CRASH TESTS

OF

FIVE-FOOT RADIUS PLATE BEAM GUARDRAIL

by

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Sponsored by

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STATE OF MINNESOTA

TEXAS TRANSPORTATION INSTITUTE

TEXAS A & M RESEARCH FOUNDATION

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ACKNOWLEDGMENTS

Vehicle crash testing of the Minnesota five-foot radius plate beam guardrail reported herein was conducted under an agreement between the Texas A&M Research Foundation and the Department of Highways, State of Minnesota. The testing was conducted by personnel of the Highway Safety Research Center of the Texas Transportation Institute. The program was conducted under the direction of Mr. Paul J. Diethelm, Research Coordination Engineer, State of Minnesota.

Sincere appreciation is expressed to the Wheeler Division, St. Regis Paper Company, St. Louis Park, Minnesota, and Lewis Bolt and Nut Company of Minneapolis, Minnesota for furnishing materials for the test installations.

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INTRODUCTION

The Minnesota Department of Highways employs a five-foot radius plate beam end treatment for median rails at twin bridges and piers on divided roadways. The crashworthiness of this end treatment was evaluated in a program which included two full-scale vehicle crash tests. The tests were conducted in February and April, 1975. The test vehicles which weighed 2250 lbs and 4500 lbs were towed head-on into the median rail system at 60 mph. Performance of the system was excellent in both tests.

DESCRIPTION OF TESTS

Full-scale vehicle crash tests of the Minnesota five-foot radius plate beam guardrail were conducted on February 14 and April 30, 1975. The 87.5 ft U-shaped guardrail test section was mounted on fifteen 6 in. x 8 in. wood posts with blockouts. The 72 in. wood posts, spaced 6 ft 3 in. on centers, were set approximately 45 in. deep in oversized holes backfilled with lean concrete to simulate frozen ground conditions. Two 22 in. diameter concrete posts (simulated piers) were placed 35 ft behind the nose, between the parallel straight sections of the guardrail. (A typical field installation consists of a full loop instead of a half loop, and the obstacle is usually 50 ft instead of 35 ft behind the nose. There are no plans to deviate from this design.) A test site layout is given in Figure 1. The guardrail system was installed in accordance with MHD Standard Plate No. 8307K and MHD Standard Plan Sheet No. 5-297.603, which are presented in Appendix A.

A 1971 Chevrolet Vega two-door sedan weighing 2290 lbs was used as the test vehicle in Test B1. For Test B2 a 1969 Chrysler Newport four-door sedan weighing 4500 lbs was used. The test vehicles were towed head-on into the barrier at a nominal impact speed of 60 mph. Directional control was provided by a cable stretched alongside the vehicle path and threaded through a guide assembly attached to the left front spindle of the test vehicle. A release mechanism was incorporated at the test vehicle attachment point to free the vehicle immediately prior to impact.

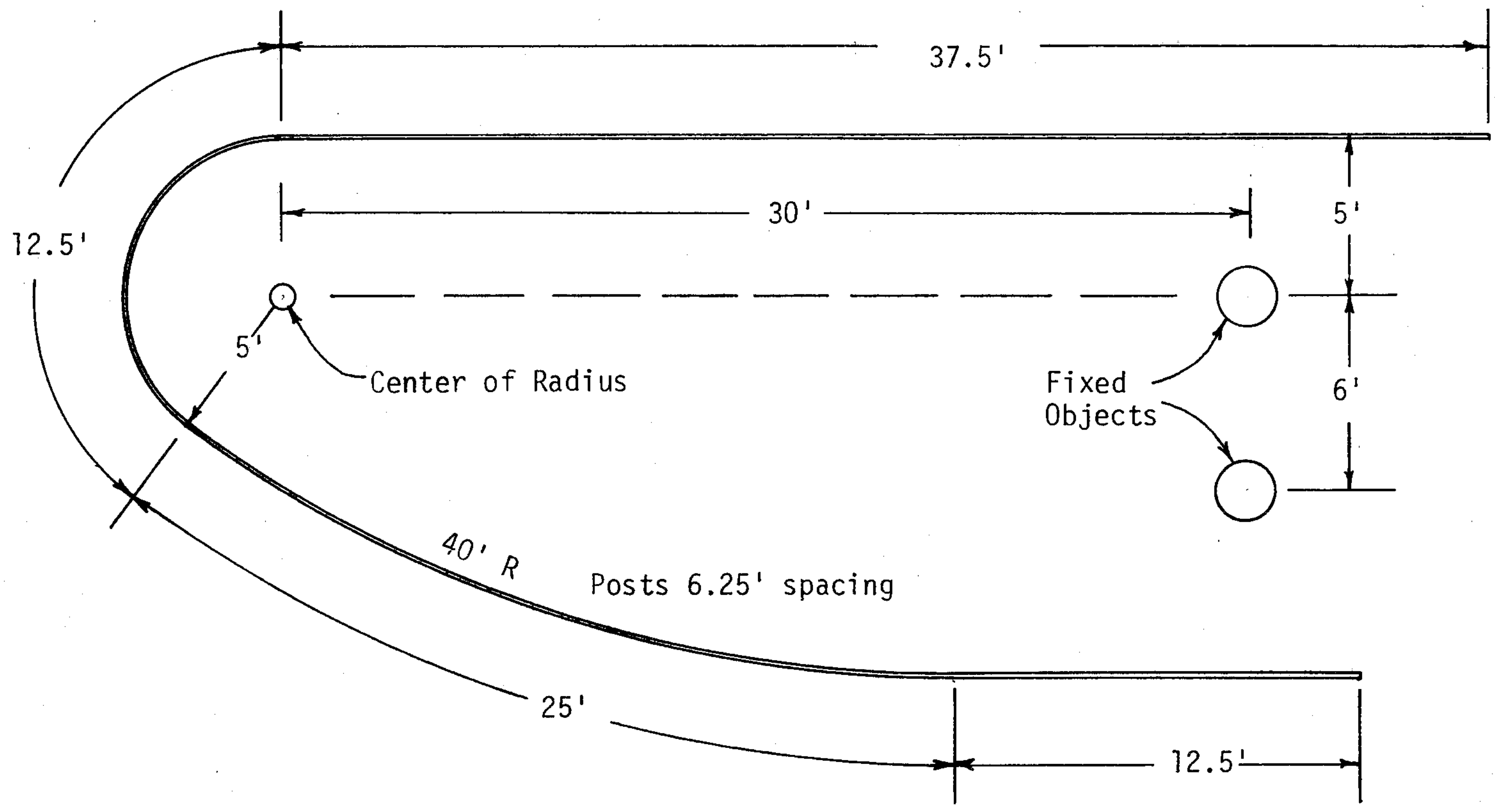


Figure 1. Test Site Layout.

Two high-speed motion picture cameras placed perpendicular to the test vehicle path and operating at 400 frames per second were used to obtain time-displacement data. A stadia board mounted on the side of the test vehicle was used to ascertain distances on the film. A third high-speed motion picture camera was mounted overhead and focused on the entire guardrail system. A stadia board, lying on the ground, was used to measure distances on this film. A tape switch fixed to the front bumper of the vehicle actuated a flash bulb on the roof of the vehicle to indicate the impact and served to synchronize the electronic and photographic instrumentation systems. A fourth camera, with a wide field of view, panned with the vehicle to record the entire scene for a documentary.

Longitudinal and transverse acceleration components of the test vehicle were measured by strain gage accelerometers mounted on the longitudinal frame members. The signals from these accelerometers were channeled through a 100 Hz. low pass filter meeting the key requirements of SAE J 211a. An Impact-O-Graph, mounted in the vehicle trunk, was installed for a backup system to measure decelerations.

A summary of the test results is presented in Table 1, and the tests are described in detail in the following paragraphs.

TABLE 1. SUMMARY OF TEST RESULTS

Film Data	Test B1	Test B2
Impact velocity, ft/sec	90.2 (27.49 m/sec)	91.4 (27.85 m/sec)
Impact velocity, mph	61.5 (98.97 km/hr)	62.3 (100.26 km/hr)
Duration of forward motion, msec	687	826
Total elapsed time (impact to stop), msec	1040	2500
Maximum penetration of c.g., ft	23.3 (7.10 m)	38.8 (11.83 m)
Maximum roll, degrees	--	45
Maximum yaw, degrees	-47	-43
Average longitudinal deceleration (impact to max. penetration), g's	5.3†	3.8†
Accelerometer Data		
Impact velocity, ft/sec	89.6 (27.31 m/sec)	89.9 (27.40 m/sec)
Longitudinal deceleration, g's		
Peak	23.2	11.6
Average over duration of significant decelerations	4.0*	2.7+
Maximum average over 200 msec	6.1	3.4
Maximum average over 50 msec	9.1	4.7
Transverse deceleration, g's		
Peak	20.3	9.9
Average over duration of significant decelerations	1.2**	1.0+
Maximum average over 200 msec	4.0	2.3
Maximum average over 50 msec	7.6	3.9

*Duration of significant deceleration was 600 msec.
**Duration of significant deceleration was 670 msec.
+Duration of significant deceleration was 902 msec.
†Computed from $\frac{V^2}{2(g)(s)}$.

RESULTS OF INDIVIDUAL TESTS

Test B1.

A 1971 Vega weighing 2290 lbs impacted the guardrail head-on (0 degrees) at 61.5 mph. Upon impact, post number 1 (Figure 3) failed at ground level. Shortly thereafter the hood of the test vehicle began to open. As the vehicle advanced into the attenuator, the guardrail buckled and wrapped around the front bumper. Then post number 2 failed at ground level. The vehicle continued to advance and began to yaw counterclockwise. The steel guardrail became taut against post numbers 3 and 4, and they failed almost simultaneously. By this time the guardrail was wrapped around the front half of the test vehicle. The left front of the test vehicle contacted post number 7 and broke it off at ground level. Subsequently, the maximum yaw of the vehicle reached 47 degrees. Pitching and rolling motions of the vehicle were negligible. After the complete failure of the five wooden posts and partial failure of four others, the vehicle came to rest with a yaw angle of 33 degrees. A diagram of the test vehicle path and position of rest is shown in Figure 3. The vehicle center of mass penetrated 23.2 ft into the barrier. Sequential photographs from the high-speed cameras are contained in Figures B-1 and B-2 of Appendix B. Time-displacement data for the test vehicle, obtained from the high-speed film, are also given in Appendix B.

The average deceleration of the test vehicle computed from the impact velocity and the stopping distance of the vehicle center of gravity (using $\frac{V^2}{2(g)(s)}$) was 5.3 g's, which is well below the acceptable

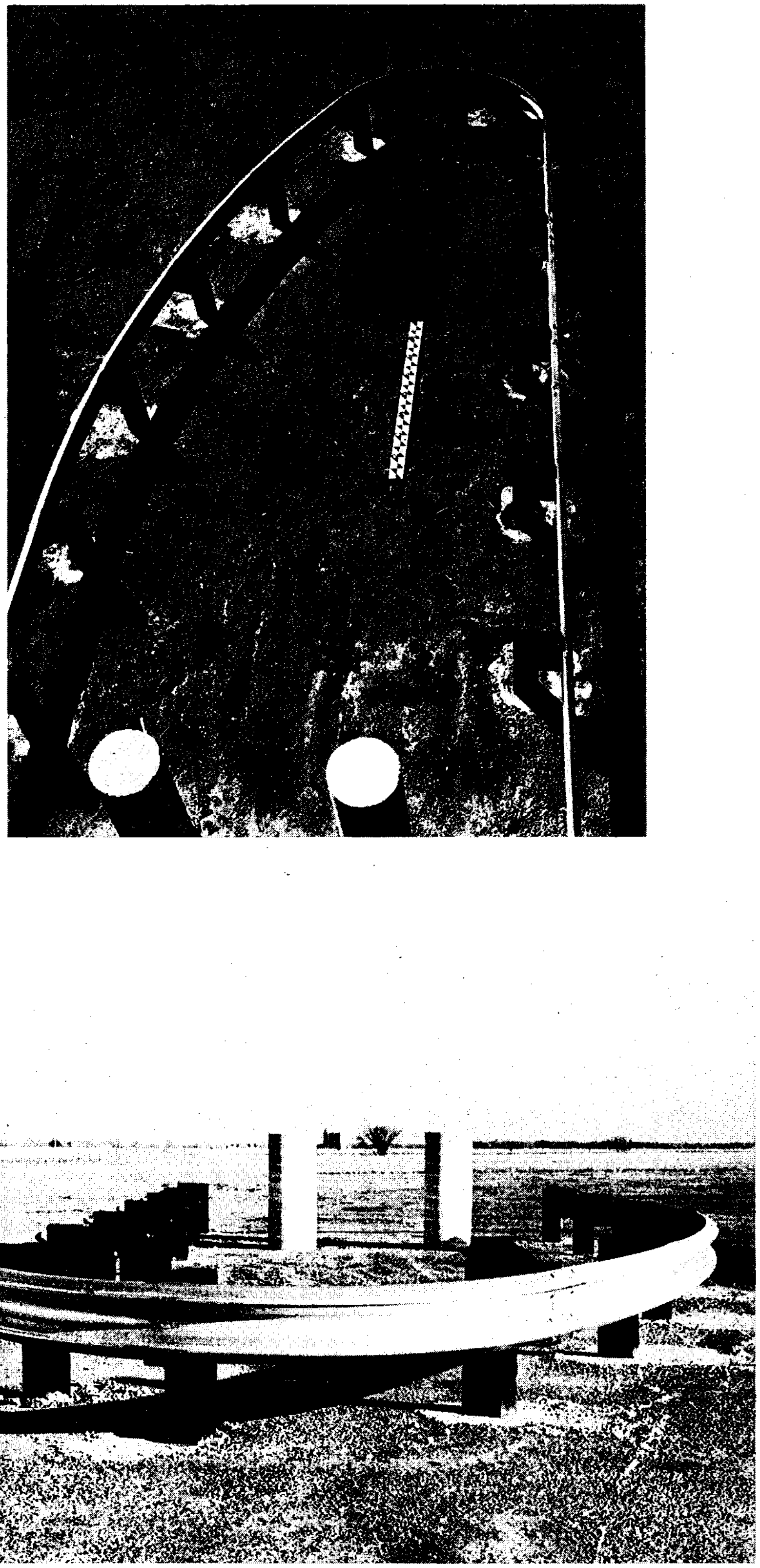


Figure 2. The Minnesota Five-Foot Radius Plate Beam Guardrail Prior to Test B1.

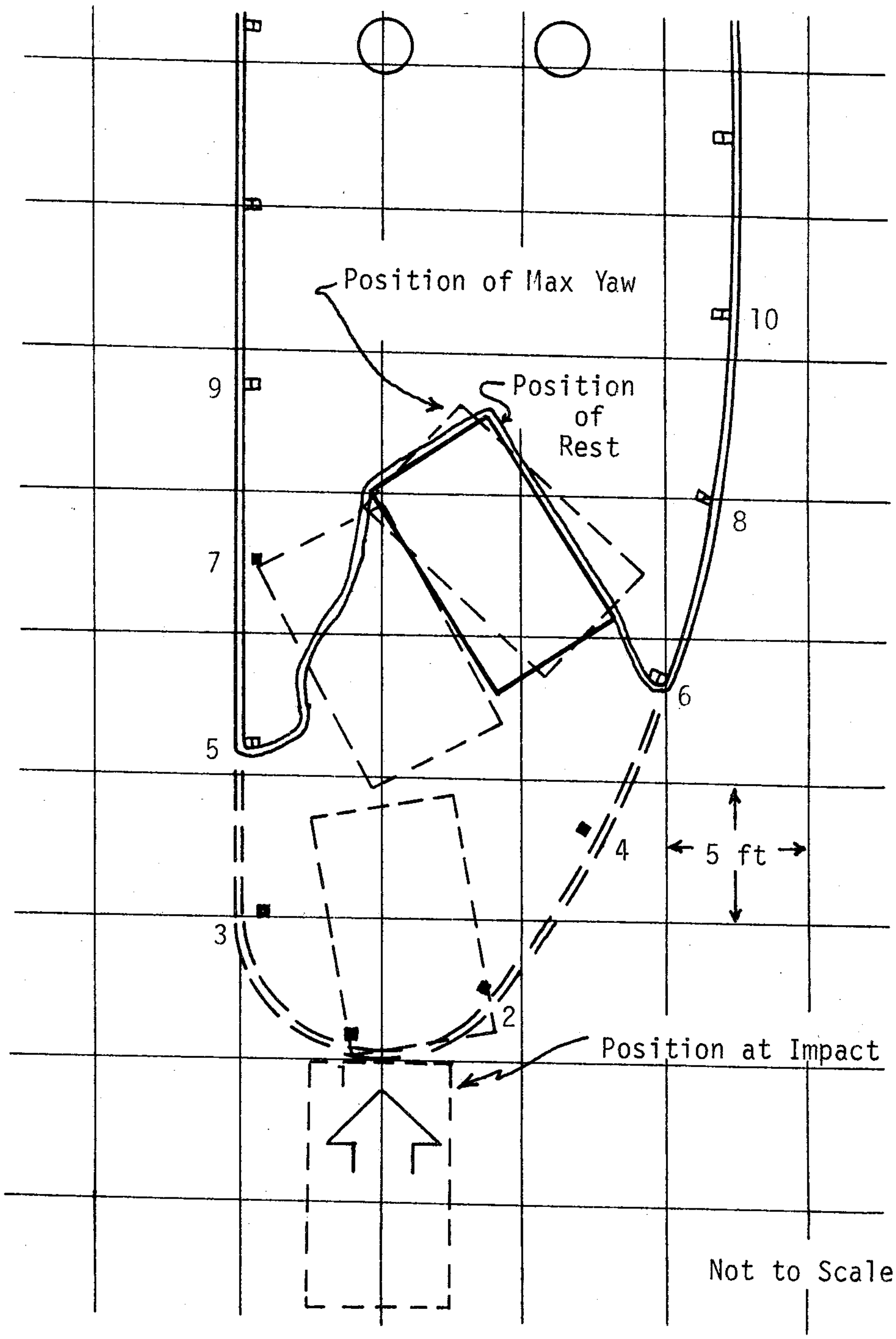


Figure 3. Vehicle Path during Test B1.

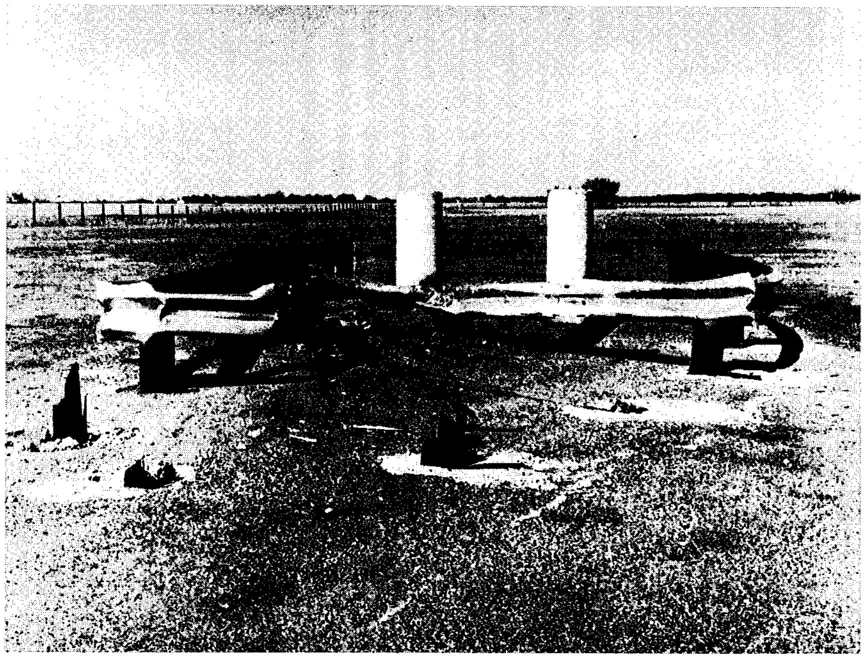


Figure 4. Minnesota Guardrail after Test B1.

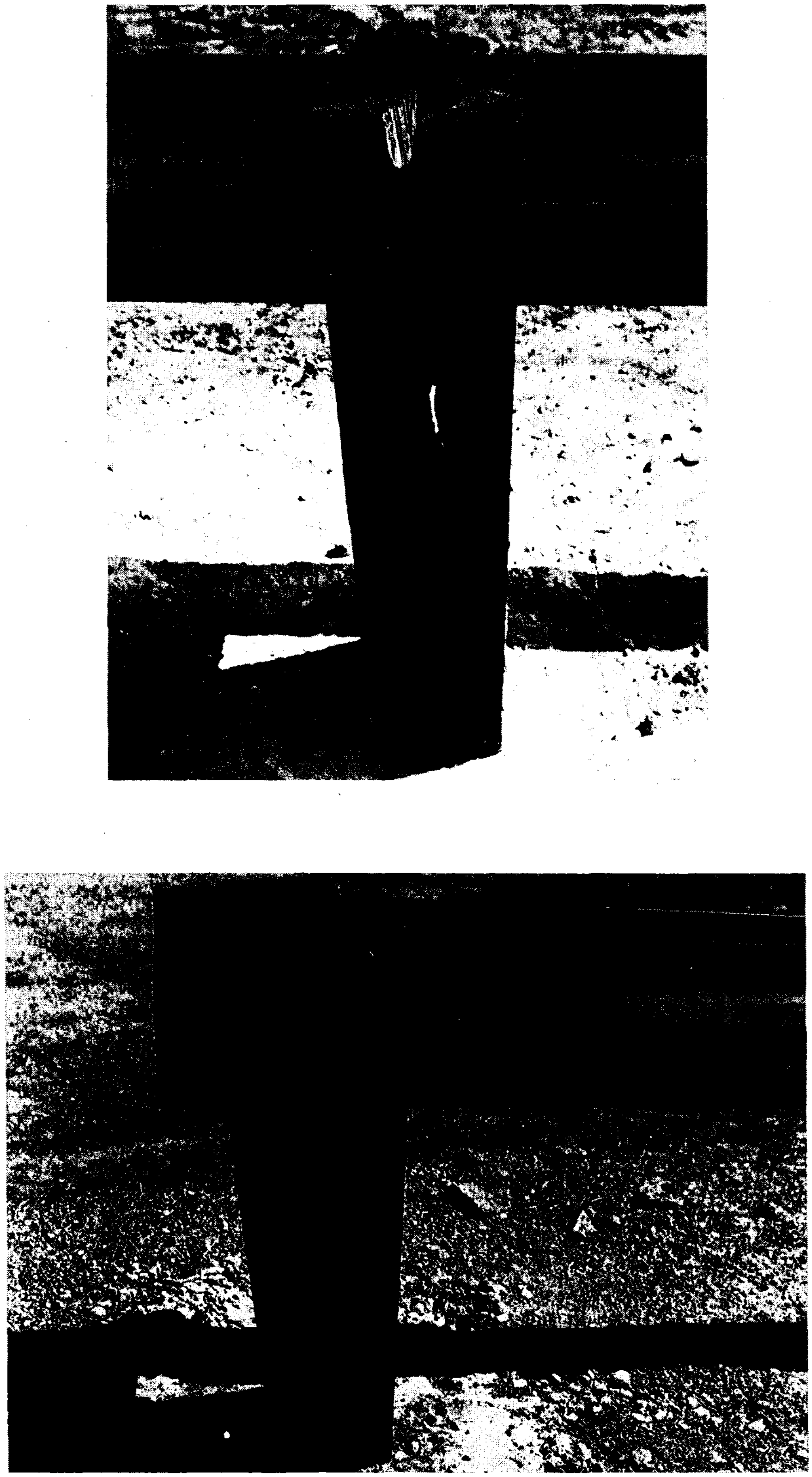


Figure 5. Post Nos. 8 and 14 after Test B1.

Figure 6. The 1971 Vega Prior to Test B1.

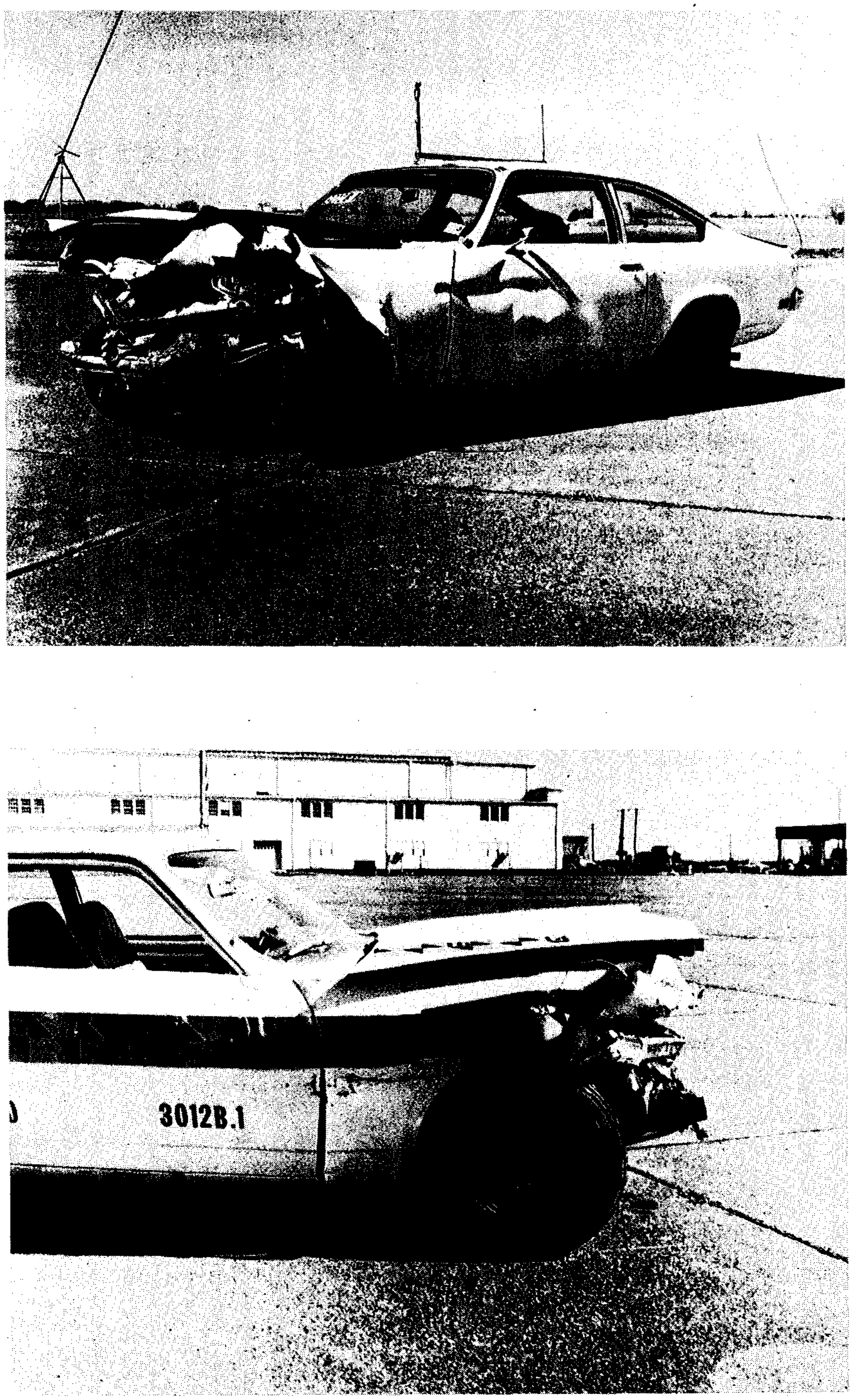


Figure 7. The Vega after Test B1.

limit of 12 g's specified in NCHRP Report 153 (1). Average decelerations determined over various time intervals from the vehicle mounted accelerometers were low, which indicates good performance. The highest average over a 200 msec interval was 6.1 g's, and over 50 msec was 9.1 g's. Acceleration traces are contained in Appendix B.

The vehicle received moderate damage in the form of distortion of front frame members and considerable sheet metal deformation. Based on the TAD scale (2), the vehicle damage rating was FD-5. The SAE collision deformation classification (3) was 12FDEW3. Damage to the test vehicle is shown in Figure 7.

Test B2.

A 1969 Chrysler weighing 4500 lbs impacted the guardrail head-on at 62.3 mph. Upon impact, post number 1 (Figure 9) broke off and the vehicle began to yaw counterclockwise. Almost immediately post number 2 failed at ground level. About the time the steel guardrail became taut against post numbers 3 and 4, the left front corner of the vehicle contacted post number 5; and the three posts failed almost simultaneously. As the vehicle advanced further into the barrier, the left front bumper pushed over post number 7. Just after the steel guardrail became taut against post number 6 and pulled it over, the front of the vehicle pushed over post number 9. The rearward force on the steel guardrail caused the remaining three posts supporting the left side to split and the guardrail fell to the ground. The test vehicle continued to advance and yaw counterclockwise. The right front corner of the vehicle impacted one of the simulated concrete piers. During contact with the pier, the vehicle roll displacement (about its longitudinal axis) reached about 45 degrees. The vehicle rebounded approximately two feet and came to rest with a yaw angle of 43 degrees as shown in Figure 9. The vehicle center of mass penetrated 38.8 ft during impact. Sequential photographs and time-displacement data are presented in Appendix C.

Average deceleration of the vehicle computed from the impact speed and stopping distance (from $\frac{V^2}{2(g)(s)}$) was 3.8 g's, which is below the acceptable limit of 12 g's specified in NCHRP Report 153 (1).

The highest average longitudinal deceleration over a 200 msec interval, obtained from the accelerometer traces, was 3.4 g's; and the highest over 50 msec was 4.7 g's, which indicates very good performance. Accelerometer traces are given in Appendix C.

The vehicle impacted one of the simulated concrete piers at 0.647 sec after initial impact. At this time, the forward velocity of the vehicle had been reduced to such a level that the impact was entirely acceptable. Both longitudinal and transverse decelerations during impact with the simulated piers are evident in Figures C-4 and C-5. Deceleration peak values are about 5 g's, well within acceptable limits. Similar observations can be made from the seat belt force trace in Figure C-6.

Damage to the front of the vehicle was moderate and consisted of severely deformed sheet metal and somewhat distorted front frame members. Damage to the right rear consisted of minor dents in the sheet metal. Based on the TAD scale, the vehicle damage rating was

FD-5 and RBQ-3. According to SAE, the collision deformation classification was 12FDEW1. The vehicle after Test B2 is shown in Figure 13.

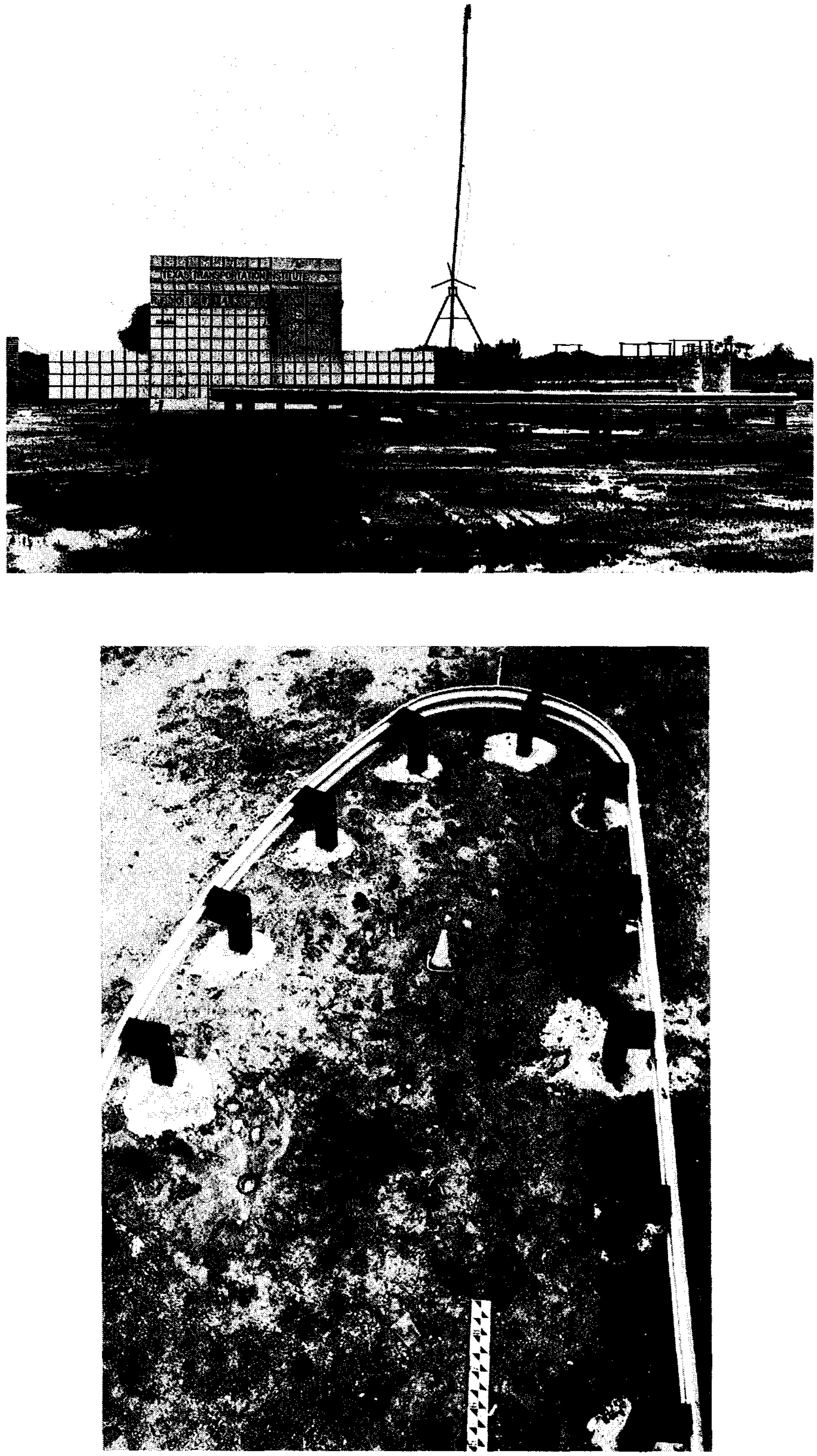


Figure 8. Minnesota Guardrail
Prior to Test B2.

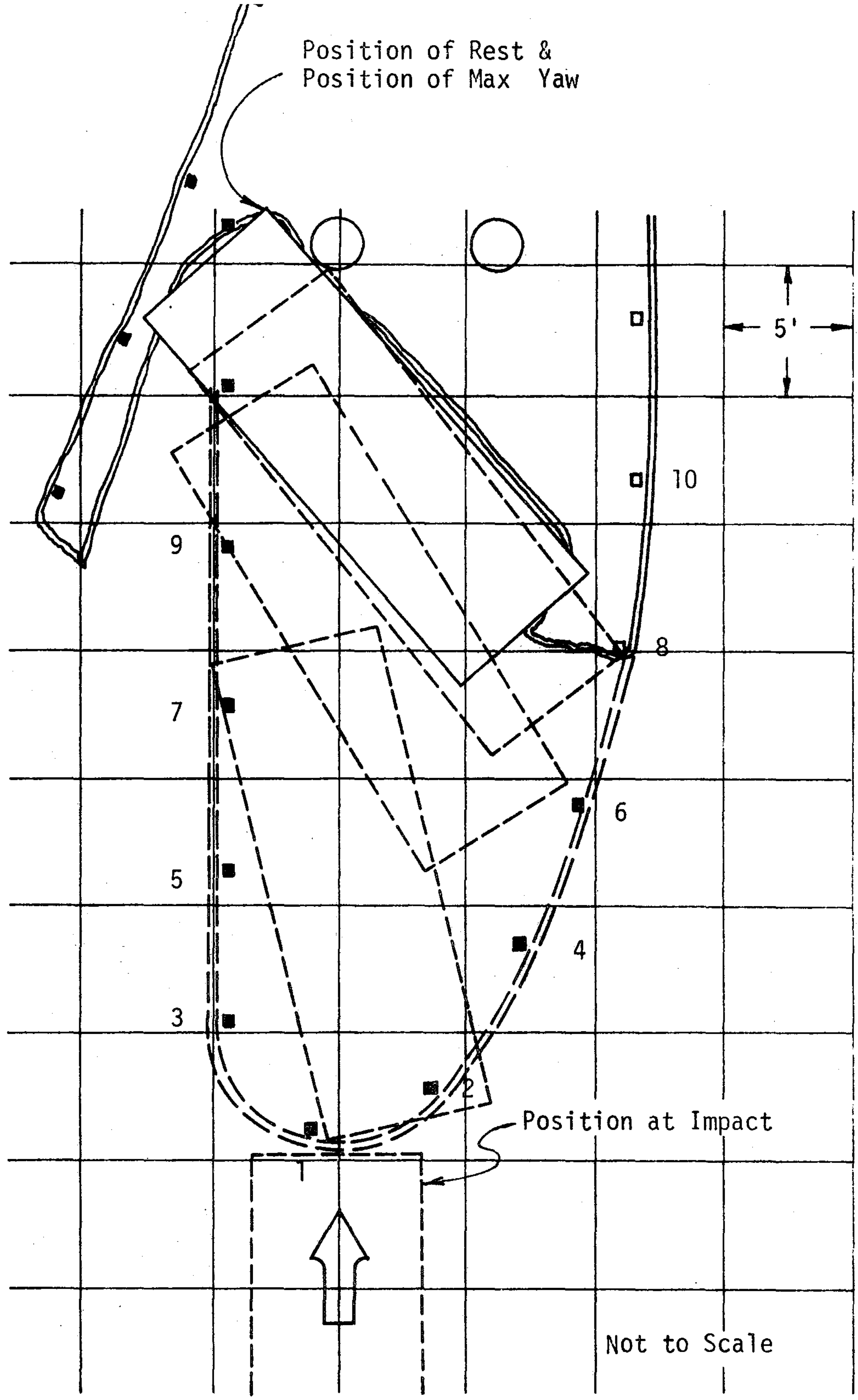


Figure 9. Vehicle Path during Test B2.

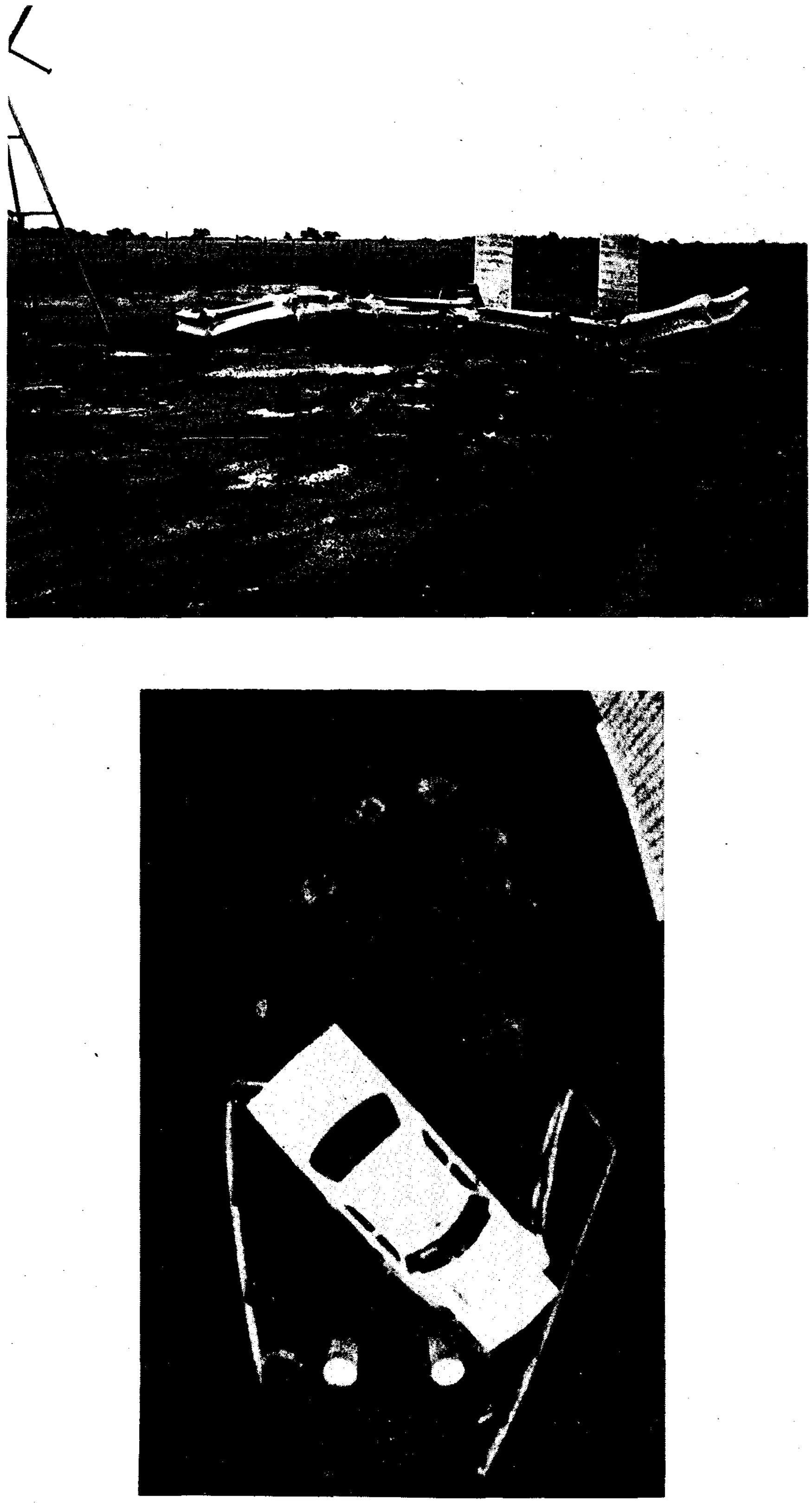
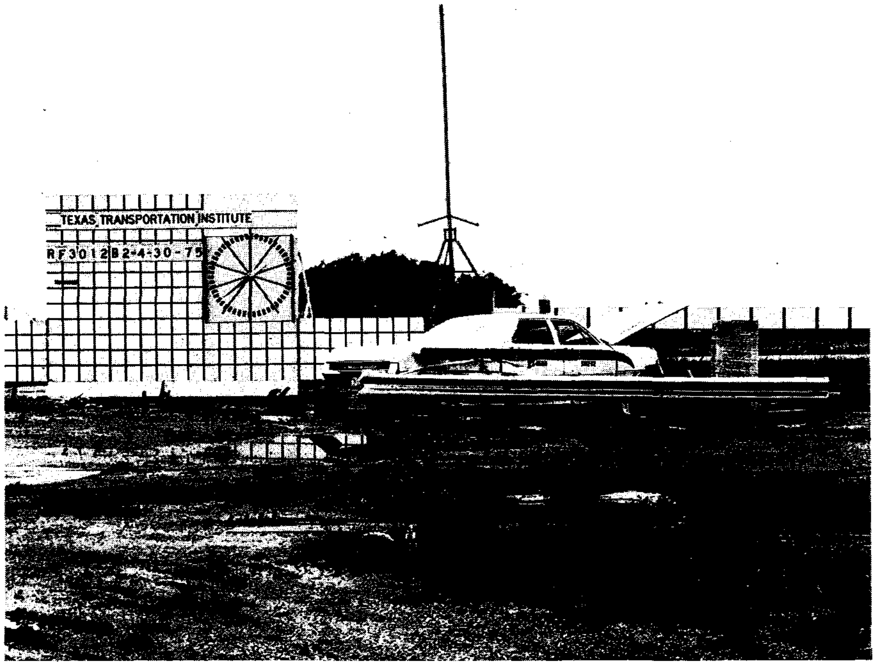


Figure 10. Minnesota Guardrail after Test B2.



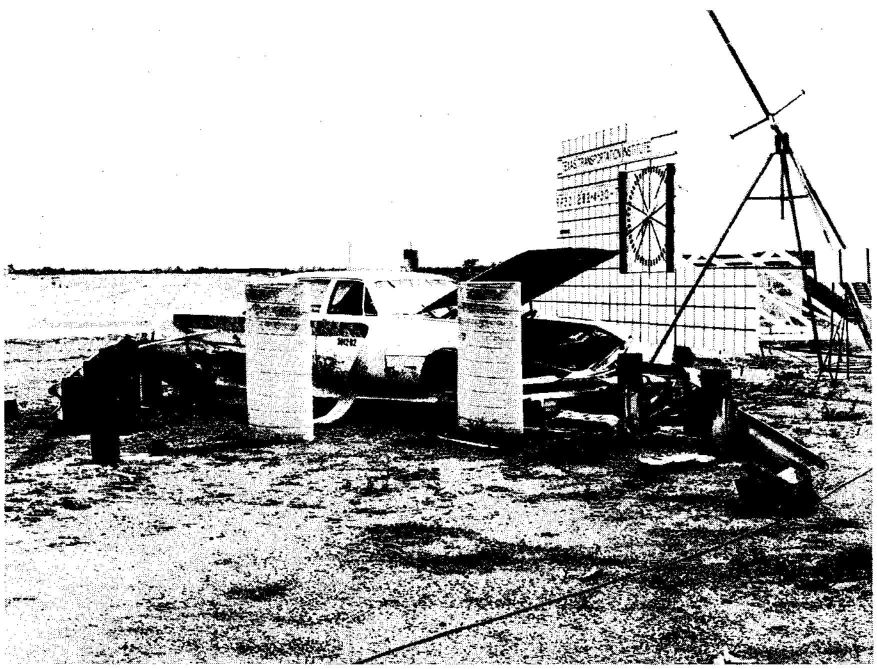


Figure 11. Vehicle and Guardrail after Test B2.

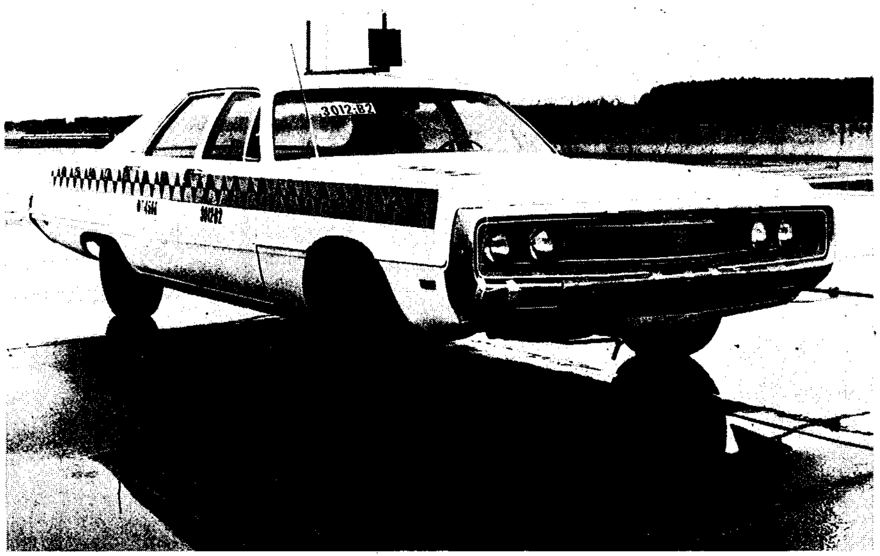


Figure 12. The 1969 Chrysler Prior to Test B2.

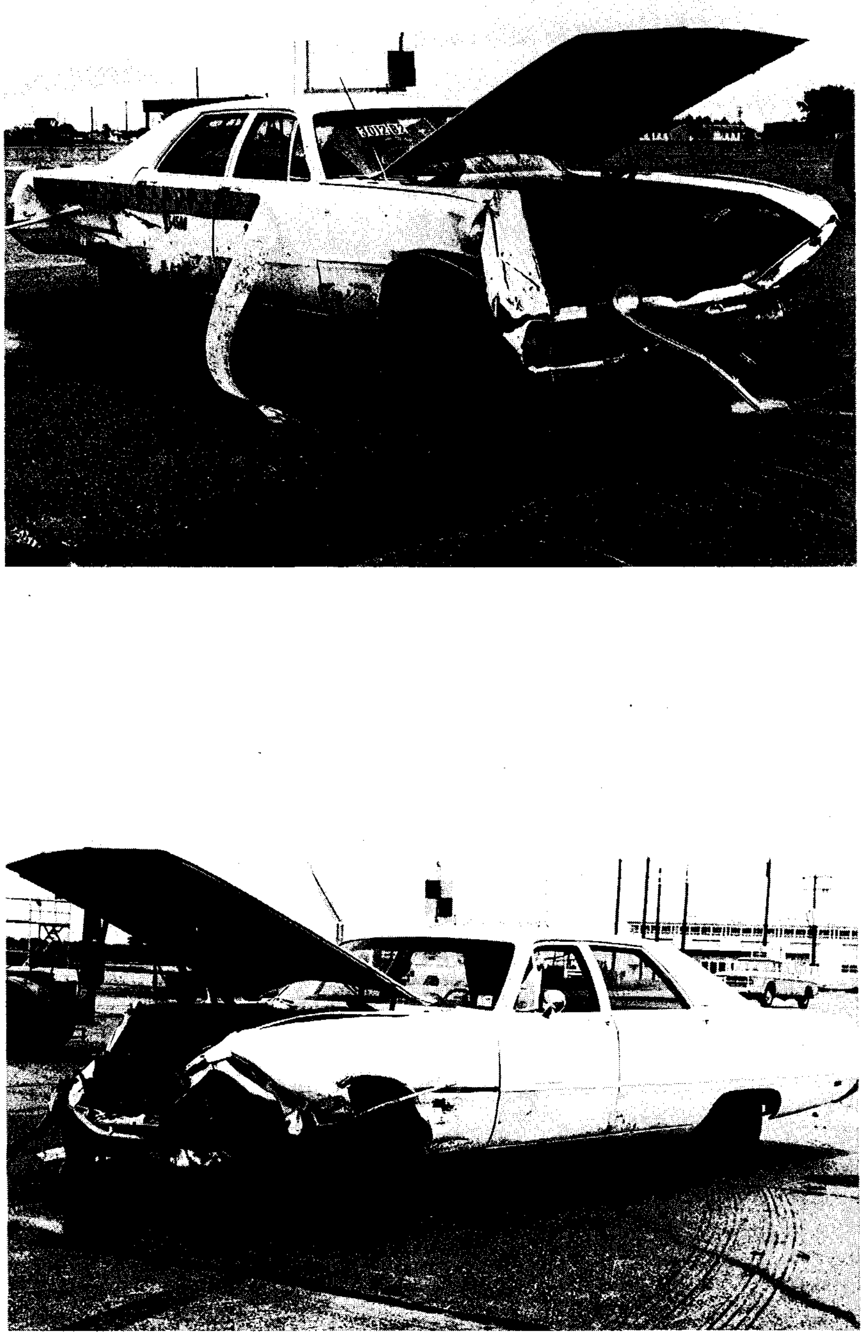


Figure 13. The Chrysler after Test B2.

CONCLUSIONS

The Minnesota five-foot radius plate beam guardrail performed satisfactorily under full-scale 60 mph, head-on impacts with 2250 lb and 4500 lb vehicles. Average deceleration over the stopping distance for the 2250 lb vehicle was 5.3 g's and for the 4500 lb vehicle was 3.8 g's. These values are well below the FHWA (4) design criteria of 12 g's for vehicles weighing from 2000 to 4500 lbs. Accelerometer data for Test B1 indicates that vehicle occupants may have received some minor injuries, but accelerometer data from Test B2 places the occupants in the "zone of safety" (5).

The passenger compartments of the test vehicles remained intact and were not penetrated by any foreign objects.

Significant but acceptable transverse accelerations were imposed on the test vehicle as a result of the yaw displacement during impact.

The 3 g's deceleration experienced by the dummy ($\frac{510 \text{ lb force}}{170 \text{ lb dummy}}$ = 3 g's) in Test B2 is well below the generally accepted level of 12 g's for a lap-belted occupant in a head-on collision and indicates a low probability of injury due to deceleration.

The system, as constructed and tested, performs very satisfactorily when struck by a small automobile. The behavior of the system is adequate when struck by a heavier automobile. It should be noted that in each case the W-section was severely damaged locally (see Figures 4 and 10). Although tensile load in this element was not measured, its condition after impact indicated that it was loaded near ultimate capacity and not much reserve strength existed, especially in Test B2.

Failure (complete rupture) of the W-section could cause a severe impact with the fixed obstacles that the rail encloses.

Observation: Examination of elements of the structural system following each collision revealed the timber posts were broken near the concrete foundations.

Commentary: Previous experience leads one to anticipate that the timber posts would rotate about the ground line were the concrete foundations eliminated. Some posts would probably be fractured at the ground line, but the post behavior would depend upon plastic index of the soil, presence of ground water and other conditions such as climate, surface drainage, etc. Such uncertainties indicate that the concrete foundations are required to produce the behavior observed in the two tests reported herein. Testing of installations founded in soil might produce results which are satisfactory.

Observation: Head-on impacts with the vehicle displaced laterally from the centerline of the structure and/or with the vehicle approaching from various directions are probable.

Commentary: In the tests conducted, the vehicle was pocketed and decelerated with yaw displacement during deceleration. Under other impact conditions on the end of the structure, it is anticipated that pocketing and deceleration will occur but yaw displacements would be expected to be more violent. In most cases, performance would be expected to be acceptable.

Observation: Angle impacts along the side of this installation are possible, and performance under such impacts is uncertain.

Commentary: Behavior of the plate beam guardrail when struck from the side is conjectural. The strength of the W-sections on the side of the structure and ability to smoothly redirect a vehicle depend upon the anchorage and the shape of the total structure. It is anticipated that a side impact would produce results less satisfactory than those observed in Tests B1 and B2 because adequate anchorage upstream of this possible zone of impact does not appear to exist in the present system. However, acceptable performance might be achieved through pocketing and deceleration of the vehicle under these impact conditions. Additional testing would be necessary to answer this question with confidence.

Observation: The deceleration levels were well below acceptable values in both tests; however, the 4500 lb vehicle used all the available stopping distance.

Commentary: The low deceleration levels indicate that the strength of the installation (impact forces) might be increased. Higher deceleration levels, brought about by strengthening the guardrail installation, could be withstood even for the 2250 lb vehicle. Added strength would provide more reserve capacity for vehicles weighing 4500 lbs or more.

REFERENCES

1. Bronstad, M. E. and Michie, J. D., "Recommended Procedures for Vehicle Crash Testing of Highway Appurtenances", National Cooperative Highway Research Program Report 153, 1974.

2. "Vehicle Damage Scale for Traffic Accident Investigators", Traffic Accident Data Project, National Safety Council, 1968.

3. "Collision Deformation Classification - SAE J224a", Automotive Safety Committee, Society of Automotive Engineers, 1972.

4. FHWA Instructional Memorandum 40-5-72, HNG-32, Subject: Use of Crash Cushions on Federal-Aid Highways, November 8, 1972.

5. Hyde, A. S., "Biodynamics and the Crashworthiness of Vehicle Structures", Wyle Laboratories, Research Staff, Huntsville Facility, Report WR 68-3, Vol. III of V, March 1968.

APPENDIX A

DESIGN DRAWINGS

MHD Standard Plate No. 8307K

and

MHD Standard Plan Sheet No. 5-297.603

APPROVED April 10, 1973

ASST. COMMISSIONER
RESEARCH AND STANDARDS

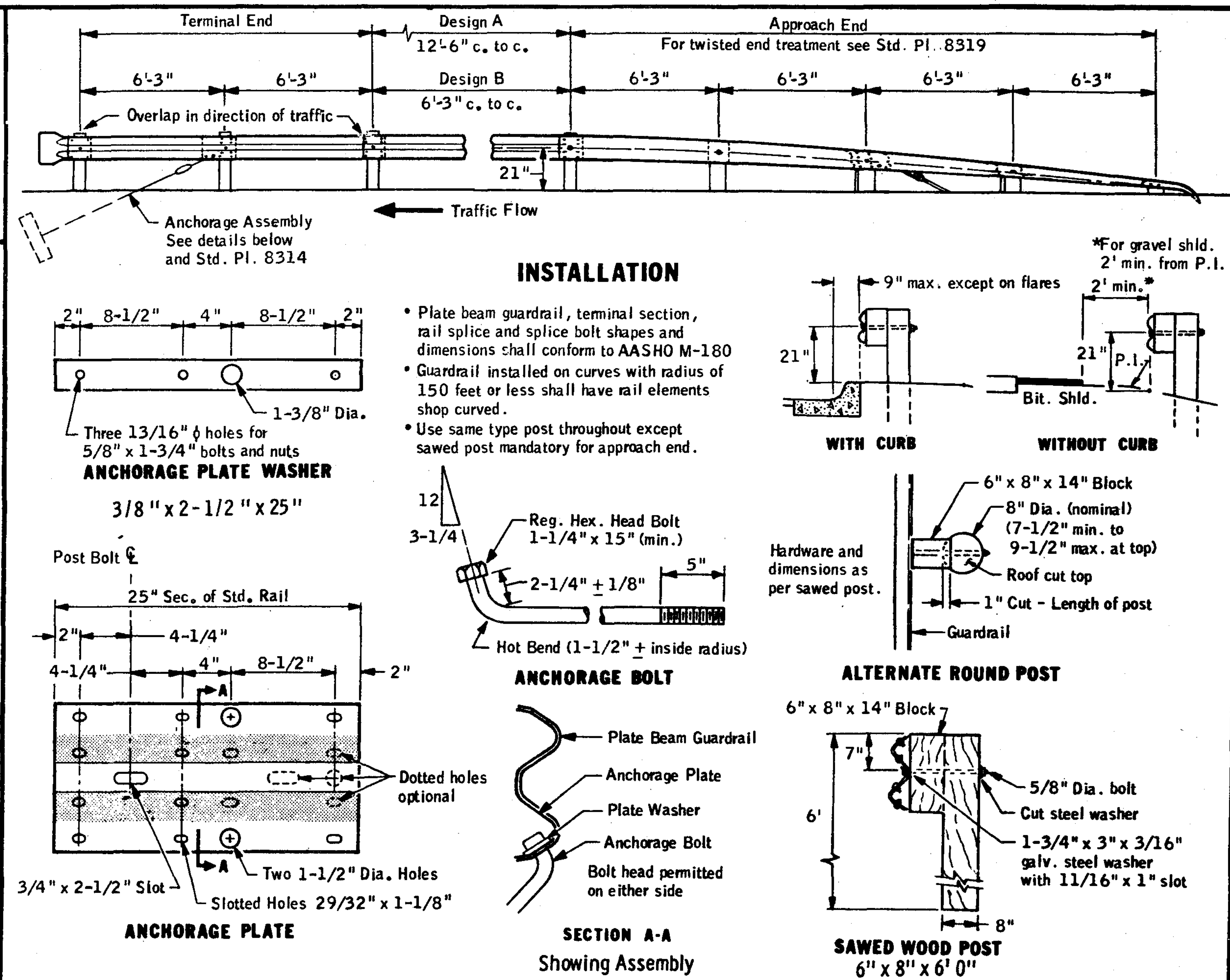
STATE OF MINNESOTA
DEPARTMENT OF HIGHWAYS

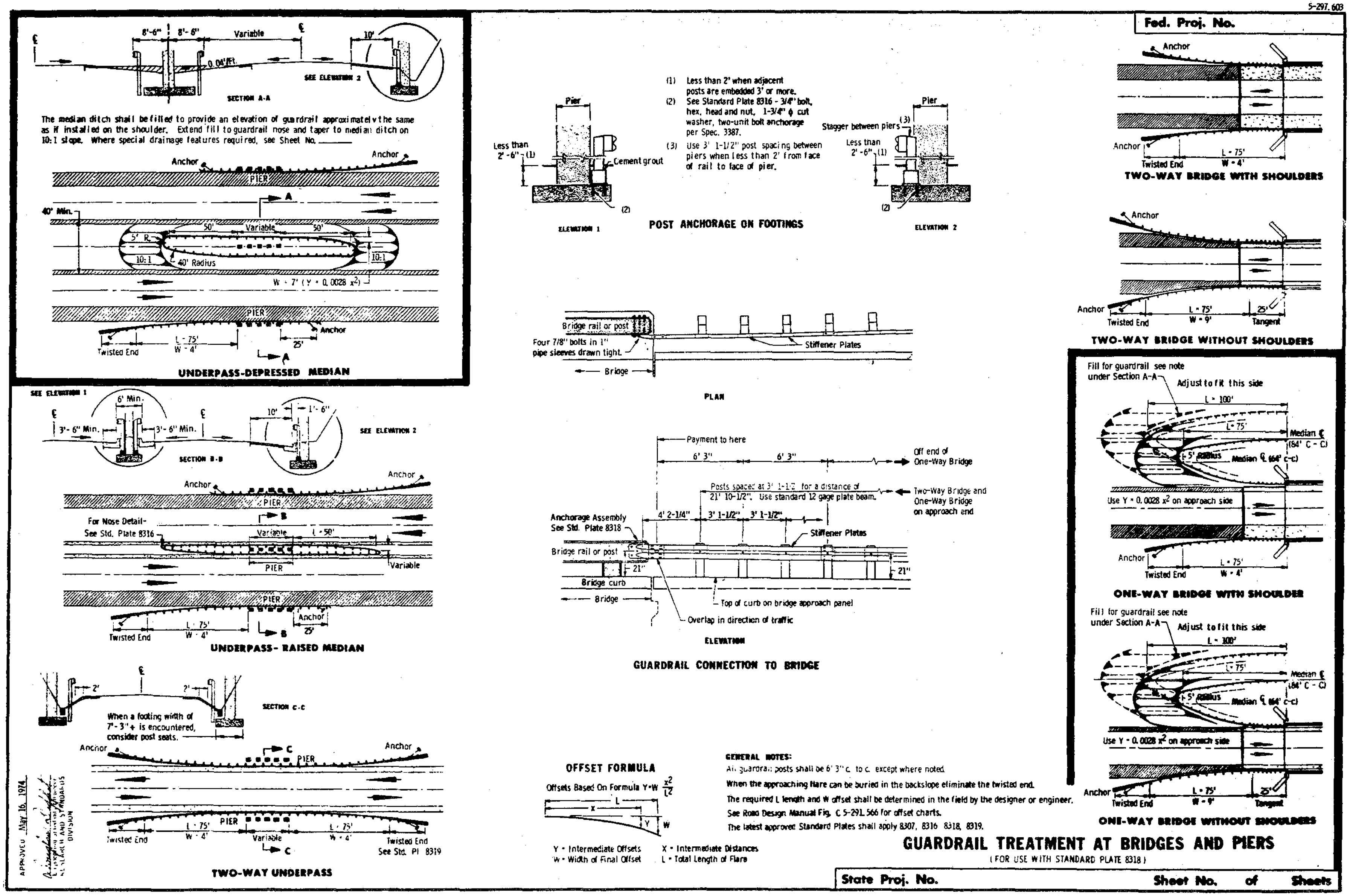
STRUCTURAL PLATE BEAM GUARDRAIL

DESIGN A (12' 6" spacing), DESIGN B (6' 3" spacing)

Spec. Ref.
2554
3306
ASTM A123

STANDARD PLATE NO. **8307K**




5-297.603
Fed. Proj. No.
SECTION A-A
SEE ELEVATION 2
The median ditch shall be filled to provide an elevation of guardrail approximately the same as if installed on the shoulder. Extend fill to guardrail nose and taper to median ditch on 10:1 slope. Where special drainage features required, see Sheet No. ______
UNDERPASS-DEPRESSED MEDIAN
SEE ELEVATION 1
SECTION B-B
For Nose Detail- See Std. Plate 8316
UNDERPASS- RAISED MEDIAN
SECTION C-C
When a footing width of 7'-3"+ is encountered, consider post seats.
TWO-WAY UNDERPASS
(1) Less than 2' when adjacent posts are embedded 3' or more.
(2) See Standard Plate 8316 - 3/4" bolt, hex. head and nut, 1-3/4" ϕ cut washer, two-unit bolt anchorage per Spec. 3387.
(3) Use 3' 1-1/2" post spacing between piers when less than 2' from face of rail to face of pier.
ELEVATION 1
POST ANCHORAGE ON FOOTINGS
ELEVATION 2
Four 7/8" bolts in 1" pipe sleeves drawn tight.
Stiffener Plates
PLAN
Payment to here
Off end of One-Way Bridge
Posts spaced at 3' 1-1/2" for a distance of 21' 10-1/2". Use standard 12 gage plate beam.
Two-Way Bridge and One-Way Bridge on approach end
Anchorage Assembly See Std. Plate 8318
Top of curb on bridge approach panel
Overlap in direction of traffic
ELEVATION
GUARDRAIL CONNECTION TO BRIDGE
TWO-WAY BRIDGE WITH SHOULDERS
TWO-WAY BRIDGE WITHOUT SHOULDERS
Fill for guardrail see note under Section A-A
Adjust to fit this side
Use Y = 0.0028 x² on approach side
ONE-WAY BRIDGE WITH SHOULDER
ONE-WAY BRIDGE WITHOUT SHOULDERS
OFFSET FORMULA
Offsets Based On Formula Y=W x²/L²
Y = Intermediate Offsets
W = Width of Final Offset
X = Intermediate Distances
L = Total Length of Flare
GENERAL NOTES:
All guardrail posts shall be 6' 3" c. to c. except where noted.
When the approaching flare can be buried in the backslope eliminate the twisted end.
The required L length and W offset shall be determined in the field by the designer or engineer.
See Road Design Manual Fig. C 5-291.566 for offset charts.
The latest approved Standard Plates shall apply 8307, 8316, 8318, 8319.
GUARDRAIL TREATMENT AT BRIDGES AND PIERS
(FOR USE WITH STANDARD PLATE 8318)
State Proj. No.
Sheet No. of Sheets
APPROVED May 16, 1974

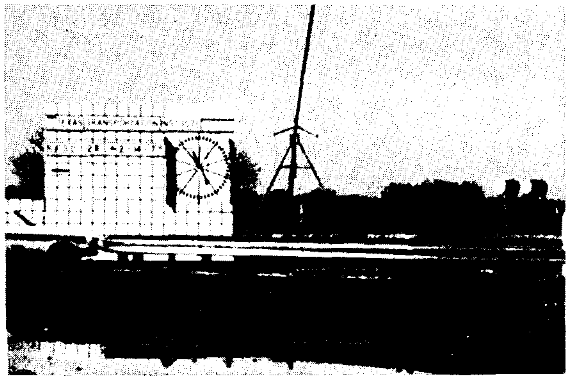
APPENDIX B

Test B1 Data: Sequential Photographs

Data for Impacting Vehicle

Time-Displacement Data

Accelerometer Traces



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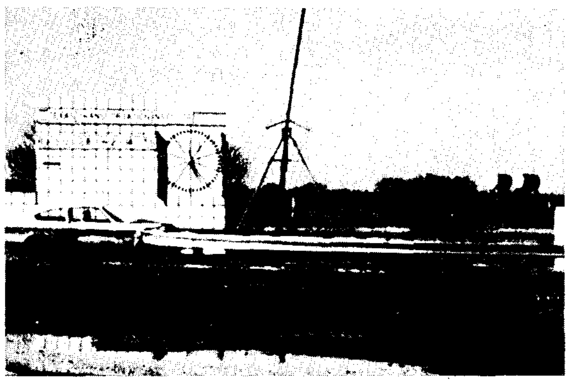

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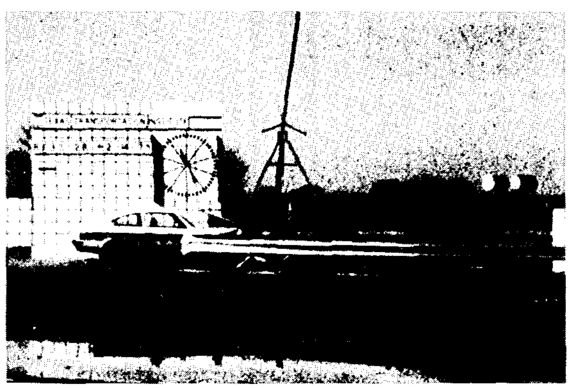

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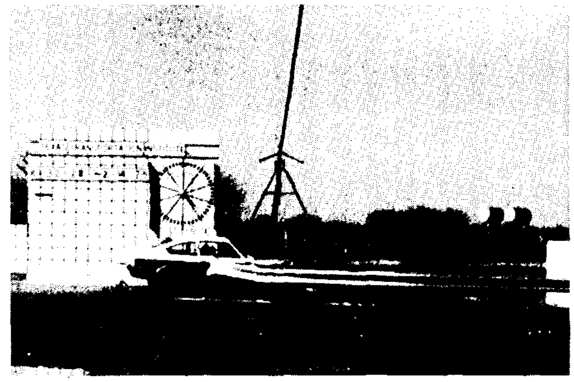

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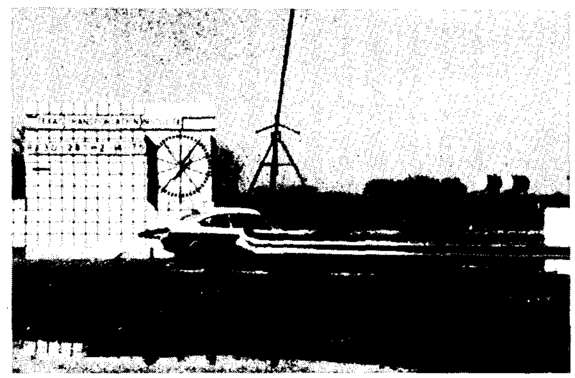

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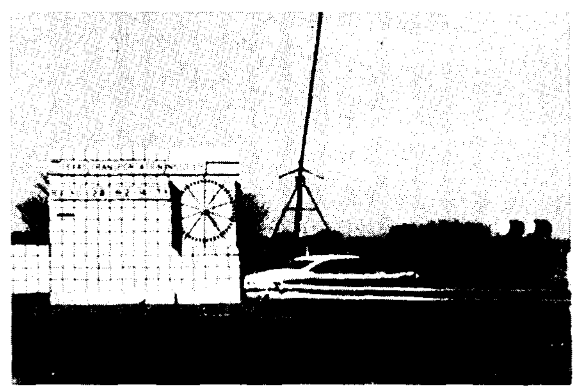
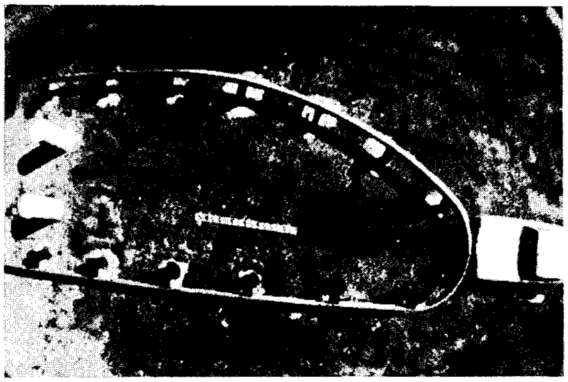


t = 1044 msec

Figure B-1. Sequential Photographs of Test B1.



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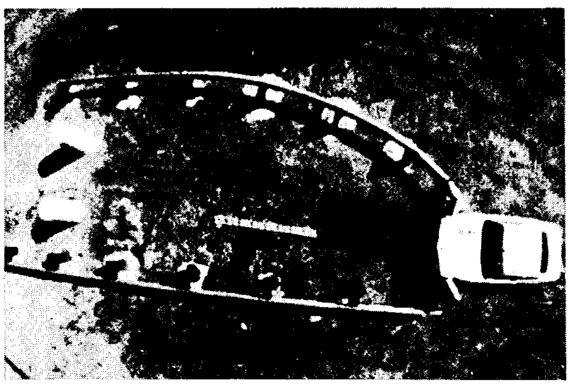

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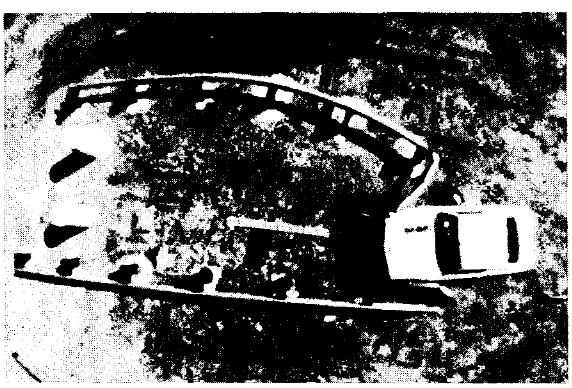

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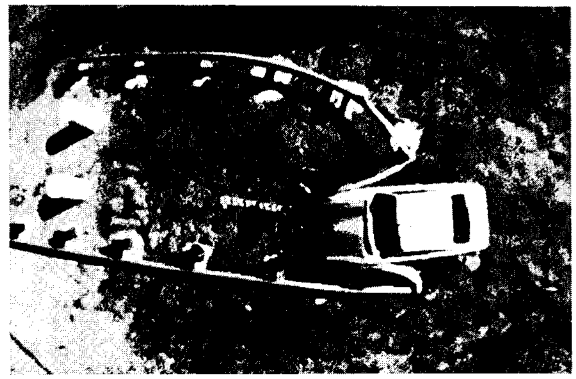

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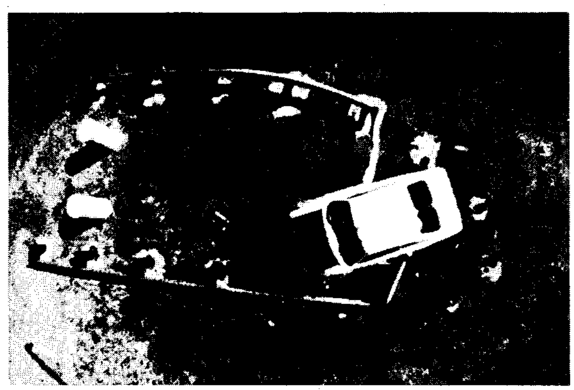

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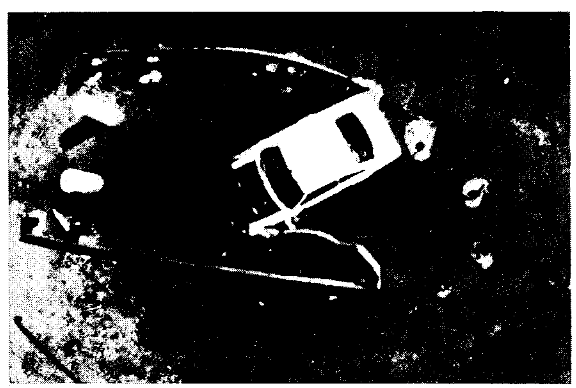


t = 959 msec

Figure B-2. Overhead Sequential Photographs of Test B1.

TABLE B-1. TIME-DISPLACEMENT-EVENT FOR VEHICLE

Time (sec)	Displacement (feet)	Comments
0.000	0.0	Impact - speed is average over 10 ft prior to impact.
0.014	1.3	Post No. 1 failed.
0.020	1.8	Hood began to open.
0.050	4.0	Restrained by Post Nos. 2 and 3.
0.089	6.7	Post No. 2 failed.
0.128	9.2	Hood opened about 15 degrees; yaw was -6 degrees.
0.182	12.3	Post No. 3 failed.
0.236	14.9	Post No. 4 failed; hood opened 30 degrees.
0.342	18.4	Left front impacted post No. 7.
0.374	19.4	Hood opened about 80 degrees; yaw was -25 degrees.
0.562	22.7	Maximum yaw, 47 degrees.
0.687	23.1	Maximum penetration.
1.044	22.8	All motion ceased.

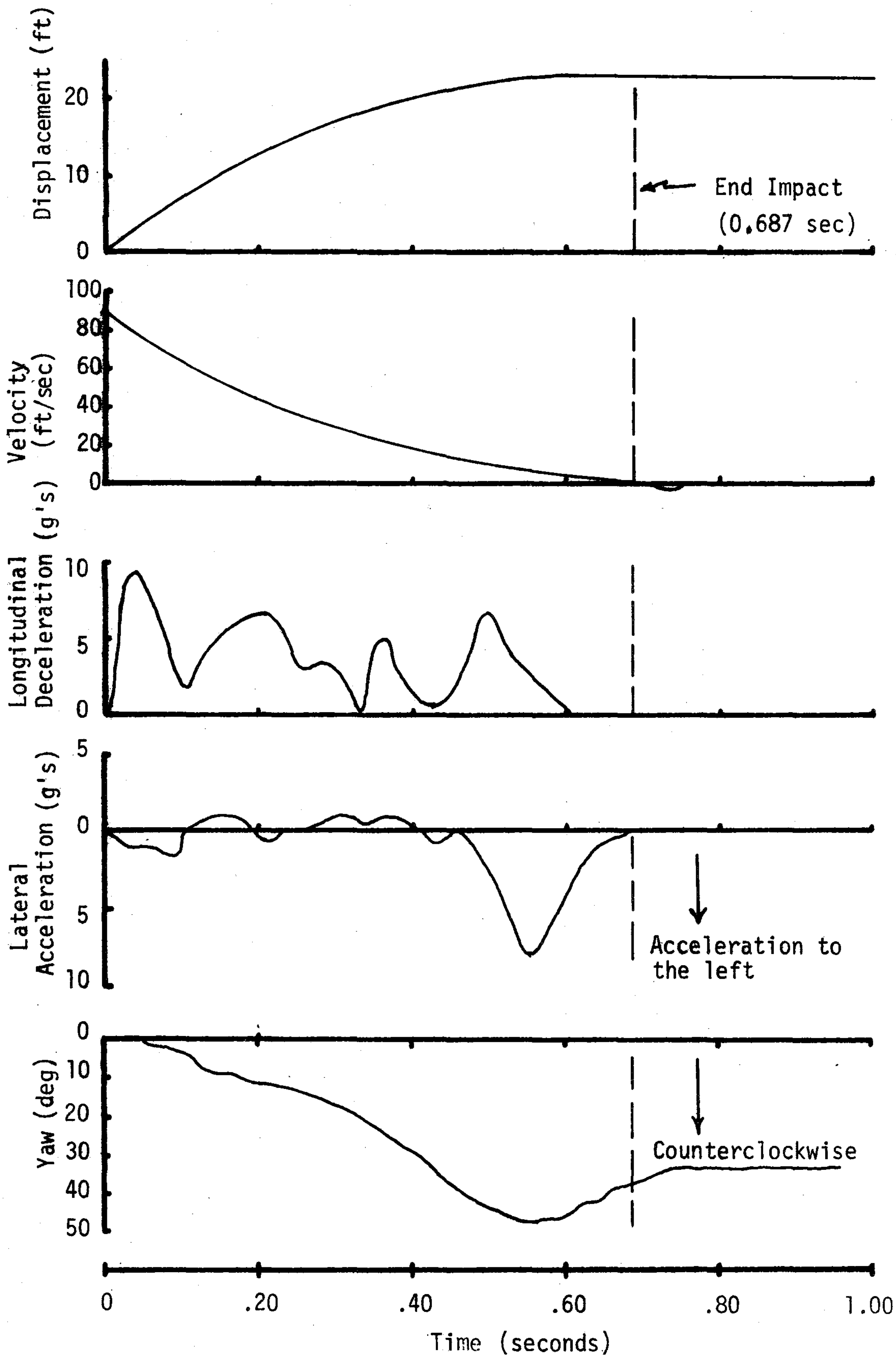
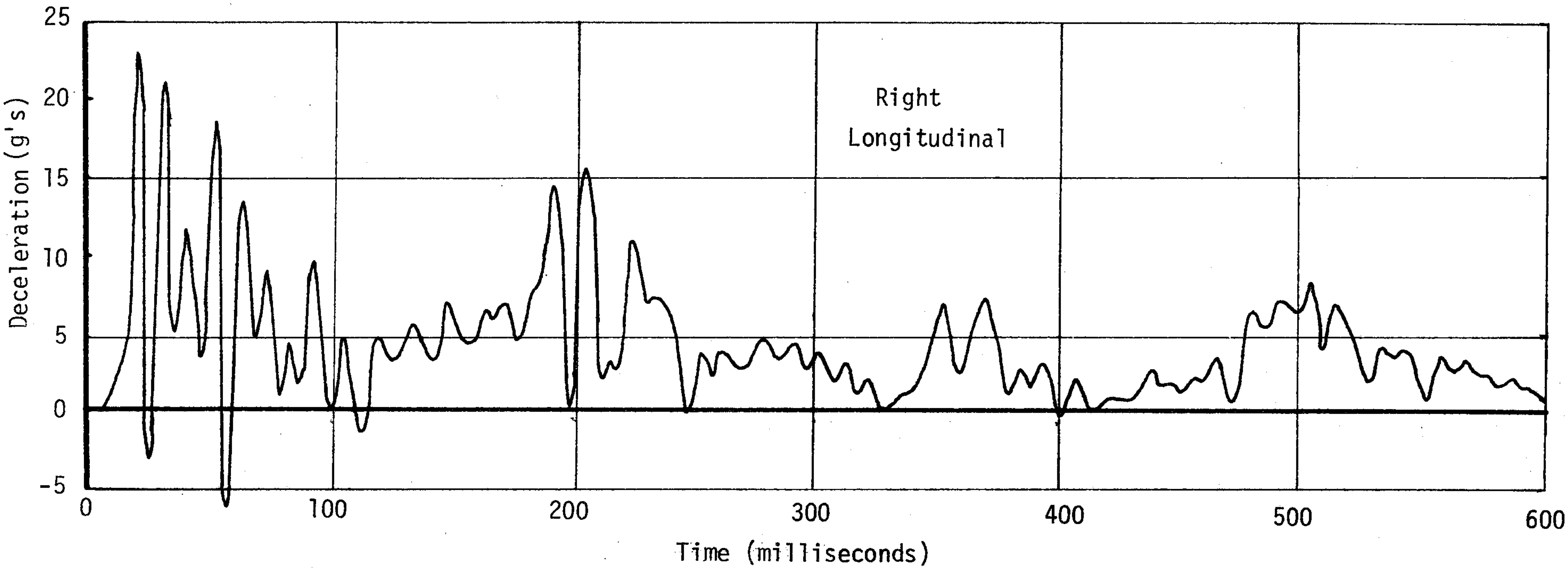


Figure B-3. Data for Impacting Vehicle for Test B1.



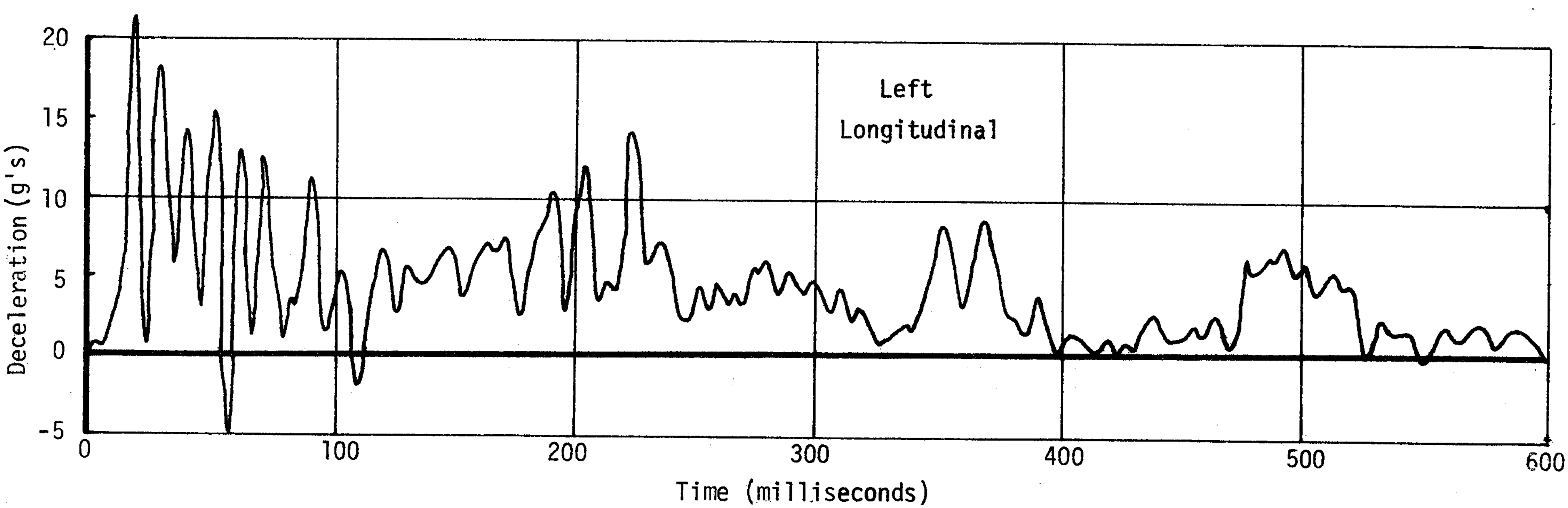


Figure B-4. Longitudinal Accelerometer Data for Test B1.
(100 Hz Max Flat Filter)

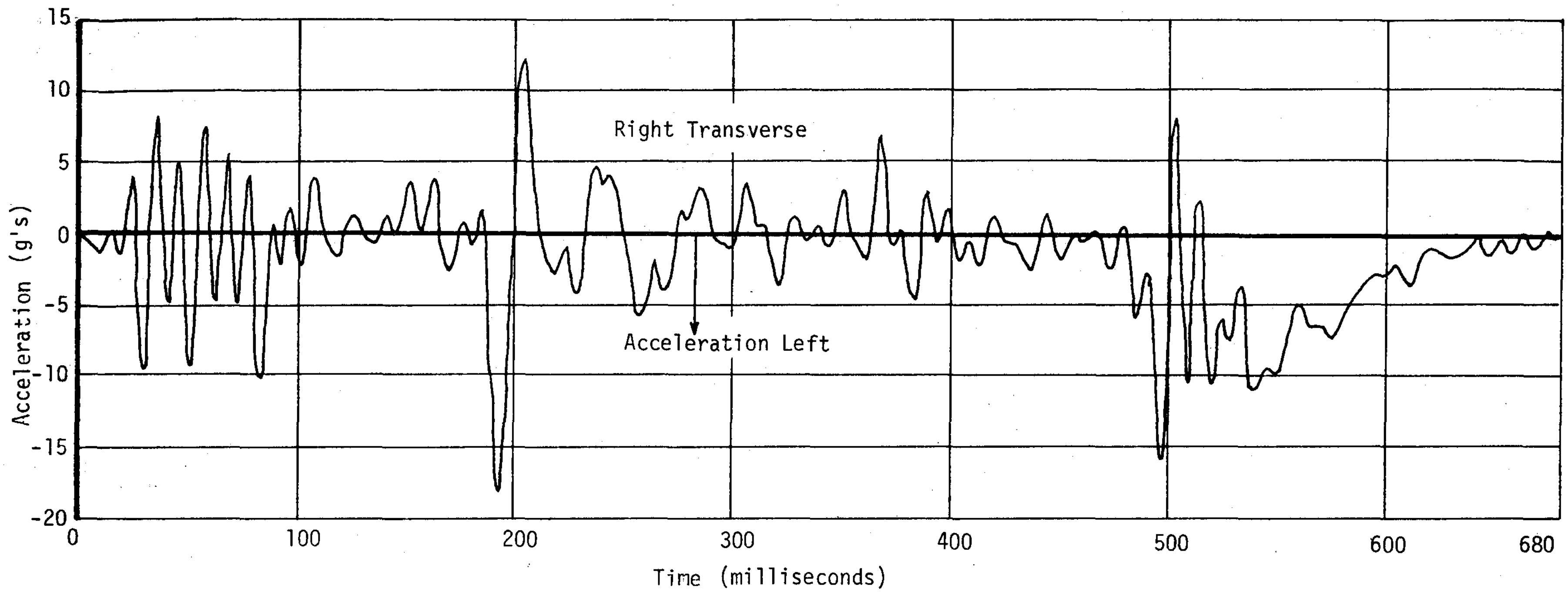


Figure B-5. Transverse Accelerometer Data for Test B1.

(100 Hz Max Flat Filter)

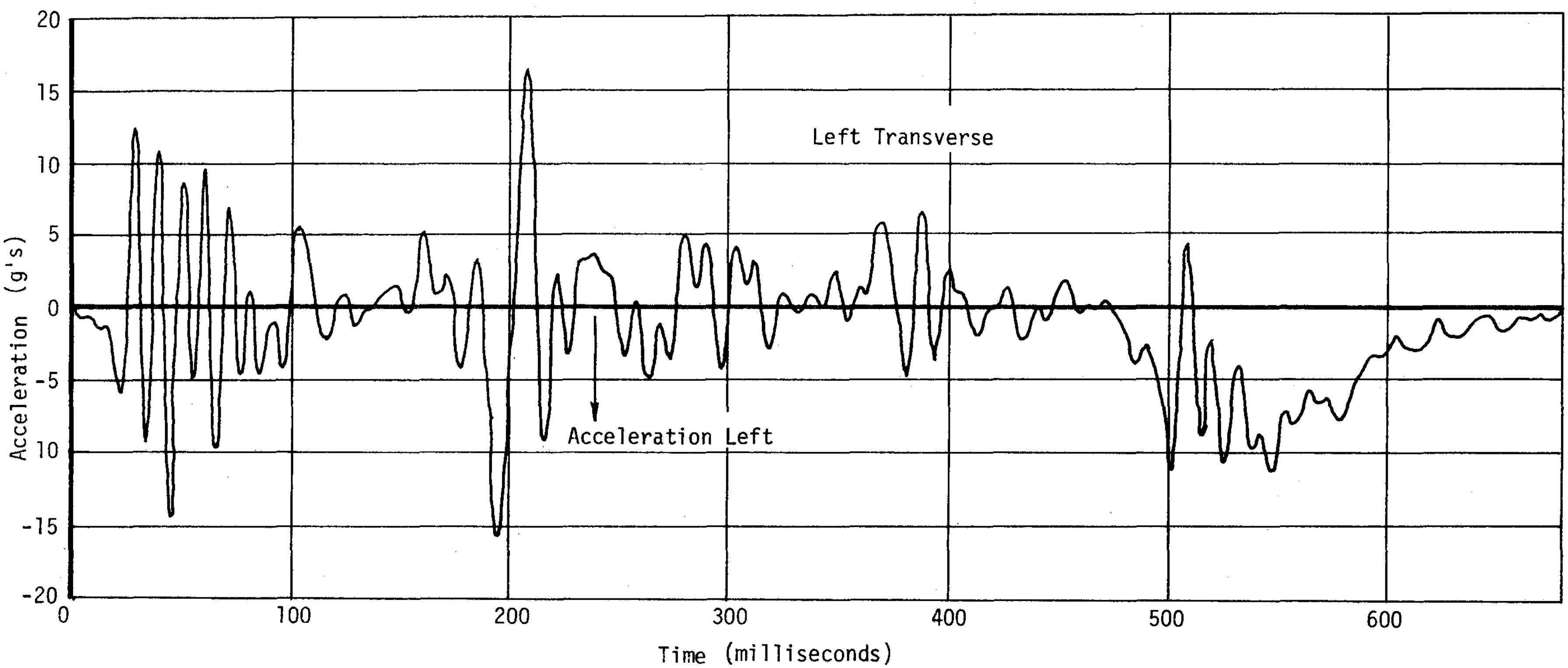


Figure B-6. Transverse Accelerometer Data for Test B1.
(100 Hz Max Flat Filter)

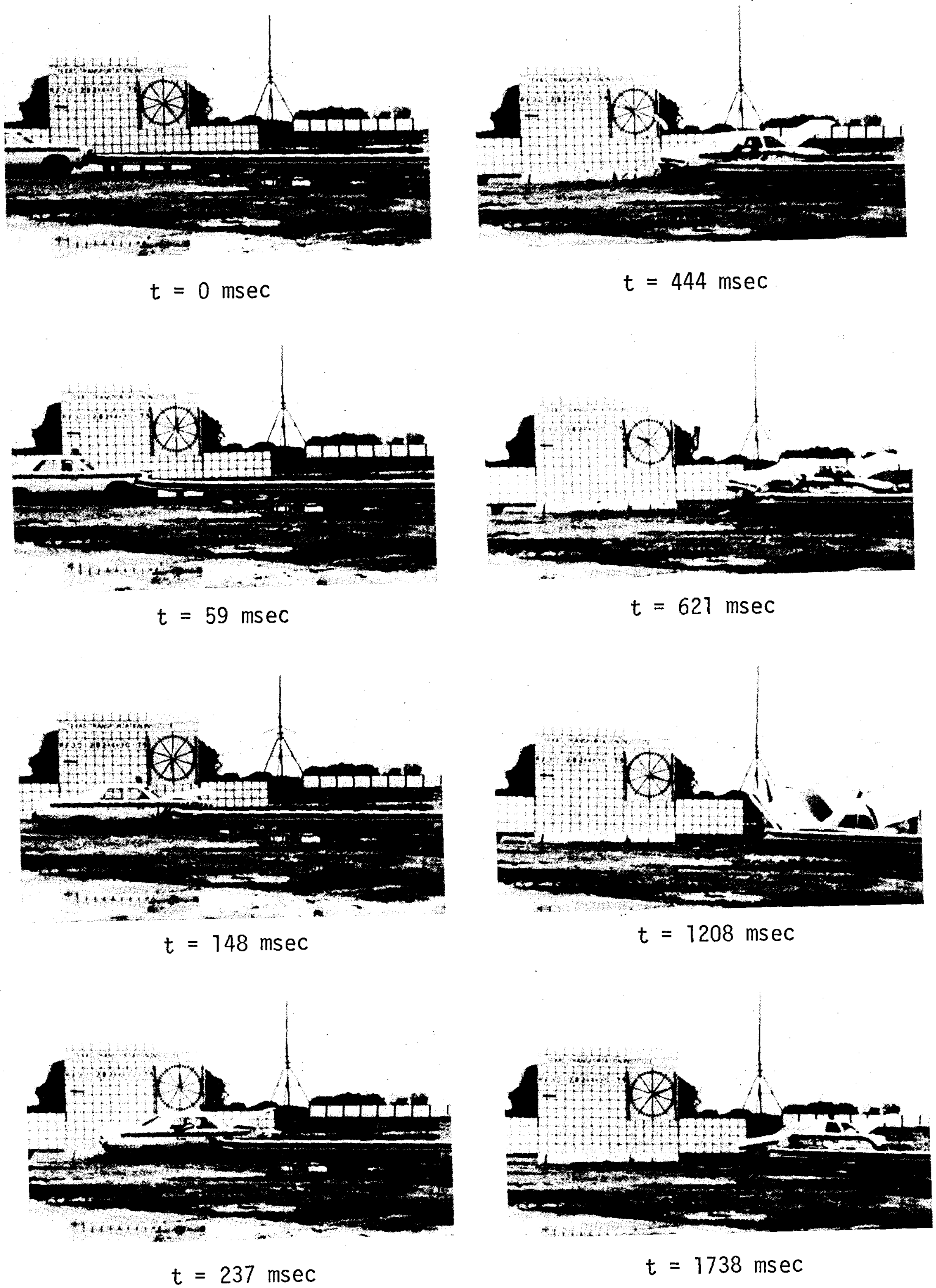
APPENDIX C

Test B2 Data: Sequential Photographs

Accelerometer Traces

Time-Displacement Data

Data for Impacting Vehicle



t = 0 msec

t = 444 msec

t = 59 msec

t = 621 msec

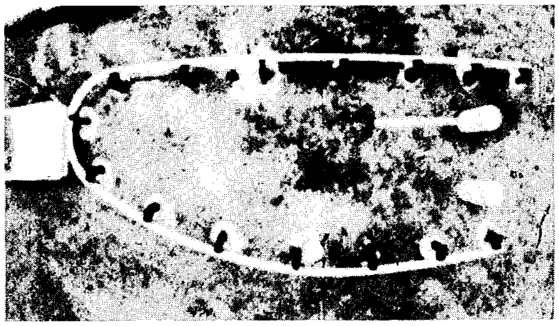
t = 148 msec

t = 1208 msec

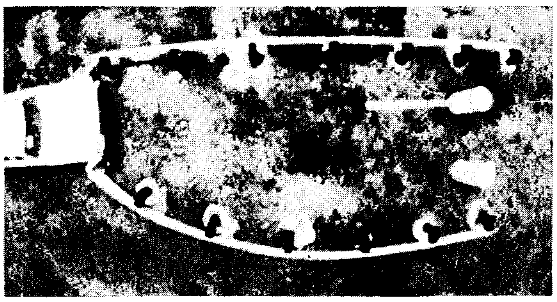
t = 237 msec

t = 1738 msec

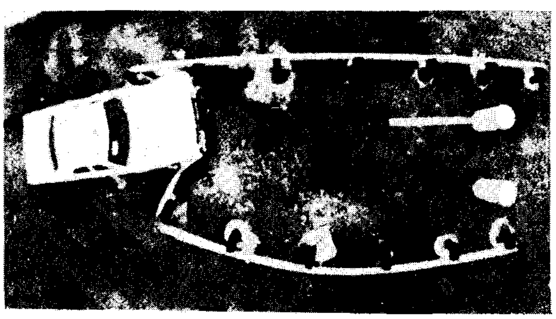
Figure C-1. Sequential Photographs of Test B2.



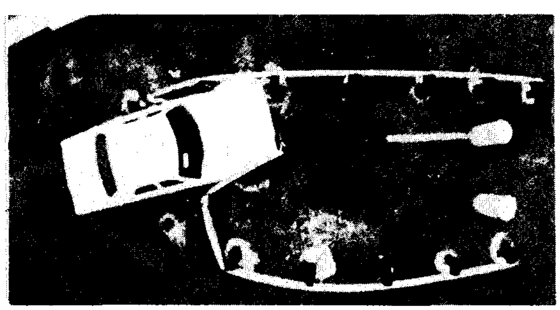
t = 0 msec



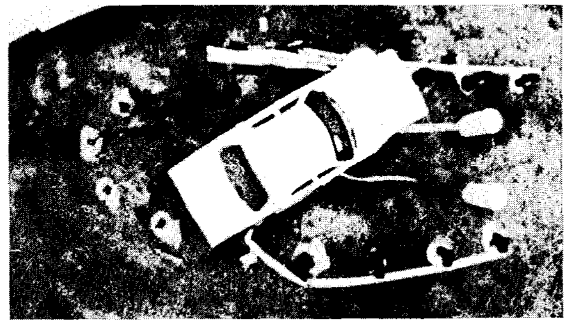
t = 59 msec



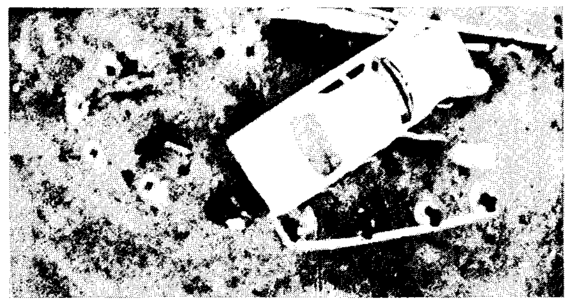
t = 147 msec



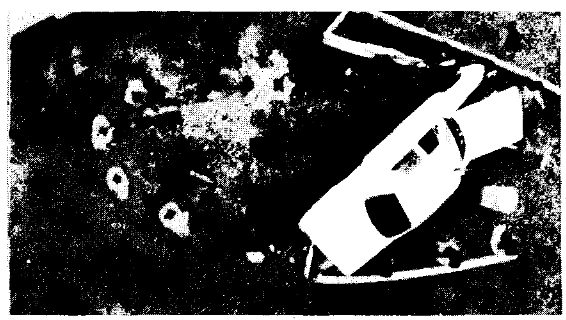
t = 235 msec



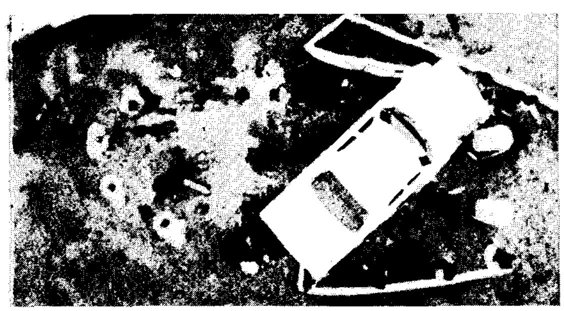
t = 441 msec



t = 618 msec



t = 1029 msec



t = 1735 msec

Figure C-2. Sequential Photographs of Test B2.

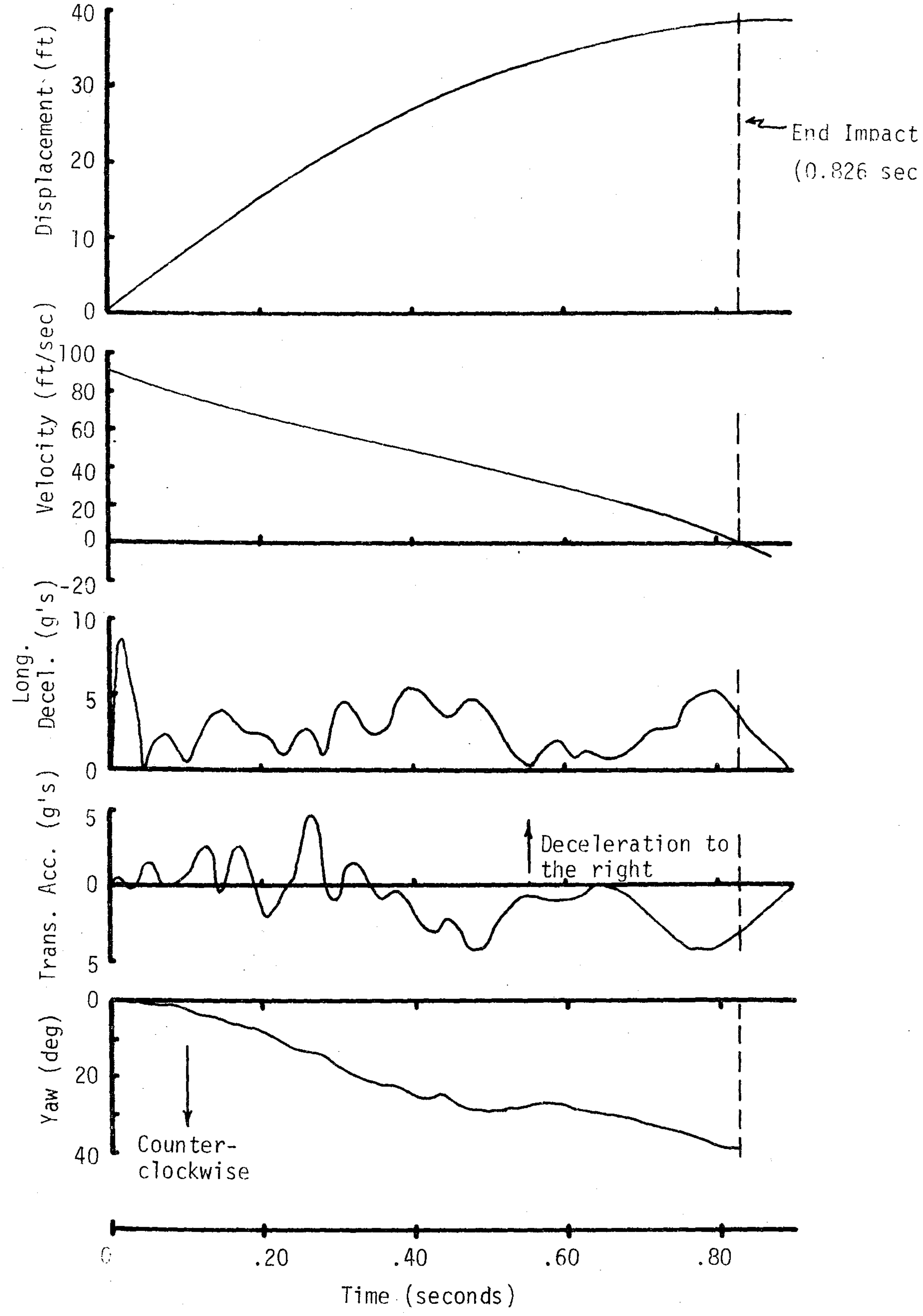


Figure C-3. Data for Impacting Vehicle for Test B2.

TABLE C-1. TIME-DISPLACEMENT-EVENT FOR VEHICLE

Time (sec)	Displacement (feet)	
0.000	0.0	Impact - speed is average over 10 ft prior to impact.
0.010	0.8	Post No. 1 failed.
0.029	2.5	Post No. 2 failed; yaw was -1 degrees.
0.098	8.0	Hood began to open.
0.127	10.3	Post No. 3 failed.
0.137	11.0	Post No. 4 failed.
0.167	13.2	Post No. 5 failed; yaw was -6 degrees.
0.275	20.3	Post No. 7 failed.
0.284	20.9	Post No. 6 failed; yaw was -16 degrees.
0.382	26.3	Post No. 9 failed; post Nos. 11, 13, 15 split.
0.637	35.2	Significant right roll begins.
0.647	35.5	Vehicle struck concrete pillar; yaw was 30 degrees.
0.826	38.7	Forward motion ceased; yaw was 40 degrees.
1.118	38.2	Vehicle reached max. roll, 45 degrees.
1.713		Vehicle rolled back to level position.
2.500		All motion stopped; yaw was 43 degrees.

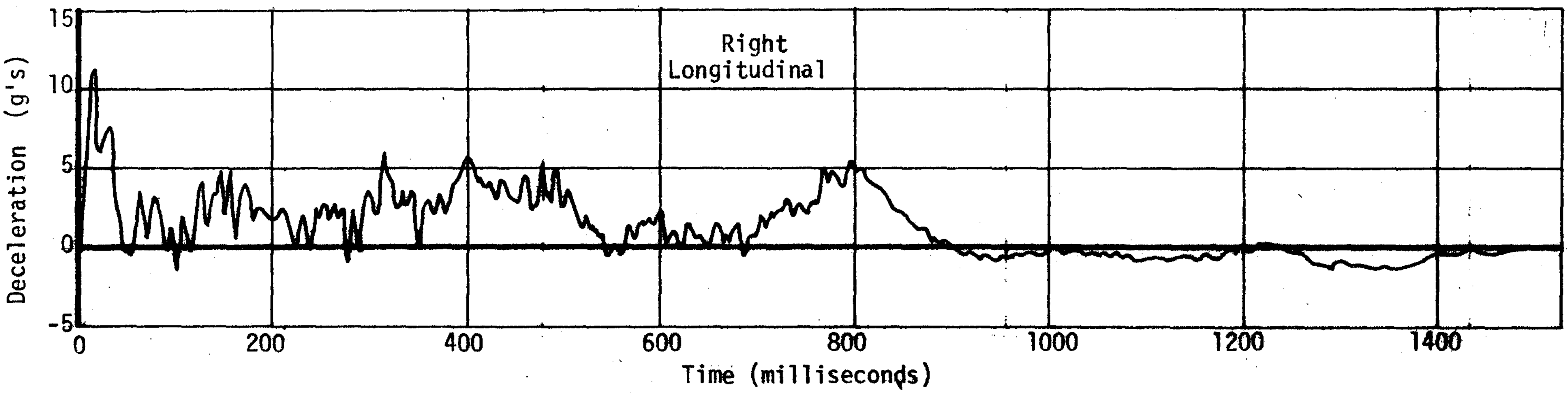


Figure C-4. Longitudinal Accelerometer Data for Test B2.

(100 Hz Max Flat Filter)

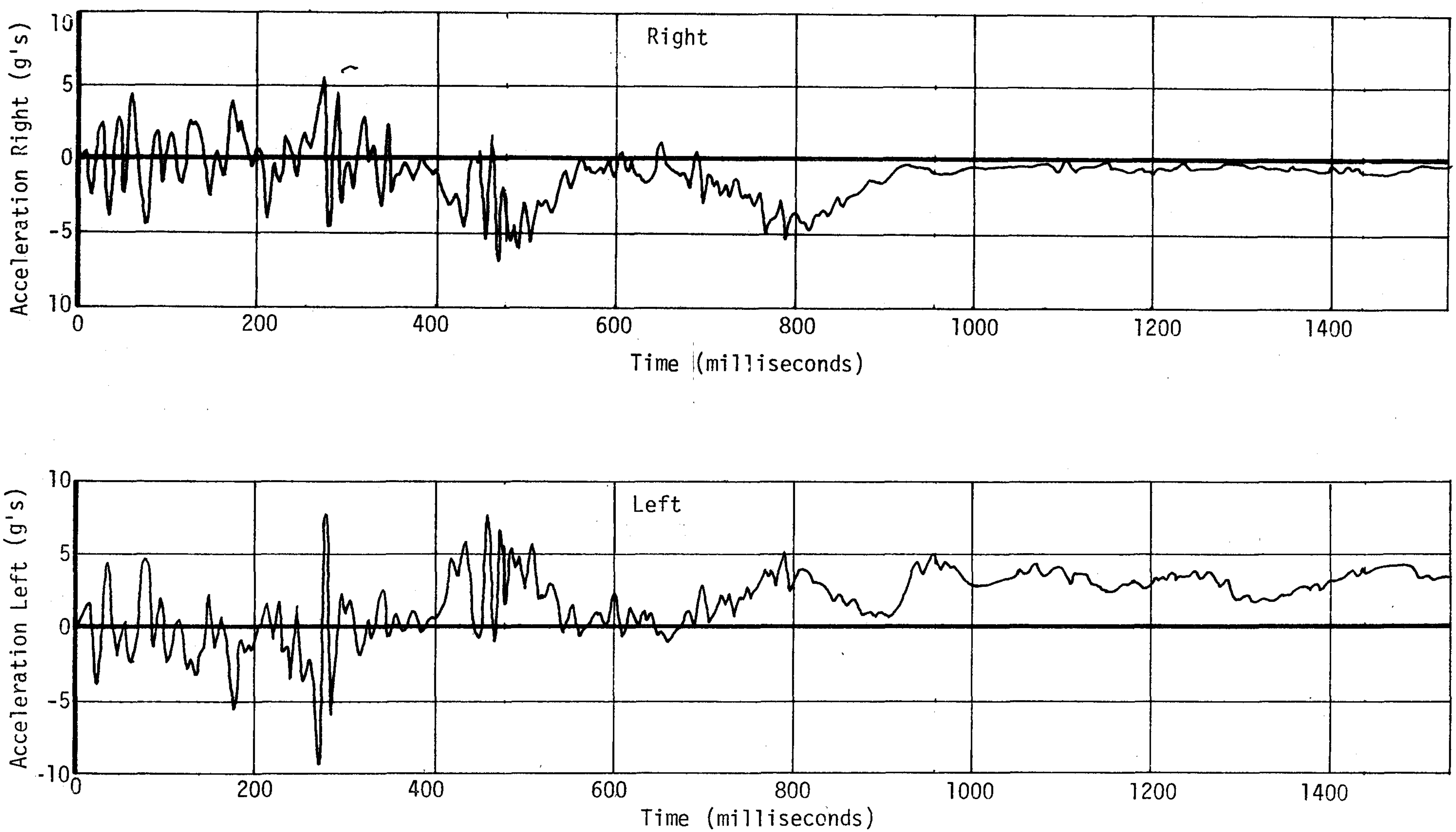


Figure C-5. Transverse Accelerometer Data for Test B2.

(100 Hz Max Flat Filter)

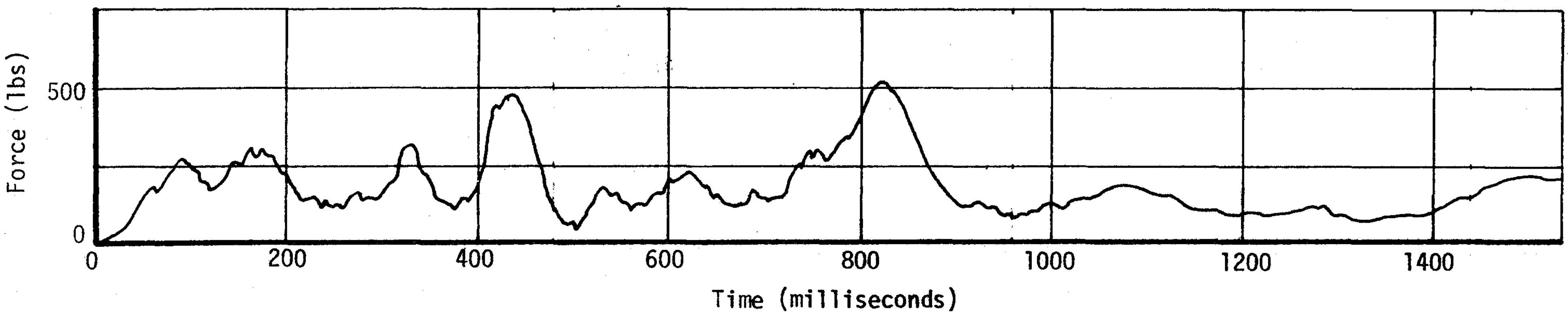


Figure C-6. Seat Belt Data for Test B2.