-2.29	-.13	-2.26	-1219	45920
.250	-2.56	-3.39	3.90	76.26	5.04	-.08	-2.23	-.09	-2.22	-1524	44563
.260	-1.80	-3.29	3.18	76.18	5.29	-.03	-2.12	-.04	-2.15	-1754	42420
.270	-1.04	-3.20	2.47	76.11	5.58	.01	-1.99	.00	-2.04	-1920	39745
.280	-.28	-3.12	1.76	76.05	5.90	.04	-1.84	.04	-1.91	-2007	36818
.290	.47	-3.04	1.07	75.99	6.25	.07	-1.70	.06	-1.77	-2017	33906
.300	1.23	-2.96	.40	75.94	6.60	.09	-1.56	.08	-1.64	-1952	31229
.310	1.99	-2.89	-.23	75.90	6.95	.10	-1.45	.10	-1.52	-1810	28999
.320	2.75	-2.83	-.81	75.86	7.28	.10	-1.35	.10	-1.42	-1591	27125
.330	3.51	-2.77	-1.36	75.82	7.58	.10	-1.29	.10	-1.34	-1297	25770
.340	4.27	-2.72	-1.86	75.78	7.83	.09	-1.24	.09	-1.28	-928	24812
.350	5.03	-2.66	-2.32	75.74	8.05	.07	-1.20	.08	-1.23	-485	24135
.360	5.79	-2.62	-2.74	75.70	8.22	.06	-1.18	.07	-1.20	29	23607
.370	6.55	-2.57	-3.13	75.66	8.36	.03	-1.16	.04	-1.17	612	23102
.380	7.31	-2.53	-3.49	75.62	8.46	.01	-1.13	.02	-1.14	1262	22527
.390	8.07	-2.49	-3.82	75.56	8.55	-.03	-1.10	-.01	-1.11	1977	21845
.400	8.83	-2.46	-4.14	75.50	8.62	-.06	-1.06	-.04	-1.08	2751	21087
.410	9.59	-2.43	-4.44	75.43	8.68	-.10	-1.03	-.08	-1.05	3583	20352
.420	10.35	-2.41	-4.73	75.35	8.73	-.14	-1.01	-.12	-1.03	4468	19801
.430	11.11	-2.38	-5.00	75.25	8.76	-.18	-1.00	-.16	-1.03	5401	19638
.440	11.86	-2.36	-5.25	75.15	8.77	-.23	-1.03	-.20	-1.05	6378	20082
.450	12.62	-2.34	-5.49	75.03	8.74	-.27	-1.10	-.24	-1.10	7393	21339
.460	13.37	-2.33	-5.70	74.91	8.69	-.30	-1.21	-.28	-1.20	8442	23543
.470	14.13	-2.32	-5.88	74.78	8.46	-.34	-1.38	-.31	-1.34	9514	26772
.480	14.88	-2.32	-6.03	74.65	8.18	-.37	-1.60	-.35	-1.53	10618	30975
.490	15.63	-2.32	-6.13	74.51	7.74	-.39	-1.85	-.37	-1.75	11733	35977

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TABLE 7 (Cont'd)

.500	16.38	-2.32	-6.20	74.37	7.21	-.41	-2.13	-.40	-2.00	12857	41476
.510	17.12	-2.33	-6.23	74.23	6.52	-.44	-2.41	-.43	-2.26	13983	47054
.520	17.87	-2.35	-6.23	74.08	5.69	-.47	-2.68	-.46	-2.51	15104	52204
.530	18.61	-2.38	-6.19	73.93	4.75	-.50	-2.89	-.49	-2.73	16214	56395
.540	19.35	-2.42	-6.13	73.77	3.72	-.54	-3.03	-.53	-2.88	17304	59079
.550	20.08	-2.47	-6.06	73.59	2.64	-.60	-3.07	-.58	-2.95	18366	59804
.560	20.81	-2.52	-5.98	73.39	1.55	-.66	-3.00	-.64	-2.93	19393	58249
.570	21.54	-2.59	-5.90	73.17	.52	-.73	-2.80	-.71	-2.79	20376	54284
.580	22.27	-2.66	-5.84	72.92	-.42	-.82	-2.50	-.78	-2.55	21307	48009
.590	22.99	-2.74	-5.79	72.64	-1.23	-.90	-2.09	-.86	-2.22	22177	39775
.600	23.71	-2.83	-5.75	72.33	-1.87	-.99	-1.62	-.95	-1.81	22977	30176
.610	24.43	-2.93	-5.74	72.00	-2.33	-1.08	-1.11	-1.03	-1.36	23697	20006
.620	25.14	-3.02	-5.73	71.64	-2.61	-1.16	-.63	-1.11	-.91	24330	10197
.630	25.85	-3.12	-5.73	71.25	-2.74	-1.23	-.21	-1.18	-.50	24864	1715
.640	26.55	-3.22	-5.73	70.85	-2.76	-1.28	.10	-1.24	-.17	25291	-4550
.650	27.25	-3.32	-5.72	70.43	-2.72	-1.31	.27	-1.28	.05	25600	-7913
.660	27.95	-3.41	-5.68	70.00	-2.67	-1.32	.27	-1.30	.12	25782	-8010
.670	28.64	-3.51	-5.62	69.58	-2.68	-1.31	.12	-1.30	.06	25826	-4842
.680	29.33	-3.60	-5.53	69.15	-2.79	-1.28	-.17	-1.28	-.12	25722	924
.690	30.01	-3.70	-5.42	68.75	-3.04	-1.23	-.54	-1.24	-.40	25459	8468
.700	30.69	-3.79	-5.29	68.35	-3.44	-1.17	-.93	-1.19	-.72	25028	16394
.710	31.37	-3.89	-5.15	67.98	-3.96	-1.11	-1.26	-1.14	-1.01	24417	23149
.720	32.04	-3.99	-5.02	67.62	-4.55	-1.06	-1.46	-1.09	-1.21	23615	27203
.730	32.71	-4.10	-4.90	67.27	-5.16	-1.01	-1.46	-1.09	-1.27	22612	27342
.740	33.37	-4.21	-4.81	66.95	-5.71	-.97	-1.23	-1.00	-1.15	21396	22466
.750	34.03	-4.33	-4.75	66.64	-6.11	-.93	-.80	-.96	-.86	19957	14365
.760	34.69	-4.44	-4.72	66.34	-6.31	-.90	-.22	-.91	-.43	18283	2871
.770	35.34	-4.56	-4.71	66.05	-6.30	-.85	.39	-.86	.04	16362	-9175
.780	36.00	-4.68	-4.69	65.79	-6.11	-.78	.87	-.79	.45	14185	-18724
.790	36.65	-4.79	-4.67	65.55	-5.81	-.68	1.08	-.69	.68	11739	-22648
.800	37.29	-4.90	-4.63	65.35	-5.53	-.52	.90	-.56	.65	9012	-18726
.810	37.94	-5.01	-4.57	65.21	-5.39	-.33	.32	-.39	.35	5994	-6856
.820	38.59	-5.11	-4.51	65.13	-5.48	-.10	-.44	-.19	-.10	2673	9690
.830	39.23	-5.22	-4.49	65.14	-5.78	.14	-1.17	.01	-.44	-963	23503
.840	39.88	-5.33	-4.54	65.22	-6.13	.34	-1.16	.19	-.29	-4926	23567
.850	40.52	-5.44	-4.67	65.37	-6.18	.45	.12	.32	[illegible]	[illegible]	[illegible]

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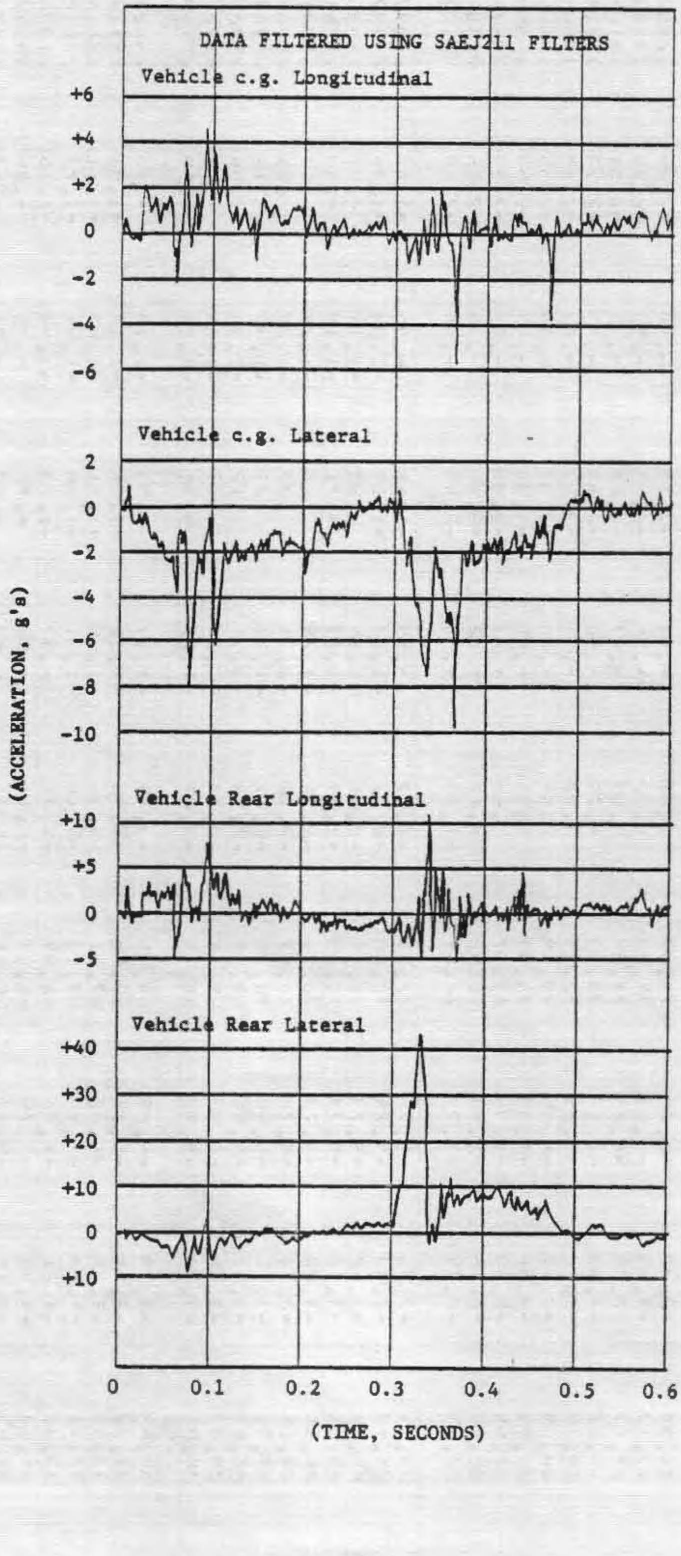


FIGURE 65. ACCELEROMETER DATA, TEST TTR-1

ment. However, the concrete foundation on which the posts were mounted proved to be inadequate. Drilled shaft footings proved to be inadequate due to flooding of the soil at the test site; multiple failures were noted in the concrete beam connecting the footings between Posts 8 through 16. Also, these foundation failures permitted more post leaning and barrier deflection than is considered allowable. Reconstruction/strengthening of the foundation was required prior to further testing. Barrier deflections are contained in Table 8, and barrier damage photographs are shown in Figure 66.

Vehicle Damage: As described previously, the bus sustained front suspension and steering linkage damage. In addition to the right front fender being torn off, the entire right side received damage in the rollover and subsequent sliding on the concrete pavement. The right corner of the front bumper was displaced rearward and embedded in the right front tire. Although all seat bottom cushions and sandbags were thrown out of the seats and scattered throughout the bus, no seat frame failures were noted. Photographs of vehicle damage are shown in Figure 67.

TEST TTR-2

Purpose: Purpose of this test was to evaluate the performance of a modified thru-truss retrofit bridgerail system when impacted by a 20,000-lb (9,072-kg) school bus at 55 mph (88.5 kmph) and a 15-deg angle.

Test Installation: The thru-truss retrofit system was installed on a 152-ft (46-m) long concrete foundation which simulated a bridge deck. The retrofit consisted of a 5-ft (1.5-m) high channel upper rail and a 32-in. (0.8-m) high tubular thrie beam lower rail attached to W6x25 posts spaced at 5-ft (1.5-m) intervals. A triangular notch in the web of the posts was incorporated to reduce the impact loads in the bus wheel. Each post was attached to the foundation with four 7/8-in. (22-mm) dia high strength anchor bolts. The tubular thrie beam lower rail was transitioned upstream into a single thrie beam and then finally into standard G4 approach guardrail with breakaway cable terminal end treatment. Photographs of the test installation are shown in Figure 68.

Test Vehicle: A 1966 International chassis with a 72-passenger Wayne school bus body was the test vehicle. To achieve the desired weight and simulate passenger loading, 6,600 lb (3000 kg) of ballast was placed in the seats. Sandbags were not secured.

Performance: Impact conditions for the bus were 56.1 mph (90.3 kmph) and a 17.8-deg angle. Initial contact with the lower rail occurred 3.4 ft (1.0 m) downstream of Post 13. As shown in the sequential photos of Figure 69, the bus impacted the barrier, rolled toward it as it was redirected (maximum roll angle 12.5 deg) and then returned to an upright position. As the bus continued after losing contact with the installation it began a hard swerve to the

TABLE 8

TEST TTR-1 BARRIER DEFLECTIONS

Location - Post No.	Upper Rail Deflection (in.)	Lower Rail Deflection (in.)
1 thru 6	0	0
7	0.25	0.50
8	1.25	1.25
9	3.25	1.75
10	6.38	4.75
11	9.63	7.00
12	10.25	8.50
13	10.00	8.25
14	8.75	7.00
15	6.50	5.00
16	4.13	2.75
17	2.25	2.25
18	1.13	1.50
19	0.25	1.00
20	0	1.00
21 thru 30	0	0

Note: Multiply inches by 25.4 to convert to millimeters

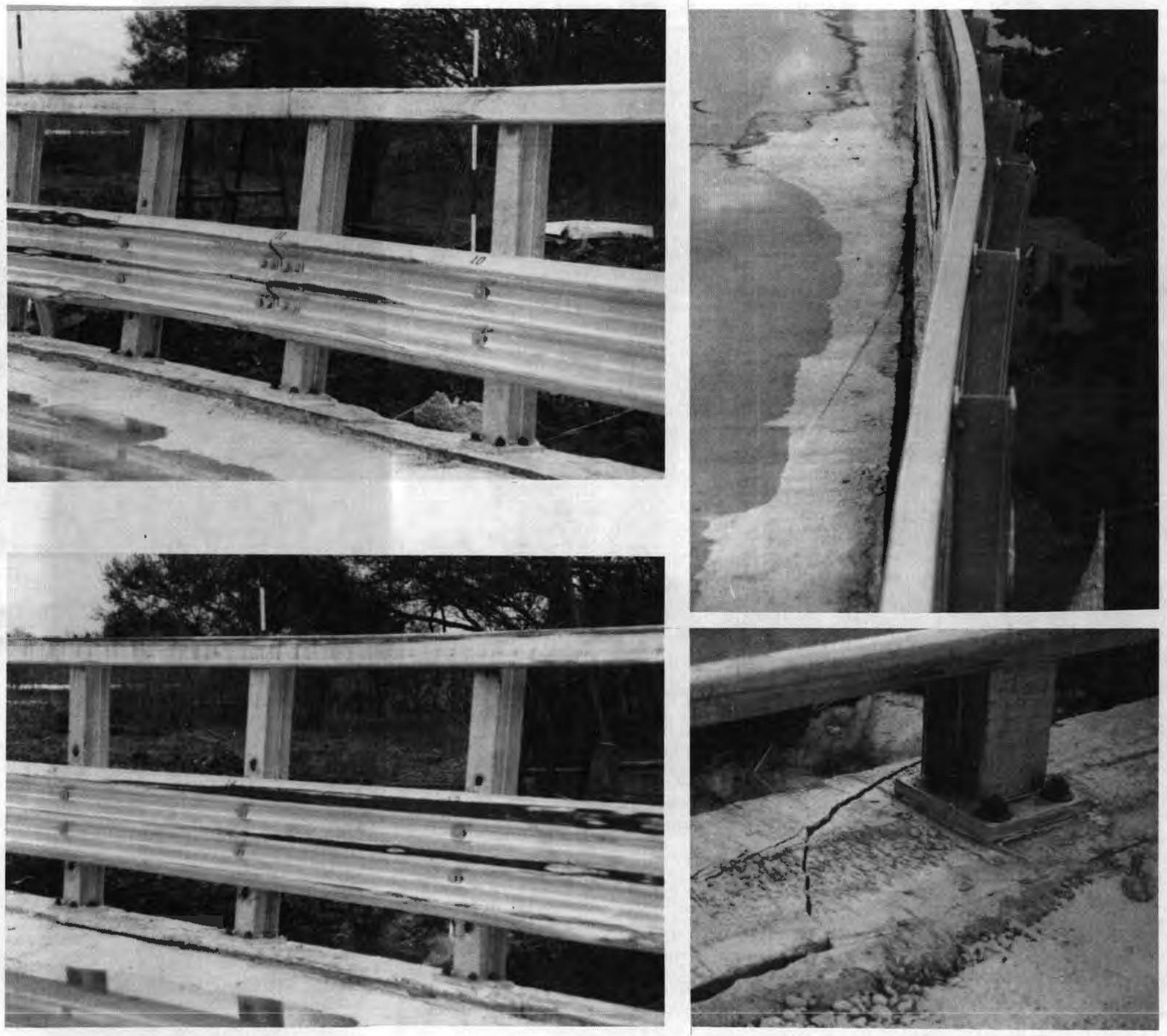


FIGURE 66. TEST TTR-1 BARRIER DAMAGE

FIGURE 67. TEST TTR-1 VEHICLE DAMAGE

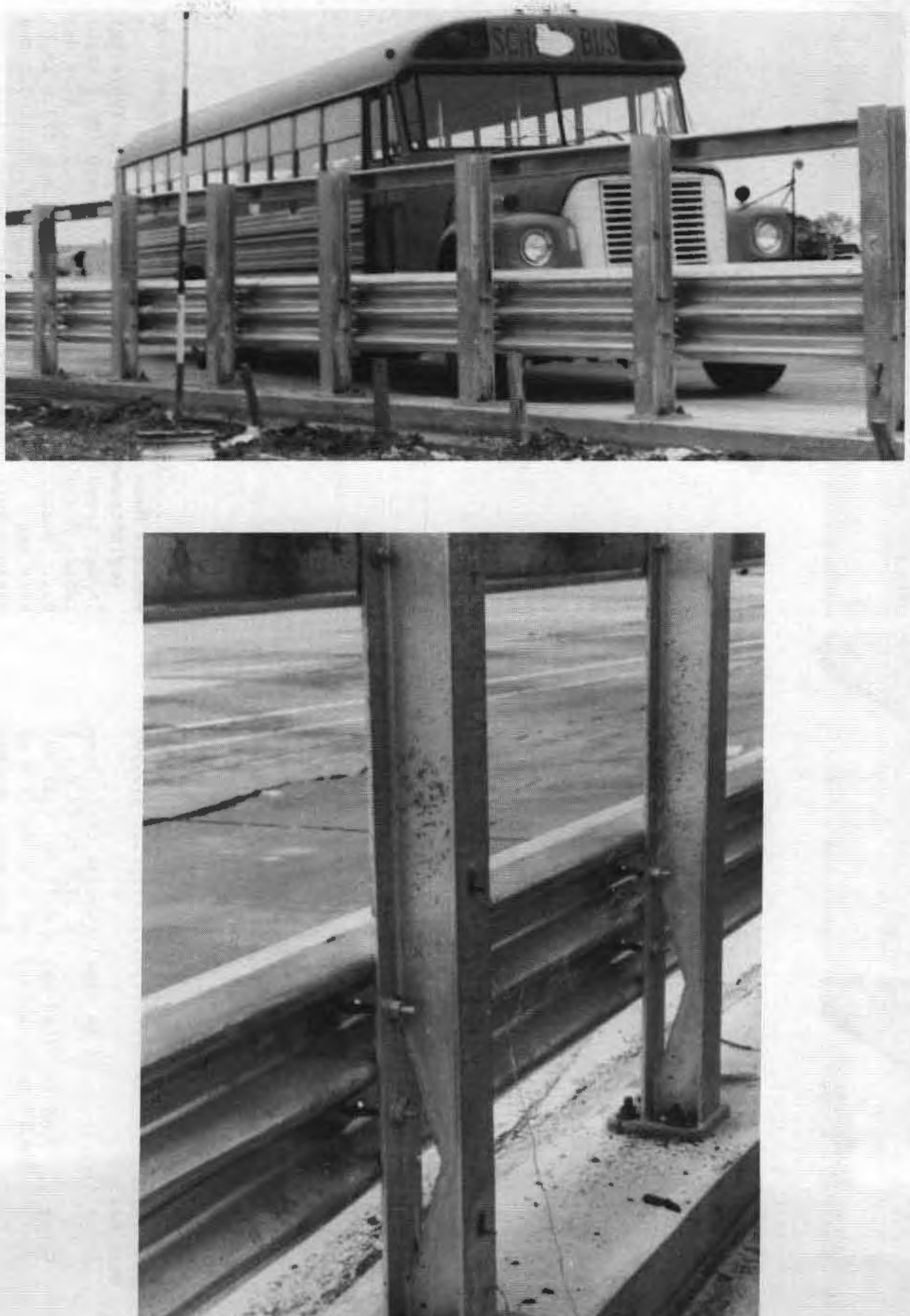
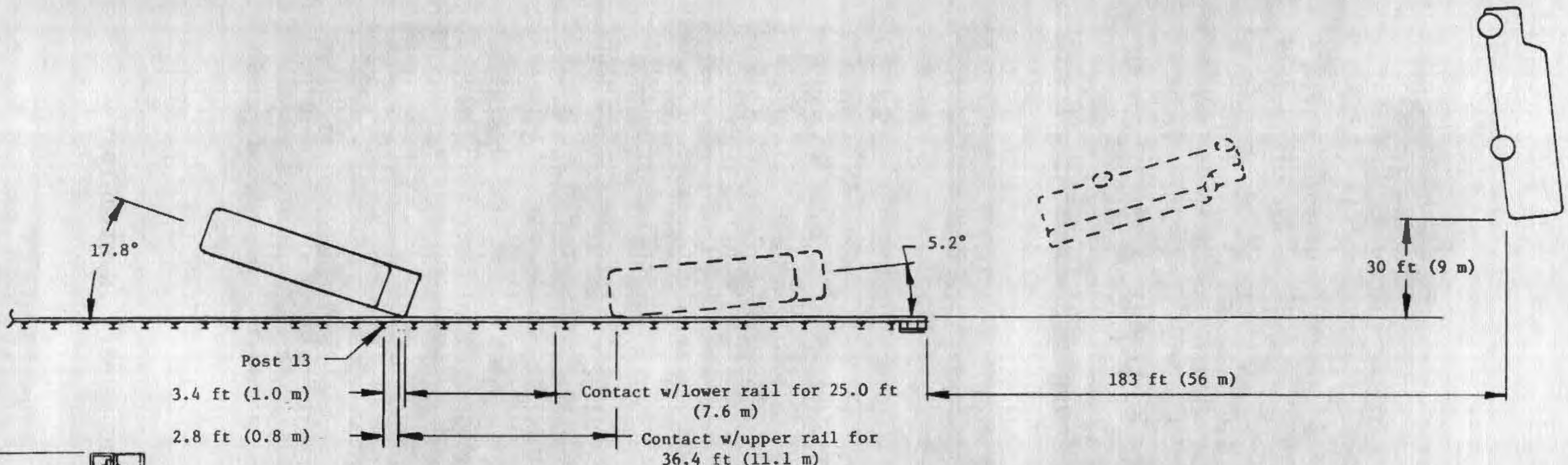
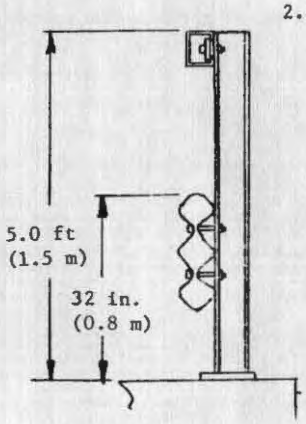


FIGURE 68. NOTCHED POST





Barrier Cross-Section

Test No. TTR-2
Date 5/27/80
Beam Rail:
  Lower .... 12 ga steel tubular thrie beam x 25.0 ft (7.6 m)
  Upper ... 5.88 in. (149 mm) x 4.75 in. (121 mm) x 0.17 in. thk (4.3 mm) x 25 ft (7.6 m) long steel channel
Post .... W6x25 steel x 5 ft (1.5 m)
Post Spacing .... 5 ft (1.5 m)
Length of Installation .... 145 ft (44.2 m)
Upper Beam Rail Deflection:
  Max Dynamic .... 8.6 in. (218 mm)
  Max Permanent .... 4.0 in. (102 mm)

Vehicle ... 1966 International Chassis/Superior Body
Vehicle Mass
  (w/instrumentation)........... 20,000 lb (9072 kg)
Impact Speed .... 56.1 mph (90.2 kmph)
Impact Angle .... 17.8 deg
Exit Speed .... 48.2 mph (77.6 kmph)
Exit Angle .... -5.2 deg
Maximum Roll Angle (During Impact Sequence).12.5 deg
Vehicle Accelerations (max 50 ms avg):
  Lateral (Cine/Electronic) .... 3.3 g/4.0 g
  Longitudinal (Cine/Electronic) ..... -3.0 g/-1.5 g

FIGURE 69. SUMMARY OF RESULTS, TEST TTR- 2

left due to front suspension and steering linkage failure inflicted during the impact, and rolled onto its right side, sliding to a stop 270 ft (82 m) past barrier Post 13. Post-test examination revealed that the rivets which attach the front spring hanger brackets to the frame were sheared on both sides. This allowed the front axle and springs to rotate (in a yaw direction) as the right front wheel was pushed rearward by the lower rail. This in turn caused the steering pitman arm/wheel link connection to fail and the bus front wheels to be turned and locked into a hard left turn position.

Maximum 50 msec average accelerations measured from high-speed film/accelerometers were 3.3/4.0 g (lateral) and -3.0/-1.5 g (longitudinal); a summary of test results is shown in Figure 69. Results of high-speed film analysis are summarized in Table 9 are accelerometer data are shown in Figure 70.

Barrier Damage: Damage to the barrier itself was relatively minor - only two upper and two lower rail sections required replacement. The concrete foundation on which the posts were mounted proved to be adequate.

The notched posts performed as designed; Posts 15, 16 and 17 deformed locally as shown in Figure 71. Due to barrier construction details, the beams are not attached to the posts at the splices; Post 16 remained detached from the railing system after test. The wheel cut a gouge in the lower corrugation of the tubular thrie beam at Post 16 splice. Permanent barrier deflections are given in Table 10.

Vehicle Damage: As described previously, the bus sustained front suspension and steering linkage damage. In addition to the right front fender being torn off, the entire right side received damage in the rollover and subsequent sliding on the concrete pavement. The right corner of the front bumper was displaced rearward and embedded in the right front tire. Although all seat bottom cushions and sandbags were thrown out of the seats and scattered throughout the bus, only one seat frame failure was noted. Photographs of vehicle damage are shown in Figure 72.

Strain Gage Data: Strain gages were placed on Posts 12 thru 18 as described in Table 11; Figure 73 contains the data. Due to local deformations occurring at the notch locations, the lower gage readings do not necessarily provide a measure of the bending moment on the post cross section. Based on analysis of strains (Gages 25 and 26) at Post 18, the apparent upper rail maximum load resisted by a post was 8.5 kips.

TEST TTR-3

Purpose: Purpose of this test was to evaluate the performance of a self-restoring thru-truss bridgerail system when impacted by a 20,000-lb (9,072-kg) school bus at 55 mph (88.5 kmph) and a 15-deg angle.

TABLE 9

FILM ANALYSIS DATA - TEST TTR-2

SUMMARY OF VEHICLE KINEMATIC AND DYNAMIC DATA THRU-TRUSS BRIDGERAIL TEST TTR-2 5/27/80

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 AVER .05 SEC. LONG	LAT	APPROX. BARRIER FORCES(LB) X	Y
0.000	-1.11	-8.21	17.76	82.21	1.23	-2.36	.89	0.00	0.00	50374.	-2644.
.010	-.33	-7.95	17.73	81.39	1.51	-2.68	.55	0.00	0.00	54457.	5467.
.020	.44	-7.69	17.70	80.49	1.65	-2.91	.14	0.00	0.00	56265.	15002.
.030	1.19	-7.43	17.67	79.53	1.67	-3.04	-.31	-2.89	-.12	56052.	24417.
.040	1.94	-7.17	17.63	78.54	1.54	-3.09	-.79	-2.99	-.56	54112.	33714.
.050	2.68	-6.92	17.58	77.54	1.29	-3.06	-1.26	-3.01	-1.02	50758.	42550.
.060	3.41	-6.68	17.49	76.57	.93	-2.97	-1.72	-2.96	-1.47	46305.	50629.
.070	4.14	-6.44	17.37	75.64	.46	-2.82	-2.14	-2.85	-1.89	41061.	57702.
.080	4.85	-6.22	17.21	74.76	-.08	-2.63	-2.51	-2.69	-2.28	35314.	63580.
.090	5.56	-6.00	17.00	73.95	-.67	-2.40	-2.83	-2.48	-2.62	29326.	68128.
.100	6.27	-5.80	16.74	73.22	-1.29	-2.14	-3.08	-2.25	-2.89	23327.	71267.
.110	6.97	-5.61	16.42	72.58	-1.90	-1.87	-3.25	-1.99	-3.10	17513.	72972.
.120	7.67	-5.43	16.04	72.04	-2.49	-1.59	-3.35	-1.72	-3.24	12044.	73269.
.130	8.37	-5.26	15.60	71.59	-3.02	-1.31	-3.38	-1.44	-3.31	7042.	72229.
.140	9.07	-5.10	15.10	71.25	-3.47	-1.04	-3.34	-1.17	-3.31	2595.	69965.
.150	9.77	-4.95	14.53	70.99	-3.83	-.78	-3.24	-.91	-3.25	-1242.	66620.
.160	10.46	-4.82	13.90	70.82	-4.07	-.53	-3.08	-.66	-3.12	-4446.	62370.
.170	11.16	-4.69	13.21	70.74	-4.18	-.31	-2.87	-.43	-2.95	-7020.	57406.
.180	11.86	-4.57	12.47	70.72	-4.15	-.12	-2.63	-.22	-2.73	-8990.	51936.
.190	12.56	-4.47	11.68	70.77	-3.98	.04	-2.37	-.04	-2.49	-10399.	46174.
.200	13.26	-4.37	10.85	70.86	-3.67	.18	-2.09	.10	-2.22	-11308.	40331.
.210	13.97	-4.27	9.98	70.98	-3.23	.28	-1.81	.22	-1.95	-11785.	34614.
.220	14.67	-4.18	9.08	71.13	-2.65	.36	-1.54	.32	-1.69	-11904.	29215.
.230	15.38	-4.10	8.17	71.29	-1.97	.41	-1.29	.38	-1.43	-11742.	24311.
.240	16.09	-4.02	7.24	71.46	-1.19	.44	-1.07	.42	-1.20	-11372.	20053.
.250	16.80	-3.94	6.31	71.61	-.35	.45	-.88	.44	-1.01	-10865.	16566.
.260	17.51	-3.87	5.39	71.76	.55	.45	-.74	.45	-.85	-10279.	13946.
.270	18.23	-3.80	4.48	71.88	1.47	.43	-.65	.44	-.73	-9666.	12255.
.280	18.94	-3.73	3.59	71.99	2.39	.42	-.60	.43	-.67	-9064.	11524.
.290	19.66	-3.66	2.73	72.08	3.28	.40	-.61	.41	-.64	-8495.	11747.
.300	20.38	-3.59	1.90	72.15	4.11	.38	-.66	.39	-.67	-7972.	12885.
.310	21.10	-3.53	1.11	72.20	4.88	.36	-.75	.37	-.74	-7491.	14868.
.320	21.82	-3.47	.37	72.25	5.55	.35	-.88	.36	-.84	-7036.	17544.
.330	22.55	-3.41	-.32	72.29	6.12	.33	-1.04	.34	-.99	-6578.	20935.
.340	23.27	-3.35	-.96	72.33	6.56	.32	-1.23	.33	-1.15	-6079.	24739.
.350	23.99	-3.30	-1.54	72.36	6.87	.31	-1.43	.32	-1.34	-5495.	28835.
.360	24.72	-3.26	-2.07	72.39	7.04	.30	-1.64	.31	-1.54	-4774.	33040.
.370	25.45	-3.21	-2.54	72.43	7.07	.28	-1.85	.28	-1.74	-3867.	37163.
.380	26.17	-3.18	-2.96	72.46	6.97	.24	-2.04	.25	-1.93	-2723.	41009.
.390	26.90	-3.15	-3.32	72.49	6.74	.19	-2.21	.21	-2.10	-1300.	44391.
.400	27.63	-3.13	-3.62	72.51	6.39	.13	-2.35	.15	-2.25	435.	47134.
.410	28.36	-3.11	-3.88	72.51	5.94	.04	-2.46	.07	-2.37	2503.	49040.
.420	29.08	-3.11	-4.09	72.48	5.40	-.07	-2.52	-.03	-2.44	4906.	50097.
.430	29.81	-3.11	-4.26	72.43	4.80	-.19	-2.53	-.14	-2.47	7626.	50095.
.440	30.53	-3.12	-4.39	72.33	4.16	-.34	-2.48	-.28	-2.46	10621.	48982.
.450	31.26	-3.14	-4.48	72.19	3.49	-.51	-2.39	-.43	-2.38	13825.	46747.
.460	31.98	-3.16	-4.55	71.99	2.83	-.68	-2.23	-.60	-2.26	17143.	43466.
.470	32.70	-3.19	-4.59	71.74	2.20	-.86	-2.03	-.77	-2.09	20456.	39197.
.480	33.41	-3.23	-4.61	71.43	1.61	-1.04	-1.79	-.94	-1.87	23617.	33958.
.490	34.12	-3.28	-4.62	71.07	1.09	-1.21	-1.51	-1.11	-1.62	26454.	28078.
.500	34.83	-3.33	-4.62	70.66	.65	-1.35	-1.20	-1.25	-1.33	28779.	21710.
.510	35.53	-3.38	-4.61	70.21	.30	-1.45	-.88	-1.36	-1.03	30389.	15143.
.520	36.23	-3.43	-4.60	69.73	.05	-1.51	-.56	-1.44	-.73	31075.	8885.
.530	36.92	-3.49	-4.58	69.24	-.09	-1.52	-.26	-1.46	-.43	30639.	2673.
.540	37.61	-3.54	-4.58	68.76	-.14	-1.45	.01	-1.42	-.15	28898.	-2560.
.550	38.29	-3.60	-4.57	68.31	-.10	-1.31	.23	-1.31	.06	25710.	-6604.
.560	38.97	-3.66	-4.58	67.93	.00	-1.08	.37	-1.12	.23	20968.	-9193.
.570	39.65	-3.71	-4.59	67.63	.16	-.77	.44	-.85	.33	14730.	-10028.
.580	40.32	-3.76	-4.62	67.44	.33	-.39	.42	-.51	.34	7041.	-8908.
.590	40.99	-3.81	-4.66	67.38	.49	.07	.29	-.11	.27	-1829.	-5745.

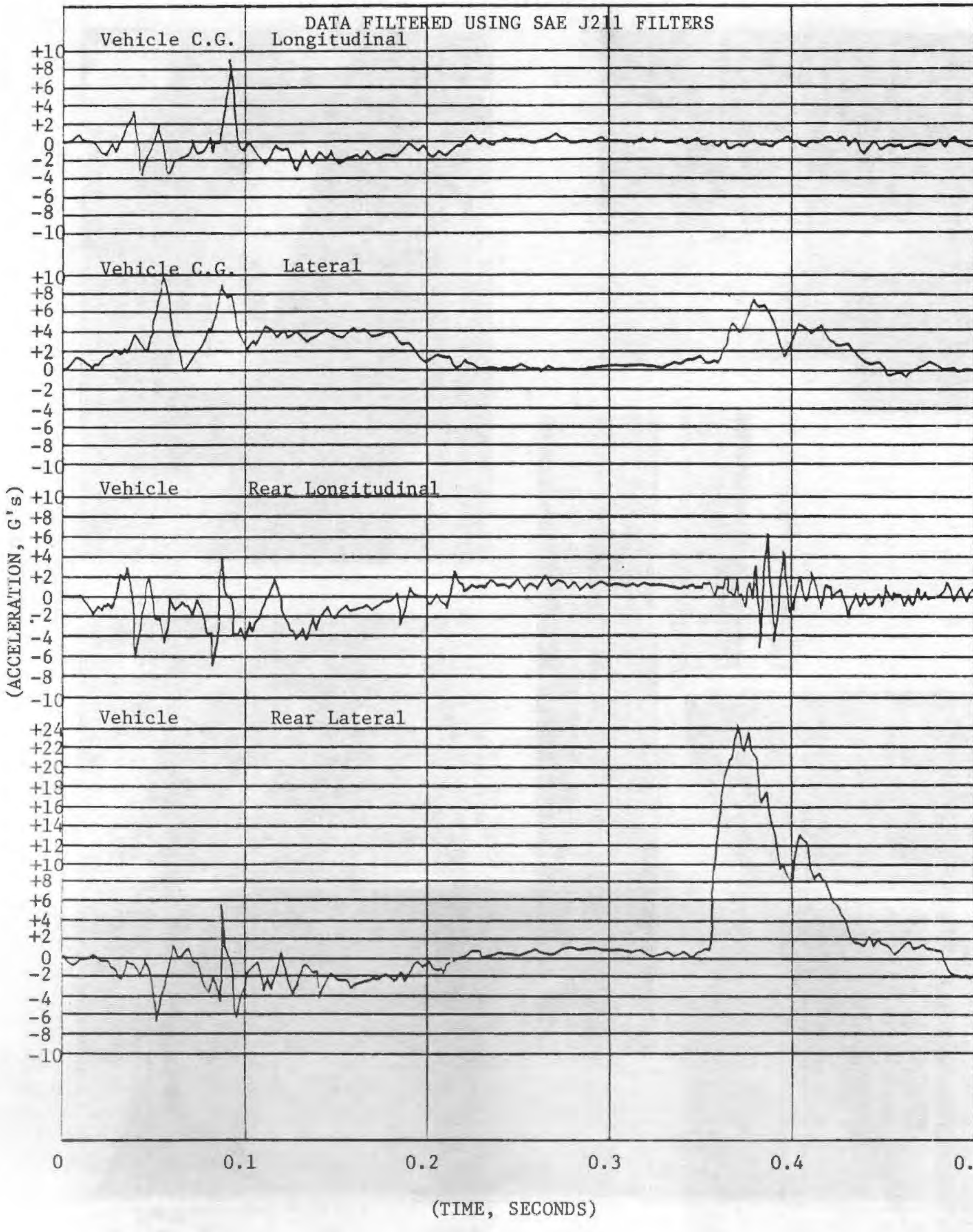


FIGURE 70. TEST TTR-2 ACCELEROMETER DATA

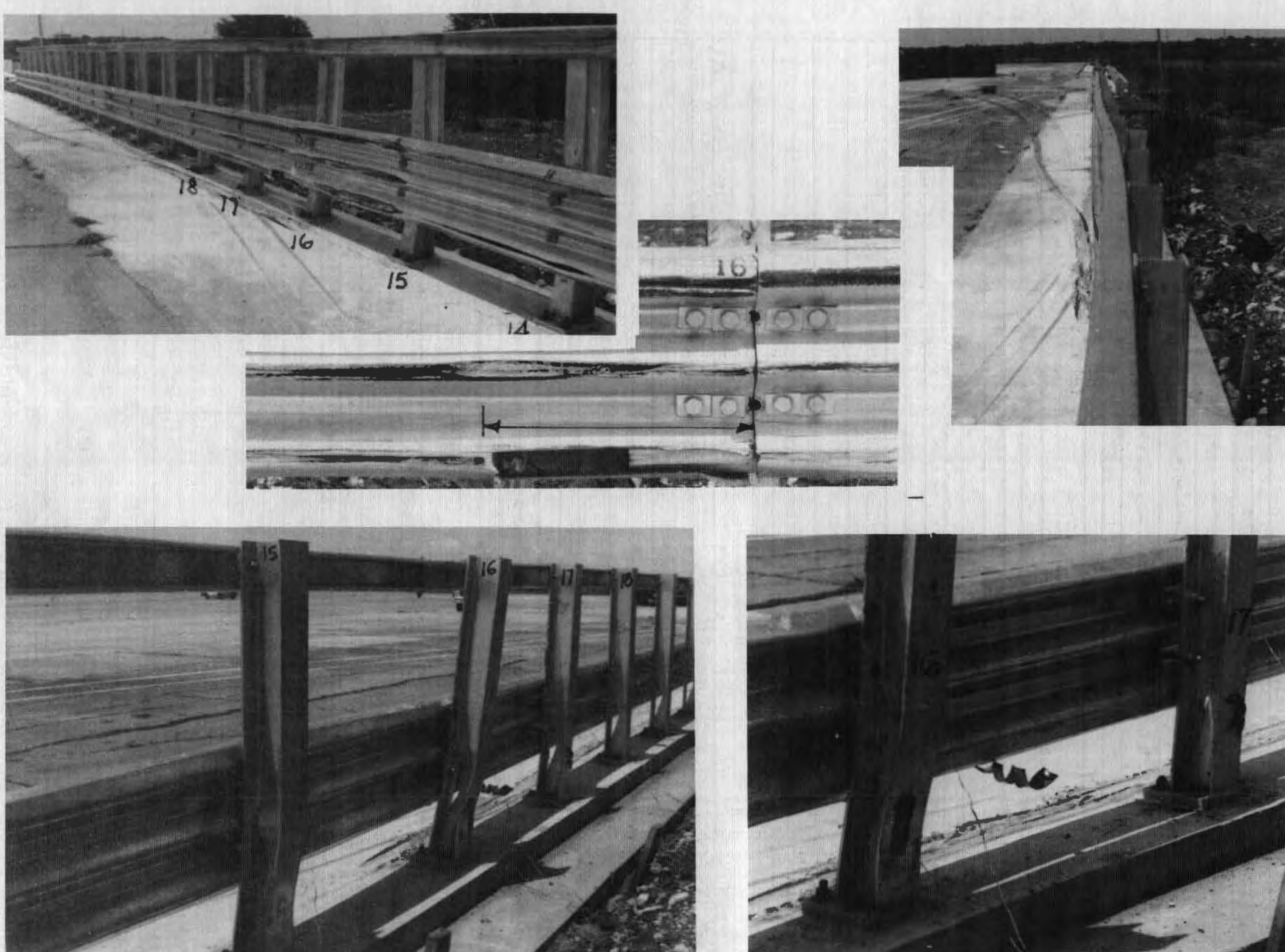


FIGURE 71. TEST TTR-2 BARRIER DAMAGE

TABLE 10

TTR-2 BARRIER DEFLECTION SUMMARY

Location-Post No.	Deflection-Top of Post (in.)	Rail Deflection Upper (in.)	Rail Deflection Lower (in.)
1-11	0	0	0
12	1.06	1.06	0.63
13	2.50	2.50	1.50
14	3.56	3.56	3.13
15	4.62	4.00	4.25
16	7.13	3.88	2.75
17	2.19	2.19	1.88
18	1.06	1.06	1.38
19	0.44	0.44	0.88
20	0	0	0.75
21-30	0	0	0

Note: Vehicle Sheet Metal Contact w/Posts 16 & 17

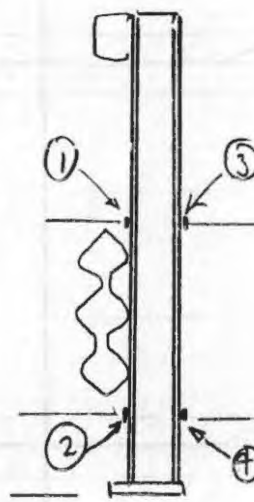
after uprighting

FIGURE 72. TTR-2 VEHICLE DAMAGE

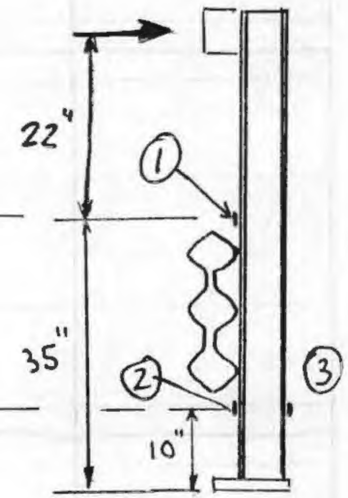
TABLE 11

STRAIN GAGE LOCATIONS

GAGE NO.	SCHEME A No.	SCHEME B No.	POST No
1	1		12
2	3		↑
3	2		↓
4	4		12
5		1	13
7		3	13
9	1		14
10	3		↑
11	2		↓
12	4		14
13		1	15
15		2	15
17	1		16
18	3		↑
19	2		↓
20	4		16
21		1	17
23		2	17
25	1		18
26	3		↑
27	2		↓
28	4		18



SCHEME A



SCHEME B

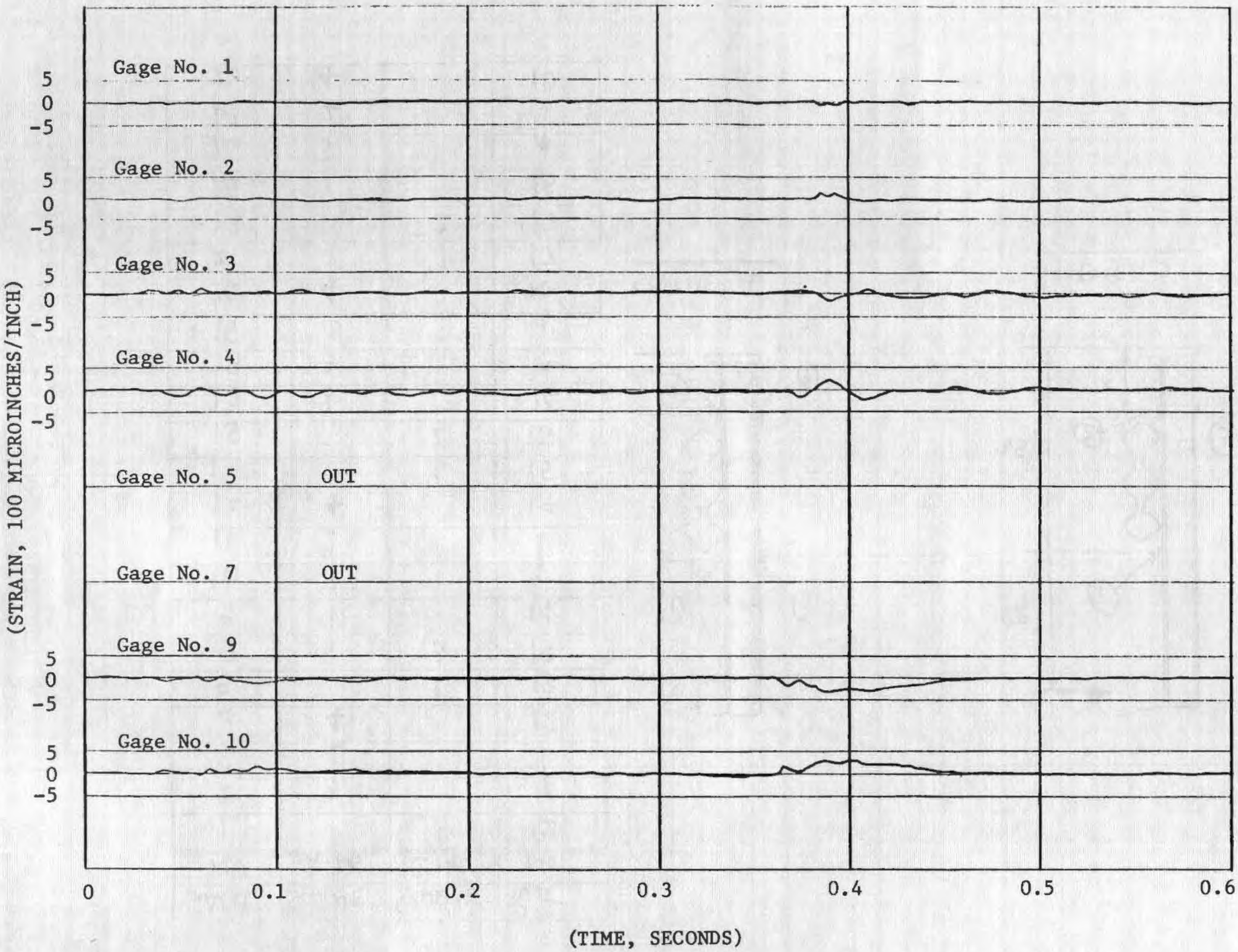


FIGURE 73. TEST TTR-2 STRAIN GAGE DATA

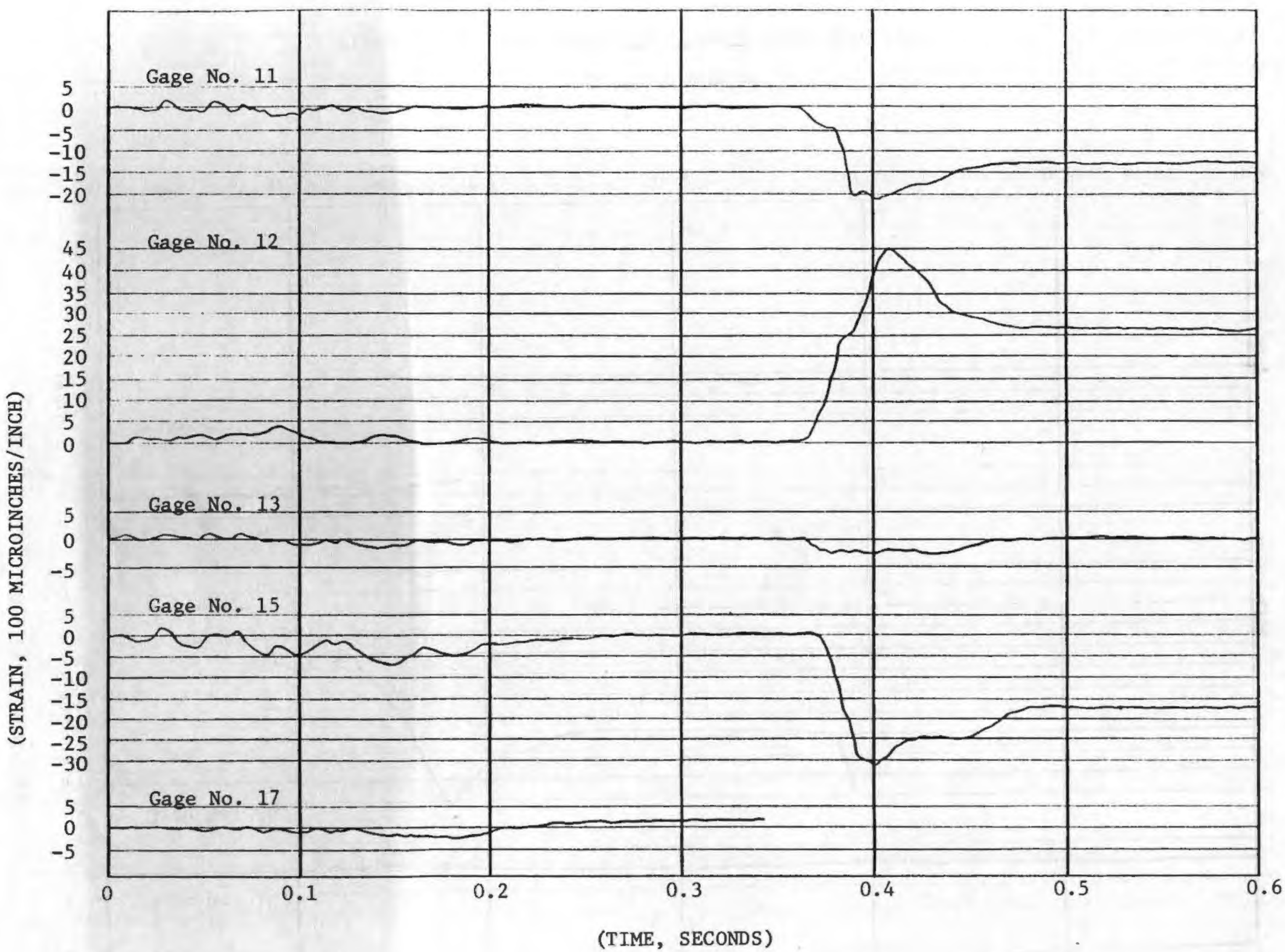


FIGURE 73. TEST TTR-2 STRAIN GAGE DATA (Cont'd)

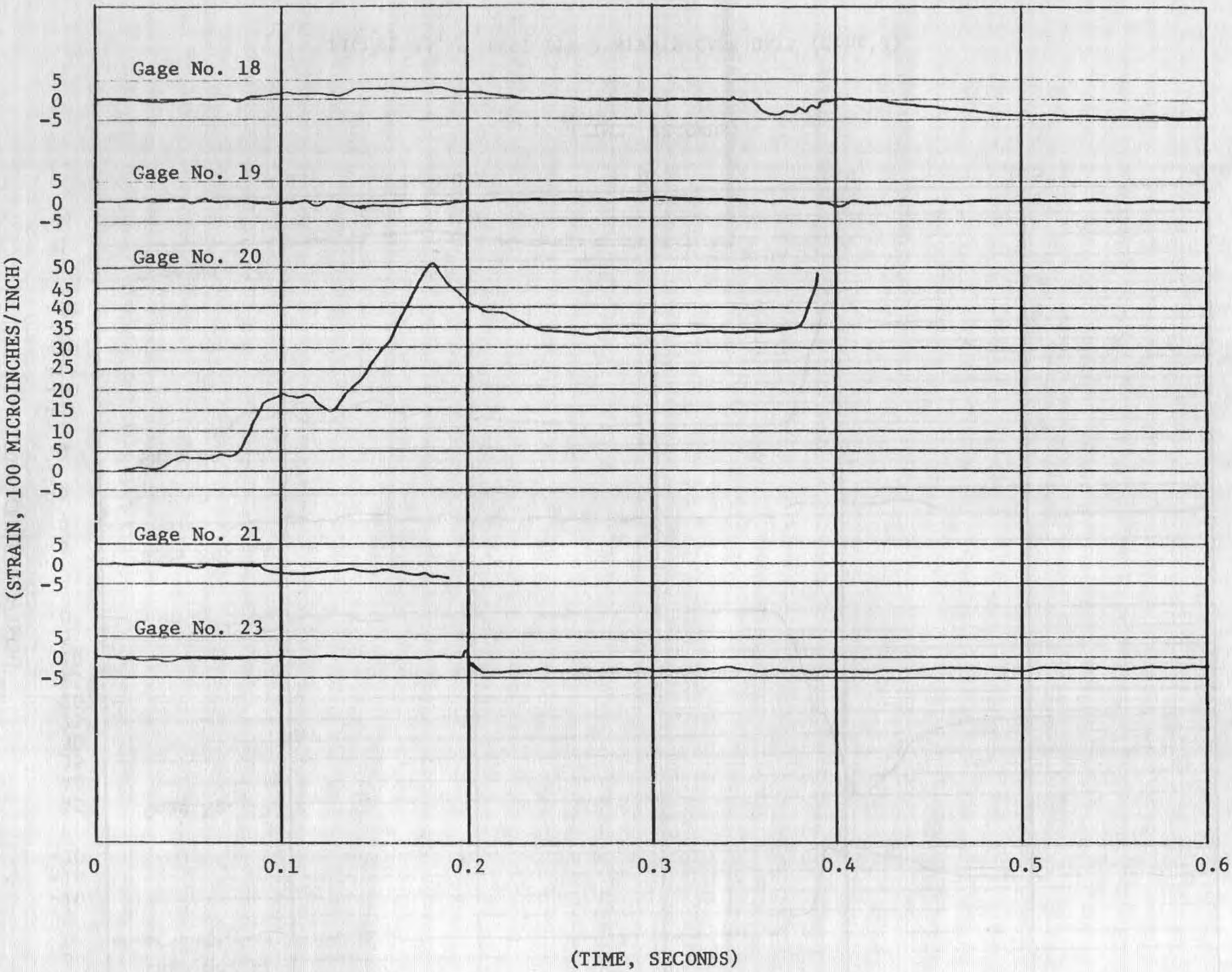


FIGURE 73. TEST TTR2 STRAIN GAGE DATA (Cont'd)

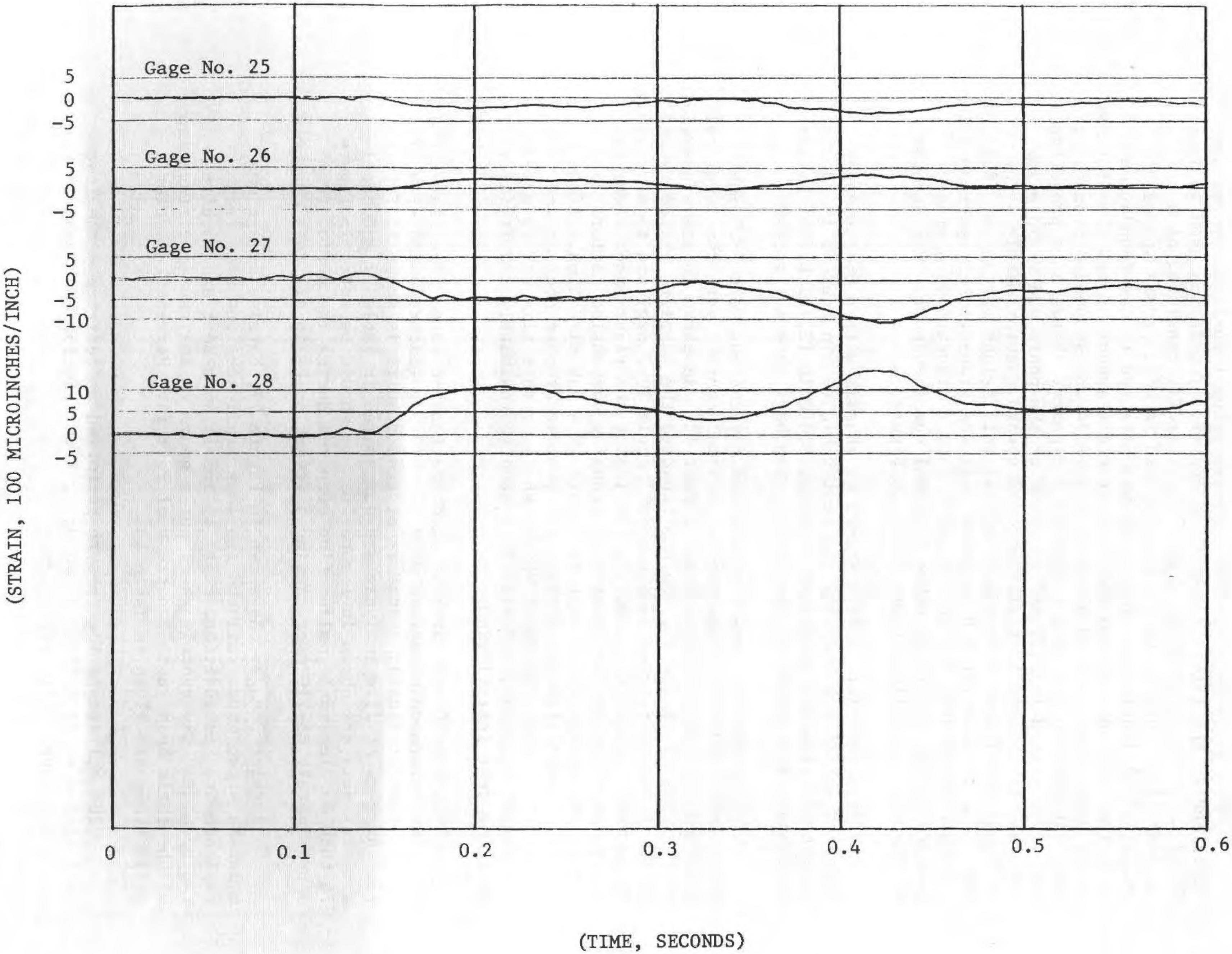


FIGURE 73. TEST TTR2 STRAIN GAGE DATA (Cont'd)

Test Installation: The self-restoring thru-truss system was installed on the 152-ft (46-m) long concrete foundation used in Test TTR-2 to simulate a bridge deck. The retrofit consisted of a 5-ft (1.5-m) high channel upper rail attached to W6x25 posts spaced at 5-ft (1.5-m) intervals. Each post was attached to the foundation with four 7/8-in. (22-mm) dia high-strength anchor bolts. The tubular thrie beam lower rail as shown in Figure 74 was suspended from pivot bars attached to the rear flange of the posts. These bars projected the lower rail 3 in. (75 mm) in front of the posts and would allow the rail to deflect both rearward and upward (approximately 4 in. [100 mm] rise) when impacted. Initial rail height was 33 in. (838 mm). The tubular thrie beam lower rail was transitioned upstream into a single thrie beam and then finally into a standard G4 approach guardrail with breakaway cable terminal end treatment. Photographs of the test installation are shown in Figure 74.

Test Vehicle: A 1969 Chevrolet chassis with a 66-passenger Bluebird school bus body was the test vehicle. To achieve the desired weight and simulate passenger loading, 6,000 lb (2,722 kg) of ballast (sandbags) was placed in the seats. Sandbags were not secured.

Performance: Impact conditions for the bus were 53.9 mph (96.7 kmph) and a 15.3-deg angle. Initial contact with the lower rail occurred 2 ft (61 m) downstream of Post 13. As shown in the sequential photographs of Figure 75, the bus impacted the barrier, rolled toward it as it was redirected (maximum roll angle 10.7 deg) and then returned to an upright position. During the impact the right front wheel was pushed rearward by the lower rail, causing suspension failure, and forced the entire front axle to rotate in a yaw direction. After losing contact with the barrier the vehicle dropped down at the right front corner onto the front wheel, which by this time was in a near horizontal attitude, and slid to a stop approximately 130 ft (42 m) past the test installation.

Maximum 50 msec average accelerations measured from high-speed film analysis/accelerometers were 2.3 g/3.5 g (lateral) and -1.9 g/ -1.3 g (longitudinal); a summary of test results is shown in Figure 75. Results of film analysis are summarized in Table 12 and accelerometer data are shown in Figure 76. It should be noted in Figure 76 than an electronic malfunction occurred during the period from approximately 85-110 msec causing a severe spike in all data channels.

Barrier Damage: As shown in Figure 77, barrier damage was moderate - two upper rail and two lower rail sections required replacement. In addition, Posts 15 and 16 were bent and required replacement. The vehicle wheel cut a gouge in the center corrugation of the thrie beam just downstream of Post 14. Permanent barrier deflections are given in Table 13.

The self-restoring feature performed as designed - the lower rail lifted as it deflected rearward, thus reducing both vehicle roll angle and upper rail deflection.

TABLE 12

FILM ANALYSIS DATA - TEST TTR-3

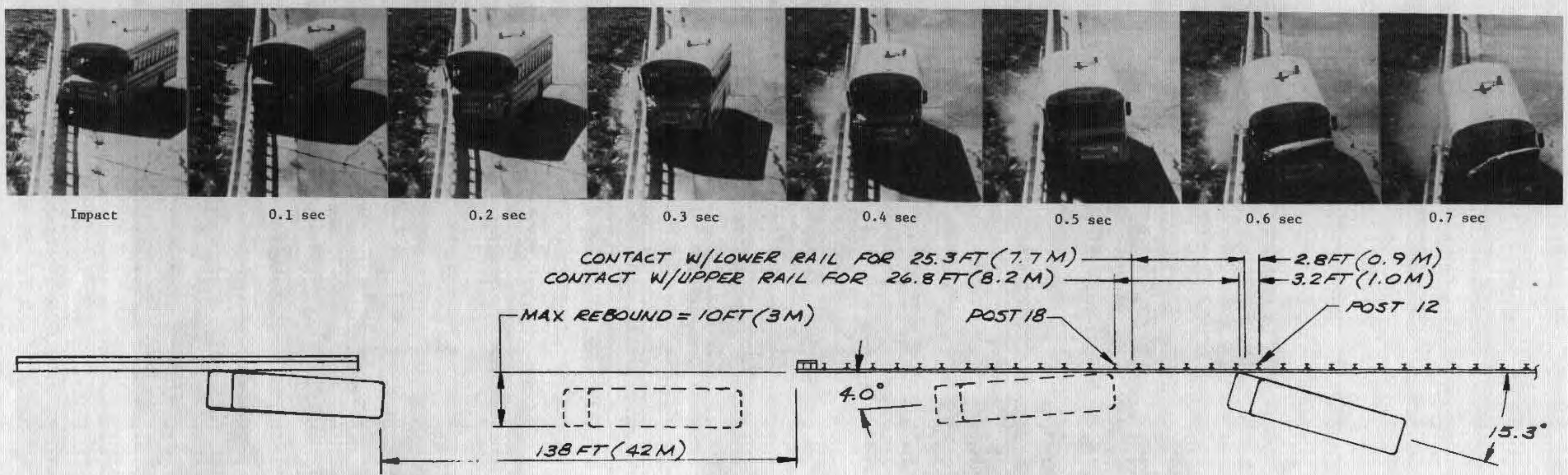
SUMMARY OF VEHICLE KINEMATIC AND DYNAMIC DATA THRU-TRUSS BRIDGERAIL TEST TTR-3 12/10/80

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 AVER .05 SEC. LONG	LAT	APPROX. BARRIER FORCES (LB) X	Y
0.000	-12.78	-12.03	15.33	79.10	-.21	-.67	.44	0.00	0.00	15245.	-4868.
.010	-12.02	-11.82	15.12	78.86	.18	-.84	.23	0.00	0.00	17439.	-142.
.020	-11.26	-11.61	14.96	78.56	.44	-1.00	-.01	0.00	0.00	19358.	5371.
.030	-10.50	-11.41	14.85	78.21	.54	-1.16	-.28	-1.08	-.17	21011.	11399.
.040	-9.75	-11.20	14.79	77.81	.49	-1.31	-.57	-1.23	-.43	22411.	17679.
.050	-9.00	-11.00	14.77	77.37	.29	-1.44	-.86	-1.36	-.71	23567.	23959.
.060	-8.25	-10.80	14.77	76.89	-.03	-1.57	-1.14	-1.49	-.99	24491.	30014.
.070	-7.51	-10.61	14.78	76.36	-.46	-1.67	-1.40	-1.60	-1.25	25192.	35643.
.080	-6.77	-10.42	14.80	75.81	-.97	-1.76	-1.64	-1.70	-1.49	25683.	40679.
.090	-6.04	-10.24	14.80	75.23	-1.54	-1.83	-1.84	-1.78	-1.71	25973.	44991.
.100	-5.31	-10.07	14.79	74.63	-2.14	-1.88	-2.01	-1.84	-1.89	26074.	48482.
.110	-4.59	-9.90	14.73	74.03	-2.74	-1.91	-2.14	-1.87	-2.04	25996.	51089.
.120	-3.87	-9.74	14.64	73.42	-3.32	-1.91	-2.23	-1.89	-2.15	25749.	52787.
.130	-3.15	-9.59	14.49	72.81	-3.86	-1.90	-2.28	-1.89	-2.22	25345.	53580.
.140	-2.44	-9.45	14.28	72.22	-4.33	-1.86	-2.29	-1.86	-2.25	24793.	53502.
.150	-1.73	-9.32	14.00	71.65	-4.72	-1.81	-2.26	-1.81	-2.25	24105.	52615.
.160	-1.02	-9.20	13.66	71.11	-5.01	-1.73	-2.20	-1.75	-2.21	23291.	50999.
.170	-.32	-9.08	13.25	70.60	-5.19	-1.65	-2.12	-1.67	-2.14	22361.	48756.
.180	.37	-8.98	12.77	70.13	-5.27	-1.55	-2.01	-1.58	-2.05	21326.	46001.
.190	1.07	-8.88	12.22	69.70	-5.23	-1.44	-1.88	-1.48	-1.94	20197.	42855.
.200	1.76	-8.78	11.62	69.31	-5.08	-1.33	-1.74	-1.37	-1.81	18983.	39450.
.210	2.45	-8.70	10.96	68.96	-4.83	-1.21	-1.59	-1.25	-1.67	17696.	35913.
.220	3.13	-8.62	10.26	68.64	-4.47	-1.09	-1.45	-1.14	-1.53	16346.	32373.
.230	3.81	-8.54	9.52	68.37	-4.03	-.98	-1.30	-1.02	-1.39	14942.	28949.
.240	4.49	-8.47	8.75	68.12	-3.51	-.86	-1.17	-.91	-1.26	13496.	25751.
.250	5.17	-8.40	7.96	67.91	-2.93	-.75	-1.05	-.80	-1.13	12017.	22876.
.260	5.85	-8.34	7.16	67.72	-2.30	-.65	-.95	-.70	-1.02	10516.	20405.
.270	6.52	-8.28	6.36	67.55	-1.65	-.55	-.86	-.59	-.93	9004.	18402.
.280	7.19	-8.22	5.56	67.41	-.98	-.45	-.81	-.50	-.86	7490.	16912.
.290	7.86	-8.17	4.79	67.28	-.32	-.36	-.77	-.41	-.82	5984.	15960.
.300	8.53	-8.12	4.03	67.18	.31	-.28	-.76	-.32	-.79	4498.	15551.
.310	9.20	-8.07	3.31	67.10	.92	-.20	-.77	-.24	-.79	3040.	15668.
.320	9.87	-8.02	2.62	67.03	1.47	-.12	-.81	-.16	-.81	1621.	16277.
.330	10.54	-7.98	1.98	66.99	1.95	-.04	-.87	-.08	-.86	252.	17324.
.340	11.21	-7.93	1.37	66.96	2.37	.03	-.94	-.00	-.92	-1058.	18741.
.350	11.88	-7.90	.81	66.96	2.72	.10	-1.02	.07	-.99	-2299.	20443.
.360	12.55	-7.86	.29	66.98	2.98	.17	-1.12	.13	-1.08	-3461.	22335.
.370	13.22	-7.83	-.18	67.01	3.15	.23	-1.21	.20	-1.17	-4533.	24314.
.380	13.89	-7.80	-.62	67.07	3.25	.29	-1.31	.26	-1.26	-5506.	26271.
.390	14.56	-7.78	-1.01	67.15	3.27	.34	-1.40	.32	-1.35	-6369.	28097.

TABLE 12 (Cont'd)

.400	15.23	-7.76	-1.36	67.25	3.22	.39	-1.48	.37	-1.42	-7114.	29685.
.410	15.91	-7.75	-1.68	67.37	3.11	.43	-1.53	.41	-1.49	-7729.	30935.
.420	16.58	-7.74	-1.97	67.50	2.95	.46	-1.57	.44	-1.53	-8205.	31758.
.430	17.26	-7.73	-2.23	67.64	2.75	.49	-1.59	.47	-1.55	-8533.	32078.
.440	17.94	-7.74	-2.46	67.79	2.52	.50	-1.57	.49	-1.55	-8702.	31839.
.450	18.62	-7.74	-2.67	67.94	2.27	.51	-1.53	.50	-1.52	-8702.	31004.
.460	19.30	-7.75	-2.87	68.10	2.02	.50	-1.46	.50	-1.46	-8524.	29505.
.470	19.98	-7.77	-3.05	68.25	1.78	.48	-1.35	.48	-1.38	-8159.	27536.
.480	20.66	-7.79	-3.21	68.39	1.56	.45	-1.22	.46	-1.27	-7595.	24962.
.490	21.35	-7.82	-3.36	68.53	1.37	.40	-1.07	.42	-1.13	-6825.	21916.
.500	22.03	-7.84	-3.50	68.65	1.21	.35	-.91	.37	-.98	-5837.	18499.
.510	22.72	-7.88	-3.62	68.74	1.09	.28	-.73	.30	-.81	-4622.	14840.
.520	23.40	-7.91	-3.72	68.82	1.02	.19	-.54	.23	-.63	-3172.	11091.
.530	24.09	-7.94	-3.81	68.86	.98	.10	-.37	.14	-.46	-1475.	7422.
.540	24.78	-7.98	-3.89	68.88	.98	-.01	-.20	.03	-.30	477.	4018.
.550	25.47	-8.02	-3.94	68.85	1.00	-.13	-.06	-.08	-.16	2694.	1064.
.560	26.15	-8.06	-3.98	68.79	1.05	-.26	.04	-.21	-.04	5186.	-1258.
.570	26.84	-8.09	-4.01	68.68	1.10	-.41	.11	-.35	.04	7962.	-2791.
.580	27.53	-8.13	-4.01	68.53	1.15	-.56	.13	-.50	.08	11031.	-3411.
.590	28.21	-8.17	-4.00	68.32	1.17	-.73	.10	-.66	.07	14403.	-3051.
.600	28.89	-8.20	-3.98	68.06	1.17	-.91	.02	-.83	.02	18087.	-1722.
.610	29.57	-8.24	-3.95	67.73	1.12	-1.10	-.10	-1.02	-.07	22093.	462.
.620	30.24	-8.27	-3.91	67.35	1.02	-1.31	-.25	-1.22	-.19	26431.	3254.
.630	30.91	-8.31	-3.87	66.89	.87	-1.53	-.42	-1.44	-.33	31108.	6239.
.640	31.58	-8.35	-3.83	66.36	.67	-1.77	-.56	-1.67	-.45	36135.	8799.
.650	32.24	-8.38	-3.80	65.75	.43	-2.04	-.64	-1.93	-.51	41522.	10068.

FIGURE 74. SELF-RESTORING THRU-TRUSS RETROFIT TEST INSTALLATION



Test No. TTR-3
Date 12/10/80
Beam Rail:
  Lower .... 12 ga. steel tubular thrie beam x 25.0 ft (7.6 m)
  Upper ..5.88 in. (149 mm) x 4.75 in. (121 mm) x 0.17 in. (4.3 mm) thk x 25.0 ft (7.6 m) long steel channel
Post .... W6x25 steel x 5 ft (1.5 m)
Post Spacing .... 5.0 ft (1.5 m)
Upper Beam Rail Deflection:
  Max Dynamic .... 7.78 in. (198 mm)
  Max Permanent .... 3.25 in. (83 mm)

Vehicle .... 1969 Chevrolet Chassis/Bluebird Body
Vehicle Mass
  (w/instrumentation) .... 20,000 lb (9072 kg)
Impact Speed .... 53.9 mph (86.7 kmph)
Impact Angle .... 15.3 deg
Exit Speed .... 44.8 mph (72.2 kmph)
Exit Angle .... -4.0 deg
Maximum Roll Angle .... 10.7 deg
Vehicle Accelerations (max 50 ms avg)
  Lateral (cine/electronic) 2.3g/3.5g
  Longitudinal (cine/electronic) ..... -1.9g/-1.3g

FIGURE 75. SUMMARY OF RESULTS, TEST TTR-3

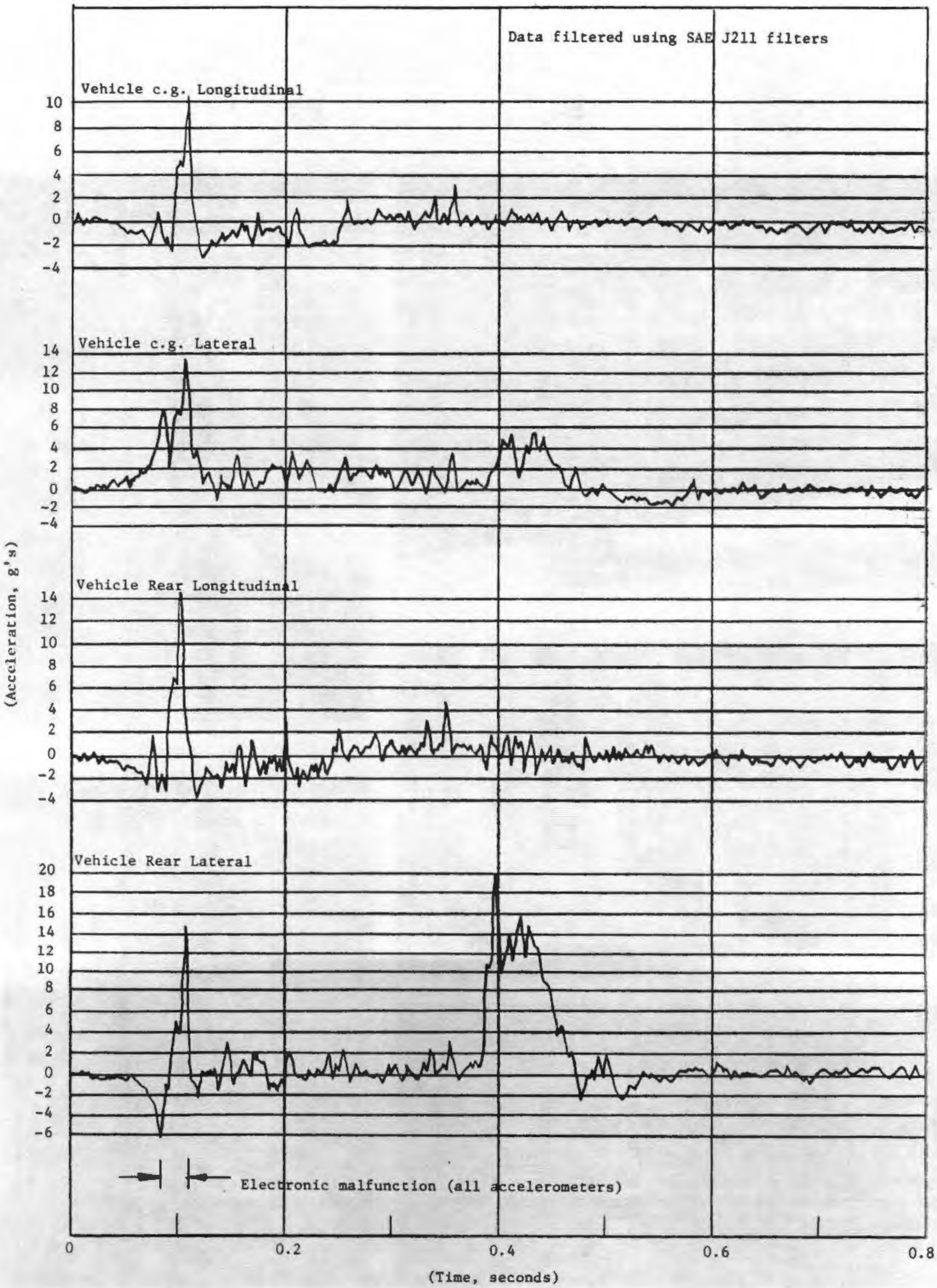


FIGURE 76. ACCELEROMETER DATA, TEST TTR-3

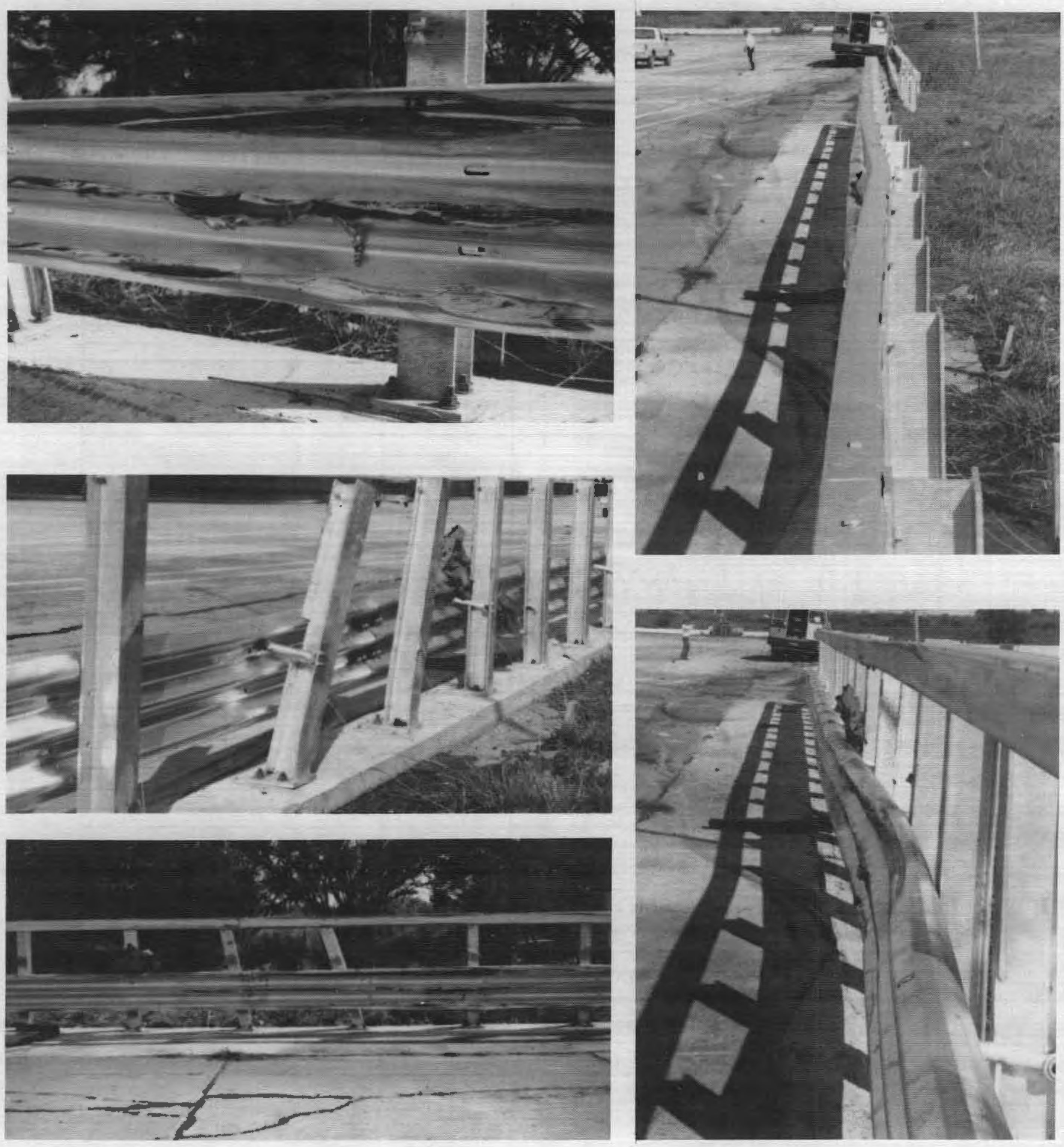


FIGURE 77. TEST TTR-3 BARRIER DAMAGE

TABLE 13

BARRIER DEFLECTIONS, TEST TTR-3

Location - Post No.	Lower Rail Defl (in.)	Upper Rail Defl (in.)
1-11	0	0
12	1.75	0
13	4.88	0.50
14	6.38	1.25
15	4.75	2.25
16	2.75	3.25 (max)
17	1.63	2.13
18	0.88	1.13
19	0.38	0.50
20-30	0	0

Max lower rail deflection - 7.00 in. (occurred 1 ft upstream of Post 14.

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

Vehicle Damage: As described previously, the bus sustained front suspension and steering linkage damage. In addition, the right front fender wedged between the lower rail and Post 17, and was torn off the vehicle. As shown in Figure 78 the area around the passenger service door was heavily damaged and the right side of the windshield thrown out. Although sandbags and seat bottom cushions were thrown out of the seats and scattered throughout the bus no seat frame failures were noted.

TEST TTR-4

Purpose: Purpose of this test was to evaluate the performance of the self-restoring thru-truss bridgerail system when impacted by an 1840-lb (835-kg) minicompact automobile at 60 mph (96.6 kmph) and a 15-deg angle.

Test Installation: The self-restoring thru-truss installation used for Test TTR-3 was repaired and utilized for this test.

Test Vehicle: A 1976 Honda Civic was the test vehicle. Total vehicle weight including instrumentation was 1840 lb (835 kg).

Performance: Impact conditions were 59.8 mph (96.2 kmph) and a 14.8-deg angle. Initial contact with the lower rail occurred 2.4 ft (0.7 m) upstream of Post 16. As shown in the sequential photographs of Figure 79, the vehicle impacted the front rail and, as it was being redirected, lifted the rail while displacing it rearward. After being in contact with the rail for 10 ft (3 m) the vehicle then exited at a -6.9 deg angle, and the front rail returned to its original position.

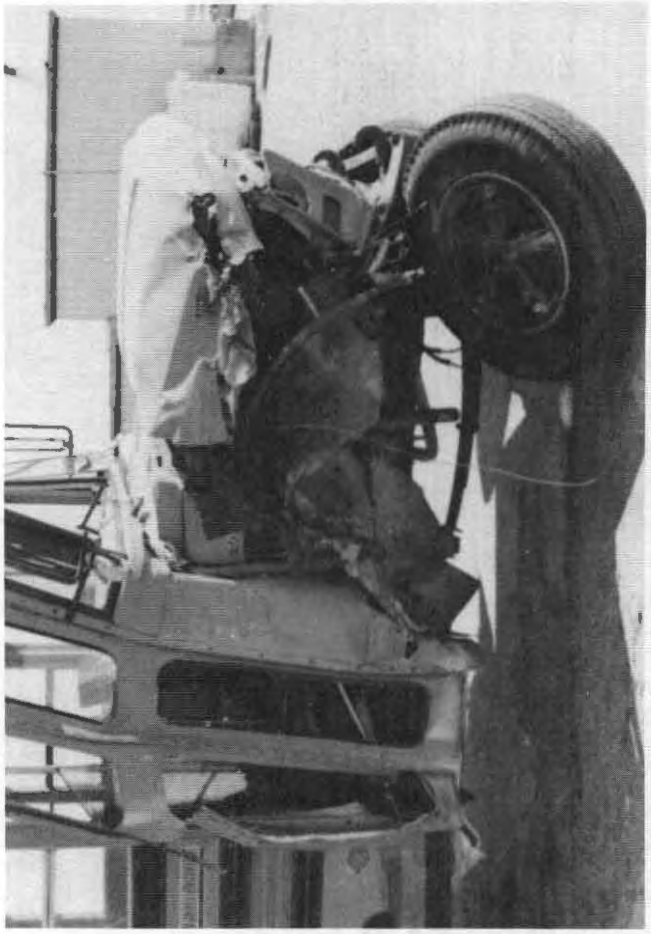
Maximum 50-msec average accelerations measured from high-speed film analysis/accelerometers were 7.3 g/8.1 g (lateral) and -3.0 g/ -2.1 g (longitudinal); a summary of test results is shown in Figure 79. Results of film analysis are summarized in Table 14 and accelerometer data are shown in Figure 80.

Barrier Damage: As shown in Figure 81 the only damage to the barrier was tire scuffing and sheet metal scrape marks on the lower rail. These were easily painted over.

Vehicle Damage: Damage to the test vehicle, also shown in Figure 81, consisted of sheet metal deformation of the right front fender, a bent front bumper, a bent wheel and suspension damage at the right front corner.

TEST TTR-5

Purpose: Purpose of this test was to evaluate the performance of the transition section of the self-restoring thru-truss bridgerail




SCHOOL BUS
14

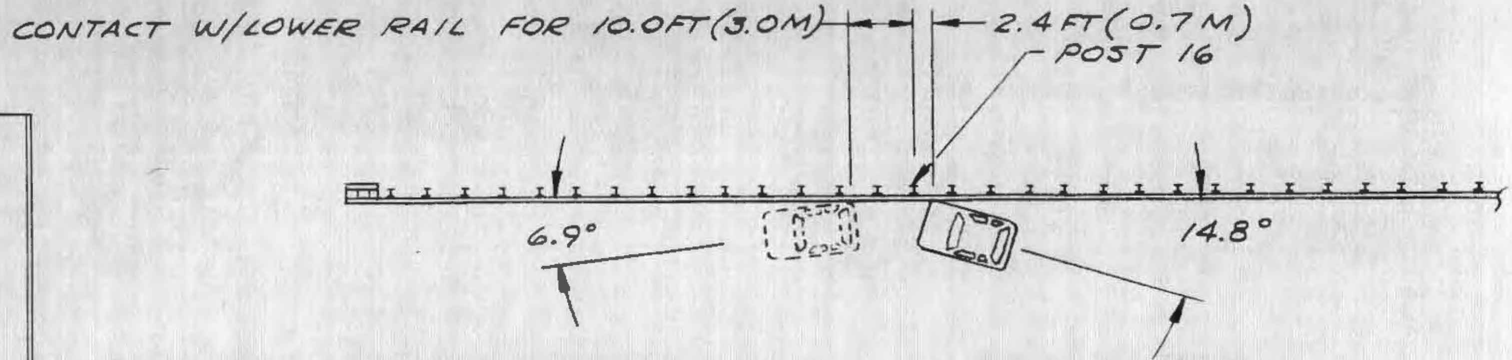

SCHOOL BUS
14
STOP
ON SIGNAL

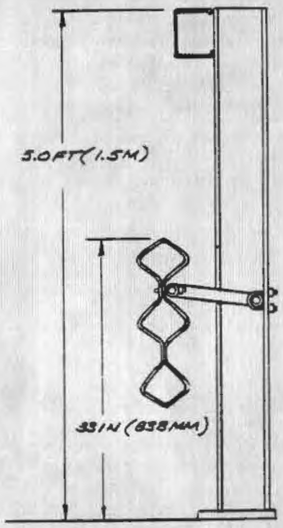
Impact

0.1 sec

0.2 sec

0.3 sec





Self-Restoring
Thru-Truss Bridgerail

Test No.	TTR-4
Date	1/16/81
Beam Rail:	
Lower	12 ga Tubular Thrie Beam x 25.0 ft (7.6 m)
Upper	5.88 in. (149 mm) x 4.75 in. (121 mm) x 0.17 in. (4.3 mm) thk x 25.0 ft (7.6 m) long steel channel
Post	W6.25 steel x 5 ft (1.5 m)
Post Spacing	5.0 ft (1.5 m)
Lower Beam Rail Deflection:	
Max Dynamic	3.0 in. (75 mm)
Max Permanent	0

Vehicle	1976 Honda Civic
Vehicle Mass (w/instrumentation)	1840 lb (835 kg)
Impact Speed	59.8 mph (96.2 kmph)
Impact Angle	14.8 deg
Exit Speed	52.4 mph
Exit Angle	-6.9 deg
Vehicle Accelerations (max 50 ms avg)	
Lateral (cine/electronic)	7.3g/8.1g
Longitudinal (cine/electronic)	-3.0g/-2.1g

FIGURE 79. SUMMARY OF RESULTS, TEST TTR-4

TABLE 14

FILM ANALYSIS DATA - TEST TTR-4

SUMMARY OF VEHICLE KINEMATIC AND DYNAMIC DATA   THRU-TRUSS BRIDGERAIL TEST TTR-4   1/16/81

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 AVER .05 SEC. LONG	LAT	APPROX. BARRIER FORCES(LB) X	Y
0.000	7.20	-5.53	14.84	87.66	.70	-1.04	.25	0.00	0.00	1975.	38.
.010	8.04	-5.29	15.03	87.24	.42	-1.53	-.30	0.00	0.00	2567.	1263.
.020	8.88	-5.07	15.11	86.68	.08	-1.98	-1.01	0.00	0.00	3038.	2738.
.030	9.71	-4.84	15.05	85.97	-.29	-2.39	-1.83	-2.14	-1.50	3380.	4393.
.040	10.54	-4.63	14.80	85.15	-.65	-2.74	-2.73	-2.51	-2.33	3588.	6146.
.050	11.36	-4.42	14.34	84.23	-.99	-2.99	-3.67	-2.79	-3.21	3663.	7907.
.060	12.18	-4.23	13.64	83.25	-1.30	-3.14	-4.60	-2.97	-4.11	3611.	9538.
.070	12.99	-4.05	12.71	82.26	-1.58	-3.15	-5.47	-3.03	-4.98	3440.	11101.
.080	13.79	-3.90	11.56	81.29	-1.83	-3.03	-6.24	-2.96	-5.76	3162.	12369.
.090	14.59	-3.76	10.22	80.40	-2.05	-2.78	-6.86	-2.76	-6.43	2792.	13328.
.100	15.38	-3.65	8.73	79.62	-2.25	-2.41	-7.29	-2.45	-6.93	2349.	13928.
.110	16.17	-3.57	7.13	78.98	-2.43	-1.95	-7.50	-2.03	-7.24	1851.	14142.
.120	16.95	-3.51	5.48	78.51	-2.58	-1.44	-7.48	-1.56	-7.33	1321.	13959.
.130	17.74	-3.47	3.82	78.20	-2.69	-.91	-7.23	-1.06	-7.20	783.	13391.
.140	18.52	-3.46	2.22	78.07	-2.77	-.40	-6.77	-.56	-6.85	261.	12471.
.150	19.30	-3.46	.72	78.09	-2.80	.04	-6.11	-.12	-6.31	-221.	11248.
.160	20.08	-3.49	-.64	78.23	-2.79	.41	-5.32	.26	-5.62	-639.	9790.
.170	20.86	-3.54	-1.83	78.46	-2.74	.67	-4.42	.54	-4.81	-971.	8176.
.180	21.65	-3.59	-2.82	78.75	-2.65	.82	-3.49	.73	-3.94	-1197.	6494.
.190	22.43	-3.66	-3.60	79.06	-2.55	.87	-2.58	.81	-3.07	-1304.	4434.
.200	23.22	-3.74	-4.19	79.36	-2.43	.82	-1.73	.80	-2.23	-1280.	3285.
.210	24.01	-3.83	-4.58	79.63	-2.32	.69	-1.00	.71	-1.48	-1121.	1929.
.220	24.81	-3.92	-4.81	79.83	-2.23	.49	-.41	.54	-.85	-831.	833.
.230	25.60	-4.01	-4.90	79.95	-2.16	.23	-.01	.32	-.37	-420.	46.
.240	26.40	-4.10	-4.89	79.97	-2.14	-.07	.22	.05	-.06	93.	-406.
.250	27.19	-4.18	-4.82	79.90	-2.15	-.39	.25	-.24	.08	679.	-525.
.260	27.98	-4.27	-4.73	79.71	-2.21	-.72	.13	-.55	.06	1302.	-341.
.270	28.78	-4.36	-4.65	79.43	-2.32	-1.04	-.13	-.85	-.10	1918.	84.
.280	29.56	-4.45	-4.62	79.05	-2.46	-1.31	-.47	-1.13	-.34	2478.	601.
.290	30.35	-4.54	-4.65	78.59	-2.63	-1.53	-.82	-1.35	-.62	2926.	1277.
.300	31.13	-4.63	-4.75	78.08	-2.80	-1.66	-1.12	-1.50	-.88	3208.	1801.
.310	31.90	-4.72	-4.93	77.55	-2.95	-1.67	-1.29	-1.56	-1.06	3272.	2098.
.320	32.67	-4.82	-5.18	77.04	-3.03	-1.56	-1.26	-1.50	-1.07	3076.	2046.
.330	33.43	-4.92	-5.47	76.58	-3.01	-1.32	-.97	-1.32	-.88	2594.	1552.
.340	34.18	-5.03	-5.79	76.23	-2.82	-.95	-.41	-1.03	-.47	1824.	542.
.350	34.94	-5.13	-6.10	76.01	-2.41	-.48	.39	-.63	.14	798.	-806.
.360	35.69	-5.23	-6.37	75.95	-1.77	.07	1.33	-.16	.87	-404.	-2422.
.370	36.45	-5.33	-6.60	76.08	-.90	.64	2.21	.34	1.53	-1641.	-3897.
.380	37.20	-5.43	-6.76	76.37	.12	1.16	2.67	.79	1.80	-2694.	-4626.
.390	37.96	-5.51	-6.89	76.60	1.11	1.51	2.21	1.11	1.23	-3245.	-3701.

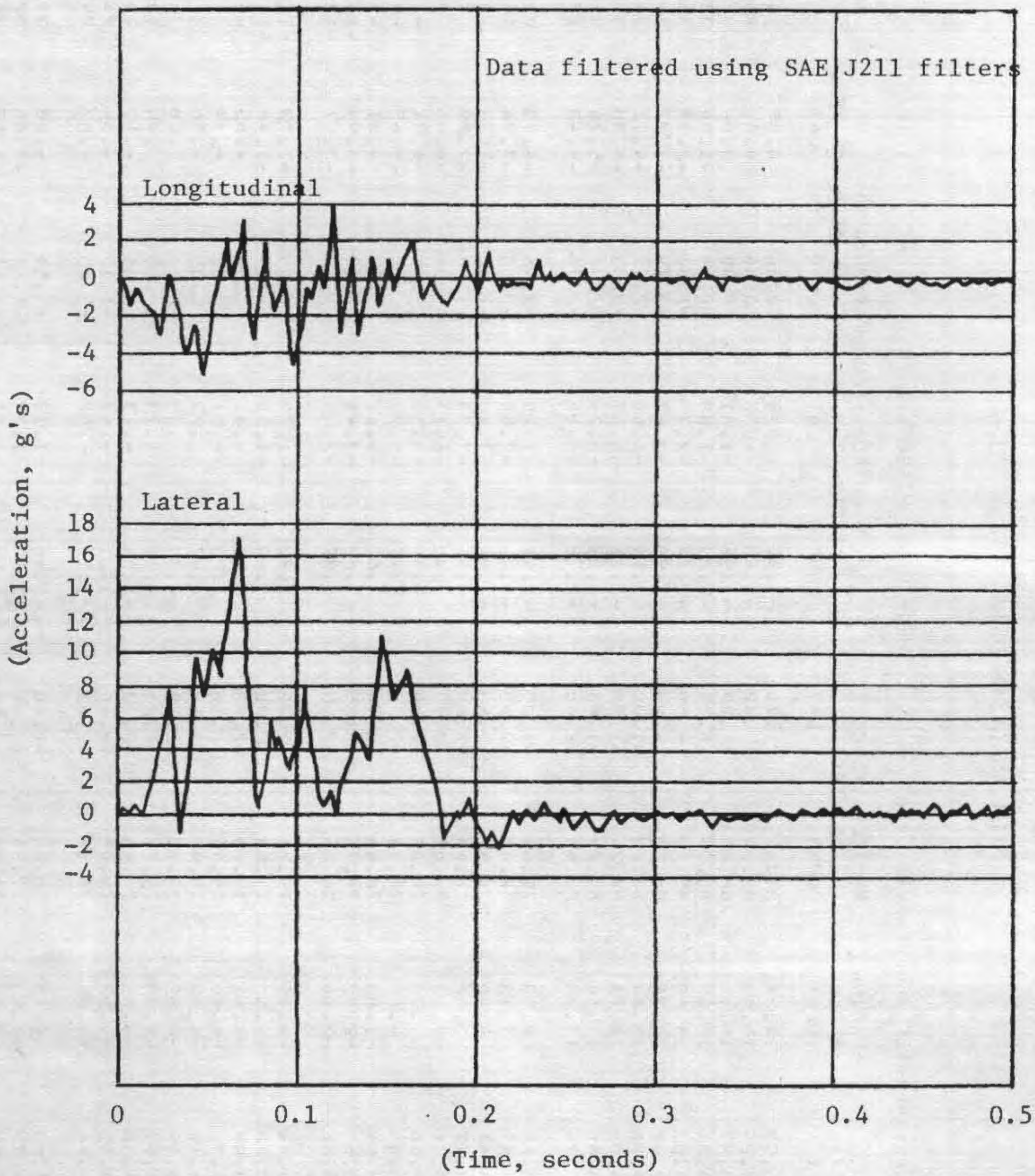


FIGURE 80. ACCELEROMETER DATA, TEST TTR-4

FIGURE 81. BARRIER AND VEHICLE DAMAGE, TEST TTR-4

system when impacted by a 20,000-lb (9073-kg) school bus at 55 mph (88.5 kmph) and a 15-deg angle.

Test Installation: The transition section of the self-restoring thru-truss bridgerail is shown in Figure 82. It continued the use of the same 5-ft (1.5-m) high channel upper rail and 33-in. (838-mm) high suspended tubular thrie beam lower rail as the deck-mounted system, but instead of the posts being anchored to the concrete they were buried 57.38 in. (1.46 m) in the soil. Each of the five W6x15.5 posts in the transition area had a soil plate to provide additional support against lateral rotation. Post spacing was 5 ft (1.5 m). The tubular thrie rail was transitioned further upstream into a single thrie beam and finally into a standard G4 approach guardrail with a breakaway cable terminal end treatment.

Test Vehicle: A 1969 Chevrolet chassis with a 66-passenger Bluebird school bus body was the test vehicle. To achieve the desired weight and simulate passenger loading 6,000 lb (2,722 kg) of ballast (sandbags) was placed in the seats. Sandbags were not secured.

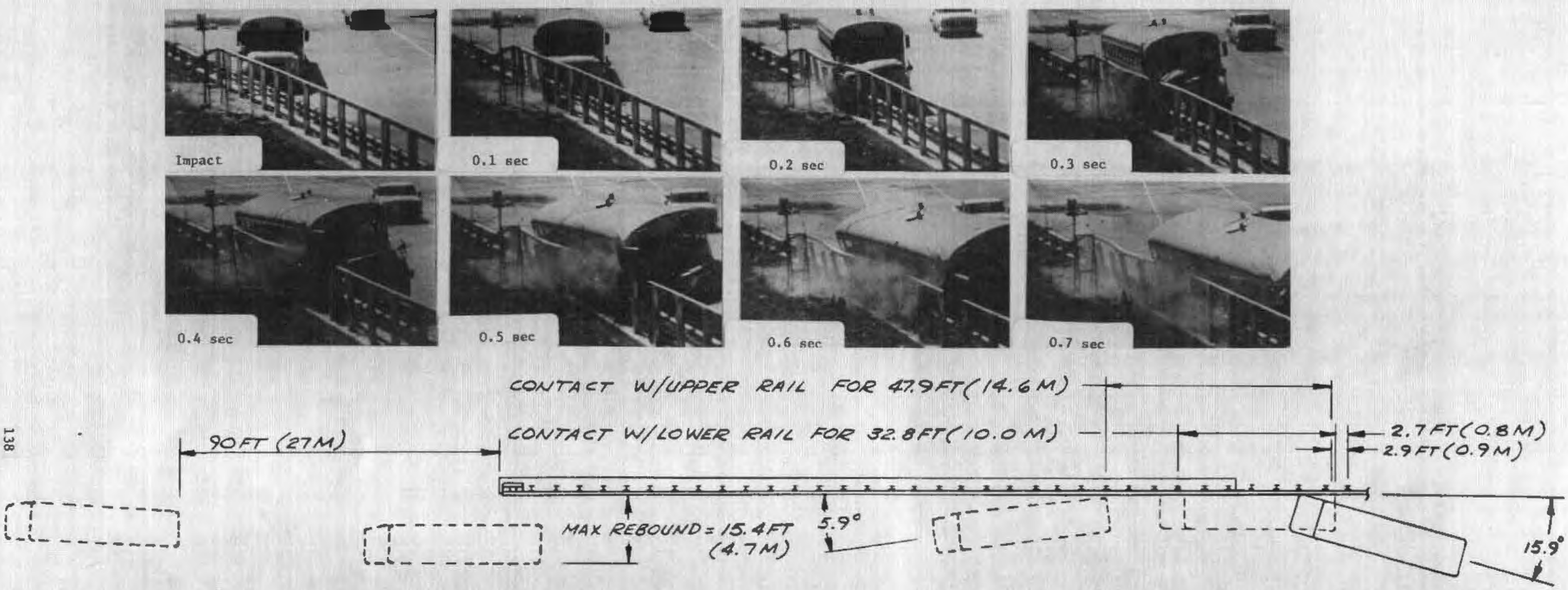
Performance: Impact conditions for the bus were 59.6 mph (95.9 kmph) and a 15.9-deg angle. Initial contact with the lower rail occurred at the third post off the bridge deck about 15 ft (4.6 m) upstream of the bridge end. As shown in the sequential photographs of Figure 83 the bus impacted the transition, pitched slightly upward as it rolled toward the barrier (maximum roll angle 15 deg) while being redirected, and then returned to an upright position. During the impact sequence the right front wheel was pushed rearward by the lower rail, causing suspension failure, and forced the entire front axle to rotate about the yaw axis. As it lost contact with the barrier the vehicle dropped down at the right front corner onto the front wheel, which by this time was in a near horizontal attitude, and slid to a stop approximately 90 ft (27 m) past the end of the installation. During the slide the vehicle made secondary contact with another test installation located downstream causing some additional vehicle damage.

Maximum 50 msec average accelerations measured from high-speed film analysis/accelerometers were 1.7 g/5.6 g (lateral) and -2.5 g/ -3.8 g (longitudinal); a summary of test results is shown in Figure 83. Results of film analysis are shown in Table 15 and accelerometer data are shown in Figure 84.

Barrier Damage: As shown in Figure 85, barrier damage consisted of two bent tubular thrie beam sections, two bent upper rail sections, two bent bridge posts, and one bent soil-mounted post. The remaining transition posts were pushed back in the soil, but were undamaged. In addition, some concrete failure around bridge Posts 1 and 2 was observed. Permanent barrier deflections are given in Table 16.

Vehicle Damage: As described previously, the bus sustained front suspension and steering linkage damage sufficient enough to totally dislodge the front axle from its mounting. In addition, the

FIGURE 82. TRANSITION AREA - THRU-TRUSS BRIDGERAIL



Test No. TTR-5
Date 3/17/81
Beam Rail:
Lower .... 12 ga. steel tubular thrie beam x 25.0 ft (7.6 m)
Upper ..... 5.88 in. (149 mm) x 4.75 in. (121 mm) x 0.17 in. (4.3 mm) thk x 25.0 ft (7.6 m) long steel channel
Transition Post ..... W6x15.5 steel x 10 ft (3.0 m)
Transition Post Spacing .... 5.0 ft (1.5 m)
Upper Beam Rail Deflection:
Max Dynamic .... 27.8 in. (707 mm)
Max Permanent .... 18.5 in. (470 mm)

Vehicle ..... 1969 Chevrolet Chassis/Bluebird Body
Vehicle Mass (w/instrumentation) .... 20,000 lb (9072 kg)
Impact Speed .... 59.6 mph (95.9 kmph)
Impact Angle .... 15.9 deg
Exit Speed .... 50.3 mph (81.0 kmph)
Exit Angle .... -5.9 deg
Maximum Roll Angle .... 10.7 deg
Vehicle Accelerations (max 50 ms avg)
Lateral (cine/electronic) 1.7g/5.6g
Longitudinal (cine/electronic)...... -2.5g/-3.8g

FIGURE 83. SUMMARY OF RESULTS, TEST TTR-5

TABLE 15

FILM ANALYSIS DATA - TEST TTR-5

SUMMARY OF VEHICLE KINEMATIC AND DYNAMIC DATA   THRU-TRUSS BRIDGERAIL TEST TTR-5   3/17/81

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 AVER .05 SEC. LONG	LAT	APPROX. BARRIER FORCES(LB) X	Y
0.000	-17.09	-8.12	15.85	87.36	-.45	-2.20	-.04	0.00	0.00	42017.	12824.
.010	-16.25	-7.89	15.76	86.61	-.33	-2.41	-.05	0.00	0.00	46186.	14091.
.020	-15.42	-7.66	15.68	85.81	-.23	-2.53	-.08	0.00	0.00	48188.	15276.
.030	-14.60	-7.43	15.61	85.00	-.16	-2.54	-.14	-2.45	-.13	48227.	16384.
.040	-13.78	-7.21	15.55	84.19	-.13	-2.48	-.21	-2.44	-.19	46556.	17420.
.050	-12.98	-6.98	15.50	83.41	-.14	-2.34	-.31	-2.35	-.27	43465.	18388.
.060	-12.18	-6.76	15.44	82.69	-.17	-2.15	-.41	-2.20	-.37	39256.	19293.
.070	-11.38	-6.55	15.38	82.03	-.23	-1.92	-.52	-2.00	-.47	34238.	20138.
.080	-10.59	-6.33	15.31	81.45	-.31	-1.66	-.63	-1.77	-.58	28710.	20929.
.090	-9.81	-6.12	15.22	80.96	-.40	-1.39	-.74	-1.52	-.69	22953.	21669.
.100	-9.03	-5.91	15.10	80.56	-.50	-1.12	-.86	-1.26	-.80	17223.	22362.
.110	-8.25	-5.71	14.96	80.24	-.59	-.86	-.96	-1.01	-.90	11747.	23010.
.120	-7.47	-5.51	14.78	80.00	-.67	-.63	-1.06	-.77	-1.00	6719.	23619.
.130	-6.70	-5.32	14.57	79.84	-.72	-.42	-1.14	-.55	-1.09	2294.	24190.
.140	-5.93	-5.12	14.32	79.74	-.75	-.24	-1.22	-.36	-1.17	-1406.	24727.
.150	-5.15	-4.94	14.02	79.69	-.74	-.10	-1.28	-.20	-1.24	-4300.	25233.
.160	-4.38	-4.75	13.68	79.68	-.69	.00	-1.32	-.08	-1.29	-6339.	25710.
.170	-3.60	-4.57	13.30	79.70	-.59	.06	-1.36	.00	-1.33	-7509.	26161.
.180	-2.82	-4.40	12.87	79.72	-.44	.09	-1.38	.04	-1.36	-7829.	26589.
.190	-2.04	-4.23	12.40	79.75	-.23	.07	-1.40	.05	-1.38	-7344.	26995.
.200	-1.26	-4.06	11.89	79.77	.03	.02	-1.40	.02	-1.39	-6124.	27381.
.210	-.48	-3.90	11.34	79.76	.34	-.06	-1.40	-.04	-1.40	-4259.	27749.
.220	.30	-3.74	10.76	79.72	.70	-.17	-1.40	-.13	-1.40	-1857.	28102.
.230	1.08	-3.58	10.15	79.63	1.11	-.30	-1.39	-.24	-1.39	964.	28440.
.240	1.86	-3.44	9.51	79.50	1.55	-.44	-1.38	-.37	-1.39	4076.	28764.
.250	2.65	-3.29	8.84	79.31	2.02	-.59	-1.38	-.51	-1.38	7349.	29077.
.260	3.43	-3.15	8.16	79.07	2.52	-.74	-1.38	-.65	-1.38	10652.	29379.
.270	4.20	-3.02	7.48	78.78	3.02	-.88	-1.38	-.79	-1.38	13857.	29670.
.280	4.98	-2.89	6.78	78.44	3.53	-1.01	-1.39	-.93	-1.39	16847.	29951.
.290	5.75	-2.76	6.09	78.05	4.02	-1.13	-1.40	-1.05	-1.40	19512.	30224.
.300	6.52	-2.64	5.40	77.61	4.50	-1.23	-1.42	-1.15	-1.42	21757.	30488.
.310	7.29	-2.53	4.73	77.15	4.96	-1.30	-1.44	-1.23	-1.43	23503.	30743.
.320	8.05	-2.42	4.07	76.67	5.38	-1.34	-1.46	-1.28	-1.46	24689.	30990.
.330	8.81	-2.31	3.43	76.17	5.76	-1.35	-1.48	-1.31	-1.48	25272.	31228.
.340	9.57	-2.21	2.81	75.67	6.09	-1.34	-1.51	-1.31	-1.50	25229.	31457.
.350	10.32	-2.11	2.23	75.18	6.37	-1.29	-1.53	-1.28	-1.53	24559.	31677.
.360	11.06	-2.02	1.67	74.72	6.60	-1.21	-1.56	-1.21	-1.55	23279.	31886.
.370	11.81	-1.94	1.15	74.28	6.77	-1.10	-1.58	-1.12	-1.58	21427.	32085.
.380	12.55	-1.86	.66	73.89	6.89	-.97	-1.60	-1.01	-1.60	19061.	32272.
.390	13.28	-1.78	.21	73.55	6.95	-.82	-1.62	-.87	-1.61	16252.	32446.

TABLE 15 (Cont'd)

.400	14.02	-1.71	-.20	73.26	6.96	-.65	-1.63	-.71	-1.63	13089.	32605.
.410	14.75	-1.65	-.58	73.03	6.91	-.47	-1.64	-.54	-1.64	9672.	32749.
.420	15.48	-1.59	-.93	72.87	6.82	-.28	-1.65	-.36	-1.65	6111.	32876.
.430	16.21	-1.54	-1.24	72.78	6.69	-.09	-1.65	-.18	-1.65	2522.	32983.
.440	16.94	-1.49	-1.52	72.74	6.52	.09	-1.65	-.00	-1.65	-977.	33070.
.450	17.67	-1.45	-1.78	72.77	6.31	.26	-1.65	.17	-1.65	-4268.	33134.
.460	18.40	-1.41	-2.00	72.86	6.07	.42	-1.64	.33	-1.65	-7238.	33173.
.470	19.13	-1.38	-2.21	73.00	5.80	.55	-1.64	.47	-1.64	-9783.	33184.
.480	19.86	-1.35	-2.40	73.17	5.51	.66	-1.63	.58	-1.63	-11811.	33166.
.490	20.59	-1.33	-2.57	73.38	5.21	.74	-1.62	.67	-1.63	-13246.	33114.
.500	21.33	-1.31	-2.73	73.61	4.89	.78	-1.62	.73	-1.62	-14032.	33028.
.510	22.07	-1.30	-2.88	73.85	4.57	.79	-1.61	.75	-1.61	-14137.	32902.
.520	22.81	-1.29	-3.03	74.09	4.24	.76	-1.60	.75	-1.60	-13553.	32736.
.530	23.55	-1.29	-3.17	74.32	3.92	.70	-1.59	.71	-1.59	-12299.	32524.
.540	24.30	-1.30	-3.32	74.52	3.60	.61	-1.58	.63	-1.58	-10426.	32264.
.550	25.05	-1.31	-3.47	74.69	3.28	.50	-1.57	.53	-1.57	-8012.	31953.
.560	25.79	-1.32	-3.62	74.82	2.97	.36	-1.56	.41	-1.56	-5165.	31586.
.570	26.54	-1.34	-3.77	74.91	2.68	.20	-1.55	.27	-1.55	-2022.	31159.
.580	27.29	-1.37	-3.93	74.94	2.39	.04	-1.53	.12	-1.54	1258.	30670.
.590	28.04	-1.40	-4.10	74.92	2.12	-.12	-1.52	-.03	-1.52	4493.	30112.
.600	28.79	-1.43	-4.28	74.85	1.86	-.26	-1.50	-.17	-1.50	7487.	29483.
.610	29.54	-1.47	-4.45	74.74	1.62	-.39	-1.47	-.30	-1.48	10038.	28778.
.620	30.28	-1.52	-4.64	74.60	1.38	-.48	-1.44	-.40	-1.45	11949.	27991.
.630	31.03	-1.56	-4.82	74.43	1.16	-.54	-1.41	-.47	-1.42	13034.	27119.
.640	31.77	-1.62	-5.01	74.25	.96	-.54	-1.36	-.49	-1.38	13142.	26157.
.650	32.51	-1.67	-5.19	74.08	.77	-.49	-1.30	-.46	-1.32	12165.	25099.
.660	33.24	-1.74	-5.38	73.93	.60	-.39	-1.24	-.39	-1.26	10066.	23940.
.670	33.98	-1.80	-5.56	73.83	.44	-.23	-1.16	-.27	-1.19	6895.	22675.
.680	34.72	-1.87	-5.74	73.79	.31	-.03	-1.07	-.10	-1.11	2821.	21299.
.690	35.45	-1.94	-5.91	73.81	.21	.19	-.98	.10	-1.02	-1839.	19806.

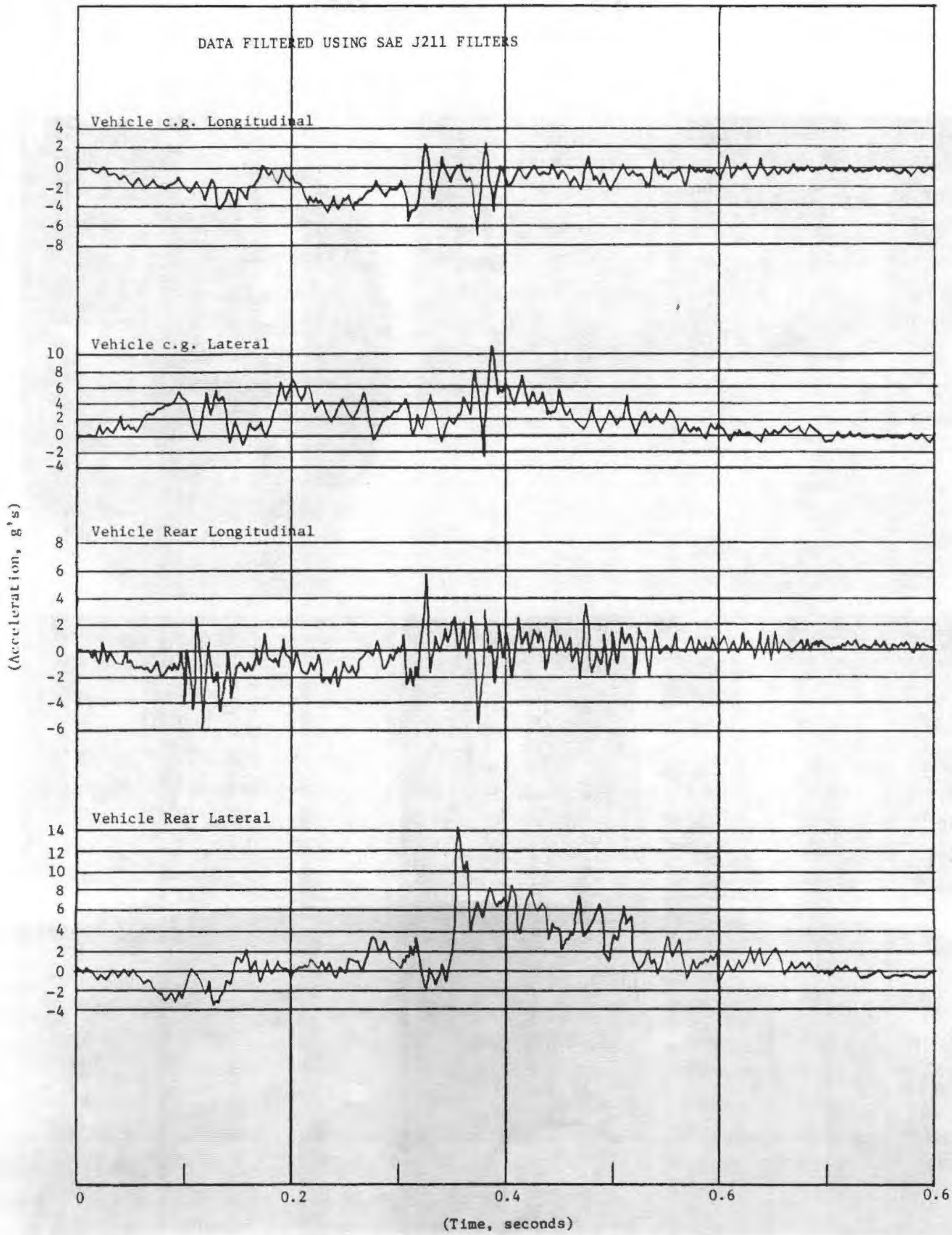


FIGURE 84. ACCELEROMETER DATA, TEST TTR-5

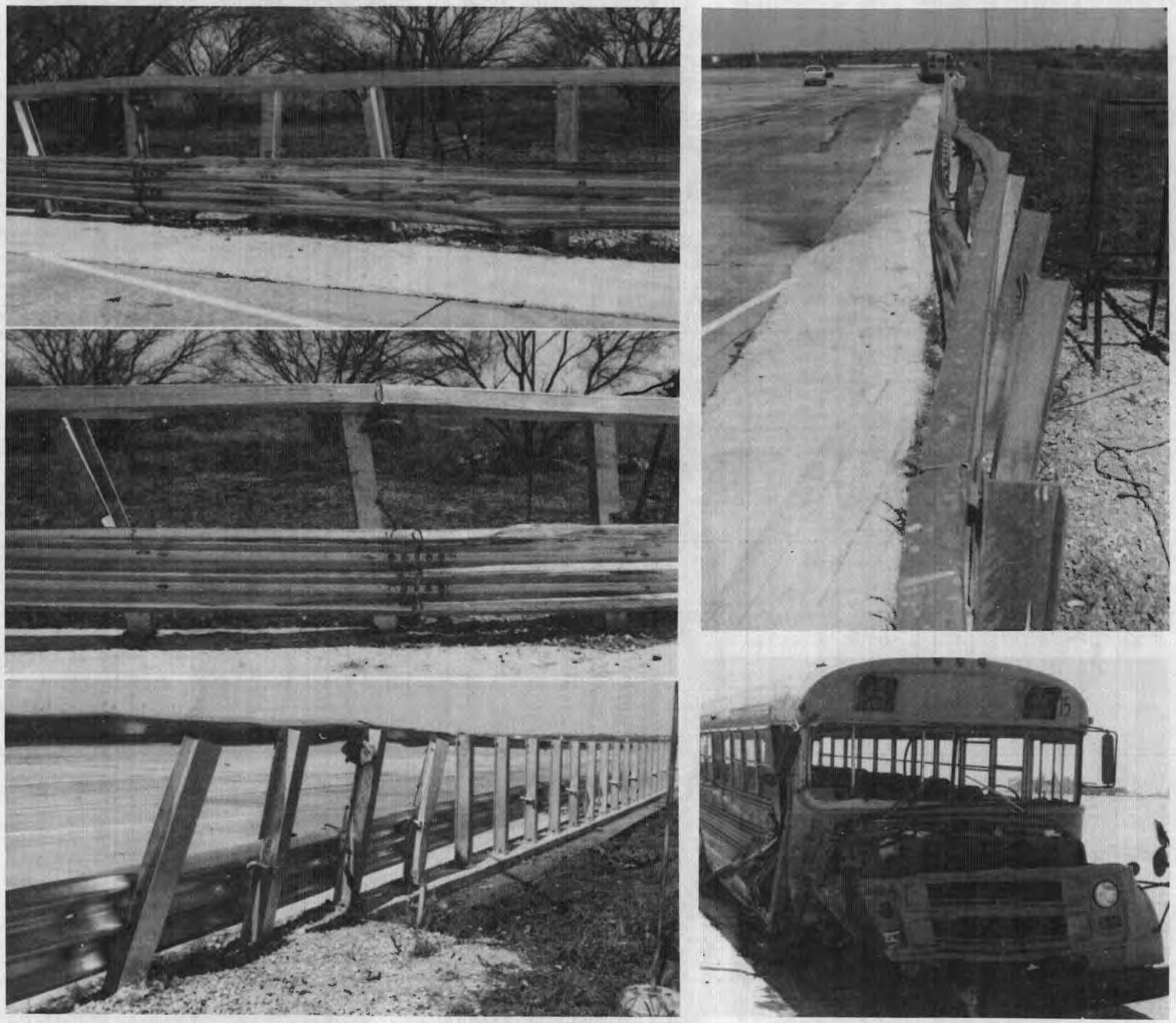


FIGURE 85. BARRIER AND VEHICLE DAMAGE, TEST TTR-5

TABLE 16

BARRIER DEFLECTIONS, TEST TTR-5

	Location - Post No.	Lower Rail Deflection** (in.)	Upper Rail Deflection (in.)	Post* Deflection (in.)
Transition	A	4.50	3.50	9.38
Transition	B	7.13	8.75	17.88
Transition	C	11.63	13.13	20.75
Transition	D	14.75	18.50	24.00
Transition	E	11.75	17.88	20.00
Bridge Deck	1	5.25	8.75	8.75
Bridge Deck	2	3.25	2.50	8.50
Bridge Deck	3	1.75	0.38	4.75
Bridge Deck	4	0.75	0	0
Bridge Deck	5	0.38	0	0
Bridge Deck	6 and on	0	0	0

*Measured at top of post
**3 in. deflection of the lower rail is in self-restoring stage
Metric conversion: Multiply inches by 25.4 to obtain millimeters

right front fender was torn off the vehicle and the area around the passenger service door was heavily damaged. The entire windshield was thrown out. Although sandbags and seat bottom cushions were thrown out of the seats and scattered throughout the bus no seat frame failures were noted. Vehicle damage is shown in Figure 85.

Performance Evaluation: Although the impact conditions were considerably more severe than the planned 55 mph (88.5 kmph), 15-deg angle condition, the transition test is considered to be a success. The impact point was selected from computer simulations as being the most critical in terms of bus involvement with the leading truss member. Deflections were kept to an acceptable level on the bridge deck based on the assumption that the leading truss member is tapered from the abutment to full height and thus some deflection can be tolerated at the bridge approach. The deflections of Post 1 and 2 were increased by the occurrence of the anchor bolt failures. This is a function of the simulated deck and revisions can be made to the anchor bolt design to prevent this.

TEST TTR-6

Purpose: Purpose of this test was to evaluate the performance of the self-restoring thru-truss bridgerail system when impacted by a 2250-lb (1021-kg) subcompact automobile at 60 mph (96.6 kmph) and a 15-deg angle.

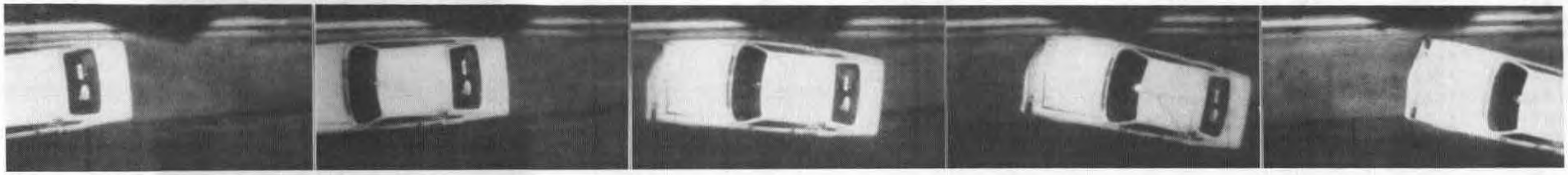
Test Installation: The test installation of Tests TTR-4 and TTR-5 was repaired and utilized for this test.

Test Vehicle: A 1974 Chevrolet Vega was the test vehicle. Gross test weight (including instrumentation and on-board controls) was 2250 lb (1021 kg).

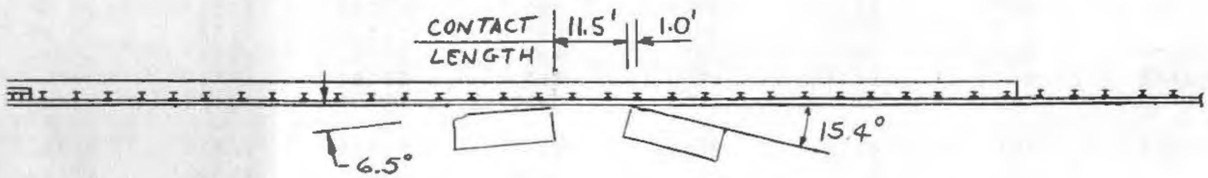
Performance: Impact conditions were 58.8 mph (94.6 kmph) and a 15.4-deg angle. As shown in the sequential photographs of Figure 86, the vehicle impacted the lower rail between Posts 12 and 13 deflecting it upward and rearward, and was then redirected after being in contact for 11.5 ft (3.5 m). Following the impact, the lower rail restored itself to its initial position. Maximum 50 msec average accelerations measured during the event were -2.4 g (cine) and -4.1 g (accelerometer) in the longitudinal direction and 6.1 g (cine) and 4.2 g (accelerometer) in the lateral direction. Test results are summarized in Figure 86; results of high speed film analysis are contained in Table 17. Accelerometer data are shown in Figure 87.

Barrier Damage: As shown in the photographs of Figure 88, the barrier was undamaged except for lower rail scuffing by vehicle contact. The only repair performed was to paint over those scuff marks.

Vehicle Damage: Vehicle damage was limited to minor sheet metal deformation and scraping at the right front and along the right side. This is shown in Figure 88.



0.20 sec | 0.15 sec | 0.10 sec | 0.05 sec | Impact



Test No. TTR-6
Date 4/16/81
Beam Rail:
  Lower .... 12 ga. steel tubular thrie beam x 25.0 ft (7.6 m)
  Upper ... 5.88 in. (149 mm) x 4.75 in. (121 mm) x 0.17 in. (4.3 mm) thk x 25.0 ft (7.6 m) long steel channel
Post .... W6x25.5 steel
Post Spacing .... 5.0 ft (1.5 m)
Lower Beam Rail Deflection:
  Max Dynamic .... 5.1 in. (130 mm)
  Max Permanent .... 0 in. (0 mm)

Vehicle .... 1974 Chevrolet Vega
Vehicle Mass
  (w/instrumentation) .... 2250 lb (1020 kg)
Impact Speed .... 58.8 mph (94.7 kmph)
Impact Angle .... 15.4 deg
Exit Speed .... 52.7 mph (84.8 kmph)
Exit Angle .... -6.5 deg
Vehicle Accelerations (max 50 ms avg)
  Lateral (cine/electronic) 6.1g/4.2g
  Longitudinal (cine/electronic).... -2.4g/-4.1g

FIGURE 86. SUMMARY OF RESULTS, TTR-6

TABLE 17

FILM ANALYSIS DATA - TEST TTR-6

SUMMARY OF VEHICLE KINEMATIC AND DYNAMIC DATA THRU-TRUSS RETROFIT BRIDGERAIL TEST .TTR-6 4/16/81

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 AVER .05 SEC. LONG	VEHICLE ACCELERATION(G"S) AVERAGE AVER .05 SEC. LAT	APPROX. BARRIER FORCES(LB) X	APPROX. BARRIER FORCES(LB) Y
0.000	-7.66	-5.65	15.40	86.36	-1.04	-1.77	-1.95	0.00	0.00	2670.	5295.
.010	-6.82	-5.43	15.07	85.75	-1.26	-2.02	-2.52	0.00	0.00	2920.	6662.
.020	-5.99	-5.23	14.56	85.08	-1.41	-2.24	-3.10	0.00	0.00	3117.	8022.
.030	-5.17	-5.03	13.87	84.35	-1.46	-2.40	-3.68	-2.27	-3.38	3252.	9335.
.040	-4.35	-4.85	13.00	83.58	-1.48	-2.49	-4.24	-2.38	-3.94	3321.	10560.
.050	-3.52	-4.69	11.95	82.80	-1.41	-2.52	-4.76	-2.43	-4.47	3320.	11659.
.060	-2.72	-4.54	10.73	82.02	-1.27	-2.46	-5.23	-2.40	-4.96	3249.	12598.
.070	-1.92	-4.41	9.37	81.28	-1.08	-2.33	-5.63	-2.29	-5.38	3111.	13347.
.080	-1.11	-4.29	7.89	80.58	-.86	-2.13	-5.93	-2.12	-5.72	2910.	13883.
.090	-.32	-4.20	6.32	79.96	-.60	-1.87	-6.14	-1.88	-5.97	2653.	14188.
.100	.48	-4.13	4.69	79.42	-.32	-1.56	-6.23	-1.60	-6.11	2349.	14252.
.110	1.27	-4.08	3.03	78.98	-.04	-1.22	-6.20	-1.28	-6.14	2011.	14071.
.120	2.05	-4.05	1.40	78.63	.23	-.88	-6.05	-.96	-6.04	1651.	13650.
.130	2.84	-4.03	-.19	78.39	.49	-.55	-5.78	-.63	-5.83	1283.	12998.
.140	3.62	-4.04	-1.68	78.25	.73	-.25	-5.40	-.33	-5.52	921.	12135.
.150	4.40	-4.07	-3.05	78.19	.93	.00	-4.93	-.07	-5.10	579.	11085.
.160	5.18	-4.10	-4.26	78.21	1.09	.21	-4.39	.14	-4.60	273.	9879.
.170	5.97	-4.16	-5.30	78.28	1.19	.35	-3.78	.29	-4.04	13.	8551.
.180	6.75	-4.23	-6.15	78.38	1.23	.42	-3.15	.38	-3.44	-188.	7141.
.190	7.53	-4.30	-6.79	78.51	1.20	.44	-2.49	.42	-2.81	-322.	5691.
.200	8.31	-4.39	-7.22	78.64	1.09	.41	-1.85	.40	-2.18	-384.	4245.
.210	9.09	-4.46	-7.45	78.75	.92	.33	-1.23	.34	-1.57	-371.	2847.
.220	9.87	-4.57	-7.50	78.84	.68	.21	-.66	.25	-.99	-284.	1538.
.230	10.65	-4.67	-7.38	78.89	.39	.08	-.15	.13	-.47	-131.	358.
.240	11.44	-4.77	-7.13	78.89	.07	-.07	.29	-.01	-.01	81.	-658.
.250	12.22	-4.86	-6.78	78.84	-.26	-.23	.64	-.15	.38	336.	-1480.
.260	13.00	-4.96	-6.37	78.74	-.58	-.38	.89	-.29	.67	618.	-2088.
.270	13.78	-5.05	-5.93	78.59	-.86	-.51	1.05	-.43	.88	904.	-2468.
.280	14.56	-5.14	-5.52	78.40	-1.09	-.63	1.11	-.55	.99	1171.	-2616.
.290	15.34	-5.22	-5.16	78.18	-1.22	-.72	1.07	-.64	1.01	1392.	-2541.
.300	16.12	-5.30	-4.89	77.93	-1.27	-.77	.94	-.70	.93	1543.	-2261.
.310	16.89	-5.38	-4.73	77.69	-1.21	-.77	.74	-.72	.78	1599.	-1806.
.320	17.67	-5.45	-4.69	77.43	-1.06	-.73	.48	-.70	.57	1539.	-1218.
.330	18.44	-5.53	-4.79	77.22	-.82	-.62	.19	-.62	.32	1350.	-551.
.340	19.20	-5.60	-5.00	77.05	-.52	-.45	-.10	-.48	.06	1027.	133.
.350	19.97	-5.67	-5.30	76.94	-.19	-.23	-.36	-.30	-.19	580.	763.
.360	20.74	-5.75	-5.66	76.91	.13	.04	-.56	-.07	-.39	36.	1261.
.370	21.50	-5.82	-6.01	76.96	.41	.32	-.66	.17	-.51	-554.	1549.
.380	22.27	-5.90	-6.31	77.10	.61	.57	-.63	.39	-.52	-1109.	1546.
.390	23.04	-5.98	-[illegible]	77.31	.68	.73	-.45	.53	-.39	-1515.	1181.

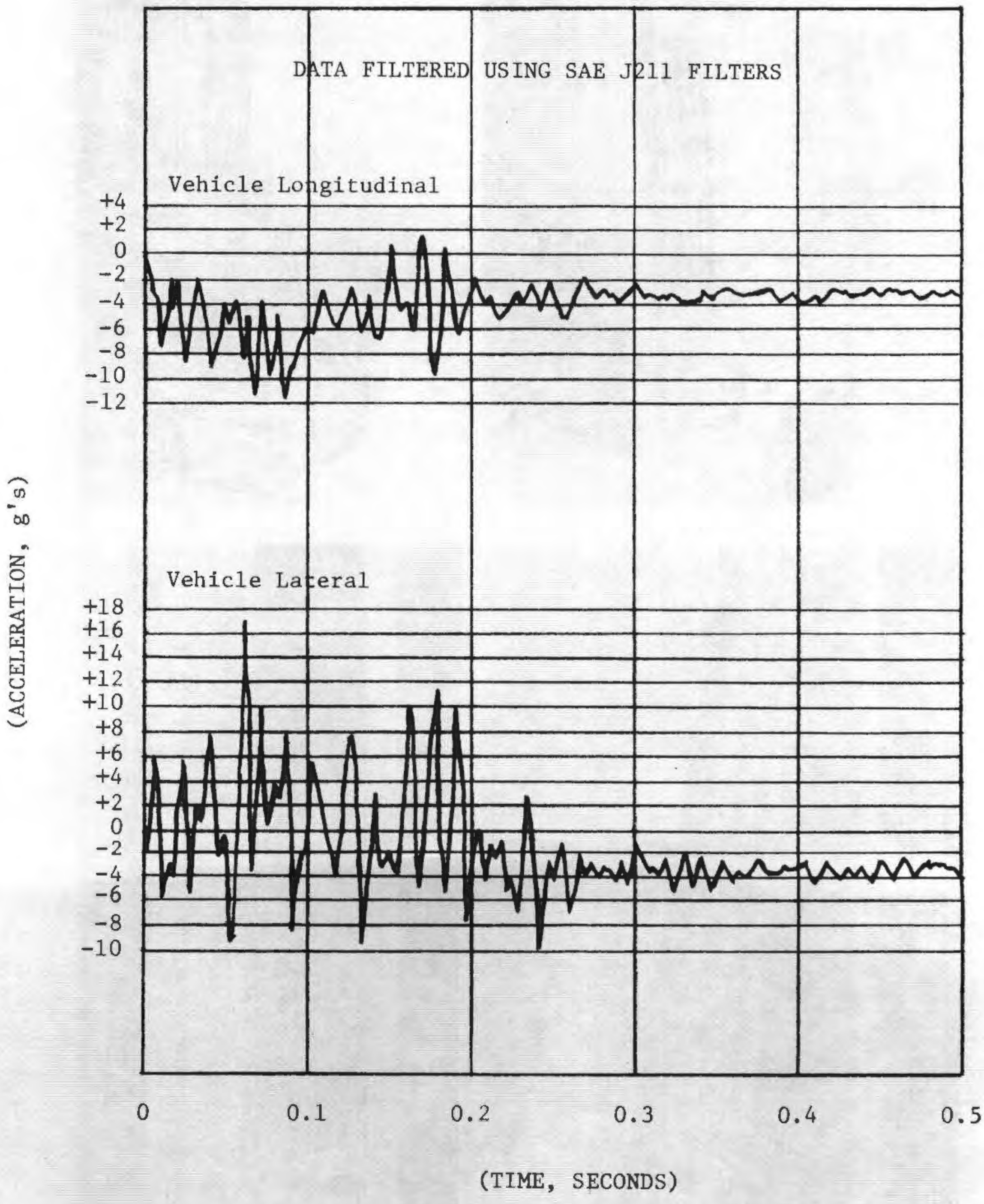


FIGURE 87. ACCELEROMETER DATA, TEST TTR-6

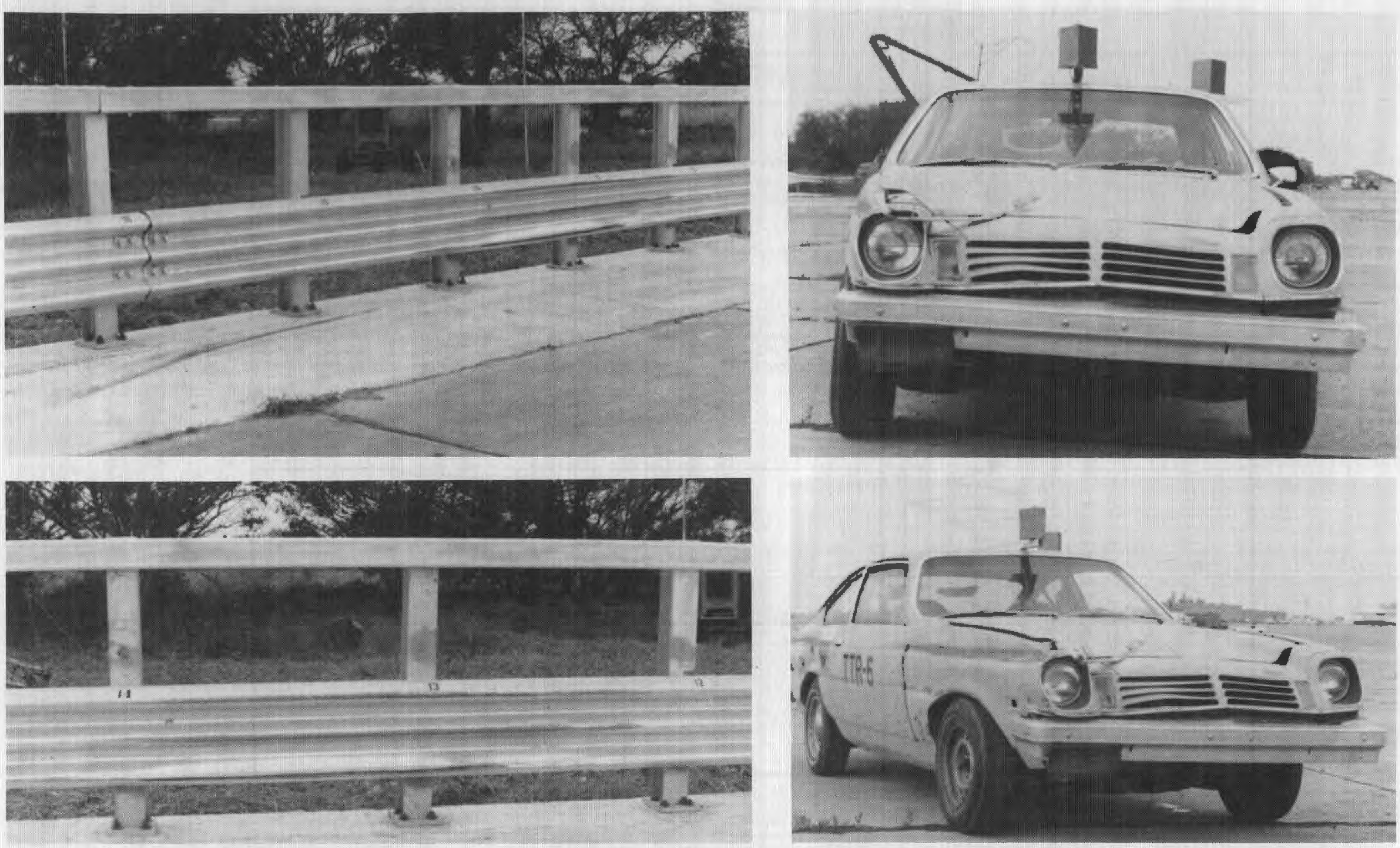


FIGURE 88. BARRIER AND VEHICLE DAMAGE, TEST TTR-6

TEST TTR-7

Purpose: Purpose of this test was to evaluate the self-restoring thru-truss bridgerail system when impacted by a 4500-lb (2041-kg) automobile at 60 mph (96.6 kmph) and a 25-deg angle.

Test Installation: The installation of Test TTR-6 was re-painted to cover vehicle scuff marks and utilized for this test.

Test Vehicle: A 1978 Ford LTD weighing 4441 lb (2014 kg), including instrumentation and controls, was the test vehicle.

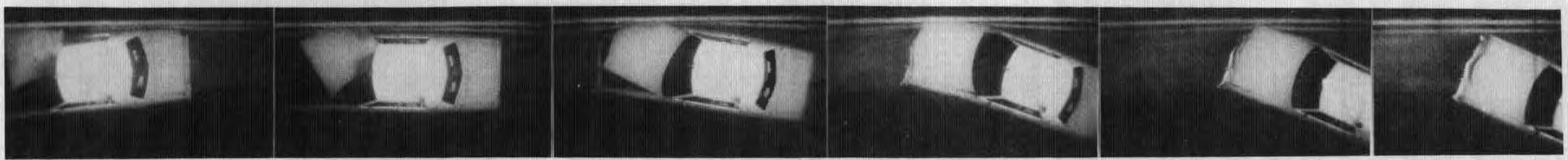
Performance: Impact conditions were 58.3 mph and a 27.1-deg angle. As shown in the sequential photographs of Figure 89, the vehicle impacted the tubular thrie beam lower rail of the system between Posts 12 and 13, and deflected it upward and rearward until it bottomed out against the posts. As the vehicle was being redirected, the right front corner of the hood projected over the lower rail and snagged on Post 14, driving it (the hood) rearward through the passenger side of the windshield and then tearing it completely off of the vehicle. After being in contact with the barrier for 13.5 ft (4.1 m) the vehicle exited at a -8.1 deg angle. Maximum 50 msec average accelerations measured during the event were -5.1 g (cine) and -9.5 g (accelerometer) in the longitudinal direction and 8.1 g (cine) and 10.4 g (accelerometer) in the lateral direction. Test results are summarized in Figure 89; analysis from high speed film is contained in Table 18, and accelerometer data are shown in Figure 90.

Barrier Damage: Barrier damage, as shown in Figure 91, was limited to one bent tubular thrie beam rail section and one bent pivot bar. Although the vehicle hood contacted one post, the post was undamaged. Permanent deflections of the tubular thrie lower rail are given in Table 19.

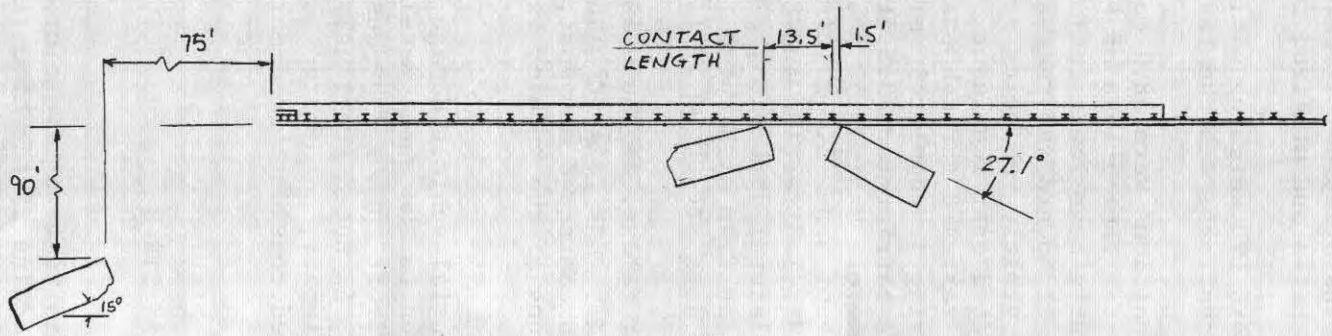
Vehicle Damage: Substantial vehicle damage was incurred as shown in Figure 91. In addition to the sheet metal and bumper bending and crushing at the right front corner, the suspension of the right front wheel was damaged. As noted previously the vehicle hood, which was torn off during the impact, penetrated the windshield on the passenger side and inflicted considerable damage to the dashboard behind it.

TEST TTR-8

Purpose: Purpose of this test was twofold: (1) to duplicate the conditions of TTR-7 to determine if the hood snagging problem experienced during that test was an isolated case or if some barrier redesign was necessary; and (2) to evaluate the transition area where the barrier changes from soil-mounted posts to deck-mounted posts.



0.25 sec | 0.20 sec | 0.15 sec | 0.10 sec | 0.05 sec | Impact



Test No. TTR-7
Date 4/16/81
Beam Rail:
  Lower .... 12 ga. steel tubular thrie beam x 25.0 ft (7.6 m)
  Upper ... 5.88 in. (149 mm) x 4.75 in. (121 mm) x 0.17 in. (4.3 mm) thk x 25.0 ft (7.6 m) long steel channel
Post .... W6x25.5 steel
Post Spacing .... 5.0 ft (1.5 m)
Lower Beam Rail Deflection:
  Max Dynamic .... 6.0 in. (152 mm)
  Max Permanent .... 1.8 in. (46 mm)

Vehicle .... 1978 Ford LTD
Vehicle Mass
  (w/instrumentation) .... 4441 lb (2010 kg)
Impact Speed .... 58.3 mph (93.9 kmph)
Impact Angle .... 27.1 deg
Exit Speed .... 38.3 mph (61.6 kmph)
Exit Angle .... -7.5°
Vehicle Accelerations (max 50 ms avg)
  Lateral (cine/electronic) ...... 8.1 g/10.4 g
  Longitudinal (cine/electronic)..-5.1 g/-9.5 g

FIGURE 89. SUMMARY OF RESULTS, TTR-7

TABLE 18

FILM ANALYSIS DATA - TEST TTR-7

SUMMARY OF VEHICLE KINEMATIC AND DYNAMIC DATA THRU-TRUSS RETROFIT TEST TTR-7 4/16/81

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 AVER .05 SEC. LONG	VEHICLE ACCELERATION (G"S) AVERAGE AVER .05 SEC. LAT	APPROX. BARRIER FORCES (LB) X	APPROX. BARRIER FORCES (LB) Y
0.000	-5.29	-7.25	27.11	85.66	-1.64	-1.91	-2.52	0.00	0.00	2452.	13846.
.010	-6.52	-6.88	27.05	84.92	-2.52	-2.66	-3.40	0.00	0.00	3648.	18831.
.020	-7.75	-6.53	26.85	83.96	-3.46	-3.36	-4.26	0.00	0.00	4752.	23619.
.030	-6.99	-6.19	26.49	82.80	-4.43	-3.97	-5.08	-3.59	-4.61	5738.	28052.
.040	-6.23	-5.87	25.95	81.49	-5.42	-4.45	-5.83	-4.13	-5.38	6590.	31995.
.050	-5.48	-5.57	25.22	80.05	-6.38	-4.88	-6.50	-4.56	-6.09	7297.	35344.
.060	-4.73	-5.30	24.31	78.54	-7.31	-5.14	-7.07	-4.87	-6.71	7854.	38021.
.070	-3.99	-5.06	23.21	77.01	-8.17	-5.26	-7.54	-5.04	-7.23	8262.	39973.
.080	-3.25	-4.85	21.94	75.51	-8.96	-5.24	-7.88	-5.08	-7.64	8524.	41177.
.090	-2.52	-4.66	20.50	74.07	-9.66	-5.11	-8.10	-5.00	-7.92	8650.	41631.
.100	-1.79	-4.51	18.92	72.74	-10.26	-4.86	-8.18	-4.80	-8.08	8648.	41358.
.110	-1.08	-4.39	17.22	71.54	-10.75	-4.53	-8.12	-4.51	-8.10	8532.	40398.
.120	-.36	-4.29	15.42	70.49	-11.10	-4.13	-7.93	-4.15	-7.98	8314.	38811.
.130	.34	-4.22	13.55	69.60	-11.32	-3.69	-7.61	-3.74	-7.73	8009.	36670.
.140	1.04	-4.18	11.64	68.86	-11.39	-3.23	-7.16	-3.30	-7.36	7633.	34059.
.150	1.74	-4.17	9.71	68.28	-11.32	-2.78	-6.62	-2.86	-6.88	7200.	31069.
.160	2.43	-4.18	7.81	67.83	-11.08	-2.35	-6.00	-2.44	-6.31	6725.	27799.
.170	3.11	-4.20	5.94	67.49	-10.71	-1.96	-5.31	-2.05	-5.66	6222.	24347.
.180	3.79	-4.25	4.15	67.24	-10.20	-1.62	-4.58	-1.71	-4.97	5705.	20812.
.190	4.47	-4.31	2.46	67.06	-9.56	-1.33	-3.84	-1.41	-4.24	5186.	17287.
.200	5.14	-4.38	.87	66.92	-8.83	-1.10	-3.11	-1.17	-3.52	4676.	13863.
.210	5.81	-4.46	-.58	66.81	-8.02	-.92	-2.40	-.97	-2.81	4185.	10619.
.220	6.47	-4.55	-1.89	66.71	-7.16	-.78	-1.74	-.83	-2.14	3721.	7626.
.230	7.14	-4.65	-3.05	66.61	-6.27	-.68	-1.15	-.72	-1.52	3291.	4944.
.240	7.80	-4.75	-4.05	66.51	-5.39	-.61	-.63	-.64	-.98	2901.	2618.
.250	8.46	-4.85	-4.90	66.40	-4.54	-.56	-.20	-.58	-.51	2554.	682.
.260	9.11	-4.95	-5.60	66.27	-3.74	-.52	.14	-.54	-.12	2253.	-846.
.270	9.77	-5.05	-6.16	66.14	-3.00	-.50	.39	-.51	.18	2000.	-1960.
.280	10.42	-5.15	-6.59	66.01	-2.35	-.47	.55	-.48	.39	1792.	-2668.
.290	11.07	-5.25	-6.91	65.87	-1.79	-.45	.63	-.46	.51	1630.	-2994.
.300	11.73	-5.35	-7.13	65.74	-1.34	-.42	.62	-.43	.55	1510.	-2970.
.310	12.38	-5.44	-7.28	65.61	-.98	-.39	.55	-.41	.53	1429.	-2641.
.320	13.03	-5.53	-7.37	65.49	-.72	-.37	.42	-.38	.44	1382.	-2060.
.330	13.67	-5.63	-7.43	65.37	-.54	-.34	.25	-.36	.30	1365.	-1287.
.340	14.32	-5.71	-7.47	65.27	-.45	-.32	.05	-.33	.13	1370.	-388.
.350	14.97	-5.80	-7.52	65.17	-.41	-.29	-.17	-.31	-.07	1392.	570.
.360	15.61	-5.89	-7.60	65.08	-.41	-.27	-.38	-.29	-.27	1425.	1519.
.370	16.26	-5.98	-7.71	65.00	-.44	-.25	-.58	-.27	-.46	1463.	2394.
.380	16.90	-6.08	-7.87	64.92	-.46	-.24	-.75	-.25	-.63	1498.	3135.
.390	17.54	-6.17	-8.10	64.85	-.47	-.22	-.87	-.23	-.77	1525.	3690.
.400	18.18	-6.27	-8.39	64.78	-.43	-.21	-.95	-.22	-.86	1539.	4016.
.410	18.82	-6.37	-8.75	64.71	-.34	-.20	-.96	-.21	-.90	1535.	4086.
.420	19.46	-6.47	-9.17	64.65	-.17	-.20	-.92	-.20	-.88	1508.	3884.
.430	20.10	-6.58	-9.65	64.59	.09	-.19	-.81	-.19	-.81	1455.	3411.
.440	20.73	-6.69	-10.17	64.52	.44	-.20	-.65	-.20	-.68	1375.	2687.
.450	21.37	-6.80	-10.72	64.45	.88	-.21	-.44	-.20	-.51	1265.	1748.
.460	22.00	-6.91	-11.28	64.37	1.42	-.22	-.19	-.21	-.29	1128.	650.
.470	22.64	-7.02	-11.84	64.28	2.02	-.24	.07	-.22	-.05	963.	-536.
.480	23.27	-7.13	-12.38	64.18	2.69	-.25	.34	-.24	.20	775.	-1722.
.490	23.90	-7.24	-12.88	64.07	3.40	-.27	.59	-.25	.43	567.	-2808.

1

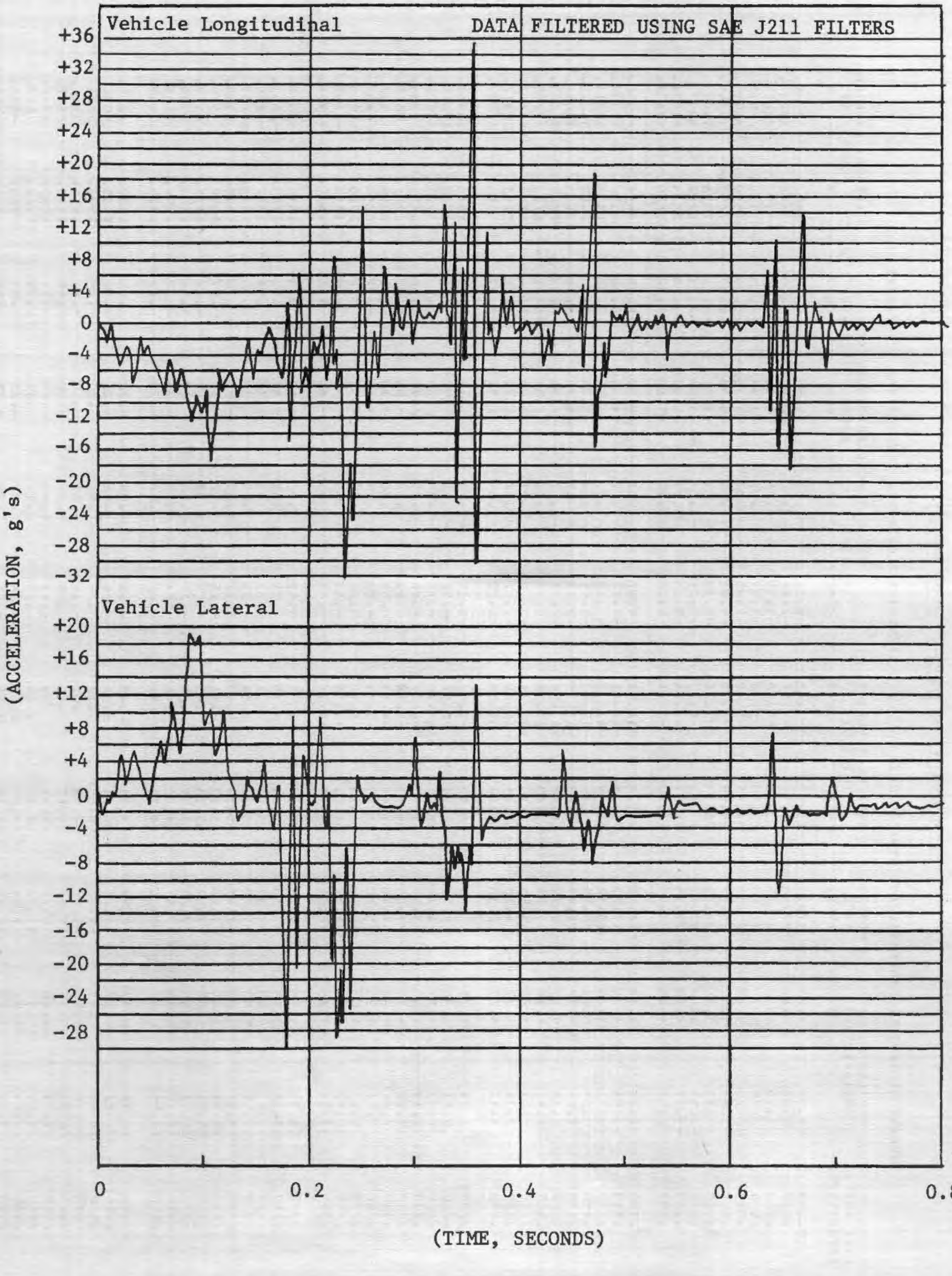


FIGURE 90. ACCELEROMETER DATA, TEST TTR-7

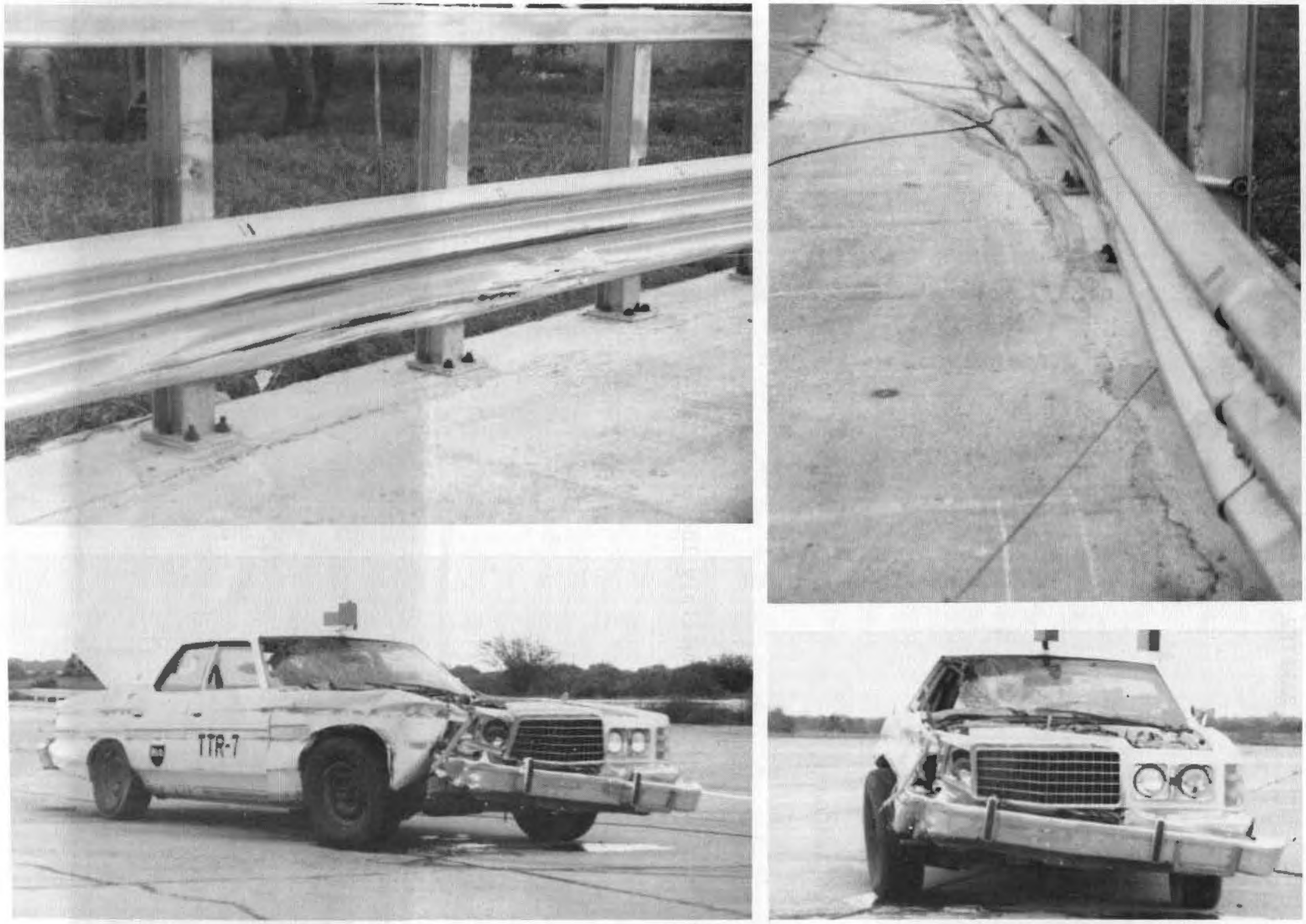


FIGURE 91. BARRIER AND VEHICLE DAMAGE, TEST TTR-7

TABLE 19

BARRIER DEFLECTIONS, TEST TTR-7

LOCATION - POST NO.	DEFLECTION - TOP OF RAIL (IN.)	DEFLECTION - BOTTOM OF RAIL (IN.)
1 Thru 11	0	0
12	0.75	2.25
13	1.75	5.88
14	1.38	4.50
15	0.75	1.88
16 And On	0	0

Metric Conversion: Multiply Inches by 25.4 to Obtain Millimeters

Test Installation; The installation of TTR-7 was repaired and utilized for this test.

Test Vehicle: A 1978 Ford LTD was the test vehicle. Gross test weight including instrumentation and controls was 4500 lb (2041 kg).

Performance: Impact conditions were 57.8 mph (93.0 kmph) and a 29.6-deg angle. Impact occurred 0.5 ft (0.2 m) upstream of the first soil-mounted post off the bridge deck, and as shown in Figure 92 the vehicle immediately deflected both the lower and upper rails. As redirection initiated the vehicle hood projected over the lower rail (as in Test TTR-7) and snagged on a bridge post again penetrating the windshield before being completely torn off. In the meantime, the concrete deck surrounding the first bridge post failed allowing the post to be completely dislodged and further barrier deflection by the vehicle (a maximum dynamic deflection of 10.4 in. [264 mm]) was measured. The vehicle finally exited at a -4 deg angle after being in contact for 18.5 ft (5.6 m). Maximum 50 msec average accelerations taken from high-speed film analysis were -9.3 g in the longitudinal direction and 6.2 g in the lateral direction. It was noted that excessive ringing and high spikes occurred in the accelerometer data during the period from 70 to 160 milliseconds such that the data taken in that period is questionable. Test results are summarized in Figure 92 and film analysis is contained in Table 20. Accelerometer data are shown in Figure 93.

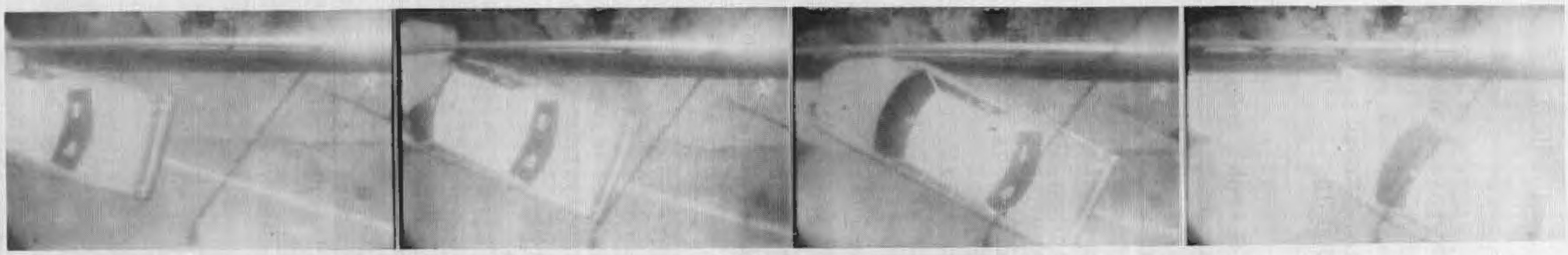
Barrier Damage: As discussed previously the concrete around Post 1 failed and that post completely separated from the deck. In addition, two tubular thrie lower rail sections were bent and the two soil-mounted posts closest to the bridge deck rotated slightly rearward. Photographs of the barrier damage are shown in Figure 94 and barrier deflections are listed in Table 21.

Vehicle Damage: As shown in Figure 94, damage to the test vehicle was extremely heavy. In addition to the windshield penetration prior to the hood being torn off, the entire front section of the vehicle was damaged. This included the right front fender, grill, bumper, right front suspension and wheel, and right front door. Longitudinal force of the impact also caused the right "A" pillar to translate rearward and upward causing the roof to buckle.

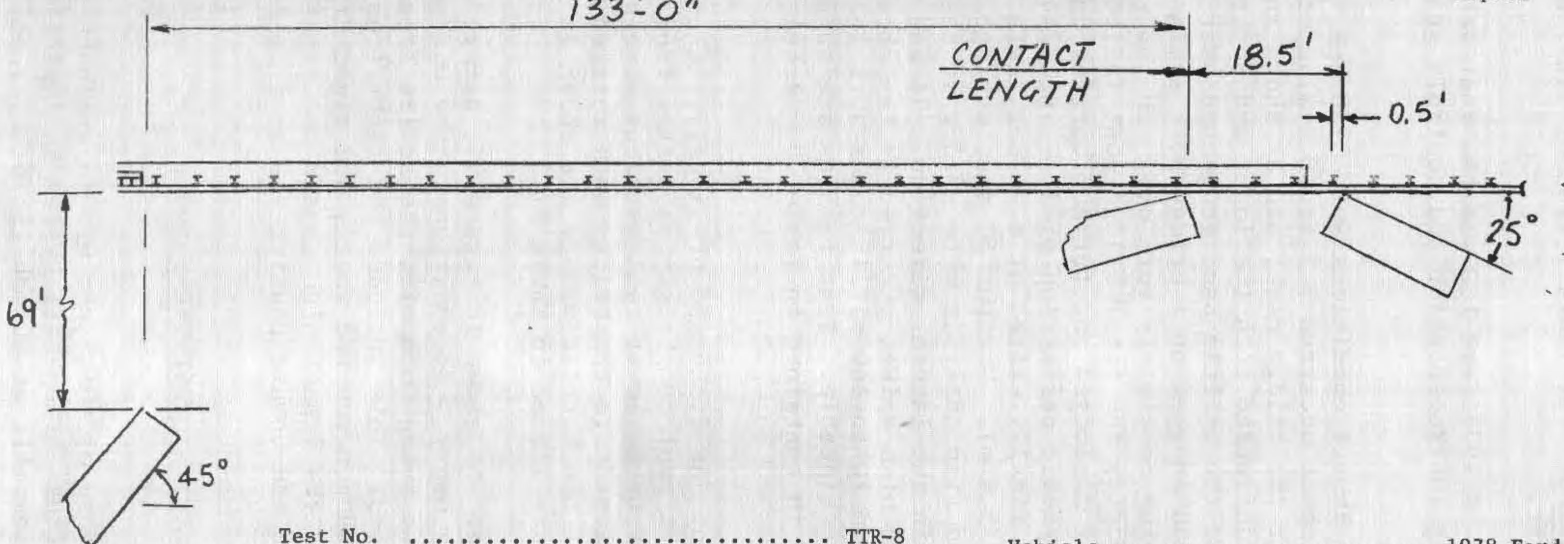
TEST TTR-9

Purpose: Purpose of this test was to evaluate the modified self-restoring thru truss bridgerail system by impacting it with a 4500-lb (2041-kg) automobile at 60 mph (96.6 kmph) and a 25-deg angle.

Test Installation: As shown in Figure 42, the barrier was modified after Test TTR-8 to incorporate a TS6x6x0.1875x20-in. (508-mm) long box beam spacer on each post. Purpose of this spacer was to project the lower rail away from the posts and alleviate the



0.15 sec 0.10 sec 0.05 sec Impact



Test No. TTR-8
Date 4/30/81
Beam Rail:
  Lower .... 12 ga. steel tubular thrie beam x 25.0 ft (7.6 m)
  Upper ... 5.88 in. (149 mm) x 4.75 in. (121 mm) x 0.17 in. (4.3 mm) thk x 25.0 ft (7.6 m) long steel channel
Transition Post ... W6x15.5 steel x 10 ft (3.0 m)
Transition Post Spacing .... 5.0 ft (1.5 m)
Upper Beam Rail Deflection:
  Max Dynamic .... 10.4 in. (264 mm)
  Max Permanent .... 1.6 in. (41 mm)

Vehicle .... 1978 Ford LTD
Vehicle Mass
  (w/instrumentation) .... 4500 lb (2040 kg)
Impact Speed .... 57.8 mph (93.0 kmph)
Impact Angle .... 29.6°
Exit Speed .... 29.3 mph (47.2 kmph)
Exit Angle .... -3.9°
Vehicle Accelerations (max 50 ms avg)
  Lateral (cine) .... 6.2 g
  Longitudinal (cine) .... -9.3 g

FIGURE 92. SUMMARY OF RESULTS, TTR-8

TABLE 20

FILM ANALYSIS DATA - TEST TTR-8

SUMMARY OF VEHICLE KINEMATIC AND DYNAMIC DATA THRU-TRUSS RETROFIT BRIDGERAIL TEST TTR-8 4/30/81

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 AVER .05 SEC. LONG	LAT	APPROX. BARRIER FORCES(LB) X	Y
0.000	.19	-5.96	29.55	84.74	-2.77	-.97	-.92	0.00	0.00	1759.	5769.
.010	.94	-5.57	29.51	84.27	-3.12	-1.97	-1.62	0.00	0.00	4139.	10696.
.020	1.68	-5.18	29.42	83.47	-3.63	-3.04	-2.33	0.00	0.00	6785.	15848.
.030	2.43	-4.81	29.29	82.32	-4.29	-4.14	-3.03	-3.60	-2.66	9582.	21007.
.040	3.16	-4.45	29.09	80.83	-5.09	-5.22	-3.70	-4.64	-3.32	12416.	25972.
.050	3.89	-4.12	28.83	79.01	-6.02	-6.23	-4.32	-5.65	-3.96	15183.	30565.
.060	4.60	-3.80	28.50	76.89	-7.06	-7.15	-4.88	-6.58	-4.54	17786.	34636.
.070	5.31	-3.51	28.10	74.51	-8.18	-7.93	-5.35	-7.41	-5.04	20143.	38065.
.080	5.99	-3.24	27.63	71.92	-9.37	-8.57	-5.74	-8.10	-5.47	22185.	40763.
.090	6.67	-3.01	27.10	69.18	-10.61	-9.04	-6.03	-8.63	-5.81	23858.	42672.
.100	7.32	-2.80	26.49	66.33	-11.87	-9.34	-6.21	-9.01	-6.06	25124.	43765.
.110	7.96	-2.63	25.83	63.45	-13.14	-9.46	-6.30	-9.21	-6.20	25958.	44040.
.120	8.58	-2.48	25.11	60.58	-14.38	-9.41	-6.27	-9.25	-6.24	26351.	43526.
.130	9.18	-2.37	24.34	57.78	-15.59	-9.20	-6.15	-9.12	-6.18	26307.	42271.
.140	9.76	-2.29	23.52	55.11	-16.73	-8.84	-5.93	-8.85	-6.02	25844.	40343.
.150	10.32	-2.24	22.66	52.59	-17.79	-8.36	-5.62	-8.45	-5.77	24990.	37828.
.160	10.87	-2.21	21.78	50.27	-18.74	-7.78	-5.23	-7.93	-5.43	23781.	34823.
.170	11.40	-2.21	20.87	48.18	-19.57	-7.11	-4.76	-7.33	-5.01	22264.	31432.
.180	11.91	-2.24	19.94	46.32	-20.26	-6.38	-4.25	-6.65	-4.54	20491.	27765.
.190	12.41	-2.28	19.01	44.72	-20.80	-5.62	-3.69	-5.93	-4.01	18516.	23933.
.200	12.89	-2.34	18.07	43.38	-21.17	-4.85	-3.10	-5.18	-3.45	16399.	20045.
.210	13.36	-2.41	17.14	42.29	-21.38	-4.08	-2.51	-4.43	-2.87	14199.	16202.
.220	13.82	-2.50	16.22	41.44	-21.42	-3.33	-1.92	-3.69	-2.28	11975.	12498.
.230	14.28	-2.59	15.32	40.82	-21.30	-2.63	-1.36	-2.99	-1.71	9782.	9017.
.240	14.73	-2.69	14.43	40.41	-21.02	-1.97	-.83	-2.33	-1.17	7673.	5830.
.250	15.17	-2.79	13.56	40.19	-20.60	-1.39	-.35	-1.72	-.67	5694.	2991.
.260	15.60	-2.90	12.72	40.13	-20.05	-.87	.07	-1.18	-.22	3888.	540.
.270	16.04	-3.01	11.90	40.20	-19.39	-.43	.43	-.71	.17	2287.	-1496.
.280	16.47	-3.11	11.10	40.39	-18.64	-.07	.72	-.31	.50	917.	-3111.
.290	16.90	-3.22	10.32	40.66	-17.83	.22	.93	.00	.75	-203.	-4312.
.300	17.33	-3.32	9.57	41.00	-16.96	.42	1.08	.25	.94	-1065.	-5121.
.310	17.77	-3.42	8.83	41.37	-16.07	.56	1.17	.42	1.07	-1668.	-5574.
.320	18.20	-3.51	8.11	41.76	-15.17	.62	1.19	.53	1.13	-2020.	-5717.
.330	18.64	-3.60	7.41	42.14	-14.27	.63	1.17	.57	1.15	-2137.	-5607.
.340	19.07	-3.68	6.71	42.51	-13.38	.59	1.12	.56	1.12	-2041.	-5307.
.350	19.51	-3.77	6.02	42.84	-12.52	.50	1.04	.50	1.07	-1763.	-4884.
.360	19.95	-3.84	5.33	43.13	-11.68	.39	.95	.41	.99	-1337.	-4407.
.370	20.39	-3.92	4.64	43.37	-10.87	.25	.86	.30	.92	-803.	-3941.
.380	20.83	-3.99	3.94	43.55	-10.08	.10	.78	.16	.84	-204.	-3548.
.390	21.28	-4.06	3.24	43.68	-9.30	-.05	.73	.02	.79	419.	-3279.
.400	21.72	-4.13	2.54	43.75	-8.53	-.20	.72	-.12	.76	1021.	-3178.
.410	22.16	-4.19	1.83	43.77	-7.76	-.32	.74	-.25	.76	1560.	-3269.
.420	22.60	-4.25	1.11	43.74	-6.96	-.43	.80	-.36	.81	2000.	-3566.
.430	23.03	-4.31	.39	43.67	-6.14	-.51	.91	-.44	.89	2308.	-4060.
.440	23.47	-4.37	-.34	43.57	-5.27	-.55	1.05	-.50	1.00	2458.	-4727.
.450	23.91	-4.42	-1.06	43.45	-4.36	-.56	1.22	-.53	1.15	2436.	-5520.
.460	24.34	-4.47	-1.78	43.32	-3.39	-.54	1.40	-.52	1.31	2235.	-6377.
.470	24.77	-4.52	-2.49	43.19	-2.38	-.48	1.58	-.49	1.48	1860.	-7218.
.480	25.20	-4.56	-3.19	43.07	-1.31	-.39	1.75	-.42	1.63	1332.	-7990.
.490	25.63	-4.59	-3.87	42.97	-.22	-.28	1.87	-.32	1.75	682.	-8472.

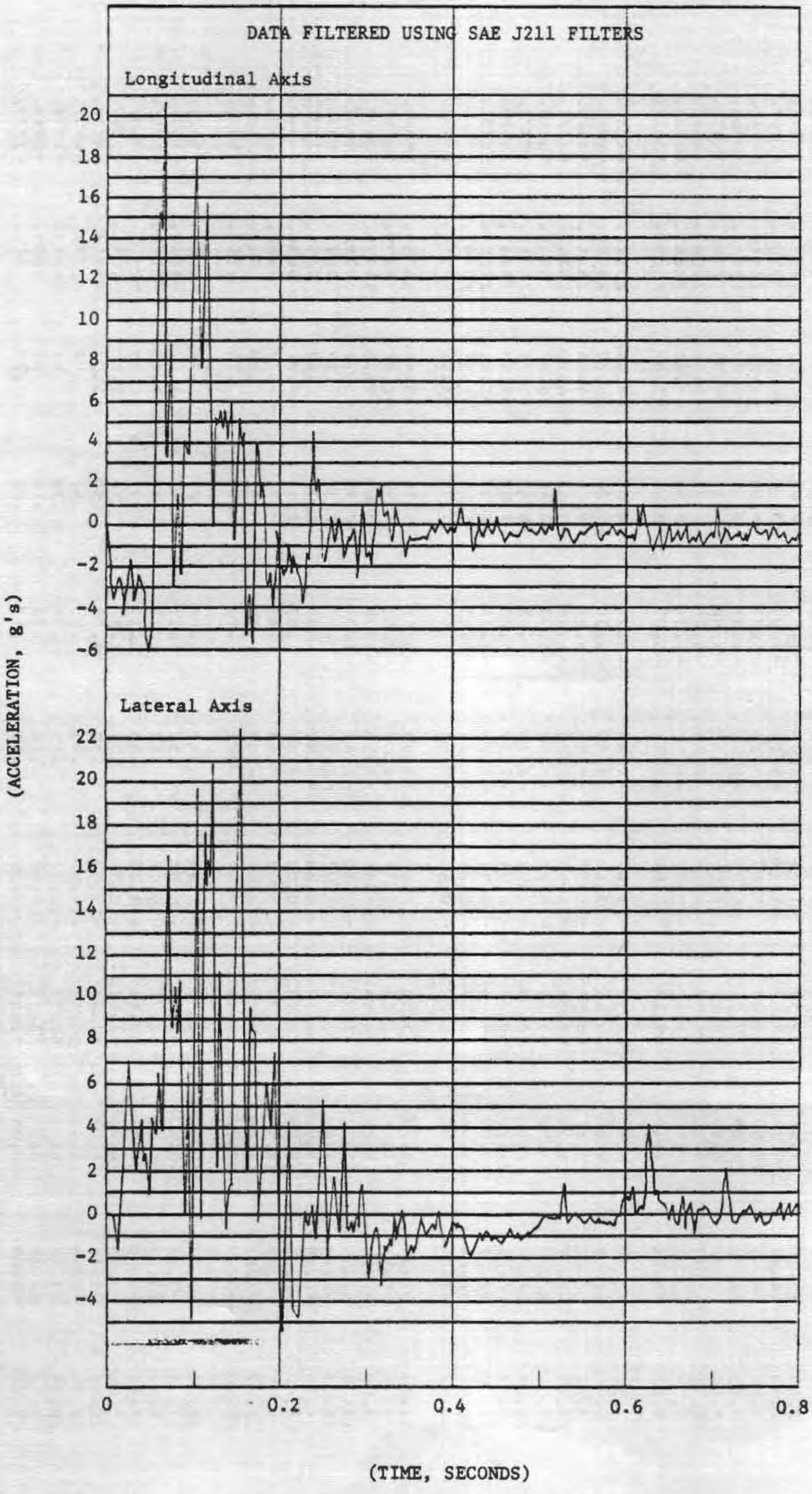


FIGURE 93. ACCELEROMETER DATA, TEST TTR-8

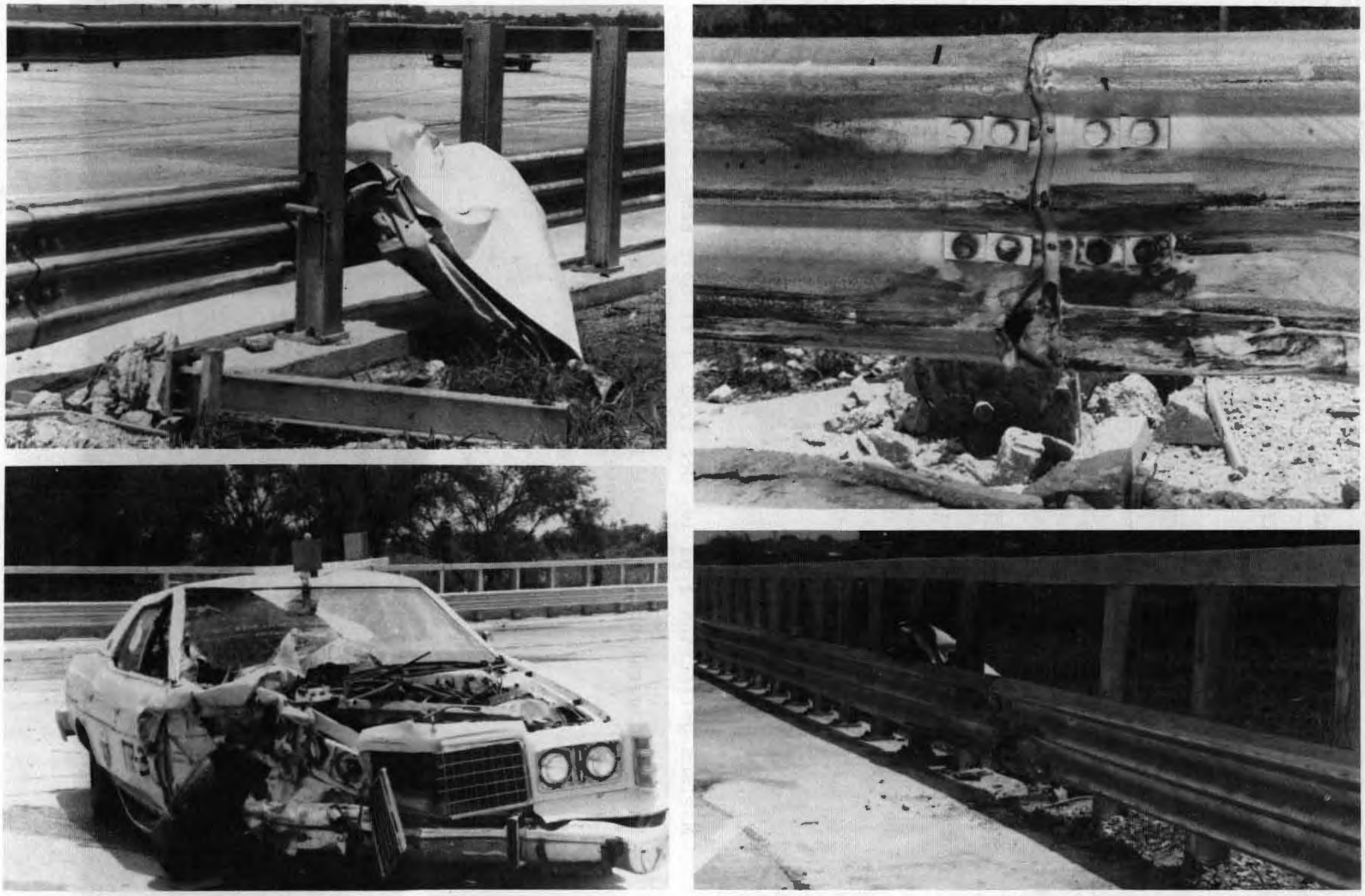


FIGURE 94. BARRIER AND VEHICLE DAMAGE, TEST TTR-8

TABLE 21

BARRIER DEFLECTIONS, TEST TTR-8

	LOCATION - POST NO.	DEFLECTION (IN.)	REMARKS
Transition	A Thru C	0	
Transition	D	0.31	
Transition	E	1.06	
Bridge Deck	1	1.38	Post Knocked Out - Concrete Failure
Bridge Deck	2	0.63	
Bridge Deck	3	0.31	
Bridge Deck	4 and on	0	

Maximum Deflection 1.63 in. Occurred 1 ft Upstream of Post 1

Metric Conversion: Multiply Inches by 25.4 to Obtain Millimeters

problem of hood snagging as had occurred in the previous two tests. An additional TS6x6x0.1875x6-in. (150-mm) long spacer connected the top rail to each post.

Test Vehicle: A 1978 Ford LTD was the test vehicle. Gross test weight, including instrumentation and controls, was 4500 lb (2041 kg).

Performance: Impact conditions were 60.2 mph and a 25.9-deg angle. As shown in Figure 95 the vehicle impacted the tubular thrie beam lower rail at the last soil-mounted post off the bridge deck displacing the rail upward and rearward (as designed) against the posts before being redirected. The vehicle left the installation at a 13.3-deg angle after being in contact for 17.5 ft (5.3 m). No hood snagging as had occurred in previous tests was observed during the impact. Maximum 50 msec average accelerations measured during the event were -4.8 g (cine) and -4.2 g (accelerometer) in the longitudinal direction, and 7.8 g (cine) and 9.0 g (accelerometer) in the lateral direction. Test results are summarized in Figure 95 and high speed film analysis is contained in Table 22. Accelerometer data are shown in Figure 96.

Barrier Damage: Vehicle damage, also shown in Figure 97, was moderate. Sheet metal of the right front fender and headlight area was deformed and the front bumper displaced. Also, the hood was pushed rearward slightly and made contact with the windshield cracking it at the lower right corner. Table 23 summarizes permanent barrier deformation.

TEST TTR-10

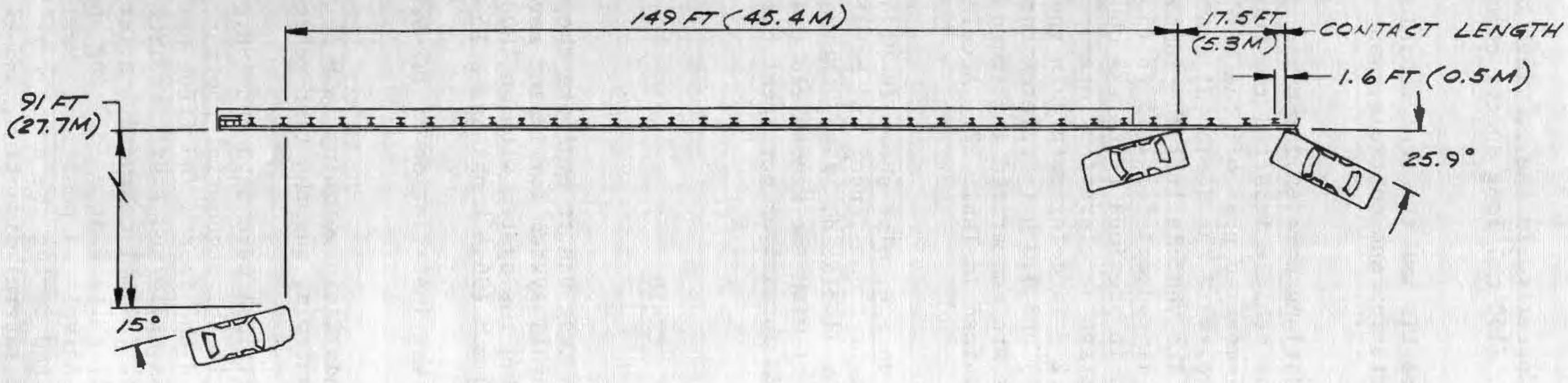
Purpose: Purpose of this test was to evaluate the modified self-restoring thru truss bridgerail system for impact severity. This was accomplished by impacting the system with an 1800-lb (816-kg) minicompact automobile at 60 mph (96.6 kmph) and a 15-deg angle.

Test Installation: The test installation of TTR-9 was repaired and used for this test.

Test Vehicle: A 1975 Honda Civic weighing 1658 lb (752 kg), including instrumentation and controls, was the test vehicle.

Performance: Impact conditions were 61.3 mph (98.6 kmph) and a 20.9-deg angle. As shown in the sequential photographs of Figure 98 impact occurred between the fourth and fifth posts off the bridge deck, and the Honda was smoothly and easily redirected after displacing the lower rail 3.5 in. (89 mm) rearward. After the vehicle lost contact with the lower rail, exiting at a -8.2 deg angle, the rail returned to its original, undisplaced position. Maximum 50 msec average accelerations measured during the event were 9.4 g (cine) and 9.5 g (accelerometer) in the lateral direction, and -4.0 g (cine) and -3.4 g (accelerometer) in the longitudinal direction. Test

0.20 SEC　　0.15 SEC　　0.1 SEC　　0.05 SEC　　IMPACT



Test TTR-9
Date 7/23/81
Beam Rail:
  Lower .... 12 ga. steel tubular thrie beam x 25.0 ft (7.6 m)
  Upper .... 5.88 in. (149 mm) x 4.75 in. (121 mm) x 0.17 in. (4.3 mm) thk x 25.0 ft (7.6 m) long steel channel
Transition Post .... W6x15.5 steel x 10 ft (3.0 m)
Transition Post Spacing .... 5.0 ft (1.5 m)
Lower Beam Rail Deflection:
  Max Dynamic .... 6.0 in. (152 mm)
  Max Permanent .... 4.6 in. (117 mm)

Vehicle .... 1978 Ford LTD
Vehicle Mass
  (w/instrumentation)............. 4500 lb (2040 kg)
Impact Speed .... 60.2 mph (96.9 kmph)
Impact Angle .... 25.9 deg
Exit Speed .... 50.4 mph (81.1 kmph)
Exit Angle .... 13.3 deg
Maximum Roll Angle .... 8 deg
Vehicle Accelerations (max 50 ms avg)
  Lateral (cine/electronic) .... 7.8 g/9.0 g
  Longitudinal (cine/electronic) ...... -4.8 g/-4.2 g

FIGURE 95. SUMMARY OF RESULTS, TEST TTR-9

TABLE 22

RESULTS OF HIGH-SPEED FILM ANALYSIS, TEST TTR-9

SUMMARY OF VEHICLE KINEMATIC AND DYNAMIC DATA THRU TRUSS BRIDGERAIL TEST TTR-9 7/23/81

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 AVER .05 SEC. LONG	LAT	APPROX. BARRIER FORCES(LB) X	Y
0.000	-.36	-6.69	25.85	88.27	-3.27	-.99	.41	0.00	0.00	4798.	265.
.010	.44	-6.34	25.94	87.84	-3.46	-1.68	-.76	0.00	0.00	5305.	6366.
.020	1.25	-5.99	25.88	87.18	-3.82	-2.46	-2.14	0.00	0.00	5748.	13497.
.030	2.05	-5.65	25.65	86.27	-4.40	-3.24	-3.59	-2.82	-2.86	6130.	20876.
.040	2.84	-5.32	25.25	85.15	-5.19	-3.93	-4.97	-3.50	-4.16	6452.	27783.
.050	3.63	-5.01	24.70	83.85	-6.17	-4.48	-6.17	-4.07	-5.37	6716.	33638.
.060	4.42	-4.73	23.99	82.42	-7.29	-4.84	-7.10	-4.49	-6.38	6926.	38047.
.070	5.20	-4.48	23.14	80.95	-8.48	-5.01	-7.72	-4.74	-7.15	7083.	40813.
.080	5.97	-4.25	22.16	79.49	-9.64	-4.99	-8.03	-4.81	-7.63	7189.	41932.
.090	6.74	-4.06	21.03	78.11	-10.69	-4.82	-8.04	-4.72	-7.83	7247.	41552.
.100	7.51	-3.89	19.78	76.84	-11.55	-4.52	-7.81	-4.50	-7.78	7258.	39940.
.110	8.27	-3.75	18.39	75.73	-12.16	-4.15	-7.39	-4.19	-7.51	7226.	37434.
.120	9.02	-3.64	16.89	74.79	-12.48	-3.74	-6.85	-3.82	-7.10	7151.	34392.
.130	9.77	-3.56	15.27	74.00	-12.49	-3.33	-6.27	-3.43	-6.60	7037.	31158.
.140	10.51	-3.49	13.57	73.36	-12.22	-2.95	-5.70	-3.05	-6.07	6886.	28026.
.150	11.25	-3.45	11.79	72.84	-11.70	-2.60	-5.18	-2.70	-5.56	6700.	25217.
.160	11.99	-3.42	9.97	72.41	-10.99	-2.30	-4.76	-2.38	-5.10	6482.	22868.
.170	12.72	-3.42	8.14	72.05	-10.16	-2.03	-4.43	-2.10	-4.73	6233.	21030.
.180	13.44	-3.42	6.33	71.74	-9.29	-1.80	-4.20	-1.85	-4.43	5956.	19675.
.190	14.16	-3.44	4.59	71.47	-8.43	-1.58	-4.04	-1.63	-4.21	5654.	18709.
.200	14.88	-3.48	2.93	71.22	-7.65	-1.39	-3.93	-1.42	-4.04	5328.	17993.
.210	15.60	-3.52	1.39	71.00	-6.99	-1.20	-3.83	-1.24	-3.90	4981.	17366.
.220	16.30	-3.58	-.01	70.81	-6.48	-1.03	-3.70	-1.06	-3.75	4616.	16665.
.230	17.01	-3.65	-1.25	70.64	-6.11	-.86	-3.52	-.90	-3.57	4235.	15746.
.240	17.71	-3.73	-2.33	70.50	-5.87	-.72	-3.26	-.76	-3.32	3840.	14504.
.250	18.42	-3.83	-3.25	70.38	-5.73	-.60	-2.90	-.64	-3.01	3434.	12882.
.260	19.11	-3.93	-4.01	70.28	-5.66	-.50	-2.46	-.53	-2.61	3019.	10878.
.270	19.81	-4.04	-4.64	70.19	-5.60	-.42	-1.94	-.45	-2.15	2597.	8547.
.280	20.50	-4.15	-5.15	70.12	-5.50	-.36	-1.37	-.38	-1.63	2172.	5993.
.290	21.20	-4.27	-5.57	70.05	-5.34	-.31	-.78	-.33	-1.08	1745.	3358.
.300	21.89	-4.39	-5.92	69.99	-5.07	-.27	-.21	-.29	-.53	1319.	809.
.310	22.58	-4.52	-6.23	69.93	-4.68	-.23	.31	-.25	-.02	896.	-1480.
.320	23.27	-4.64	-6.50	69.89	-4.17	-.19	.73	-.20	.42	480.	-3348.
.330	23.96	-4.76	-6.77	69.85	-3.56	-.14	1.03	-.15	.76	72.	-4604.
.340	24.65	-4.87	-7.05	69.83	-2.86	-.07	1.19	-.10	.98	-324.	-5341.
.350	25.34	-4.98	-7.34	69.83	-2.11	.00	1.20	-.02	1.06	-707.	-5350.
.360	26.03	-5.09	-7.65	69.86	-1.37	.10	1.07	.06	1.02	-1074.	-4720.
.370	26.72	-5.20	-7.98	69.91	-.66	.20	.82	.16	.85	-1422.	-3544.
.380	27.41	-5.30	-8.33	70.00	-.01	.32	.49	.26	.60	-1749.	-1967.
.390	28.10	-5.40	-8.70	70.12	.53	.44	.11	.38	.28	-2052.	-176.
.400	28.80	-5.50	-9.08	70.28	.97	.57	-.27	.50	-.06	-2328.	1622.
.410	29.49	-5.60	-9.48	70.47	1.31	.68	-.61	.61	-.38	-2575.	3220.
.420	30.19	-5.71	-9.89	70.70	1.58	.78	-.86	.71	-.65	-2790.	4435.
.430	30.89	-5.82	-10.31	70.95	1.80	.85	-1.00	.79	-.82	-2970.	5134.
.440	31.60	-5.93	-10.76	71.22	2.02	.90	-1.02	.85	-.90	-3114.	5250.
.450	32.30	-6.04	-11.22	71.49	2.28	.91	-.91	.88	-.86	-3217.	4801.
.460	33.01	-6.16	-11.70	71.76	2.63	.89	-.70	.88	-.73	-3278.	3890.
.470	33.72	-6.28	-12.21	72.01	3.06	.84	-.43	.85	-.53	-3294.	2700.
.480	34.43	-6.40	-12.73	72.24	3.64	.78	-.16	.81	-.31	-3261.	1476.
.490	35.14	-6.53	-13.26	72.45	4.29	.71	.06	.75	-.12	-3178.	490.

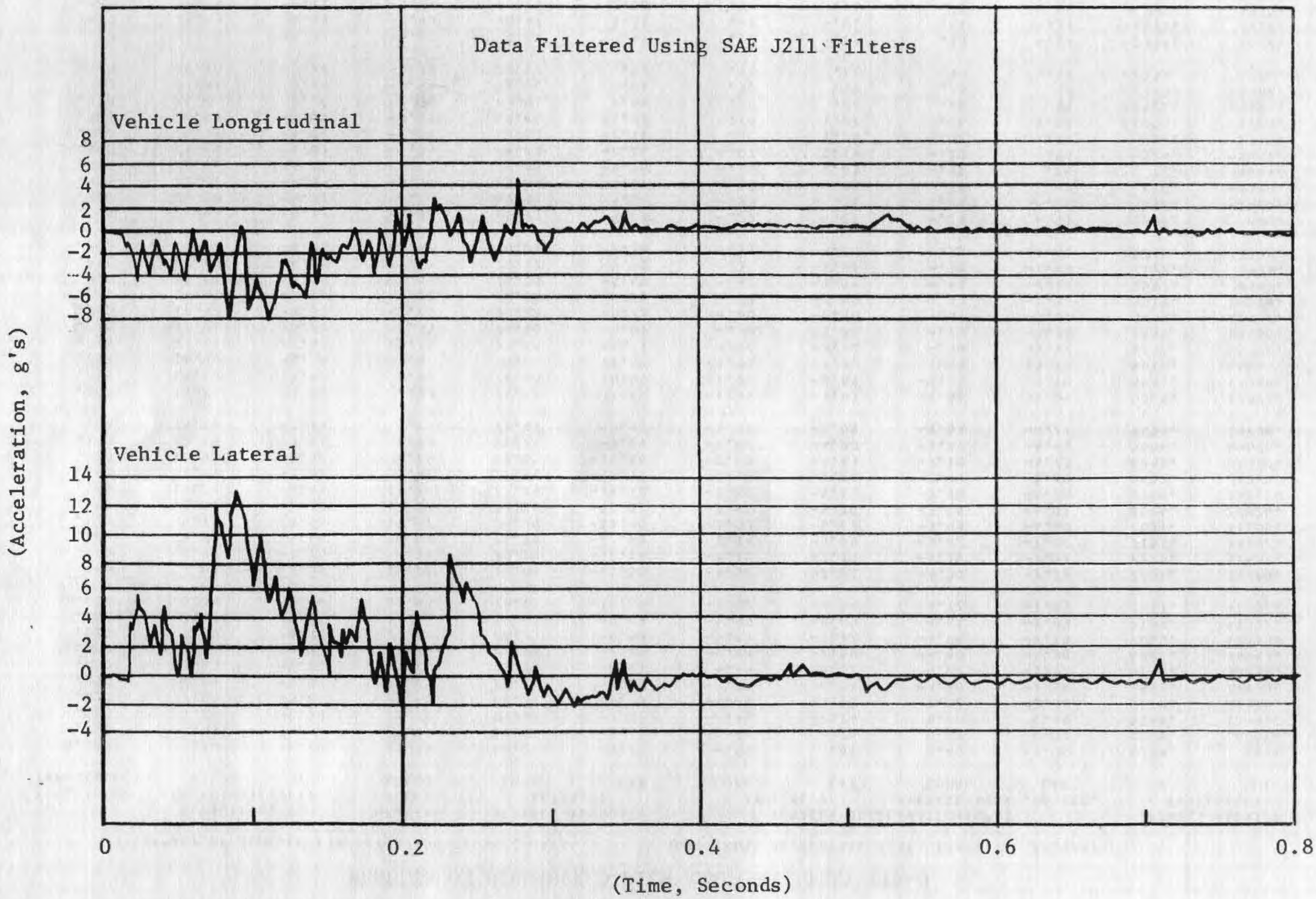


FIGURE 96. ACCELEROMETER DATA, TEST TTR-9

FIGURE 97. BARRIER AND VEHICLE DAMAGE, TEST TTR-9

TABLE 23

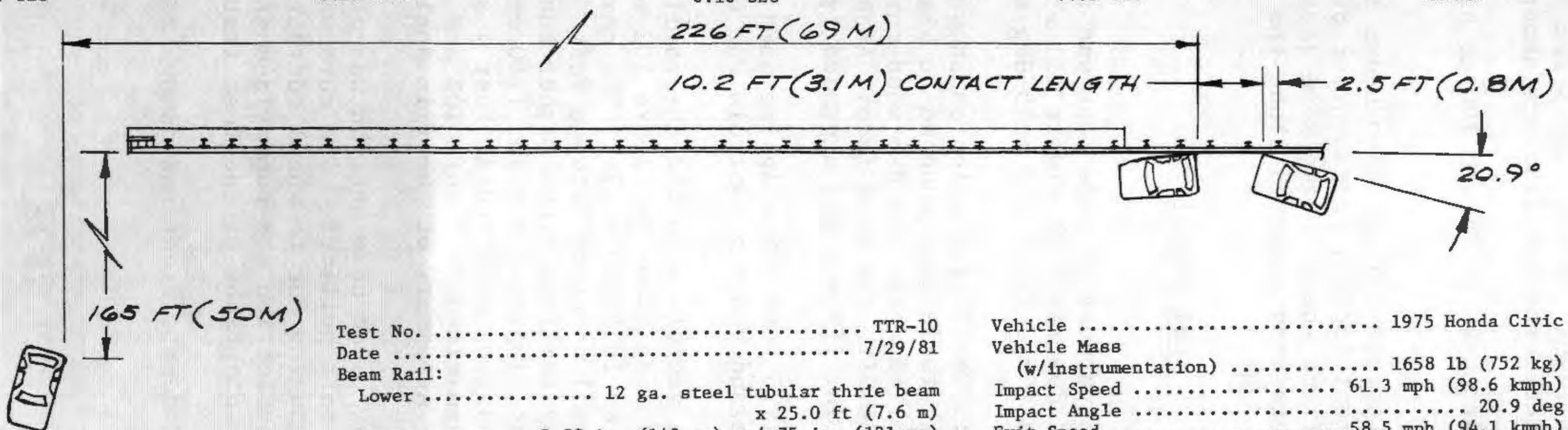
BARRIER DEFLECTIONS, TEST TTR-9

	Location - Post No.	Deflection - Top of Post (in.)	Rail Deflection (in.)
Transition	A	2.00	1.75
	B	8.00	4.00
	C	6.25	3.63
	D	0	1.63
	E	0	0.50
Bridge Deck	1	0	0
	2	0	0
	3	0	0
	4	0	0
	5	0	0

Maximum Rail Deflection of 4.63 in. occurs at point 28 in. downstream of Post B.

Metric Conversion: Multiply inches by 25.4 to obtain millimeters.

0.20 SEC 0.15 SEC 0.10 SEC 0.05 SEC IMPACT



Test No. TTR-10
Date 7/29/81
Beam Rail:
  Lower .... 12 ga. steel tubular thrie beam x 25.0 ft (7.6 m)
  Upper .... 5.88 in. (149 mm) x 4.75 in. (121 mm) x 0.17 in. (4.3 mm) thk x 25.0 ft (7.6 m) long steel channel
Transition Post .... W6x15.5 steel x 10 ft (3.0 m)
Transition Post Spacing .... 5.0 ft (1.5 m)
Lower Beam Rail Deflection:
  Max Dynamic .... 3.5 in. (89 mm)
  Max Permanent 0

Vehicle .... 1975 Honda Civic
Vehicle Mass
  (w/instrumentation) .... 1658 lb (752 kg)
Impact Speed .... 61.3 mph (98.6 kmph)
Impact Angle .... 20.9 deg
Exit Speed .... 58.5 mph (94.1 kmph)
Exit Angle .... -8.2 deg
Maximum Roll Angle .... 4 deg
Vehicle Accelerations (max 50 ms avg)
  Lateral (cine/electronic) .... 9.4 g/9.5 g
  Longitudinal (cine/electronic) ...... -4.0 g/-3.4 g

FIGURE 98. SUMMARY OF RESULTS, TEST TTR-10

results are summarized in Figure 98 and high-speed film analysis is contained in Table 24. Accelerometer data are shown in Figure 99.

Barrier Damage: As shown in Figure 100 no barrier damage except scuffing occurred.

Vehicle Damage: Vehicle damage, also shown in Figure 100, was sustained by the right front fender, hood, corner of the bumper, and suspension of the right front wheel. Also some scraping by contact with the lower rail corrugations occurred along the right side.

TEST TTR-11

Test Purpose: The purpose of this test was to evaluate the low cost bridge rail retrofit described in Figure 101 when impacted by a full-size sedan at 60 mph (96.6 kmph) and a 15-deg angle.

Test Installation: The installation as shown in Figure 101 was constructed with 12-ga thrie beam mounted to W6x15.5-lb posts spaced at 8.33-ft (2.54-m) centers. An 8x8 wood curb was installed with the curb face in-line with the beam face. Anchor bolts for both posts and curbs were 3/4 in. (19 mm) dia expanded type concrete anchors.

Test Vehicle: A 1975 Ford LTD weighing 4588 lb (2081 kg) including instrumentation and vehicle controls was used.

Test Results: The vehicle impacted the railing 3.3 ft (1.0 m) downstream of bridge post 2 as shown in Figure 102 with a speed of 61.7 mph (99.3 kmph) and an 18.4-deg angle. The maximum dynamic deflection (9.25 in. [235 mm]) occurred between Posts 3 and 4. Maximum encroachment of barrier system into truss member zone was at Post 3 where the back of the post displaced 5.5 in. (140 mm - dynamic). Some evidence of wheel snagging occurred at Post 4 as shown in Figure 104. Test results are summarized in Figure 102 and accelerometer data are shown in Figure 103. A summary of the film analyzed is in Table 25.

Installation Damage: One beam section was damaged and Posts 3 and 4 experienced anchor bolt pull-out. The curb was essentially undamaged although some gouging due to wheel contact was noted. Permanent beam and post deflection are summarized in Table 26. Figure 104 contains after test photographs of the test installation.

Vehicle Damage: Moderate front end damage resulted as shown in Figure 105.

TEST TTR-13

Purpose: Purpose of this test was to evaluate the low cost bridgerail system when impacted by a 4500-lb (2041-kg) vehicle at 60 mph (96.6 kmph) and a 15-deg angle.

TABLE 24

RESULTS OF HIGH-SPEED FILM ANALYSIS, TEST TTR-10

SUMMARY OF VEHICLE KINEMATIC AND DYNAMIC DATA   THRU TRUSS BRIDGERAIL TEST   TTR-10   7/30/81

TIME AFTER	VEHICLE C. G. COORDINATES(FT)		HEADING ANGLE	VEHICLE VELOCITY (FT/SEC)		VEHICLE ACCELERATION(G"S) AT TIME T		AVERAGE AVER .05 SEC.		APPROX. BARRIER FORCES(LB)	
IMPACT(SEC)	X	Y	(DEG)	LONG	LAT	LONG	LAT	LONG	LAT	X	Y
0.000	4.46	-4.80	20.85	89.85	-3.65	-1.04	-1.72	0.00	0.00	593.	3283.
.010	5.31	-4.52	20.75	89.40	-4.32	-1.80	-3.49	0.00	0.00	743.	6463.
.020	6.16	-4.25	20.73	88.70	-5.72	-2.60	-5.42	0.00	0.00	859.	9927.
.030	7.01	-4.00	20.71	87.74	-7.74	-3.35	-7.26	-2.89	-6.15	943.	13219.
.040	7.86	-3.78	20.58	86.58	-10.14	-3.94	-8.77	-3.48	-7.63	1000.	15905.
.050	8.70	-3.59	20.21	85.33	-12.57	-4.26	-9.77	-3.87	-8.76	1035.	17647.
.060	9.54	-3.43	19.46	84.12	-14.70	-4.27	-10.17	-3.99	-9.41	1053.	18249.
.070	10.39	-3.30	18.26	83.12	-16.20	-3.95	-9.93	-3.81	-9.53	1060.	17689.
.080	11.22	-3.21	16.58	82.42	-16.85	-3.39	-9.13	-3.38	-9.13	1060.	16111.
.090	12.06	-3.16	14.45	82.06	-16.56	-2.70	-7.90	-2.80	-8.29	1058.	13803.
.100	12.90	-3.12	11.99	81.99	-15.34	-2.02	-6.44	-2.17	-7.14	1056.	11139.
.110	13.73	-3.11	9.32	82.11	-13.36	-1.46	-4.97	-1.61	-5.86	1054.	8521.
.120	14.56	-3.12	6.63	82.28	-10.88	-1.07	-3.70	-1.18	-4.65	1053.	6305.
.130	15.39	-3.14	4.05	82.40	-8.22	-.83	-2.81	-.89	-3.67	1048.	4752.
.140	16.22	-3.17	1.73	82.44	-5.70	-.70	-2.38	-.71	-3.02	1035.	3976.
.150	17.04	-3.20	-.26	82.39	-3.60	-.60	-2.37	-.59	-2.73	1007.	3933.
.160	17.86	-3.25	-1.88	82.30	-2.07	-.49	-2.69	-.48	-2.75	954.	4431.
.170	18.68	-3.30	-3.15	82.20	-1.18	-.35	-3.14	-.36	-2.95	866.	5166.
.180	19.50	-3.36	-4.13	82.13	-.86	-.19	-3.51	-.22	-3.18	730.	5787.
.190	20.32	-3.43	-4.87	82.11	-.96	-.02	-3.61	-.07	-3.27	535.	5967.
.200	21.14	-3.52	-5.44	82.14	-1.25	.15	-3.31	.09	-3.09	269.	5484.
.210	21.96	-3.61	-5.91	82.23	-1.54	.31	-2.56	.26	-2.58	-77.	4277.
.220	22.77	-3.72	-6.30	82.36	-1.64	.47	-1.45	.42	-1.78	-510.	2481.
.230	23.59	-3.83	-6.63	82.55	-1.43	.65	-.18	.61	-.80	-1029.	423.
.240	24.41	-3.93	-6.91	82.80	-.88	.87	.98	.82	.17	-1628.	-1440.
.250	25.23	-4.04	-7.16	83.13	-.07	1.17	1.74	1.10	.90	-2286.	-2623.
.260	26.06	-4.14	-7.40	83.56	.88	1.56	1.87	1.44	1.22	-2971.	-2747.
.270	26.89	-4.24	-7.65	84.14	1.78	2.03	1.30	1.83	1.04	-3631.	-1692.
.280	27.73	-4.33	-7.93	84.86	2.43	2.53	.18	2.23	.44	-4191.	287.
.290	28.58	-4.43	-8.21	85.73	2.69	2.93	-1.11	2.56	-.35	-4547.	2523.

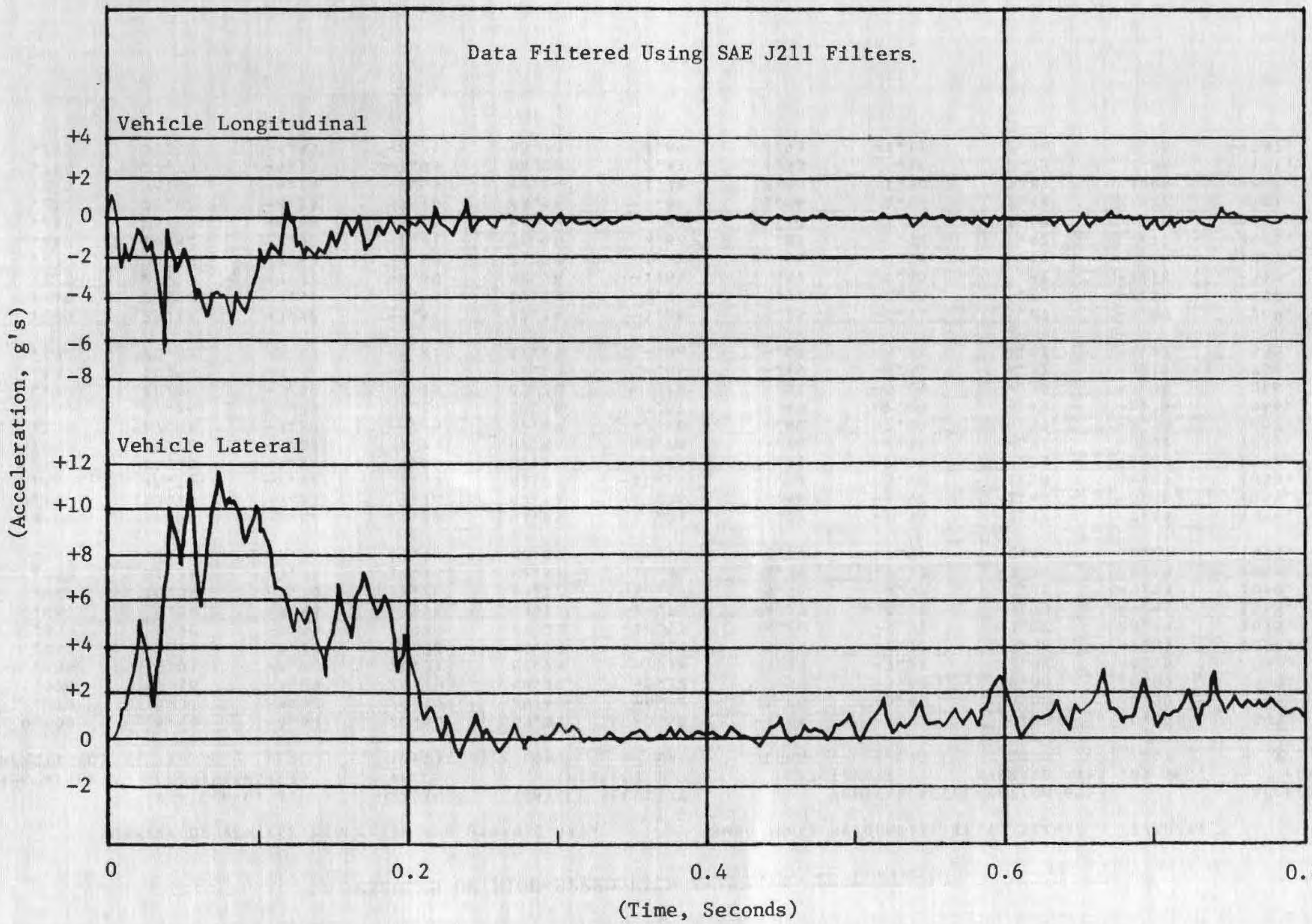


FIGURE 99. ACCELEROMETER DATA, TEST TTR-10

FIGURE 100. BARRIER AND VEHICLE DAMAGE, TEST TTR-10

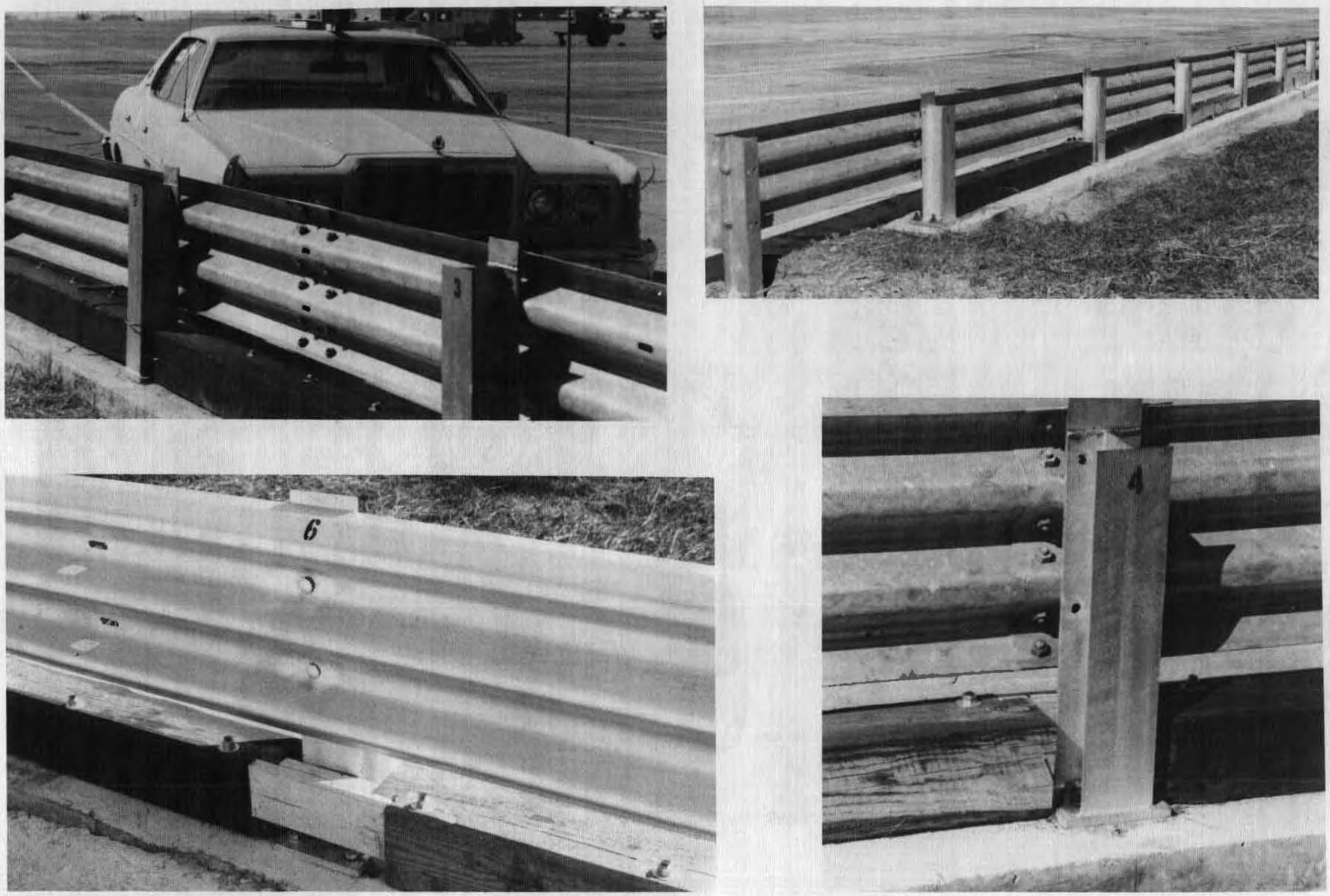
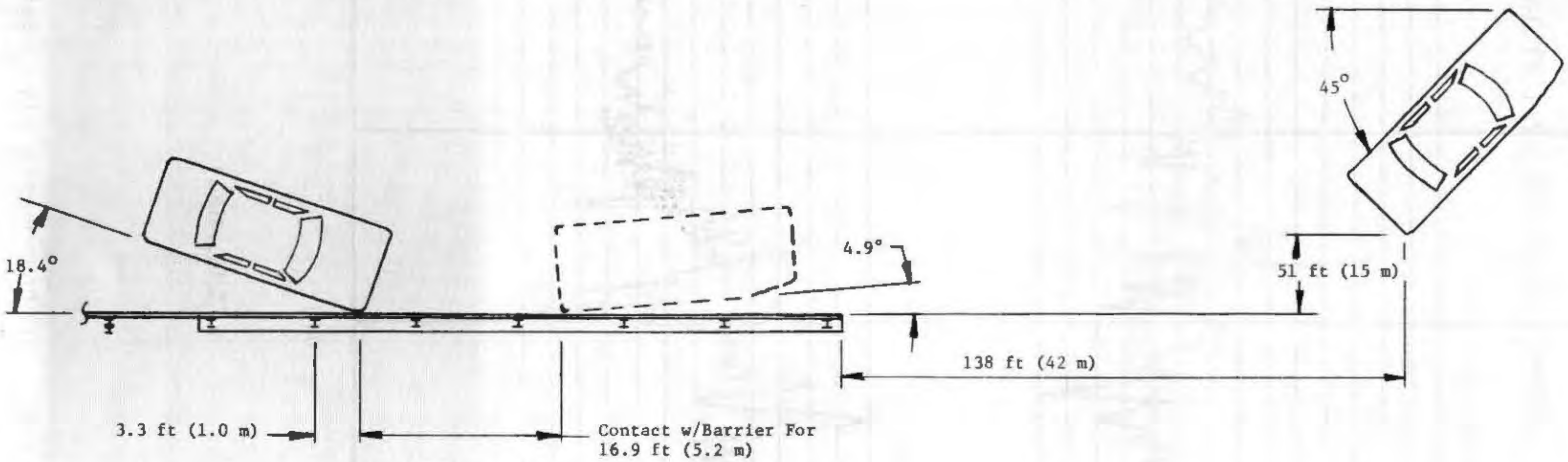


FIGURE 101. TTR-11 TEST INSTALLATION

IMPACT   0.05 SEC   0.15 SEC   0.20 SEC   0.25 SEC



Test TTR-11
Date 11/24/81
Beam Rail:
  Upper .... 12 ga steel thrie beam
  Lower Curb .... 8x8 wood
Bridge Post ..... W6x15.5 steel x 2'-9" (8m)
Upper Beam Rail Deflection:
  Max Dynamic .... 9.0 in. (0.2m)
  Max Permanent .... 7.3 in. (0.2m)

Vehicle .... 1975 Ford LTD
Vehicle Mass
  (w/instrumentation)........ 4588 lb (2081 kg)
Impact Speed .... 61.7 mph (99.3 kmph)
Impact Angle .... 18.4 deg
Exit Speed .... 48 mph (78 kmph)
Exit Angle .... 4.9 deg
Maximum Roll Angle
Vehicle Accelerations (max 50 ms avg):
  Lateral (cine/electr)............ 6.0 g/8.3 g
  Longitudinal (cine/electr)..... -3.5 g/-4.2 g

FIGURE 102. SUMMARY OF RESULTS, TEST TTR-11

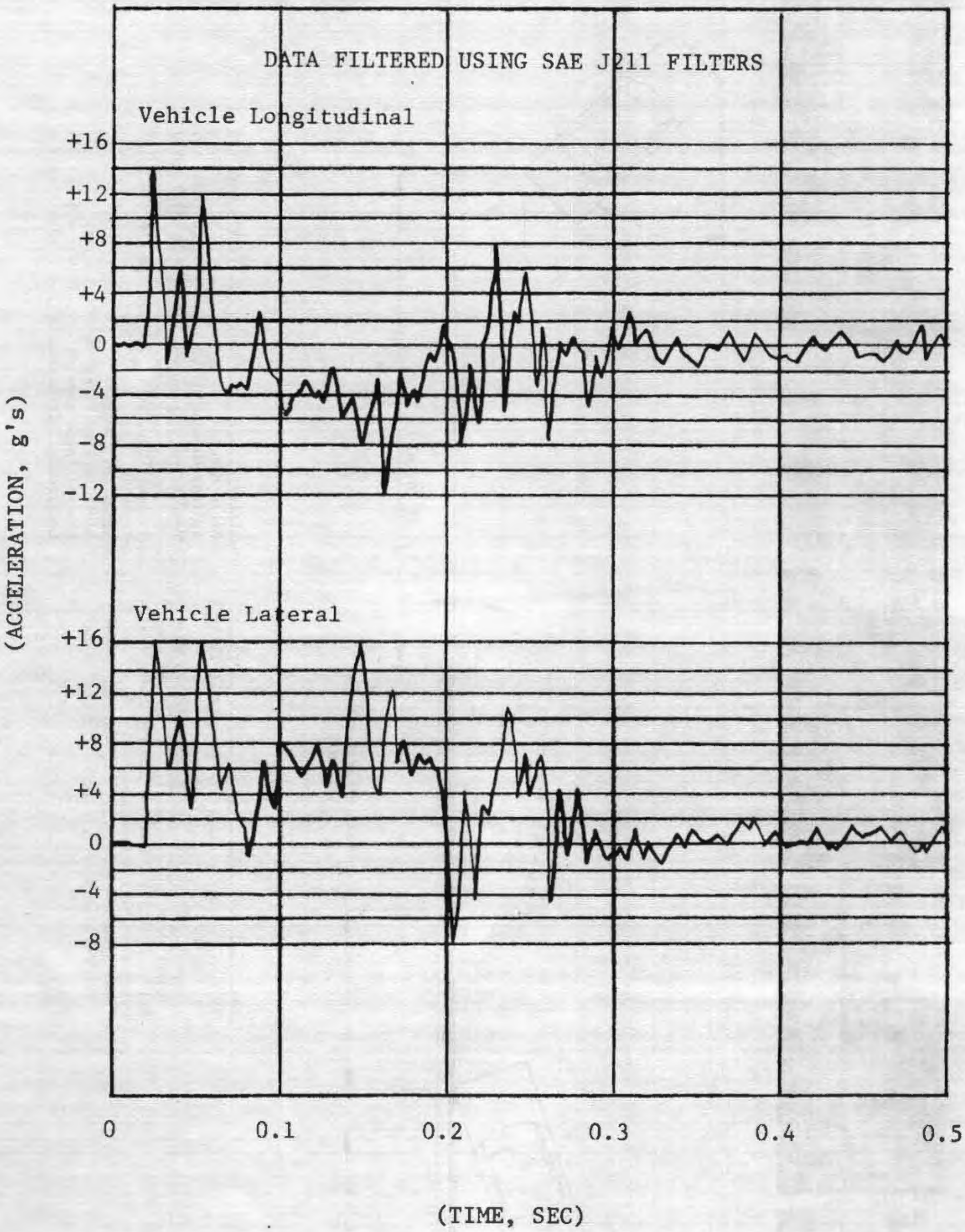


FIGURE 103. ACCELEROMETER DATA, TEST TTR-11

TABLE 25

SUMMARY OF VEHICLE KINEMATIC AND DYNAMIC DATA, TEST TTR-11

SUMMARY OF VEHICLE KINEMATIC AND DYNAMIC DATA   THRU TRUSS RETROFIT TEST   TTR-11   11/24/81

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 AV.ER .05 SEC. LONG	LAT	APPROX. BARRIER FORCES(LB) X	Y
0.000	1.17	-5.23	18.37	90.54	-1.31	-3.16	-.35	0.00	0.00	13235.	6077.
.010	2.02	-4.96	18.40	89.45	-1.54	-3.57	-.80	0.00	0.00	14365.	8667.
.020	2.87	-4.69	18.41	88.26	-1.90	-3.79	-1.35	0.00	0.00	14556.	11364.
.030	3.71	-4.44	18.39	87.03	-2.40	-3.84	-1.96	-3.67	-1.70	13894.	14095.
.040	4.54	-4.19	18.32	85.81	-3.03	-3.74	-2.61	-3.68	-2.31	12536.	16789.
.050	5.36	-3.95	18.18	84.64	-3.77	-3.53	-3.28	-3.56	-2.95	10702.	19377.
.060	6.17	-3.73	17.94	83.57	-4.58	-3.26	-3.94	-3.36	-3.59	8645.	21795.
.070	6.98	-3.53	17.57	82.60	-5.41	-2.96	-4.55	-3.11	-4.19	6631.	23982.
.080	7.78	-3.34	17.04	81.75	-6.21	-2.68	-5.08	-2.85	-4.75	4914.	25886.
.090	8.58	-3.17	16.33	81.00	-6.90	-2.46	-5.52	-2.63	-5.22	3713.	27462.
.100	9.37	-3.02	15.41	80.35	-7.44	-2.33	-5.84	-2.47	-5.59	3194.	28672.
.110	10.17	-2.88	14.28	79.76	-7.78	-2.31	-6.04	-2.39	-5.85	3450.	29491.
.120	10.96	-2.77	12.95	79.18	-7.89	-2.41	-6.13	-2.42	-6.00	4485.	29902.
.130	11.75	-2.68	11.43	78.58	-7.78	-2.62	-6.12	-2.53	-6.05	6214.	29900.
.140	12.53	-2.61	9.76	77.92	-7.45	-2.90	-6.02	-2.73	-6.02	8452.	29490.
.150	13.31	-2.57	7.98	77.15	-6.97	-3.23	-5.86	-2.97	-5.91	10930.	28608.
.160	14.08	-2.54	6.17	76.28	-6.39	-3.53	-5.65	-3.22	-5.74	13304.	27523.
.170	14.84	-2.53	4.38	75.29	-5.81	-3.73	-5.40	-3.40	-5.53	15181.	26032.
.180	15.59	-2.54	2.70	74.24	-5.32	-3.77	-5.12	-3.45	-5.27	16158.	24264.
.190	16.32	-2.56	1.20	73.19	-4.97	-3.56	-4.78	-3.32	-4.97	15866.	22276.
.200	17.05	-2.61	-.08	72.23	-4.83	-3.05	-4.39	-2.94	-4.60	14029.	20135.
.210	17.77	-2.66	-1.09	71.46	-4.91	-2.22	-3.95	-2.29	-4.18	10543.	17914.
.220	18.48	-2.73	-1.82	70.98	-5.19	-1.10	-3.46	-1.40	-3.72	5560.	15693.
.230	19.19	-2.81	-2.31	70.88	-5.82	.21	-2.95	-.35	-3.23	-407.	13556.
.240	19.89	-2.90	-2.61	71.19	-6.12	1.50	-2.46	.68	-2.75	-6364.	11588.
.250	20.60	-3.00	-2.82	71.86	-6.57	2.44	-2.04	1.39	-2.33	-10699.	9877.
.260	21.32	-3.10	-3.07	72.71	-6.87	2.50	-1.72	1.31	-2.01	-11025.	8507.
.270	22.05	-3.21	-3.46	73.37	-6.89	.97	-1.59	-.20	-1.86	-4010.	7559.
.280	22.78	-3.33	-4.07	73.19	-6.64	-3.11	-1.77	-4.03	-1.99	14823.	7105.
.290	23.49	-3.45	-4.88	71.12	-6.29	-11.01	-2.32	-11.34	-2.65	51302.	7209.

TABLE 26

TTR-11 PERMANENT BARRIER DEFLECTIONS

Location - Post No.	Deflection* (in.)
1	0
2	0.63
3	4.75**
4	1.63
5	0
6	0
7	0

*Deflection measured at top peak of thrie beam.

**Max defl 7.25 in. located 50 in. downstream of Post 3.

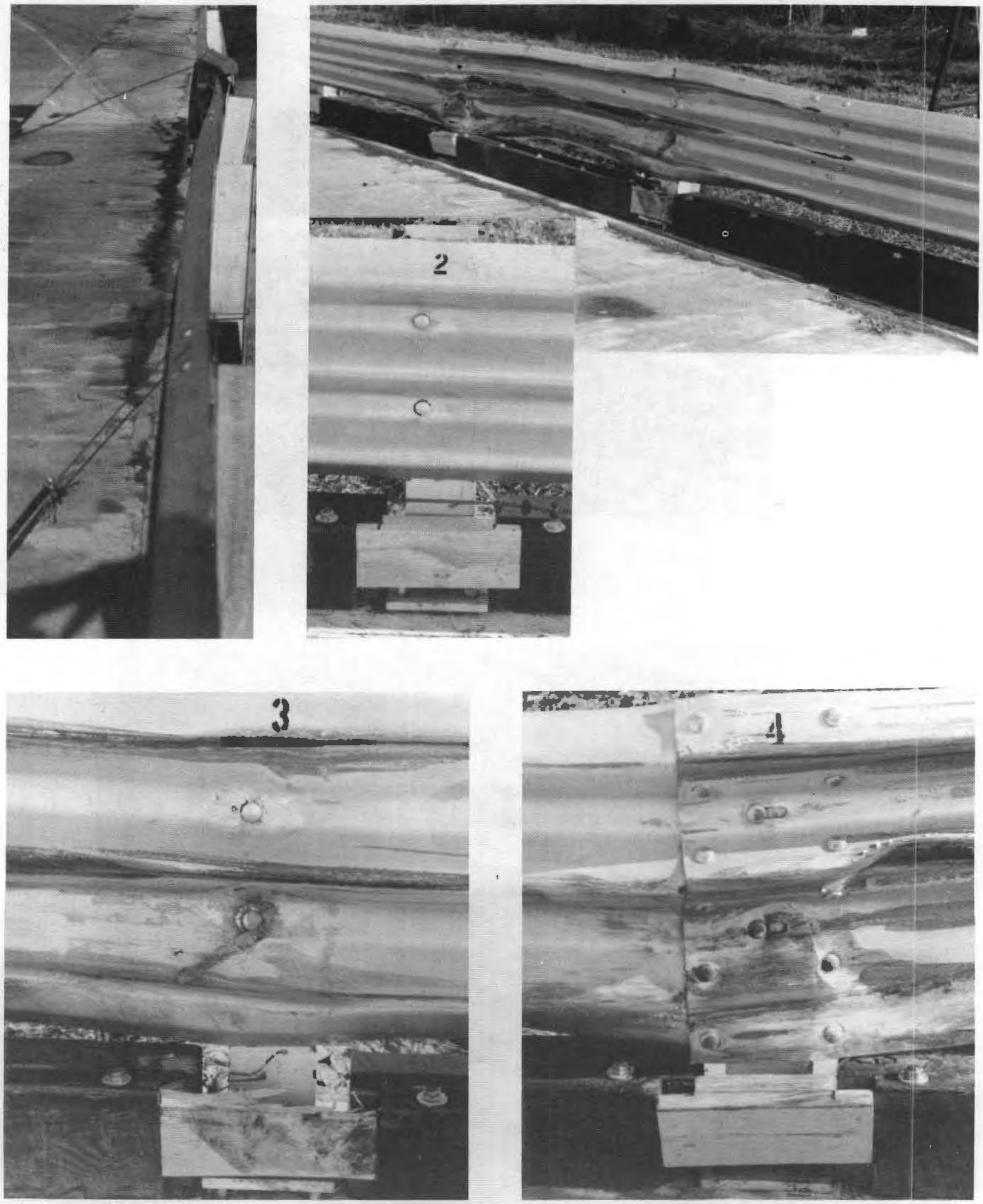


FIGURE 104. TTR-11 BARRIER DAMAGE

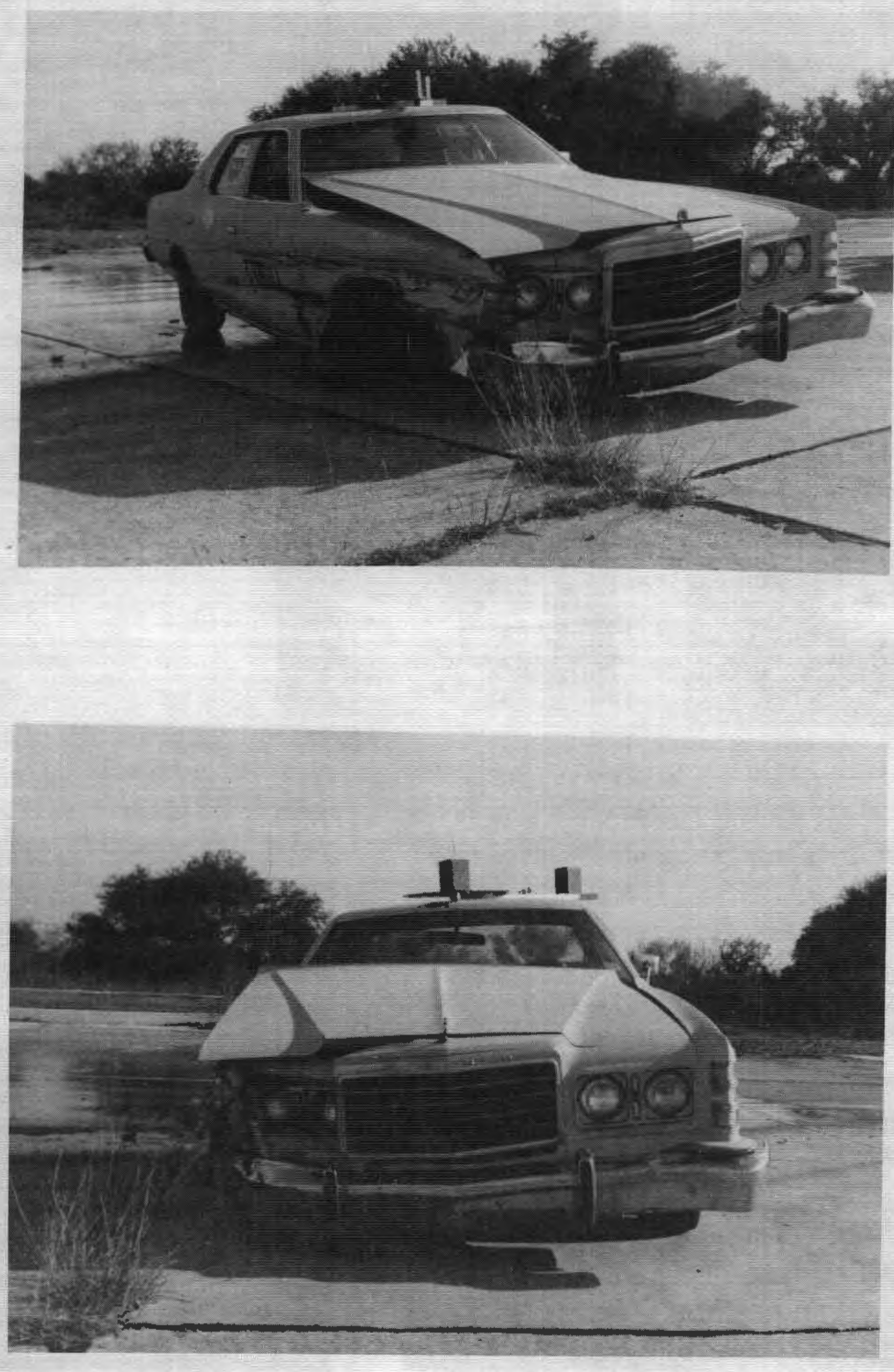


FIGURE 105. TTR-11 VEHICLE DAMAGE

Test Installation: Photographs of the 50-ft (15-m) long test installation are shown in Figure 106. Spacing between the W6x8.5 posts was 5 ft (1.5 m) and height of the thrie beam rail was 32 in. (813 mm). The installation transitioned upstream into thrie beam rail attached to soil mounted W6x8.5 posts.

Test Vehicle: A 1978 Ford LTD was the test vehicle. Total weight of the vehicle and instrumentation was 4466 lbs (2026 kg).

Performance: Impact conditions were 59.3 mph (95.4 kmph) and a 19.1-deg angle. As shown in the sequential photographs of Figure 107, the vehicle impacted the installation at Post 5, deflected it rearward and was then redirected. After losing contact with the barrier the vehicle began to swerve to the right due to the right front tire being deflated during the event. The vehicle then impacted another test installation located approximately 150 ft (45 m) downstream, and came to rest with its rear section on top of that installation. Maximum 50 msec average accelerations measured during the event were 7.2 g (accelerometer) and 6.6 g (film) in the lateral direction, and -4.1 g (accelerometer) and -4.1 g (film) in the longitudinal direction. A summary of test results is contained in Figure 107; high speed film analysis is shown in Table 27, and electronic data in Figure 108.

Barrier Damage: As shown in Figure 109 two rail sections and three posts were damaged and will require replacement. Also, the two traffic side anchor bolts at Posts 6, 7 and 8 were pulled up as noted in Table 28.

Vehicle Damage: The test vehicle as shown in Figure 109 was only slightly damaged in the initial impact - most of the damage occurring in the right front corner sheet metal (fender, hood, grille) and bumper. As noted previously, the right front tire was "blown out" during the impact and the rim bent. The other damage was incurred during the secondary impact with the other test installation.

TEST TTR-14

Purpose: Purpose of this test was to evaluate the low service retrofit system when impacted by an 1800-lb (816-kg) vehicle at 60 mph (96.6 kmph) and a 15-deg angle.

Test Installation: Same as TTR-13.

Test Vehicle: The 1978 Honda Civic weighed 1751 lb (794 kg) with instrumentation.

Performance: Impact conditions were 60.9 mph (98.0 kmph) and a 19.9-deg angle. As shown in the sequential photographs of Figure 110, the force on upper right front wheel caused rotation of the wheel under the rail, causing snagging on two of the posts. Maximum 50-msec average accelerations measured during the event were 10.9 g (accel-

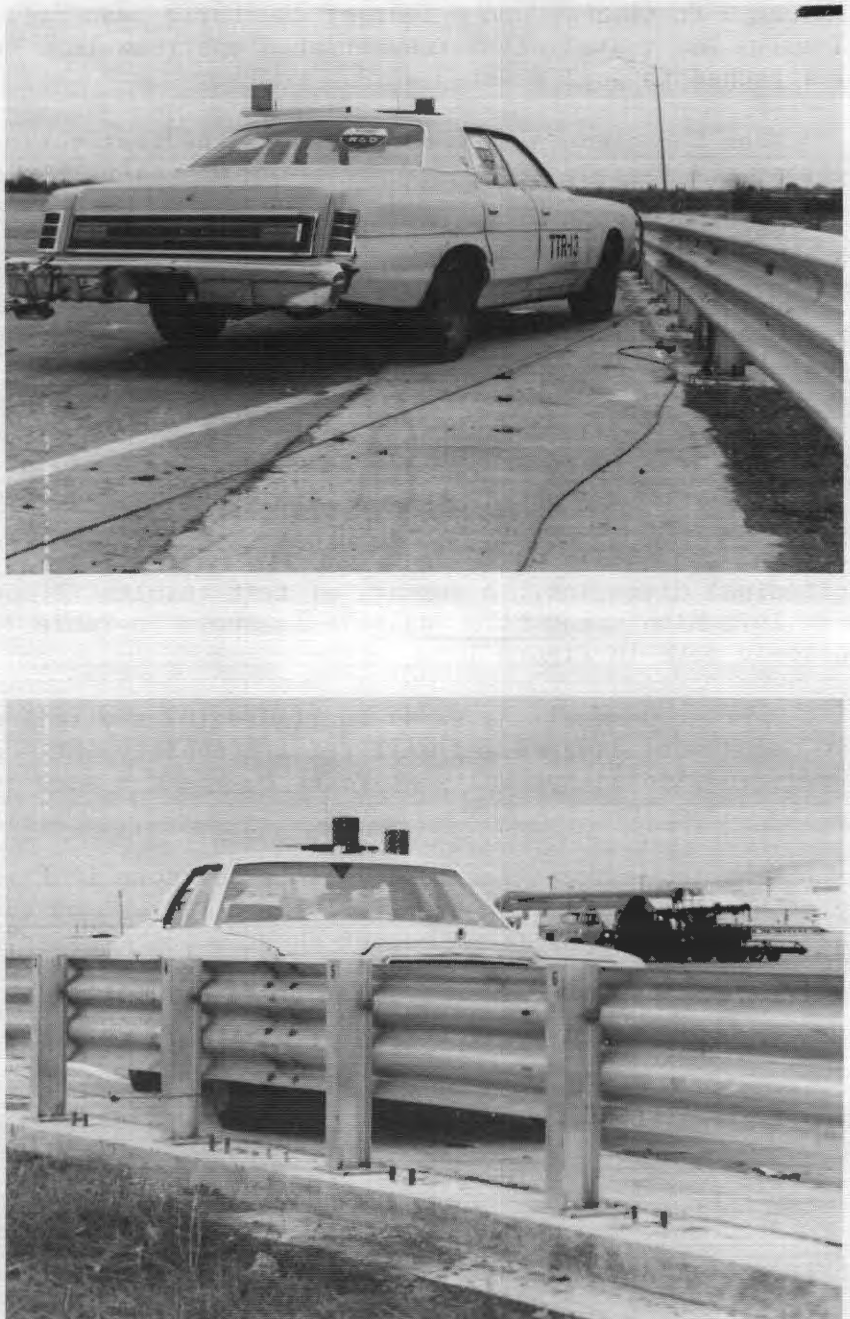
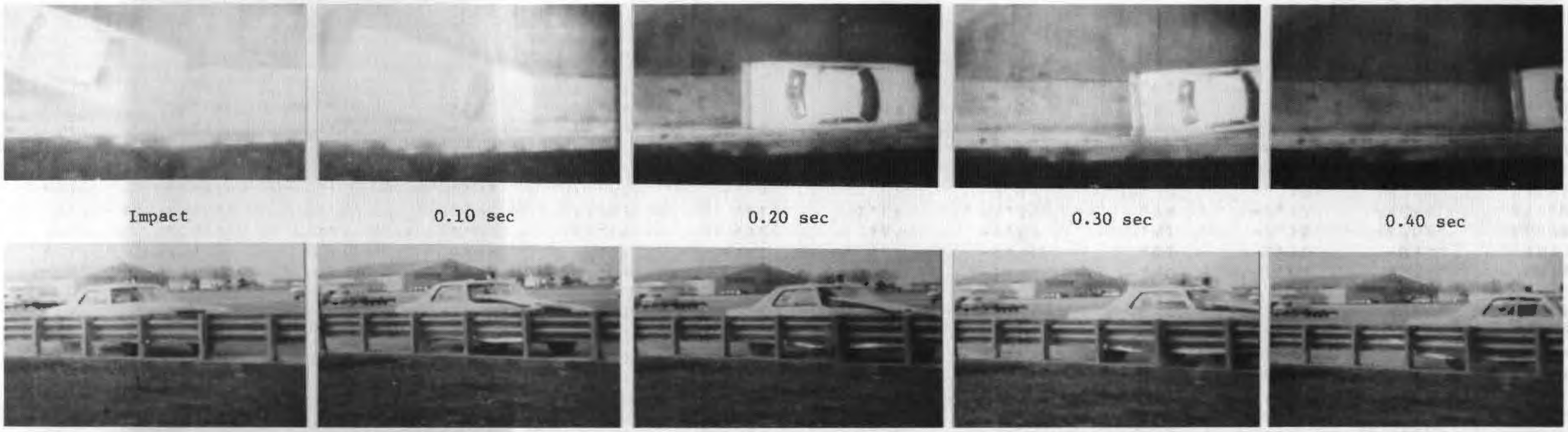
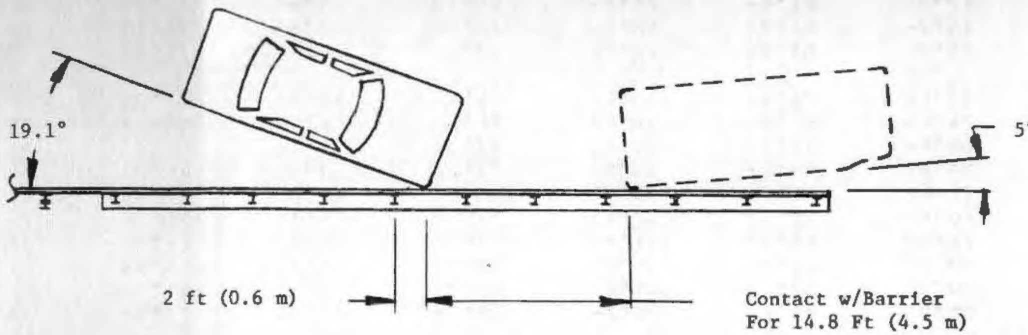


FIGURE 106. PRE-TEST PHOTOGRAPHS, TEST TTR-13





Test No. TTR-13
Date 2/1/82
Beam Rail .. 12 ga thrie beam x 12.5 ft (3.8 m)
Post .... W6x8.5 steel x 33 in. (838 mm)
Post Spacing .... 5 ft (1.5 m)
Length of Installation .... 50 ft (15 m)
Beam Rail Deflection:
  Max Dynamic .... 3.6 in. (91 mm)
  Max Permanent .... 2.4 in. (61 mm)

Vehicle .... 1978 Ford LTD
Vehicle Mass
  (w/instrumentation)....... 4466 lb (2026 kg)
Impact Speed .... 59.3 mph (95.4 kmph)
Impact Angle .... 19.1 deg
Exit Speed .... 49.1 mph (79.1 ,mph)
Exit Angle .... -5.0 deg
Vehicle Acceleraton (max 50 ms avg)
  Lateral (electr/film) .... 7.2 g/6.6 g
  Longitudinal (electr/film)... -4.1 g/-4.1 g

FIGURE 107. SUMMARY OF RESULTS, TEST TTR-13

TABLE 27

RESULTS OF HIGH-SPEED FILM ANALYSIS

SUMMARY OF VEHICLE KINEMATIC AND DYNAMIC DATA THRU TRUSS RETROFIT TEST TTR-13 2/2/82

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 AVER .05 SEC. LONG	LAT	APPROX. BARRIER FORCES(LB) X	Y
0.000	8.73	-5.41	19.12	86.71	-2.25	-2.96	1.12	0.00	0.00	14134.	-390.
.010	9.55	-5.22	19.13	85.66	-2.04	-3.55	.29	0.00	0.00	15403.	3984.
.020	10.36	-4.96	19.13	84.45	-2.10	-3.95	-.77	0.00	0.00	15556.	9050.
.030	11.16	-4.71	19.07	83.13	-2.46	-4.18	-1.97	-3.92	-1.45	14770.	14429.
.040	11.95	-4.47	18.94	81.73	-3.10	-4.25	-3.21	-4.09	-2.58	13288.	19724.
.050	12.73	-4.24	18.69	80.44	-3.99	-4.16	-4.39	-4.11	-3.71	11381.	24551.
.060	13.50	-4.03	18.32	79.15	-5.05	-3.95	-5.42	-4.00	-4.74	9324.	28567.
.070	14.26	-3.84	17.80	77.95	-6.21	-3.73	-6.21	-3.80	-5.59	7363.	31501.
.080	15.02	-3.67	17.10	76.39	-7.37	-3.40	-6.72	-3.52	-6.21	5699.	33167.
.090	15.77	-3.53	16.23	75.37	-8.41	-3.06	-6.92	-3.19	-6.56	4470.	33480.
.100	16.52	-3.41	15.19	75.20	-9.24	-2.71	-6.80	-2.85	-6.61	3741.	32460.
.110	17.27	-3.31	13.95	74.58	-9.77	-2.39	-6.39	-2.51	-6.38	3502.	30235.
.120	18.02	-3.24	12.59	74.10	-9.95	-2.12	-5.73	-2.21	-5.90	3676.	27025.
.130	18.76	-3.18	11.07	73.71	-9.73	-1.90	-4.91	-1.95	-5.24	4126.	23132.
.140	19.50	-3.14	9.49	73.39	-9.11	-1.73	-4.00	-1.74	-4.45	4675.	18914.
.150	20.24	-3.12	7.84	73.10	-8.15	-1.59	-3.12	-1.57	-3.64	5128.	14761.
.160	20.98	-3.10	6.17	72.83	-6.90	-1.45	-2.33	-1.41	-2.88	5297.	11061.
.170	21.70	-3.10	4.53	72.57	-5.47	-1.27	-1.73	-1.24	-2.25	5028.	8166.
.180	22.43	-3.10	2.96	72.33	-3.98	-1.02	-1.37	-1.03	-1.81	4232.	6358.
.190	23.15	-3.10	1.50	72.14	-2.56	-.66	-1.28	-.75	-1.60	2904.	5813.
.200	23.87	-3.11	.18	72.03	-1.33	-.26	-1.47	-.40	-1.64	1144.	6576.
.210	24.60	-3.12	-.93	72.04	-.41	.22	-1.91	.01	-1.90	-833.	8533.
.220	25.32	-3.14	-1.86	72.19	.12	.69	-2.53	.41	-2.35	-2702.	11399.
.230	26.04	-3.17	-2.77	72.47	.21	1.06	-3.25	.74	-2.92	-4044.	14720.
.240	26.76	-3.21	-3.41	72.85	-.14	1.22	-3.94	.90	-3.49	-4388.	17884.
.250	27.49	-3.26	-3.90	73.22	-.87	1.04	-4.45	.80	-3.95	-3277.	20162.
.260	28.22	-3.33	-4.28	73.48	-1.87	.43	-4.63	.35	-4.15	-361.	20769.
.270	28.95	-3.41	-4.56	73.47	-2.95	-.66	-4.31	-.50	-3.95	4471.	18952.
.280	29.68	-3.50	-4.80	73.04	-3.91	-2.17	-3.35	-1.67	-3.22	10920.	14118.
.290	30.40	-3.61	-5.01	72.07	-4.47	-3.91	-1.69	-3.01	-1.89	18057.	5994.

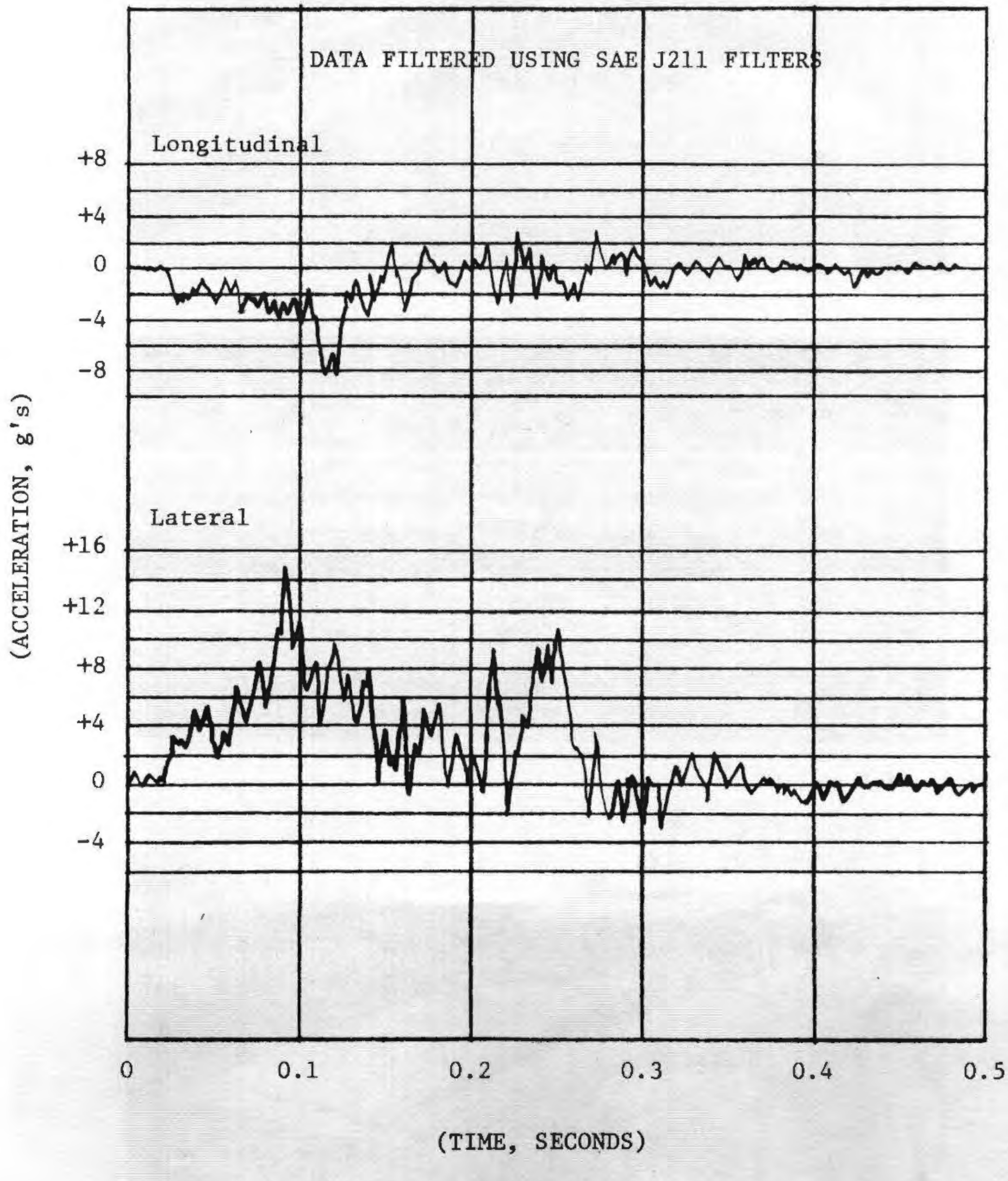


FIGURE 108. ACCELERATION DATA, TEST TTR-13

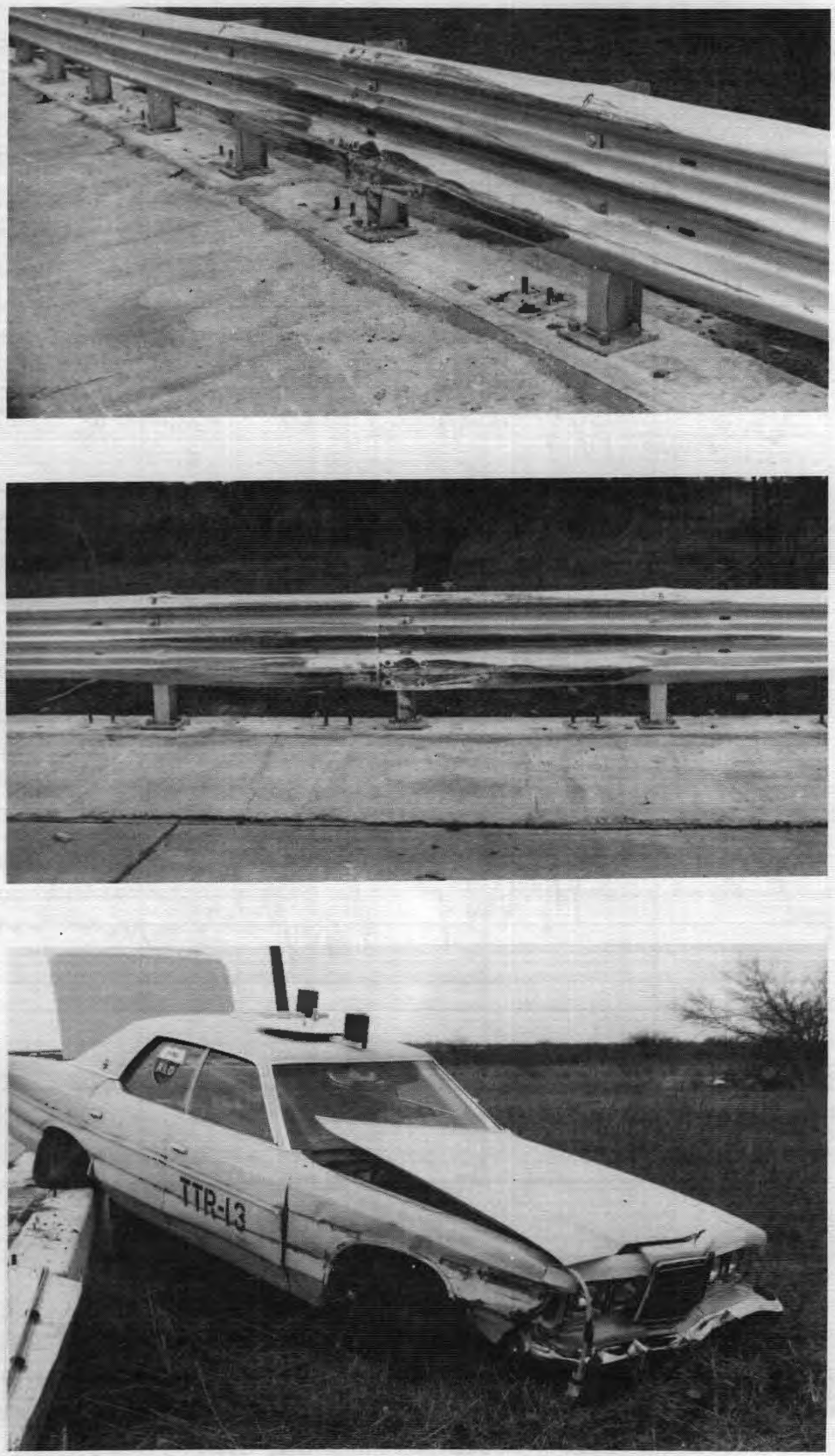


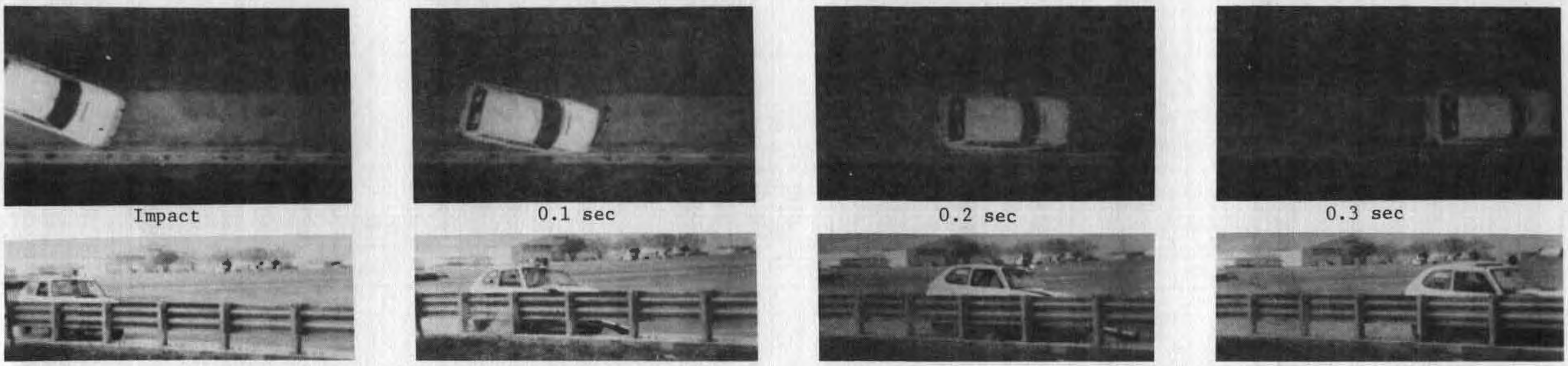
FIGURE 109. BARRIER AND VEHICLE DAMAGE, TEST TTR-13

TABLE 28

BARRIER DEFLECTIONS, TEST TTR-13

Location - Post No.	Deflection* (in.)	Remarks
4	0.50	
5	0.75	
6	1.50	Traffic side studs pulled up 0.06"
7	2.38 (max)	Traffic side studs pulled up 0.50"
8	1.25	Traffic side studs pulled up 0.06"
9	0.25	

*Measured at top corrugation of thrie beam



Test No. TTR-14
Date 3/12/82
Beam Rail ... 12 ga thrie beam x 12.5 ft (3.8 m)
Post .... W6x8.5 steel x 33 in. (838 mm)
Post Spacing .... 5 ft (1.5 m)
Length of Installation .... 50 ft (15 m)
Beam Rail Deflection:
  Max Dynamic .... 1.3 in. (33 mm)
  Max Permanent 0

Vehicle .... 1979 Honda Civic
Vehicle Mass .... 1751 lb (794 kg)
  (w/instrumentation)
Impact Speed .... 60.9 mph (98.0 kmph)
Impact Angle .... 19.9 deg
Exit Speed .... 43.0 mph (69.2 kmph)
Exit Angle .... -5.5 deg
Vehicle Acceleration (max 50 ms avg)
  Lateral (electr/film) 10.9g/8.7g
  Longitudinal (electr/film)... -5.6g/-6.5g

FIGURE 110. SUMMARY OF RESULTS, TEST TTR-14

erometer) and 8.7 g (film) in the lateral direction, and -5.6 g (accelerometer) and -6.5 g (film) in the longitudinal direction. A summary of the test results is contained in Figure 110. The film analysis data is in Table 29 and electronic data are shown in Figure 111.

Barrier Damage: As shown in Figure 112, one rail section was damaged and some local deformation of the post occurred.

Vehicle Damage: Damage to the vehicle front wheel and bumper was extensive as shown in Figure 112. There appears to be a difference in performance of the 5-mph bumper design incorporated into the Honda Civic in 1978 as compared to pre-1978 models.

TEST TTR-15

Purpose: This test is a repeat of Test TTR-14; the test was repeated due to the 19.9-deg impact angle observed in Test TTR-14.

Test Installation: Same as TTR-13.

Test Vehicle: A 1976 Honda Civic weighing 1750 lb (794 kg) including instrumentation.

Performance: The vehicle impacted at 57.9 mph (93.3 kmph) and 16.9 deg as shown in Figure 113. The vehicle was smoothly redirected with no wheel snagging and with the bumper reaction significantly different from Test TTR-14. Maximum 50-msec average accelerations were 16.7 g (accelerometer) and 8.3 g (film) in the lateral direction, and -2.7 g (accelerometer) and -2.9 g (film) in the longitudinal direction. In addition, the film data from this test was processed for the new occupant risk criteria as shown in Table 30. Figure 114 contains the accelerometer data traces.

Barrier Damage: As shown in Figure 115, there was no significant barrier damage. The slightly deformed W-beam would likely not require replacement in the field. Although there was evidence of wheel sidewall scuffing on the faces of Posts 4 and 5, no marks indicative of snagging were evident on the flange edge.

Vehicle Damage: The right front tire deflated due to rim damage; local sheet metal damage was also sustained as shown in Figure 115. The bumper was not significantly damaged although it impacted a post of another test installation at the mid point.

TABLE 29

RESULTS OF HIGH SPEED FILM ANALYSIS, TTR-14

SUMMARY OF VEHICLE KINEMATIC AND DYNAMIC DATA THRU TRUSS RETROFIT TEST TTR-14 3/12/82

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 AVER .05 SEC. LONG	LAT	APPROX. BARRIER FORCES (LB) X	Y
0.000	1.37	-4.39	19.89	89.32	-.09	-1.62	-3.90	0.00	0.00	334.	7389.
.010	2.21	-4.10	19.79	88.42	-1.41	-2.75	-5.20	0.00	0.00	1454.	10198.
.020	3.04	-3.82	19.58	87.56	-2.95	-3.84	-6.36	0.00	0.00	2598.	12746.
.030	3.87	-3.57	19.23	86.19	-4.63	-4.81	-7.34	-4.20	-6.66	3711.	14909.
.040	4.70	-3.34	18.74	84.56	-6.39	-5.61	-8.10	-5.04	-7.51	4743.	16593.
.050	5.52	-3.15	18.09	82.73	-8.14	-6.21	-8.62	-5.70	-8.14	5651.	17732.
.060	6.32	-2.99	17.28	80.79	-9.82	-6.59	-8.89	-6.16	-8.54	6398.	18290.
.070	7.12	-2.86	16.33	78.81	-11.36	-6.75	-8.89	-6.41	-8.68	6958.	18261.
.080	7.90	-2.76	15.24	76.88	-12.71	-6.68	-8.64	-6.45	-8.58	7314.	17666.
.090	8.67	-2.70	14.03	75.04	-13.82	-6.42	-8.14	-6.29	-8.23	7455.	16546.
.100	9.42	-2.66	12.73	73.36	-14.64	-6.00	-7.41	-5.96	-7.65	7383.	14967.
.110	10.16	-2.66	11.36	71.87	-15.14	-5.44	-6.48	-5.50	-6.87	7107.	13008.
.120	10.89	-2.68	9.94	70.60	-15.30	-4.80	-5.40	-4.93	-5.90	6645.	10762.
.130	11.61	-2.71	8.51	69.55	-15.09	-4.10	-4.19	-4.30	-4.80	6020.	8328.
.140	12.31	-2.77	7.10	68.71	-14.54	-3.39	-2.92	-3.64	-3.60	5265.	5811.
.150	13.01	-2.83	5.73	68.06	-13.63	-2.70	-1.63	-2.97	-2.36	4413.	3314.
.160	13.69	-2.90	4.43	67.60	-12.41	-2.04	-.38	-2.34	-1.12	3505.	934.
.170	14.37	-2.97	3.21	67.29	-10.92	-1.43	.79	-1.74	.06	2580.	-1237.
.180	15.05	-3.04	2.11	67.11	-9.20	-.89	1.82	-1.20	1.12	1680.	-3121.
.190	15.72	-3.11	1.13	67.04	-7.32	-.43	2.67	-.72	2.04	845.	-4653.
.200	16.39	-3.16	.27	67.04	-5.36	-.05	3.30	-.32	2.77	112.	-5784.
.210	17.07	-3.21	-.45	67.15	-3.38	.25	3.71	.00	3.28	-487.	-6484.
.220	17.74	-3.24	-1.04	67.29	-1.46	.46	3.86	.25	3.55	-926.	-6740.
.230	18.41	-3.26	-1.50	67.47	.32	.58	3.76	.41	3.59	-1185.	-6560.
.240	19.09	-3.27	-1.86	67.66	1.90	.60	3.43	.49	3.39	-1253.	-5970.
.250	19.76	-3.27	-2.12	67.83	3.23	.54	2.89	.47	2.98	-1130.	-5014.
.260	20.44	-3.25	-2.29	67.97	4.26	.38	2.16	.37	2.38	-823.	-3750.
.270	21.13	-3.24	-2.41	68.05	4.95	.15	1.29	.19	1.62	-352.	-2254.
.280	21.81	-3.21	-2.48	68.04	5.31	-.16	.34	-.06	.76	254.	-610.
.290	22.49	-3.19	-2.53	67.93	5.32	-.52	-.65	-.38	-.16	956.	1090.
.300	23.17	-3.17	-2.58	67.69	5.01	-.90	-1.61	-.72	-1.08	1706.	2748.
.310	23.85	-3.15	-2.65	67.34	4.42	-1.28	-2.50	-1.08	-1.96	2448.	4269.
.320	24.52	-3.14	-2.74	66.86	3.60	-1.63	-3.26	-1.41	-2.74	3123.	5561.
.330	25.18	-3.14	-2.86	66.28	2.60	-1.90	-3.84	-1.69	-3.37	3667.	6542.
.340	25.84	-3.16	-3.03	65.63	1.49	-2.08	-4.20	-1.88	-3.80	4019.	7145.
.350	26.50	-3.18	-3.25	64.95	.36	-2.11	-4.31	-1.96	-4.02	4124.	7320.
.360	27.14	-3.22	-3.50	64.28	-.72	-2.00	-4.15	-1.90	-3.99	3936.	7044.
.370	27.78	-3.28	-3.79	63.69	-1.67	-1.71	-3.73	-1.69	-3.71	3428.	6317.
.380	28.41	-3.34	-4.12	63.22	-2.41	-1.27	-3.05	-1.34	-3.19	2597.	5176.
.390	29.04	-3.42	-4.46	62.92	-2.88	-.67	-2.17	-.84	-2.45	1471.	3688.

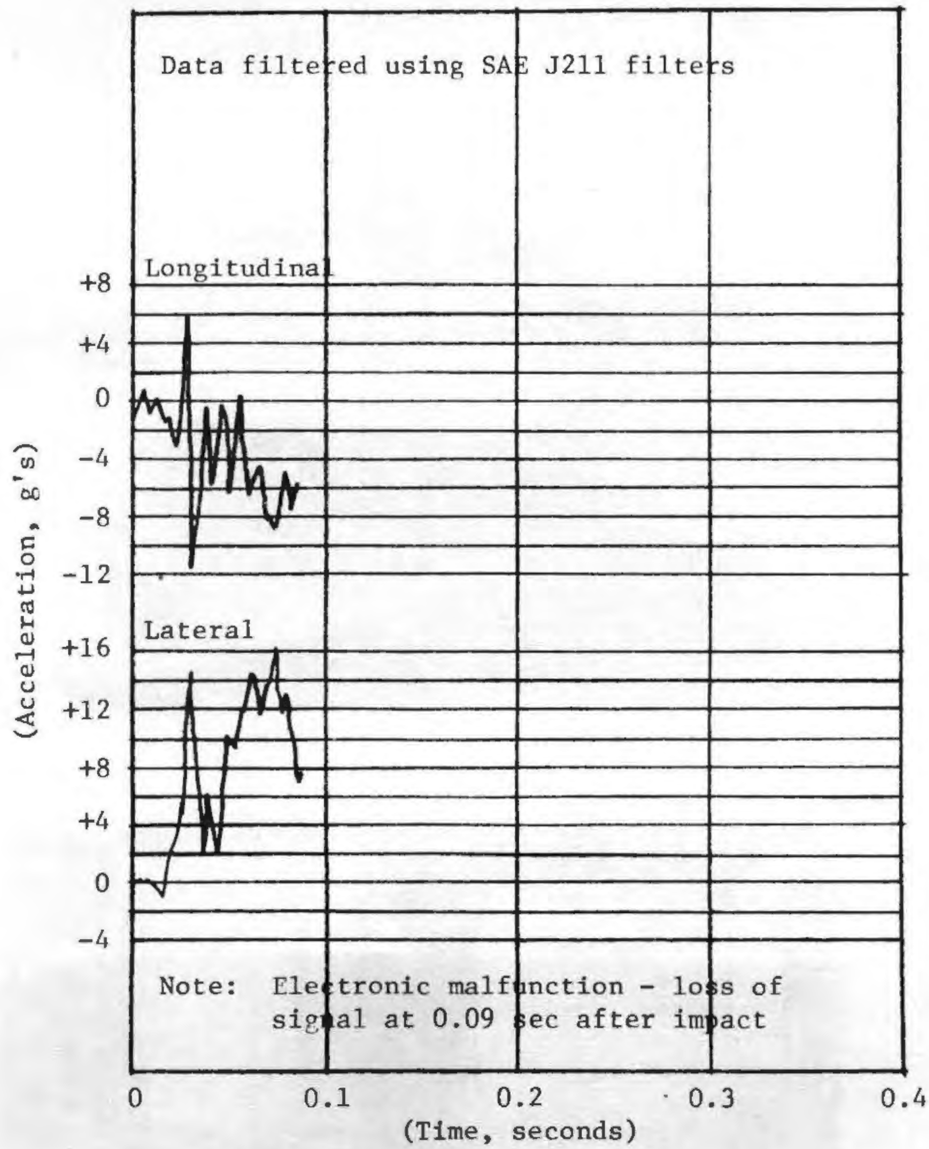
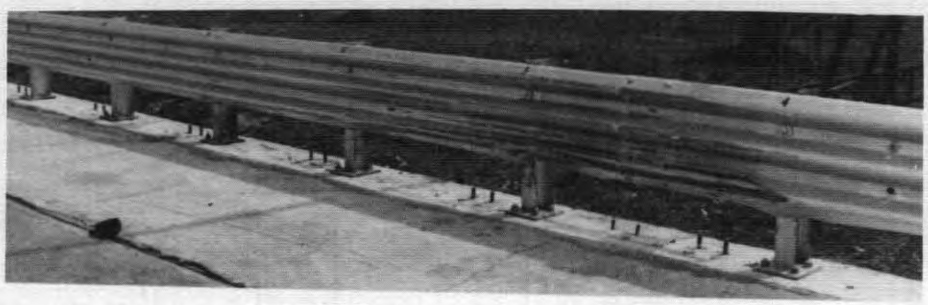


FIGURE 111. ACCELERATION DATA, TEST TTR-14



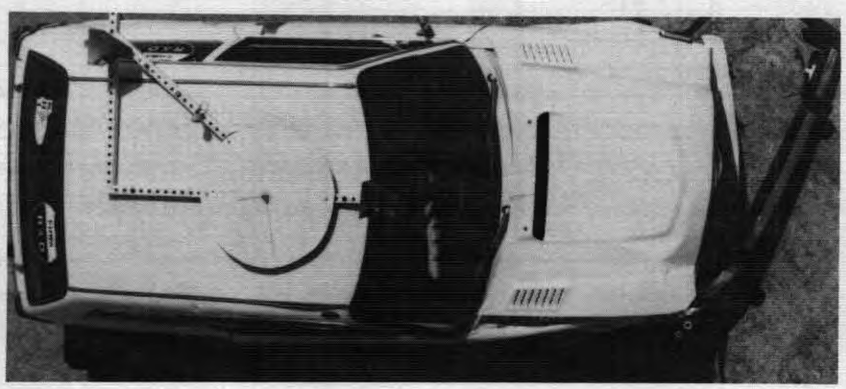


FIGURE 112. PHOTOGRAPHS AFTER TTR-14

Impact   0.05 sec   0.10 sec   0.15 sec   0.20 sec

Test No. TTR-15
Date 3/31/82
Installation
  Dwg No. 03-5270
  Length - Ft (m).............. 50(15)
Beam Rail
  Member .... 12GA Steel Thrie Beam
  Length - Ft (m).......... 12.5 (3.8)
  Maximum Deflections
  Dynamic-In. (mm)............ 1.0(25)
  Permanent-In. (mm)................ 0

Post
  Material .... Steel
  Dimensions-In. (m).... W6x8.5x32(0.2x0.1x0.8)
  Spacing-Ft(m) .... 5(1.5)
Vehicle
  Model .... 1976 Honda Civic
  Mass-Lb(kg) Test Inertia .... 1750(794)
    Dummy 0
    Gross .... 1750(794)
Speed-mph(kmph)
  Impact .... 57.9(93.2)
  Exit .... 53.9(86.7)

Angle-Deg
  Impact 16.9
  Exit .... -5.9
Occupant Impact Velocity-Ft/Sec(m/s)
  Forward .... 10.0(3.0)
  Lateral 0
Occupant Ridedown Acceleration-g's
  Forward .... -1.8
  Lateral 0
Vehicle
  Damage
    TAD 1-FR-2
    VDI .... 1 FREW 2

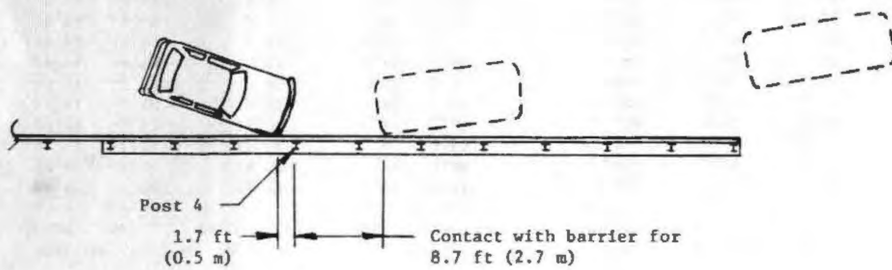


FIGURE 113. SUMMARY OF RESULTS, TEST TTR-15

TABLE 30

HIGH SPEED FILM ANALYSIS

LOW COST BRIDGERAIL TEST TTR-15 3/31/82

VEHICLE KINETICS SUMMARY--FROM FILM ANALYSIS

TIME (S)	VEH. ACCEL.(G'S) LONG.	LAT.	VEH. VEL.(FPS) LONG.	LAT.	HEADING ANGLE (DEG)	VEH. DISP.(F) LONG.	LAT.
0.000	-2.16	-3.69	84.96	-.00	16.89	-.73	-3.51
.010	-2.60	-4.87	84.19	-.91	16.57	.08	-3.28
.020	-2.92	-5.94	83.31	-1.76	15.96	.89	-3.05
.030	-3.09	-6.88	82.38	-2.53	15.06	1.69	-2.85
.040	-3.10	-7.63	81.44	-3.18	13.88	2.49	-2.68
.050	-2.96	-8.18	80.54	-3.72	12.45	3.29	-2.52
.060	-2.69	-8.48	79.74	-4.13	10.82	4.08	-2.40
.070	-2.31	-8.55	79.07	-4.42	9.05	4.87	-2.31
.080	-1.87	-8.38	78.54	-4.60	7.19	5.66	-2.24
.090	-1.41	-7.97	78.16	-4.68	5.32	6.44	-2.20
.100	-.96	-7.37	77.93	-4.67	3.50	7.22	-2.19
.110	-.56	-6.61	77.83	-4.58	1.77	8.00	-2.20
.120	- 22	-5.73	77.83	-4.43	.20	8.78	-2.23
.130	.05	-4.77	77.91	-4.22	-1.20	9.56	-2.28
.140	.24	-3.79	78.04	-3.98	-2.39	10.34	-2.34
.150	.35	-2.83	78.21	-3.70	-3.38	11.12	-2.42
.160	.41	-1.92	78.38	-3.38	-4.17	11.90	-2.51
.170	.41	-1.11	78.55	-3.02	-4.78	12.68	-2.60
.180	.37	-.40	78.70	-2.62	-5.25	13.46	-2.70
.190	.29	.17	78.82	-2.17	-5.61	14.24	-2.80
.200	.19	.59	78.91	-1.65	-5.89	15.02	-2.90
.210	.05	.87	78.95	-1.07	-6.14	15.81	-2.99
.220	-.11	1.02	78.95	-.42	-6.38	16.59	-3.09
.230	-.29	1.03	78.88	.28	-6.65	17.37	-3.18
.240	-.49	.93	78.75	1.02	-6.96	18.16	-3.26
.250	-,70	.75	78.55	1.78	-7.32	18.94	-3.35
.260	-.92	.51	78.28	2.53	-7.71	19.72	-3.43
.270	-1.14	.24	77.93	3.22	-8.13	20.50	-3.51
.280	-1.34	-.03	77.50	3.83	-8.55	21.27	-3.59
.290	-1.51	-.26	77.01	4.31	-8.95	22.04	-3.66
.300	-1.65	-.43	76.47	4.67	-9.30	22.81	-3.74
.310	-1.73	-.52	75.90	4.90	-9.59	23.57	-3.82
.320	-1.73	-.49	75.32	5.04	-9.82	24.32	-3.90
.330	-1.63	-.35	74.76	5.13	-9.99	25.07	-3.98

HIGHEST 50-MS AVG.ACCEL.

	G'S	TIME (SEC) START	END
LONG.	-2.94	.0150	.0650
LAT.	-8.34	.0450	.0950

OCCUPANT RISK SUMMARY -- FROM FILM ANALYSIS
NOTE: AVG. ACCEL. FOR PRIOR 0.010 SEC. CALCULATED
FROM VEHICLE VELOCITY CHANGE

TIME (S)	OCCUP. ACCEL.(G'S) LONG.	LAT.	OCCUP. VEL.(FPS) LONG.	LAT.	OCCUP DISP.(F) LONG.	LAT.
0.000	0.00	0.00	0.00	0.00	0.00	0.00
.010	-2.38	-2.81	.77	.90	.00	.00
.020	-2.72	-2.66	1.64	1.76	.02	.02
.030	-2.91	-2.38	2.58	2.53	.04	.04
.040	-2.92	-2.04	3.52	3.18	.07	.07
.050	-2.77	-1.66	4.41	3.72	.11	.10
.060	-2.49	-1.27	5.22	4.13	.16	.14
.070	-2.10	-.90	5.89	4.42	.21	.18
.080	-1.64	-.56	6.42	4.60	.27	.23
.090	-1.17	-.24	6.80	4.68	.34	.28
.100	-.72	.03	7.03	4.66	.41	.32
.110	-.32	.27	7.13	4.58	.48	.37
.120	.00	.47	7.13	4.43	.55	.41
.130	.25	.63	7.05	4.22	.62	.46
.140	.41	.76	6.92	3.98	.69	.50
.150	.51	.88	6.75	3.69	.76	.54
.160	.54	.99	6.58	3.38	.83	.57
.170	.52	1.11	6.41	3.02	.89	.60
.180	.47	1.24	6.26	2.62	.95	.63
.190	.38	1.41	6.14	2.17	1.02	.66
.200	.27	1.60	6.05	1.65	1.08	.67
.210	.14	1.80	6.01	1.07	1.14	.69
.220	-.02	2.01	6.01	.42	1.20	.70
.230	-.20	2.19	6.08	-.28	1.26	.70
.240	-.40	2.31	6.20	-1.03	1.32	.69
.250	-.62	2.36	6.40	-1.79	1.38	.68
.260	-.86	2.31	6.68	-2.53	1.45	.65
.270	-1.09	2.15	7.03	-3.22	1.52	.63
.280	-1.32	1.88	7.46	-3.83	1.59	.59
.290	-1.52	1.52	7.95	-4.31	1.67	.55
.300	-1.67	1.11	8.48	-4.67	1.75	.50
.310	-1.77	.72	9.05	-4.90	1.84	.46
.320	-1.80+	.41	9.63+	-5.04	1.93+	.41
.330	-1.74	.28	10.19	-5.13*	2.03	.36*

OCCUP. RISK FACTORS	TIME(S)	VELOCITY-(FPS) TEST	NORMALIZED
<LONG. VEL. AFTER 2.0 FT. DISP. --	.327	10.04	7.64
<LAT. VEL. AFTER 1.0 FT. DISP. --	0.000	0.00	0.00

MAX. ACCEL. AFTER OCCUPANT IMPACT	TIME(S)	ACC.(G'S)
<LONG. ACCELERATION --	.320	-1.80
<LAT. ACCELERATION --	0.000	0.00

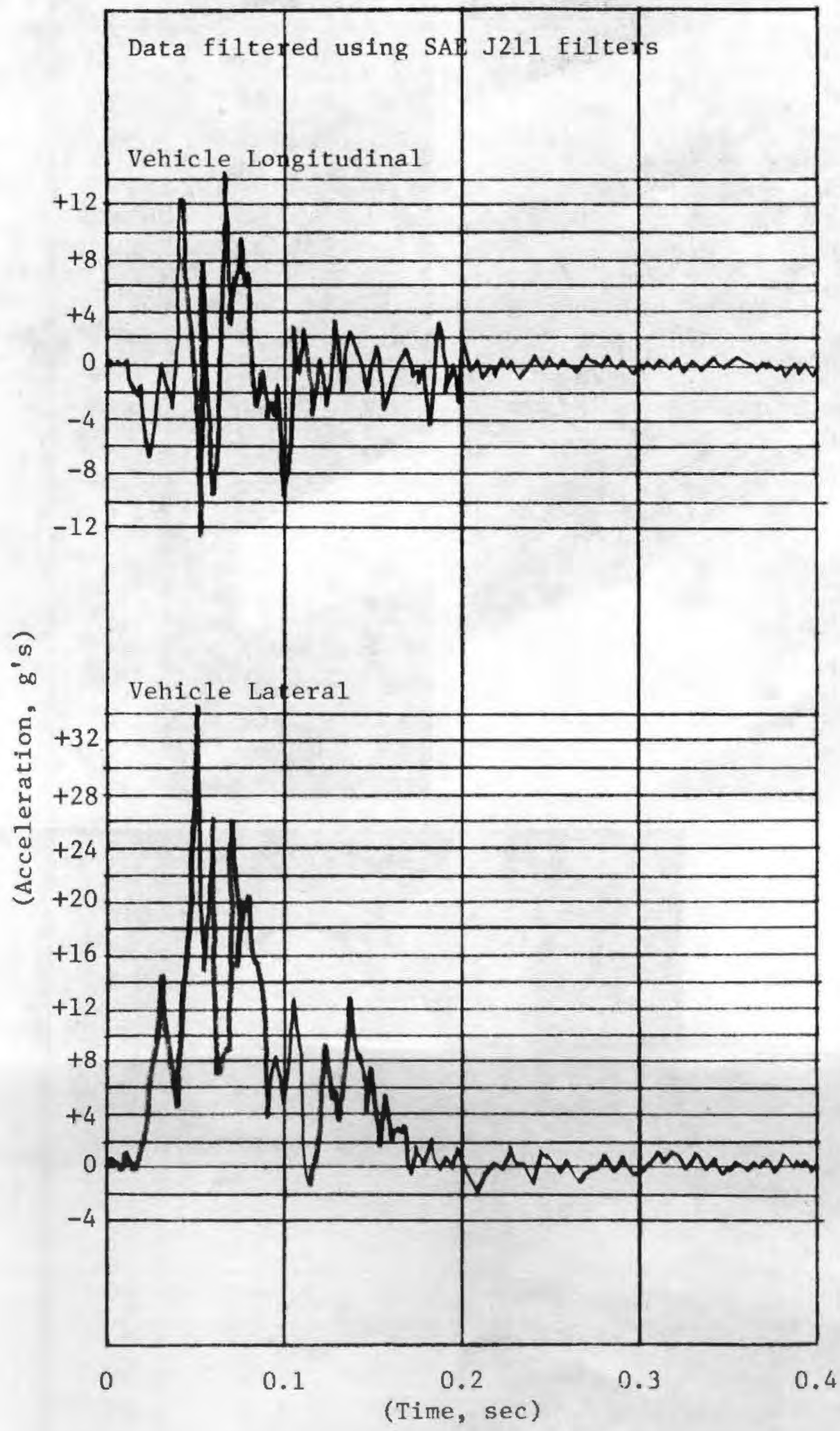


FIGURE 114. ACCELEROMETER DATA, TEST TTR-15

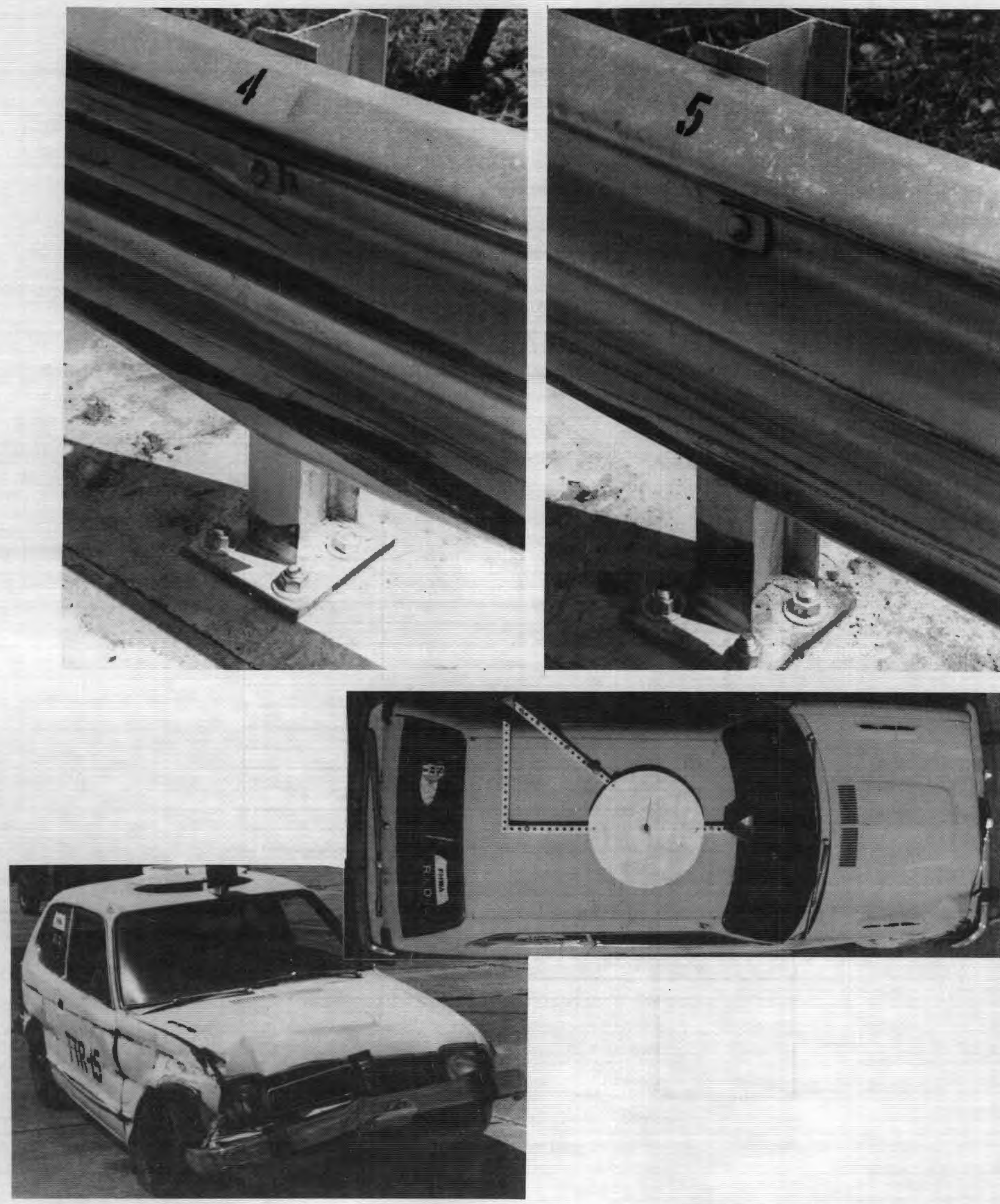


FIGURE 115. PHOTOGRAPHS AFTER TTR-15

APPENDIX B

TEST PROCEDURES

Tests in this program were conducted using the procedures of TRB Circular No. 191* as a guideline. Since those procedures were only directly applicable for 2250-lb (1021-kg) and 4500-lb (2041-kg) automobiles, some judgments were made to expand these guidelines for the 1800-lb (816-kg) minicompact automobile, 20,000-lb (9072-kg) school bus. These decisions were primarily in the areas of ballast placement and restraint, and vehicle accelerometer locations.

Tests were conducted with vehicles either operating under their own power or towed and released just prior to impact. Guidance to the barrier was accomplished using either a steering cable attached to the vehicle right front wheel spindle (automobile tests) or remote steering from a chase vehicle (bus tests). If the steering cable was utilized the spindle/cable attachment bracket was sheared off just prior to impact to eliminate any cable interference with impact sequence and trajectory. Vehicle engine and brakes were controlled remotely through a tether cable, whereas data from on-board electronic transducers was transmitted/received by telemetry.

Electronic Instrumentation. Data channels for accelerometers plus an event marker channel were monitored and recorded on high-speed tape recorder during the test series. These were mounted at the vehicle center of gravity (also in the rear if the test vehicle was a bus) and oriented in the lateral and longitudinal directions. A summary of data acquisition systems is presented in Table 31.

After test each data channel was played back through appropriate filters recommended by SAE J211** for a "quick-look" analysis. These were later transferred to standard forms and are presented in the test details of Appendix A. A summary of data processing equipment is shown in Table 32.

Photography. Each test was documented by both still and movie cameras. Photographs were taken of important details of barrier elements as well as vehicle configuration in both an undamaged and damaged condition. In addition, these details were also documented by movie film, and became part of a summary test movie which included film from high-speed movie cameras. High-speed movie coverage was provided by as many as eight cameras placed to provide views along, normal to, and above the barrier as well as on-board the test vehicle.

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*Transportation Research Circular No. 191, "Recommended Procedures for Vehicle Crash Testing of Highway Appurtenances," Transportation Research Board, National Academy of Sciences, February, 1978.

**Society of Automotive Engineers Recommended Practice J211, "Instrumentation for Barrier Collision Tests," 1970.

Micromotion analysis of high-speed film was performed using a Vanguard motion analyzer in conjunction with the SwRI DATA III motion analysis computer program. This provided data on the rigid body motion of the test vehicle and tabular output of this analysis is shown in the details of each test in Appendix A.

TABLE 31

DATA ACQUISITION SYSTEMS

Component	Function	Equipment Used	Location
Transducer	Converts a physical phenomenon to an electric signal	Bell & Howell 4-202-001 strain gage	Vehicle center of gravity; rear of bus
Signal Conditioning Unit/Multiplexer	Scales and amplifies transducer signal; converts multiple signals into bits for transmission as a single signal	EMR Schlumberger 602-5-1-2-C5603 signal conditioner/multiplexer	Test vehicle
Transmitter	Transmits electromagnetic signals at a single specified frequency	Conic Data Systems CTP 405 transmitter	Test vehicle
Receiver	Receives electromagnetic signals from transmitter	Genisco Model 70-258 receiver	Instrumentation trailer
Demultiplexer	Inverts bits of a single signal back to multiple signals	EMR Schlumberger Power Supply and Rack No. 606-01, Card Nos. 660-01	Instrumentation trailer
Tape Recorder	Provides permanent, high quality magnetic tape record of test data	Sangamo Electric Co. Sabre VII, Model 8246 FM Recorder	Instrumentation trailer
		Sangamo Electric Co. Sabra III, Model 3614 FM Recorder	Instrumentation trailer

TABLE 32

DATA PROCESSING EQUIPMENT

1. Electronic Filters

   SwRI Design per SAE J211

2. Oscillograph

   Honeywell Model 1858

APPENDIX C

PRELIMINARY DESIGN CONCEPTS

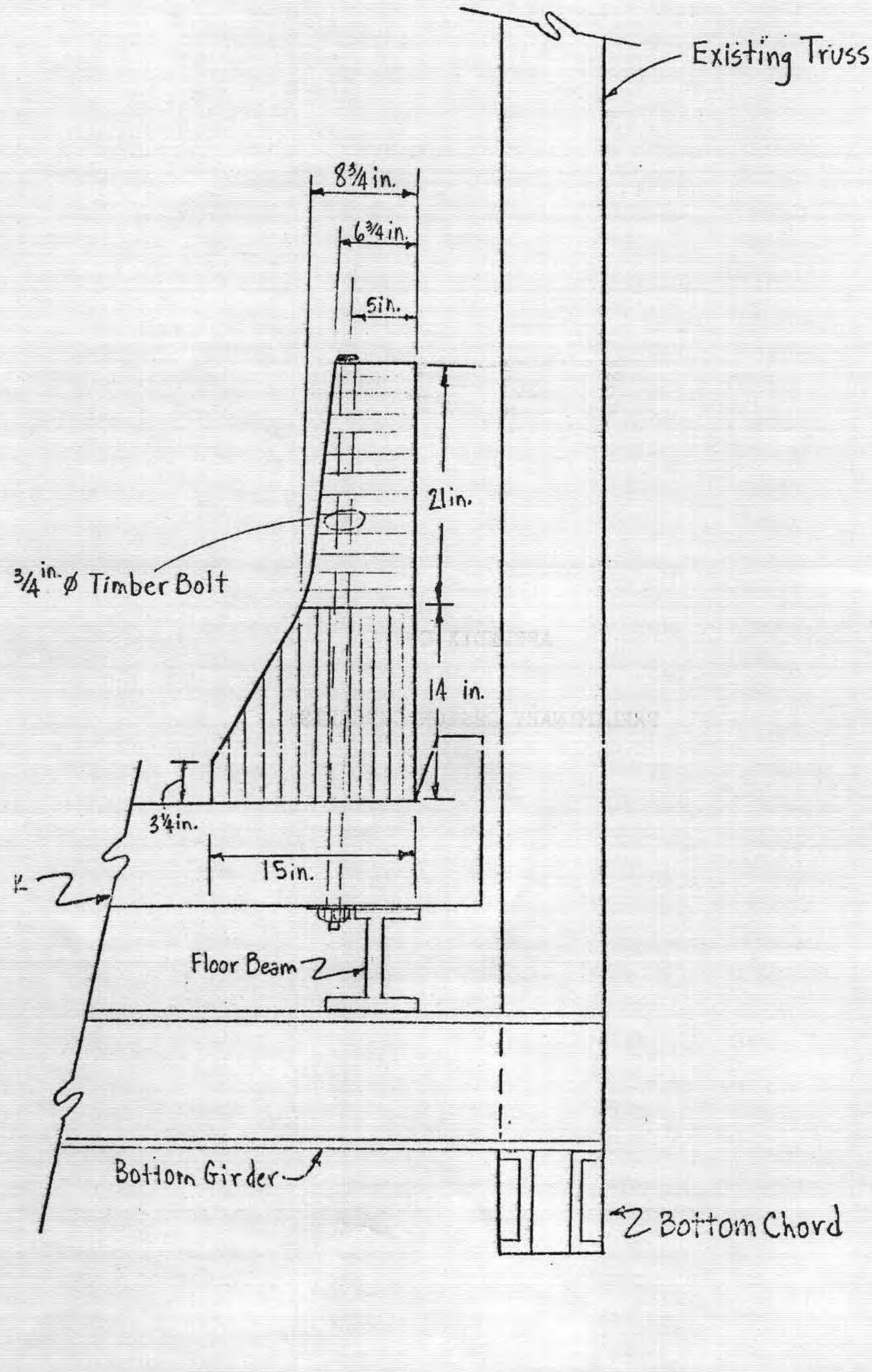


FIGURE 116. LAMINATED WOOD SAFETY SHAPE

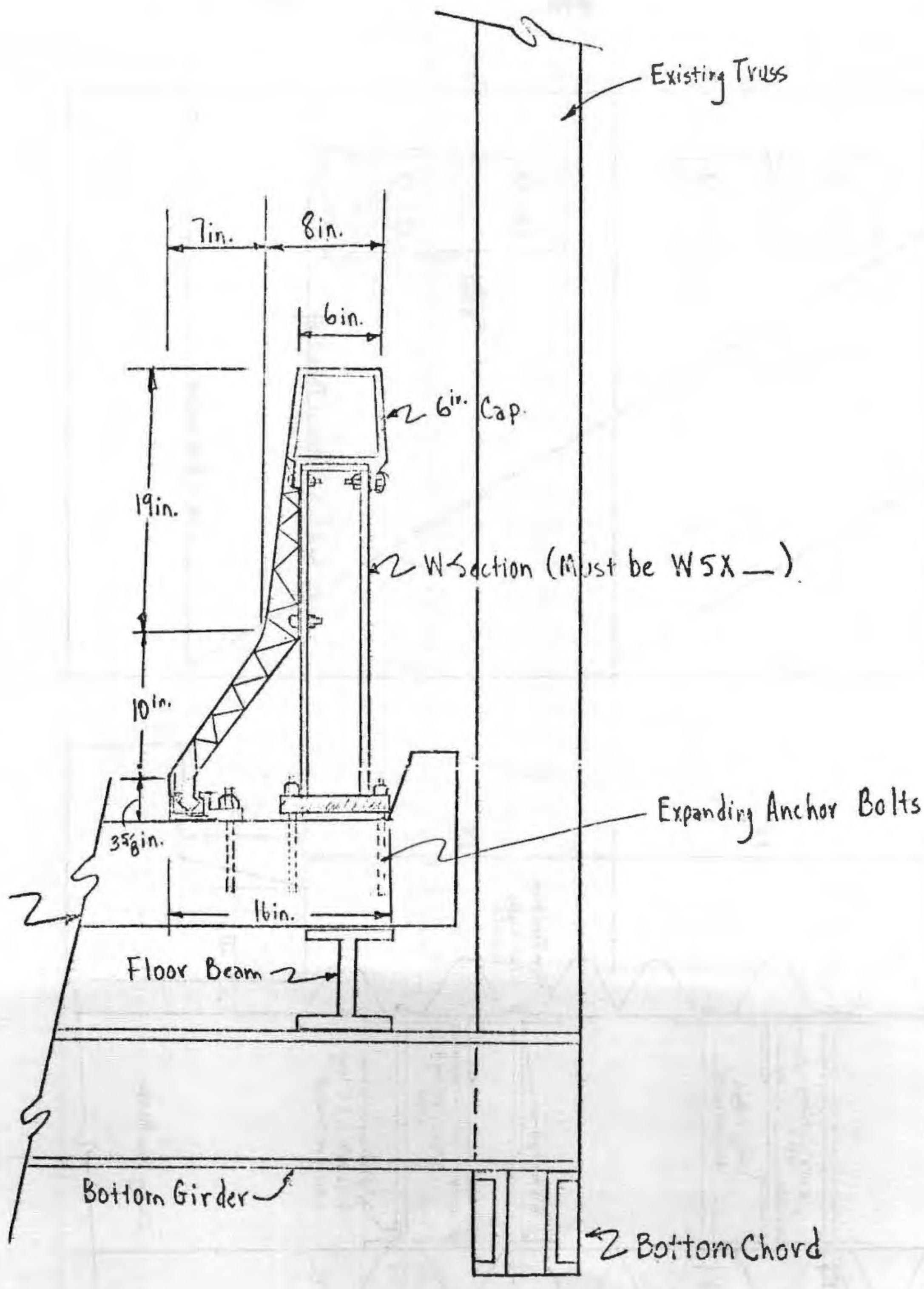


FIGURE 117. ALUMINUM SAFETY SHAPE

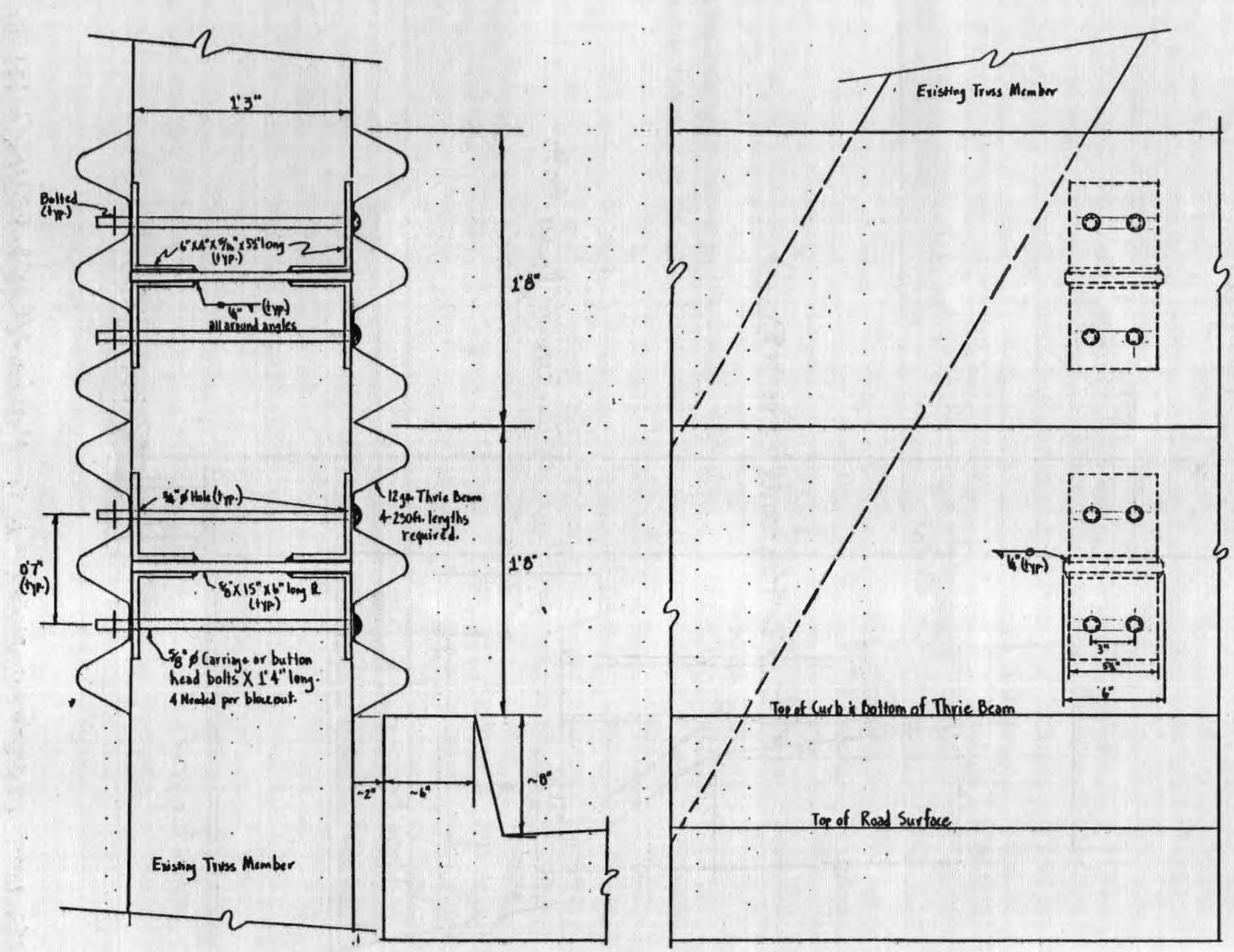


FIGURE 118. RAILING ATTACHED TO TRUSS

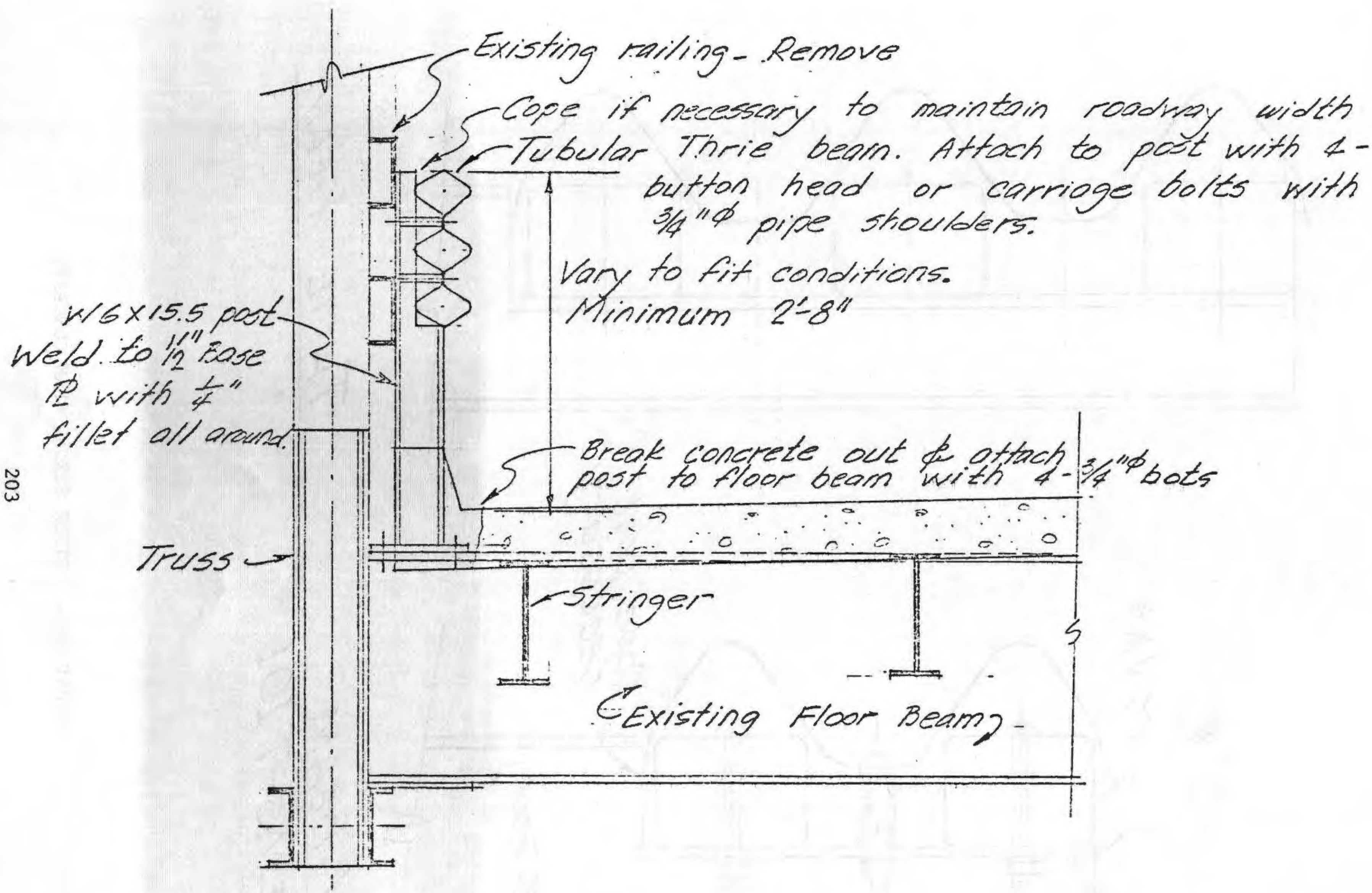


FIGURE 119. STRONG BEAM (TUBULAR THRIE) ATTACHED TO FLOOR BEAM

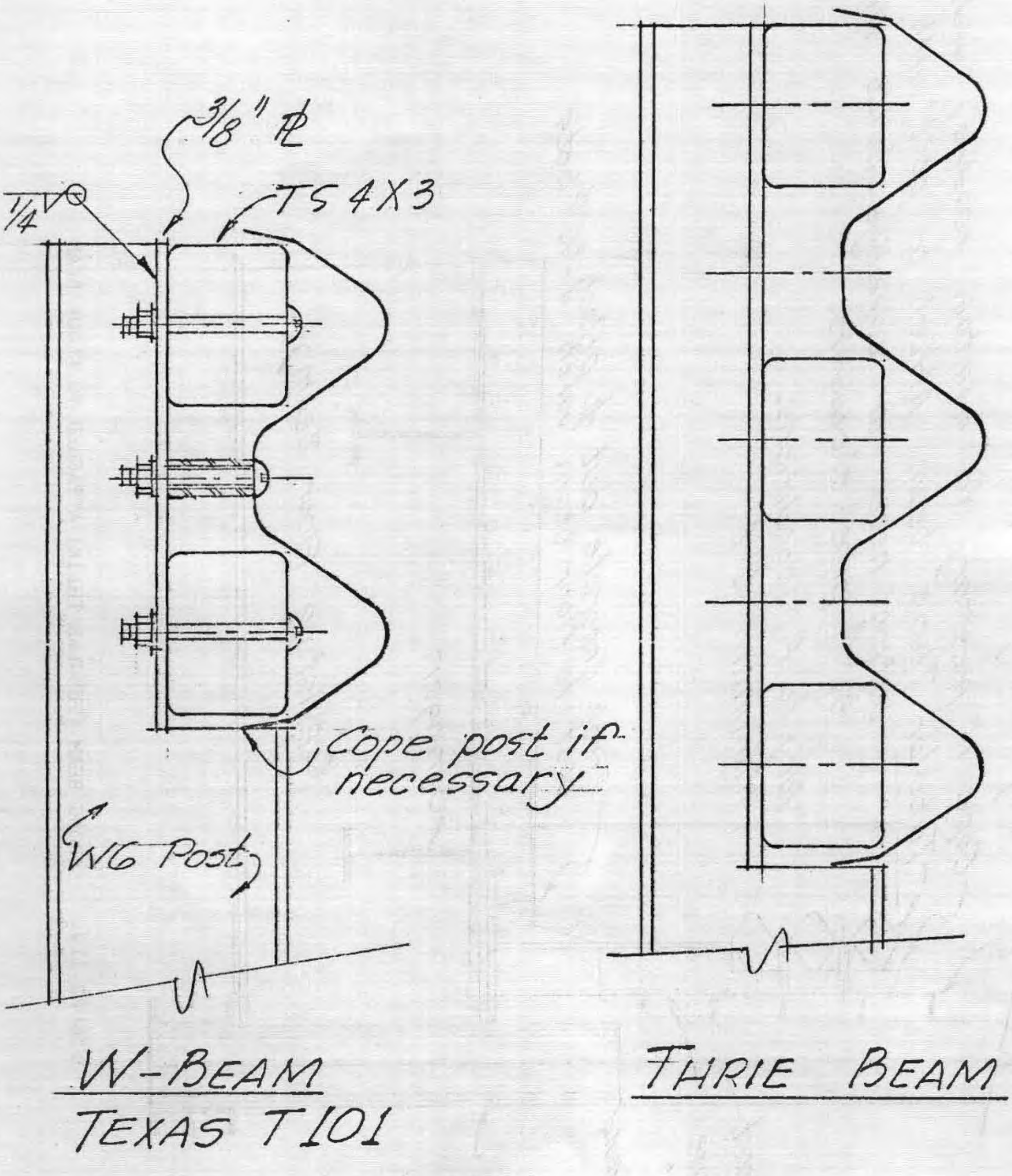


FIGURE 120. OTHER STRONG BEAM CONCEPTS

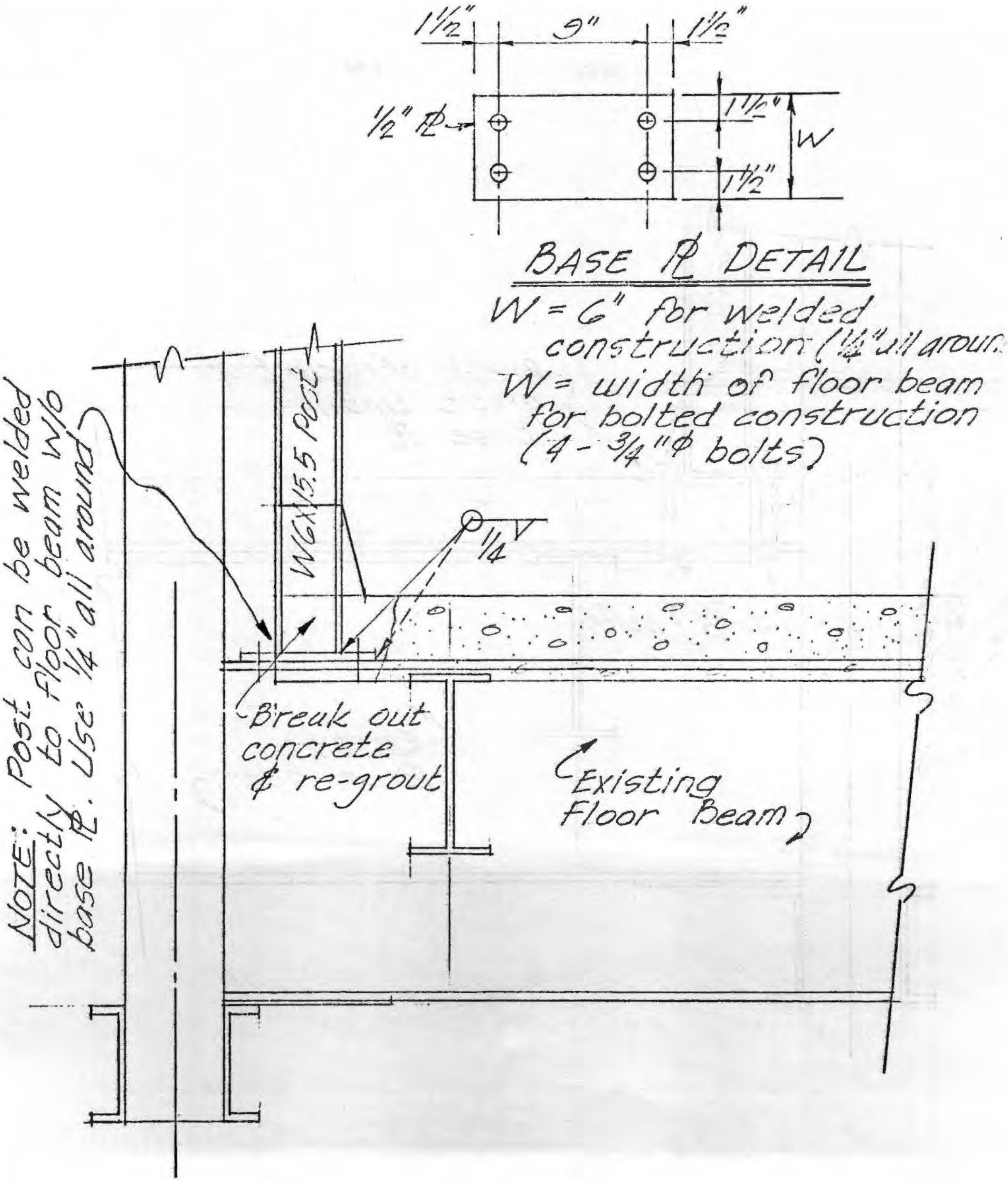


FIGURE 121. POST ATTACHMENT AT FLOOR BEAM

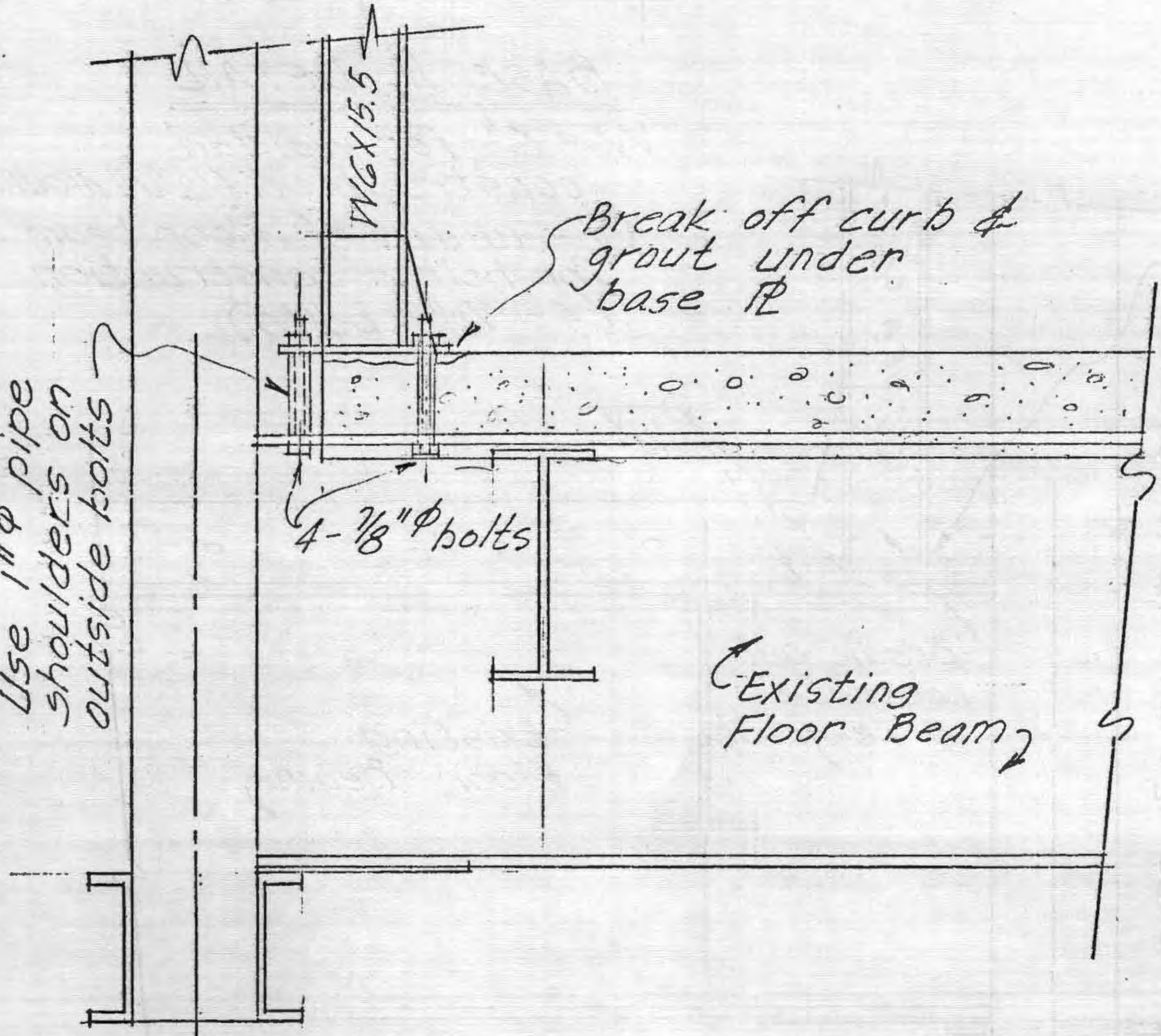


FIGURE 122. POST ATTACHMENT AT FLOOR BEAM

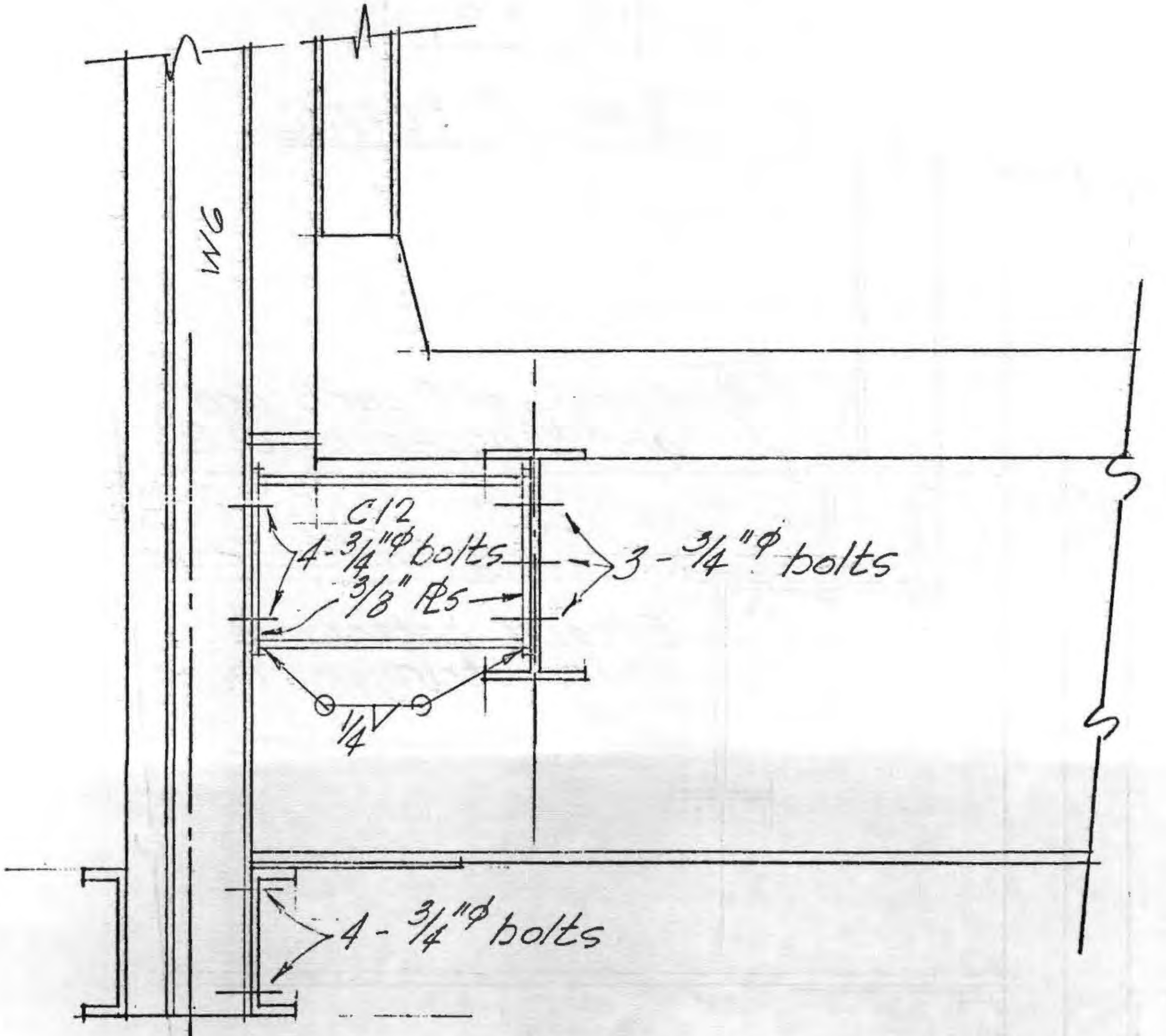


FIGURE 123. INTERMEDIATE POST ATTACHMENT

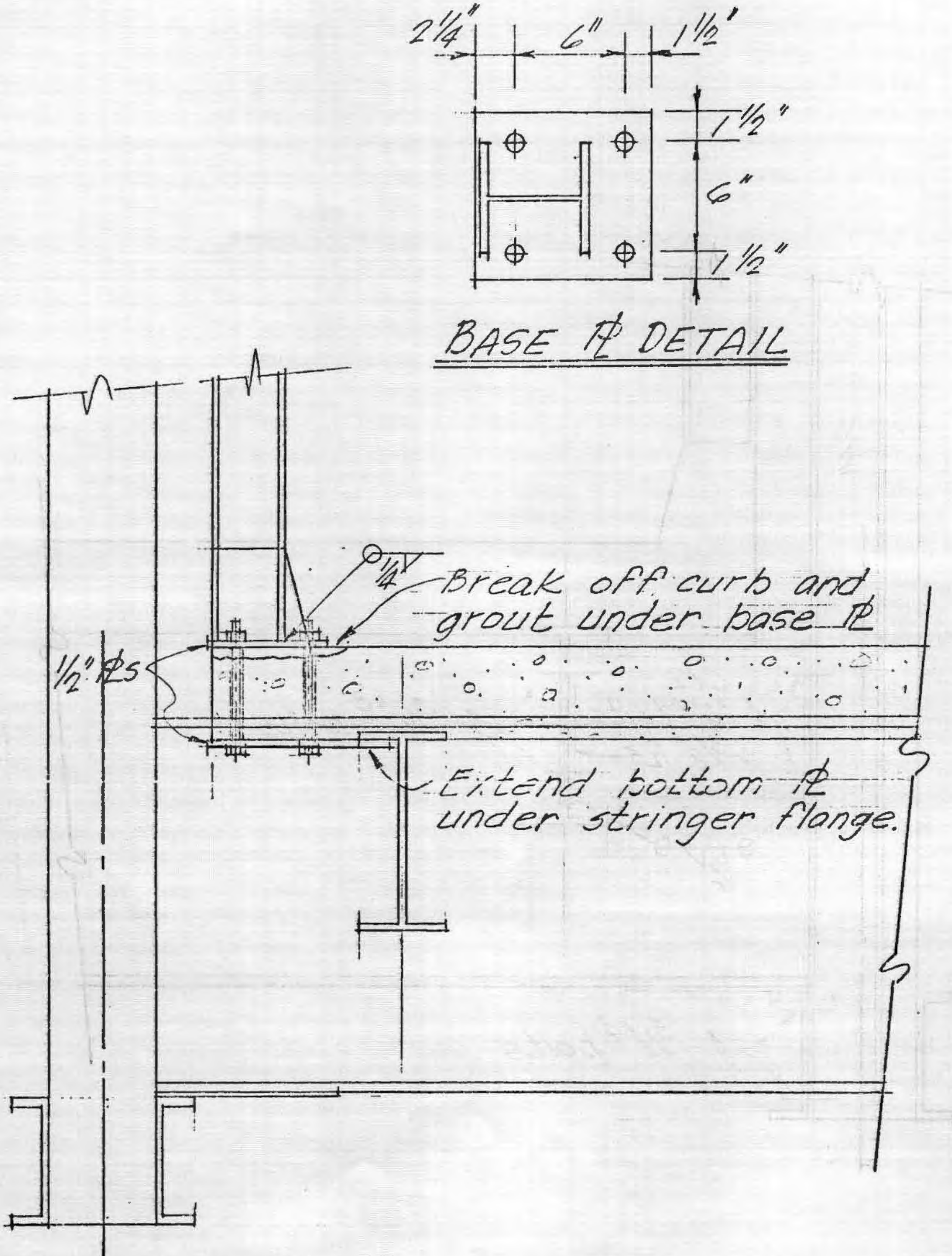


FIGURE 124. INTERMEDIATE POST ATTACHMENT

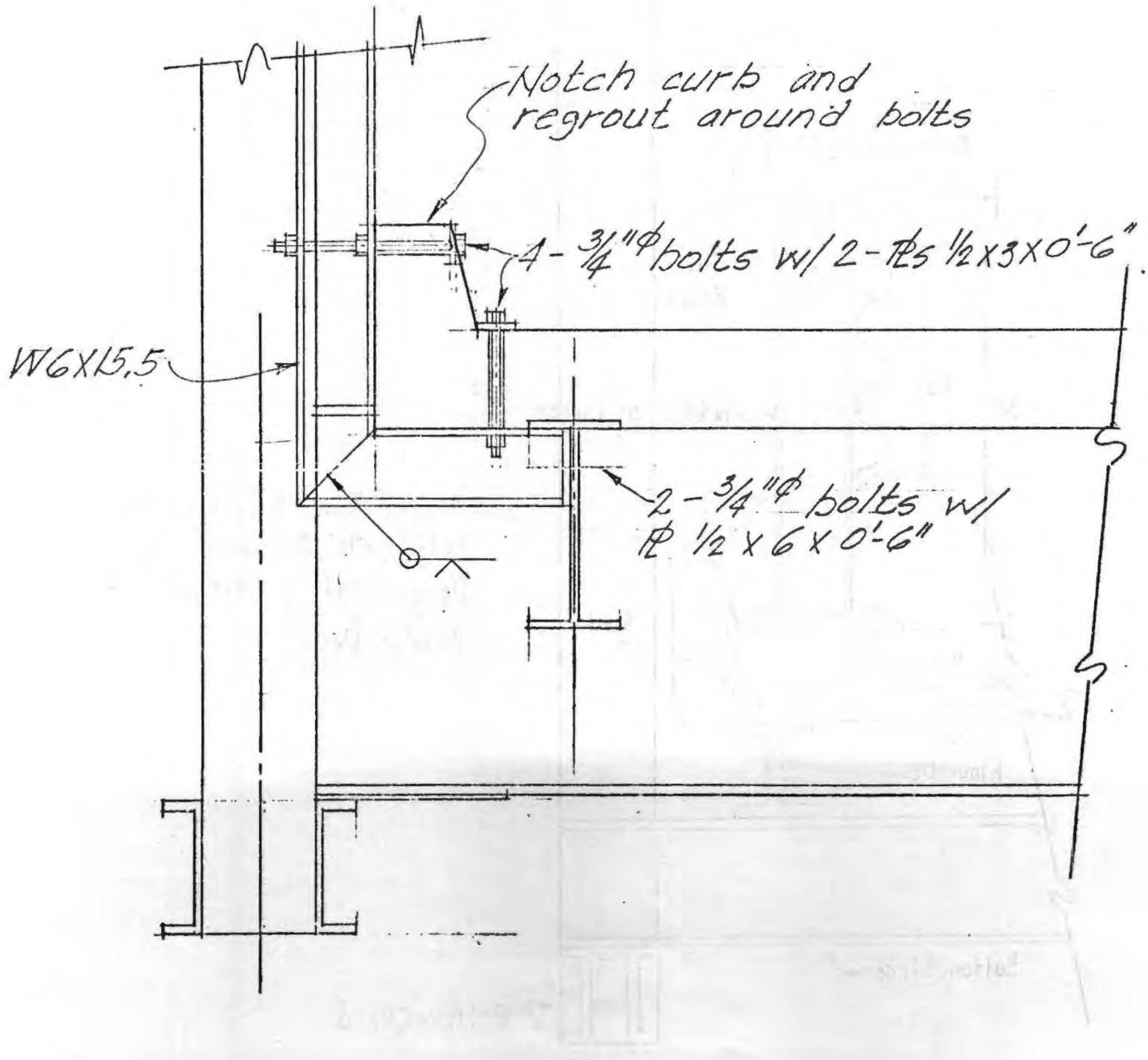


FIGURE 125. INTERMEDIATE POST ATTACHMENT

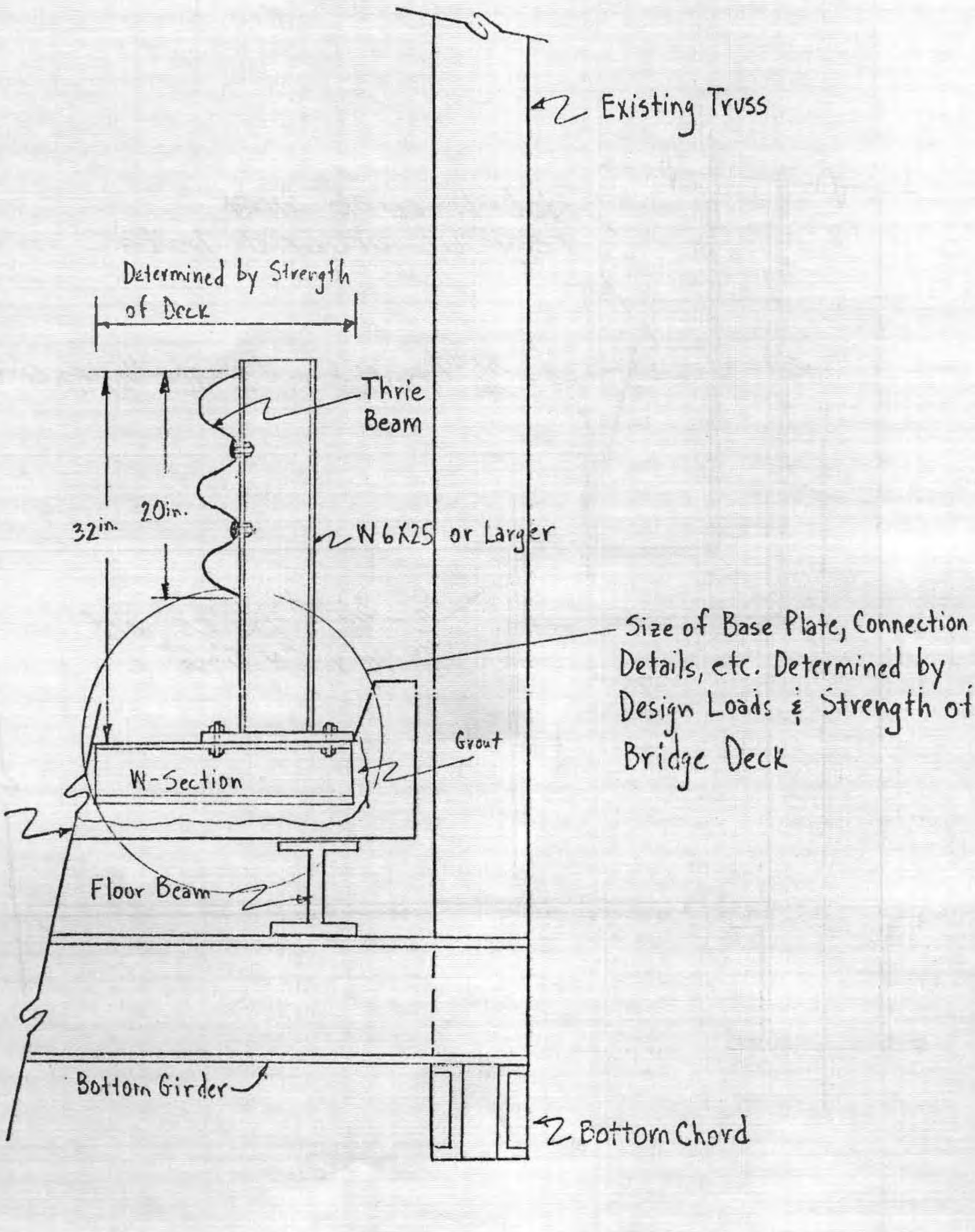


FIGURE 126. INTERMEDIATE POST ATTACHMENT

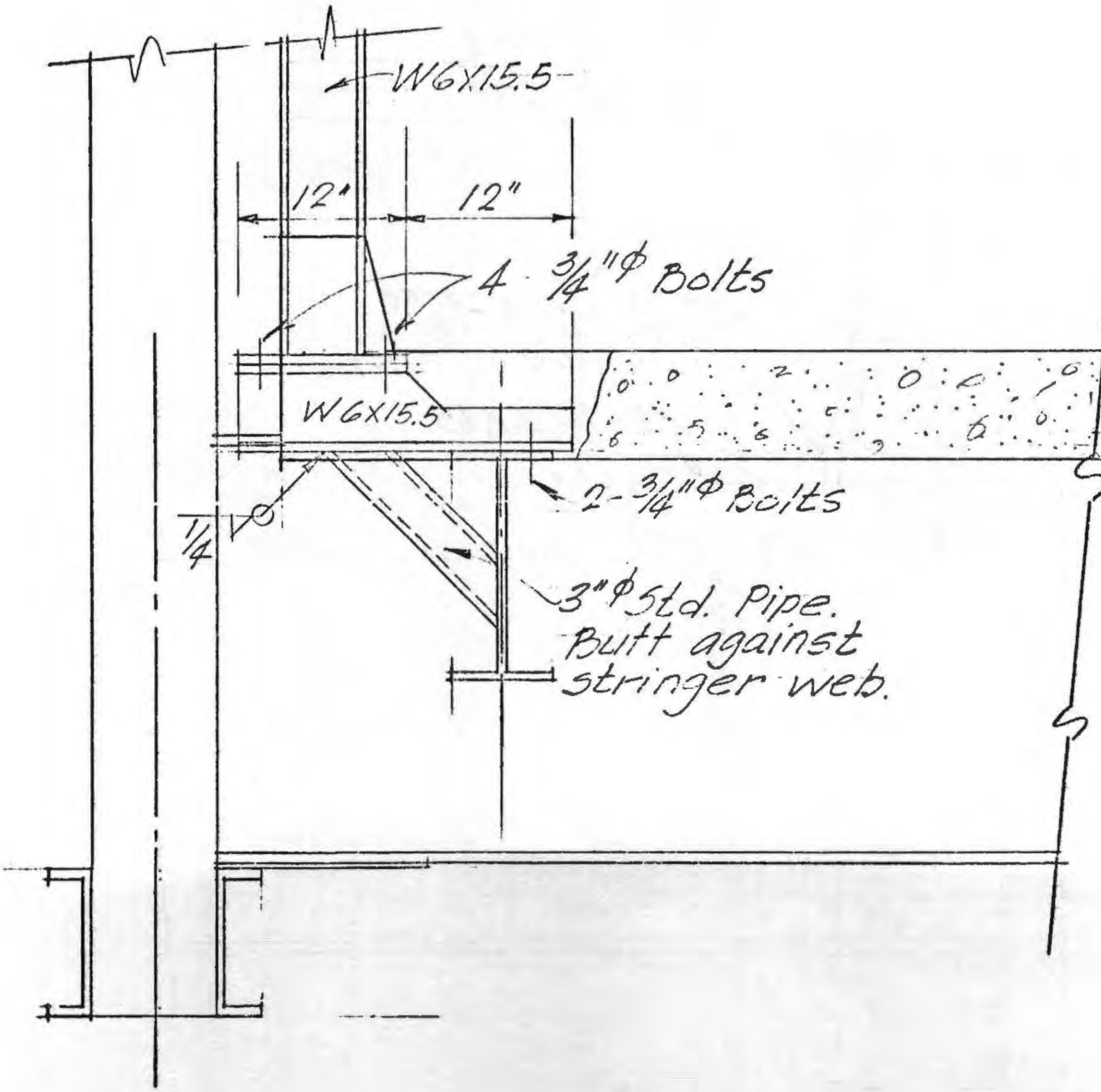


FIGURE 127. INTERMEDIATE POST ATTACHMENT

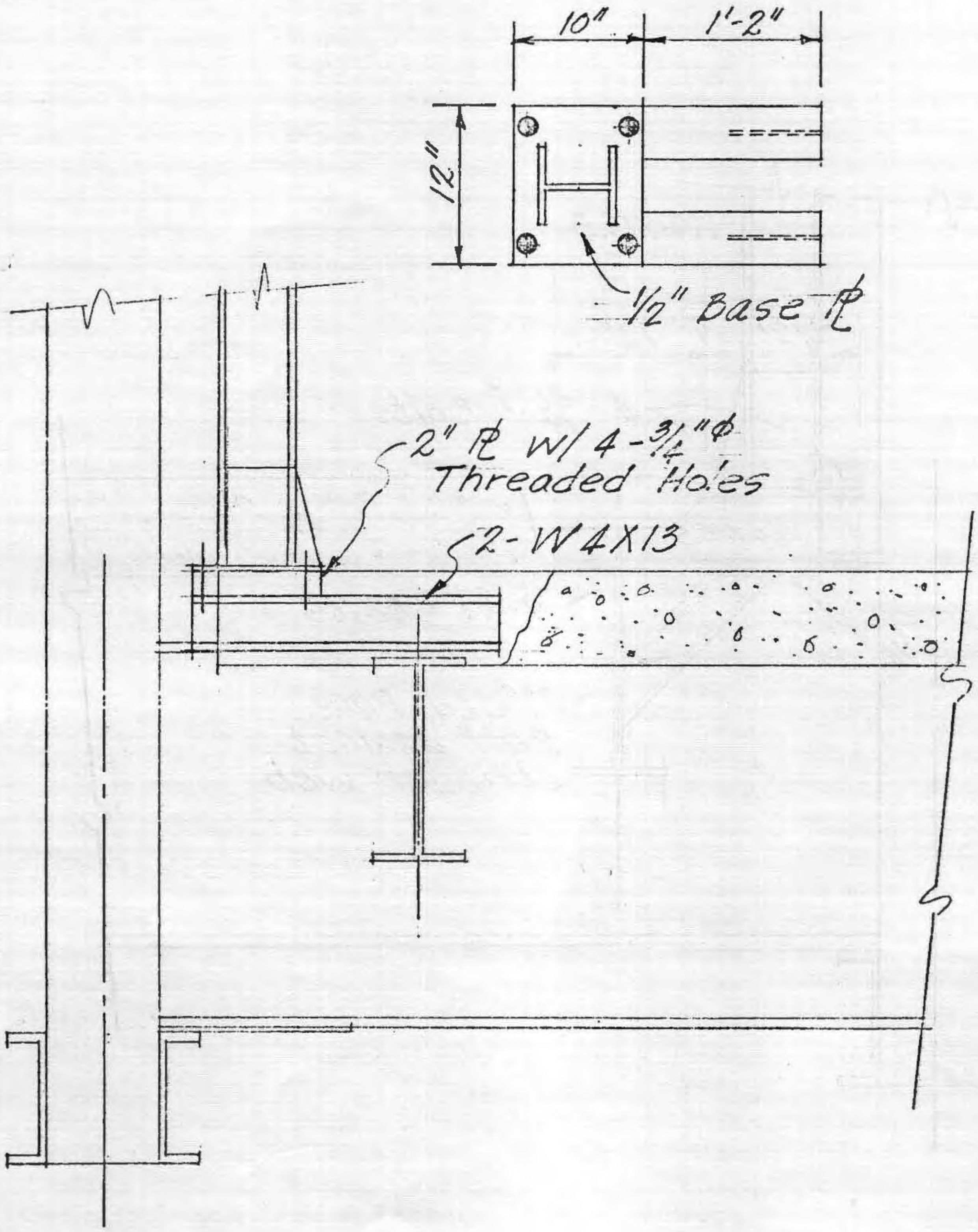


FIGURE 128. INTERMEDIATE POST ATTACHMENT

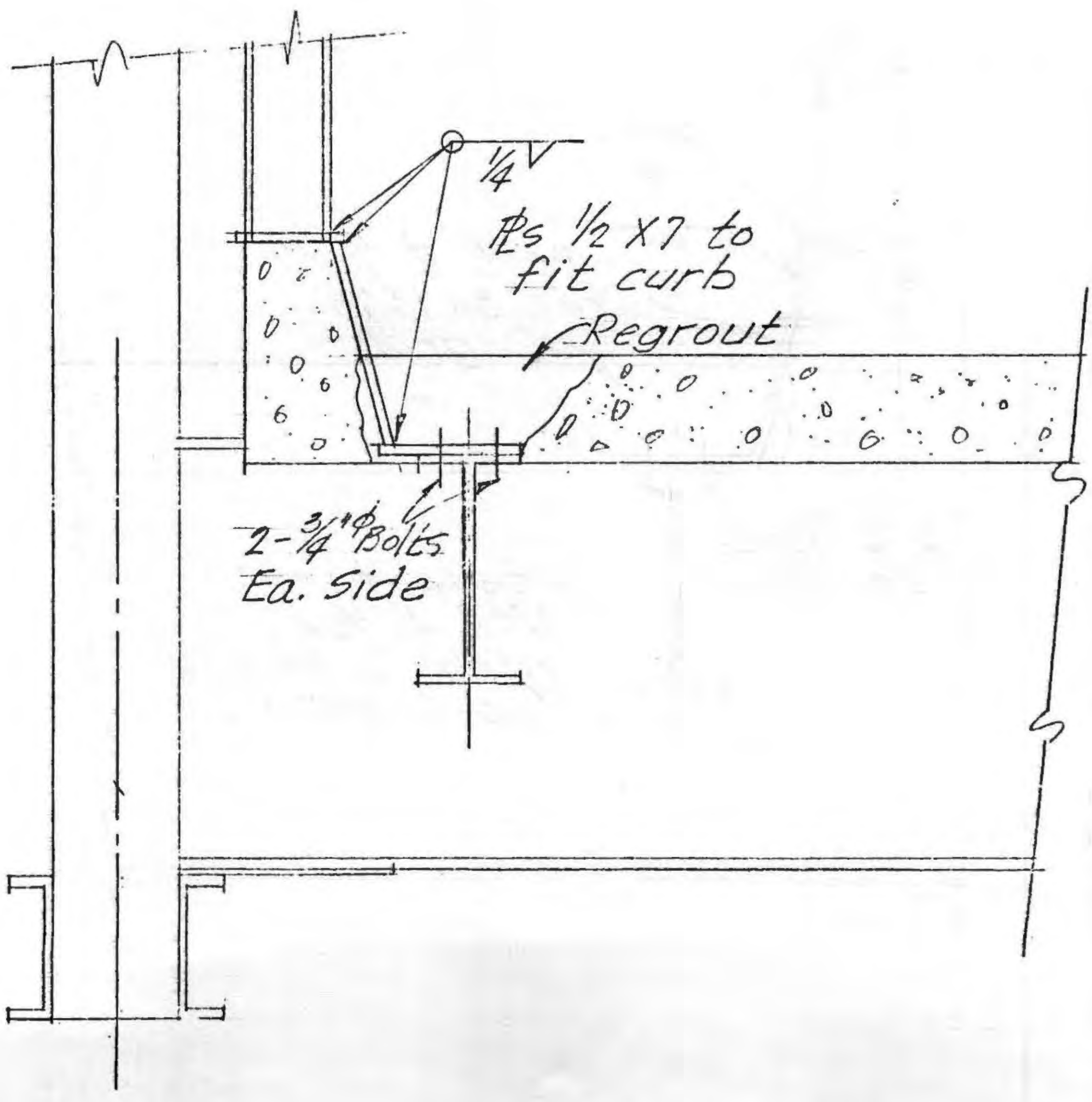


FIGURE 129. INTERMEDIATE POST ATTACHMENT

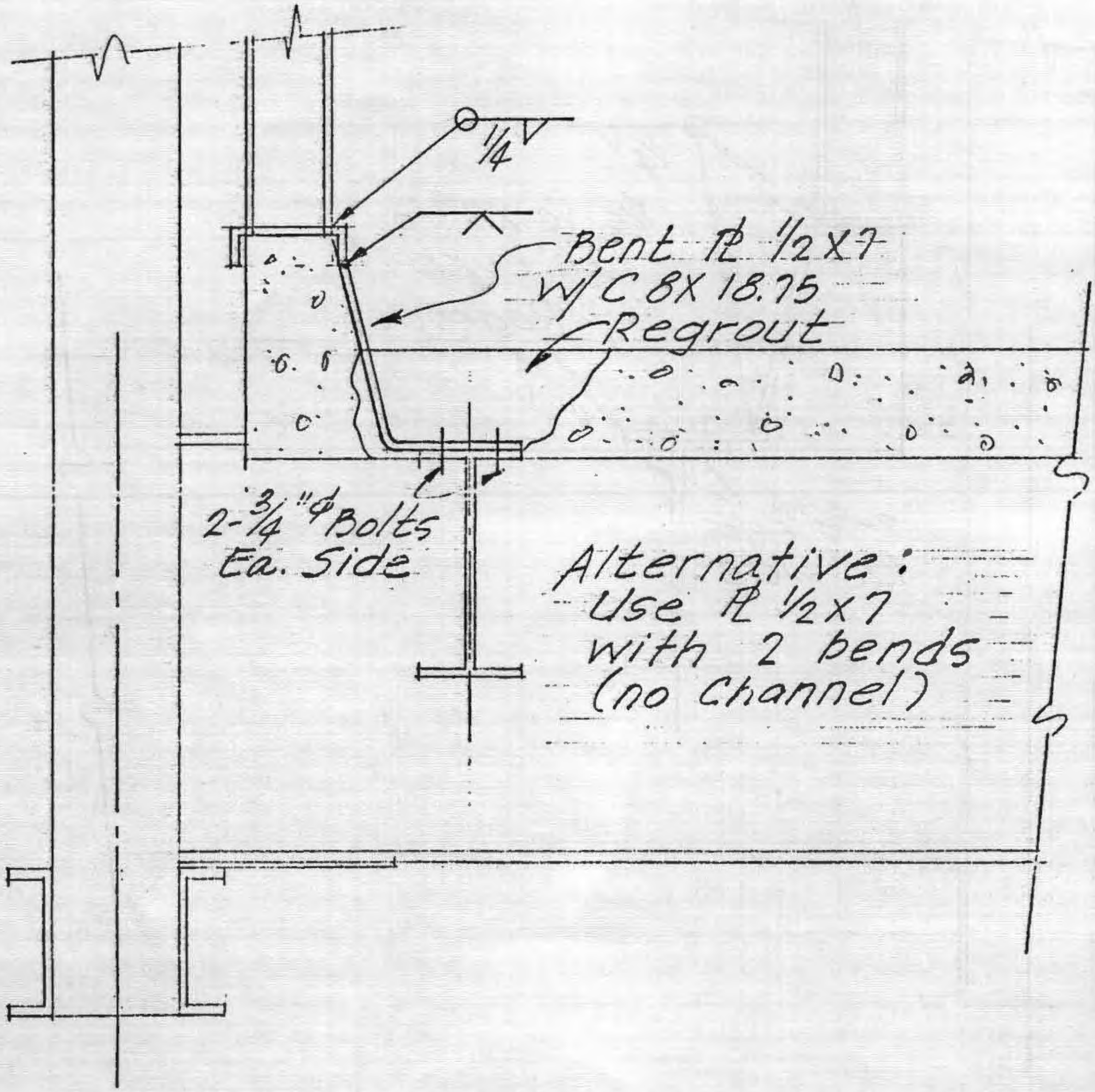


FIGURE 130. INTERMEDIATE POST ATTACHMENT

APPENDIX D

DISCUSSION OF HOOD SNAGGING/WINDSHIELD INTRUSION PROBLEM

Tests TTR-7 and TTR-8 resulted in vehicle windshield penetration due to hood intrusion as shown in Figure 131. This phenomena was attributed to the following sequential events:

1. The essentially undeformed hood corner protrudes over the lower tubular beam as the vehicle structure crushes.

2. The hood corner snags on a post extending above the lower beam.

3. The hood twists off at the hinges and the rear hood corner penetrates the windshield as illustrated in Figure 131.

The problem of hood snagging on a post projecting above the beam in this case is somewhat unique. Most in-service barriers have single beams mounted with the top below the hood line; thus there is no need for a post projection above the beam. In the case of multiple railing systems such as the thru truss retrofit system of this project, the possibility of the hood going over the lower railing and snagging on the post section between railings exists. Hood behavior in other crash tests as illustrated in Figure 132 would have prevented the windshield intrusion. In recent years the major domestic manufacturers have "designed in" the folded hood behavior illustrated in Figure 132(a).

In a limited survey of late model cars made by the Big 3, these controlled hinge locations are designed by locally weakening of the hood structural members as illustrated in Figure 133. Ford and GM employ a stud that engages the hood (Ford) or hinge (GM) to prevent rearward hood translation (Figure 133). In the case of the 1978 Ford LTD used in TTR-7 and TTR-8, it appears that hinge attachment to the quarter panel is the weak link; i.e., the hinges remain with the hood. The rather loose fit of the hood sheet metal with the stud [Figure 133(a)] appears to defeat the purpose of the detail. The local crimping of the hood structure shown in Figure 133(b) is much less significant than that employed by GM and Chrysler as shown in Figures 133(d), (f) and (h). Of the cars surveyed, the Ford designed hood fold points seemed to be minimally weakened in comparison with the others. Folding of the hood as shown in Figure 132(a) could have prevented the undesirable windshield penetration problem.

A ready solution to the hood snagging problem would be to raise the height of the lower beam to prevent the hood from going over the beam. The 33-in. (0.8-m) mounting height appears to be an upper bound, however, when considering the bumper interfaced with the tubular thrie beam as shown in Figure 134. By raising the beam only 2 in. (50 mm) the liklihood of the Honda Civic bumper sliding under the beam and snagging on the posts appears to be probable. This 2-in. (50-mm) increase in height would not be sufficient to engage the bumper.

(a) TTR-7

(b) TTR-7 vehicle

(c) Bridge rail retrofit, TTR-8

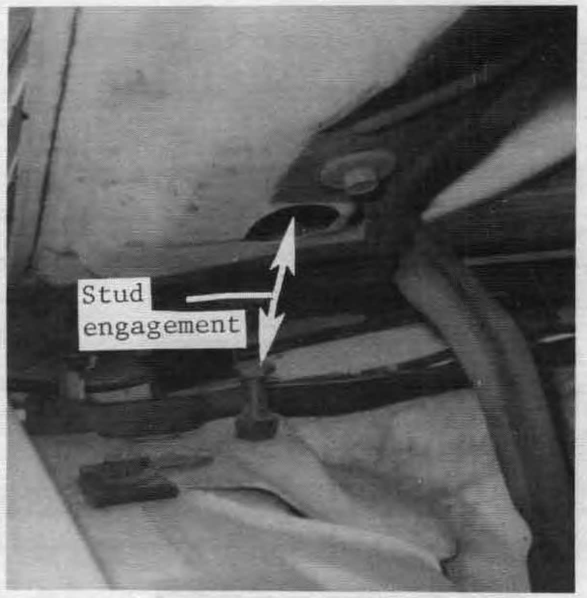
(d) TTR-8 vehicle

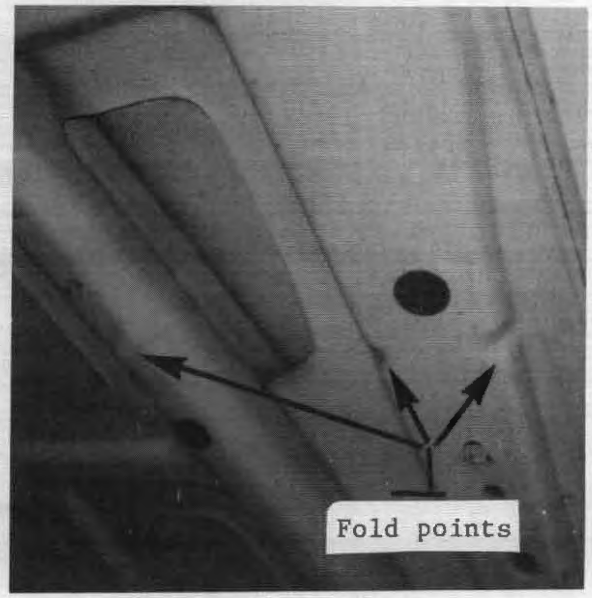
FIGURE 131. PHOTOGRAPHS AFTER TESTS TTR-7 AND TTR-8

(a) Folded hood, 1974 Oldsmobile Delta 88

(b) Open hood, 1974 AMC Ambassador

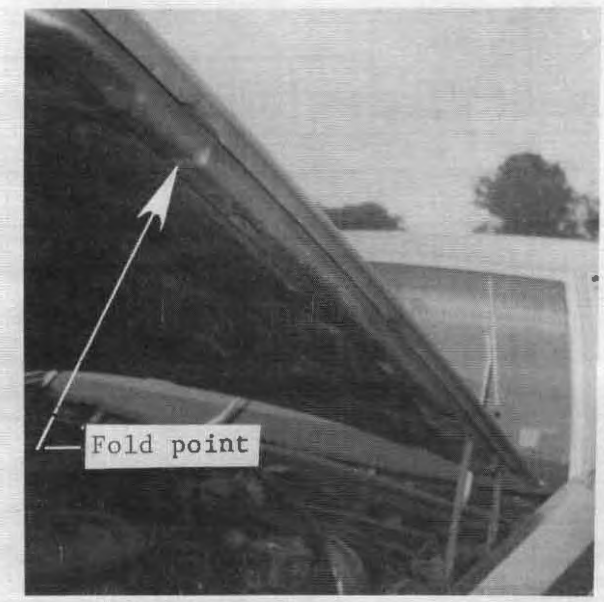
FIGURE 132. DESIRABLE HOOD BEHAVIOR





(a) 1978 Ford LTD stud and engagement hole in sheet metal

(b) 1978 Ford LTD fold point details

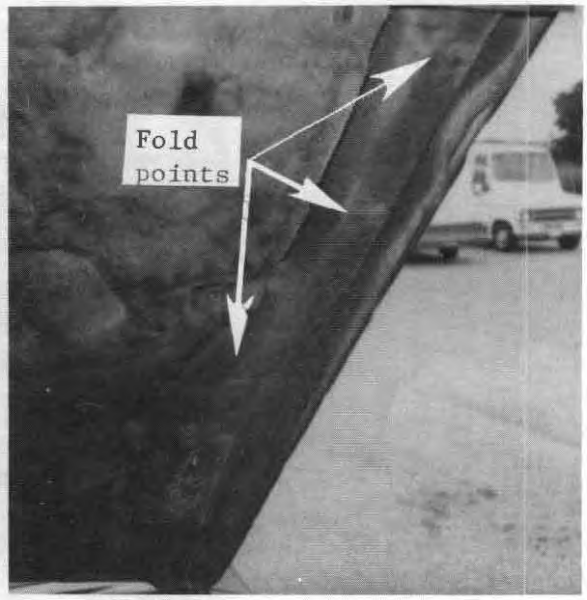


(c) 1978 Buick Le Sabre stud tightly engages with hinge

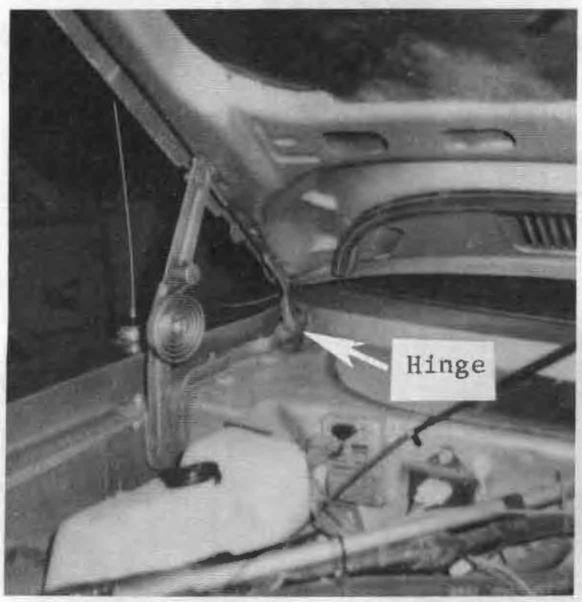
(d) 1978 Buick LeSabre fold point location

FIGURE 133. VEHICLE HOOD DETAILS

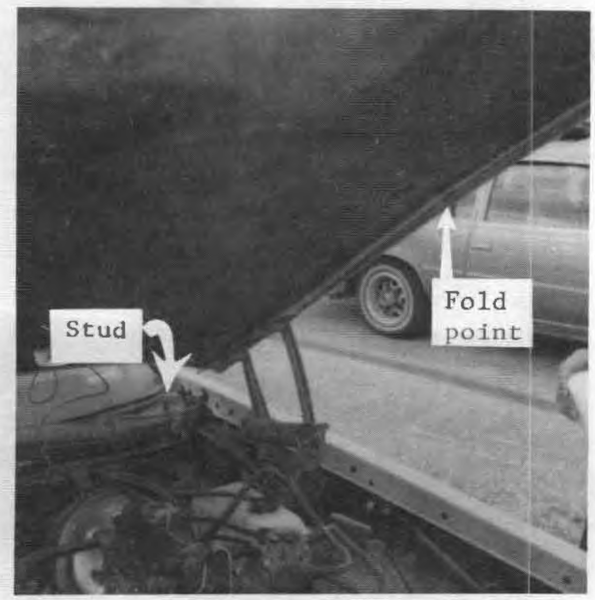
(e) 1980 Chrysler Newport hinge detail



(f) Multiple fold points, 1980 Chrysler Newport



(g) 1980 Volare hinge detail



(h) 1980 Oldsmobile details

FIGURE 133. (Cont'd)

FIGURE 134. HONDA CIVIC WITH CURRENT TUBULAR THRIE BEAM MOUNTING HEIGHT (33 in.)

* U.S. Government Printing Office: 1986 0-181-763 (40123)

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5. **Structural Design and Hydraulics**
   Structural RD&T is concerned with furthering the latest technological advances in structural and hydraulic designs, fabrication processes, and construction techniques to provide safe, efficient highways structures at reasonable costs. This category deals with bridge superstructures, earth structures, foundations, culverts, river mechanics, and hydraulics. In addition, it includes material aspects of structures (metal and concrete) along with their protection from corrosive or degrading environments.

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