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EVALUATION OF GUARDRAIL BREAKAWAY CABLE TERMINALS

May 1982

Final Report

Prepared for

U.S. Department of Transportation
Federal Highway Administration

Offices of Research & Development
Structures and Applied Mechanics Division
Washington, D.C. 20590

FOREWORD

This report presents a summary and evaluation of the performance of current guardrail and median barrier (BCT) designs. Due to early results, the project was redirected to develop a retrofit solution for the predominant wood end post BCT design. Full-scale crash tests were used principally for the evaluations although laboratory tests, bogie tests, and a simplified dynamic algorithm were used in the retrofit development effort.

This report is being distributed by memorandum to individual researchers concerned with highway safety and those involved in assessing guardrail terminal performance.

A limited number of additional copies of this report is available from the Protective Systems Group, Structures and Applied Mechanics Division, FHWA, HRS-12, Washington, D.C. 20590.

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

NOTICE

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16. Abstract

Currently recommended guardrail and median barrier breakaway cable terminals (BCT) were to be evaluated for performance with 1800-lb (800-kg) class minicars. Early findings indicated unsatisfactory performance of the guardrail BCT for end-on impacts at 60 mph (97 km/h). The study was redirected to develop and evaluate a retrofit design for achieving satisfactory performance with the minicar.

Subsequent to the baseline crash tests, a series of analytical studies, laboratory tests, bogie tests, and full-scale crash tests were conducted to upgrade the recommended BCT. Findings include a satisfactory end-on test, but subsequent strength test produced a vehicle penetration. Thus, a recommended upgrade design is given except that further strengthening of the beam is necessary for angular impacts downstream of the end.

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I. INTRODUCTION

A. Background

As part of a comprehensive National Cooperative Highway Research Program (NCHRP) research project conducted at Southwest Research Institute (SwRI) in the late 60's, guardrail and median barrier terminals were evaluated by full-scale crash tests.(1) Findings from this project indicated that rollover was likely to occur with full-size sedans impacting terminals with turned-down ends constructed according to NCHRP Report 54.(2) In a subsequent NCHRP project at SwRI, three crash tests using full-size sedans were conducted on a device referred to as the breakaway cable terminal (BCT).(3) Evaluation included an end-on impact for a flared and straight guardrail BCT, and a redirection test featuring an impact near the end anchorage locations.

It was concluded in the original work that the flared terminal was superior.

Since the initial research reported in NCHRP Report 129,(3) a series of NCHRP Research Results Digests (RRD) have been published. Some of the RRD's were based on further research and development work and others were issued based on new findings or limited investigations. Chronologically, the RRD's on BCT's are summarized.

- RRD 43(4) (October 1972) - This digest reported findings from an NCHRP R&D project at SwRI and included modified drawings showing an additional concrete footing at end post 2 and an increase in the footing size.

- RRD 53(5) (December 1973) - Drawings and test results were presented on both steel and wood median barrier BCT designs.

- RRD 84 (6) (March 1976) - This digest included some cost saving recommendations (e.g., removal of BCT nose diaphragms, new anchor plate design) and the inclusion of slip base steel end post designs for both guardrail and median barrier BCT based on an NCHRP R&D contract at SwRI.

  Based on California DOT work, the 8x8 wood end posts were replaced with 6x8-in. members.

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● RRD 102(7) (May 1978) - This digest was issued to address the following problem areas:

- Difficulty in removing the fractured wood post from the concrete footing
- Excessive cost of some BCT components
- Unreasonable cost of concrete footings at rural locations
- Snagging of a subcompact vehicle underside by the steel post BCT design (slip base)
- Lack of requirements in several state standards that the terminal be flared as recommended.

Recommendations including some design modifications were made in this digest based on above considerations. By the time of this digest issue, it was estimated that over 30 states had adopted the guardrail BCT.

● RRD 124(8) (November 1980) - This digest again was concerned with concrete footing cost, post removal and the "flare". A limited laboratory investigation produced a steel foundation alternate to the concrete footings. This design also facilitates broken post removal. This digest re-emphasized the need for BCT "flaring" and mentioned problems observed from baseline BCT/mini-car tests conducted in this project.

Throughout the course of the past near-decade since BCT usage began, SwRI has received both fragmentary and formal reports on BCT performance as summarized in Table 1. By far the most predominant inquiry has regarded the removal of the broken post or the expense of the concrete footings. Some negative reports have come from accident experience. Based on our observation, the unsatisfactory accident experience has rarely involved a properly flared BCT. The user agencies have taken considerable license in some of the BCT details adopted, but the flare is the predominant problem. It is a legitimate concern as many limited right-of-way areas cannot readily accommodate a flare.

The flare on the guardrail BCT is considered essential with the current design in order to:

- buckle the beam for end-on impacts at an acceptable force level,
- permit the vehicle to "gate" behind the rail installation.

Unless the full 4-ft (1.2m) flare is used, the two above objectives are compromised.

Recognizing the trend toward smaller cars, the Federal Highway Administration (FHWA) has recently added the 1800-lb (800-kg) class mini-car to many of its research and development programs. Since the BCT had been essentially developed using full-size sedans, FHWA set up this project initially to evaluate the current versions of

1) wood end post guardrail BCT
2) steel slip base end post guardrail BCT
3) steel slip base end post median barrier BCT

It was estimated that over 100,000 guardrail BCT's and a much smaller number of median barrier BCT's were in-place at that time.

Based on unsatisfactory mini-car crash test results with both wood and steel end post BCT designs, and in recognition of the usage, the project emphasis was shifted to the more predominant wood end post design for possible retrofit upgrading. The mini-car testing of this project imposed severe requirements on the BCT that had previously been unaddressed. High-speed off-center impacts not only caused high accelerations on the vehicle, but induced severe yawing. The severe yawing exposed the more vulnerable side structure of the car to the rail end and in all cases rollover and/or spearing occurred.

B. Objective

The objectives of this project were to evaluate the performance of current guardrail and median barrier BCT designs. Due to early results, the project was redirected to develop a retrofit solution for the predominant wood end post BCT design.

C. Scope

Full-size crash tests were used principally for the evaluations although laboratory tests, bogie tests, and a simplified dynamic algorithm were also used in the retrofit development effort.

II. BASELINE CRASH TESTS

Two guardrail BCT systems have been developed; the basic difference is the two end posts which are either wood or steel slip base designs. Usage of the wood post has been more widespread due to the lower cost.

A. Wood Post

The current wood post BCT(7,11) is described in Figures 1 and 2. Three crash tests were conducted on this design as summarized in Table 2.

B. Steel Post

The current steel post BCT(7,11) is described in Figures 3 and 4. One crash test was conducted on this design as summarized in Table 2.

C. Crash Test Results

The results of the crash tests are discussed briefly; complete details are contained in Appendix A. Crash test vehicles were Honda Civic sedans weighing approximately 1840 lb (835 kg) without dummies. All test vehicles contained a fully restrained driver and unrestrained front seat passenger dummy (Part 572, 50th percentile male).

WBCT-1. The objective of this test was to evaluate the wood post BCT for a 30-mph (48-kmph) end-on (0-deg) impact with the vehicle centerline 15 in. (0.4 m) to left of the end post centerline.

The vehicle fractured the first post and began to yaw about the vehicle vertical axis as shown in Figures 5 and 6. This yawing continued with nominal translation along the original travel direction until the vehicle came to rest with a heading angle approximately 90 deg from the original.

WBCT-2. The objective of this test was to evaluate the wood post BCT for a 60-mph (97-kmph), 0-degree, 15-in. (0.4-m) offset impact with the minicompact vehicle.

The vehicle impacted the end and immediately began yawing at a rapid rate as shown in Figures 7 and 8. As the vehicle rear end was nearing contact with the remaining upright portion of the railing, the vehicle front pitched downward and the upright railing element contacted the right rear wheel. The force applied to the rear wheel induced a rolling motion to the car that caused the vehicle to roll on its side before sliding to rest.

WBCT-3. The objective of this test was to evaluate the wood post BCT for a 60-mph (97-kmph), 15-degree angle impact with minicompact centerline in line with end post centerline.

As shown in Figures 9 and 10, the test vehicle behavior was similar to the previous test except that complete rollover of the vehicle occurred.

SBCT-1. The objective of this test was to evaluate the steel post BCT when impacted by a minicompact at 60 mph (97 kmph) with a 0-degree angle and a 15-in. (0.4-m) offset.

The test vehicle impacted the end as shown in Figures 11 and 12; a high yaw rate was induced and as the vehicle spun around, the beam end penetrated through the right front window of the test vehicle.

Summary. Results of all of the 60-mph (97-kmph) baseline crash tests were considered entirely unsatisfactory. For these test conditions, the current BCT design was clearly not compatible with the minicompact vehicle used in the tests.

III. GUARDRAIL BCT RETROFIT DEVELOPMENT

As a result of the unsatisfactory results of the baseline crash tests, the original test matrix was redirected. Redirection of the project focused on retrofitting current BCT designs to make them more compatible with the minicompact vehicle.

The retrofitting investigation included the development of a mathematical analog to permit parametric evaluations of the problem, analysis of the current BCT design(s), bogie tests, pendulum tests, and crash tests.

A. Math Analog

A simple algorithm was developed to examine the problem of end-on impacts such as experienced with the BCT. The two-dimensional program ENDON consists of a rigid vehicle structure which includes:

- yaw moment of inertia
- total weight
- front axle location
- rear axle location
- wheel track

The collision event is initially modeled as a concentrated point loading with a specified eccentricity. This concentrated impulsive force is assumed to act in the vehicle longitudinal direction. Development of the ENDON program is described in Appendix B.

Parametric studies were conducted using the ENDON program to provide insight into off center impacts using Honda Civic vehicle properties. Since the yaw moment of inertia for the Honda Civic was not available, this property was measured using a torsional pendulum; this value determined, I_z = 8000 in.-lb-sec^2. Based on the parametric evaluation, a formula was determined using curve fit techniques, that provides a relationship between impact velocity change (impulse), yaw rate, and eccentricity.

$$\Delta V = \frac{366\ (\psi/x)^{0.70}}{E^{1.20}} \qquad (1)$$

where

ΔV - velocity change, ft/sec
E - eccentricity of impact, in.
ψ/x - vehicle yaw rate, deg/ft

for

I_z = 8000 in.-lb-sec^2
μ = 1.0 (pavement/tire coefficient of friction)

In considering the desired behavior of the BCT, it was determined that a yaw rate of approximately 10 deg/12 ft would result in desirable redirection of the vehicle behind the guardrail as determined graphically in Figure 13. From Equation 1, the maximum velocity change (ΔV) can be solved using this yaw rate (ψ/x) and the 15-in. (0.4-m) eccentricity (E) as input. Thus, based on ENDON formulations, a velocity change (ΔV) due to end-on impact with a BCT of 8.5 mph (13.7 kmph) would result in desirable performance for the 15-in. (0.4-m) off-center impact.

B. Current BCT Analysis

The current BCT design was analyzed for easy ways to reduce the resistance of end-on impacts. Since the wood end post BCT has by far the greatest usage to date as compared to the steel slip base post, this design was selected for this analysis.

Elements of the BCT considered were the following:

End post(s)
Nose
Beam
Anchor cable

End Post. Based on pendulum tests conducted during BCT development, the force required to fracture the end post produces an impulse considerably below the 8.5 mph (13.7 kmph) threshold value determined from ENDON; therefore, the beam element was considered the chief contributor to the resistance. Accordingly, it was deemed desirable to explore ways of reducing the end-on resistance of the beam element.

Nose. The nose of the BCT is designed to spread the load over a large area of the car; unfortunately it is too high at the lower extremity to intercept lower cross members present on most minicompact cars for end-on impacts or the floor sill for side impacts. By intercepting the cross member or the sill, the possibilities of beam intrusion into the passenger compartment is diminished. Diaphragms used in early BCT designs were subsequently omitted due to cost-effectiveness analysis.

Beam. Based on previous discussion of the post, the beam element was examined for ways to reduce resistance. As shown in Figure 14, there were two apparent features of the beam detail that contribute to the end-on resistance problem. As shown in Figure 14(b), as the nose collapses, vehicle contact with the beam end occurs before contact with the breakaway post; thus, the anchor cable "reinforces" the beam against buckling until the post breaks away and releases the cable. Secondly, the beam is bolted to each post in the flared area; each post bolt provides a resistance to buckling.

Anchor Cable. The function of the anchor cable is to develop beam strength for oblique impacts downstream of the anchorage. Release of the anchor cable for end-on impacts is critical due to capacity of cable to reinforce beam against buckling prior to release from the breakaway end post.

C. Initial Retrofit Formulations

Based on the analysis of the current BCT design, an experiment was recommended for test using a bogie vehicle. The purpose of the experiment (BBCT-1) was to eliminate the end-post/anchor cable contribution to the end-on resistance. Accordingly, the first post was eliminated; the W-beam was shop-bent to conform to the parabolic curve without post attachment. The beam was attached to the steel line posts with No. 10 machine screws which offered only nominal resistance. Appendix A has complete details of this test (BBCT-1). Results of this test were favorable, and a second bogie test designed to evaluate a BCT installation with an added wood nose spacer and beam/post bolts removed at all posts in parabolic flare. Results of this test (BBCT-2) as described in Appendix A were again considered favorable.

D. Full-Scale Retrofit Tests

Subsequent to the initial bogie tests, seven full-scale tests were conducted to retrofit designs as summarized in Table 3. All but one of these tests (WBCT-10) were conducted with Honda Civics impacting end-on, 15 in. (0.4 m) off-center at 60 mph.

WBCT-4. The purpose of the test was to evaluate the installation that had performed favorably in bogie test BBCT-2. As shown in Figures 15 and 16, the test vehicle yawed and pitched violently before coming to rest. The difference in vehicle and bogie behavior was attributed to lack of similitude between bogie and vehicle properties (notably crush, suspension, and roll moment of inertia).

WBCT-5. The purpose of this test was to evaluate the performance of the wood post BCT which was further modified from that of WBCT-4 to reduce end-on impact resistance. The installation was modified by redesigning the wood nose spacer, and the use of three sawcuts in the W-beam rail to cause the forming of hinges in desired locations.

Although it was recognized that determination of the dynamic strength of the W-beam during end-on impacts was exceedingly complex, a simple Euler column analogy was assumed to examine methods of reducing the W-beam end-on resistance. As shown in Figure 17, different schemes for removing material from the basic W-beam cross section were investigated (i.e., no change in the basic cross section geometry was made). The saw cut geometry for WBCT-5 is described along with other schemes later in Figure 23.

As shown in Figure 18, the nose spacer was lengthened to further distribute the impact loading over a larger area of the vehicle, particularly to the vehicle lower cross member. An examination of some subcompact and minicompact vehicles as summarized in Table 4 revealed the presence of a lower cross member that could be effective in front load distribution if the nose was lowered.

As shown in Figures 19 and 20, the test results were not significantly improved over the previous test. Although the vehicle remained upright, there was considerable yaw and pitch instability noted.

WBCT-6. The purpose of this test was to evaluate a retrofit scheme with a different distribution of cut out hinges in the beam.

As shown in Figures 21 and 22, the vehicle impacted the end with resulting fracturing of end post and hinges formed as desired on the beam section. Yawing of the vehicle initiated by the initial impact continued until the second post fractured and the beam separated at the two hinge locations. Due to the pronounced yaw, the rear side of the vehicle rode over the next three steel posts causing a downward pitch of the vehicle front resulting in a 90 deg frontward roll ending in a 90 deg side roll as shown.

The velocity change for this test during the initial impulse was 44 ft/sec (13.4 m/sec) which is over three times the desired value from ENDON program.

WBCT-7. Based on performance noted in Tests WBCT-5 and WBCT-6, it was concluded that the cut out hinge design was not promoting buckling of the beam soon enough. As shown in Figure 23, the hinge design was changed to cause earlier collapse of the beam during end-on impacts. In addition to the change in cut out geometry, an additional cut out was installed as shown in Figure 23.

As shown in Figures 24 and 25, the vehicle impacted the end with upward movement of the railing of over 4 ft (1.2 m) as the vehicle yawed over 90 deg before the rear side rode over the first three steel posts. Although considerable pitching and rolling instability was noted, the vehicle remained upright.

Pendulum investigation. In order to further reduce the end-on resistance and reduce the yaw rate of the vehicle, it was proposed to weaken the end post by saw cutting as shown in Figure 26. Since this would weaken the end post anchor strength function, a pendulum test was conducted to verify that the saw cut did not compromise the anchor strength function of the end post; results of the test are given in Appendix A.

WBCT-8. The purpose of this test was to evaluate the modified BCT using a saw cut in the end post (see Figure 26) and an additional hinge 2 ft (0.6 m) downstream of the end post.

As shown in Figures 27 and 28, the vehicle fractured the first post and climbed over the railing which had dropped to grade. When the vehicle reached the second post its elevated position caused this post to rotate in a bending mode rather than a shear type fracture, and this contributed to further launching and rollover of the vehicle.

WBCT-9. The purpose of this test was to evaluate the modified BCT with four hinges as in Test WBCT-7 and the saw-cut end post. The hinge 2 ft (0.6 m) downstream of the end post from the previous test was deleted as it contributed to the undesirable behavior of Test WBCT-8.

As shown in Figures 29 and 30, the vehicle was redirected behind the installation although yawing and pitching instability were again noted.

WBCT-10. The purpose of this test was to evaluate the strength of the WBCT-9 retrofit for an angular impact at the third post.

The 4819-lb (2186-kg) vehicle impacted the railing at 24.9 deg (measured from the guardrail straight alignment). As shown in Figures 31 and 32 the vehicle pocketed at the third hinge location and penetrated the rail when the beam severed at the hinge.

E. Current Research

As part of a new FHWA Contract (DTFH61-81-00076) at SwRI, methods of reinforcing the retrofitted BCT design of Test WBCT-9 are being investigated. All of these tests were conducted with full-size Ford LTD's impacting the third post at 60 mph (96.6 kmph).

RBCT-1. For this test two wire ropes were nested in the corrugations behind the W-beam rail extending from a location just upstream of Post 3 to one just downstream of Post 8 (as shown in Figure 33). Ends of the wire ropes were attached to the W-beam with special brackets. Although the vehicle was redirected by the system, impact velocity was only 50.0 mph (81.3 kmph) necessitating a test rerun.

RBCT-2. In this repeat test of RBCT-1 the vehicle pocketed causing the rail to sever at the notch between Posts 5 and 6, and fractured Posts 1 and 2, subsequently penetrating the installation as shown in Figures 34 and 35. Vehicle pocketing was attributed to excess barrier deflection prior to reinforcement by the wire ropes.

RBCT-3. To provide stronger upstream anchorage of the wire ropes which in turn would allow less barrier deflection, the ropes were connected to a flat plate attached near grade to Post 2. In addition, the wire ropes were attached to the blockout of each interim post with U-bolts (four per post), as shown in Figure 36.

As shown in the sequential photographs of Figures 37 and 38 the vehicle was redirected by the reinforced installation although it did reach a high roll angle (approximately 31.5 deg) during the event.

IV. CONCLUSIONS AND RECOMMENDATIONS

Based on the findings of this project, conclusions and recommendations are made regarding guardrail BCT installations.

A. Conclusions

1. The current recommended guardrail BCT(7) designs are not compatible for high-speed off-center impacts with 1800-lb (800-kg) class minicars.

2. Since many agencies have not installed the guardrail BCT with the recommended 4-ft (1.2-m) flare, performance of these installations can be expected to be even poorer than those tested in this project.

3. The current BCT can be retrofitted for compatibility with the 1800-lb (800-kg) minicar; however further work on the retrofit design is needed to provide adequate strength for angular impacts near the end. Test results from WBCT-9 indicate marginal conformance with NCHRP Report 230(12) as shown in Table 2. Table 2 also illustrates criteria applicable to terminals from TRB Circular 191 (11) which preceded Report 230.

4. Highway safety hardware in general may not be compatible for high-speed, off-center impacts with 1800-lb (800-kg) minicompacts.

B. Recommendations

1. The basic retrofit concept of Test WBCT-9 should be modified to provide adequate strength for angular impacts near the end.

2. The steel slip base post BCT design should be evaluated for performance with the modifications used in the wood end post retrofit development.

3. Agencies should consider these modifications in new BCT installations and cease installation of straight or modified BCT flare geometries.

4. A straight terminal is needed for roadway sites which will not accommodate a 4-ft (1.2-m) flare.

5. The median barrier BCT (MBCT) should be evaluated for high-speed, off-center impacts with minicompact vehicles.

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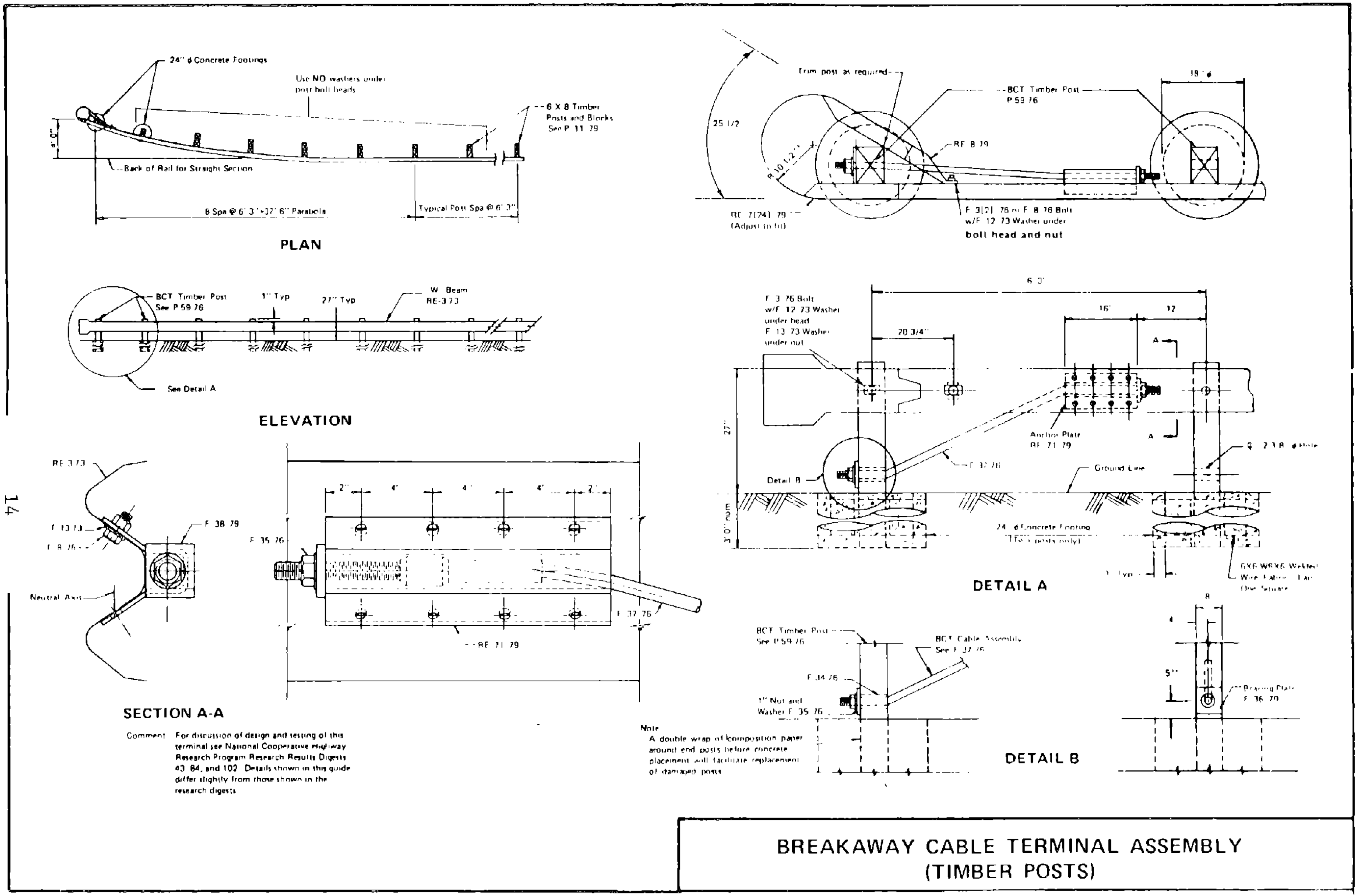


FIGURE 1. WOOD POST BCT DRAWING (REF 9)

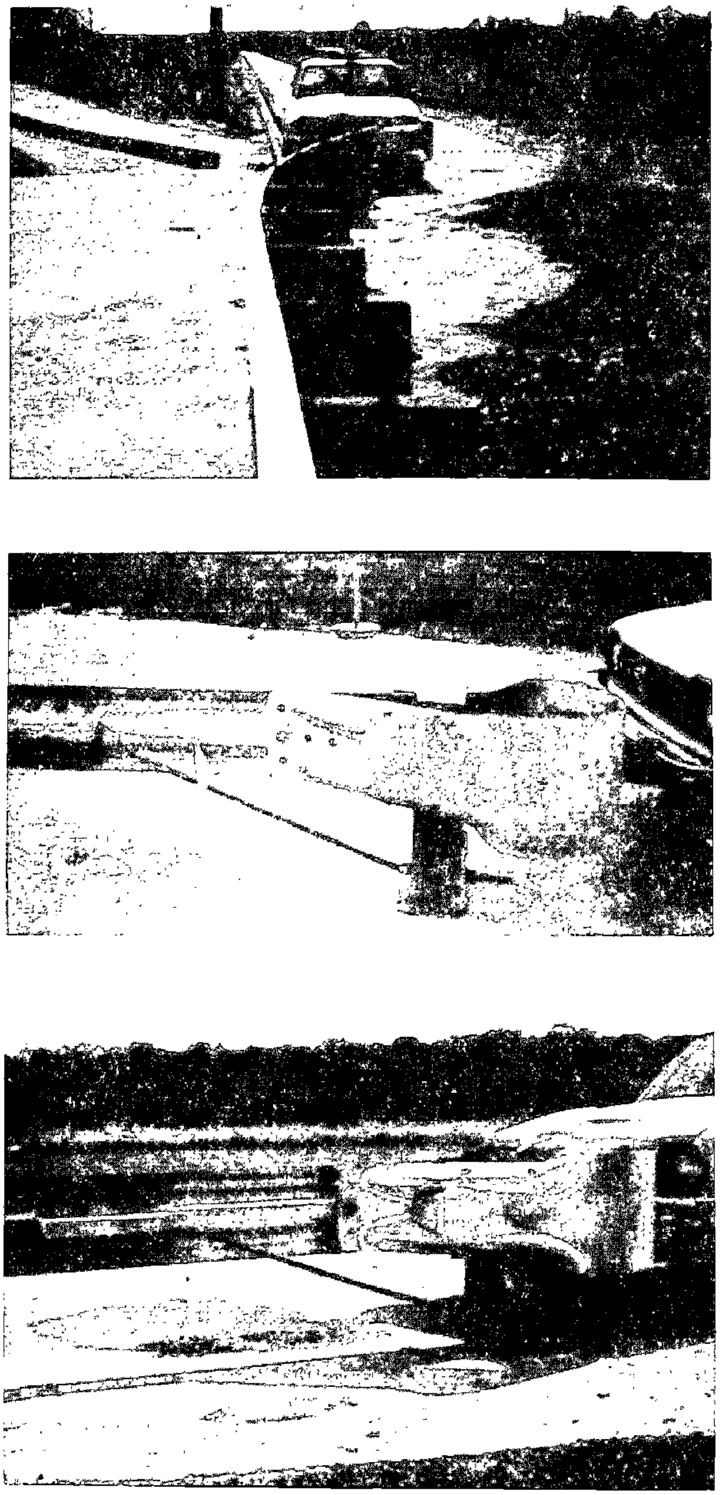


FIGURE 2. WOOD POST BCT PHOTOGRAPHS

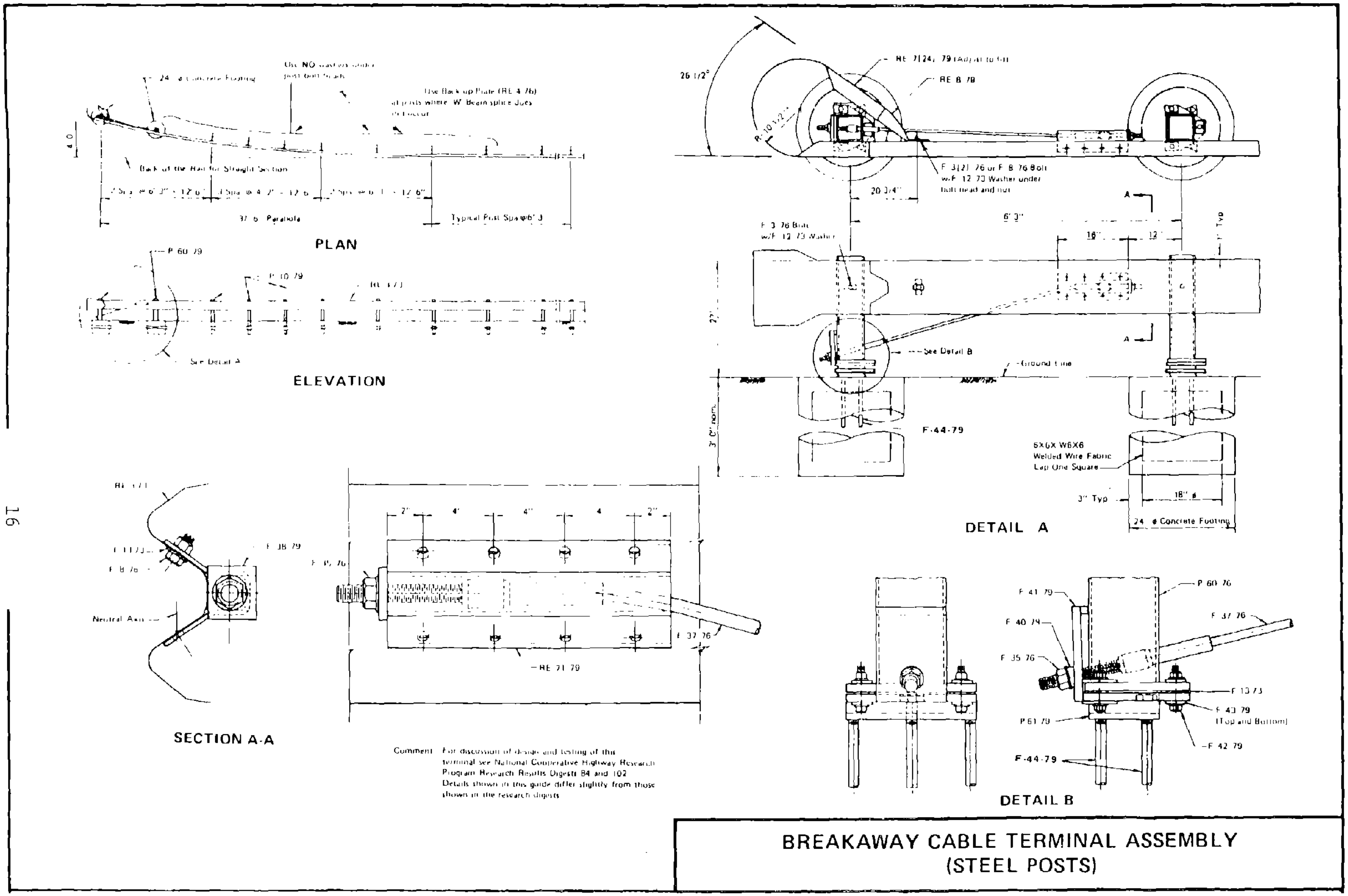
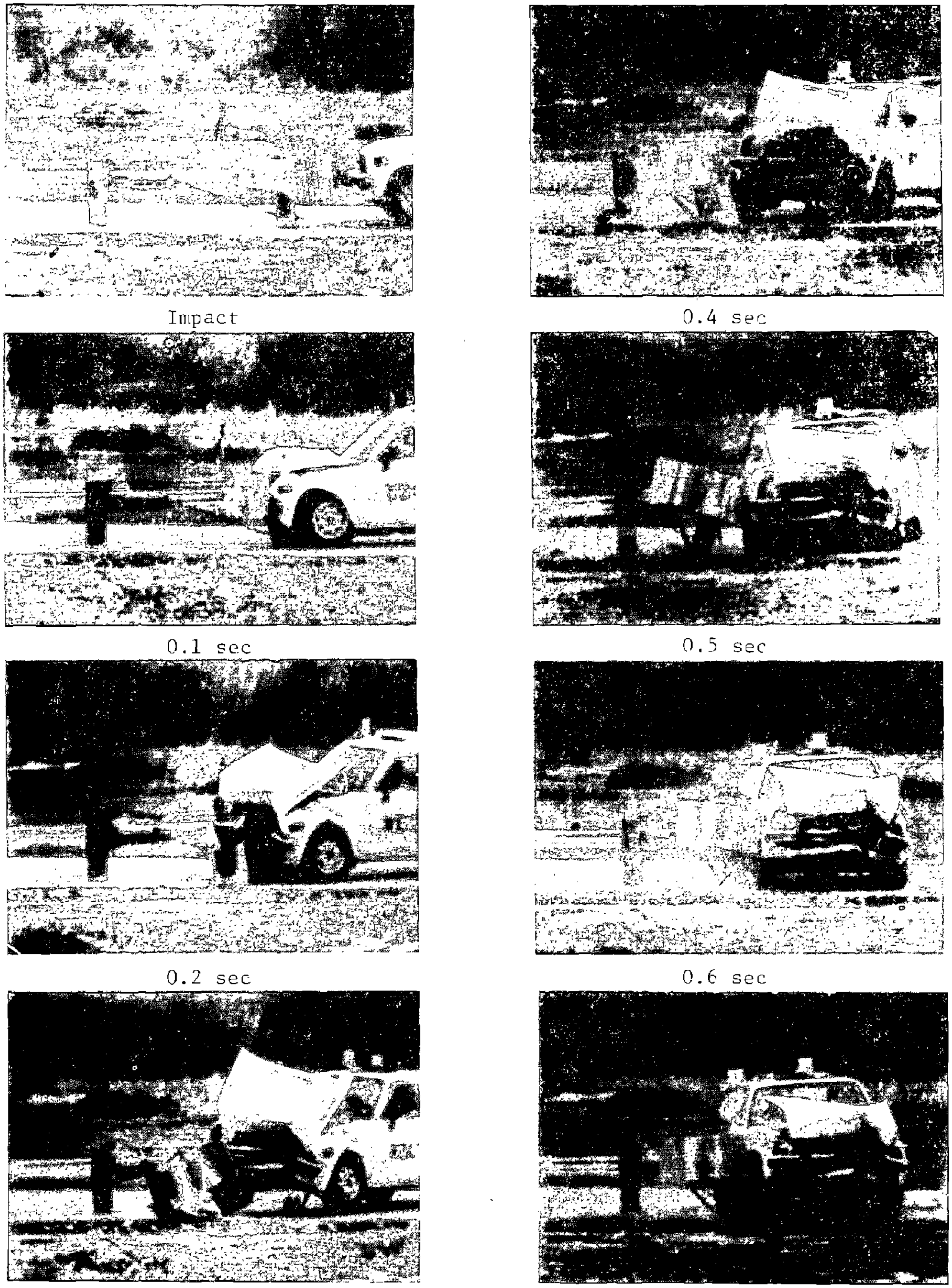


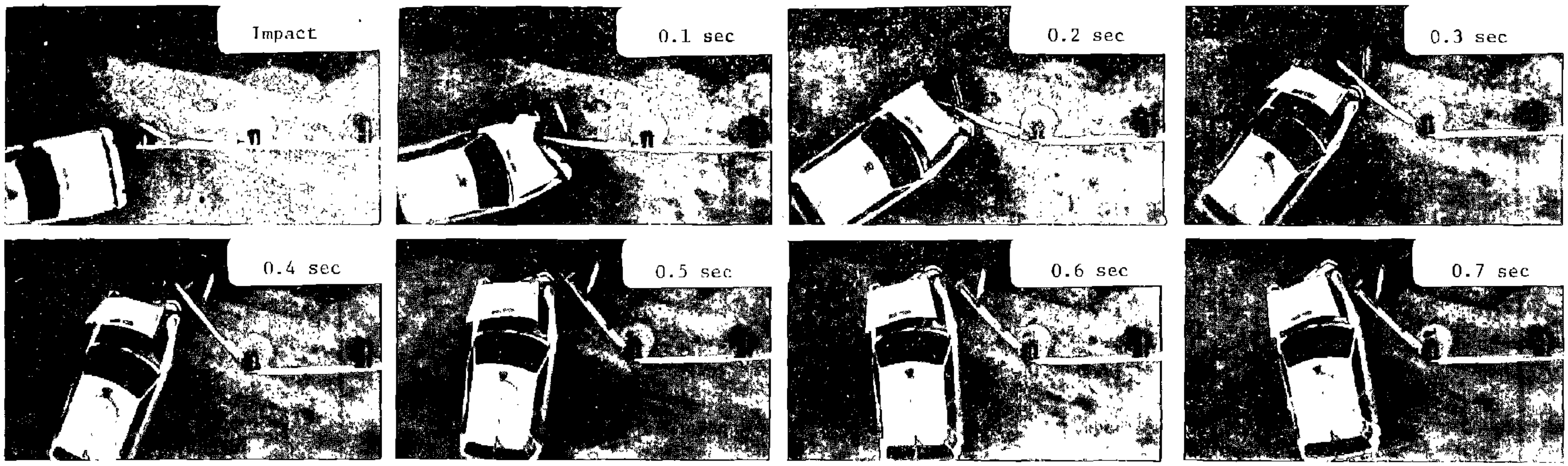
FIGURE 3. STEEL POST BCT DRAWING (REF 9)

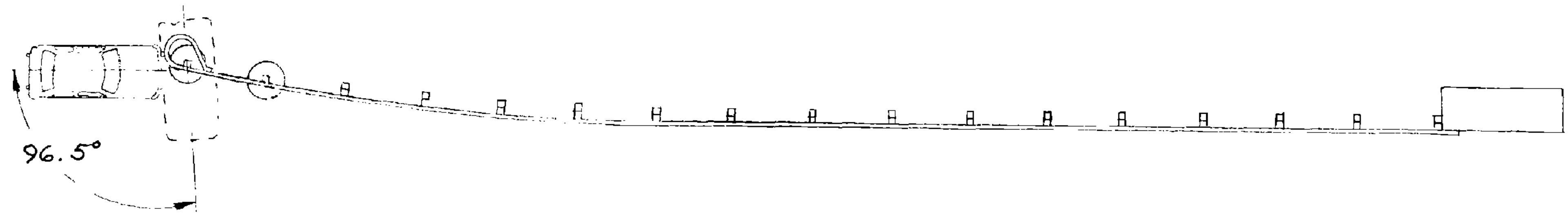
FIGURE 4. STEEL POST BCT PHOTOGRAPHS



Impact | 0.4 sec
0.1 sec | 0.5 sec
0.2 sec | 0.6 sec
0.3 sec | 0.7 sec

FIGURE 5. TEST WBCT-1 IMPACT SEQUENCE





Test No. WBCT-1
Date 3/31/80
Test Installation Drawing No. 03-5433-01
Rail .... 12 ga steel x 12.5 ft (3.8 m) lg W-beam
Post (footing mounted) ..... 6 in. (152 mm) x 8 in. (203 mm) x 5.33 ft (1.6 m) lg wood
Post (soil mounted) .... 6 in. (152 mm) x 8 in. (203 mm) x 6 ft (1.8 m) lg wood
Post Spacing .... 6.25 ft (1.9 m)
Length of Installation .... 100 ft (30 m)
Soil Condition .... Dry

Vehicle .... 1975 Honda Civic
Vehicle Mass .... 2167 lb (983 kg) (w/dummies and instrumentation)
Impact Speed .... 30.7 mph (49.4 kmph)
Impact Angle .... -0.3 deg
Exit Speed 0
Exit Angle .... 96.5 deg
Vehicle Front-End Crush .... 20.0 in. (508 mm)
Vehicle Accelerations (max 50 ms avg)
Lateral (cine/electr)........... (2.1 g/1.5 g)
Longitudinal (cine/electr)..... (-9.0 g/-9.6 g)
Vehicle Damage
TAD 12-FC-5
VDI 12FCEW4

FIGURE 6. SUMMARY OF RESULTS, TEST WBCT-1

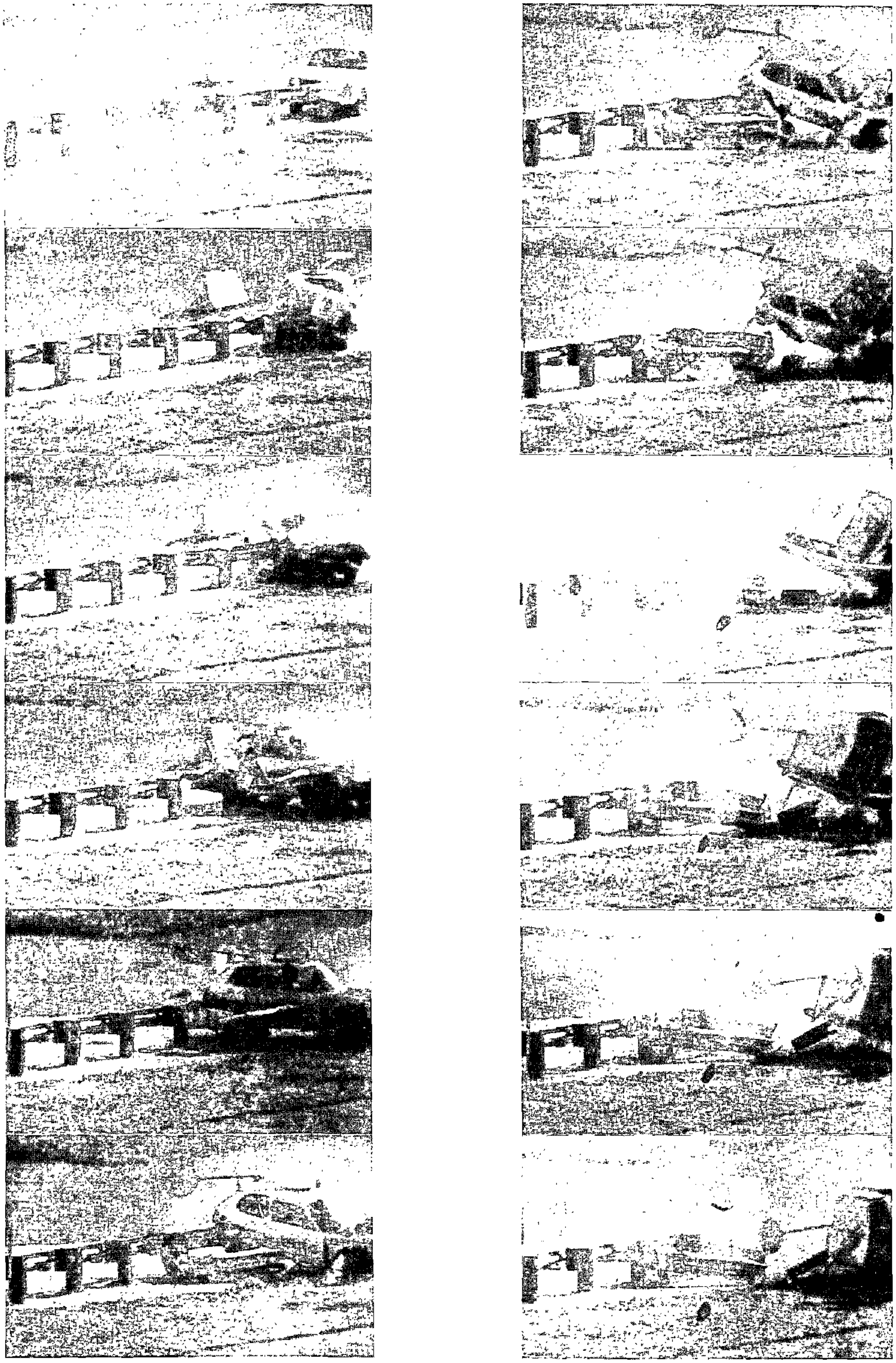
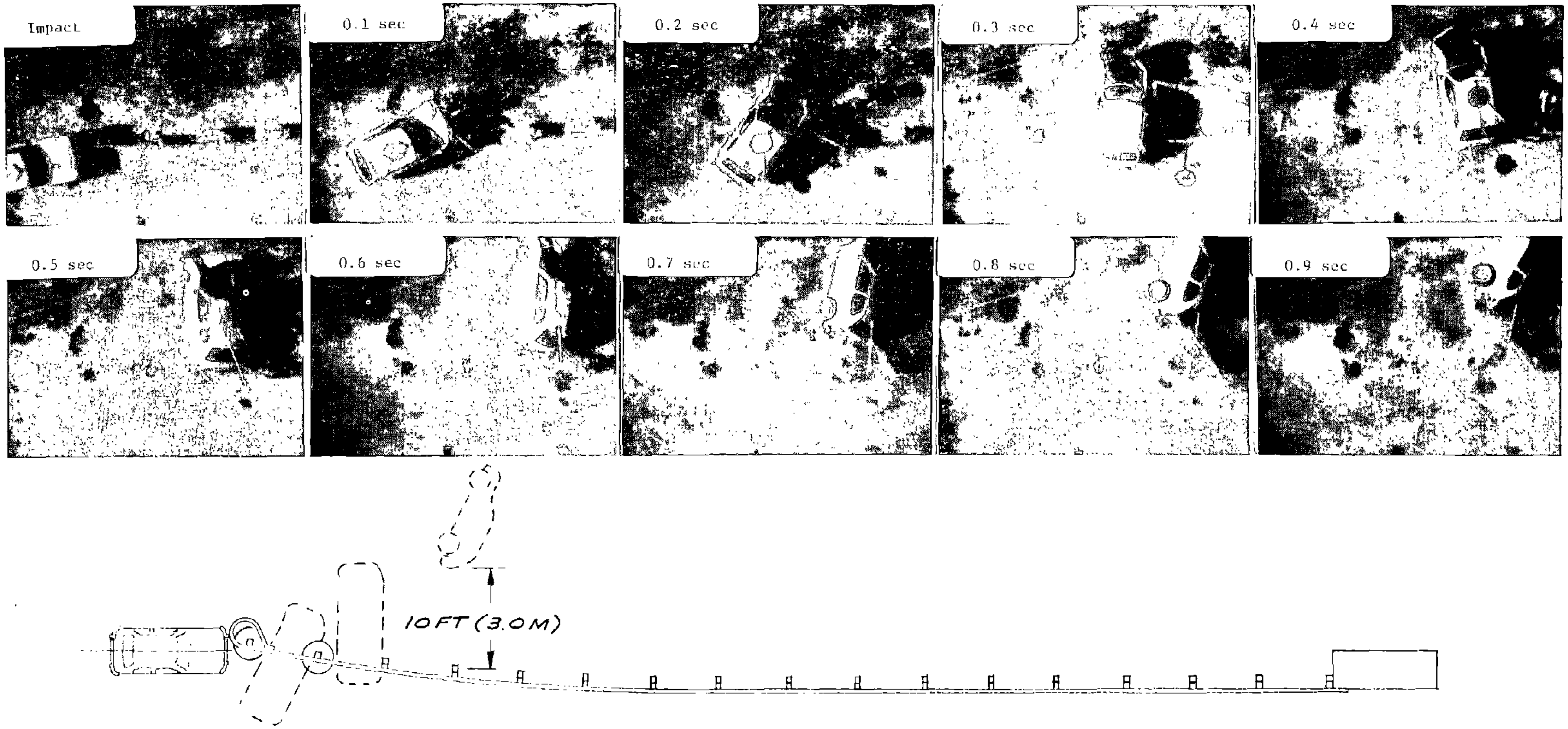


FIGURE 7. TEST WBCT-2 IMPACT SEQUENCE

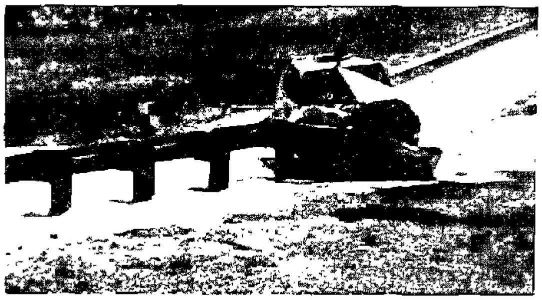


Test No. WBCT-2
Date 4/3/80
Test Installation Drawing No. 03-5433-01
Rail ....12 ga steel x 12.5 ft (3.8 m) lg W-beam
Post (footing mounted)... 6 in. (152 mm) x 8 in. (203 mm) x 5.33 ft (1.6 m) lg wood
Post (soil mounted)...... 6 in. (152 mm) x 8 in. (203 mm) x 6 ft (1.8 m) lg wood
Post Spacing .... 6.25 ft (1.9 m)
Length of Installation .... 100 ft (30 m)
Soil Condition .... Dry

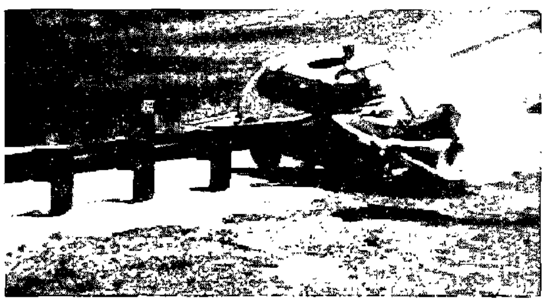
Vehicle .... 1975 Honda Civic
Vehicle Mass .... 2178 lb (988 kg)
(w/dummies and instrumentation)
Impact Speed .... 59.0 mph (95.0 kmph)
Impact Angle .... -0.3 deg
Exit Speed 0
Vehicle Front-End Crush ..... 20.0 in. (508 mm)
Vehicle Accelerations (max 50 ms avg)
Lateral (cine/electr).......... (3.7 g/7.9 g)
Longitudinal (cine/electr)..(-13.1 g/-15.0 g)
Vehicle Damage
TAD 12-FC-6
VDI 12FCEW6

FIGURE 8. SUMMARY OF RESULTS, TEST WBCT-2

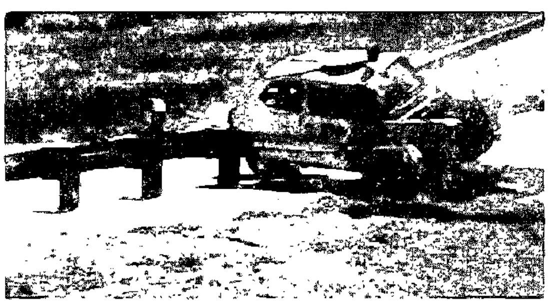
Impact



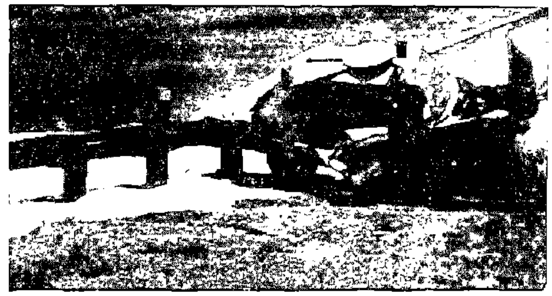
0.1 sec



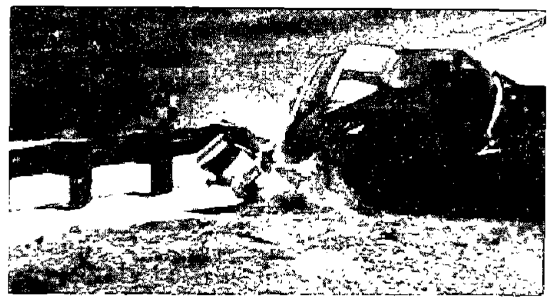
0.2 sec



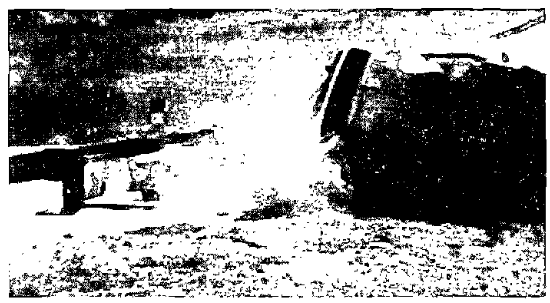
0.3 sec



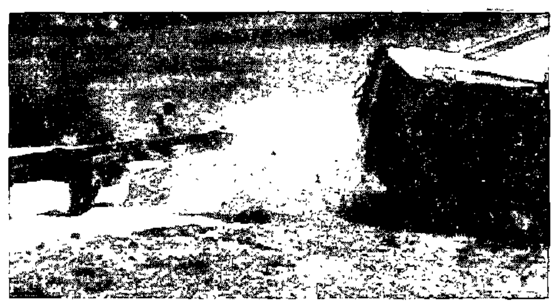
0.4 sec



0.5 sec

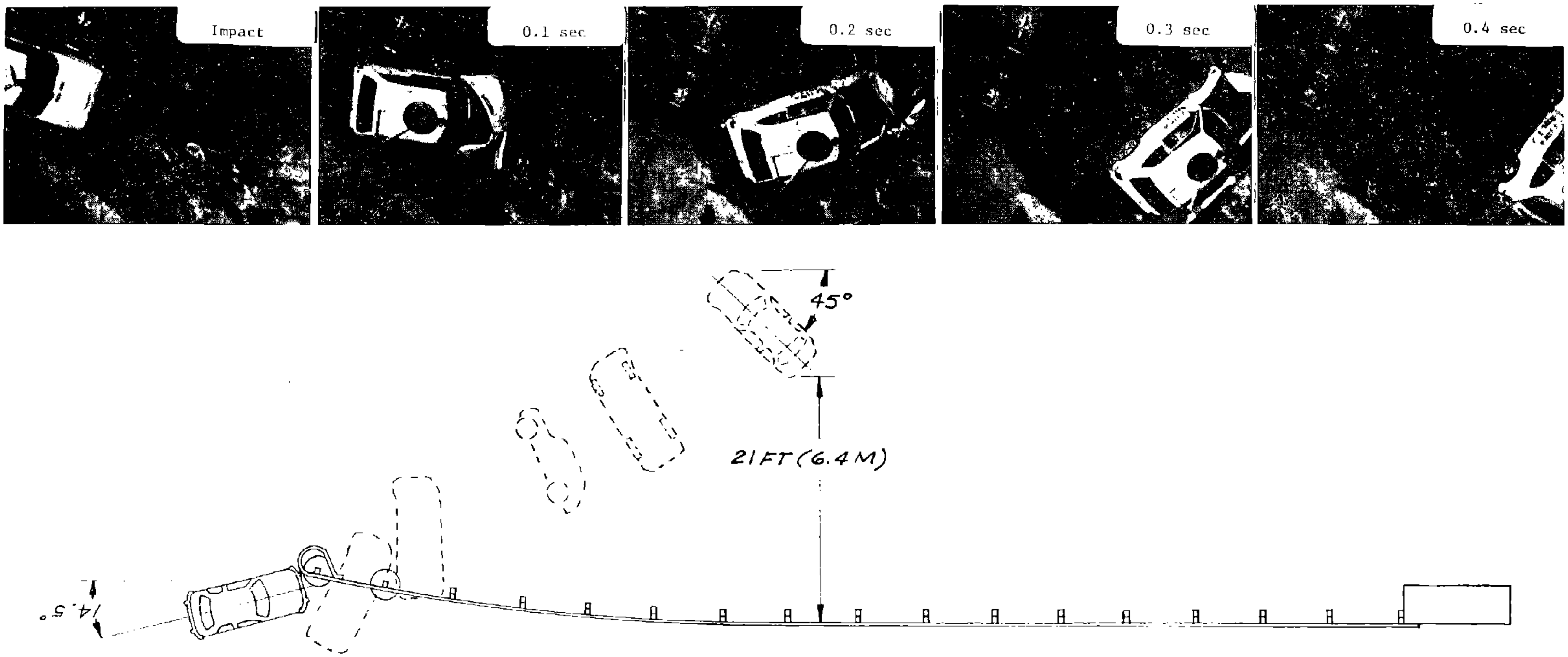


0.6 sec



0.7 sec

FIGURE 9. TEST WBCT-3 IMPACT SEQUENCE



Test No. WBCT-3
Date 4/17/80
Test Installation Drawing No. 03-5433-01
Rail .... 12 ga steel x 12.5 ft (3.8 m) lg W-beam
Post (footing mounted) ... 6 in. (152 mm) x 8 in. (203 mm) x 5.33 ft (1.6 m) lg wood
Post (soil mounted) ..... 6 in. (152 mm) x 8 in. (203 mm) x 6 ft (1.8 m) lg wood
Post Spacing .... 6.25 ft (1.9 m)
Length of Installation .... 100 ft (30 m)
Soil Condition .... Dry

Vehicle .... 1975 Honda Civic
Vehicle Mass .... 2178 lb (988 kg) (w/dummies and instrumentation)
Impact Speed .... 59.3 mph (95.4 kmph)
Impact Angle .... 14.5 deg
Exit Speed 0
Vehicle Front-End Crush....... 24.0 in. (610 mm)
Vehicle Accelerations (max 50 ms avg)
Lateral (cine/electr)........... (6.6 g/7.6 g)
Longitudinal (cine/electr)...(-14.6 g/-13.8 g)
Vehicle Damage
TAD 12-FC-6
VDI 12FCEW6

FIGURE 10. SUMMARY OF RESULTS, TEST WBCT-3

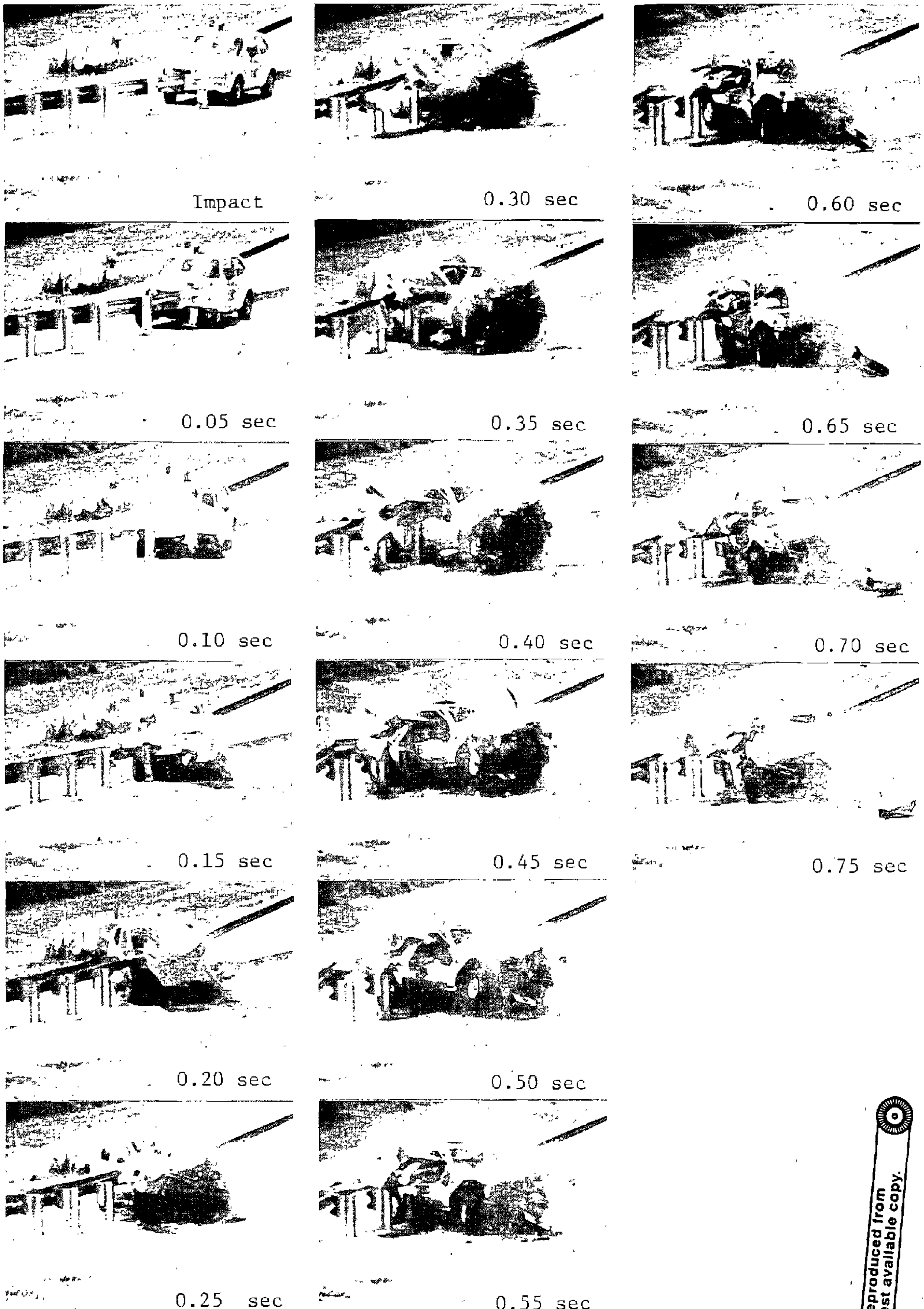
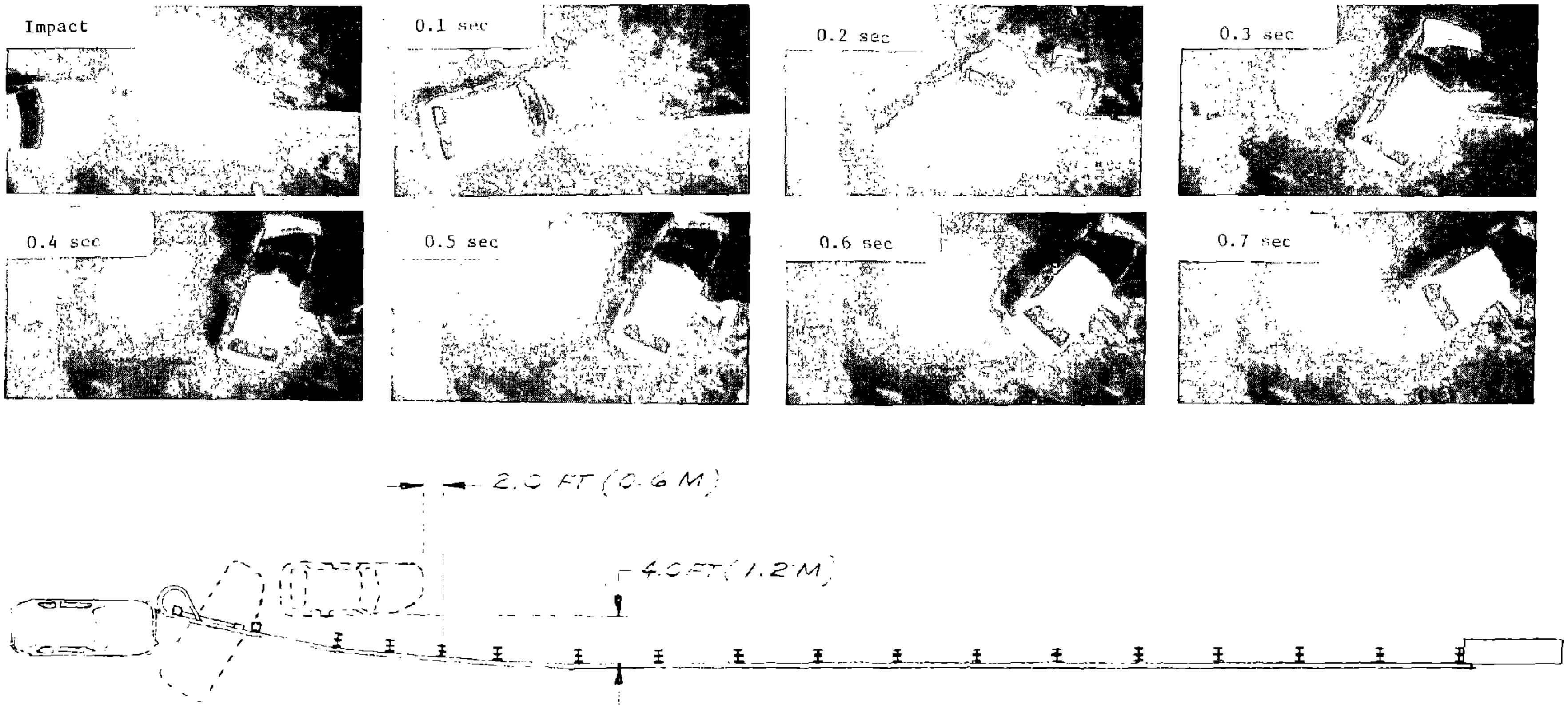


FIGURE 11. TEST SBCT-1 IMPACT SEQUENCE



Test No. SBCT-1
Date 6/5/80
Test Installation Drawing No. 03-5433-02
Rail ...... 12 ga steel x 12.5 ft (3.8m) lg W-beam
Post (footing mounted) ..... TS6x6x0.1875x25.5 in. (648mm) lg steel
Post (soil mounted) .... W6x9x6 ft (1.8m) lg steel
Post Spacing .... 6.25 ft (1.9m)
Length of Installation .... 100 ft (30m)
Soil Condition .... Dry

Vehicle .... 1975 Honda Civic
Vehicle Mass .... 2180 lb (989kg)
(w/dummies and instrumentation)
Impact Speed .... 60.0 mph (96.6kmph)
Impact Angle .... 0.5 deg
Exit Speed 0
Vehicle Front-End Crush ...... 22.0 in. (671mm)
Vehicle Accelerations (max 50ms avg)
Lateral (cine/electr) 5.0g/4.5g
Longitudinal (cine/electr)...... -11.2g/-15.2g
Vehicle Damage
TAD 12-FC-6
VDI 12FCEW6

FIGURE 12. SUMMARY OF RESULTS, TEST SBCT-1

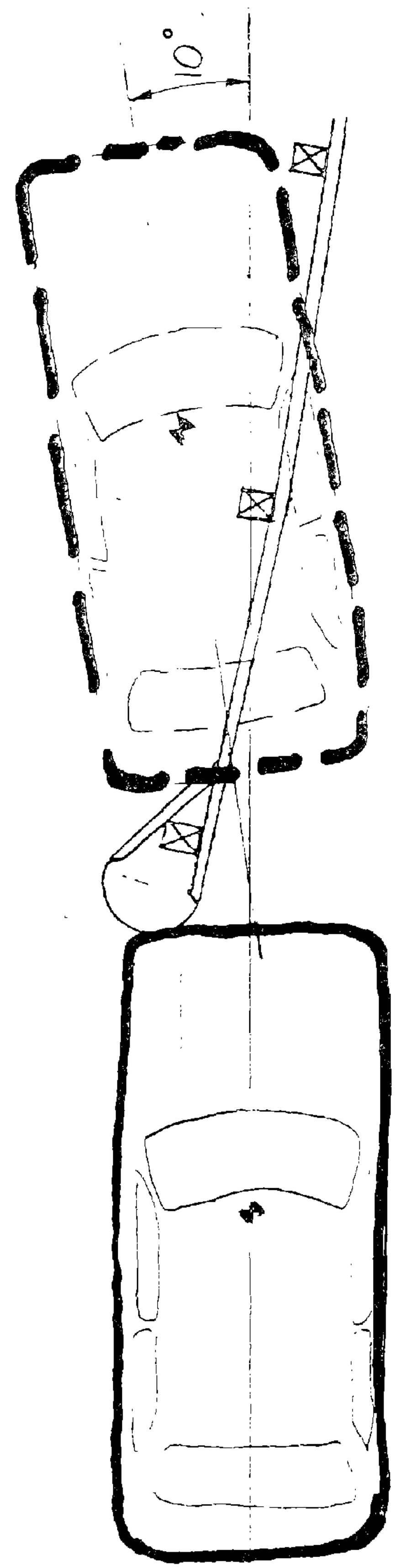
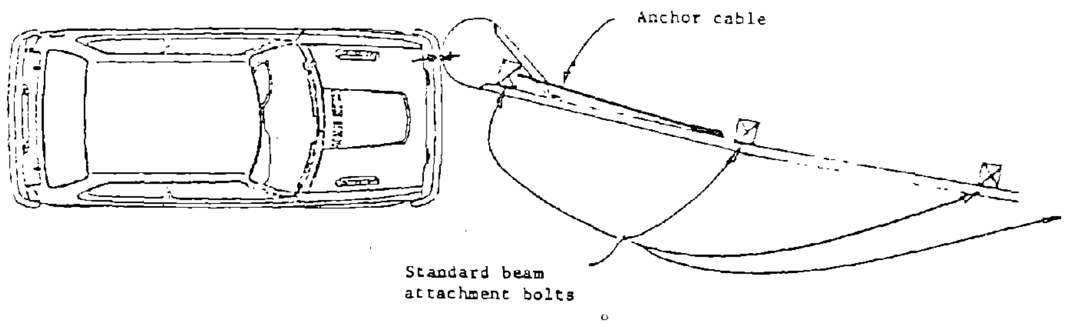
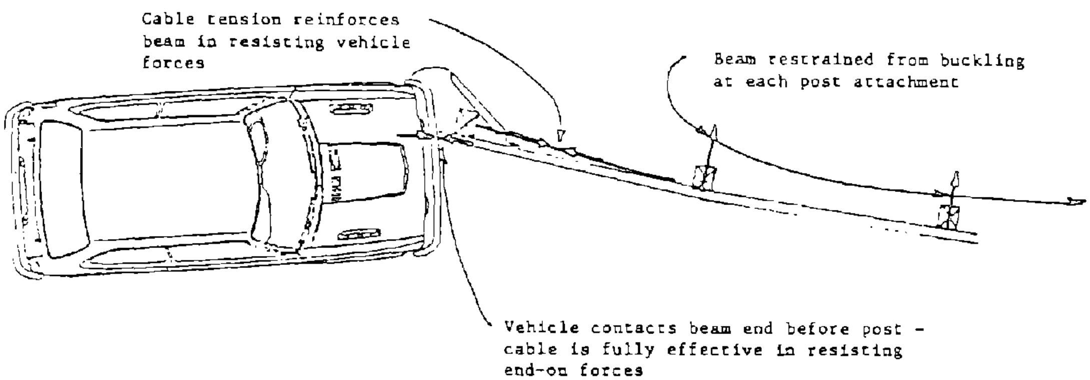


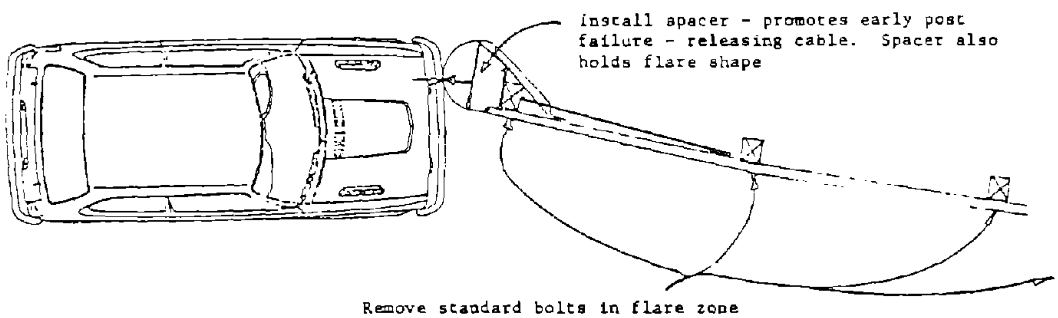
FIGURE 13. GATING THROUGH BCT



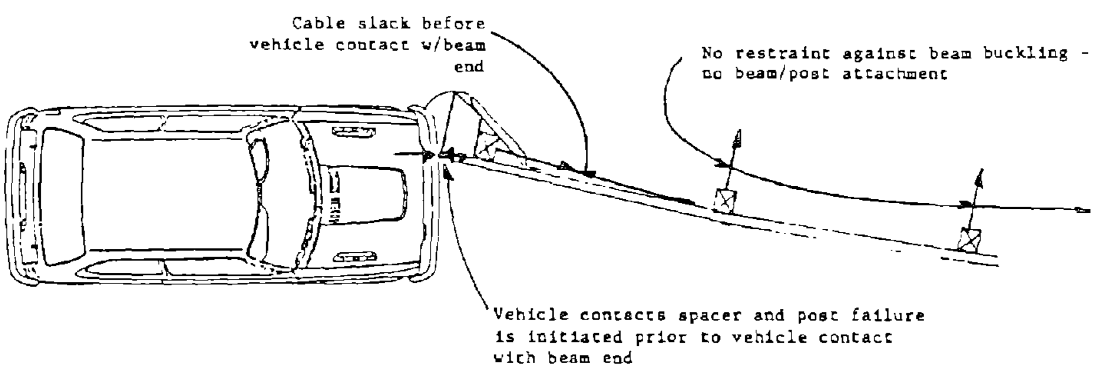
(a) Current BCT design (flared)



(b) Undesirable features of current BCT



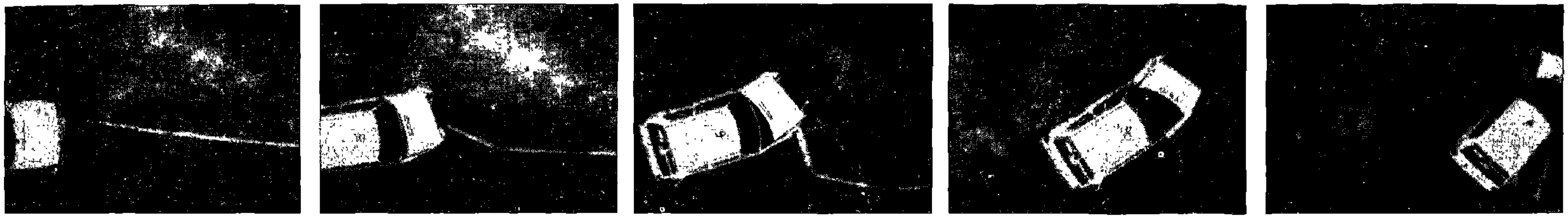
(c) Retrofit features



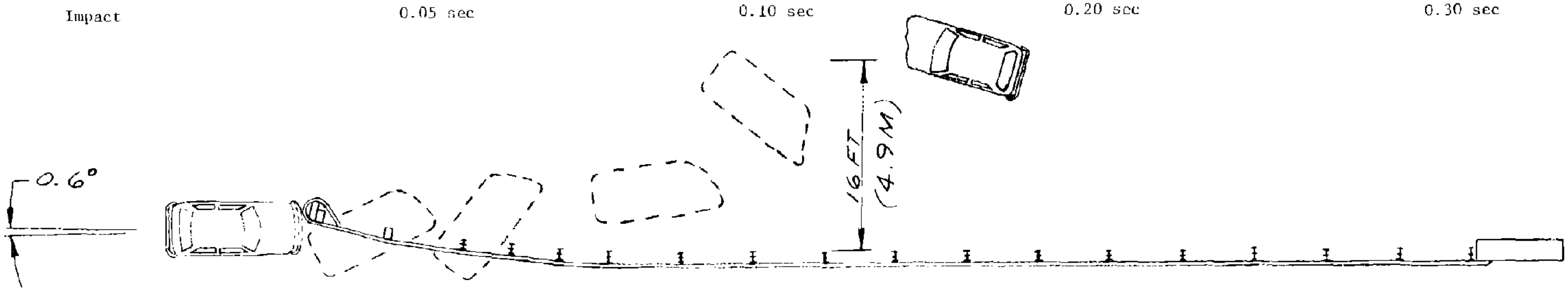
(d) Retrofit changes in behavior during initial impact sequence

FIGURE 14. CURRENT BCT AND RETROFIT

FIGURE 15. TEST WBCT-4 IMPACT SEQUENCE



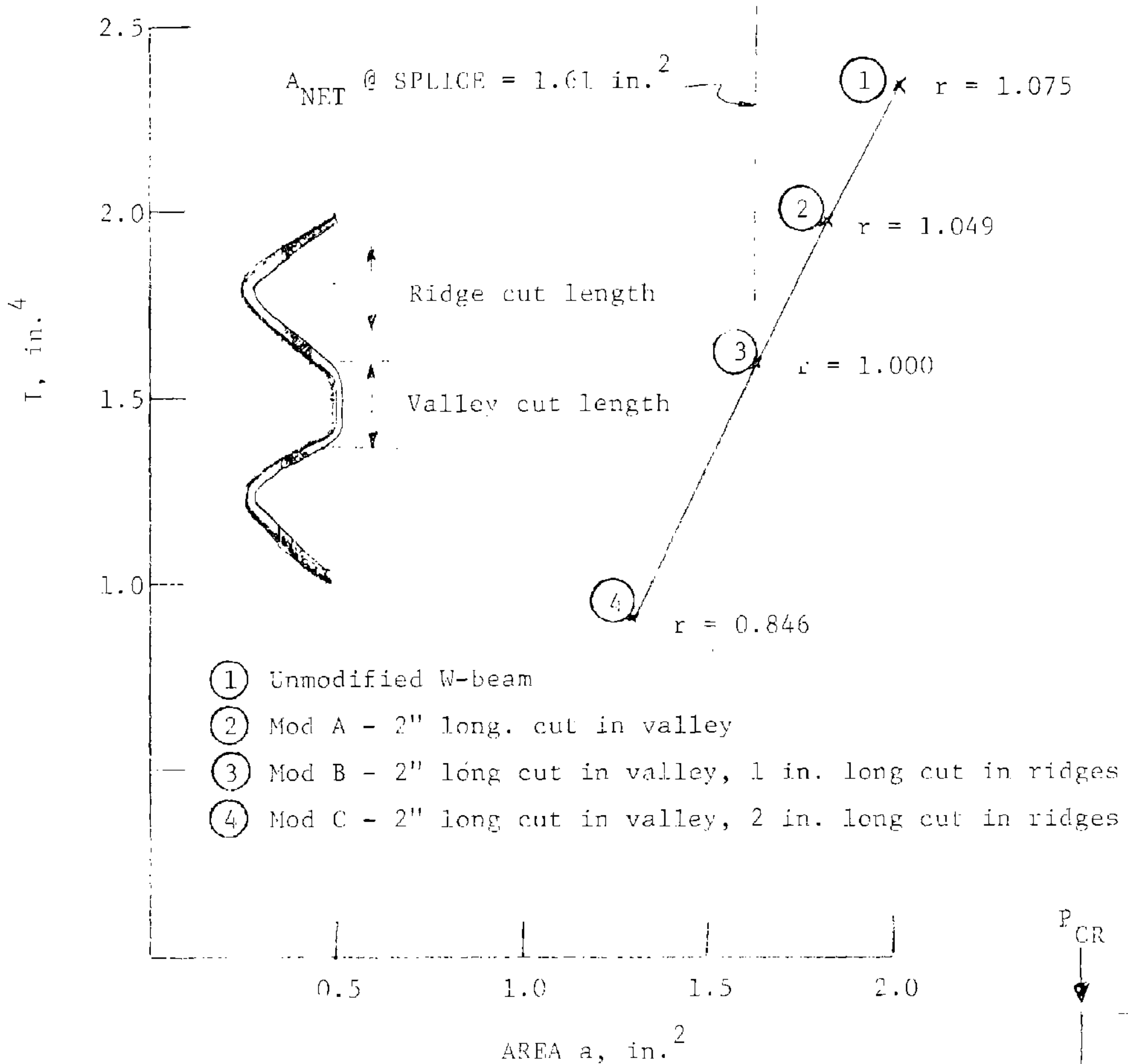
Impact | 0.05 sec | 0.10 sec | 0.20 sec | 0.30 sec

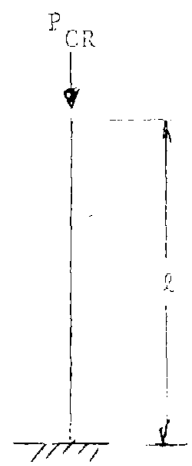


Test No. WBCT-4
Date 4/8/81
Test Installation Dwg. No. 03-5433-03
Rail .... 12 ga steel x 12.5 ft (3.8 m) lg W-beam
Post (footing mounted) ... 6 in. (152 mm) x 8 in. (203 mm) x 5.33 ft (1.6 m) lg wood
Post (soil mounted) .. W6x9x6 ft (1.8 m) lg steel
Post Spacing .... 6.25 ft (1.9 m)
Length of Installation .... 100 ft (30 m)
Soil Condition .... Dry

Vehicle .... 1975 Honda Civic
Vehicle Mass .... 2170 lb (984 kg) (w/dummies & instrumentation)
Impact Speed .... 59.4 mph (95.6 kmph)
Impact Angle .... 0.6 deg
Exit Speed 0
Vehicle Accelerations (max 50ms avg)
Lateral (cine/electr) .... 1.6 g/6.0 g
Longitudinal (cine/electr) .. -10.0 g/-16.4 g
Vehicle Damage
TAD 12-FD-6
VDI 12FDEW6

FIGURE 16. SUMMARY OF RESULTS, TEST WBCT-4

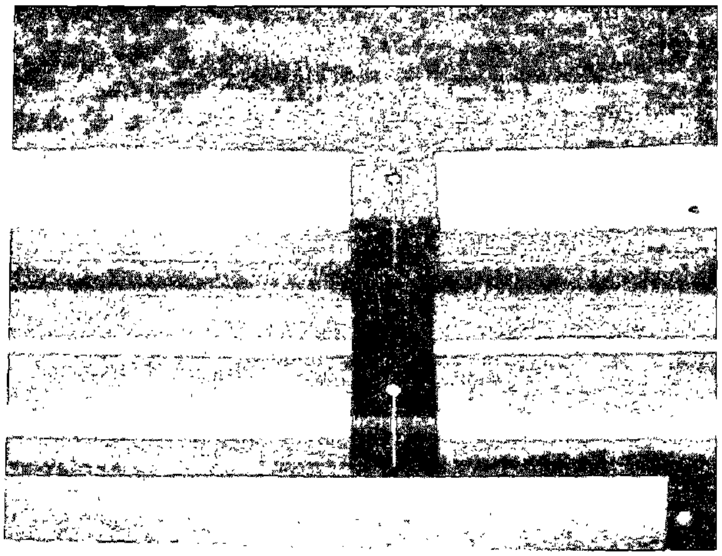




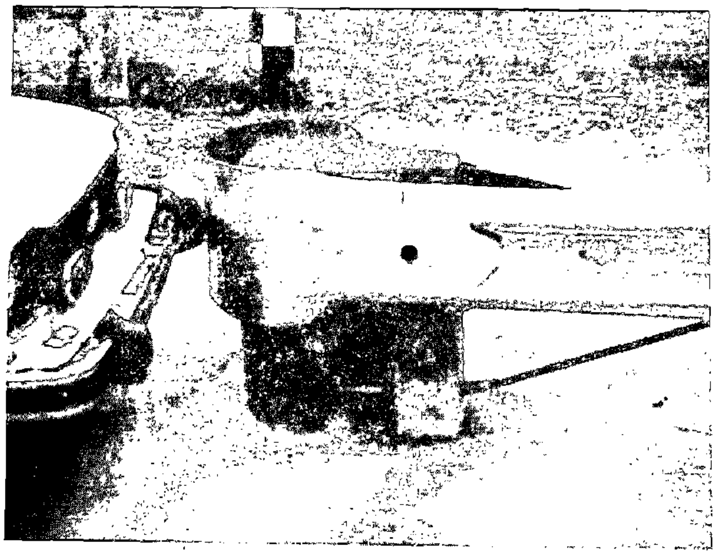
Assume Euler $\sigma_{CR} = \frac{P_{CR}}{a} = \frac{\pi^2 E}{(\ell/r)^2}$ - Only a & r vary; $P_{CR} \sim ar^2 + I$

	% P_{CR} Reduction
(1) I = 2.3, a = 1.99, r = 1.075	0
(2) I = 1.97, a = 1.79, r = 1.049	15
(3) I = 1.59, a = 1.59, r = 1.000	31
(4) I = 0.924, a = 1.29, r = 0.846	60

FIGURE 17. W-BEAM STRENGTH REDUCTION INVESTIGATION



(a) Beam cut-out (see Fig. 15 for location)



(b) Nose spacer

FIGURE 18. WBCT-5 DETAILS

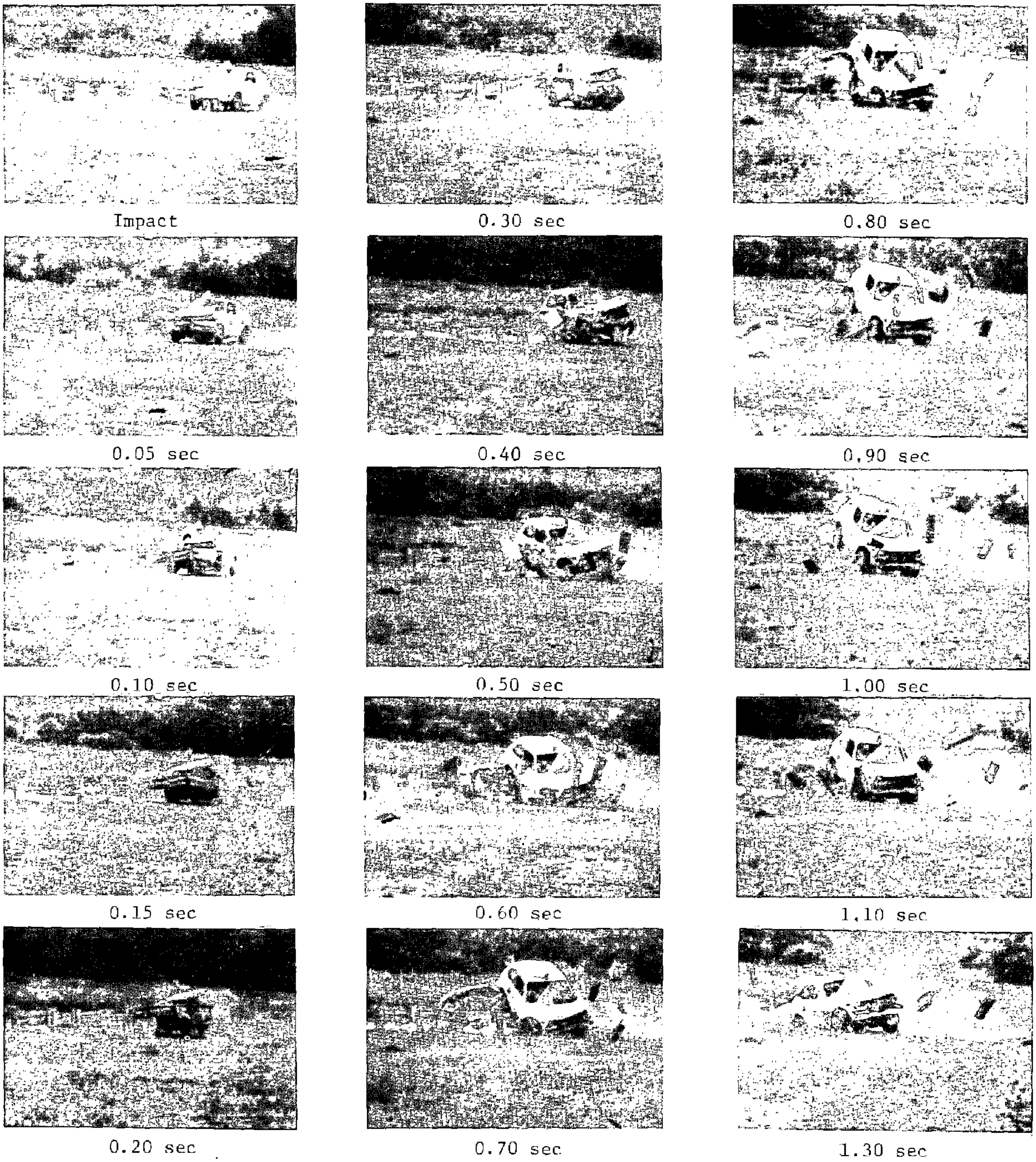
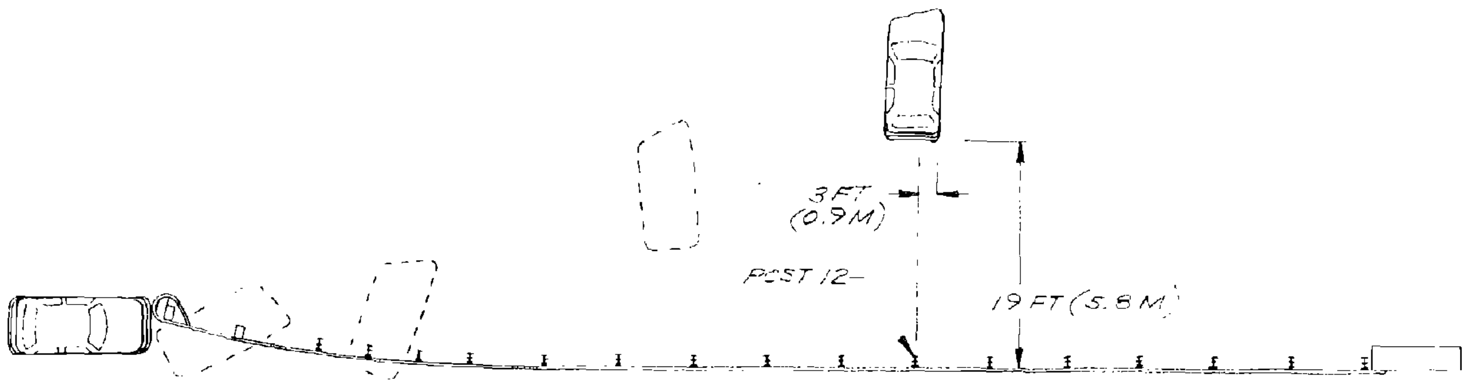


FIGURE 19. TEST WBCT-5 IMPACT SEQUENCE

Impact | 0.1 sec | 0.2 sec | 0.3 sec | 0.4 sec | 0.6 sec



Test No. WBCT-5
Date 5/8/81
Test Installation Dwg. No. 03-5433-03
Rail .... 12 ga steel x 12.5 ft (3.8 m) lg W-beam
Post (footing mounted) ... 6 in. (152 mm) x 8 in. (203 mm) x 5.33 ft (1.6 m) lg wood
Post (soil mounted) .. W6x9x6 ft (1.8 m) lg steel
Post Spacing .... 6.25 ft (1.9 m)
Length of Installation .... 100 ft (30m)
Soil Condition .... Dry

Vehicle .... 1977 Honda Civic
Vehicle Mass .... 2170 lb (984 kg)
(w/dummies & instrumentation)
Impact Speed .... 56.8 mph (91.4 kmph)
Impact Angle .... 0 deg
Exit Speed 0
Vehicle Accelerations (max 50ms avg)
Lateral (cine/electr) .... n.a./3.9 g
Longitudinal (cine/electr) ..... n.a./-16.9 g
Vehicle Damage
TAD 12-FD-6
VDI 12FDAW6

FIGURE 20. SUMMARY OF RESULTS, TEST WBCT-5

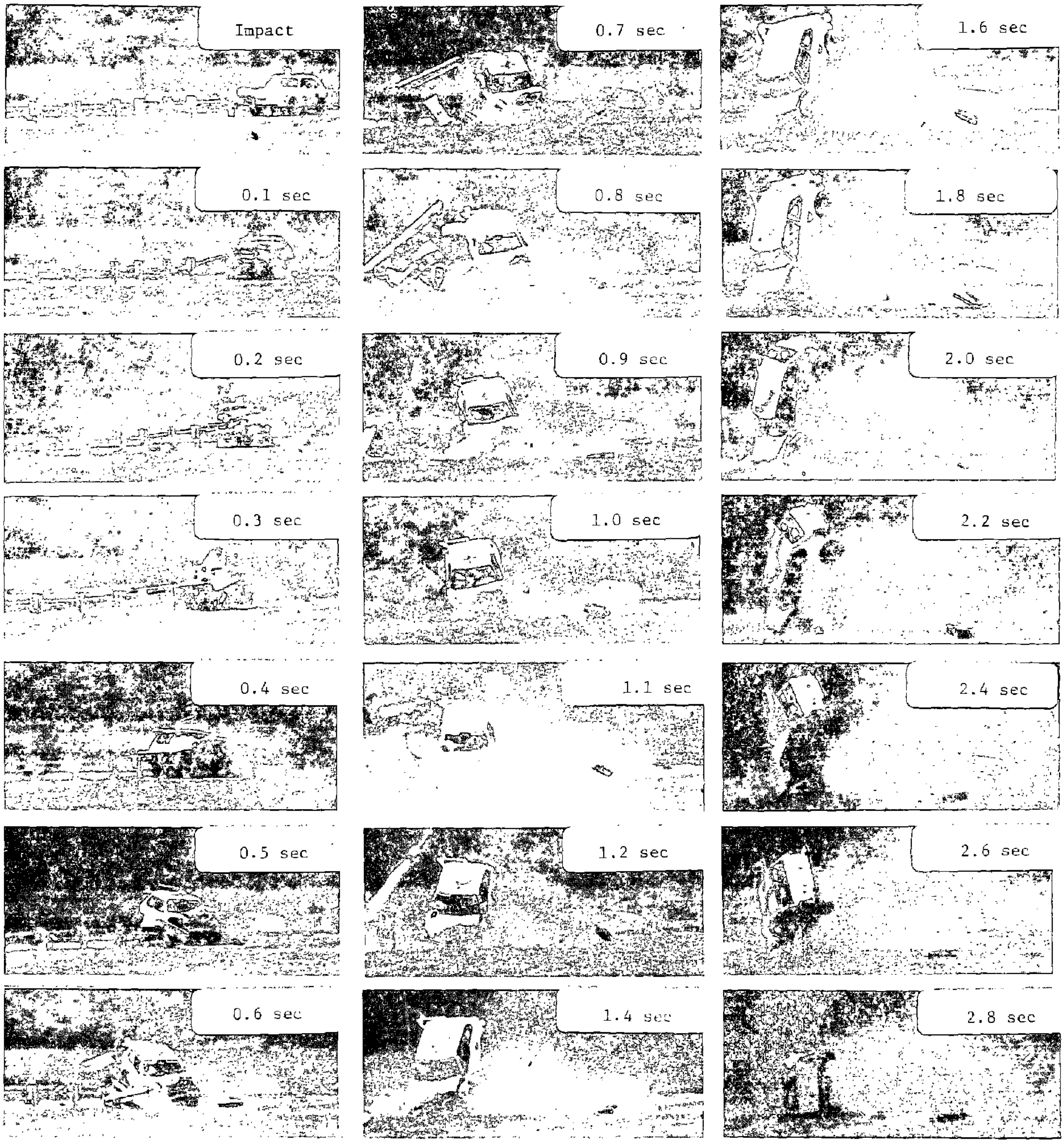
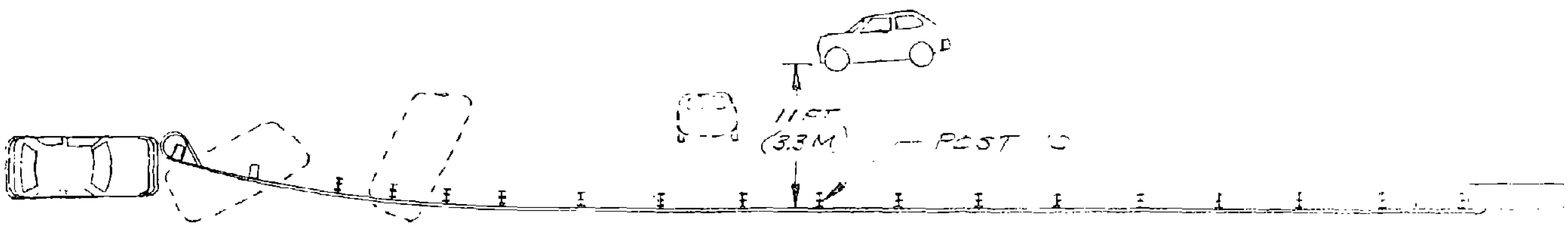


FIGURE 21. TEST WBCT-6 IMPACT SEQUENCE

Impact 0.1 sec 0.2 sec 0.3 sec 0.4 sec



Test No. WBCT-6
Date 5/22/81
Test Installation Dwg. No. 03-5433-03
Rail ..... 12 ga steel x 12.5 ft (3.8 m) lg W-beam
Post (footing mounted) .... 6 in. (152 mm) x 8 in. (203 mm) x 5.33 ft (1.6 m) lg wood
Post (soil mounted) ... W6x9x6 ft (1.8 m) lg steel
Post Spacing .... 6.25 ft (1.9 m)
Length of Installation .... 100 ft (30 m)
Soil Condition .... Dry

Vehicle .... 1974 Honda Civic
Vehicle Mass .... (2124 lb (963 kg)
(W/dummies & instrumentation)
Impact Speed .... 60.4 mph (97.2 kmph)
Impact Angle .... 0 deg
Exit Speed 0
Vehicle Accelerations (max 50 ms avg)
Lateral (cine/electr) .... 4.2 g/3.5 g
Longitudinal (cine/electr)..-11.2 g/-18.7 g
Vehicle Damage
TAD 12-FD-6
VDI 12FDAW6

FIGURE 22. SUMMARY OF RESULTS, TEST WBCT-6

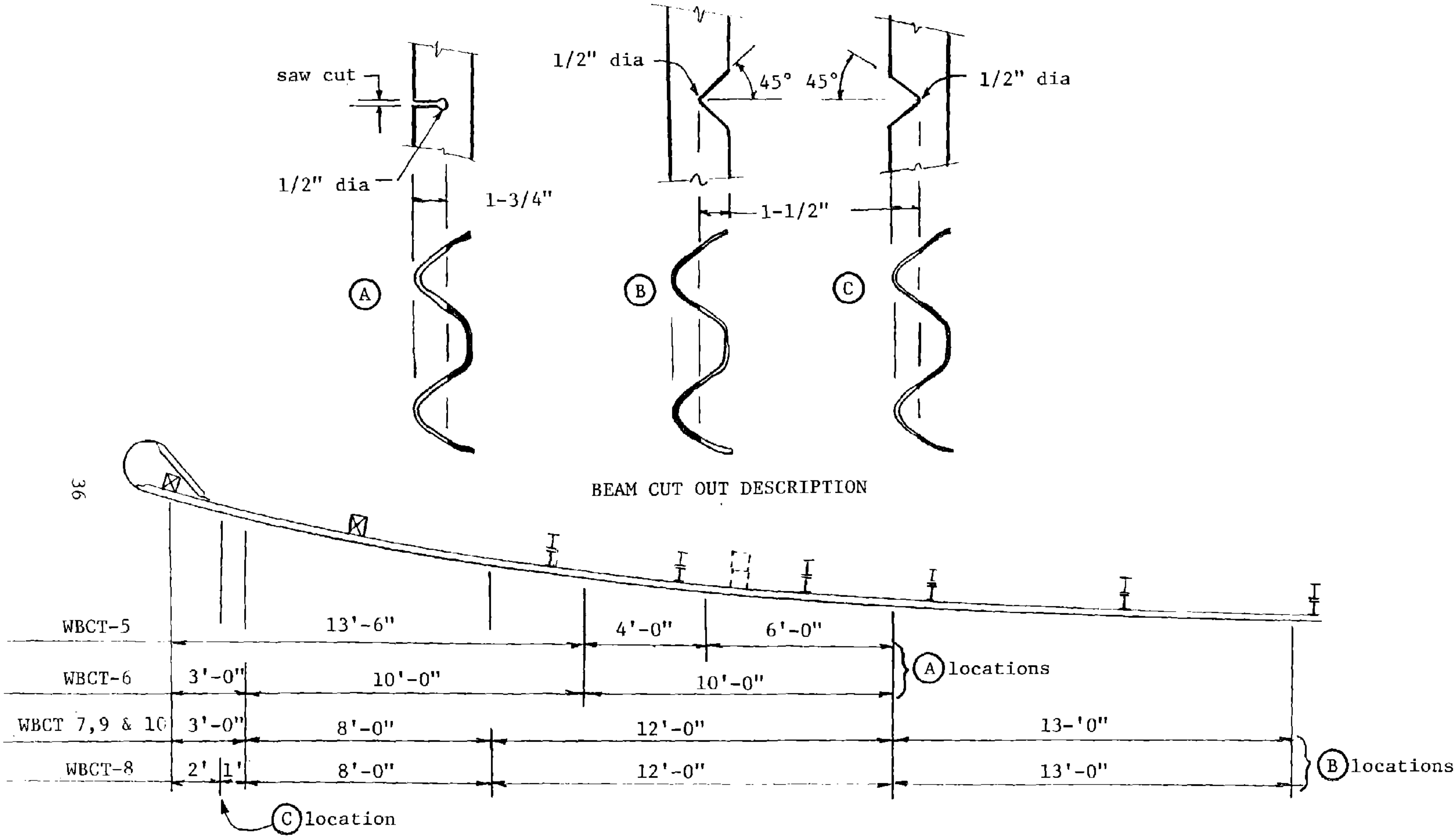


FIGURE 23. BEAM CUT OUT GEOMETRY

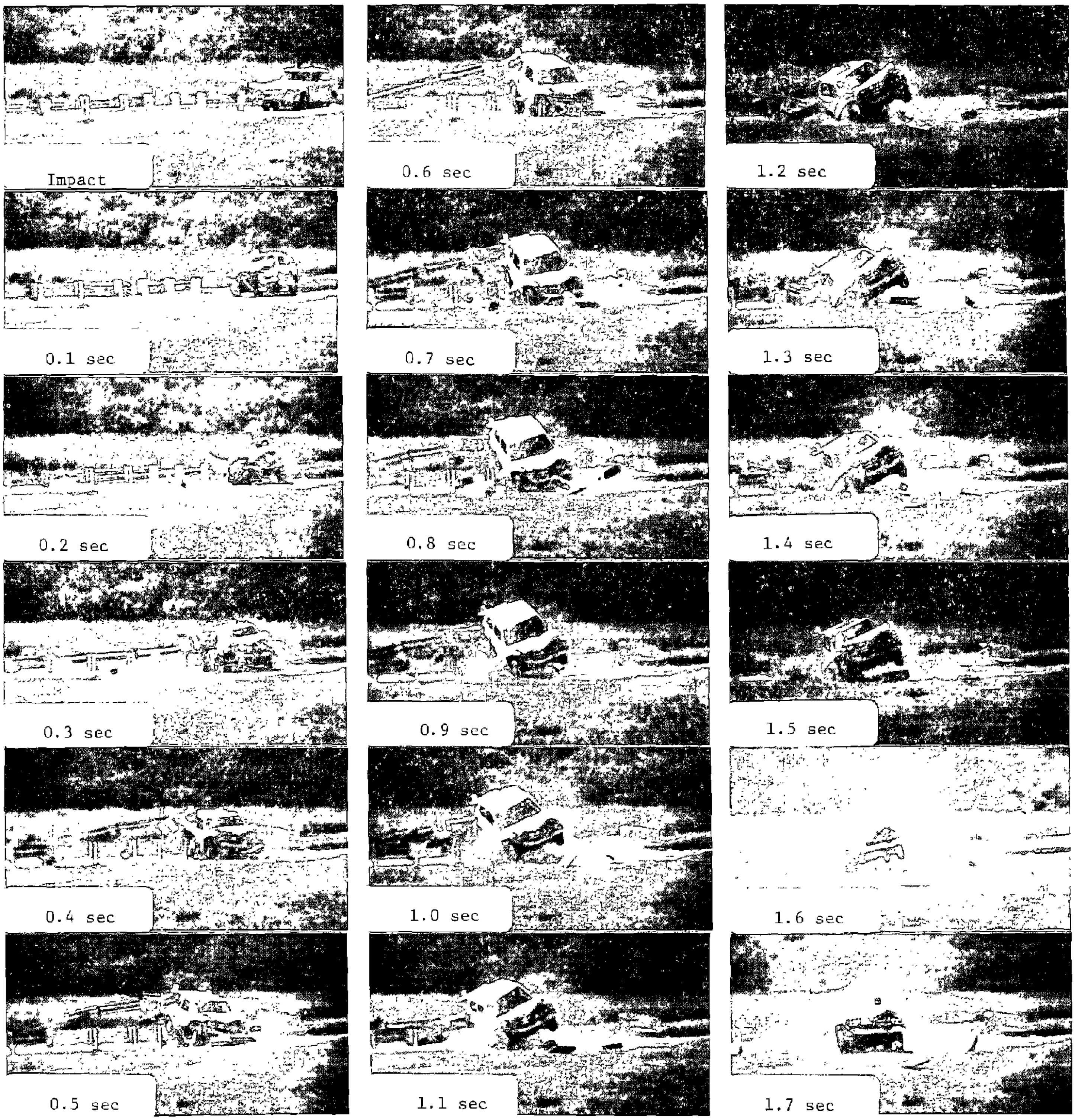
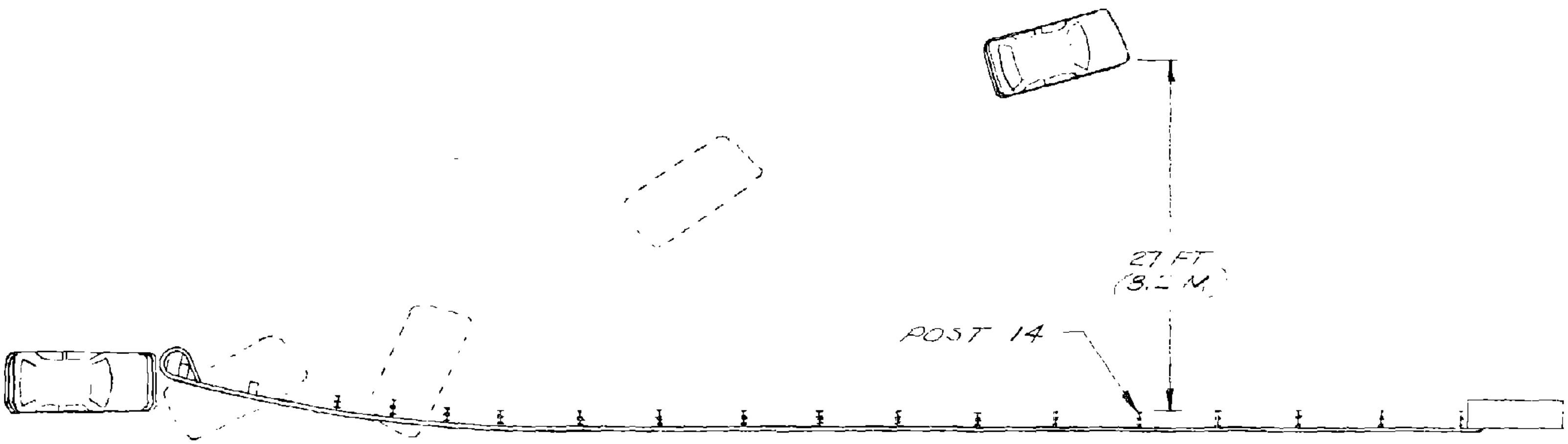


FIGURE 24. TEST WBCT-7 IMPACT SEQUENCE

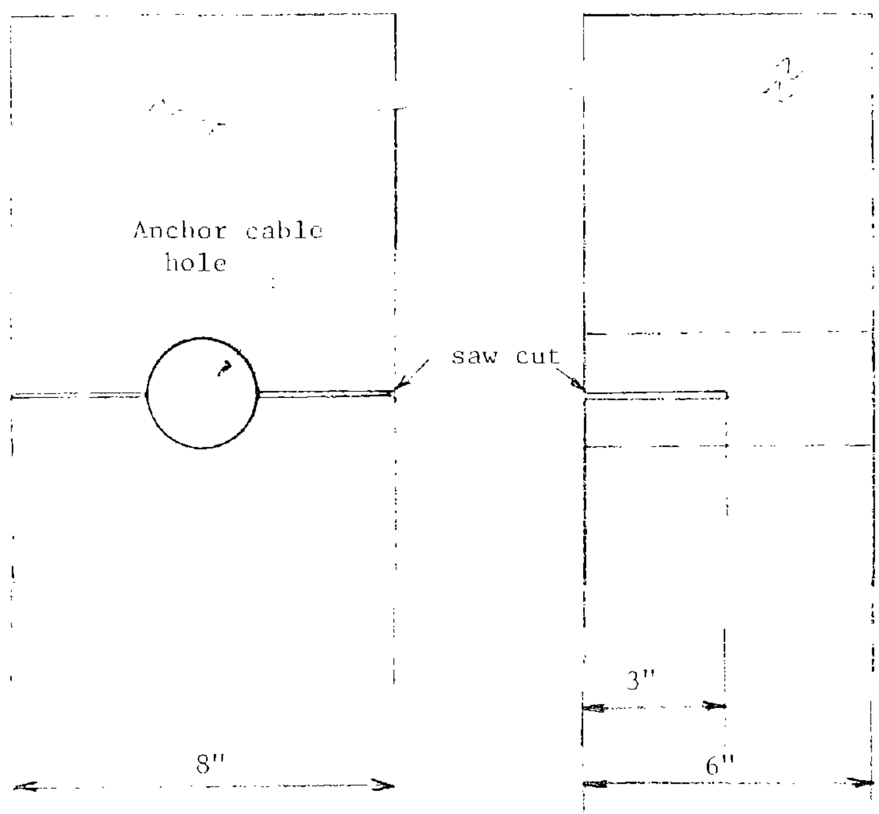
Impact 0.1 sec 0.2 sec 0.3 sec 0.4 sec



Test No. WBCT-7
Date 6/29/81
Test Installation Drawing No. 03-5433-03
Rail ... 12 ga steel x 12.5 ft (3.8 m) lg W-beam
Post (footing mounted) ... 6 in. (152mm) x 8 in. (203mm) x 5.33 ft (1.6m) lg wood
Post (soil mounted) ...W6x9x6 ft (1.8m) lg steel
Post Spacing .... 6.25 ft (1.9m)
Length of Installation .... 100 ft (30m)
Soil Condition .... Dry

Vehicle .... 1975 Honda Civic
Vehicle Mass .... 2120 lb (962 kg)
(w/dummies & instrumentation)
Impact Speed .... 59.2 mph (95.3 kmph)
Impact Angle .... 0.2 deg
Exit Speed 0
Vehicle Accelerations (max 50ms avg)
Lateral (cine/electr) 3.1g/4.5g
Longitudinal (cine/electr) ...... -8.8g/-14.1g
Vehicle Damage
TAD 12-FD-6
VDI 12FDEW6

FIGURE 25. SUMMARY OF RESULTS, TEST WBCT-7



WOOD BCT END POST

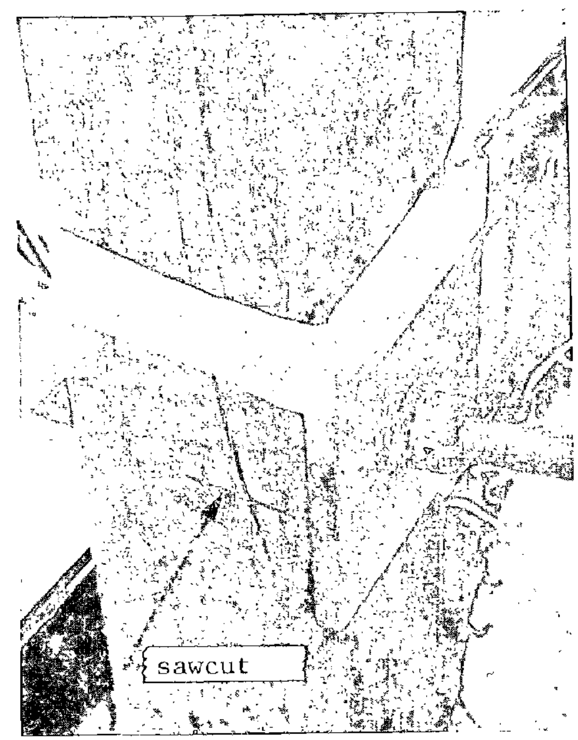


FIGURE 26. END POST SAW CUT DETAIL

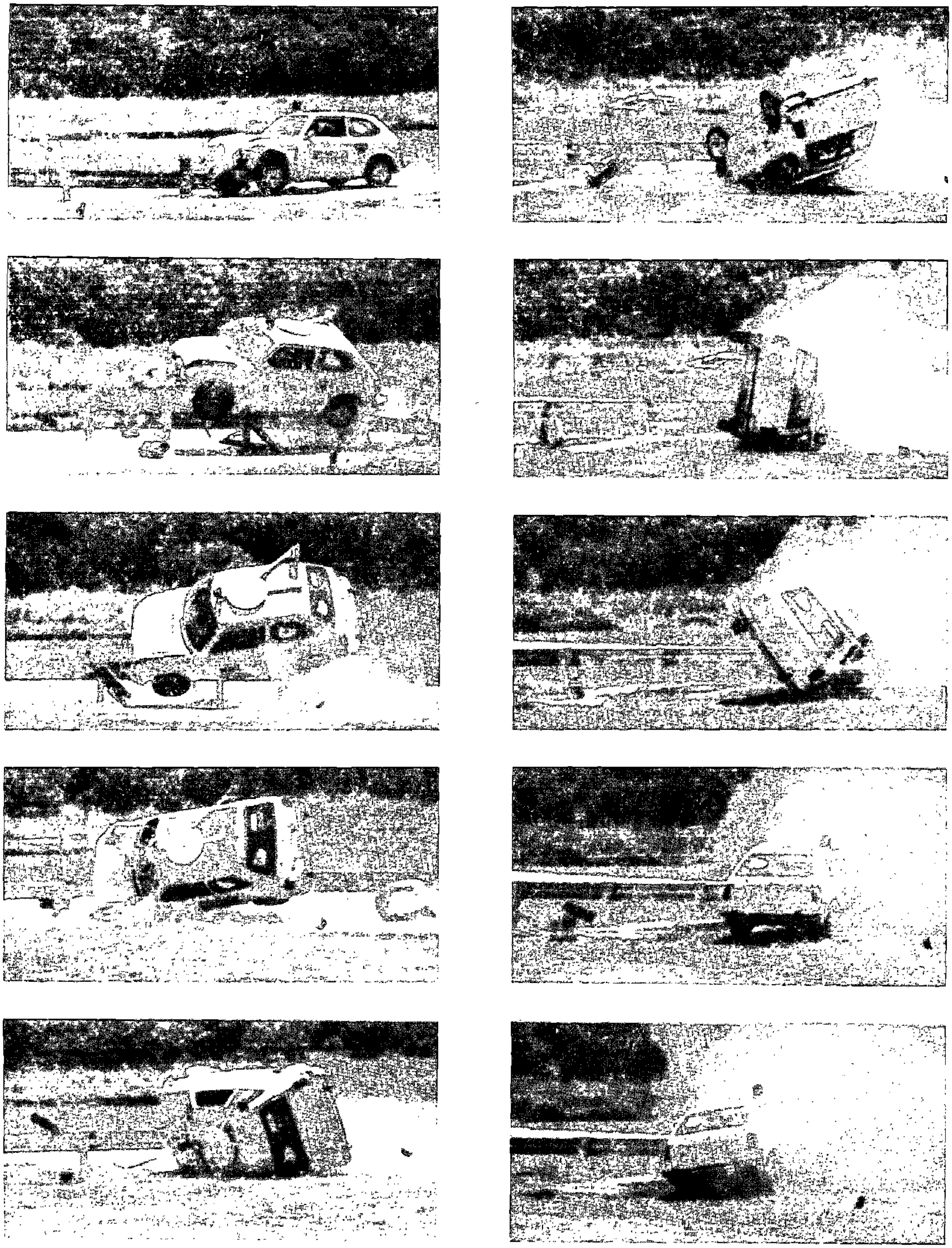
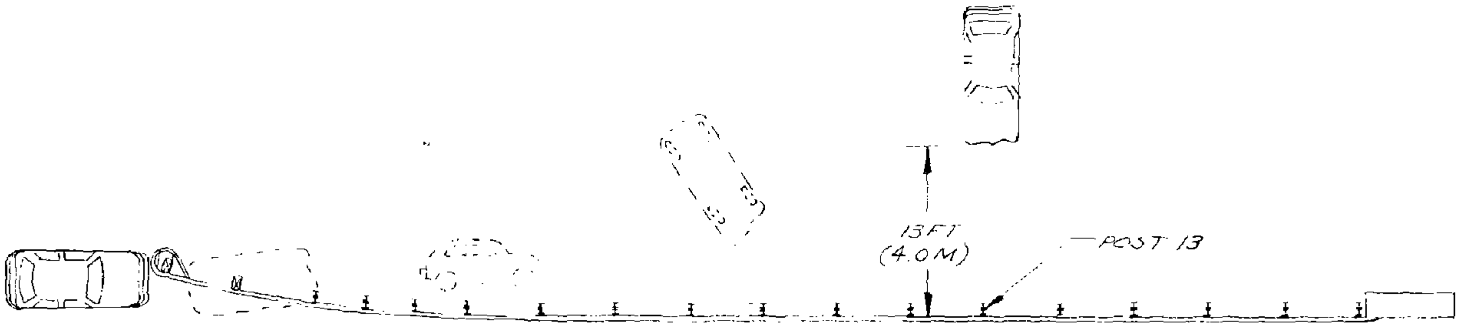


FIGURE 27. TEST WBCT-8 IMPACT SEQUENCE

Impact   0.5 sec   0.10 sec   0.15 sec   0.20 sec   0.25 sec   0.35 sec



Test No. WBCT-8
Date 8/7/81
Test Installation Drawing No. 03-5433-03
Rail .... 12 ga steel x 12.5 ft (3.8 m) lg W-beam
Post (footing mounted) ... 6 in. (152 mm) x 8 in. (203 mm) x 5.33 ft (1.6 m) lg wood
Post (soil mounted) .. W6x9x6 ft (1.8 m) lg steel
Post Spacing .... 6.25 ft (1.9 m)
Length of Installation .... 100 ft (30 m)
Soil Condition .... Dry

Vehicle .... 1975 Honda Civic
Vehicle Mass .... 2014 lb (914 kg) (w/dummies & instrumentation)
Impact Speed .... 59.3 mph (95.4 kmph)
Impact Angle .... 0.2 deg
Exit Speed 0
Vehicle Accelerations (max 50 ms avg)
Lateral (cine/electr)............. 4.1g/-2.7g
Longitudinal (cine/electr) .... -7.6g/-8.3g
Vehicle Damage
TAD 12-FD-6
VDI 12FDEW6

FIGURE 28. SUMMARY OF RESULTS, TEST WBCT-8

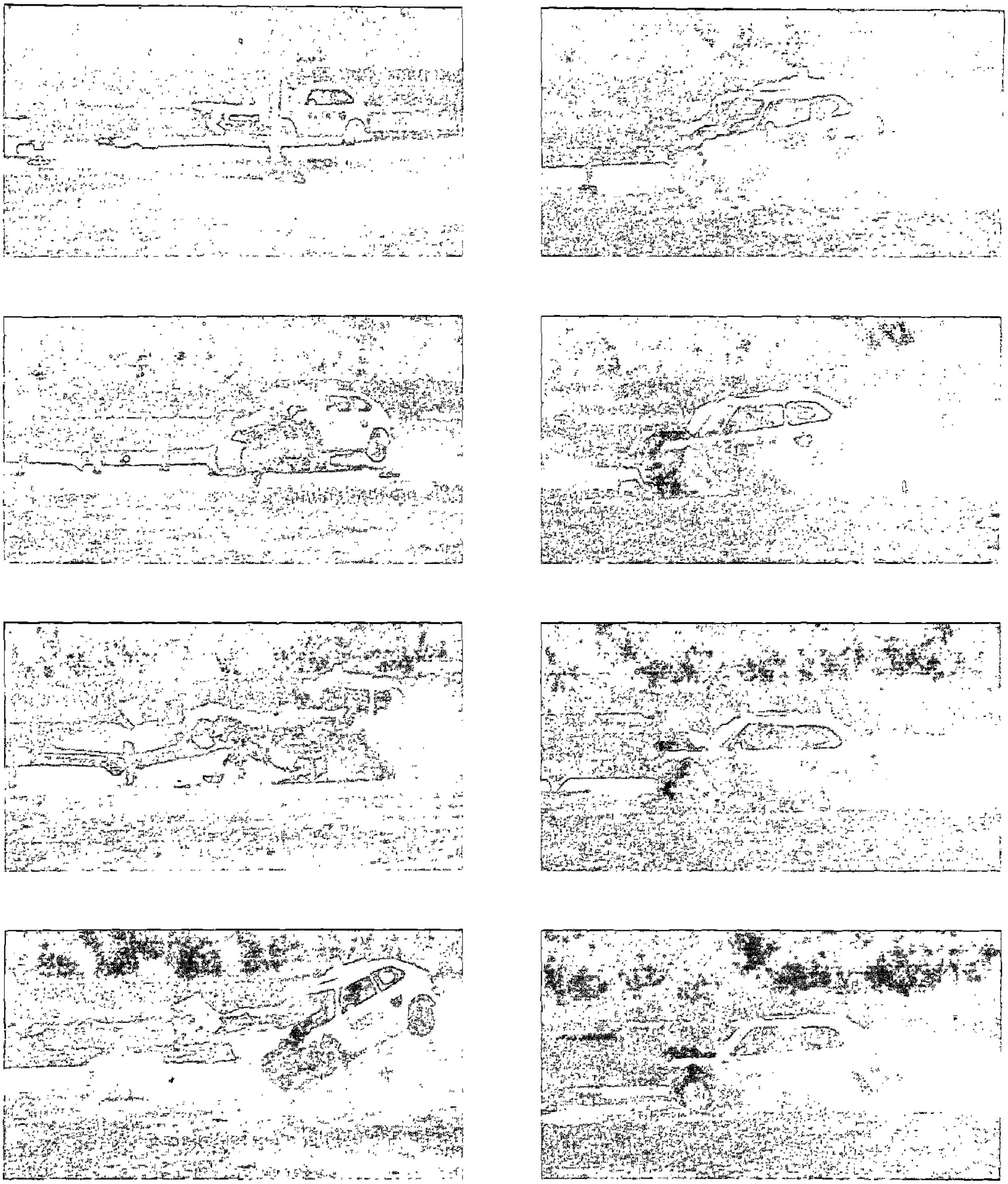
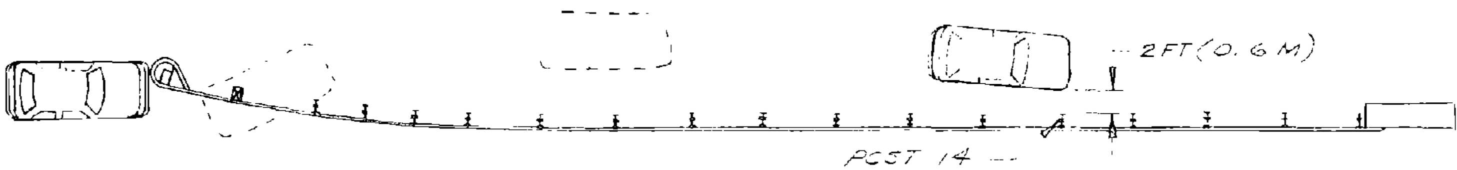


FIGURE 29. TEST WBCT-9 IMPACT SEQUENCE

Impact 0.05 sec 0.10 sec 0.15 sec 0.20 sec 0.25 sec



Test No. WBCT-9
Date 8/24/81
Test Installation Drawing No. 03-5433-03
Rail .... 12 ga steel x 12.5 ft (3.8 m) lg W-beam
Post (footing mounted) ... 6 in. (152 mm) x 8 in. (203 mm) x 5.33 ft (1.6 m) lg wood
Post (soil mounted) .. W6x9x6 ft (1.8 m) lg steel
Post Spacing .... 6.25 ft (1.9 m)
Length of Installation .... 100 ft (30 m)
Soil Condition .... Dry

Vehicle .... 1975 Honda Civic
Vehicle Mass .... 2040 lb (925 kg) (w/dummies & instrumentation)
Impact Speed .... 59.3 mph (95.4 kmph)
Impact Angle .... -1.3 deg
Exit Speed 0
Vehicle Accelerations (max 50 ms avg)
Lateral (cine/electr)............n.a./-3.3 g
Longitudinal (cine/electr) ...... n.a./-12.2 g
Vehicle Damage
TAD 12-FD-6
VDI 12FDEW6

FIGURE 30. SUMMARY OF RESULTS, TEST WBCT-9

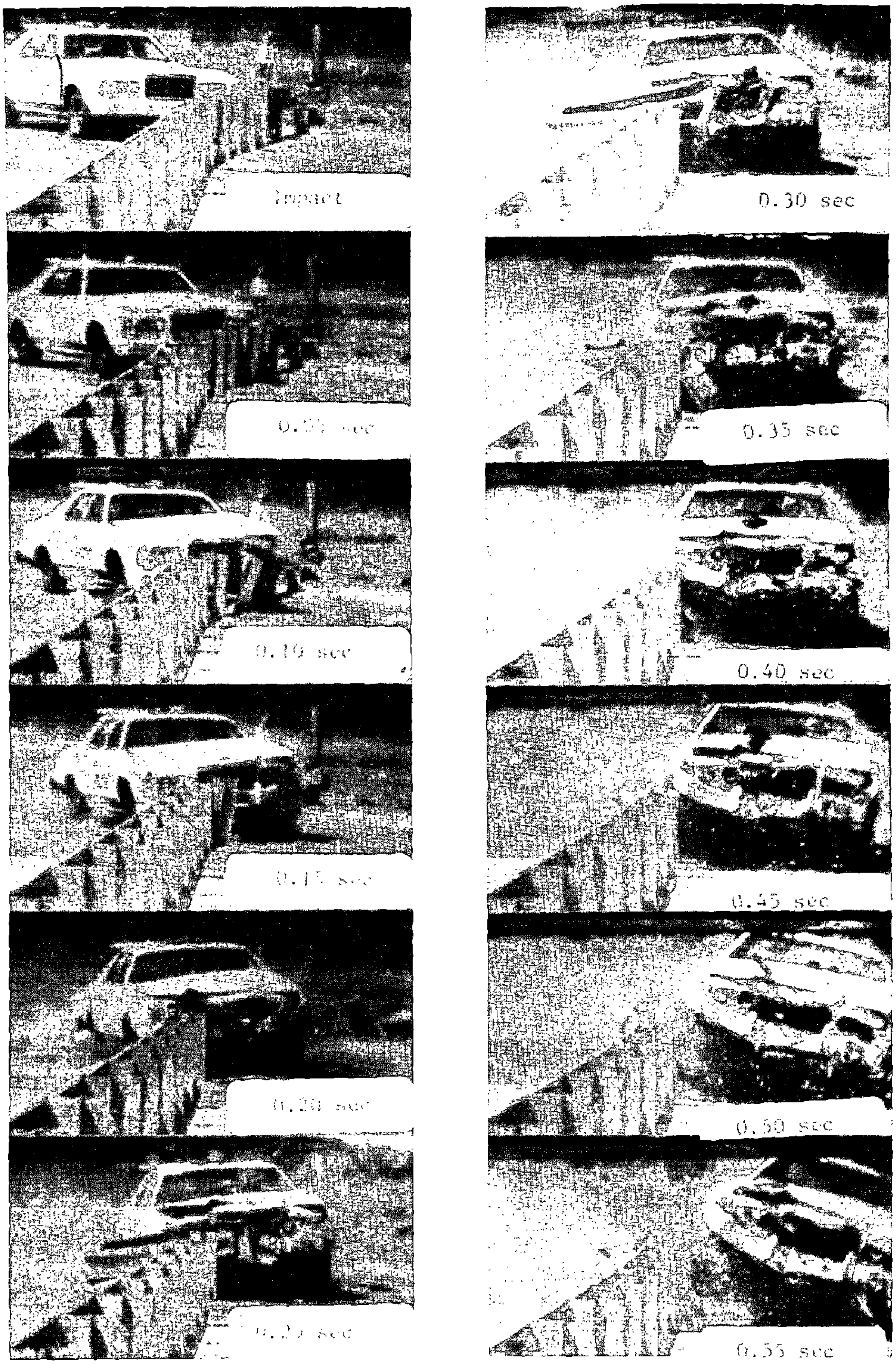
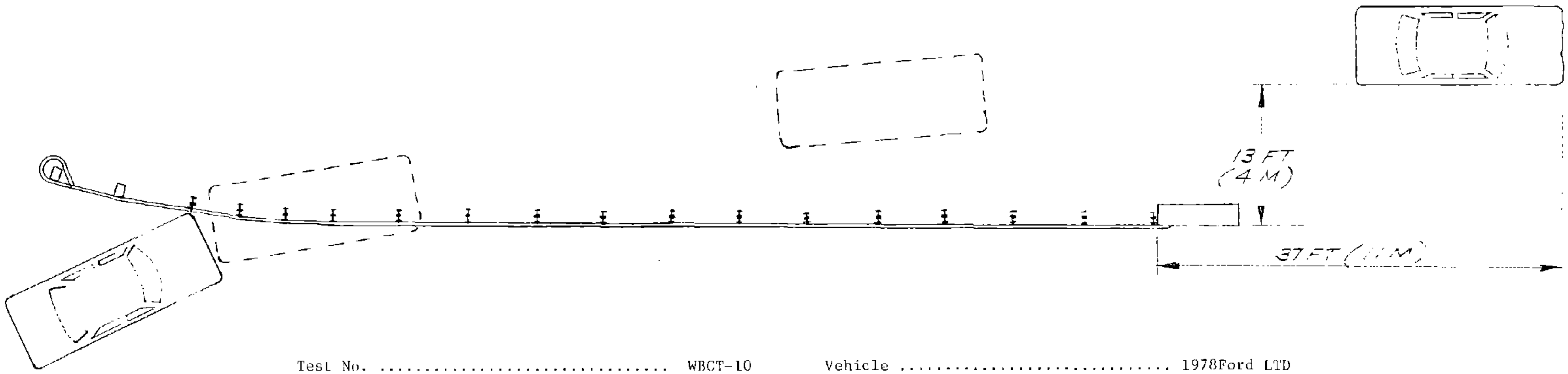


FIGURE 31. TEST WBCT-10 IMPACT SEQUENCE

Impact — 0.05 sec — 0.10 sec — 0.15 sec — 0.20 sec



Test No. WBCT-10
Date 9/18/81
Test Installation Drawing No.......... 03-5433-03
Rail .... 12 ga steel x 12.5 ft (3.8 m) lg W-beam
Post (footing mounted) ... 6 in. (152 mm) x 8 in. (203 mm) x 5.33 ft (1.6 m) lg wood
Post (soil mounted) .. W6x9x6 ft (1.8 m) lg steel
Post spacing .... 6.25 ft (1.9 m)
Length of Installation .... 100 ft (30 m)
Soil Condition .... Dry

Vehicle .... 1978Ford LTD
Vehicle Mass .... 4500 lb (2041 kg)
(w/dummies & instrumentation)
Impact Speed .... 58.1 mph (93.5kmph)
Impact Angle .... 24.9 deg
Exit Speed .... 51.3 mph (82.6kmph)
Exit Angle .... 0 deg
Vehicle Accelerations (max 50 ms avg)
Lateral (cine/electr)............. -4.6 g/-3.2 g
Longitudinal (cine/electr)......... -4.8 g/-5.2 g
Vehicle Damage
TAD 11-FL-3
VDI 11FLEW3

FIGURE 32. SUMMARY OF RESULTS, TEST WBCT-10

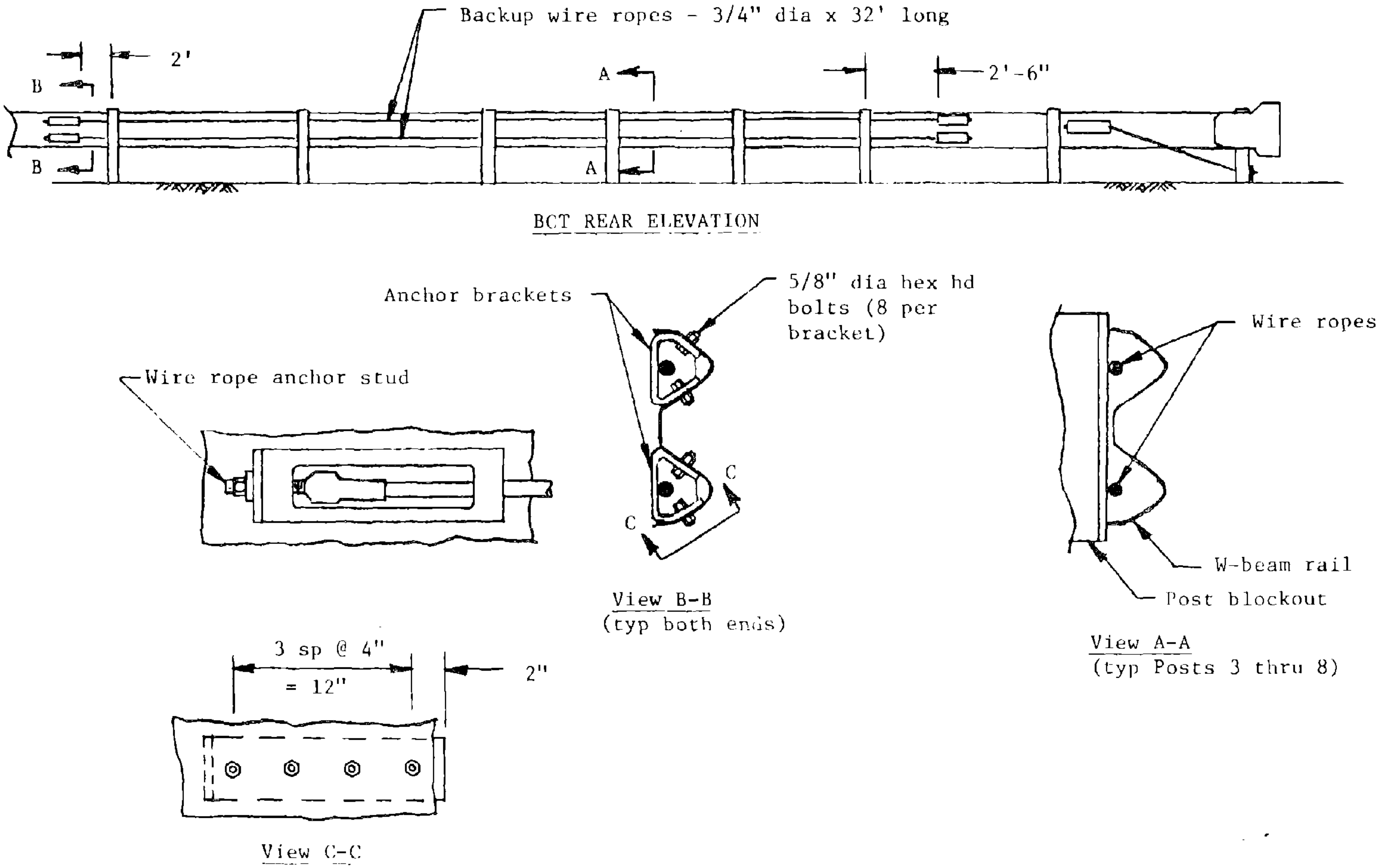
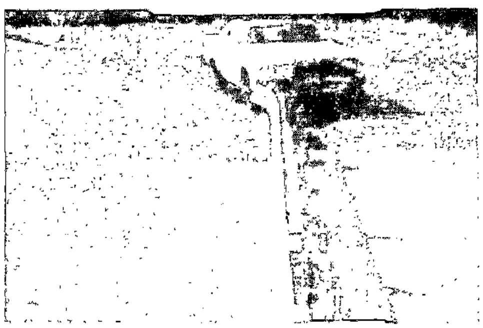


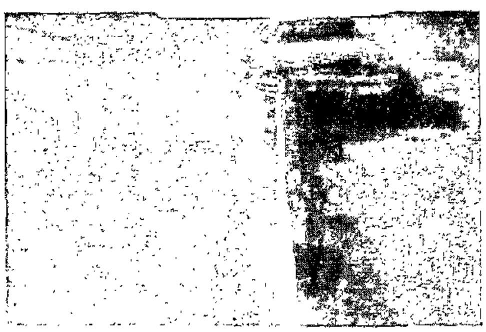
FIGURE 33. WIRE ROPE BACKUP SYSTEM - TEST RBCT-3

IMPACT

0.1 SEC



0.2 SEC



0.3 SEC

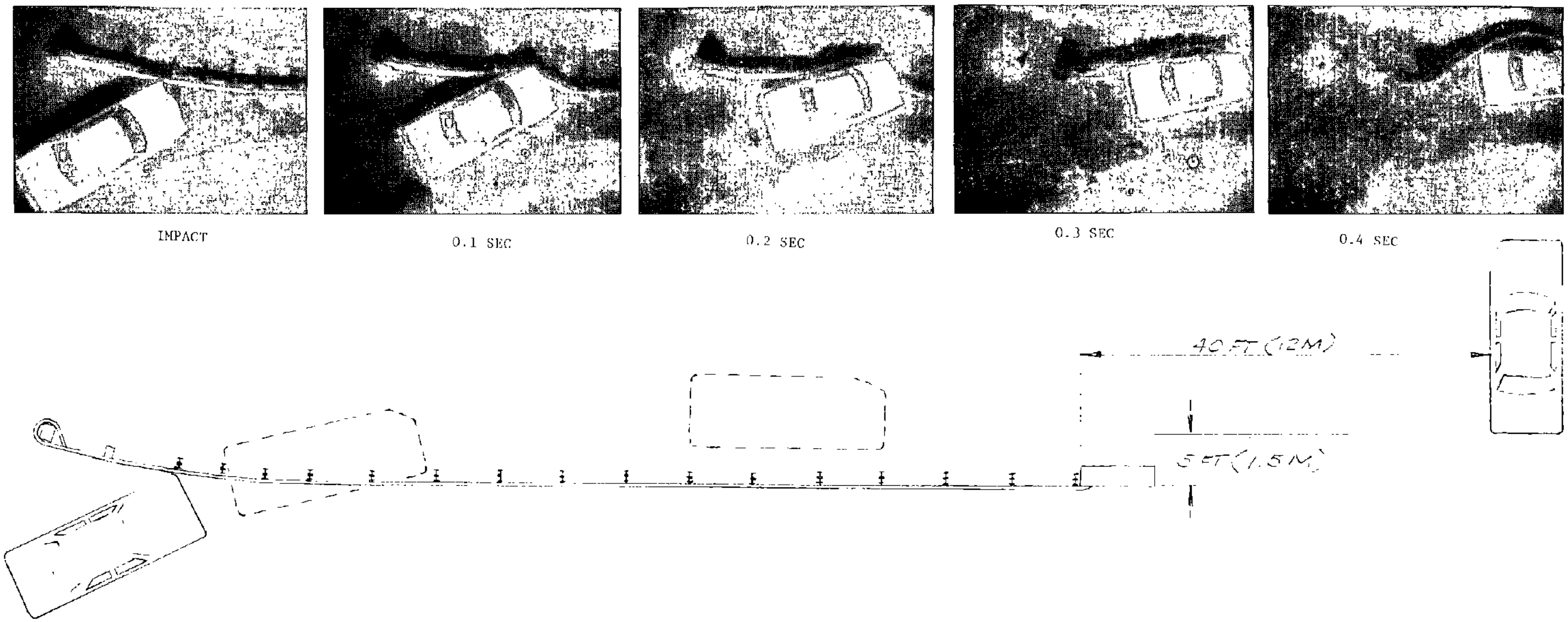
0.4 SEC

0.5 SEC

0.6 SEC

0.7 SEC

FIGURE 34. TEST RBCT-2 IMPACT SEQUENCE



Test No.	RBCT-2
Date	11/13/81
Installation	
DWG No	SWRI 6628-1
Length - Ft (M)	100(30)
Beam Rail	
Member	12 GA Steel W-Beam
Length - Ft (M)	12.5(3.8)
Maximum Deflections	
Dynamic - Ft (M)	10(3)
Permanent - Ft (M)	10(3)
Post (Footing Mounted)	
Material	Wood
Dimensions - In (M)	6x8x64 (0.15x0.2x1.6)
Embedment - In (M)	36(0.9)
Spacing - Ft (M)	6.25(1.9)

Post (Soil Mounted)	
Material	Steel
Dimensions - In (M)	W6x9x72 (0.15x0.23.1.8)
Embedment - In (M)	44 (1.1)
Spacing - Ft (M)	6.25 (1.9)
Soil Type and Condition	S-1/Dry
Vehicle	
Model	1978 Ford LTD
Mass - Lb (kg) Test Inertia	4555 (2066)
Dummy	165 (75)
Gross	4720 (2141)
Speed - MPH (kmph)	
Impact	58.7 (94.5)
Exit	33.7 (54.2)

Angle - Deg	
Impact	26.8
Exit	-7.4
Occupant Impact Velocity - Ft/Sec (M/S)	
Forward	
Lateral	
Occupant Ridedown Acceleration - g's	
Forward	
Lateral	
Vehicle	
Rebound Distance - Ft (M)	Penetration
Damage	
TAD	11-FL-3
VDI	11 FLEW 3

FIGURE 35. SUMMARY OF RESULTS, TEST RBCT-2

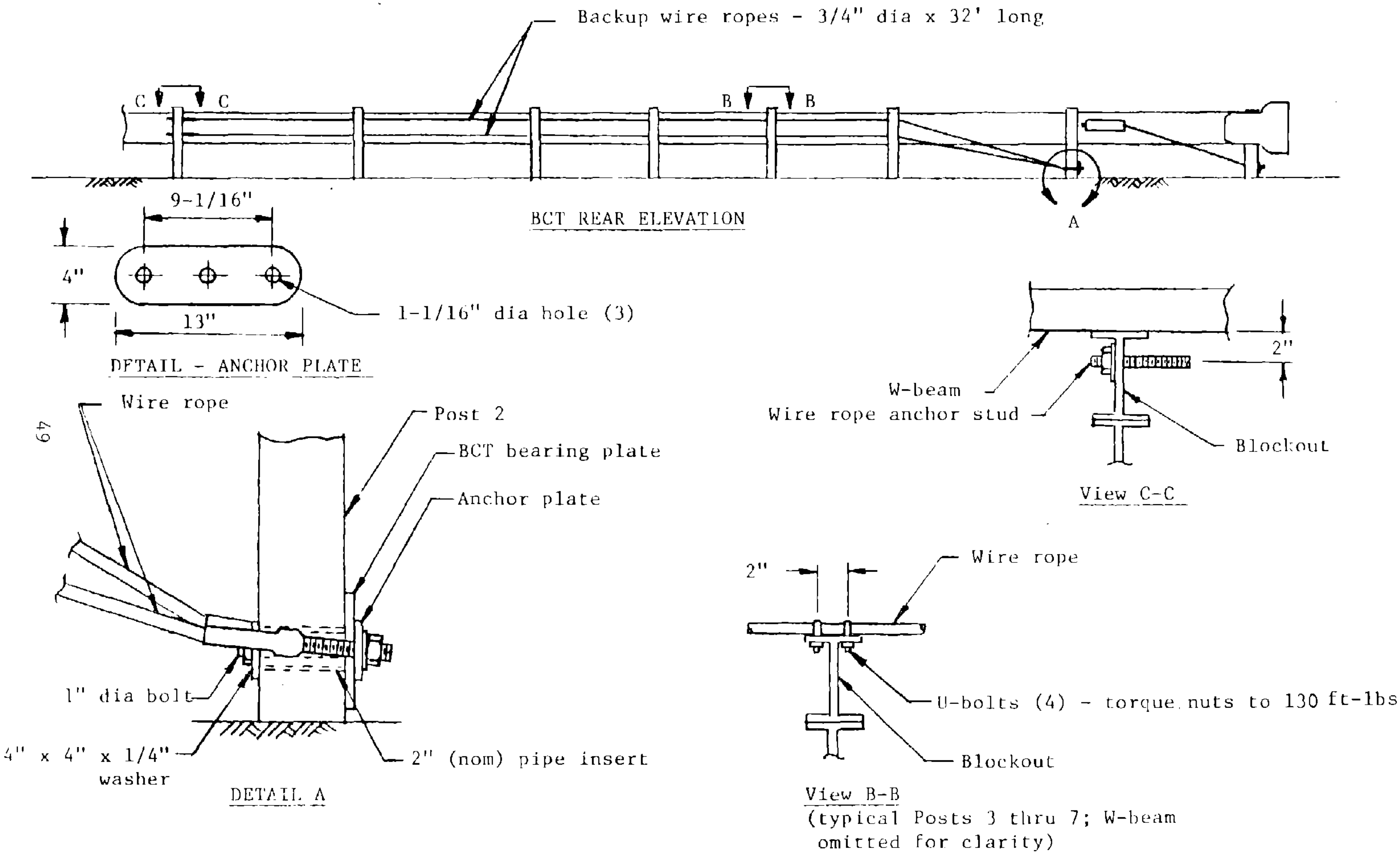


FIGURE 36. WIRE ROPE BACKUP SYSTEM - TESTS RBCT-1 & RBCT-2

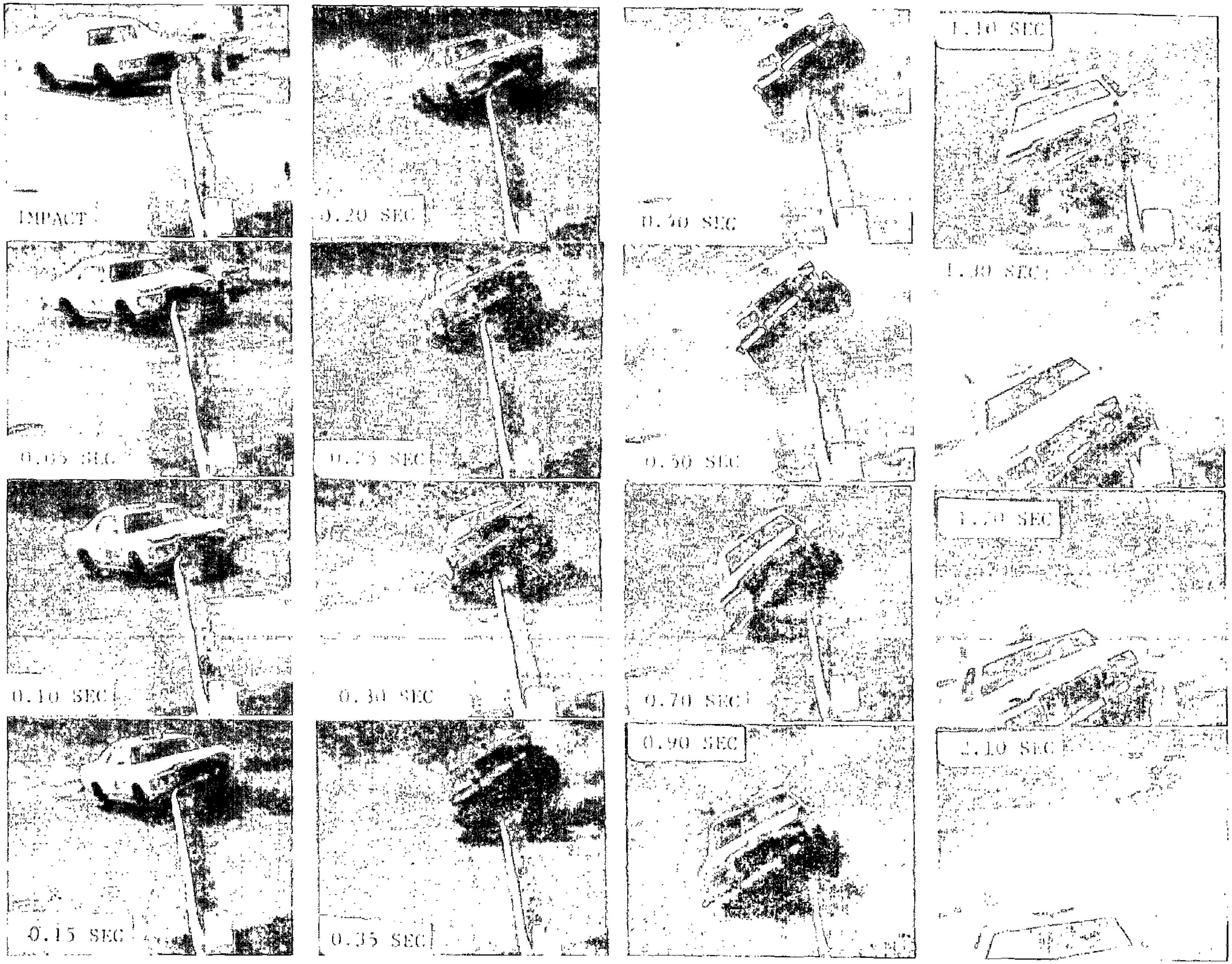
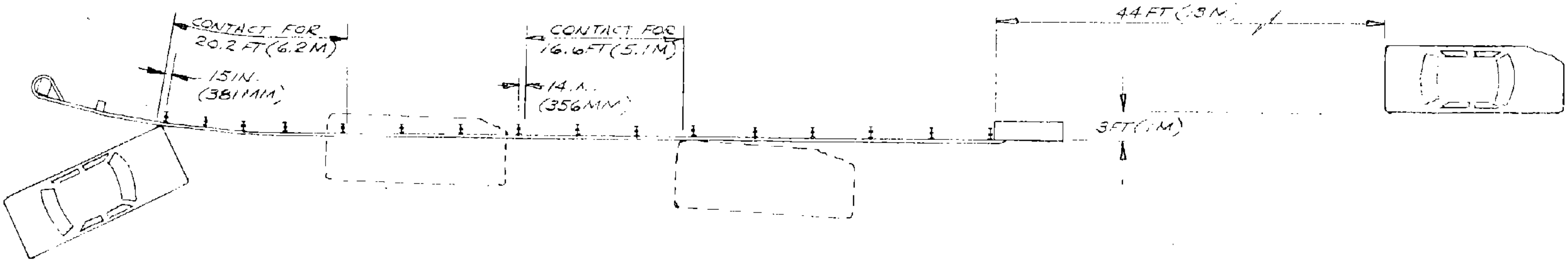


FIGURE 37. TEST RBCT-3 IMPACT SEQUENCE

IMPACT | 0.05 SEC | 0.10 SEC | 0.20 SEC | 0.30 SEC | 0.40 SEC



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Test No. RBCT-3
Date 12/10/81
Installation
  DWG No. .... SWRI 6628-1
  Length - Ft (M) .... 100(30)
Beam Rail
  Member .... 12 GA Steel W-Beam
  Length Ft (M) .... 12.5(3.8)
  Maximum Deflections
    Dynamic - In (MM) .... 23.6(599)
    Permanent - In (MM) .... 23.6(599)
Post (Footing Mounted)
  Material .... Wood
  Dimensions - In (M) 6x8x64 (0.15x0.2x1.6)
  Embedment - In (M) .... 36(0.9)
  Spacing - Ft (M) .... 6.25(1.9)

Post (Soil Mounted)
  Material .... Steel
  Dimensions - In (M).... W6x9x72 (0.15x0.23x1.8)
  Embedment - In (M) 44 (1.1)
  Spacing - Ft (M) 6.25 (1.9)
Soil Type and Condition S-1/Dry
Vehicle
  Model .... 1978 Ford LTD
  Mass - Lb (kg) Test Inertia 4527 (2053)
    Dummy 165 (75)
    Gross 4692 (2128)
Speed - MPH (kmph)
  Impact 55.9 (89.9)
  Exit 31.3 (50.4)

Angle - Deg
  Impact 24.9
  Exit .... -3.4
Occupant Impact Velocity - Ft/Sec (M/S)
  Forward ....
  Lateral ....
Occupant Ridedown Acceleration - g's
  Forward ....
  Lateral ....
Vehicle
  Rebound Distance - Ft (M) 6 (1.8)
  Damage
    TAD 11-FL-3
    VDI .... 11 FLEW 3

FIGURE 38. SUMMARY OF RESULTS, TEST RBCT-3

TABLE 1

SUMMARY OF BCT ACCIDENT CASES

Source	Vehicle	Impact Location (vehicle)	Impact Angle (deg)	Installation Geometry	End Posts	Nose	Line Posts	Remarks
1. New Jersey [8]								
#1	69 VW	frontal	>0	straight	8x8 wood	diaf	steel	1st post broke away, but vehicle contained - serious injury to driver, BCT behind 8" curb
#2	71 Chevrolet	frontal	>0	straight	6x8 wood	no diaf	steel	Broke 1st post, minor accident, no injuries
#3	75 Pontiac	frontal	-30	straight (taper)	6x8 wood	no diaf	steel	Splintered 1st post - no injuries
#4	76 Ford	frontal	>0	straight	6x8 wood	no diaf	steel	Broke 1st post, no injuries - BCT behind 8" curb
#5	64 Rambler	frontal	>0	straight (taper)	6x8 wood	no diaf	steel	Broke first post, vehicle struck utility pole immediately behind BCT, serious injuries
#6	72 Chevrolet	frontal	>0	straight	8x8	diaf	steel	Split 1st post, no injuries
#7	Ford Van	frontal	0	straight	6x8	no diaf	steel	Rail speared vehicle, moderate injury - BCT behind 8" curb
#8	Dodge Dart	frontal	>0	straight	6x8	no diaf	steel	Rail speared vehicle, severe injury
#9	70 Chrysler	frontal	>0	straight	6x8	no diaf	steel	Vehicle hit BCT and rode 80 ft on top. Vehicle overturned, moderate injury
#10	Vega	frontal	>0	straight	6x8	no diaf	steel	Rail speared vehicle, serious injury
#11	77 Chevrolet	frontal	>0	straight	6x8	no diaf	steel	Vehicle ramped on BCT which did not break-away, but leaned in soil - moderate injury
#12	Chevrolet Van	frontal	0	straight	6x8	no diaf	steel	1st post split, 2nd post broke; head injuries
#13	Plymouth Satellite	frontal	>0	straight	6x8	no diaf	steel	1st post broke, rail speared vehicle
2. Indiana [9]								
#1	77 Buick Skylark	side	90	not known	steel slip base	no diaf	steel	Nose of BCT penetrated driver's door, fatal
#2	79 Dodge Van	side	>90	not known	steel slip base	no diaf	steel	Nose of BCT penetrated passenger compartment - fatal
#3	70 Ford Van	frontal	>0	1 ft flare	steel slip base	no diaf	steel	Nose penetrated vehicle, fatal
#4	78 Camaro	side	>0	4 ft flare	steel slip base	no diaf	steel	Nose of BCT pushed fender under hood, fatal
#5	77 Camaro	side	>90	1 ft flare	steel slip base	no diaf	steel	BCT penetrated into driver's door, fatal
#6	80 Pontiac Phoenix	side	>0	not known	steel slip base	no diaf	steel	BCT penetrated thru door, fatal
#7	75 Camaro	frontal	5-10	1 ft flare	steel slip base	no diaf	steel	Vehicle left front broke BCT away - satisfactory performance, no injuries
#8	69 Ford Pickup	frontal	>0	1 ft flare	steel slip base	no diaf	steel	BCT performed satisfactorily, no injuries
#9	68 Buick (full size)	frontal	60	not known	steel slip base	no diaf	steel	BCT performed satisfactorily, BCT behind 6" bitum. curb
#10	72 Ford	frontal	>0	1 ft flare	steel slip base	no diaf	steel	BCT performed satisfactorily, no injuries

TABLE 2

SUMMARY OF BASELINE CRASH TEST RESULTS

	Vehicle Weight, lb		Impact Conditions			Max 50 msec avg Vehicle Accel., g's				
						Longitudinal		Lateral		
Test	Inertia	Gross	Location*	Angle, deg	Speed, mph	Cine	Electr.	Cine	Electr.	Remarks
WBCT-1	1837	2167	A	-0.3	30.7	-9.0	-9.6	2.1	1.5	Vehicle yawed over 90 deg
WBCT-2	1848	2178	A	-0.3	59.0	-13.1	-15.0	3.7	7.9	Vehicle rolled on side
WBCT-3	1848	2178	B	14.5	59.3	-14.6	-13.8	6.6	7.6	Vehicle rolled over
SBCT-1	1850	2180	A	0.5	60.0	-11.2	-15.2	5.0	4.5	Vehicle speared by rail

*A - vehicle centerline offset 15 in. from end post centerline

B - vehicle centerline in line with end post centerline

TABLE 3

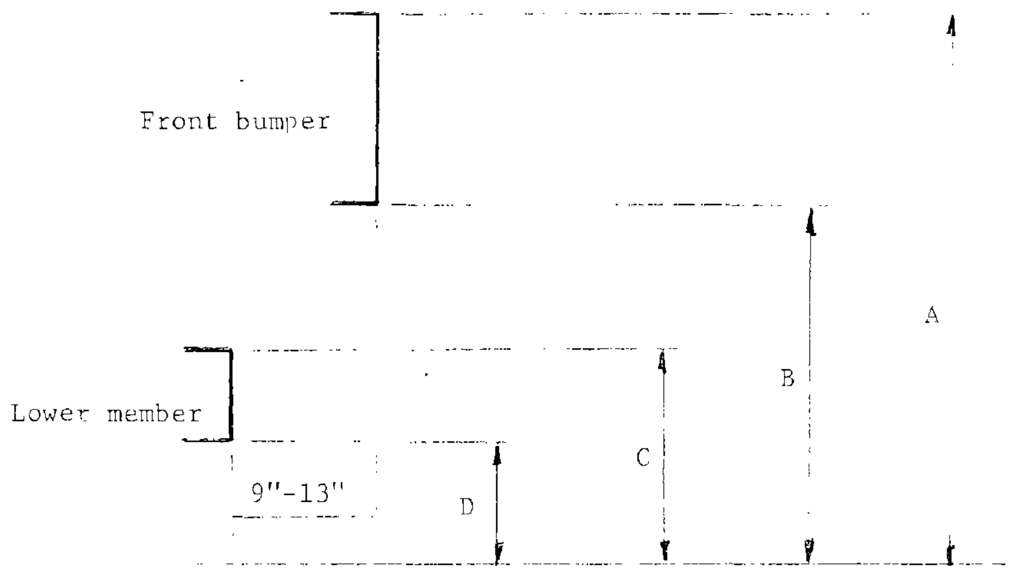
SUMMARY OF BCT RETROFIT TESTS

Test**	Vehicle Weight, lb		Impact Conditions			Max 50 msec Avg Accelerations, g's				Occupant Risk				Remarks
						Long.		Lat.		Impact Velocity, fps		Ridedown Accel, g's		
	Inertia	Gross	Location	Angle, deg	Speed, mph	Cine	Electr	Cine	Electr	Long.	Lat	Long.	Lat	
WBCT-4	1840	2170	A	0.6	59.4	10.0	-16.4	1.6	6.0	33.4	12.2	-3.6	-3.7	Vehicle roll and pitch instability
WBCT-5	1840	2170	A	0.0	56.8	n/a	-16.9	n/a	3.9	37.7	*	-6.7	*	Vehicle roll and pitch instability
WBCT-6	1794	2124	A	0.0	60.4	-11.2	-18.7	4.2	3.5	38.6	*	-12.2	*	Vehicle tumbled and rolled onto side
WBCT-7	1790	2120	A	0.2	59.2	-8.8	-14.1	3.1	4.5	34.2	7.8	-10.3	2.6	Vehicle roll and pitch instability
WBCT-8	1684	2014	A	0.2	59.3	-7.6	-8.3	4.1	-2.7	27.1	*	-10.9	*	Vehicle launched and rolled over
WBCT-9	1710	2040	A	-1.3	59.3	n/a	-12.2	n/a	-3.3	30.2	*	-8.4	*	Vehicle remained upright although pitch and roll was significant
WBCT-10	4489	4819	B	24.9	58.1	-4.8	-5.2	-4.6	3.2	20.5	10.2	-6.2	4.1	Vehicle penetrated beam
RBCT-2	4555	4720	B	26.8	58.7	-4.7	-3.7							Vehicle penetrated beam
RBCT-3	4527	4692	B	24.9	55.9	-7.5	-4.9							Vehicle redirected

*Insufficient lateral pulse for occupant to displace 1.0 ft; therefore, criteria is not applicable.
**See Figure 15 for installation description.

TABLE 4

SMALL VEHICLE GEOMETRIES



	A	B	C	D
Ford Fiesta	19-3/4	15-1/4	7-1/2	6-1/4
Honda Civic (pre '78)	20-1/4	16-1/4	9	6-3/4
Honda Civic ('78 or later)	19	14-1/2	8-1/2	6-1/2
Chevette	20-1/2	15	9-1/2	7
Rabbit	19-1/4	15	6-3/4	5-3/4
Omni	20-1/8	15-1/8	8	6-3/8
K-car	21-1/2	14	8-1/2	6-3/4

APPENDIX A

IMPACT TEST RESULTS

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APPENDIX A

IMPACT TEST RESULTS

Data presented in this section were taken from pendulum, bogie, and full-scale vehicle impact tests performed during the course of this program. These are presented in the chronological sequence in which they were performed.

TEST WBCT-1

Purpose: Objective of this test was to evaluate the wood post breakaway cable terminal end treatment when impacted by a minicompact automobile at 30 mph (48.3 kmph) and a 0-deg angle. The desired impact point on the vehicle was 15 in. (381 mm) to the left of the vehicle centerline.

Test Installation: The test installation as shown in Figure A.1 consisted of a 37.5-ft (11.4-m) long standard design wood post BCT attached to a 62.5-ft (19.1-m) section of G4 wood post guardrail. The system was anchored at the downstream end by a concrete deadman. Post spacing was 6.25 ft (1.9 m) and the 6-in. x 8-in. (150-mm x 203-mm) posts were embedded either 36 in. (0.91 m) in concrete footings (Posts 1 and 2) and 44 in. (1.12 m) in soil (Posts 3 thru 17). Height of the steel W-beam rail was 27 in. (0.69 m).

Test Vehicle: The test vehicle was a 1975 Honda Civic sedan. Two 50th percentile anthropomorphic dummies were placed in the driver and right front passenger seating positions; dummies were restrained by lap/shoulder belts. Total weight of the vehicle, dummies, and instrumentation was 2167 lb (983 kg).

Performance: Impact conditions were 30.7 mph (49.5 kmph) and a -0.3 deg angle. As shown in the sequential photographs of Figure 5 the vehicle impacted the buffer end section, displaced it, and then contacted the first post/protruding end of the rail section. Substantial vehicle front end crush was observed before the first post fractured and a plastic hinge formed in the rail at Post 2 allowing the vehicle to bend it rearward. As the vehicle accomplished this yielding of the barrier it yawed in a counterclockwise direction and came to a stop with the vehicle c.g. approximately over the stub of the first post and oriented 96.5 deg to the straight section of the barrier. Maximum 50 millisecond average vehicle accelerations measured were 2.2 g (film analysis) and 1.5 g (accelerometer) in the lateral direction, and -9.0 g (film analysis) and -9.6 g (accelerometer) in the longitudinal direction. A summary of test results is shown in Figure 6, and Table A.1 contains results of high-speed film analysis.

Approximately 130 milliseconds into the event a momentary power loss was experienced at the SwRI instrumentation trailer and only data gathered to that point was recorded. Since peak vehicle accelerations occurred during that period (as verified by film analysis) that data is meaningful and is shown in Figure A.2. As there is a time interval after impact in which the dummies move relative to the vehicle, the dummy transducers had only begun to transmit data signals when the power failure occurred. Therefore, dummy data is meaningless and not reported.

Barrier Damage: As shown in Figure A.3 only the first section of the barrier was damaged. Post 1, the buffer end section, and one rail section required replacement prior to the next test.

Vehicle Damage: Vehicle damage, as shown in Figure A.4, was substantial. Maximum vehicle crush was 20 in. (508 mm). The left front wheel and suspension system was driven rearward until it contacted the wheel well. All engine mounts were broken and the engine forced back into the firewall. The entire front portion of the unibody was deformed, and the left door was bowed outward as a result of high compression forces in that area.

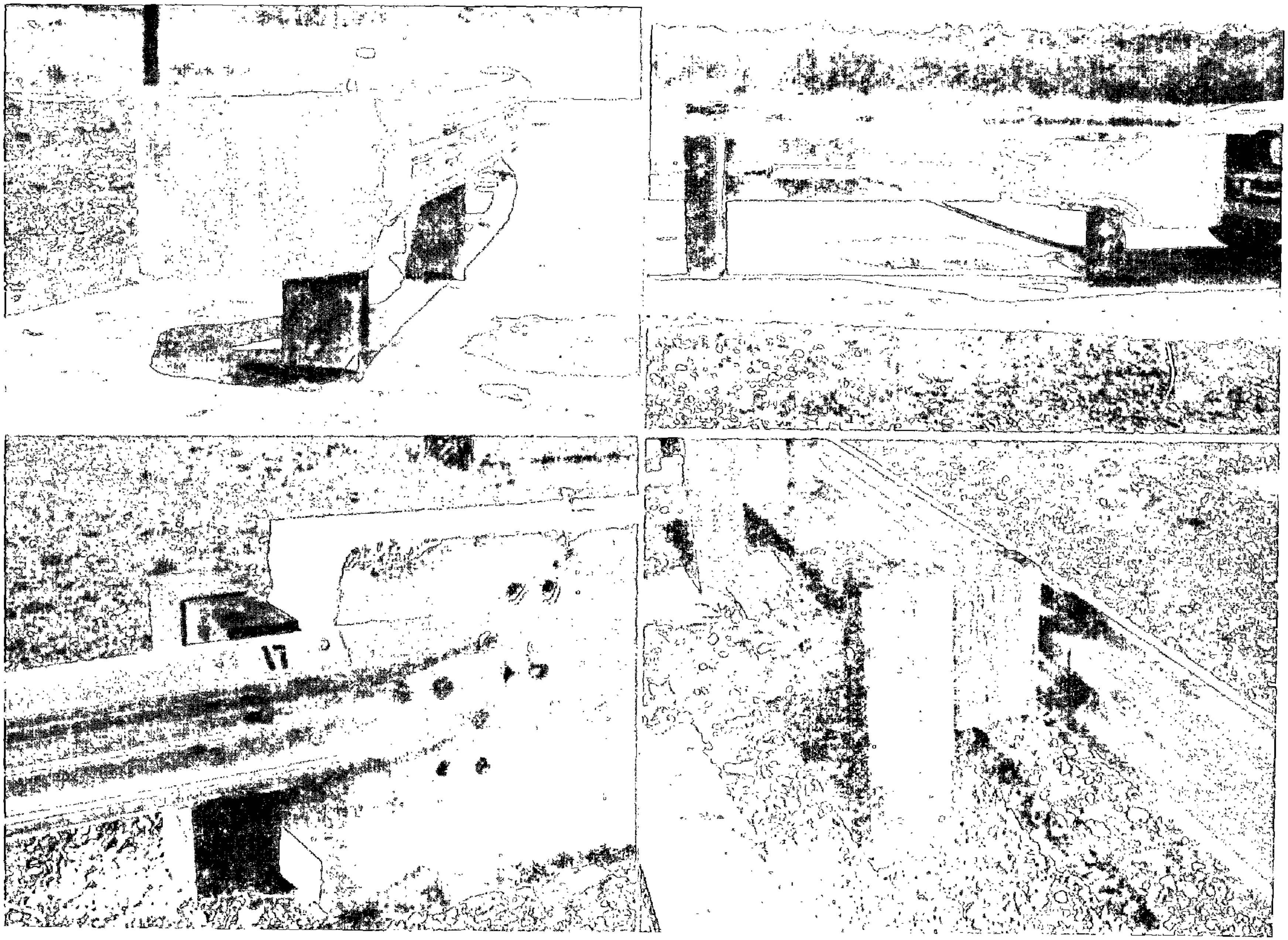


FIGURE A.1 WOOD POST BREAKAWAY CABLE TERMINAL TEST INSTALLATION

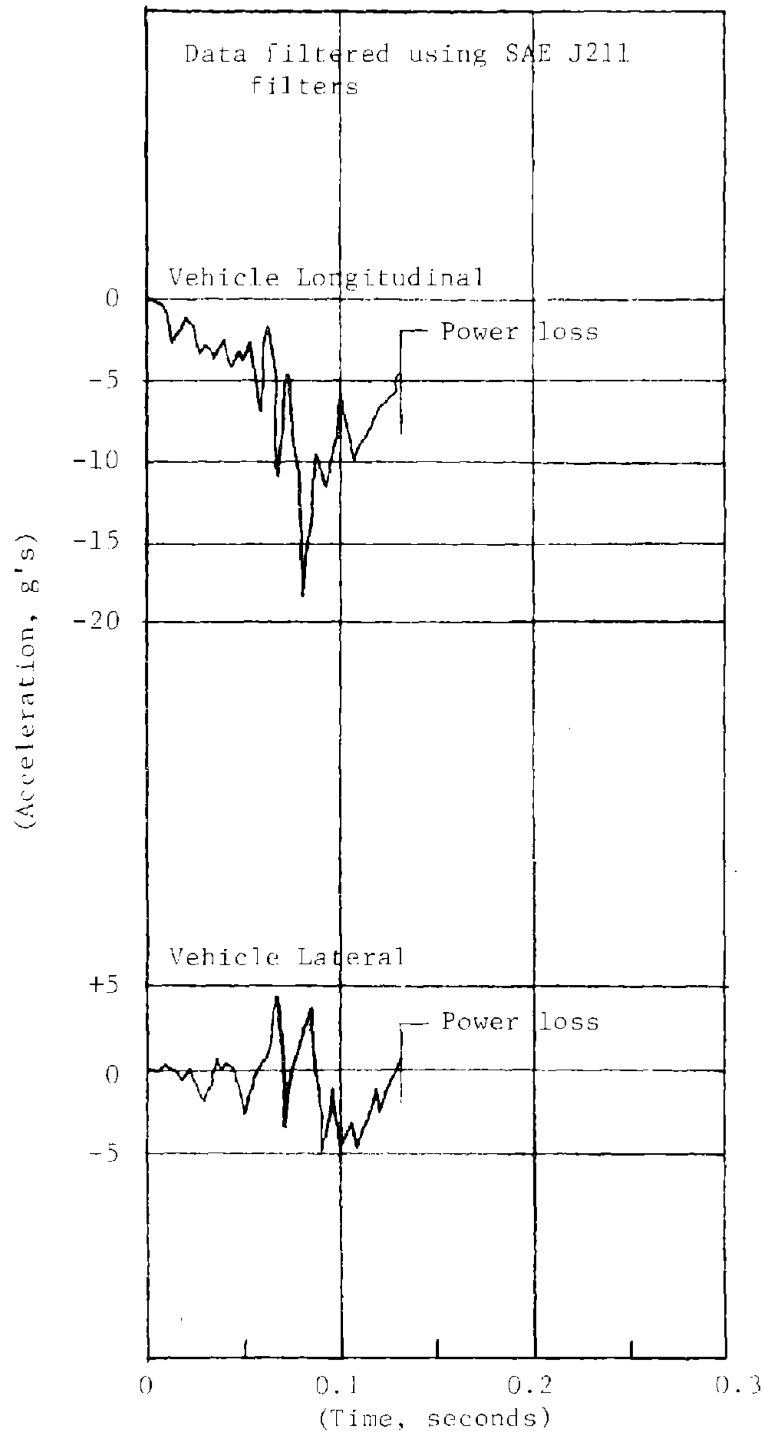


FIGURE A.2 ACCELEROMETER DATA, TEST WBCT-1

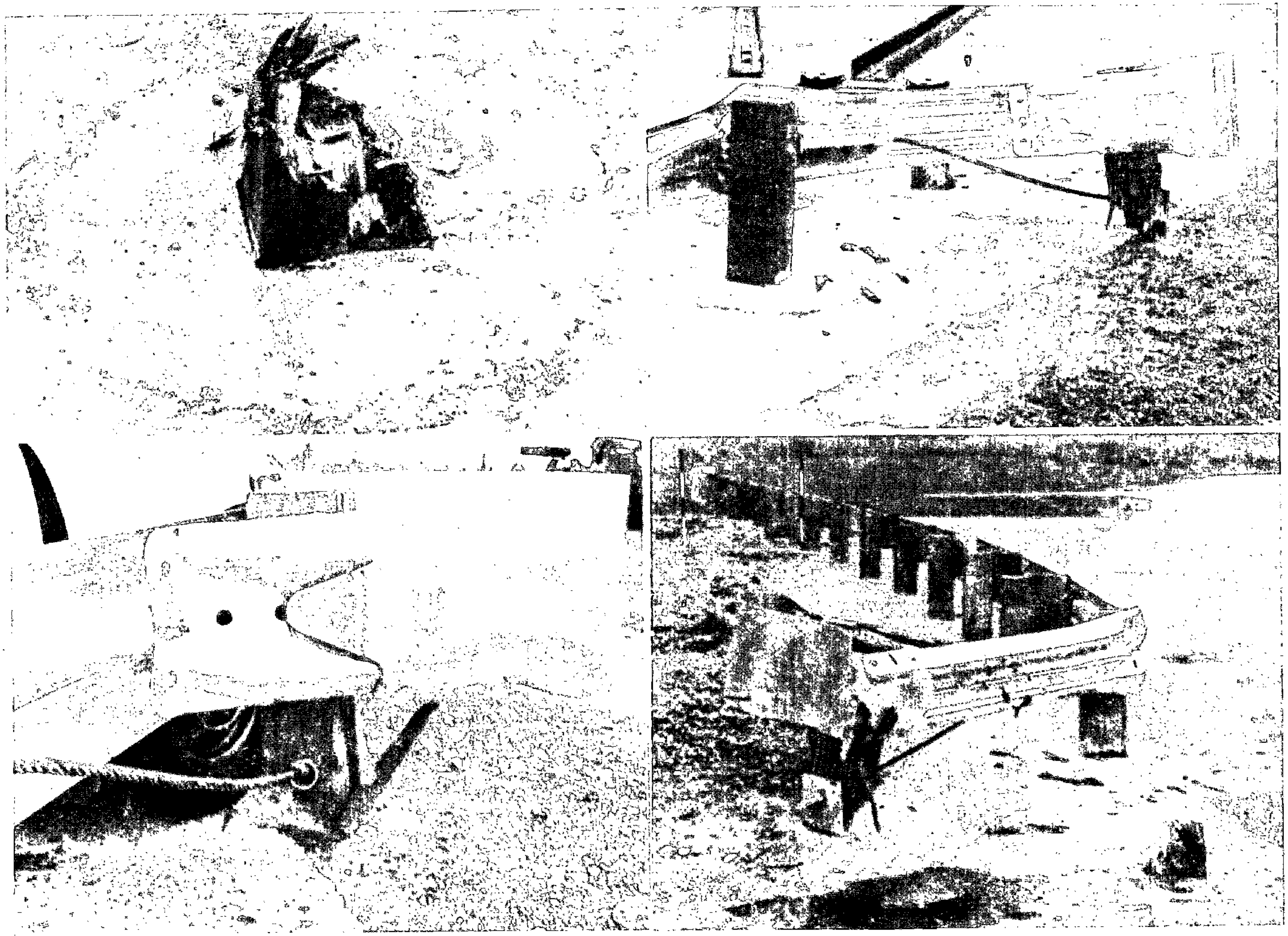


FIGURE A.3 TEST WBCT-1 BARRIER DAMAGE

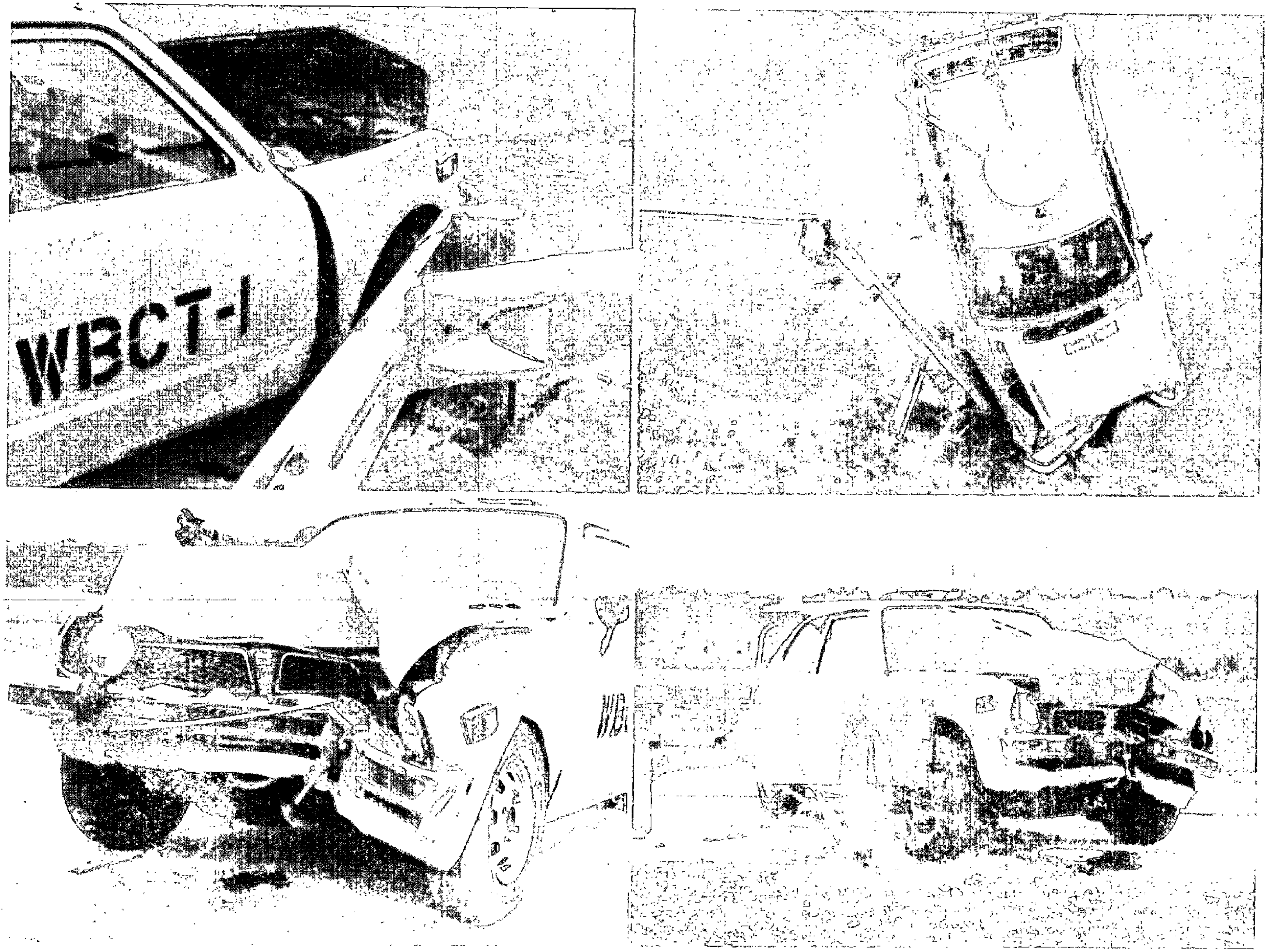


FIGURE A.4 TEST WBCT-1 VEHICLE DAMAGE

TABLE A.1

TEST WBCT-1 FILM ANALYSIS RESULTS

SUMMARY OF VEHICLE KINEMATIC AND DYNAMIC DATA   WOOD POST BCT TEST WBCT-1   3/31/80

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	-7.47	3.71	-.27	45.06	-1.34	-1.62	-1.20	0.00	0.00	3527	2564
.010	-7.02	3.69	-.40	44.27	-1.54	-3.28	-.64	0.00	0.00	7113	1338
.020	-6.58	3.67	-.52	42.97	-1.56	-4.82	-.08	0.00	0.00	10449	72
.030	-6.16	3.65	-.59	41.19	-1.45	-6.18	.45	-5.32	.14	13391	-1116
.040	-5.76	3.63	-.58	39.01	-1.23	-7.32	.92	-6.53	.62	15842	-2156
.050	-5.38	3.62	-.45	36.50	-.95	-8.20	1.32	-7.53	1.04	17749	-3001
.060	-5.03	3.61	-.17	33.75	-.65	-8.81	1.65	-8.27	1.41	19089	-3627
.070	-4.71	3.60	.29	30.85	-.33	-9.16	1.90	-8.75	1.71	19867	-4025
.080	-4.42	3.60	.93	27.88	-.01	-9.25	2.09	-8.98	1.95	20112	-4198
.090	-4.15	3.61	1.76	24.92	.30	-9.10	2.20	-8.97	2.12	19865	-4162
.100	-3.92	3.63	2.80	22.05	.59	-8.75	2.25	-8.74	2.23	19182	-3938
.110	-3.71	3.65	4.04	19.32	.87	-8.23	2.22	-8.33	2.26	18126	-3552
.120	-3.53	3.67	5.46	16.80	1.12	-7.57	2.13	-7.76	2.22	16762	-3036
.130	-3.38	3.70	7.07	14.52	1.35	-6.81	1.97	-7.07	2.11	15161	-2421
.140	-3.25	3.73	8.83	12.50	1.53	-5.98	1.74	-6.31	1.93	13391	-1740
.150	-3.14	3.77	10.74	10.77	1.66	-5.13	1.45	-5.50	1.68	11517	-1022
.160	-3.04	3.80	12.78	9.31	1.72	-4.29	1.11	-4.68	1.38	9600	-299
.170	-2.96	3.84	14.92	8.13	1.69	-3.48	.73	-3.87	1.02	7696	405
.180	-2.89	3.88	17.14	7.19	1.57	-2.73	.33	-3.11	.63	5855	1065
.190	-2.83	3.91	19.42	6.48	1.34	-2.05	-.09	-2.42	.22	4120	1661
.200	-2.78	3.95	21.74	5.97	.99	-1.45	-.50	-1.80	-.20	2525	2178
.210	-2.73	3.98	24.08	5.62	.53	-.95	-.89	-1.27	-.60	1098	2604
.220	-2.68	4.00	26.41	5.39	-.04	-.54	-1.24	-.82	-.97	-139	2929
.230	-2.63	4.02	28.74	5.25	-.70	-.22	-1.54	-.46	-1.30	-1175	3150
.240	-2.58	4.04	31.03	5.18	-1.45	.01	-1.77	-.19	-1.56	-2002	3264
.250	-2.53	4.05	33.29	5.14	-2.25	.18	-1.93	.01	-1.76	-2620	3276
.260	-2.47	4.06	35.49	5.11	-3.08	.29	-2.01	.15	-1.89	-3035	3189
.270	-2.41	4.06	37.64	5.08	-3.92	.34	-2.02	.24	-1.94	-3258	3012
.280	-2.34	4.06	39.73	5.04	-4.75	.36	-1.95	.28	-1.92	-3303	2754
.290	-2.27	4.05	41.76	4.97	-5.53	.35	-1.82	.29	-1.83	-3189	2428
.300	-2.19	4.04	43.72	4.88	-6.26	.33	-1.62	.28	-1.67	-2937	2046
.310	-2.11	4.03	45.63	4.76	-6.90	.29	-1.37	.26	-1.46	-2570	1622
.320	-2.03	4.02	47.47	4.62	-7.45	.26	-1.08	.24	-1.20	-2114	1171
.330	-1.94	4.00	49.26	4.46	-7.89	.23	-.77	.22	-.91	-1591	707
.340	-1.85	3.98	51.01	4.28	-8.22	.21	-.44	.20	-.60	-1029	245
.350	-1.76	3.96	52.71	4.10	-8.43	.20	-.11	.19	-.28	-450	-203
.360	-1.67	3.94	54.37	3.92	-8.53	.20	.21	.19	.04	124	-624
.370	-1.57	3.93	56.00	3.75	-8.52	.21	.52	.20	.34	670	-1007
.380	-1.48	3.91	57.60	3.58	-8.41	.23	.79	.22	.62	1173	-1342
.390	-1.39	3.90	59.18	3.43	-8.21	.26	1.02	.25	.87	1616	-1622
.400	-1.31	3.89	60.74	3.30	-7.94	.29	1.21	.28	1.07	1986	-1840
.410	-1.22	3.88	62.29	3.19	-7.62	.33	1.36	.32	1.24	2276	-1994
.420	-1.14	3.87	63.83	3.10	-7.25	.36	1.45	.35	1.35	2480	-2082
.430	-1.07	3.87	65.35	3.03	-6.85	.38	1.49	.38	1.42	2595	-2104
.440	-.99	3.87	66.87	2.98	-6.45	.40	1.49	.40	1.44	2622	-2062
.450	-.92	3.87	68.37	2.95	-6.06	.40	1.43	.41	1.42	2566	-1960
.460	-.86	3.88	69.86	2.92	-5.69	.40	1.34	.41	1.35	2435	-1806
.470	-.80	3.89	71.33	2.91	-5.35	.37	1.22	.39	1.24	2237	-1606
.480	-.74	3.90	72.78	2.89	-5.05	.33	1.06	.36	1.11	1986	-1369
.490	-.68	3.91	74.20	2.86	-4.81	.28	.89	.31	.96	1694	-1106

TABLE A.1 (Cont'd)

.500	-.63	3.93	75.59	2.83	-4.62	.21	.71	.25	.79	1378	-827
.510	-.58	3.94	76.95	2.78	-4.49	.13	.53	.18	.62	1052	-543
.520	-.53	3.96	78.26	2.71	-4.41	.05	.36	.10	.45	733	-265
.530	-.48	3.98	79.52	2.61	-4.38	-.03	.20	.02	.29	436	-4
.540	-.43	4.00	80.74	2.49	-4.39	-.12	.06	-.06	.15	175	230
.550	-.39	4.01	81.89	2.35	-4.44	-.19	-.04	-.14	.03	-37	428
.560	-.34	4.03	82.99	2.20	-4.51	-.26	-.12	-.21	-.05	-189	583
.570	-.29	4.05	84.02	2.02	-4.59	-.30	-.16	-.26	-.11	-275	690
.580	-.24	4.06	84.98	1.84	-4.68	-.33	-.16	-.30	-.13	-290	744
.590	-.20	4.08	85.88	1.66	-4.75	-.34	-.13	-.31	-.11	-233	745
.600	-.15	4.09	86.72	1.49	-4.81	-.32	-.07	-.31	-.07	-107	694
.610	-.10	4.10	87.50	1.32	-4.84	-.28	.02	-.28	.00	79	595
.620	-.05	4.11	88.22	1.18	-4.83	-.21	.14	-.23	.10	316	455
.630	-.00	4.12	88.88	1.07	-4.77	-.14	.27	-.16	.22	586	284
.640	.05	4.13	89.50	.99	-4.68	-.05	.40	-.08	.34	873	93
.650	.09	4.14	90.08	.94	-4.54	.05	.53	.00	.46	1155	-104
.660	.14	4.15	90.62	.93	-4.35	.14	.65	.09	.57	1408	-291
.670	.18	4.16	91.13	.95	-4.14	.22	.74	.17	.67	1609	-451
.680	.22	4.17	91.63	1.00	-3.90	.29	.79	.23	.73	1735	-569
.690	.26	4.18	92.11	1.07	-3.65	.32	.80	.28	.76	1766	-628
.700	.29	4.19	92.58	1.14	-3.41	.32	.76	.29	.74	1687	-615
.710	.32	4.21	93.04	1.21	-3.18	.28	.67	.26	.67	1492	-519
.720	.35	4.22	93.50	1.26	-3.00	.19	.54	.20	.56	1186	-338
.730	.38	4.24	93.96	1.28	-2.86	.06	.36	.09	.42	788	-74
.740	.41	4.25	94.42	1.25	-2.79	-.11	.16	-.05	.26	337	259
.750	.44	4.27	94.87	1.17	-2.77	-.30	-.02	-.21	.10	-103	635
.760	.46	4.28	95.31	1.02	-2.81	-.48	-.16	-.37	-.02	-440	1011
.770	.49	4.29	95.74	.82	-2.88	-.63	-.19	-.50	-.04	-543	1325
.780	.52	4.30	96.14	.58	-2.93	-.70	-.04	-.55	.10	-240	1492
.790	.55	4.31	96.53	.34	-2.88	-.60	.39	-.47	.49	693	1398

TEST WBCT-2

Purpose: Objective of this test was to evaluate the wood post breakaway cable terminal end treatment when impacted by a minicompact automobile at 60 mph (96.6 kmph) and a 0-deg angle. The target impact point on the vehicle was 15 in. (381 mm) to the left of vehicle centerline.

Test Installation: The installation was the same as that used for Test WBCT-1; all damage sustained during that test was repaired.

Test Vehicle: The test vehicle was a 1975 Honda Civic sedan. Two 50th percentile anthropomorphic dummies were placed in the driver and right front passenger seating positions; the driver dummy was restrained by a lap/shoulder belt while the passenger dummy was unrestrained. Total weight of the vehicle, dummies, and instrumentation was 2178 lb (988 kg).

Performance: Impact conditions were 59.0 mph (95.0 kmph) and a -0.3 deg angle. As shown in the sequential photographs of Figure 7 the vehicle impacted the buffer end section, displaced it rearward, and then contacted the first post/end of the first rail section. Considerable vehicle front end crush was observed before the first post fractured and a plastic hinge formed in the rail at the post allowing the vehicle to bend it rearward. As the vehicle penetrated past Post 1 it started a counterclockwise rotation and the right side of the vehicle (near the forward edge of the door) impacted the barrier at Post 2 fracturing that post also and continued bending the rail as a hinge formed at Post 3. The vehicle continued its rotation and the rear section of the vehicle impacted Post 3, fracturing it and bending the rail section as a hinge formed at Post 4. At this point the vehicle was oriented approximately normal to the barrier and began a rolling motion toward the downstream end. This continued until the vehicle rolled onto its right side and slid to a stop approximately 10 ft (3.0 m) behind Post 4. Maximum 50 millisecond average accelerations measured were 3.7 g (film analysis) and 7.9 g (accelerometer) in the lateral direction and -13.1 g (film analysis) and -15.0 g (accelerometer) in the longitudinal direction. A summary of test results is shown in Figure 8 and results of high speed film analysis are contained in

Table A.2. Results of analog to digital conversion of vehicle and dummy transducer data are shown in Table A.3 and plotted in Figures A.5 through A.11.

Barrier Damage: As shown in Figure A.12 Posts 1 through 3, rail sections between Posts 1 and 5, and the buffer end section required replacement prior to further testing. In addition, all remaining posts were deflected in the soil and required realigning and retamping.

Vehicle Damage: As shown in Figure A.13 vehicle damage was very extensive. Sheet metal crush and deformation were sustained by the entire front portion of the unibody forward of the firewall, at the leading edge of the right door, and the right rear fender just forward of the rear bumper. Again, as in Test WBCT-1, the engine was broken loose from its mounts and was driven rearward into the firewall. The windshield was dislodged and thrown forward upon impact of the passenger dummy's head. In addition, the right hand portion of the rear axle was forced rearward misaligning it.

Dummy Injury: Instrumentation in the lap/shoulder belt-restrained driver dummy indicated an HIC of 1062.2 and maximum chest resultant acceleration of 51.0 g's. The driver dummy contacted the steering wheel and bent both the upper and lower rims. In addition, the center shaft of the wheel punctured the skin of the right side of the dummy's upper chest.

The head of the unrestrained passenger dummy impacted the windshield knocking it out of the vehicle; small pices of glass were embedded in the dummy's forehead. An HIC of 655.8 was calculated for that dummy. An electronic malfunction during impact of the passenger dummy X-axis accelerometer caused data to be lost for that channel and a chest resultant acceleration of only the Y and Z axes could be calculated - 32.0 g's.

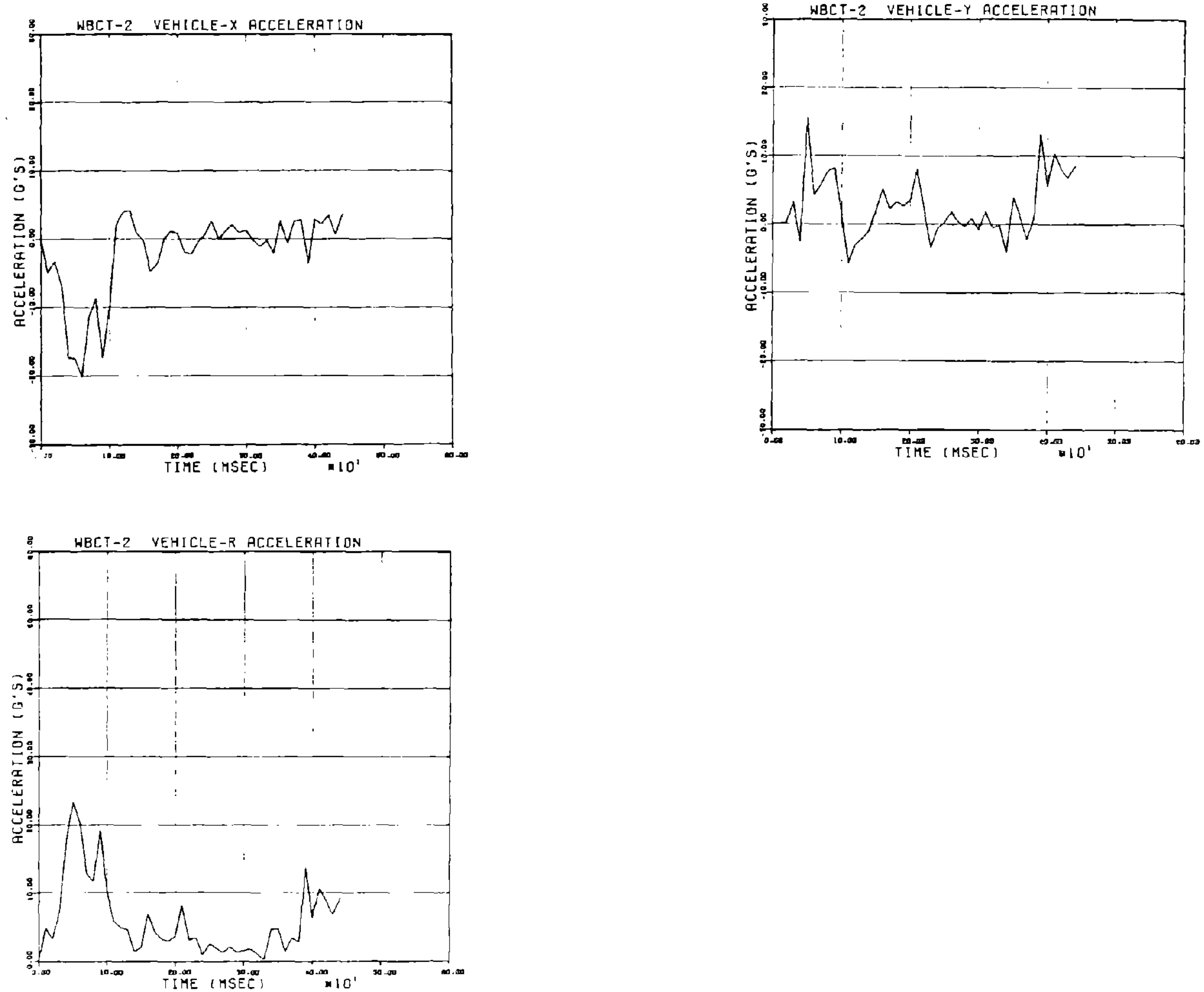


FIGURE A.5 VEHICLE ACCELERATION PLOTS, TEST WBCT-2

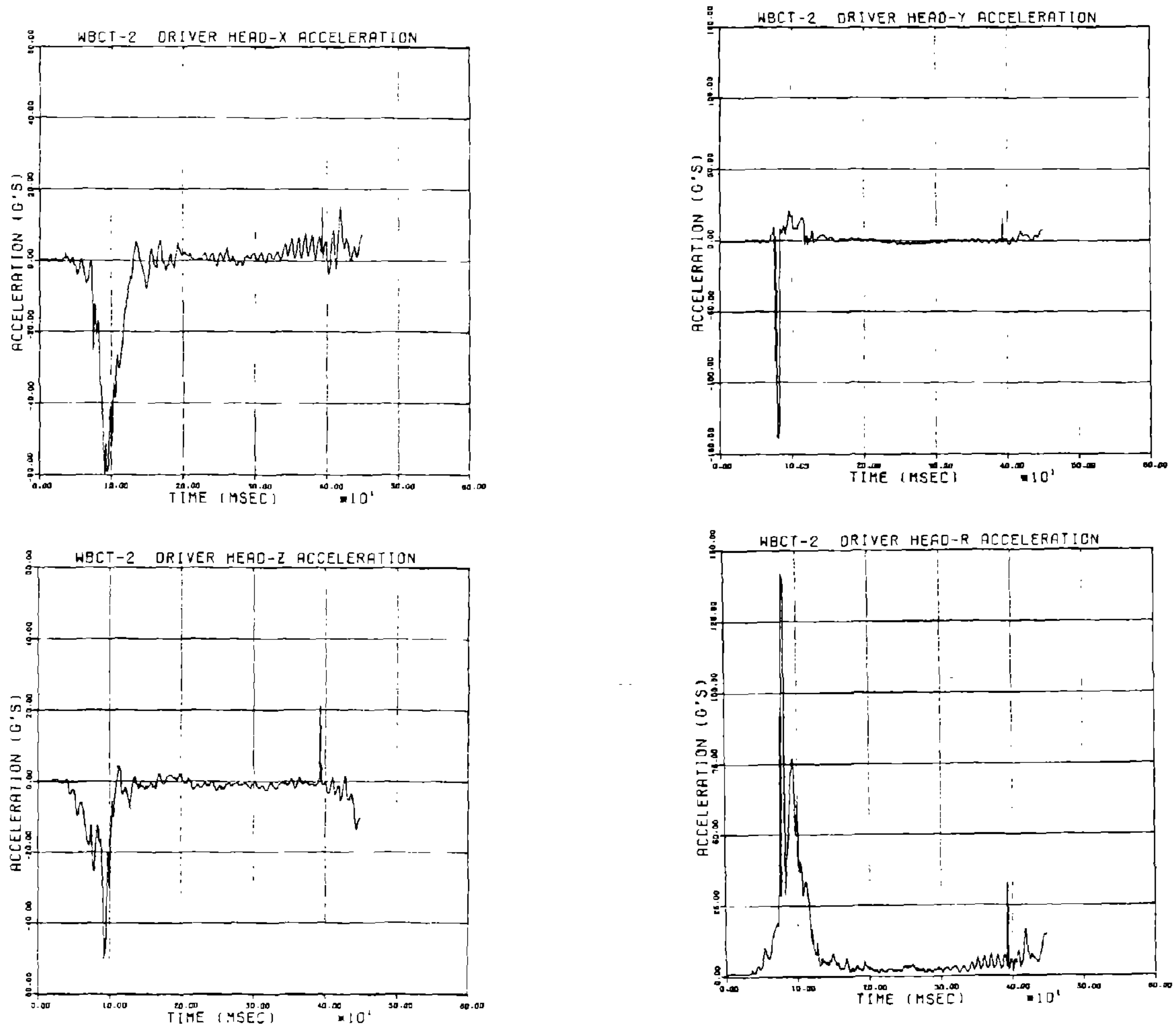


FIGURE A.6 DRIVER DUMMY HEAD ACCELERATION PLOTS, TEST WBCT-2

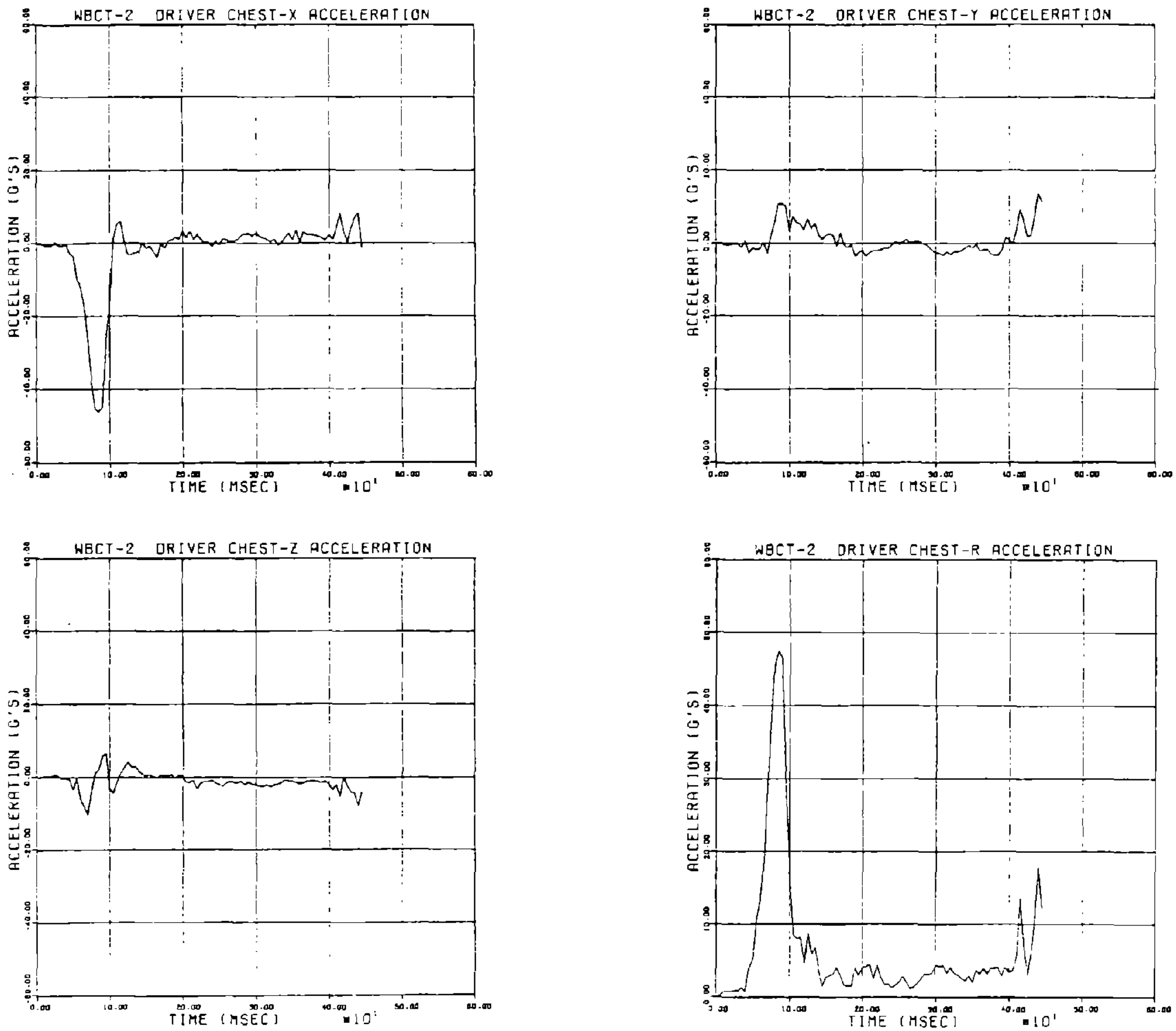
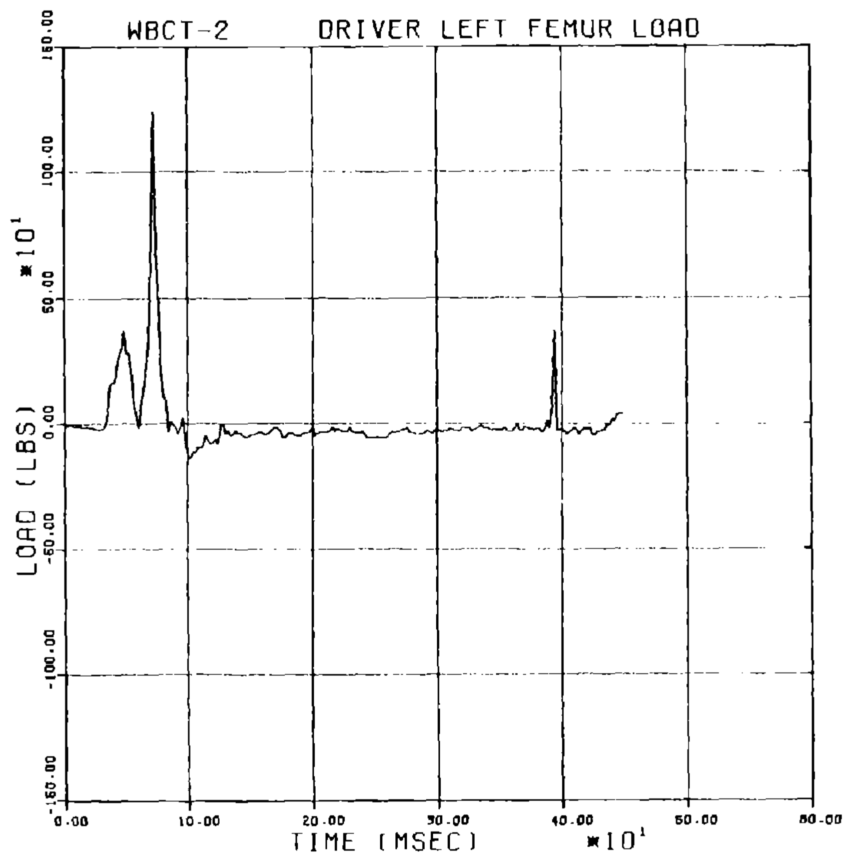


FIGURE A.7 DRIVER DUMMY CHEST ACCELERATION PLOTS, TEST WBCT-2



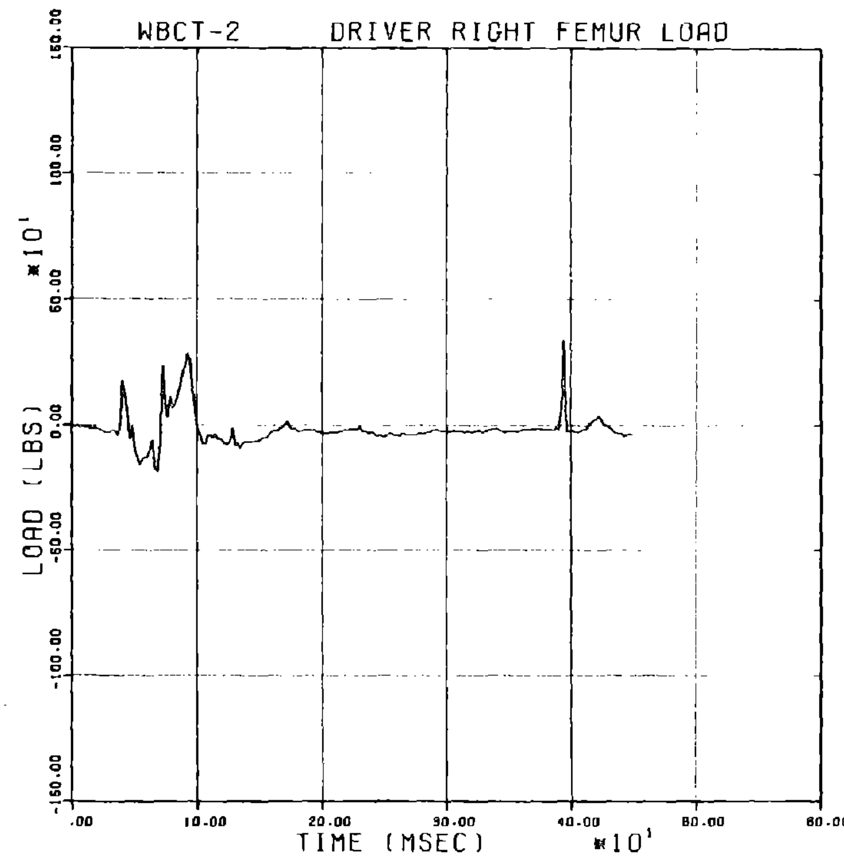


FIGURE A.8 DRIVER DUMMY FEMUR LOAD PLOTS, TEST WBCT-2

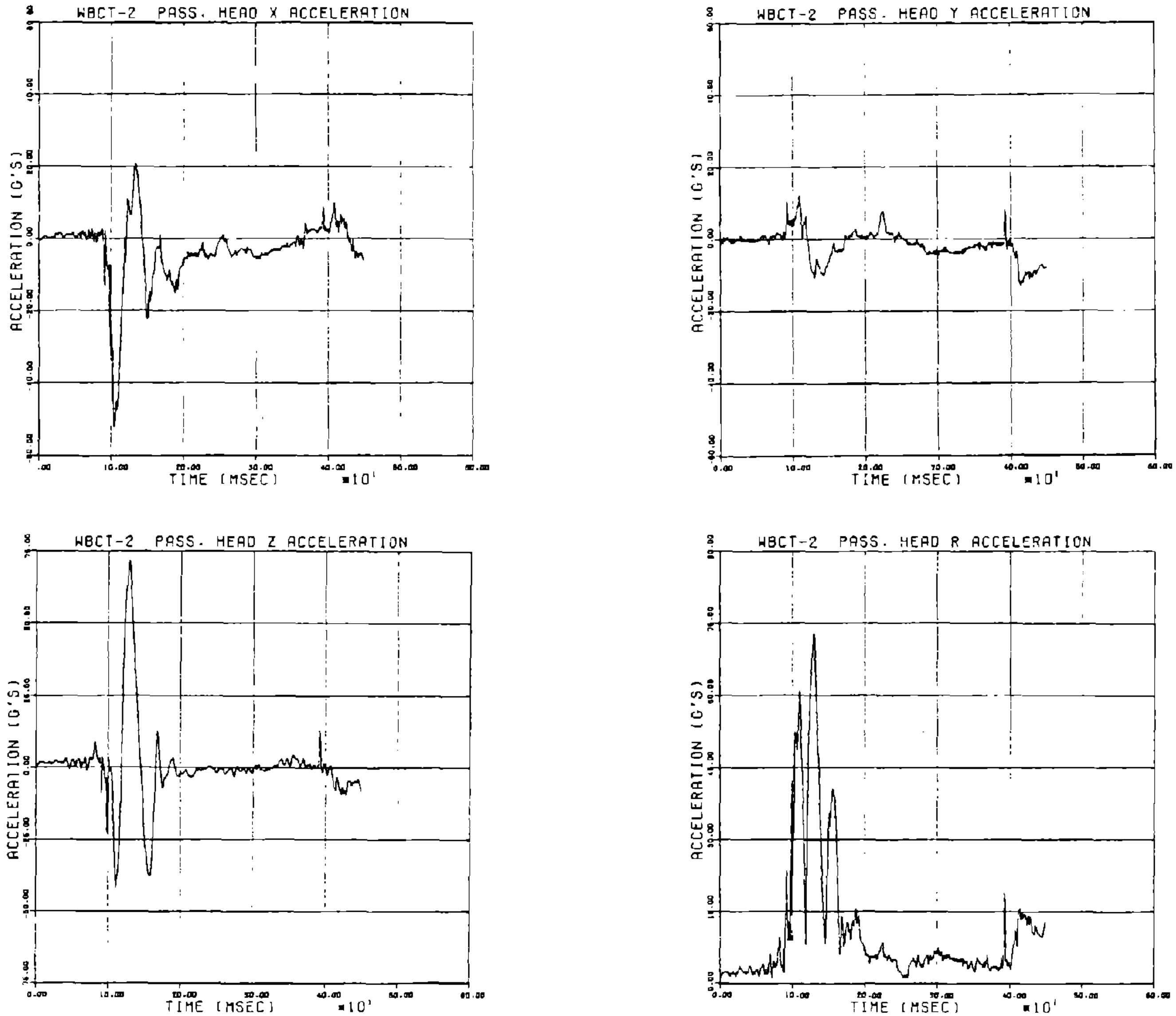
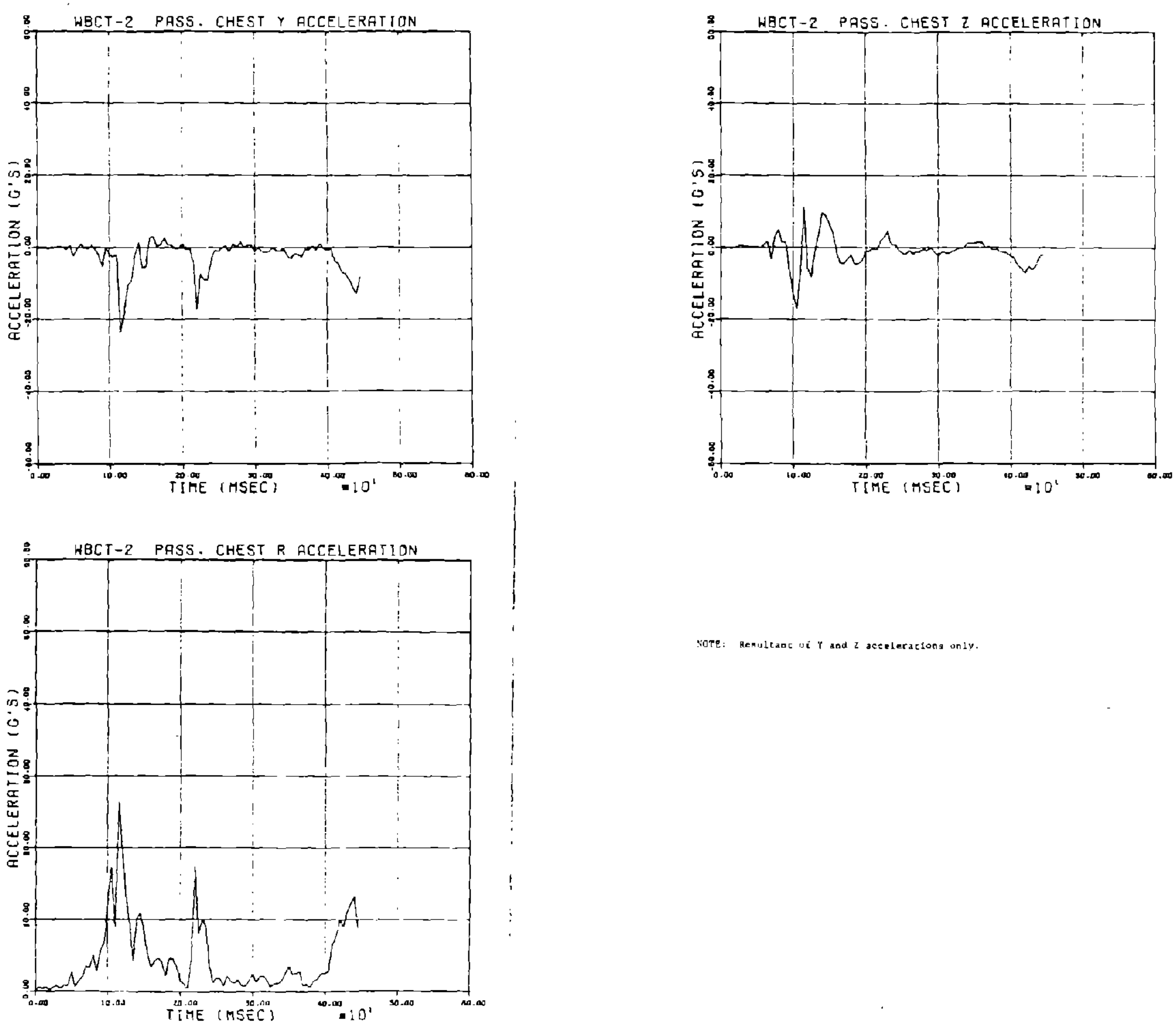
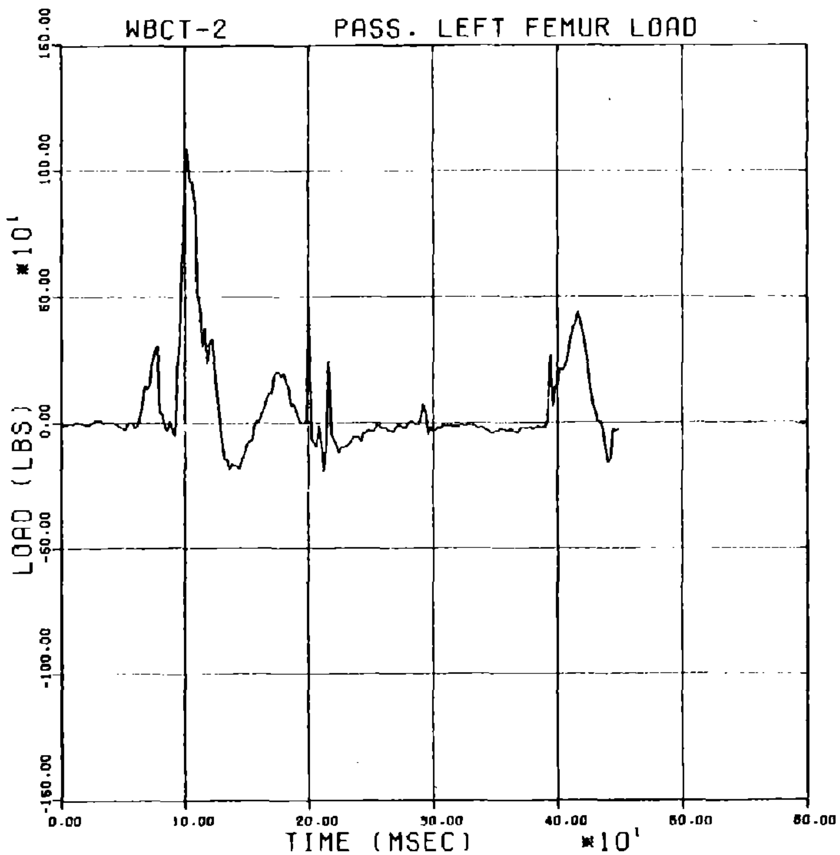


FIGURE A.9 PASSENGER DUMMY HEAD ACCELERATION, PLOTS



NOTE: Resultant of Y and Z accelerations only.

FIGURE A.10 PASSENGER DUMMY CHEST ACCELERATION PLOTS, TEST WBCT-2



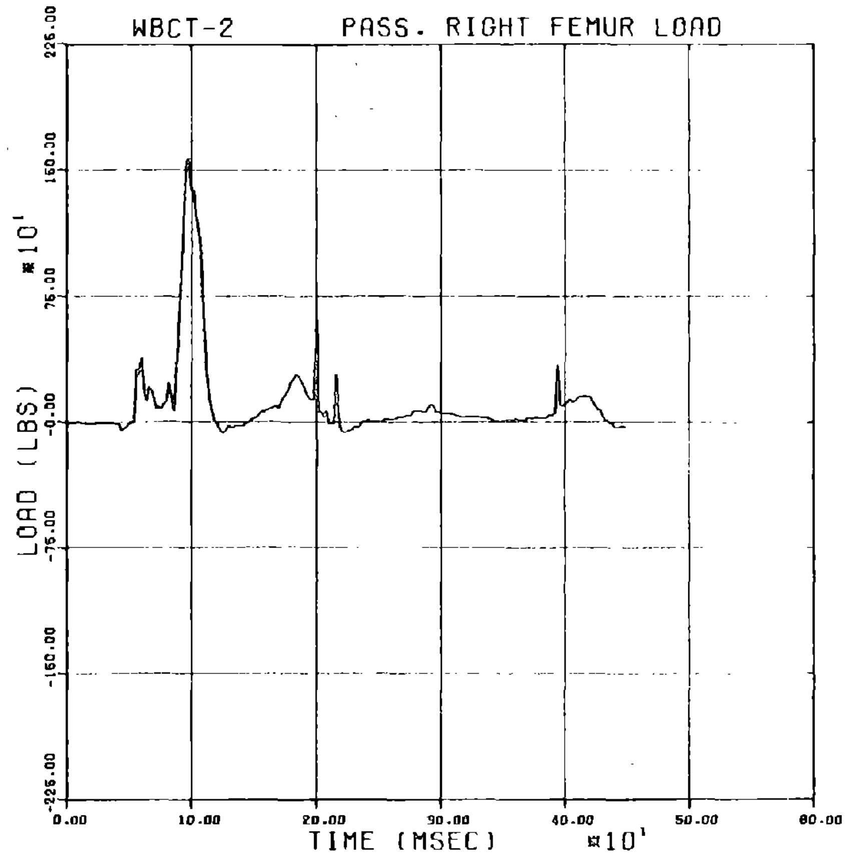


FIGURE A.11 PASSENGER DUMMY FEMUR LOADS, TEST WBCT-2

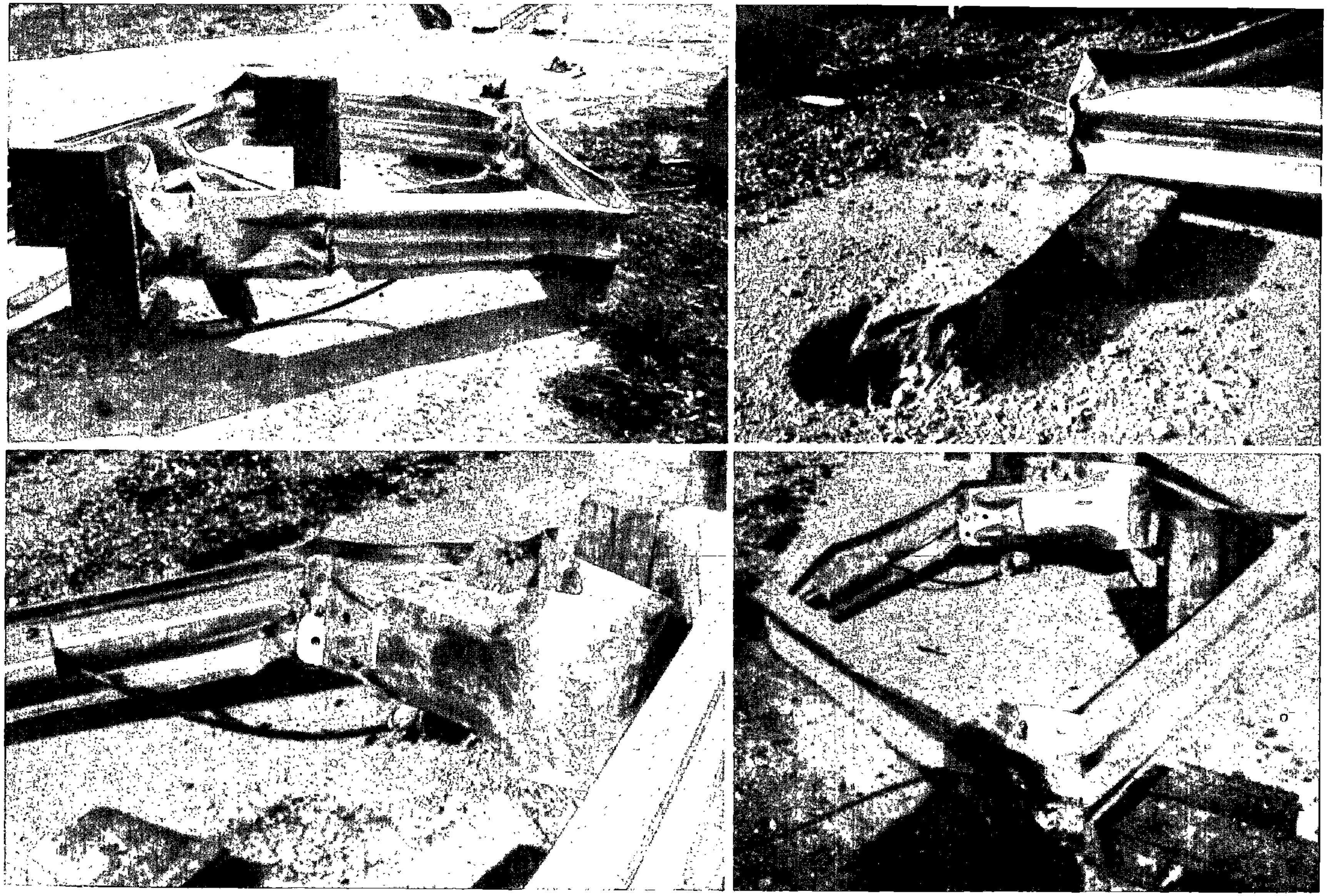


FIGURE A.12 TEST WBCT-2 BARRIER DAMAGE

FIGURE A.13 TEST WBCT-2 VEHICLE DAMAGE

TABLE A.2

TEST WBCT-2 FILM ANALYSIS RESULTS

SUMMARY OF VEHICLE KINEMATIC AND DYNAMIC DATA   WOOD POST BCT TEST WBCT-2   4/3/80

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	-6.83	3.44	-.31	86.53	.50	-4.50	.63	0.00	0.00	9788	-1432
.010	-5.97	3.44	-.33	84.66	.82	-7.11	1.25	0.00	0.00	15464	-2806
.020	-5.14	3.44	-.17	81.99	1.09	-9.44	1.84	0.00	0.00	20557	-4075
.030	-4.34	3.46	.20	78.63	1.26	-11.35	2.39	-9.97	2.04	24737	-5125
.040	-3.57	3.48	.79	74.76	1.32	-12.72	2.87	-11.53	2.55	27788	-5875
.050	-2.84	3.50	1.62	70.54	1.27	-13.50	3.26	-12.58	3.00	29599	-6278
.060	-2.16	3.54	2.67	66.16	1.10	-13.70	3.55	-13.07	3.36	30158	-6322
.070	-1.52	3.59	3.96	61.82	.84	-13.34	3.69	-13.03	3.61	29540	-6022
.080	-.93	3.64	5.44	57.66	.49	-12.51	3.69	-12.50	3.72	27887	-5420
.090	-.37	3.71	7.11	53.83	.03	-11.31	3.53	-11.56	3.67	25394	-4578
.100	.14	3.78	8.95	50.41	-.55	-9.85	3.21	-10.33	3.47	22290	-3571
.110	.63	3.85	10.92	47.46	-1.27	-8.27	2.76	-8.91	3.12	18820	-2483
.120	1.08	3.93	13.02	44.99	-2.16	-6.67	2.20	-7.41	2.64	15229	-1397
.130	1.51	4.01	15.22	42.99	-3.23	-5.16	1.59	-5.94	2.09	11747	-391
.140	1.93	4.09	17.50	41.39	-4.50	-3.82	.98	-4.59	1.51	8574	464
.150	2.33	4.18	19.86	40.14	-5.95	-2.71	.43	-3.42	.95	5872	1113
.160	2.73	4.25	22.27	39.12	-7.55	-1.86	.01	-2.47	.47	3756	1521
.170	3.11	4.33	24.74	38.26	-9.26	-1.27	-.26	-1.77	.13	2289	1667
.180	3.50	4.41	27.26	37.47	-11.02	-.93	-.32	-1.30	-.05	1480	1556
.190	3.88	4.48	29.82	36.66	-12.77	-.79	-.19	-1.03	-.04	1290	1208
.200	4.26	4.55	32.41	35.80	-14.42	-.79	.14	-.92	.16	1629	663
.210	4.64	4.62	35.04	34.83	-15.92	-.89	.63	-.92	.52	2373	-22
.220	5.01	4.69	37.69	33.76	-17.21	-1.00	1.23	-.97	1.01	3365	-783
.230	5.38	4.76	40.36	32.59	-18.25	-1.09	1.86	-1.02	1.55	4434	-1546
.240	5.75	4.83	43.04	31.36	-19.05	-1.11	2.44	-1.03	2.09	5405	-2237
.250	6.10	4.91	45.72	30.11	-19.63	-1.04	2.90	-.98	2.55	6115	-2788
.260	6.45	4.99	48.39	28.87	-20.02	-.88	3.16	-.84	2.86	6427	-3142
.270	6.79	5.08	51.05	27.69	-20.30	-.64	3.17	-.63	2.96	6246	-3259
.280	7.11	5.17	53.68	26.59	-20.57	-.35	2.89	-.38	2.81	5528	-3119
.290	7.43	5.26	56.29	25.58	-20.90	-.05	2.34	-.10	2.41	4294	-2732
.300	7.74	5.36	58.86	24.66	-21.40	.21	1.54	.15	1.78	2631	-2134
.310	8.05	5.46	61.40	23.80	-22.13	.41	.59	.34	.98	698	-1393
.320	8.36	5.57	63.91	22.96	-23.13	.51	-.41	.46	.12	-1285	-604
.330	8.67	5.67	66.40	22.10	-24.39	.51	-1.30	.49	-.70	-3048	117
.340	8.99	5.77	68.88	21.16	-25.86	.44	-1.95	.45	-1.34	-4296	641
.350	9.31	5.88	71.37	20.13	-27.43	.33	-2.19	.37	-1.66	-4743	837
.360	9.64	5.98	73.88	18.99	-28.96	.27	-1.91	.31	-1.57	-4163	597
.370	9.97	6.08	76.41	17.77	-30.27	.33	-1.08	.35	-1.02	-2449	-141
.380	10.31	6.18	78.96	16.54	-31.18	.59	.26	.53	-.06	303	-1362
.390	10.64	6.29	81.49	15.41	-31.54	1.08	1.88	.90	1.13	3695	-2931
.400	10.97	6.40	83.95	14.52	-31.33	1.74	3.37	1.38	2.18	6906	-4545
.410	11.30	6.51	86.21	13.96	-30.66	2.34	4.09	1.78	2.51	8547	-5671
.420	11.60	6.54	88.09	13.75	-29.90	2.41	3.06	1.68	1.24	6490	-5478

TABLE A.3

TEST WBCT-2 TRANSDUCER DATA

TEST -- WBCT-2 | VEHICLE TYPE -- MINI-AUTO | VEHICLE WT. -- 2178 LBS
TEST DATE -- 04/03/1980 | IMPACT VELOCITY -- 60.0 MPH | IMPACT ANGLE -- 0.0 DEGREES
TYPE DUMMY -- 572-50% MALE | DUMMY LOCATION -- DRIVER | TYPE RESTRAINT -- (L+S) BELTS

	ACCELERATIONS-G'S														FEMUR LOAD-LBS	
	VEHICLE			HEAD					CHEST							
TIME	X	Y	R	X	Y	Z	R	SI	X	Y	Z	R	SI		LEFT	RIGHT
.000	.0	.0	.1	-.0	-.0	-.0	.1	.	-.0	-.0	-.0	.1	.		-.	-.
.010	-4.9	.0	4.9	.4	-1.1	.2	1.3	.	-.5	-.4	.3	.7	.		-10.	-9.
.020	-3.2	.2	3.2	.2	-.0	.4	.8	.	-.6	-.3	.2	.7	.		-12.	-13.
.030	-6.8	3.3	7.5	-.0	-.6	-.0	1.0	.	-.7	-.1	.3	.8	.		-20.	-29.
.040	-17.4	-2.6	17.6	.6	-.5	.4	1.1	.	-.2	.7	-.3	.8	.		167.	181.
.050	-17.4	15.6	23.4	-1.3	-1.1	-2.7	3.2	.	-3.5	-1.2	-3.6	5.2	.		279.	-99.
.060	-20.1	4.2	20.6	-.2	-.6	-6.0	6.1	2.	-11.7	-1.5	-5.9	13.2	5.		-19.	-129.
.070	-11.6	5.8	12.9	-.9	2.1	-17.9	18.1	9.	-26.3	-2.9	-10.3	28.4	24.		731.	-75.
.080	-8.6	7.8	11.7	-19.8	-138.6	-19.0	141.3	665.	-45.3	5.6	.9	45.7	119.		113.	65.
.090	-17.4	8.3	19.3	-57.4	7.2	-31.7	66.1	1251.	-44.8	10.9	5.9	46.5	269.		-10.	240.
.100	-10.1	1.4	10.2	-52.0	16.5	-28.3	61.7	1619.	-16.9	3.1	-3.1	17.5	322.		-125.	-12.
.110	1.8	-5.7	6.0	-29.3	12.4	1.0	32.0	1706.	5.3	5.7	-1.3	7.9	325.		-94.	-37.
.120	4.0	-3.0	5.0	-13.2	.3	-2.8	16.8	1744.	.6	3.5	2.9	4.6	327.		-75.	-62.
.130	4.2	-2.1	4.7	-.3	-1.1	-2.8	3.6	1747.	-3.1	3.9	2.8	5.7	328.		-41.	-83.
.140	.9	-1.0	1.4	.8	4.0	-2.1	4.7	1747.	-2.4	2.4	1.8	3.9	329.		-38.	-68.
.150	-.2	2.0	2.0	-7.5	.8	-1.6	7.8	1748.	-1.4	2.2	.4	2.7	329.		-47.	-60.
.160	-4.8	5.2	7.1	-1.7	-.2	-1.6	2.9	1749.	-2.3	2.1	.3	3.2	329.		-33.	-26.
.170	-3.6	2.2	4.3	3.6	.3	1.1	3.8	1749.	.1	2.9	.8	3.0	329.		-10.	1.
.180	-.1	3.3	3.3	-1.1	.5	1.4	1.9	1749.	.7	-1.2	.3	1.4	329.		-40.	-24.
.190	1.2	2.7	3.0	1.1	1.0	.8	1.8	1749.	1.7	-3.7	-.4	4.0	330.		-49.	-20.
.200	.9	3.6	3.7	2.1	.0	1.4	3.4	1750.	3.4	-2.0	.2	4.0	330.		-10.	-37.
.210	-1.9	8.1	8.3	1.9	.7	.8	2.3	1750.	3.5	-2.6	-1.3	4.5	330.		-33.	-31.
.220	-2.2	2.2	3.1	.2	-.2	-1.6	1.7	1750.	2.4	-2.1	-3.2	4.5	330.		-16.	-23.
.230	-.5	-3.4	3.5	2.0	-.8	-1.1	2.5	1750.	.2	-1.3	-1.0	1.7	331.		-11.	-8.
.240	.7	-.6	.9	2.0	-.3	-.3	2.3	1750.	-.9	-.5	-.7	1.2	331.		-29.	-29.
.250	2.7	.2	2.7	1.6	-1.7	-2.3	3.5	1750.	-.6	-.4	-1.9	2.1	331.		-57.	-48.
.260	-.1	1.9	1.9	3.3	-2.0	-1.6	4.2	1750.	1.0	1.1	-1.5	2.1	331.		-53.	-38.
.270	1.2	.4	1.3	1.0	-.8	-1.4	2.0	1751.	.4	.2	-1.3	1.4	331.		-33.	-39.
.280	2.1	-.3	2.1	-.1	-1.8	-1.1	2.2	1751.	2.2	-.0	-1.0	2.5	331.		-35.	-38.
.290	.9	.9	1.2	1.5	-.5	-.6	1.8	1751.	2.7	-.9	-1.2	3.1	331.		-34.	-22.
.300	1.3	-.9	1.6	2.0	-.7	-.4	2.2	1751.	2.9	-2.7	-2.0	4.5	331.		-29.	-23.
.310	-.2	1.8	1.8	1.9	-.8	-1.5	2.6	1751.	1.5	-3.3	-2.5	4.4	332.		-17.	-26.
.320	-1.1	-.4	1.2	2.2	.7	-2.4	3.4	1751.	.4	-3.2	-2.6	4.2	332.		-16.	-30.
.330	-.2	-.2	.2	2.0	.1	-2.1	3.0	1751.	-.7	-2.2	-1.9	3.0	332.		-23.	-28.
.340	-2.1	-4.2	4.7	3.2	-.2	-.3	3.4	1751.	1.6	-1.3	-.7	2.2	332.		-16.	-13.
.350	2.7	4.0	4.8	5.6	.7	-.6	5.7	1751.	.8	-1.4	-1.1	2.0	333.		-23.	-21.
.360	-.7	1.2	1.3	6.3	.9	-1.4	6.6	1752.	.2	-2.3	-1.9	3.1	333.		-33.	-20.
.370	2.5	-2.3	3.4	7.8	.3	-.4	7.8	1753.	2.3	-1.8	-1.2	3.2	333.		-11.	-21.
.380	2.7	.6	2.8	7.1	1.0	-.8	7.3	1753.	2.1	-3.3	-.9	4.0	333.		-21.	-17.
.390	-3.6	13.3	13.8	6.4	.9	.0	6.5	1754.	1.4	-1.9	-1.6	2.9	334.		-26.	-21.
.400	3.0	5.5	6.3	2.2	.2	-.6	2.5	1766.	2.4	1.0	-2.0	3.4	339.		-20.	-20.
.410	2.2	10.5	10.7	7.1	.7	1.3	7.3	1767.	4.2	3.4	-1.9	5.8	339.		-15.	-16.
.420	3.5	8.1	8.8	12.7	5.2	-3.5	14.2	1771.	3.3	6.3	.3	7.1	350.		-28.	22.
.430	.6	6.8	6.8	4.9	2.9	-2.8	6.4	1772.	4.0	2.1	-4.0	6.0	351.		-36.	-9.
.440	3.5	8.4	9.1	3.3	3.0	-6.8	8.2	1773.	8.5	13.7	-7.8	17.9	357.		19.	-33.
.450	.7	-.1	.7	7.6	7.0	-9.7	14.2	1780.	1.3	5.6	-6.2	8.5	363.		32.	-53.

TABLE A.3 (Cont'd)

MAXIMA--TIME	X/L	--------SEC	Y/R	-------SEC	Z	-------SEC	R	-------SEC	SI	------SEC
VEHICLE	-21.4	.062	19.5	.053			28.1	.053		
HEAD	-59.7	.091	-138.6	.081	-50.2	.092	142.1	.079	1780.1	.450
CHEST	-48.7	.087	17.7	.394	12.8	.394	51.0	.087	363.1	.450
FEMUR	1242.9	.072	398.4	.393						

CUMULATIVE PERIOD FOR 60G LEVEL IS .0 MSEC

HIC IS 1062.2 DURING .075 TO .101 SEC

TABLE A.3 (Cont'd)

TEST -- WRCT-2 VEHICLE TYPE -- MINI-AUTO VEHICLE WT. -- 2178 LBS
TEST DATE -- 04/03/1980 IMPACT VELOCITY -- 60.0 MPH IMPACT ANGLE -- 0.0 DEGREES
TYPE DUMMY -- 572-509 MALE DUMMY LOCATION -- PASSENGER TYPE RESTRAINT -- NONE

	ACCELERATIONS-G'S														FEMUR LOAD-LBS	
	VEHICLE			HEAD					CHEST							
TIME	X	Y	R	X	Y	Z	R	SI	X	Y	Z	R*	SI		LEFT	RIGHT
.000	.0	.0	.0	-.0	-.0	-.0	.0	.	.0	.0	.0	.0	.		.	-.
.010	.0	.0	.0	.8	.1	1.9	2.3	.	.0	.3	-.1	.3	.		-4.	2.
.020	.0	.0	.0	.2	-.9	1.6	2.2	.	.0	.2	-.0	.2	.		-7.	-12.
.030	.0	.0	.0	1.8	.9	1.9	3.1	.	.0	.4	.6	.8	.		10.	-4.
.040	.0	.0	.0	1.4	-.6	2.5	3.2	.	.0	-.9	-.0	.9	.		-.	-4.
.050	.0	.0	.0	.5	-.4	2.5	2.7	1.	.0	-2.7	.3	2.7	.		-17.	-13.
.060	.0	.0	.0	2.6	.5	3.2	4.2	1.	.0	1.0	.9	1.4	.		-21.	391.
.070	.0	.0	.0	1.9	1.1	-1.2	6.3	1.	.0	-.7	-3.4	3.5	.		134.	150.
.080	.0	.0	.0	-1.1	1.8	5.2	5.7	1.	.0	-.6	5.0	5.1	1.		43.	124.
.090	.0	.0	.0	-11.1	1.3	-9.0	14.6	4.	.0	-5.5	1.8	5.8	1.		-27.	631.
.100	.0	.0	.0	-24.9	3.6	3.8	25.7	39.	.0	-1.8	-12.4	12.5	3.		978.	1395.
.110	.0	.0	.0	-45.0	10.1	-39.9	61.1	221.	.0	-2.1	-6.3	8.9	26.		521.	583.
.120	.0	.0	.0	-6.7	.5	26.0	27.9	307.	.0	-18.5	-5.7	19.4	41.		324.	4.
.130	.0	.0	.0	12.5	-10.8	70.3	72.2	613.	.0	-9.5	-.8	9.6	50.		-89.	-15.
.140	.0	.0	.0	10.4	-9.7	20.8	25.3	793.	.0	1.3	10.0	10.1	51.		-166.	-19.
.150	.0	.0	.0	-22.3	-6.2	-25.1	34.1	812.	.0	-5.4	6.4	8.3	55.		-88.	22.
.160	.0	.0	.0	-7.5	-3.4	-32.5	33.6	898.	.0	3.1	-1.4	3.4	55.		9.	71.
.170	.0	.0	.0	-6.9	-3.0	7.7	10.8	910.	.0	.8	-4.6	4.7	56.		118.	77.
.180	.0	.0	.0	-8.4	1.6	-2.9	9.0	914.	.0	.7	-2.0	2.1	56.		201.	238.
.190	.0	.0	.0	-11.2	1.0	3.6	12.4	920.	.0	-.4	-4.5	4.5	56.		47.	220.
.200	.0	.0	.0	-7.3	.8	-1.2	7.6	923.	.0	1.2	-.8	1.5	57.		462.	610.
.210	.0	.0	.0	-4.9	1.5	-2.1	5.6	924.	.0	.0	-.0	.3	57.		-81.	-5.
.220	.0	.0	.0	-5.4	3.6	-1.8	7.0	925.	.0	-17.3	1.8	17.4	59.		-61.	-50.
.230	.0	.0	.0	-5.3	1.8	-1.0	5.8	926.	.0	-8.9	4.7	10.1	64.		-92.	-27.
.240	.0	.0	.0	-4.8	.5	.7	5.1	927.	.0	-3.6	1.0	3.7	66.		-55.	8.
.250	.0	.0	.0	-.6	.6	-1.9	2.4	927.	.0	-1.2	-1.4	1.9	66.		-30.	5.
.260	.0	.0	.0	-1.1	-1.1	-1.4	2.3	927.	.0	.4	-.5	.7	66.		-14.	23.
.270	.0	.0	.0	-4.0	-1.2	-.1	4.3	927.	.0	1.2	-.9	1.5	66.		-18.	31.
.280	.0	.0	.0	-2.4	-3.1	-.3	4.0	928.	.0	1.6	-.4	1.6	66.		1.	71.
.290	.0	.0	.0	-2.9	-3.6	-1.5	4.9	928.	.0	.6	.0	.6	66.		18.	90.
.300	.0	.0	.0	-4.9	-3.5	-.6	6.1	929.	.0	-1.1	-2.3	2.6	66.		-30.	59.
.310	.0	.0	.0	-4.7	-3.6	-.6	6.0	930.	.0	-1.3	-1.5	2.0	66.		-8.	47.
.320	.0	.0	.0	-3.0	-4.1	-1.0	5.3	931.	.0	-1.2	-1.0	1.6	66.		-14.	31.
.330	.0	.0	.0	-3.0	-4.0	.7	5.1	932.	.0	-1.0	-.0	1.0	66.		-5.	38.
.340	.0	.0	.0	-2.1	-2.6	3.3	4.8	932.	.0	-.3	1.4	1.4	66.		-15.	21.
.350	.0	.0	.0	-1.8	-1.4	.6	2.5	933.	.0	-3.3	1.3	3.5	66.		-32.	6.
.360	.0	.0	.0	-2.0	-1.7	2.9	3.9	933.	.0	-1.9	1.5	2.4	67.		-35.	21.
.370	.0	.0	.0	2.9	-1.1	3.1	4.5	933.	.0	-.2	.6	.8	67.		-22.	25.
.380	.0	.0	.0	2.9	-.9	.5	3.2	934.	.0	.4	-.1	.4	67.		-25.	22.
.390	.0	.0	.0	2.7	-1.3	-.0	3.1	934.	.0	1.2	-1.1	1.7	67.		-21.	37.
.400	.0	.0	.0	2.7	-2.0	1.7	3.9	946.	.0	-.9	-2.3	2.5	70.		156.	109.
.410	.0	.0	.0	3.2	-5.9	-3.3	7.6	948.	.0	-3.9	-5.1	6.4	70.		331.	141.
.420	.0	.0	.0	5.7	-10.1	-8.1	14.2	956.	.0	-6.9	-7.2	10.0	73.		354.	154.
.430	.0	.0	.0	-.1	-10.6	-6.3	12.4	963.	.0	-8.9	-6.2	10.9	75.		47.	37.
.440	.0	.0	.0	-4.2	-7.8	-5.1	10.3	966.	.0	-13.0	-2.5	13.2	81.		-157.	-27.
.450	.0	.0	.0	-4.3	-7.6	-9.2	12.7	970.	.0	-7.9	-.9	8.0	83.		-19.	-43.

*Resultant of Y and Z accelerations only.

TABLE A.3 (Cont'd)

MAXIMA--TIME	X/L	SEC	Y/R	SEC	Z	SEC	R	SEC	SI	SEC
VEHICLE	.0	.450	.0	.450			.0	.450		
HEAD	-52.3	.104	-13.3	.414	71.7	.129	73.1	.129	970.5	.450
CHEST	.0	.450	-23.7	.115	-31.6	.108	32.0*	.108	83.3	.450
FEMUR	1117.7	.103	1577.1	.098						

CUMULATIVE PERIOD FOR 60G LEVEL IS .0 MSEC

HIC IS 655.8 DURING .097 TO .161 SEC

*Resultant of Y and Z accelerations only.

TEST WBCT-3

Purpose: Objective of this test was to evaluate the wood post breakaway cable terminal end treatment when impacted by a minicompact automobile at 60 mph (96.6 kmph) and a 15-deg angle. The target impact point was the centerline of Post 1.

Test Installation: The installation was the same as that used for Tests WBCT-1 and -2; all damage sustained in Test WBCT-2 was repaired.

Test Vehicle: The test vehicle was a 1975 Honda Civic sedan. Two 50th percentile anthropomorphic dummies were placed in the driver and right front passenger seating positions; the driver dummy was restrained by a lap/shoulder belt while the passenger dummy was unrestrained. Total weight of the vehicle, dummies, and instrumentation was 2178 lb (988 kg).

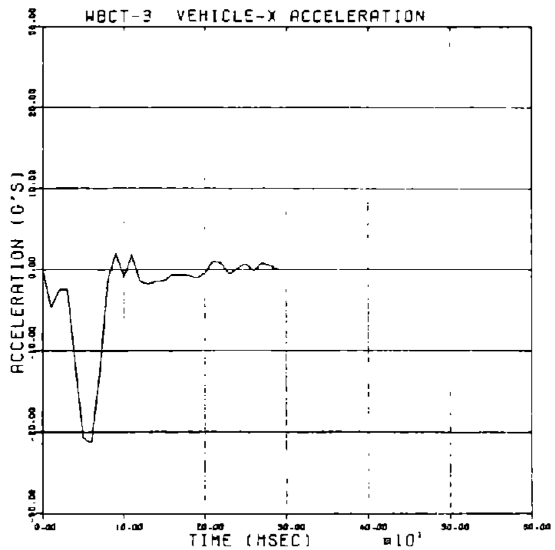
Performance: Impact conditions were 59.3 mph (95.4 kmph) and a 14.5-deg angle. As shown in the sequential photographs of Figure 9 the vehicle impacted the W-beam rail at Post 1 and almost immediately began a counterclockwise rotation as the vehicle front end sustained considerable crushing before Post 1 fractured and a plastic hinge formed in the rail at Post 2. As the vehicle deflected the end section of the barrier rearward it not only continued its yaw rotation, but also began a rolling motion toward the barrier. The vehicle then impacted Post 2 (with the right side A-pillar approximately in line with the post), fractured it and continued its penetration of the barrier as a plastic hinge formed in the rail at Post 3. Although the vehicle was achieving breakaway and penetration of the barrier it was continuing to roll and finally resulted in a complete 360-deg rollover before coming to a stop approximately 21 ft (6.4 m) behind Post 8. Maximum 50-millisecond average accelerations measured were 6.6 g (film analysis) and 7.6 g (accelerometers) in the lateral direction and -14.6 g (film analysis) and -13.8 g (accelerometers) in the longitudinal direction. A summary of test results is shown in Figure 10 and results of high-speed film analysis are contained in Table A.4. Results of analog to digital conversion of vehicle and dummy transducer data are shown in Table A.5 and plotted in Figures A.14 thru A.20.

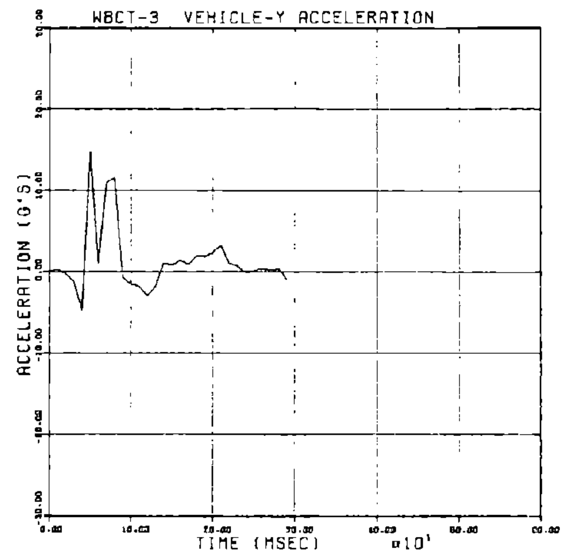
Barrier Damage; As shown in Figure A.21 Posts 1 and 2, the rail section between Posts 1 and 3, and the buffer end section required replacement prior to further testing. In addition, Post 3 was deflected 0.75 in. (19 mm) rearward and 0.50 in. (13 mm) toward the downstream end (both measurements at grade).

Vehicle Damage: As might be expected in a rollover vehicle damage was very extensive. Approximately 24 in. (610 mm) of vehicle crush was sustained in the area around the left bumper support during the initial impact before Post 1 fractured. Although almost all body sheet metal was deformed during the test, the front fenders, hood, and right rear corner received the most severe damage. In addition, the suspension on the right side (both front and rear) was heavily damaged, and the engine was torn loose from its mounts. Again, as in Test WBCT-2, the head of the passenger dummy impacted the windshield and dislodged it.

Dummy Injury: Transducers in the lap/shoulder belt-restrained driver dummy indicated an HIC of 675.4 and a maximum chest resultant acceleration of 61.1 g's. During the course of the rollover the driver dummy contacted the steering wheel and bent both the upper and lower rims.

As discussed previously the head of the unrestrained passenger dummy impacted the windshield and small pieces of glass were embedded in the dummy's forehead. Although an HIC value of only 113.4 and a maximum chest resultant of only 37.9 g's were calculated, a review of test films indicated the passenger dummy's head remained forward of the windshield opening (in much the same position as the final position shown in Figure A.22) throughout the rollover, exposing it to extreme hazard. Also, it should be noted that power was lost to the electronic instrumentation before the rollover and it is conjectured that a higher HIC value would have been attained during the rollover sequence.





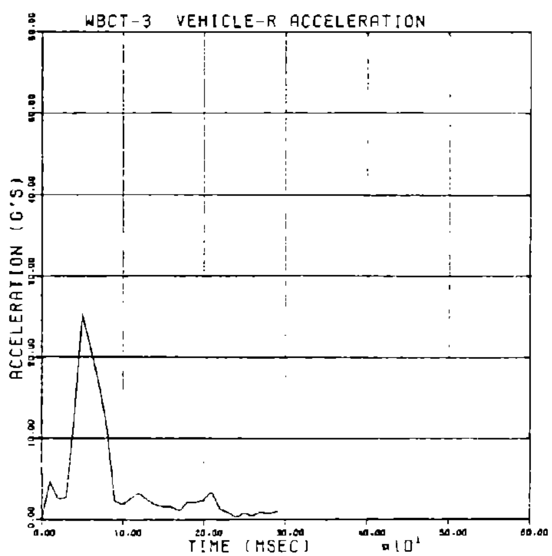


FIGURE A.14 VEHICLE ACCELERATION PLOTS, TEST WBCT-3

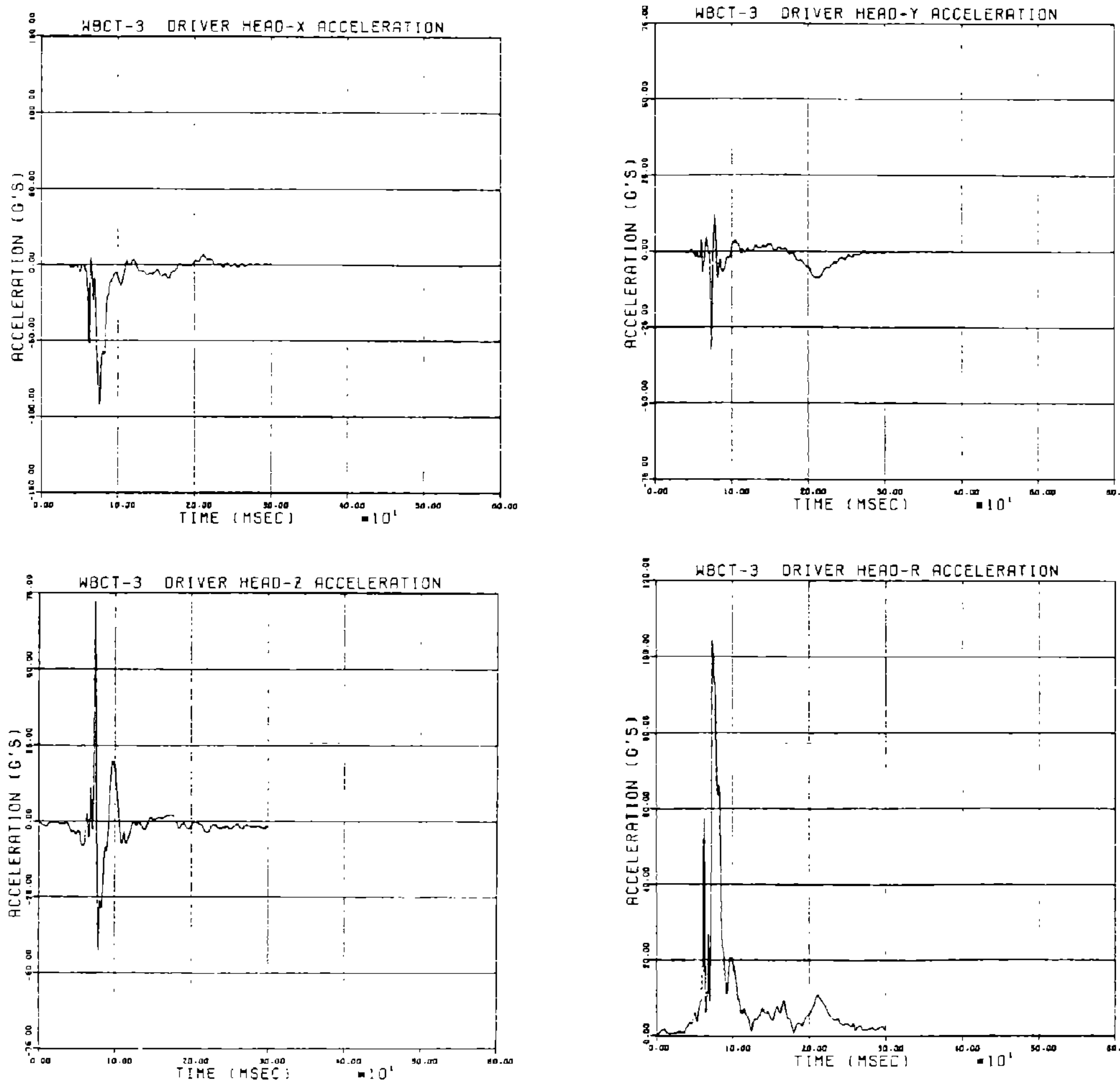


FIGURE A.15 DRIVER DUMMY HEAD ACCELERATION PLOTS, TEST WBCT-3

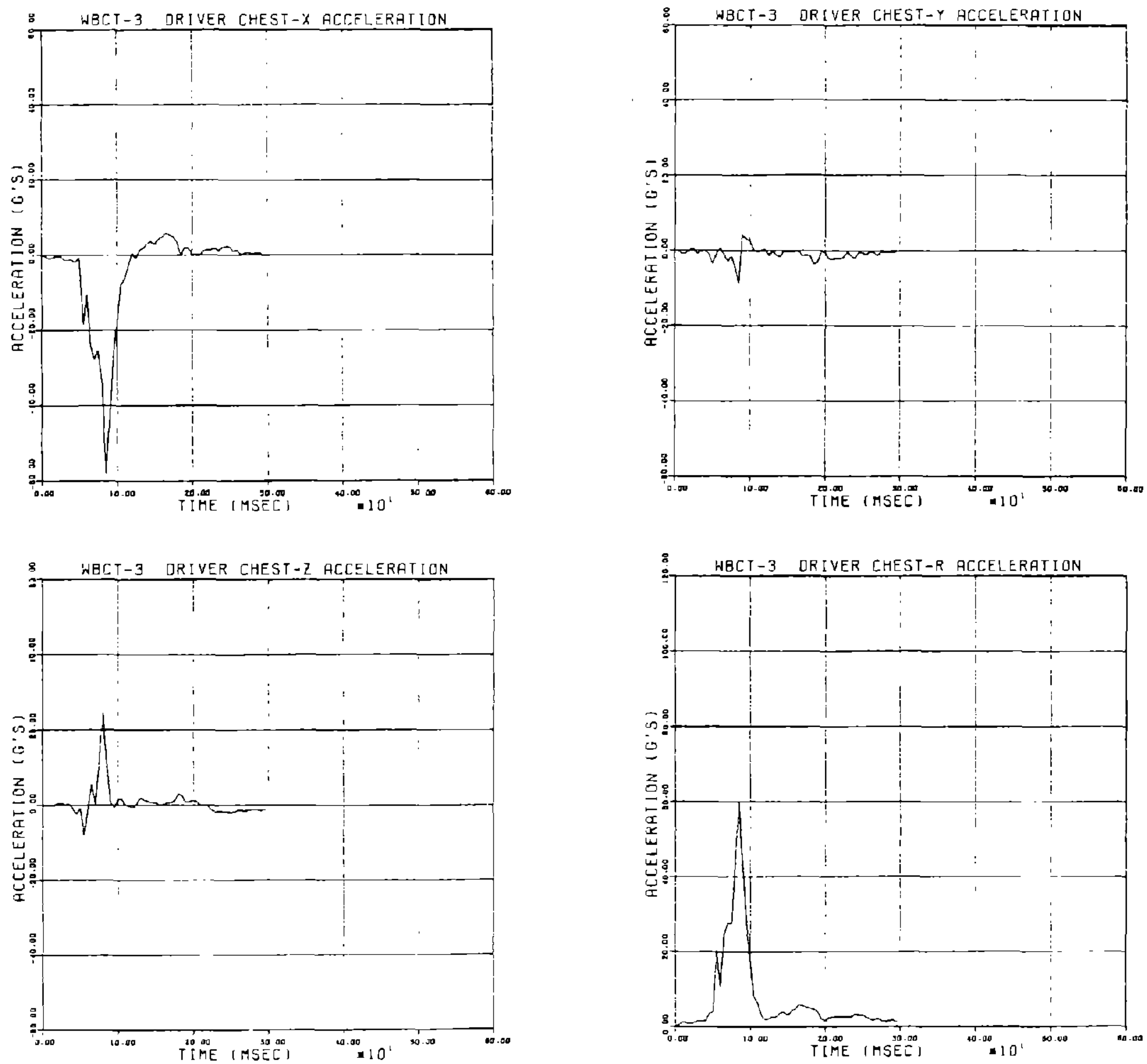
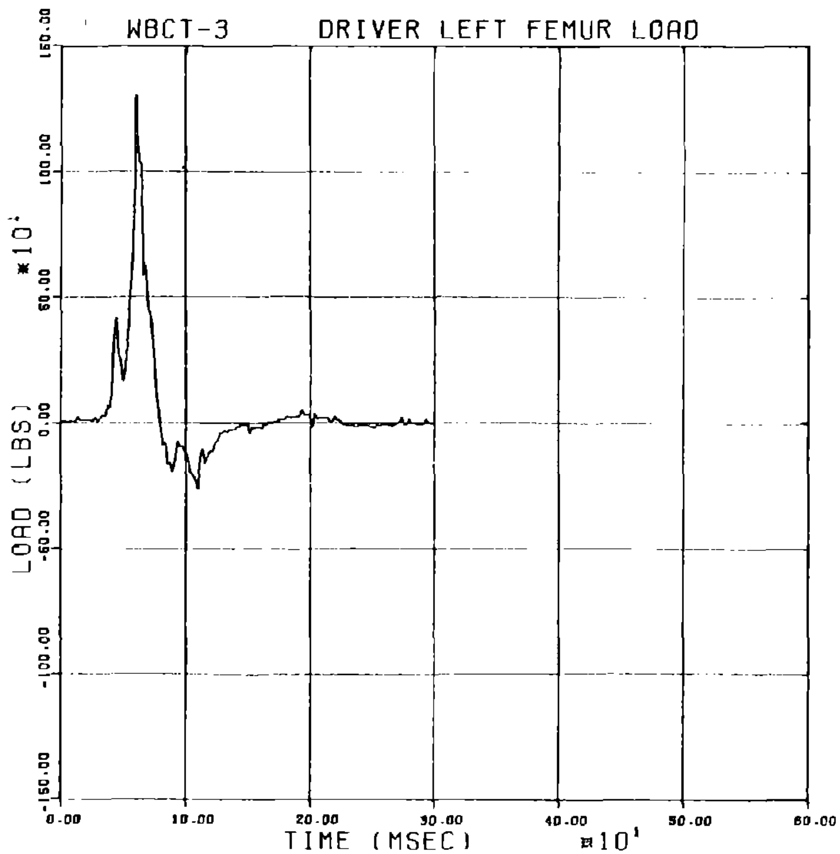


FIGURE A.16 DRIVER DUMMY CHEST ACCELERATION PLOTS, TEST WBCT-3



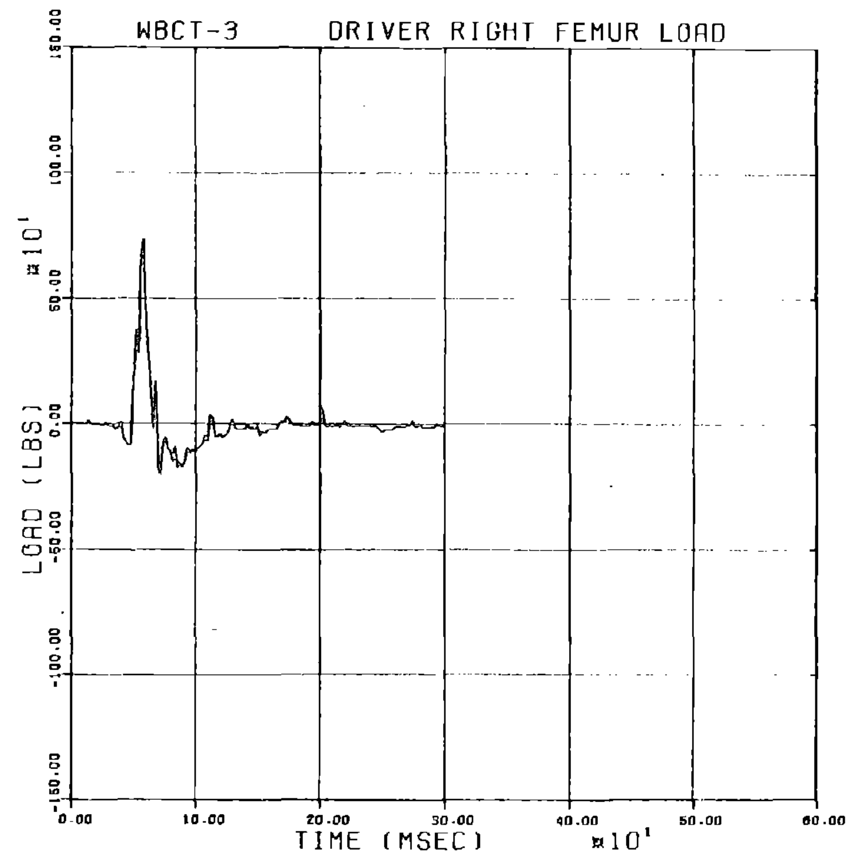


FIGURE A.17 DRIVER DUMMY FEMUR LOAD PLOTS, TEST WBCT-3

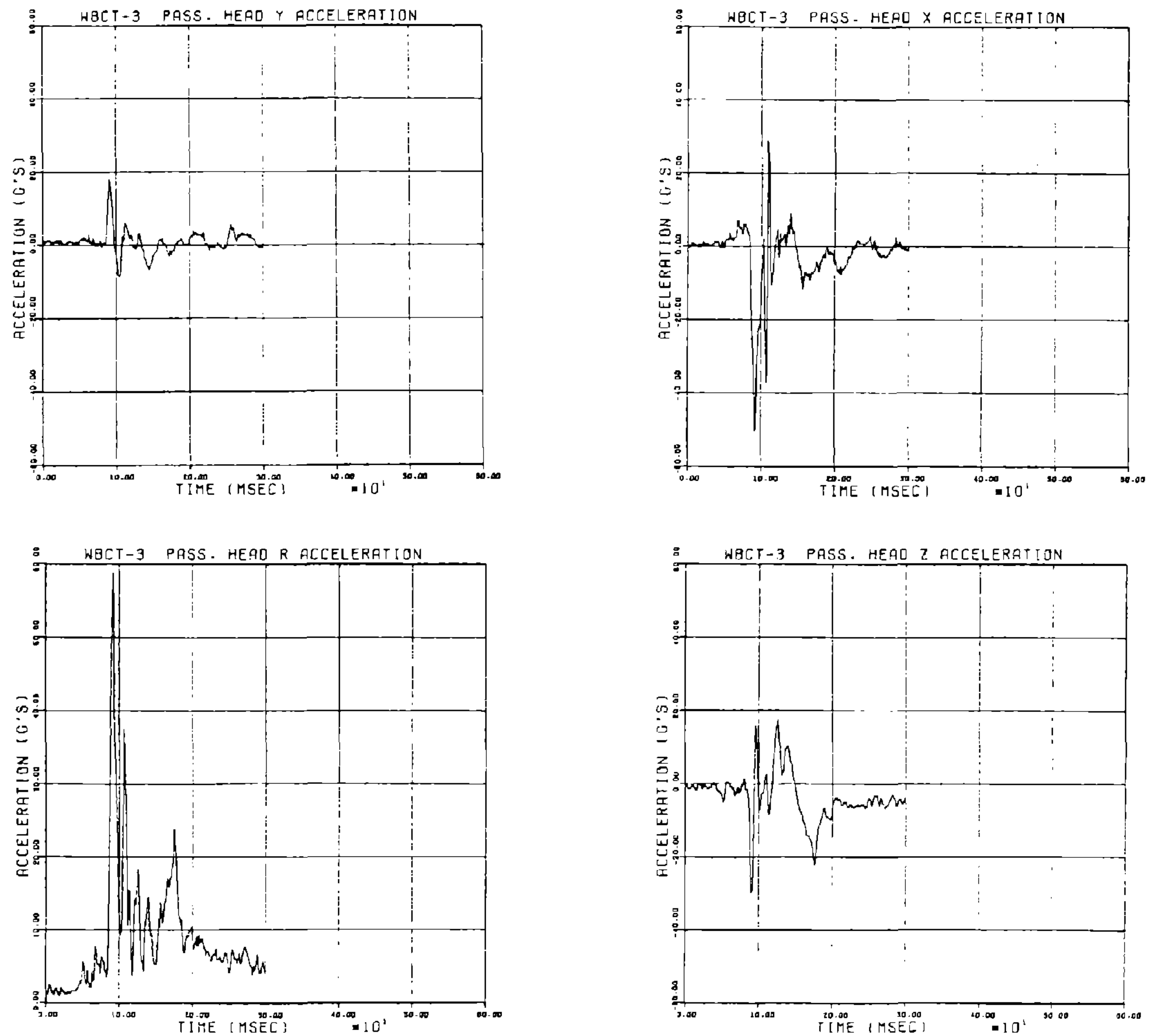


FIGURE A.18 PASSENGER DUMMY HEAD ACCELERATION PLOTS, TEST WBCT-3

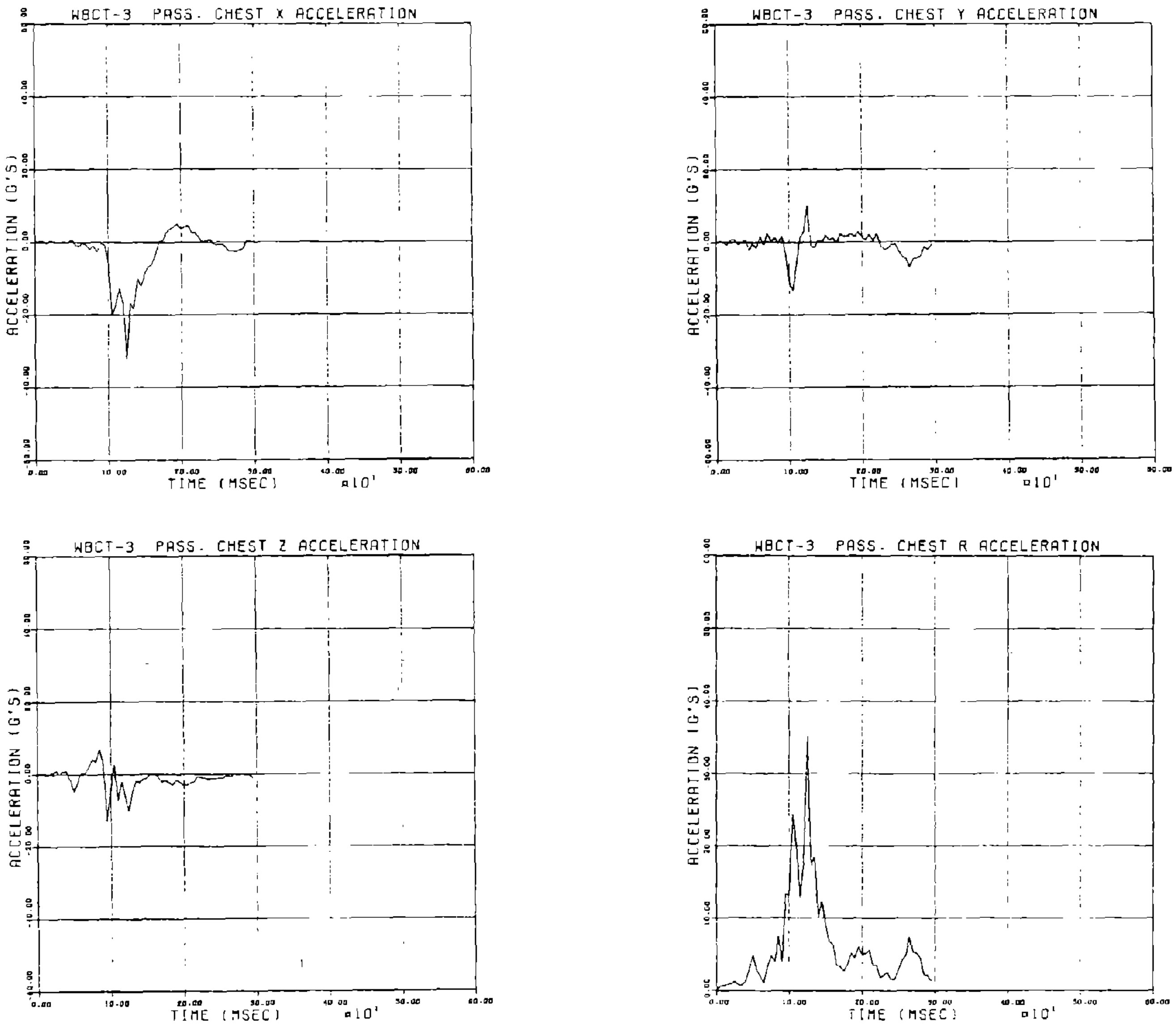
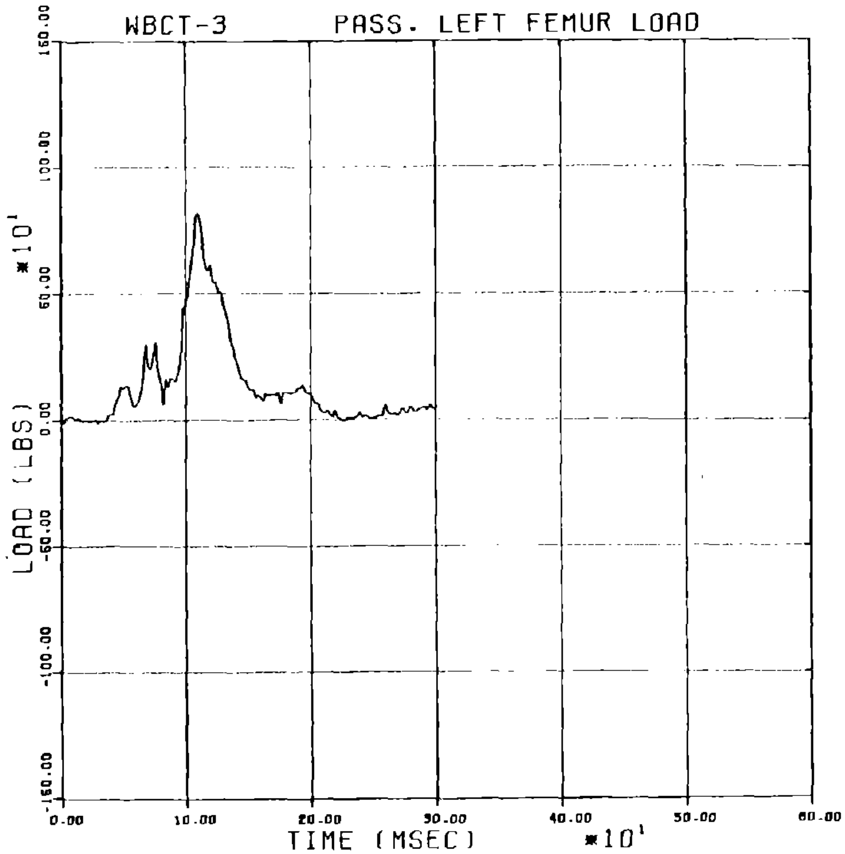


FIGURE A.19 PASSENGER DUMMY CHEST ACCELERATION PLOTS, TEST WBCT-3



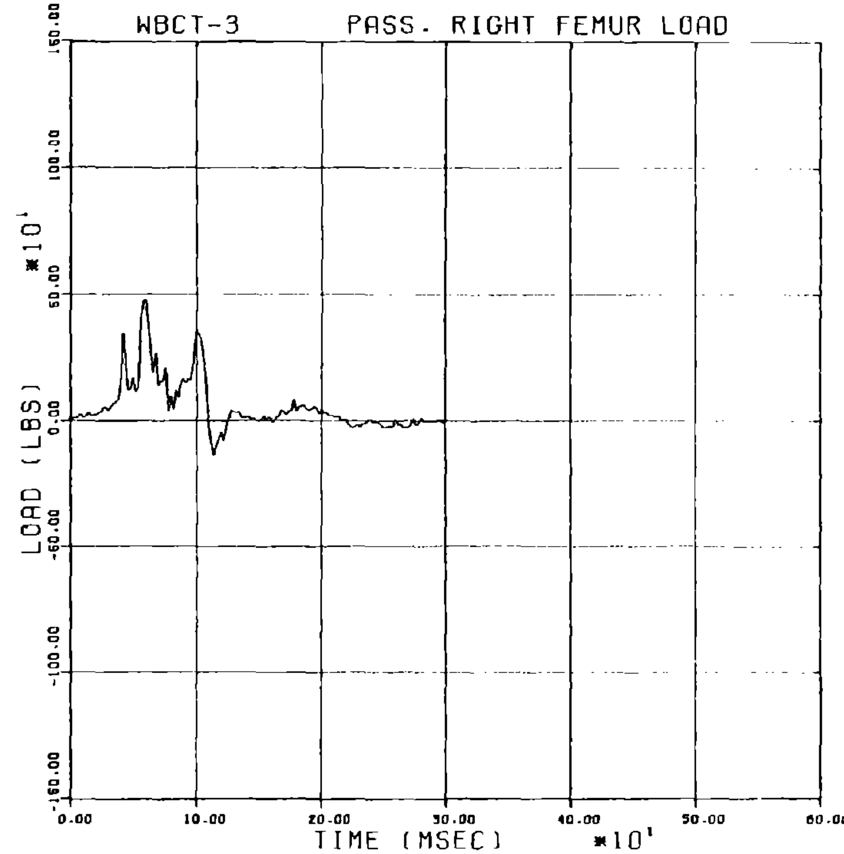


FIGURE A.20 PASSENGER DUMMY FEMUR LOAD PLOTS, TEST WBCT-3

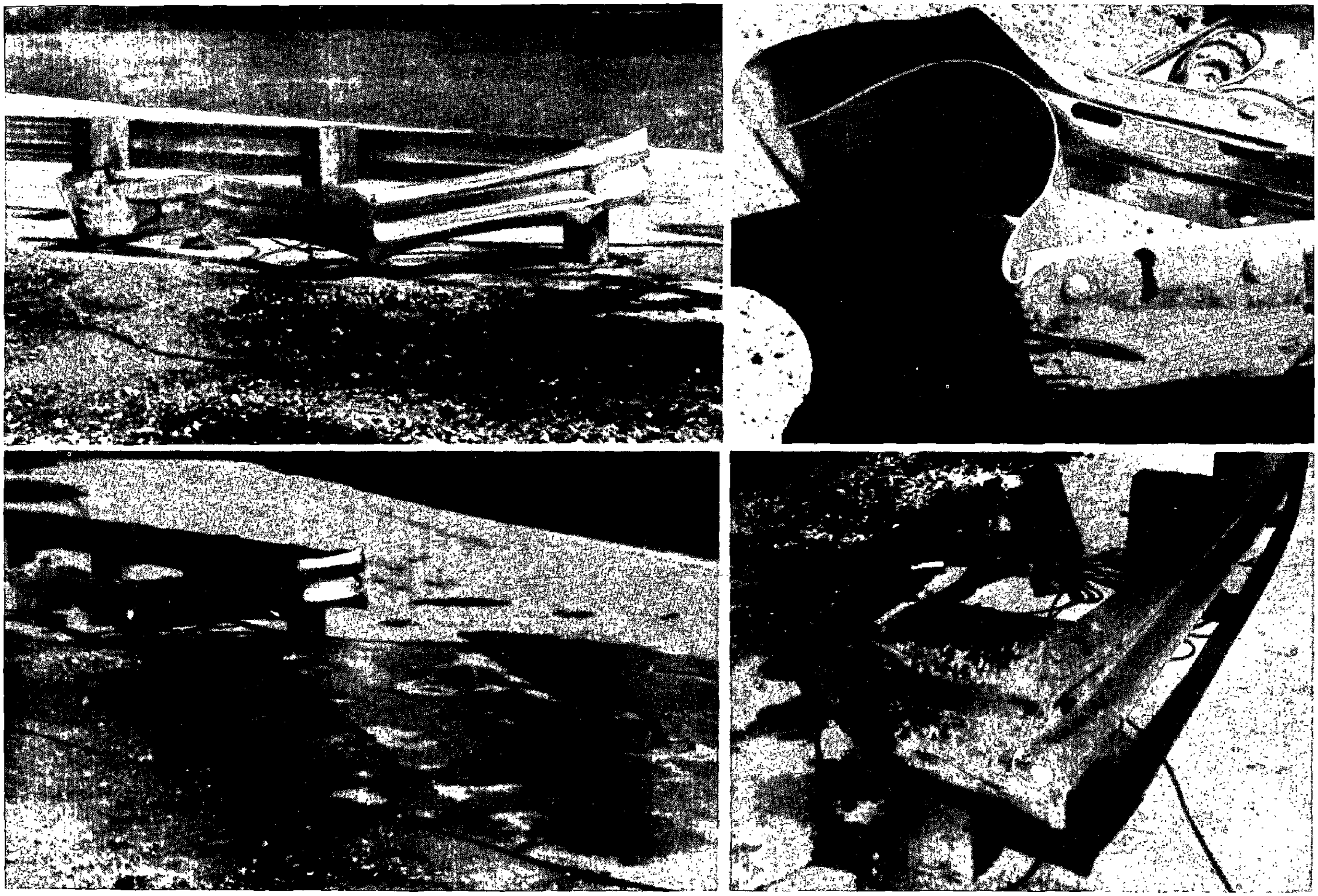


FIGURE A.21   TEST WBCT-3 BARRIER DAMAGE

FIGURE A.22 TEST WBCT-3 VEHICLE DAMAGE

TABLE A.4

TEST WBCT-3 FILM ANALYSIS RESULTS

SUMMARY OF VEHICLE KINEMATIC AND DYNAMIC DATA   WOOD POST BCT TEST WBCT-3   4/17/80

TIME AFTER IMPACT(SEC)	VEHICLE C. G. COORDINATES(FT)		HEADING ANGLE (DEG)	VEHICLE VELOCITY (FT/SEC)		VEHICLE ACCELERATION(G'S) AT TIME T		AVERAGE AVER .05 SEC.		APPROX. BARRIER FORCES(LB)	
	X	Y		LONG	LAT	LONG	LAT	LONG	LAT	X	Y
0.000	-6.68	1.24	14.52	86.97	2.64	-.07	-.34	0.00	0.00	-36	253
.010	-5.85	1.50	14.65	86.79	2.06	-1.26	-1.94	0.00	0.00	1582	4740
.020	-5.02	1.73	14.73	86.05	1.11	-3.54	-3.17	0.00	0.00	5704	8640
.030	-4.19	1.95	14.80	84.43	-.09	-6.66	-3.45	-5.62	-2.15	12097	10968
.040	-3.39	2.16	14.96	81.72	-1.29	-10.13	-2.46	-8.44	-1.91	19942	10875
.050	-2.61	2.35	15.29	77.91	-2.24	-13.37	-.27	-11.25	-.56	27931	8237
.060	-1.87	2.53	15.94	73.17	-2.71	-15.69	2.68	-13.49	1.47	34454	3767
.070	-1.19	2.70	16.99	67.90	-2.65	-16.48	5.62	-14.64	3.76	37903	-1210
.080	-.56	2.88	18.49	62.65	-2.19	-15.38	7.66	-14.30	5.66	37052	-5192
.090	.01	3.06	20.44	58.07	-1.66	-12.41	8.06	-12.39	6.57	31438	-6940
.100	.54	3.25	22.78	54.68	-1.57	-8.07	6.44	-9.19	6.06	21626	-6130
.110	1.04	3.45	25.34	52.77	-2.45	-3.24	3.07	-5.31	4.10	9247	-3016
.120	1.52	3.66	28.15	52.29	-4.66	1.06	-1.18	-1.51	1.16	-3257	1184
.130	2.01	3.86	30.91	52.84	-8.21	4.03	-5.04	1.45	-1.94	-13167	4913
.140	2.52	4.06	33.55	53.91	-12.70	5.25	-7.19	3.18	-4.20	-18183	6733
.150	3.05	4.25	36.00	54.92	-17.35	4.78	-6.78	3.55	-4.82	-17106	5820
.160	3.61	4.42	38.26	55.44	-21.29	3.06	-3.74	2.80	-3.49	-10286	2265
.170	4.18	4.60	40.38	55.23	-23.29	.75	1.12	1.36	-.54	336	-2910
.180	4.75	4.78	42.42	54.23	-24.53	-1.46	6.35	-.28	3.19	11673	-8063
.190	5.31	4.97	44.50	52.62	-23.74	-2.97	10.31	-1.61	6.57	20343	-11479
.200	5.83	5.18	46.70	50.67	-22.10	-3.43	11.70	-2.31	8.65	23722	-11980
.210	6.32	5.41	49.07	48.73	-20.57	-3.02	10.06	-2.31	8.56	20862	-9388
.220	6.79	5.65	51.62	47.01	-20.07	-2.02	5.98	-1.81	6.66	12935	-4645
.230	7.23	5.89	54.33	45.57	-21.13	-.98	.98	-1.16	3.62	2971	494
.240	7.66	6.14	57.13	44.28	-23.71	-.31	-3.01	-.67	.63	-5140	4125
.250	8.11	6.38	59.96	42.97	-27.14	-.12	-4.38	-.49	-1.19	-8123	5004
.260	8.56	6.61	62.76	41.50	-30.41	-.28	-2.61	-.59	-1.20	-4765	3149
.270	9.03	6.84	65.48	39.86	-32.57	-.59	1.39	-.81	.38	3300	-82
.280	9.48	7.07	68.12	38.09	-31.22	-.94	5.55	-1.00	2.57	11975	-2602
.290	9.92	7.30	70.69	36.25	-32.70	-1.30	7.51	-1.08	4.07	16378	-2745
.300	10.34	7.53	73.23	34.35	-32.01	-1.57	5.90	-.97	3.90	13248	-936
.310	10.74	7.77	75.83	32.39	-32.32	-1.94	1.17	-.57	1.94	3239	2406
.320	11.13	8.00	78.58	30.47	-34.37	-.47	-4.38	.13	-1.01	-9157	2887
.330	11.54	8.23	81.46	28.79	-37.92	1.41	-7.92	.91	-3.71	-17508	-470
.340	11.97	8.46	84.26	27.62	-41.94	3.26	-7.88	1.29	-5.07	-17782	-5351
.350	12.43	8.70	86.48	27.04	-45.11	3.13	-4.92	1.09	-4.17	-11108	-6159

TABLE A.5

TEST WBCT-3 TRANSDUCER DATA

TEST -- WBCT-3 VEHICLE TYPE -- MINI-AUTO VEHICLE WT. -- 2178 LBS
TEST DATE -- 04/17/1980 IMPACT VELOCITY -- 60.0 MPH IMPACT ANGLE -- 15.0 DEGREES
TYPE DUMMY -- 572-50% MALE DUMMY LOCATION -- DRIVER TYPE RESTRAINT -- (L+S) BELTS

	ACCELERATIONS-G'S														FEMUR LOAD-LBS	
	VEHICLE			HEAD					CHEST							
TIME	X	Y	R	X	Y	Z	R	SI	X	Y	Z	R	SI		LEFT	RIGHT
.000	-.0	.0	.1	.0	.0	.0	.0	.	.0	.0	.0	.0	.		.	.
.010	-4.8	.2	4.8	-.7	-.1	-1.8	1.9	.	-1.0	-.9	-.2	1.4	.		3.	1.
.020	-2.5	-.3	2.5	-.4	.1	-.3	.5	.	-.3	.2	.4	.6	.		10.	-2.
.030	-2.4	-1.3	2.7	-.7	-.1	-.9	1.2	.	-1.2	-.9	.0	1.5	.		6.	-5.
.040	-11.7	-4.9	12.6	-1.5	-.4	-1.6	2.3	.	-1.2	.2	-.7	1.4	.		57.	7.
.050	-20.6	14.9	25.4	-4.8	-.3	-3.8	6.1	.	-.6	-3.7	-.6	3.8	.		163.	166.
.060	-21.4	1.0	21.4	-18.9	2.8	-7.4	21.4	5.	-10.5	.7	-1.0	10.7	8.		1305.	395.
.070	-13.0	11.1	17.0	-8.8	-.5	-.9	9.1	110.	-27.8	-3.0	.4	27.9	45.		470.	-163.
.080	-1.3	11.7	11.8	-58.0	2.4	-26.0	63.7	748.	-34.2	-4.5	24.6	42.5	122.		-5.	-109.
.090	2.1	-.7	2.3	-11.4	-6.1	-8.0	15.3	885.	-43.4	4.2	.6	43.8	311.		-195.	-173.
.100	-1.0	-1.6	1.8	-6.9	1.4	18.3	19.6	898.	-17.6	2.6	1.7	17.9	358.		-114.	-112.
.110	1.9	-1.8	2.6	.2	1.9	-6.1	6.7	905.	-6.3	-.7	-.1	6.3	361.		-268.	-70.
.120	-1.4	-3.0	3.3	3.6	.7	-3.6	5.2	906.	.6	.3	-.8	1.6	362.		-113.	-38.
.130	-1.7	-1.8	2.5	-3.9	1.4	-.2	4.2	906.	1.3	-.2	2.1	2.6	362.		-40.	18.
.140	-1.4	1.1	1.8	-6.3	1.4	-2.6	7.0	907.	2.9	-1.8	1.0	3.6	362.		-28.	-19.
.150	-1.4	.8	1.6	-3.9	2.5	.5	4.6	908.	2.7	-.3	.7	2.8	362.		3.	-8.
.160	-.6	1.5	1.6	-6.5	1.1	1.2	6.7	909.	4.6	-.3	.0	4.6	363.		-16.	-22.
.170	-.7	.8	1.1	-5.6	1.2	2.1	6.2	911.	5.4	-1.6	.6	5.6	364.		3.	8.
.180	-.7	2.0	2.1	.6	-.3	-.1	.8	911.	3.5	-1.4	3.0	4.9	364.		12.	-7.
.190	-1.1	1.8	2.1	-.4	-2.7	-.7	2.9	911.	2.0	-3.2	.6	3.9	365.		22.	-12.
.200	-.4	2.4	2.4	2.1	-4.9	-1.4	5.6	912.	.3	-.4	1.3	1.4	365.		35.	-3.
.210	1.1	3.3	3.5	5.9	-8.6	-.7	10.5	914.	-.1	-2.4	-.2	2.5	365.		21.	-12.
.220	.8	1.0	1.3	3.9	-6.4	-3.3	8.3	917.	1.3	-2.2	-.4	2.6	365.		28.	13.
.230	-.6	.7	.9	.1	-4.6	-.9	4.7	918.	1.8	-.4	-1.8	2.6	365.		-7.	-13.
.240	.2	-.1	.2	-.3	-2.7	-2.1	3.4	918.	1.9	-2.2	-1.8	3.4	365.		-10.	-8.
.250	.8	.1	.8	-.6	-2.0	-2.6	3.4	918.	2.2	-.6	-2.1	3.1	365.		-14.	-32.
.260	-.1	.4	.4	-.1	-1.0	-.6	1.2	918.	1.3	-.3	-1.3	1.9	365.		2.	-15.
.270	.9	.2	.9	.1	-.3	-1.4	1.4	918.	.4	-1.4	-1.7	2.3	366.		-2.	-11.
.280	.5	.3	.6	.3	-.0	-1.7	1.9	918.	.2	-.6	-1.2	1.3	366.		14.	-1.
.290	.0	-.9	.9	-.1	-.3	-1.9	1.9	919.	.6	-.7	-1.6	1.8	366.		-5.	-14.
.300	1.6	.0	1.6	.5	-.1	-1.2	1.5	919.	.0	.8	-.7	1.1	366.		22.	9.

TABLE A.5 (Cont'd)

MAXIMA--TIME	X/L	-------SEC	Y/R	-------SEC	Z	-------SEC	R	-------SEC	SI	------SEC
VEHICLE	-27.7	.058	15.0	.051			28.7	.058		
HEAD	-92.0	.076	-32.3	.073	72.1	.074	104.4	.073	918.6	.300
CHEST	-59.1	.084	-8.8	.085	-29.5	.063	61.1	.084	365.6	.300
FEMUR	1304.9	.060	886.5	.057						

CUMULATIVE PERIOD FOR 60G LEVEL IS 2.1 MSEC

HIC IS 675.4 DURING .072 TO .085 SEC

TABLE A.5 (Cont'd)

TEST -- WACT-3 | VEHICLE TYPE -- MINI-AUTO | VEHICLE WT. -- 2178 LBS
TEST DATE -- 04/17/1980 | IMPACT VELOCITY -- 60.0 MPH | IMPACT ANGLE -- 15.0 DEGREES
TYPE DUMMY -- 572-50% MALE | DUMMY LOCATION -- PASSENGER | TYPE RESTRAINT -- NONE

	ACCELERATIONS-G'S														FEMUR LOAD-LBS	
	VEHICLE			HEAD					CHEST							
TIME	X	Y	R	X	Y	Z	R	SI	X	Y	Z	R	SI		LEFT	RIGHT
.000	.0	.0	.0	-.0	-.0	-.0	.0	.	-.0	.0	.0	.0	.		-.	-.
.010	.0	.0	.0	.6	1.5	-.2	1.8	.	.5	-.1	.2	.6	.		14.	14.
.020	.0	.0	.0	.7	.6	-.0	1.1	.	.3	.7	.3	.8	.		5.	22.
.030	.0	.0	.0	-.2	.2	-1.5	1.5	.	-.3	-.6	.3	.8	.		-11.	38.
.040	.0	.0	.0	1.4	.8	-.1	1.7	.	.2	.8	.9	1.2	.		25.	137.
.050	.0	.0	.0	.6	.8	-3.7	3.9	.	.9	-.3	-4.8	4.9	.		126.	171.
.060	.0	.0	.0	1.7	1.0	-.3	2.1	1.	-1.1	1.7	.5	2.1	.		58.	477.
.070	.0	.0	.0	4.8	1.0	-2.6	5.6	1.	-.7	2.6	1.9	3.3	.		221.	140.
.080	.0	.0	.0	5.3	.4	1.5	5.6	2.	-1.0	1.4	3.6	4.0	1.		160.	101.
.090	.0	.0	.0	-37.9	15.7	-29.7	50.7	44.	-.3	1.7	3.5	3.9	2.		165.	166.
.100	.0	.0	.0	-10.1	-2.3	-4.3	11.3	141.	-5.7	-11.1	-4.1	13.1	7.		447.	351.
.110	.0	.0	.0	25.8	1.0	2.7	26.5	176.	-17.5	-6.2	-7.2	20.0	30.		821.	-17.
.120	.0	.0	.0	2.9	1.7	7.5	8.3	182.	-16.9	2.3	-6.0	18.1	39.		618.	-44.
.130	.0	.0	.0	2.6	2.6	4.8	6.2	190.	-16.6	-1.0	-4.6	17.2	78.		475.	37.
.140	.0	.0	.0	9.2	-3.8	10.1	14.5	194.	-9.9	.7	-2.2	10.2	89.		250.	18.
.150	.0	.0	.0	-4.1	-3.1	-1.3	5.4	196.	-9.0	2.0	-1.1	9.2	94.		131.	-1.
.160	.0	.0	.0	-6.6	1.7	-9.5	11.7	200.	-6.3	1.2	.3	6.5	95.		93.	12.
.170	.0	.0	.0	-7.5	-1.6	-15.3	17.2	210.	.1	2.5	-2.2	3.4	95.		104.	36.
.180	.0	.0	.0	-4.8	.2	-13.3	14.1	227.	2.4	1.5	-2.2	3.6	95.		111.	34.
.190	.0	.0	.0	-.3	1.4	-7.0	7.4	231.	4.1	1.2	-1.4	4.5	96.		125.	42.
.200	.0	.0	.0	-3.5	1.7	-7.0	10.1	234.	3.5	1.3	-3.2	5.0	97.		108.	45.
.210	.0	.0	.0	-6.5	3.4	-4.0	8.4	236.	4.6	2.1	-2.4	5.6	97.		34.	20.
.220	.0	.0	.0	-3.1	1.9	-6.0	7.1	238.	2.6	2.4	-.6	3.6	98.		41.	9.
.230	.0	.0	.0	1.4	-.2	-6.5	6.7	239.	-.2	-1.8	-1.1	2.1	98.		13.	-15.
.240	.0	.0	.0	.1	-.1	-5.8	5.8	240.	.7	-.8	-1.1	1.5	98.		34.	4.
.250	.0	.0	.0	.4	-.3	-3.7	3.9	240.	-.9	-2.4	-.9	2.8	98.		8.	-25.
.260	.0	.0	.0	-2.8	4.4	-3.1	6.1	241.	-1.2	-4.6	-.2	4.8	98.		62.	4.
.270	.0	.0	.0	-2.9	3.2	-6.0	7.4	242.	-2.5	-4.7	.1	5.3	99.		20.	-26.
.280	.0	.0	.0	.5	3.1	-3.8	5.1	244.	-2.3	-3.9	.1	4.5	100.		55.	10.
.290	.0	.0	.0	-.7	.5	-4.5	4.6	244.	.3	-2.1	-.1	2.1	100.		46.	-1.
.300	.0	.0	.0	-.5	-.2	-3.5	3.8	245.	.4	-.5	.1	1.0	100.		80.	25.

TABLE A.5 (Cont'd)

MAXIMA--TIME	X/L	SEC	Y/R	SEC	Z	SEC	R	SEC	SI	SEC
VEHICLE	.0	.300	.0	.300			.0	.300		
HEAD	-50.4	.092	18.0	.091	-29.9	.089	58.8	.092	244.6	.300
CHEST	-35.1	.124	-13.9	.106	-14.0	.096	37.9	.124	99.9	.300
FEMUR	821.5	.110	487.1	.059						

CUMULATIVE PERIOD FOR 60G LEVEL IS .0 MSEC

HIC IS 113.4 DURING .088 TO .098 SEC

TEST SBCT-1

Purpose: Objective of this test was to evaluate the steel post breakaway cable terminal when impacted by a minicompact automobile at 60.0 mph (96.6 kmph) and a 0-deg angle. The desired impact point on the vehicle was 15 in. (381 mm) to the left of vehicle centerline.

Test Installation: The test installation as shown in Figure A.23 consisted of a 37.5-ft (11.4-m) long standard length of G4 steel post guardrail. The system was anchored at the downstream end by a concrete deadman. Post spacing was 6.25 ft (1.9 m) except between Posts 3 thru 6 where spacing was 4.17 ft (1.3 m). Posts 1 and 2 were attached to foundation plates/concrete footings and the remaining posts were embedded 44 in. (1.12 m) in the soil. Height of the steel W-beam rail was 27 in. (0.69 m).

Test Vehicle: The test vehicle was a 1975 Honda Civic sedan. Two 50th percentile anthropomorphic dummies were placed in the driver and right front passenger seating positions. The driver dummy was restrained by a lap/shoulder belt whereas the passenger dummy was unrestrained. Total weight of the vehicle, dummies, and instrumentation was 2180 lb (989 kg).

Performance: Impact conditions were 60.0 mph (96.6 kmph) and a 0.5-deg angle. As shown in the sequential photographs of Figure 11 the vehicle impacted the buffer end, displaced it and then contacted Post 1 causing it to slip at the baseplate (as designed). As the vehicle continued downstream it began to yaw in a counterclockwise direction and the right front corner impacted Post 2. Although Post 2 was the same slipbase design as Post 1, it did not immediately release at the baseplate, but instead leaned rearward before finally releasing and allowing the vehicle to continue its longitudinal trajectory. In the meantime a hinge formed in the rail section between Posts 2 and 3, and the portion of the rail upstream of the hinge rotated around toward the remaining section forming an almost knifelike section with the hinge as its point. As the vehicle was continuing its yawing motion it impacted this section, the point penetrated the front portion of the right door and continued across the passenger compartment stopping at the rear of the left door. This penetration together with the impact of Post 3 by the rear of the vehicle caused it to reverse rotation and it came to a stop 4 ft (1.2 m) behind the barrier in a position approximately parallel to the straight portion. Maximum 50 millisecond average vehicle accelerations measured were 5.0 g (film analysis) and 4.5 g (accelerometer) in the lateral direction and -11.2 g (film analysis) and -15.2 g (accelerometer) in the longitudinal direction. A summary of test results is shown in Figure 12, and Table A.6 contains results of high-speed film analysis. Results of analog to digital conversion of vehicle and dummy transducer data are shown in Table A.7 and plotted in Figures A.24 thru A.30.

Barrier Damage: As shown in Figure A.31 most of the barrier damage occurred between Posts 1 and 4. Posts 1 and 2 were displaced from their slip-base mounting and Post 3 was bent. The remaining posts were displaced in their soil footings but were undamaged. The buffer end section and two rail sections were damaged and required replacement. The concrete footing at Post 2 was rotated slightly in the soil and one anchor bolt failed.

Vehicle Damage: Vehicle damage as shown in Figure A.32 was severe. Maximum front end crush was 22 in. (559 mm). The entire front section of the unibody was deformed and the engine was driven rearward into the firewall. The top portion of the right door was torn by the rail as it penetrated and the left door was bent outward before it stopped penetration. Both front seat backs were displaced rearward by the penetrating rail and the windshield was knocked out by the unrestrained passenger dummy's head.

Dummy Injury: Transducers in the lap/shoulder belt-restrained driver dummy indicated an HIC of 447.1 and a maximum chest resultant acceleration of 45.9 g's. The penetrating rail section forced the driver dummy forward and outboard resulting in the dummy's head shattering the left door glass. Small pieces of glass were embedded in the dummy's head. When the vehicle stopped the dummy was wedged between the penetrating rail section and forward portion of the left door.

As discussed previously the head of the unrestrained passenger dummy impacted the windshield and small pieces of glass were embedded in the dummy's forehead. An HIC value of 173.4 and maximum chest resultant of 41.4 g's were calculated for the passenger dummy. In addition, a jagged edge of the door sheet metal tore a large hole in the dummy's right side.

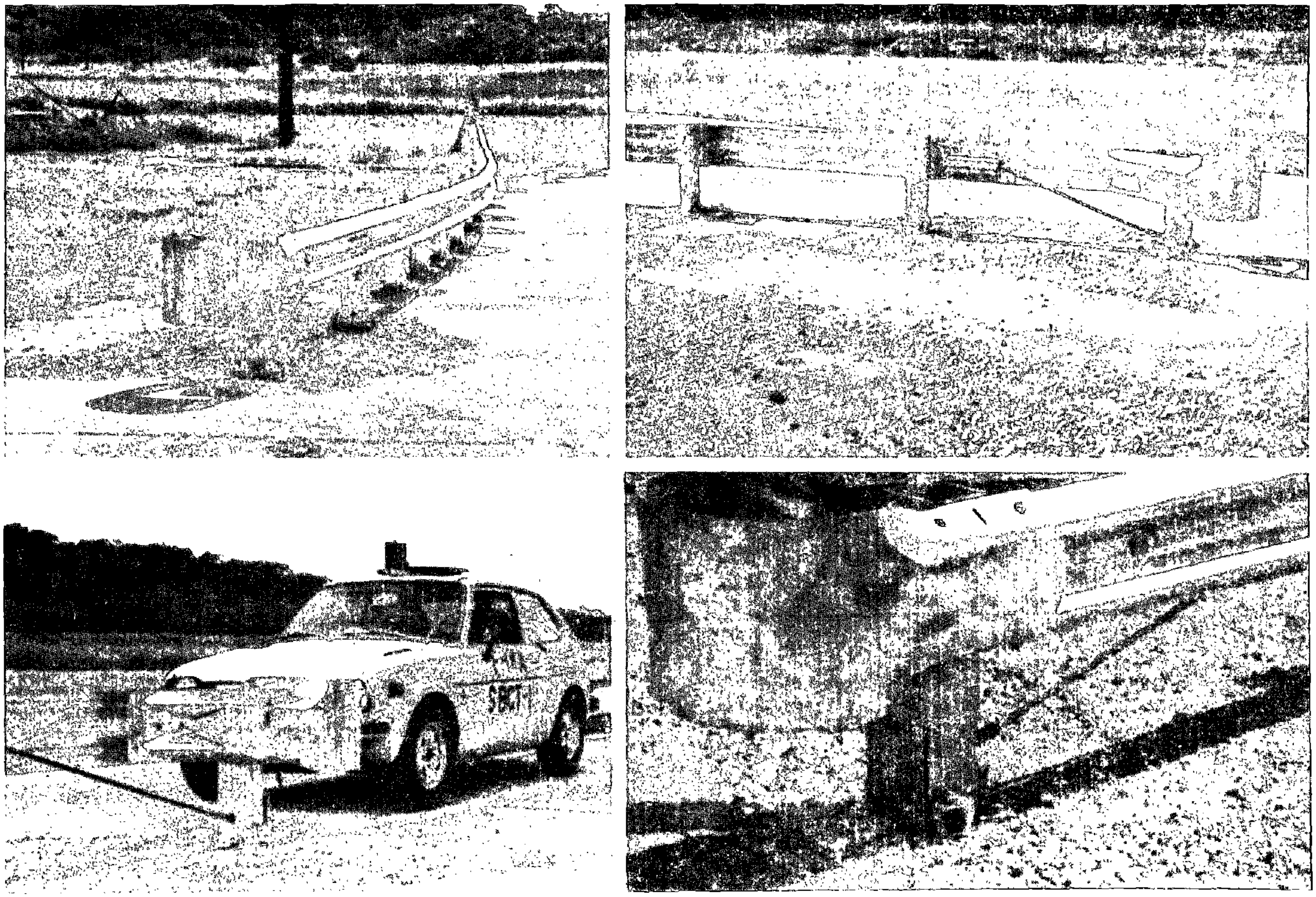
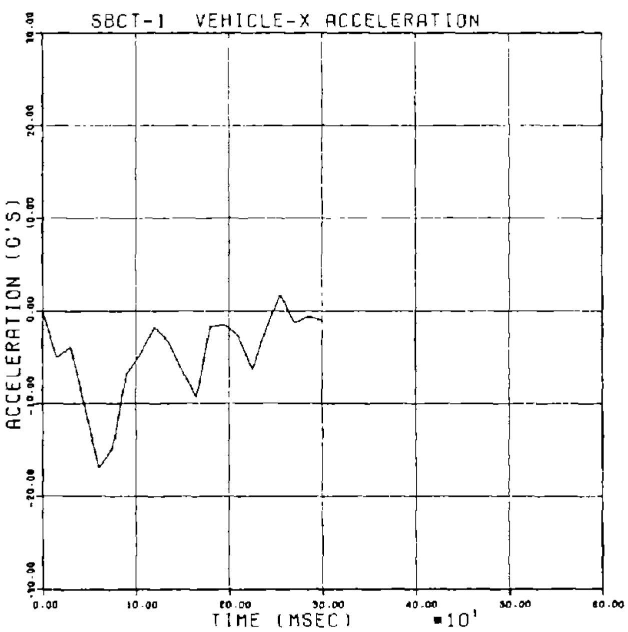
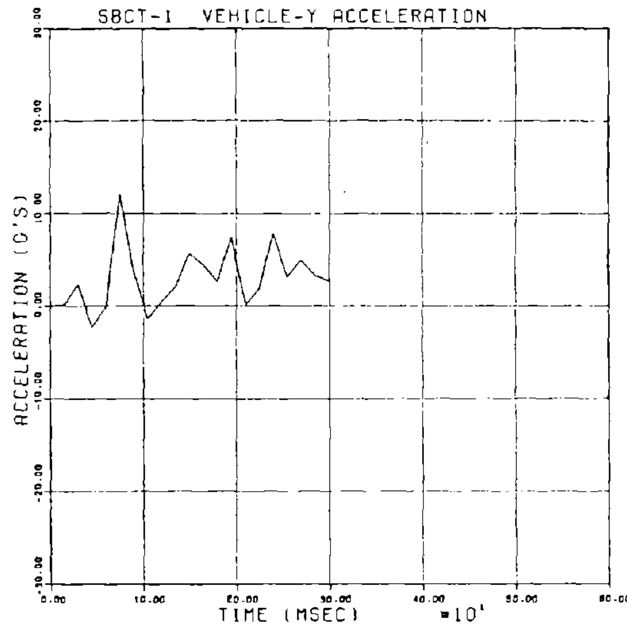


FIGURE A.23 STEEL POST BREAKAWAY CABLE TERMINAL TEST INSTALLATION





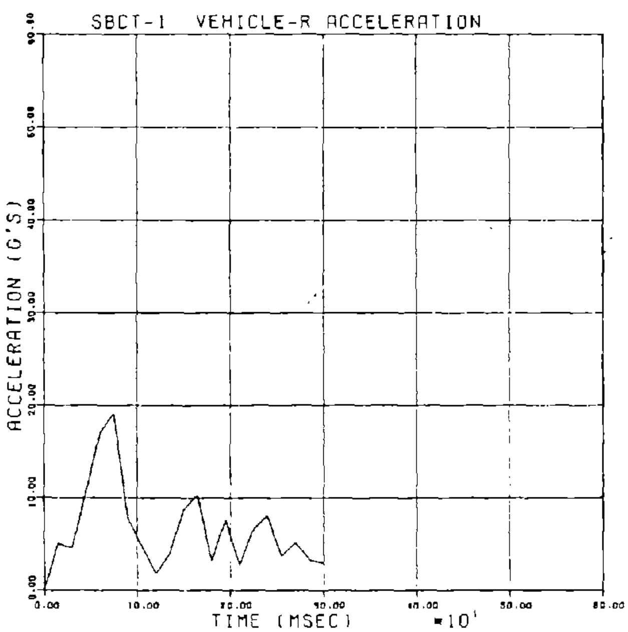


FIGURE A.24 VEHICLE ACCELERATION PLOTS, TEST SBCT-1

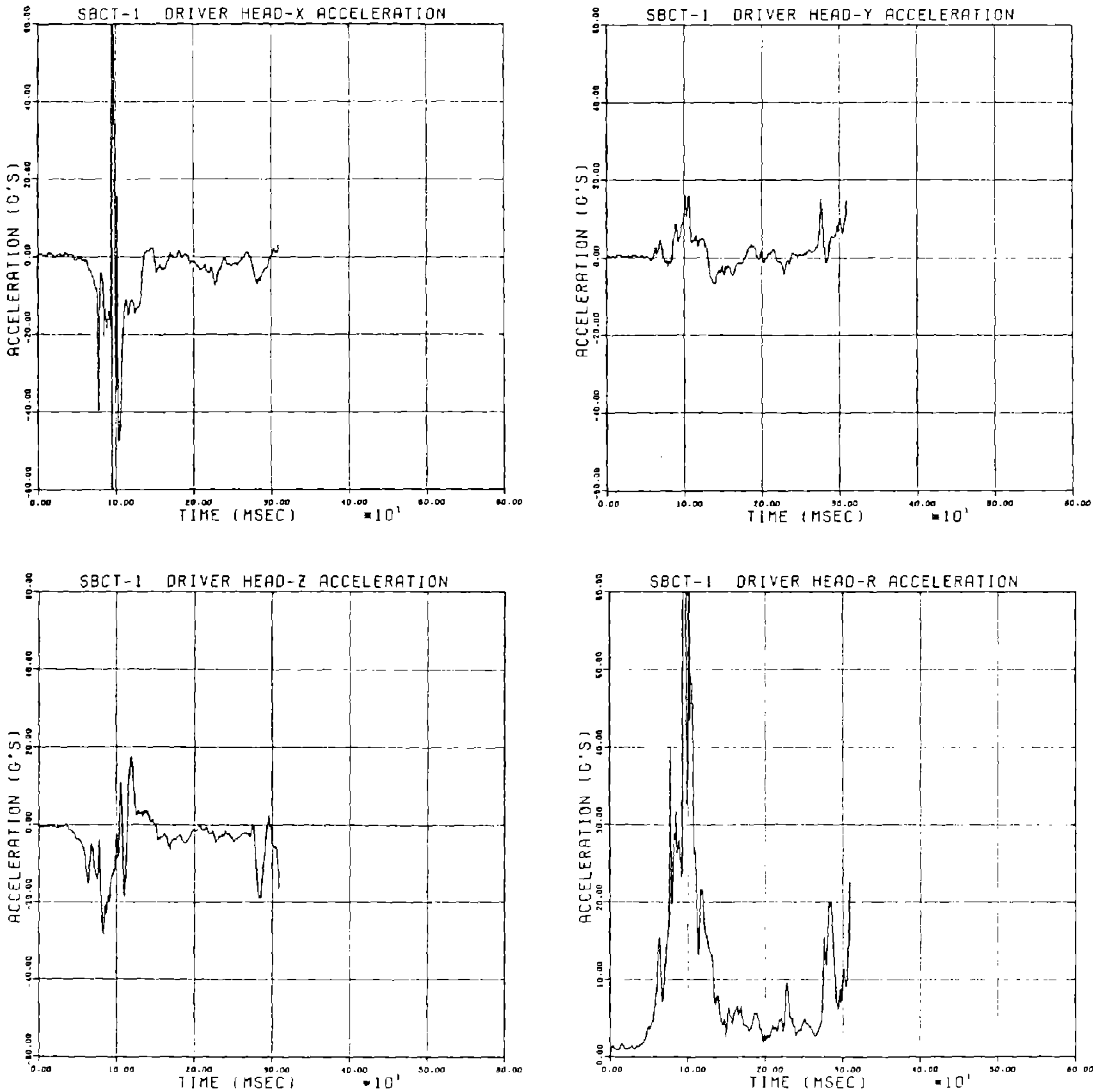


FIGURE A.25 DRIVER DUMMY HEAD ACCELERATION PLOTS, TEST SBCT-1

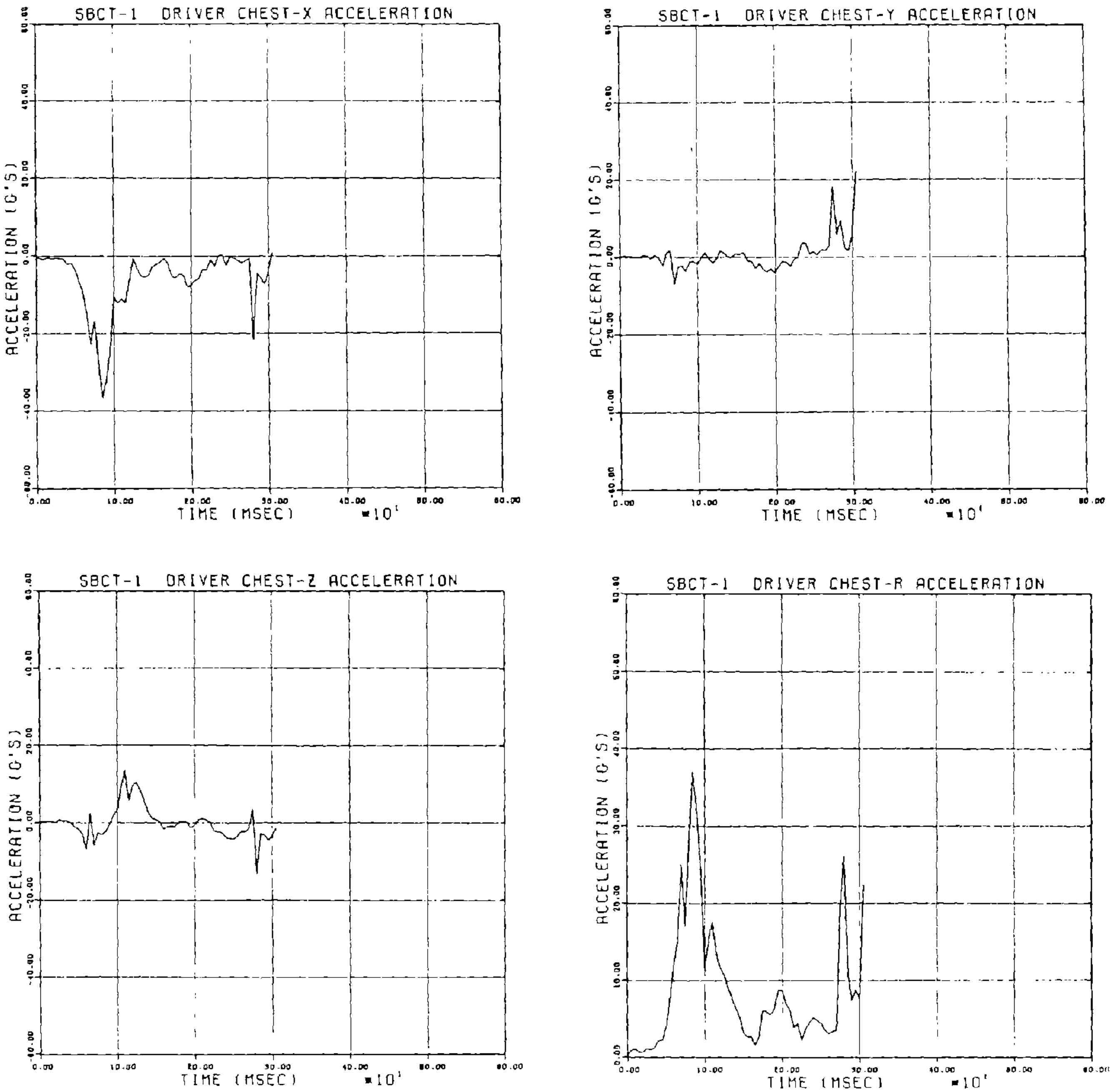
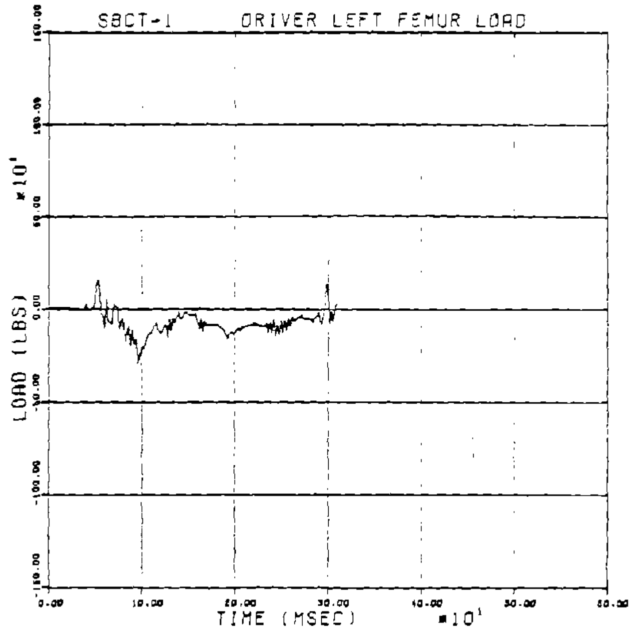


FIGURE A.26 DRIVER DUMMY CHEST ACCELERATION PLOTS, TEST SBCT-1



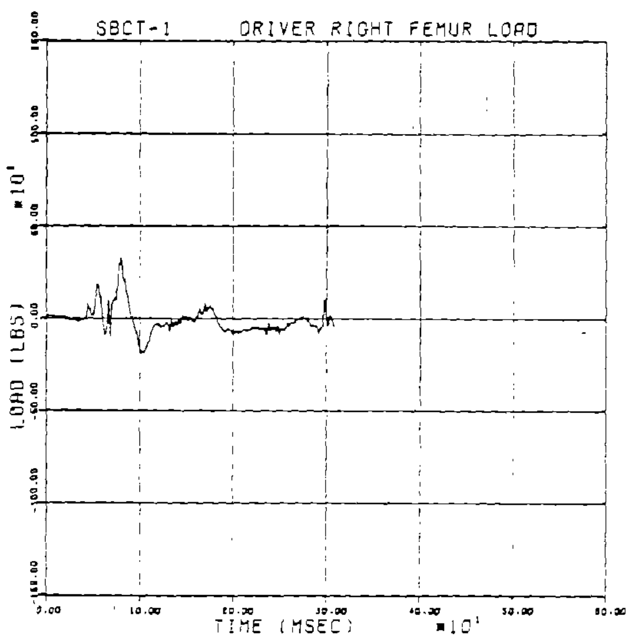


FIGURE A.27 DRIVER DUMMY FEMUR LOAD PLOTS, TEST SBCT-1

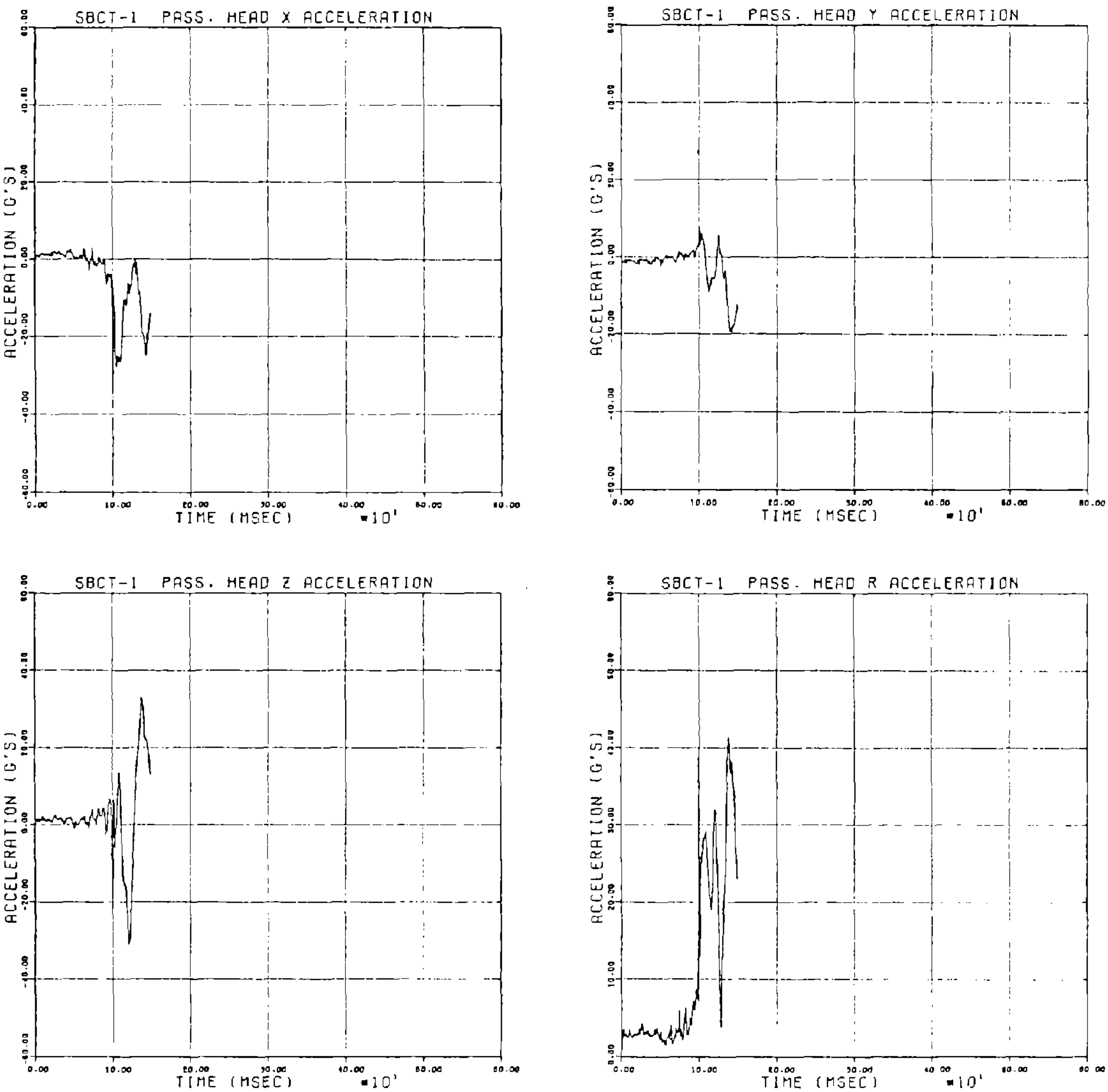


FIGURE A.28 PASSENGER DUMMY HEAD ACCELERATION PLOTS, TEST SBCT-1

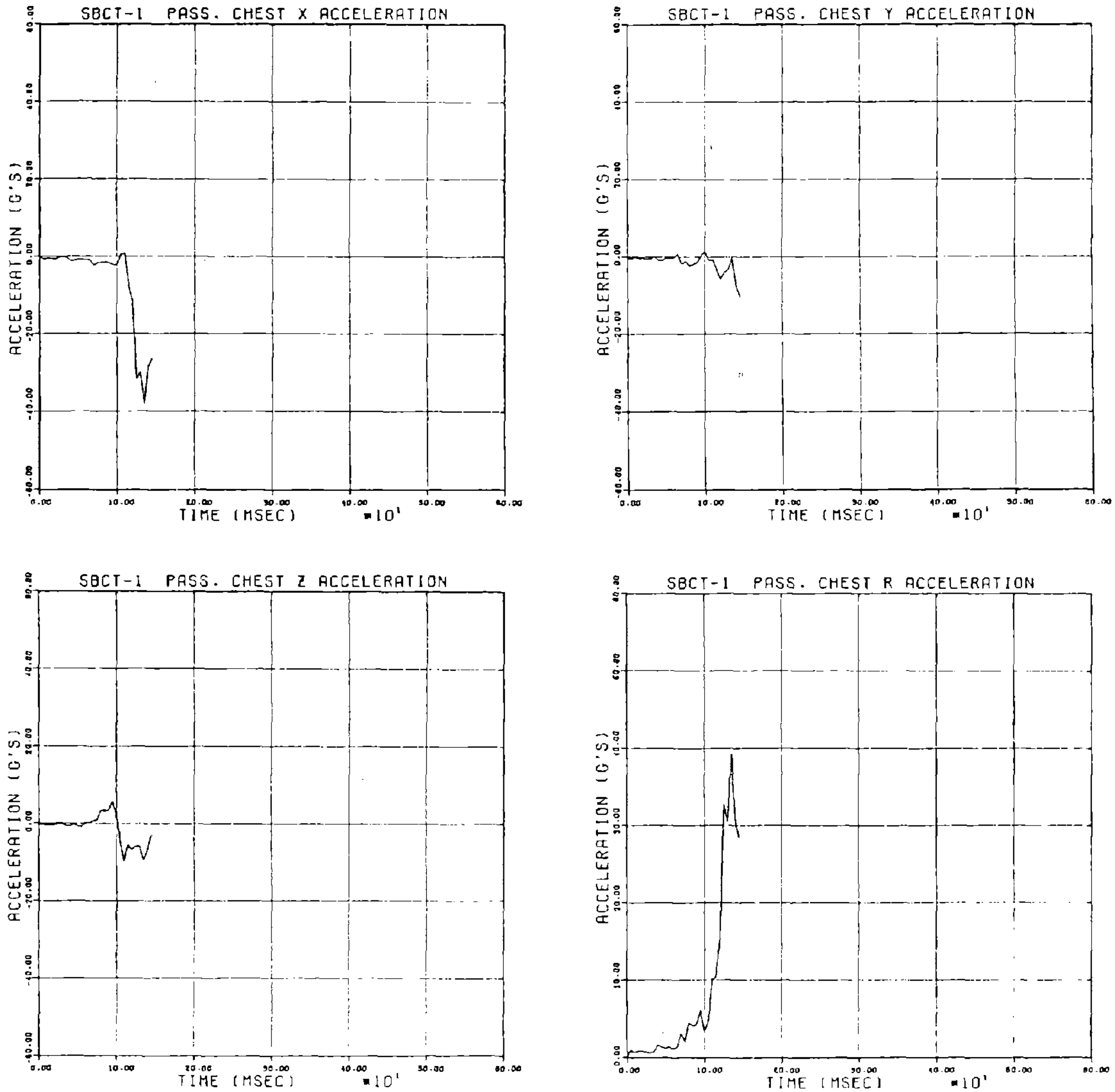
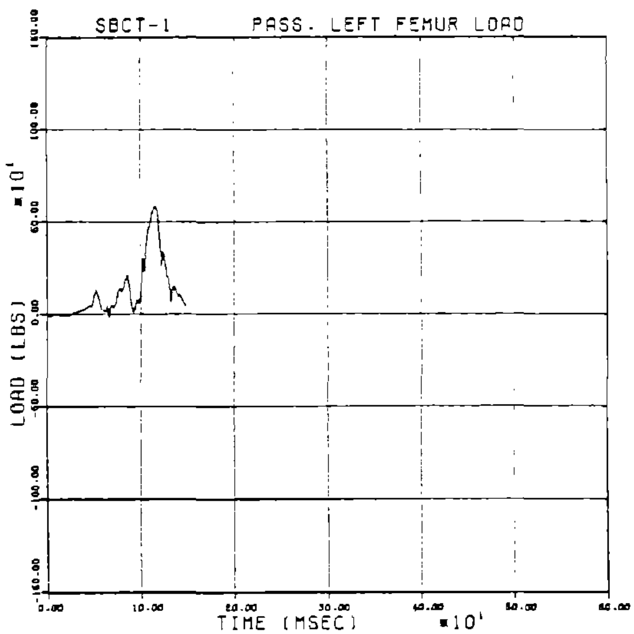


FIGURE A.29 PASSENGER DUMMY CHEST ACCELERATION PLOTS, TEST SBCT-1



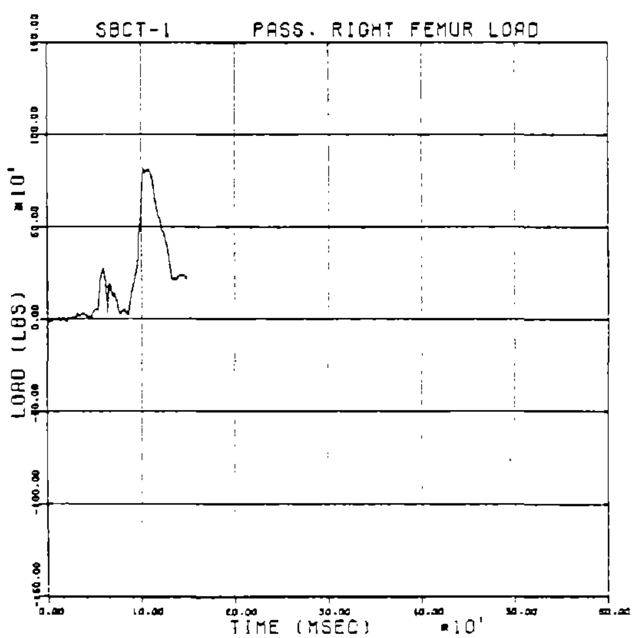


FIGURE A.30 PASSENGER DUMMY FEMUR LOAD PLOTS, TEST SBCT-1

FIGURE A.31 TEST SBCT-1 BARRIER DAMAGE

FIGURE A.32 TEST SBCT-1 VEHICLE DAMAGE

TABLE A.6

TEST SBCT-1 FILM ANALYSIS RESULTS

SUMMARY OF VEHICLE KINEMATIC AND DYNAMIC DATA   STEEL POST BCT TEST SBCT-1   6/5/80

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	-4.81	2.66	.47	88.02	4.10	-3.90	2.89	0.00	0.00	8193.	-6692.
.010	-3.93	2.67	.29	86.16	4.97	-7.53	2.99	0.00	0.00	16093.	-7257.
.020	-3.09	2.68	.23	83.32	5.39	-10.17	2.71	0.00	0.00	21915.	-6783.
.030	-2.27	2.71	.37	79.83	5.37	-11.64	2.19	-9.89	2.26	25212.	-5524.
.040	-1.49	2.74	.76	76.06	4.96	-12.03	1.52	-10.96	1.79	26169.	-3763.
.050	-.74	2.78	1.42	72.30	4.24	-11.62	.79	-11.21	1.20	25334.	-1771.
.060	-.04	2.82	2.36	68.75	3.21	-10.73	.06	-10.84	.55	23398.	209.
.070	.63	2.86	3.56	65.52	1.89	-9.67	-.60	-10.11	-.06	21020.	1983.
.080	1.27	2.90	5.00	62.59	.28	-8.66	-1.10	-9.25	-.58	18723.	3409.
.090	1.88	2.93	6.65	59.92	-1.60	-7.86	-1.41	-8.45	-.95	16842.	4394.
.100	2.47	2.96	8.49	57.41	-3.71	-7.32	-1.49	-7.81	-1.12	15522.	4897.
.110	3.03	2.98	10.46	54.96	-5.98	-7.01	-1.31	-7.35	-1.06	14746.	4918.
.120	3.57	2.99	12.60	52.47	-8.29	-6.86	-.89	-7.05	-.78	14386.	4493.
.130	4.09	3.00	14.81	49.90	-10.52	-6.75	-.27	-6.84	-.29	14248.	3684.
.140	4.59	3.00	17.09	47.26	-12.54	-6.57	.50	-6.61	.36	14133.	2572.
.150	5.07	3.00	19.41	44.60	-14.27	-6.25	1.33	-6.29	1.10	13866.	1249.
.160	5.53	2.99	21.75	42.00	-15.63	-5.73	2.15	-5.83	1.87	13333.	-191.
.170	5.97	2.99	24.09	39.57	-16.60	-5.02	2.87	-5.21	2.58	12490.	-1655.
.180	6.39	2.98	26.41	37.37	-17.20	-4.15	3.45	-4.45	3.19	11362.	-3057.
.190	6.79	2.99	28.68	35.49	-17.48	-3.21	3.86	-3.59	3.65	10039.	-4323.
.200	7.18	2.99	30.89	33.94	-17.52	-2.26	4.09	-2.71	3.96	8651.	-5394.
.210	7.56	3.01	33.04	32.73	-17.38	-1.40	4.19	-1.87	4.13	7350.	-6225.
.220	7.92	3.04	35.13	31.80	-17.14	-.71	4.16	-1.15	4.18	6285.	-6789.
.230	8.28	3.07	37.17	31.09	-16.84	-.23	4.13	-.60	4.17	5583.	-7072.
.240	8.62	3.12	39.15	30.51	-16.53	-.00	4.06	-.27	4.12	5327.	-7077.
.250	8.96	3.17	41.11	29.98	-16.22	-.02	4.03	-.16	4.09	5550.	-6821.
.260	9.29	3.24	43.05	29.41	-15.90	-.27	4.07	-.27	4.09	6231.	-6332.
.270	9.62	3.32	45.00	28.72	-15.57	-.70	4.17	-.56	4.16	7291.	-5645.
.280	9.93	3.40	46.98	27.86	-15.20	-1.26	4.34	-1.00	4.28	8610.	-4803.
.290	10.22	3.49	48.99	26.82	-14.76	-1.86	4.56	-1.51	4.46	10033.	-3853.
.300	10.51	3.59	51.05	25.58	-14.23	-2.45	4.79	-2.04	4.65	11388.	-2844.
.310	10.77	3.69	53.16	24.18	-13.59	-2.96	4.99	-2.53	4.84	12509.	-1821.
.320	11.02	3.79	55.30	22.66	-12.86	-3.33	5.10	-2.92	4.96	13244.	-828.
.330	11.25	3.90	57.46	21.08	-12.04	-3.54	5.07	-3.18	4.98	13478.	95.
.340	11.46	4.00	59.60	19.49	-11.19	-3.59	4.86	-3.30	4.85	13140.	917.
.350	11.65	4.11	61.69	17.97	-10.36	-3.47	4.46	-3.27	4.55	12214.	1612.
.360	11.82	4.21	63.68	16.55	-9.60	-3.22	3.86	-3.12	4.06	10736.	2165.
.370	11.98	4.31	65.52	15.28	-8.98	-2.86	3.08	-2.85	3.40	8796.	2567.
.380	12.12	4.40	67.16	14.17	-8.54	-2.44	2.17	-2.51	2.59	6526.	2817.
.390	12.25	4.49	68.55	13.26	-8.34	-1.98	1.18	-2.12	1.70	4089.	2925.
.400	12.38	4.58	69.66	12.53	-8.37	-1.52	.20	-1.71	.77	1666.	2903.
.410	12.51	4.66	70.44	11.99	-8.63	-1.09	-.71	-1.31	-.13	-563.	2773.
.420	12.63	4.74	70.89	11.62	-9.09	-.69	-1.47	-.93	-.91	-2435.	2559.
.430	12.76	4.81	70.98	11.43	-9.69	-.35	-2.01	-.59	-1.53	-3820.	2288.
.440	12.89	4.88	70.72	11.40	-10.36	-.08	-2.31	-.30	-1.93	-4630.	1988.
.450	13.04	4.95	70.13	11.50	-11.01	.10	-2.34	-.06	-2.10	-4830.	1689.
.460	13.18	5.01	69.23	11.72	-11.56	.18	-2.13	.06	-2.03	-4441.	1415.
.470	13.34	5.08	68.07	12.02	-11.94	.15	-1.70	.09	-1.75	-3537.	1190.
.480	13.50	5.14	66.70	12.35	-12.09	.01	-1.13	.02	-1.31	-2238.	1032.
.490	13.66	5.20	65.15	12.66	-12.00	-.24	-.48	-.16	-.77	-700.	953.

TABLE A.6 (Cont'd)

.500	13.83	5.25	63.49	12.90	-11.65	-.59	.15	-.43	-.19	907.	958.
.510	13.99	5.31	61.76	13.01	-11.09	-.97	.71	-.77	.34	2407.	1048.
.520	14.15	5.37	60.00	12.99	-10.37	-1.36	1.11	-1.13	.77	3644.	1214.
.530	14.30	5.42	58.24	12.81	-9.56	-1.71	1.34	-1.47	1.05	4498.	1442.
.540	14.45	5.47	56.51	12.50	-8.73	-1.95	1.36	-1.75	1.16	4897.	1713.
.550	14.59	5.52	54.82	12.08	-7.96	-2.08	1.19	-1.93	1.10	4827.	2004.
.560	14.72	5.56	53.18	11.62	-7.30	-2.07	.88	-1.99	.90	4336.	2286.
.570	14.85	5.61	51.57	11.16	-6.78	-1.94	.47	-1.93	.59	3530.	2531.
.580	14.97	5.65	49.98	10.73	-6.42	-1.71	.04	-1.78	.23	2562.	2711.
.590	15.09	5.68	48.39	10.39	-6.21	-1.44	-.35	-1.56	-.11	1612.	2800.
.600	15.21	5.71	46.79	10.13	-6.10	-1.18	-.62	-1.36	-.38	869.	2777.
.610	15.32	5.74	45.17	9.95	-6.05	-1.00	-.72	-1.17	-.52	503.	2626.
.620	15.43	5.76	43.51	9.81	-5.98	-.93	-.61	-1.06	-.49	636.	2341.
.630	15.55	5.78	41.82	9.69	-5.83	-1.03	-.29	-1.11	-.28	1323.	1922.
.640	15.66	5.79	40.10	9.50	-5.53	-1.31	.22	-1.28	.10	2534.	1382.
.650	15.76	5.81	38.37	9.19	-5.05	-1.74	.85	-1.60	.61	4148.	742.
.660	15.86	5.82	36.65	8.70	-4.38	-2.26	1.53	-2.02	1.19	5955.	34.
.670	15.96	5.83	34.98	8.00	-3.52	-2.80	2.17	-2.47	1.76	7686.	-703.
.680	16.04	5.85	33.37	7.12	-2.52	-3.22	2.69	-2.86	2.26	9038.	-1421.
.690	16.10	5.87	31.86	6.09	-1.42	-3.42	3.02	-3.10	2.62	9728.	-2073.
.700	16.16	5.88	30.46	5.02	-.30	-3.29	3.12	-3.09	2.60	9542.	-2608.
.710	16.20	5.91	29.17	4.02	.78	-2.81	2.97	-2.78	2.77	8396.	-2981.
.720	16.22	5.93	27.98	3.22	1.74	-1.99	2.58	-2.20	2.54	6377.	-3158.
.730	16.24	5.97	26.88	2.71	2.54	-.96	2.03	-1.41	2.15	3767.	-3118.
.740	16.25	6.00	25.84	2.52	3.13	.10	1.39	-.55	1.65	1032.	-2859.
.750	16.26	6.04	24.82	2.64	3.53	.95	.79	.20	1.15	-1241.	-2404.
.760	16.27	6.09	23.80	2.95	3.76	1.35	.35	.64	.73	-2455.	-1801.
.770	16.29	6.14	22.75	3.28	3.90	1.11	.13	.65	.46	-2173.	-1123.
.780	16.31	6.18	21.67	3.43	4.01	.21	.15	.19	.36	-325.	-469.
.790	16.32	6.23	20.59	3.20	4.16	-1.13	.35	-.58	.36	2586.	47.

TABLE A.7

TEST SBCT-1 TRANSDUCER DATA

TEST -- SBCT-1
TEST DATE -- 06/05/1980
TYPE DUMMY -- 572-50% MALE

VEHICLE TYPE -- MINI-AUTO
IMPACT VELOCITY -- 60.0 MPH
DUMMY LOCATION -- DRIVER

VEHICLE WT. -- 2180 LBS
IMPACT ANGLE -- 0.0 DEGREES
TYPE RESTRAINT -- (L+S) BELTS

	ACCELERATIONS-GIS													FEMUR LOAD-LBS	
	VEHICLE			HEAD					CHEST						
TIME	X	Y	R	X	Y	Z	R	SI	X	Y	Z	R	SI	LEFT	RIGHT
.000	-.0	.0	.0	-.0	-.0	.0	.0	.	-.0	.0	-.0	.0	.	-.	.
.010	-4.4	-.6	4.5	.3	.0	-.6	1.0	.	-.8	.4	.5	1.1	.	3.	7.
.020	-4.7	-.6	4.7	.4	.6	-.2	1.1	.	-.6	.1	.1	.6	.	11.	8.
.030	-3.8	2.4	4.5	.4	.4	-.5	1.1	.	-.6	.6	.5	.9	.	4.	-6.
.040	-13.2	-4.0	13.8	.6	.3	-1.5	1.7	.	-2.1	-.4	.1	2.1	.	31.	-7.
.050	-17.3	-1.7	17.4	-.8	.1	-3.9	4.0	.	-3.4	-.2	-1.5	3.8	.	56.	14.
.060	-17.0	-.2	17.0	-.7	.4	-8.3	8.4	1.	-9.3	1.1	-7.0	11.8	2.	-106.	-4.
.070	-16.0	12.4	20.3	-4.8	4.5	-7.2	9.6	6.	-22.9	-7.2	-5.8	25.1	19.	28.	68.
.080	-12.4	12.5	17.6	-7.8	-1.1	-18.0	19.7	31.	-27.7	-2.0	-3.1	27.9	43.	-47.	124.
.090	-6.7	3.8	7.7	-16.8	7.9	-18.1	26.1	70.	-32.2	-1.0	-.5	32.3	117.	-111.	-1.
.100	-4.1	-1.3	4.3	-15.2	13.0	-2.5	37.7	730.	-10.4	-1.8	3.2	11.0	146.	-209.	-168.
.110	-2.2	2.3	3.2	-17.6	4.0	-18.7	26.0	885.	-11.0	1.4	13.7	17.6	154.	-133.	-122.
.120	-1.7	.5	1.8	-11.0	4.9	16.0	20.1	901.	-6.5	-1.5	9.5	11.6	163.	-125.	-27.
.130	-3.4	2.2	4.0	-13.2	.5	2.6	13.5	910.	-3.0	1.9	8.4	9.1	167.	-48.	-27.
.140	-4.4	3.6	5.7	1.7	-6.7	3.6	7.9	913.	-5.5	-.0	3.0	6.3	169.	-13.	-41.
.150	-6.6	5.7	8.7	-.2	-3.1	-.1	3.1	913.	-2.4	1.1	1.0	3.2	170.	-25.	15.
.160	-9.9	2.5	10.4	-3.5	-3.2	-2.9	5.7	914.	-1.6	1.3	-1.6	2.7	170.	-62.	-10.
.170	-3.9	7.5	8.4	1.2	-1.0	-4.5	4.9	915.	-2.1	-1.0	-.8	2.7	170.	-91.	83.
.180	-1.6	2.6	3.1	1.0	.6	-3.0	3.3	915.	-5.7	-1.5	.4	5.9	171.	-86.	22.
.190	-12.7	2.9	13.0	.7	3.2	-4.6	5.7	916.	-5.0	-3.9	.2	6.4	172.	-126.	-66.
.200	-9.1	5.0	10.3	-1.0	1.3	-1.1	2.1	916.	-7.7	-4.0	-.6	8.7	174.	-139.	-92.
.210	-2.7	.2	2.7	-3.3	1.3	-1.5	4.0	916.	-5.8	-1.0	1.3	6.0	175.	-95.	-70.
.220	-1.5	3.7	4.0	-4.2	-.7	-2.7	4.8	917.	-3.8	-2.4	.1	4.5	176.	-74.	-47.
.230	-5.7	1.1	5.8	-6.5	-3.7	-3.8	8.4	918.	-2.8	-.0	-2.2	3.6	176.	-89.	-59.
.240	-1.8	7.5	8.1	-.0	1.5	-1.4	2.7	918.	.4	3.6	-3.7	5.2	176.	-133.	-64.
.250	3.7	3.1	4.8	-2.1	1.8	-4.0	4.8	919.	-.2	1.5	-4.2	4.5	177.	-57.	-91.
.260	3.1	3.9	5.0	-1.3	2.1	-2.7	3.7	919.	-1.1	1.0	-2.0	3.0	177.	-89.	-45.
.270	-1.3	5.0	5.2	1.2	2.7	-2.3	3.8	919.	-1.3	2.8	-1.5	3.5	177.	-48.	-3.
.280	-1.0	.6	1.2	-2.0	3.6	-11.9	13.4	923.	-21.8	5.6	-13.3	26.2	207.	-56.	-1.
.290	-1.0	2.7	2.9	-4.1	5.5	-8.6	11.1	935.	-5.9	2.4	-3.1	7.3	213.	-10.	-39.
.300	-1.1	2.7	2.9	.6	9.1	-4.4	10.3	937.	-3.3	5.8	-3.1	7.5	215.	102.	33.
.310	-2.7	.8	2.8	30.6	92.7	-38.2	105.1	1060.	-13.6	35.5	-22.9	45.9	245.	-92.	-53.

MAXIMA--(IFF	X/L	SEC	Y/R	SEC	Z	SEC	R	SEC	SI	SEC
VEHICLE	-27.6	.056	14.9	.072			28.9	.054		
HEAD	126.1	.097	92.7	.310	-38.2	.310	127.1	.097	1060.0	.310
CHEST	-36.7	.085	42.4	.274	-29.5	.309	45.9	.310	245.1	.310
FEMUR	-292.4	.096	326.5	.079						

CUMULATIVE PERIOD FOR 60G LEVEL IS .0 MSEC

HIC IS 447.1 DURING .093 TO .096 SEC

TABLE A.7 (Cont'd)

TEST -- [illegible]   VEHICLE TYPE -- [illegible]-AUTO   VEHICLE WT. -- 2100 LBS
TEST DATE -- [illegible]/05/1980   IMPACT VELOCITY -- 60.0 MPH   IMPACT ANGLE -- 0.0 DEGREES
TYPE DUMMY -- 572-50% MALE   DUMMY LOCATION -- PASSENGER   TYPE RESTRAINT -- NONE

	ACCELERATIONS-G'S															
	VEHICLE			HEAD					CHEST					FEMUR LOAD-LBS	
TIME	X	Y	R	X	Y	Z	R	SI	X	Y	Z	R	SI	LEFT	RIGHT
.000	.0	.0	.0	.0	-.0	.0	.0	.	-.0	-.0	.0	.0	.	-.	.
.010	.0	.0	.0	1.9	-.8	2.3	3.6	.	-.4	.0	-.4	.6	.	4.	5.
.020	.0	.0	.0	.0	-1.5	1.8	2.7	.	-.7	-.3	-.4	.9	.	-8.	-14.
.030	.0	.0	.0	2.0	-1.0	1.3	3.2	1.	-.1	-.5	.1	.6	.	6.	8.
.040	.0	.0	.0	.8	-.9	1.4	2.7	1.	-1.2	-.9	-.7	1.6	.	23.	23.
.050	.0	.0	.0	.9	-1.5	-.2	2.8	1.	-.7	-.3	-.6	1.1	.	95.	52.
.060	.0	.0	.0	.5	-.4	1.7	2.6	1.	-.9	-.4	.2	1.1	.	20.	277.
.070	.0	.0	.0	-2.9	-1.5	-1.0	3.7	1.	-2.3	-2.0	.7	3.2	.	46.	124.
.080	.0	.0	.0	-1.9	.4	1.3	2.9	2.	-1.6	-2.5	3.4	4.5	.	119.	48.
.090	.0	.0	.0	.2	1.0	3.4	4.0	2.	-1.7	-1.6	3.3	4.1	1.	48.	156.
.100	.0	.0	.0	-24.5	7.9	-22.2	38.9	14.	-2.2	1.4	2.0	3.3	1.	91.	629.
.110	.0	.0	.0	-26.6	-4.1	7.7	28.2	50.	.9	-.7	-10.0	10.1	2.	490.	798.
.120	.0	.0	.0	-6.1	-5.7	-30.6	31.7	76.	-11.9	-5.9	-6.9	15.4	6.	429.	547.
.130	.0	.0	.0	-4.0	-1.9	12.6	13.9	99.	-29.7	-3.4	-5.8	30.4	53.	186.	327.
.140	.0	.0	.0	-20.2	-19.2	27.5	39.2	159.	-28.5	-7.7	-7.0	30.4	119.	97.	241.
.150	.0	.0	.0	-12.5	-11.9	10.8	20.5	218.	-20.6	-9.1	-3.1	22.8	155.	35.	232.

MAXIMA--TIME	X/L	SEC	Y/R	SEC	Z	SEC	R	SEC	SI	SEC
VEHICLE	.0	.150	.0	.150			.0	.150		
HEAD	-26.5	.100	-19.5	.142	33.1	.137	41.5	.138	217.5	.150
CHEST	[illegible]	.136	-13.6	.132	-10.6	.121	41.4	.136	155.3	.150
FEMUR	5[illegible].2	.116	823.1	.102						

CUMULATIVE PERIOD FOR 60G LEVEL IS .0 MSEC

HIC IS 173.4 DURING .099 TO .150 SEC

TEST BBCT-1

Purpose: Purpose of this test was to determine the end-on resistance of the flared W-beam rail which is part of the BCT system. To accomplish this a bogie vehicle impacted the buffer end of the system at 60 mph and a 0-deg angle.

Test Installation: Total length of the test installation was 100 ft (30 m) with a 37.5-ft (11.4-m) flared BCT system at the upstream end. This transitioned into a standard G4S (steel post) guardrail system which was anchored at the downstream end by a concrete deadman. As shown in Figure A.33 the first post was eliminated and the second post was 6x8 timber in a concrete footing; thereafter, all posts and blockouts were soil-mounted W6x8.5 steel. The W-beam rail was shop-bent to conform to the recommended parabolic configuration without being attached to the posts. It was then attached to the steel posts with No. 10 machine screws which would offer only minimum fracture resistance.

Test Vehicle: The test vehicle was a bogie which was based on the recommendations of SAE J972a, but had the heavy steel front bumper assembly replaced with a 6x8 wood bumper. Total weight of the bogie was 1846 lb (837 kg). Target impact location was 15 in. (381 mm) to the left of vehicle centerline.

Performance: Impact conditions for the bogie were 56.2 mph (90.4 kmph) and a -0.2 deg angle. As shown in Figure A.34 the bogie impacted the buffer end, turned slightly left as it bent the first rail section panel rearward (between Post position 1 and Post 2), and then turned back to the right as it fractured Post 2 and bent Posts 3 and 4. After losing contact with Post 4 the bogie was traveling 39.7 mph (64 kmph) at a -5.3 deg angle and it continued this trajectory behind the installation until it contacted the concrete deadman and was rolled over by the secondary impact. The W-beam rail which had released from the posts immediately after impact formed hinges at Posts 2 and 3, and bent rearward about those points. Maximum 50 msec average accelerations measured were -1.8 g in the lateral direction and -3.5 g in the longitudinal direction. These were taken from high-speed film analysis data as shown in Table A.8; excessive ringing occurred in the accelerometers and that data was, therefore, not usable.

Barrier Damage: As shown in Figure A.35 the W-beam rail was bent and twisted as far back as Post 8 (where the straight section began). Post 2 was fractured at grade and Posts 3 and 4 were bent and twisted by contact with the bogie.

Comment: The yaw rate of the bogie was approximately 3 deg/ 12.5 ft which is considerably below the threshold value of 10 deg/ 12.5 ft considered necessary for "gating" through the BCT. Although the bogie is considerably more stable than the Honda due to its low slung weight distribution and wider track, the I_{yaw} value should not be that different. Based on test observations, there was a considerable reduction in both the impulsive load and yaw rate for this end-on impact when compared to previous end-on Honda tests.

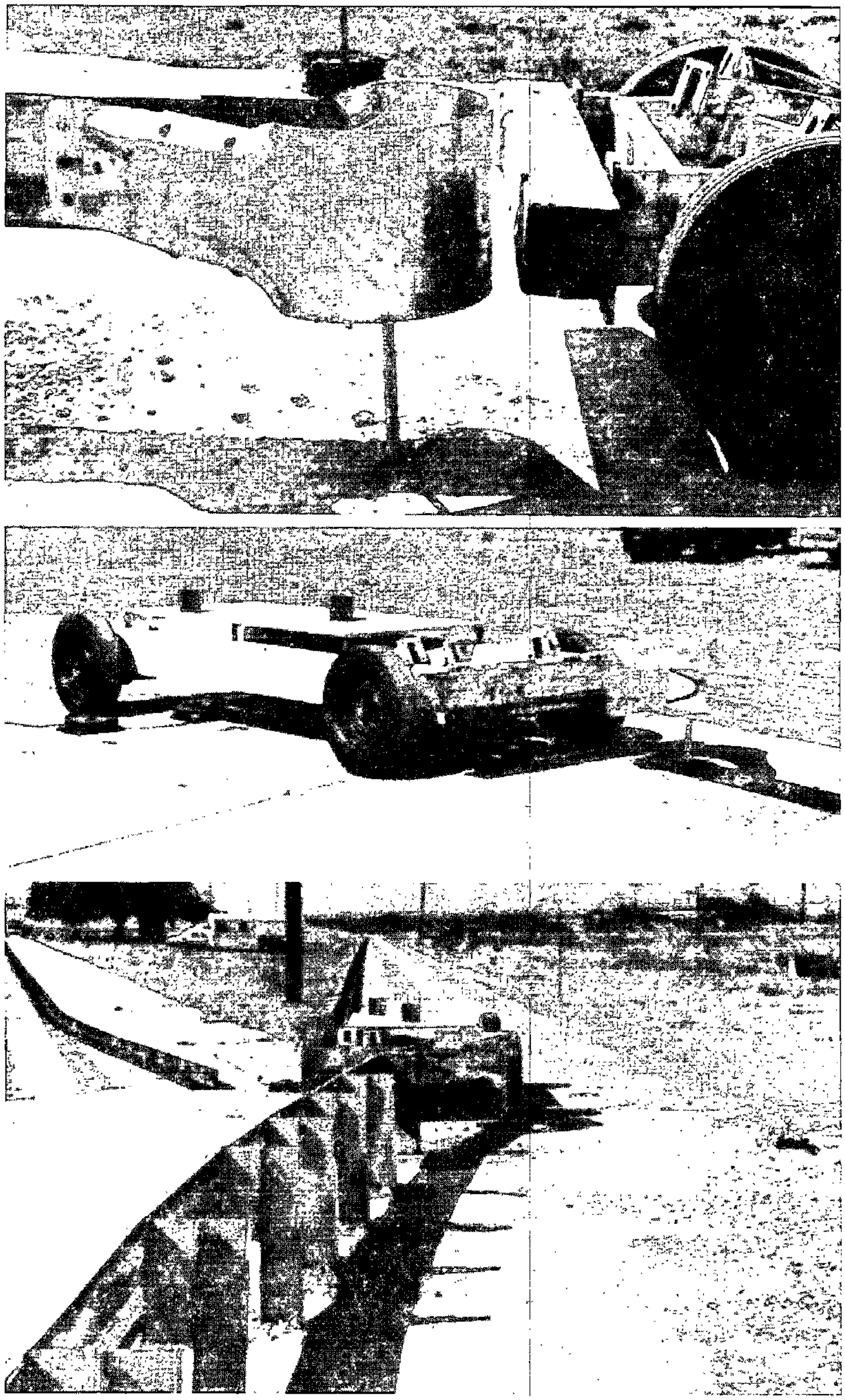
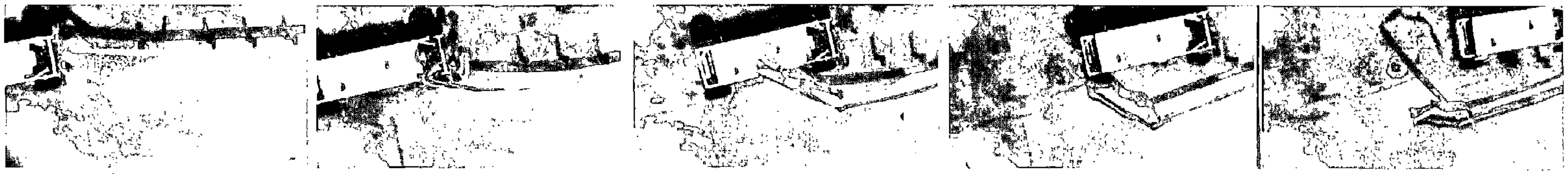
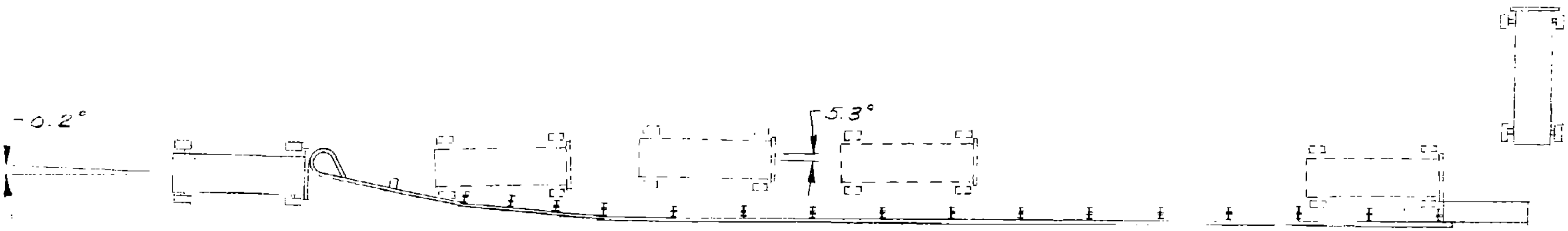


FIGURE A.33 PRE-TEST PHOTOGRAPHS, TEST BBCT-1



Impact 0.1 sec 0.2 sec 0.3 sec 0.4 sec



Test No.	BBCT-1
Date	2/24/81
Vehicle	Bogie
Vehicle Weight (including instrumentation)	1846 lb (837 kg)

Impact Speed	56.2 mph (90.4 kmph)
Impact Angle	-0.2 deg
Exit Speed	39.7 mph (64.0 kmph)
Exit Angle	-5.3 deg
Vehicle Accelerations (max 50ms average)	
Lateral	-1.8 g
Longitudinal	-3.5 g

FIGURE A.34 SUMMARY OF RESULTS, TEST BBCT-1

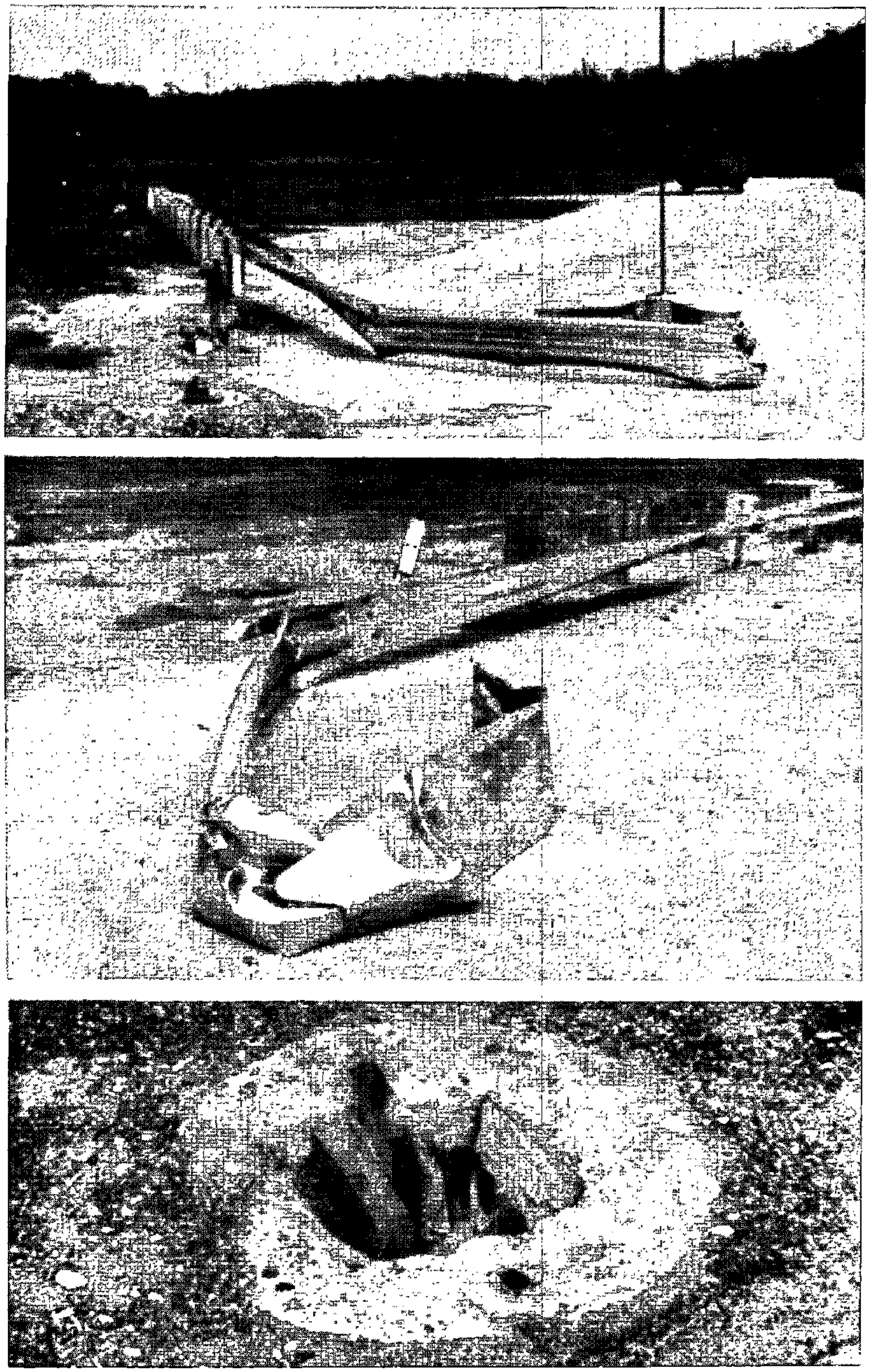


FIGURE A.35 BARRIER DAMAGE, TEST BBC-1

TABLE A.8

FILM ANALYSIS DATA -
TEST BBCT-1

SUMMARY OF VEHICLE KINEMATIC AND DYNAMIC DATA   BOGIE BCT TEST BBCT-1   2/24/81

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 AVER .05 SEC. LONG	LAT	APPROX. BARRIER FORCES(LB) X	Y
0.000	-10.03	2.41	-.17	82.39	1.01	-2.88	.74	0.00	0.00	5311.	-1380.
.010	-9.21	2.41	-.20	81.41	1.31	-3.15	.61	0.00	0.00	5806.	-1521.
.020	-8.41	2.43	-.20	80.37	1.56	-3.35	.85	0.00	0.00	6171.	-1590.
.030	-7.61	2.44	-.17	79.27	1.82	-3.47	.65	-3.35	.82	6408.	-1595.
.040	-6.82	2.46	-.11	78.14	2.01	-3.54	.83	-3.45	.82	6524.	-1543.
.050	-6.04	2.48	-.02	77.00	2.14	-3.54	.78	-3.48	.79	6529.	-1447.
.060	-5.28	2.50	.11	75.88	2.21	-3.48	.72	-3.46	.74	6435.	-1315.
.070	-4.53	2.52	.27	74.78	2.22	-3.39	.64	-3.40	.68	6257.	-1160.
.080	-3.78	2.55	.46	73.71	2.17	-3.25	.56	-3.29	.60	6008.	-991.
.090	-3.05	2.58	.68	72.70	2.06	-3.08	.48	-3.14	.53	5702.	-818.
.100	-2.33	2.61	.92	71.75	1.89	-2.90	.40	-2.97	.45	5356.	-649.
.110	-1.62	2.64	1.18	70.85	1.68	-2.69	.32	-2.78	.37	4981.	-491.
.120	-.91	2.67	1.46	70.03	1.43	-2.48	.25	-2.58	.30	4591.	-350.
.130	-.22	2.70	1.75	69.27	1.16	-2.27	.19	-2.37	.24	4197.	-230.
.140	.47	2.74	2.04	68.58	.86	-2.06	.15	-2.17	.19	3810.	-134.
.150	1.15	2.77	2.33	67.95	.56	-1.86	.11	-1.97	.15	3439.	-64.
.160	1.83	2.80	2.61	67.39	.25	-1.67	.09	-1.78	.12	3091.	-19.
.170	2.50	2.84	2.89	66.88	-.04	-1.50	.08	-1.60	.10	2771.	0.
.180	3.16	2.87	3.14	66.42	-.31	-1.34	.08	-1.44	.09	2483.	-3.
.190	3.82	2.90	3.38	66.01	-.56	-1.21	.09	-1.29	.09	2231.	-28.
.200	4.48	2.94	3.59	65.64	-.77	-1.09	.11	-1.16	.11	2016.	-69.
.210	5.14	2.97	3.77	65.30	-.94	-.99	.13	-1.05	.13	1836.	-124.
.220	5.79	3.00	3.92	64.99	-1.06	-.91	.16	-.96	.15	1692.	-188.
.230	6.43	3.04	4.04	64.71	-1.14	-.84	.20	-.89	.18	1580.	-257.
.240	7.08	3.07	4.12	64.44	-1.16	-.80	.23	-.83	.22	1497.	-326.
.250	7.72	3.11	4.17	64.19	-1.14	-.76	.27	-.79	.25	1440.	-392.
.260	8.36	3.14	4.18	63.95	-1.06	-.74	.30	-.76	.28	1404.	-451.
.270	9.00	3.18	4.16	63.71	-.94	-.73	.32	-.74	.31	1384.	-500.
.280	9.63	3.22	4.10	63.48	-.76	-.72	.34	-.73	.33	1375.	-535.
.290	10.27	3.26	4.01	63.25	-.55	-.72	.35	-.72	.34	1372.	-555.
.300	10.90	3.29	3.90	63.02	-.31	-.72	.35	-.72	.34	1369.	-559.
.310	11.52	3.33	3.75	62.79	-.03	-.72	.34	-.72	.34	1363.	-545.
.320	12.15	3.38	3.57	62.56	.28	-.71	.32	-.71	.32	1346.	-514.
.330	12.77	3.42	3.38	62.33	.57	-.70	.30	-.70	.30	1321.	-468.
.340	13.39	3.46	3.16	62.10	.90	-.68	.26	-.68	.27	1279.	-406.
.350	14.01	3.50	2.93	61.88	1.22	-.65	.21	-.66	.23	1218.	-333.
.360	14.63	3.55	2.69	61.68	1.55	-.61	.16	-.62	.18	1139.	-250.
.370	15.24	3.59	2.44	61.48	1.86	-.56	.11	-.57	.13	1038.	-161.
.380	15.85	3.64	2.18	61.30	2.16	-.50	.06	-.52	.08	918.	-70.
.390	16.47	3.68	1.92	61.14	2.45	-.42	.00	-.45	.03	778.	19.
.400	17.08	3.73	1.66	61.01	2.73	-.34	-.05	-.37	-.02	621.	103.
.410	17.68	3.77	1.40	60.90	2.98	-.25	-.09	-.29	-.06	449.	176.
.420	18.29	3.82	1.14	60.82	3.22	-.15	-.13	-.19	-.10	266.	236.
.430	18.90	3.86	.89	60.78	3.44	-.04	-.15	-.09	-.13	76.	280.
.440	19.51	3.90	.64	60.77	3.65	.06	-.17	.01	-.15	-116.	304.
.450	20.11	3.95	.41	60.79	3.85	.16	-.17	.11	-.16	-305.	306.
.460	20.72	3.99	.17	60.84	4.04	.26	-.16	.21	-.15	-484.	287.
.470	21.33	4.03	-.05	60.92	4.23	.35	-.13	.30	-.13	-648.	245.
.480	21.94	4.07	-.27	61.03	4.43	.43	-.10	.38	-.10	-789.	183.
.490	22.55	4.12	-.48	61.16	4.63	.49	-.05	.44	-.07	-903.	102.
.500	23.16	4.16	-.69	61.31	4.84	.53	.00	.49	-.02	-984.	7.
.510	23.78	4.20	-.89	61.47	5.07	.55	.06	.52	.04	-1025.	-97.
.520	24.39	4.24	-1.10	61.63	5.32	.55	.12	.53	.09	-1022.	-203.
.530	25.01	4.28	-1.30	61.78	5.59	.52	.18	.51	.14	-971.	-305.
.540	25.63	4.32	-1.51	61.92	5.88	.47	.22	.47	.19	-870.	-392.
.550	26.25	4.37	-1.73	62.04	6.19	.38	.26	.40	.23	-717.	-455.
.560	26.88	4.41	-1.95	62.12	6.52	.27	.27	.30	.25	-513.	-485.
.570	27.50	4.45	-2.18	62.16	6.85	.13	.26	.18	.24	-259.	-472.
.580	28.12	4.50	-2.41	62.14	7.19	-.03	.22	.03	.21	41.	-405.
.590	28.75	4.54	-2.66	62.07	7.51	-.21	.14	-.14	.15	381.	-276.
.600	29.37	4.59	-2.92	61.94	7.82	-.41	.02	-.32	.05	752.	-80.
.610	29.99	4.64	-3.18	61.74	8.09	-.61	-.14	-.52	-.09	1143.	189.
.620	30.61	4.68	-3.45	61.47	8.31	-.82	-.34	-.71	-.27	1541.	528.
.630	31.23	4.73	-3.73	61.13	8.46	-1.01	-.57	-.90	-.48	1931.	933.
.640	31.84	4.77	-4.01	60.74	8.53	-1.19	-.84	-1.08	-.73	2293.	1391.
.650	32.45	4.81	-4.29	60.29	8.51	-1.33	-1.12	-1.23	-.99	2607.	1883.
.660	33.06	4.85	-4.57	59.80	8.39	-1.43	-1.41	-1.34	-1.25	2847.	2378.
.670	33.66	4.89	-4.84	59.29	8.18	-1.48	-1.67	-1.40	-1.50	2988.	2833.
.680	34.25	4.92	-5.09	58.78	7.87	-1.47	-1.87	-1.41	-1.70	3001.	3191.
.690	34.84	4.94	-5.33	58.29	7.49	-1.37	-1.97	-1.34	-1.80	2854.	3380.

TEST BBCT-2

Purpose: Purpose of this test was to evaluate the performance of the wood post BCT which had been modified to reduce its end-on impact resistance. This was accomplished by a bogie vehicle impacting the buffer end of the system at 60 mph and a 0-deg angle.

Test Installation: Total length of the test installation was 100 ft (30 m) with a 37.5-ft (11.4-m) flared BCT at the upstream end. Posts 1 and 2 were 6x8 wood installed in concrete footings and the remaining posts were W6x8.5 steel mounted in the soil. Height of the W-beam front rail was 27 in. (686 mm). To improve its performance with 1800-lb (816-kg) class vehicles several modifications were incorporated into the standard configuration BCT. These were: (1) addition of a wood blockout assembly which was attached to Post 1 inside the buffer end, (2) addition of wood blocks to Posts 1 and 2 beneath the W-beam rail, and (3) removal of post/rail attachment bolts from Posts 1 thru 7. Purpose of these retrofits was to break away Post 1 before contacting the end of the W-beam rail (blockout assembly), and provide no lateral restraint to buckling of the W-beam (bolt removal). The wood blocks provided vertical support only for the rail. Photographs of the modifications are shown in Figure A.36.

Test Vehicle: The 1846-lb (837-kg) bogie vehicle used in Test BBCT-1 was also used in this test. Target impact location was 15 in. (381 mm) to the left of vehicle centerline.

Performance: Impact conditions for the bogie were 58.8 mph (94.6 kmph) and a -0.8 deg angle. As shown in Figure A.37 the bogie impacted the buffer end and turned slightly to the left as it fractured Post 1 and initiated buckling of the W-beam. The front rail translated in the longitudinal direction the threaded end of the anchor cable contacted Post 2 and fractured it. As the bogie continued its trajectory the right wehels rode over Posts 3 and 4 bending and twisting them. The W-beam rail in the meantime formed a hinge at Post 4 and as the section between Posts 4 and 8 swung away from the posts the section between Posts 1 and 4 rotated in the opposite direction about the hinge. The bogie continued behind the rail and stopped 24 ft (7.3 m) past the downstream end of the installation. Maximum 50-msec average accelerations were -7.7 g (film) and -19.8 g (accelerometer) in the longitudinal direction, and 1.6 g (film) and 0.4 g (accelerometer) in the lateral direction. Results of high-speed film analysis are shown in Table A.9, and accelerometer data are contained in Figure A.38.

Barrier Damage: As shown in Figure A.39 the W-beam rail was bent and twisted as far back as Post 8. Posts 1 and 2 were fractured, and Posts 3 and 4 bent due to wheel contact. In addition, Posts 8 thru 18 were twisted slightly due to translation of the rail toward the downstream end.

Comment: The yaw rate for the bogie was 6.7 deg/12.5 ft (3.8 m) which is below the 10 deg/12.5 ft (3.8 m) threshold value necessary for gating through the BCT. Again, as in the previous bogie test, it appears that the impulsive loading and yaw rate of the vehicle have been reduced in comparison to previous end-on Honda tests.

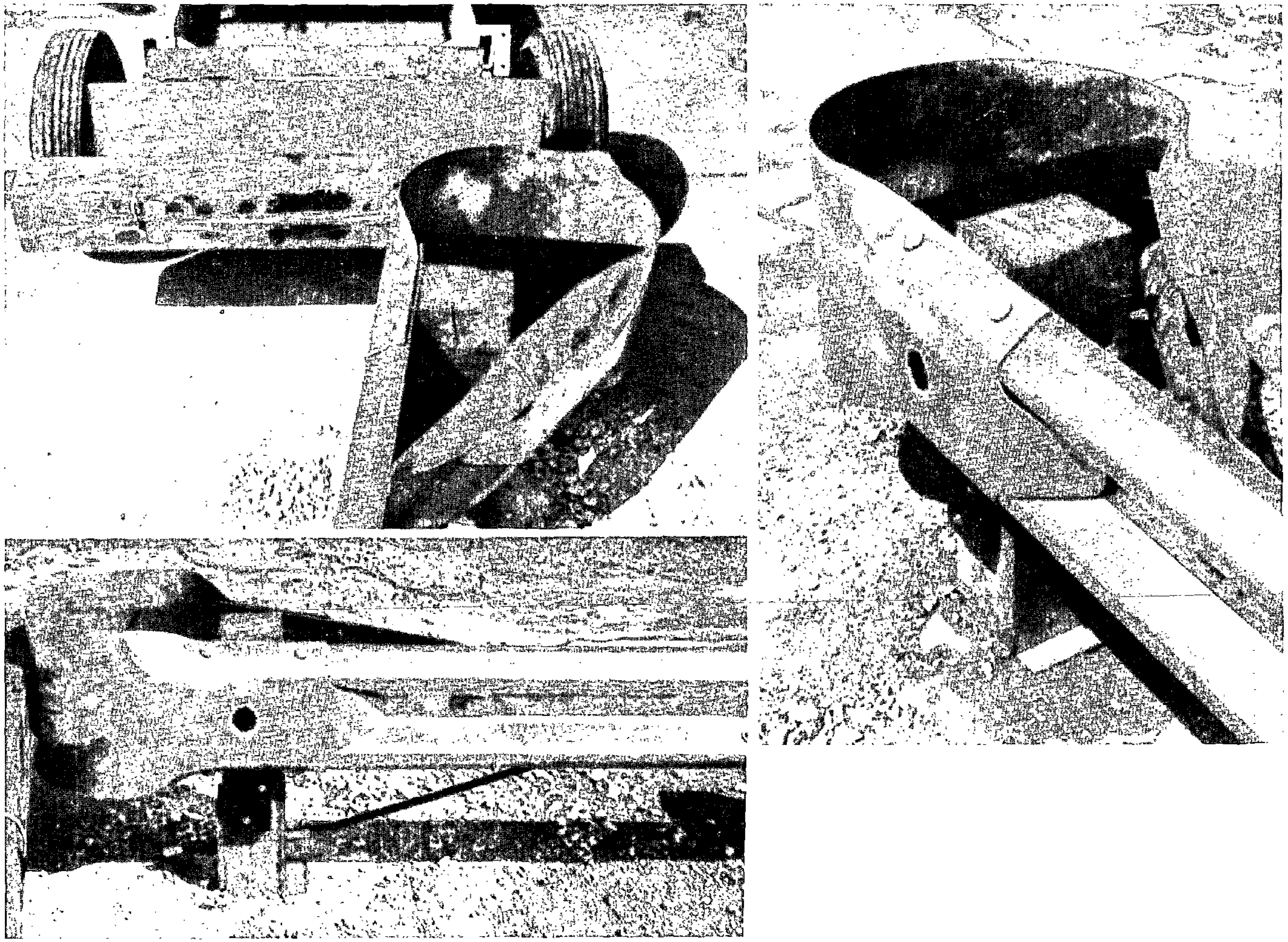
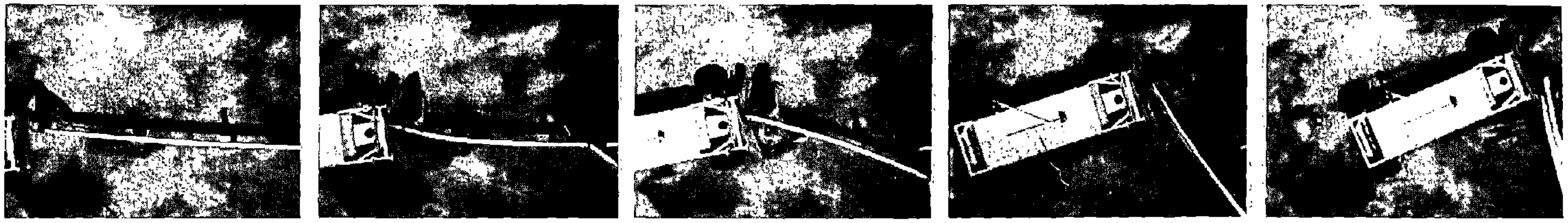
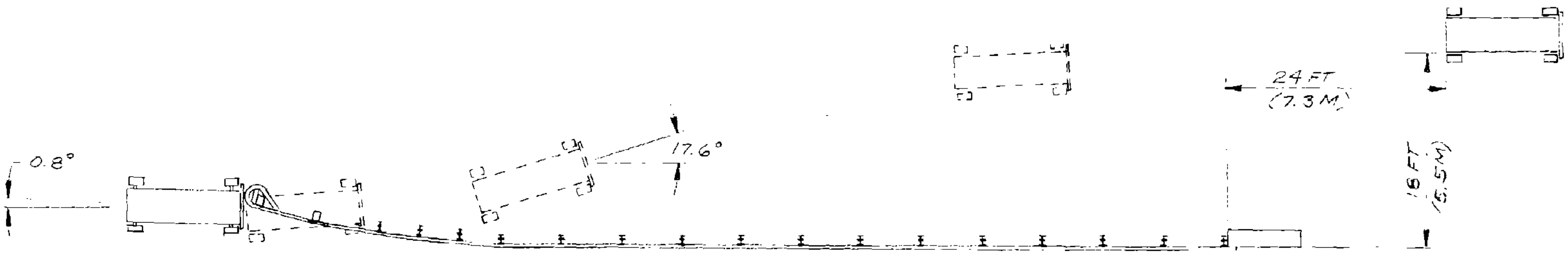


FIGURE A.36 PRETEST PHOTOGRAPHS, TEST BBCT-2



Impact | 0.05 sec | 0.10 sec | 0.20 sec | 0.30 sec



Test No. BBCT-2
Date 3/24/81
Vehicle .... bogie
Vehicle Weight
(including instrumentation) ...1846 lb (837 kg)

Impact Speed .... 58.8 mph (94.6 kmph)
Impact Angle .... -0.8 deg
Exit Speed .... 29.8 mph (48.0 kmph)
Exit Angle .... 17.6 deg
Vehicle Accelerations (max 50 ms average)
Lateral (cine/electronic)........... 1.6g/0.4g
Longitudinal (cine/electronic).... -7.7g/-19.8g

FIGURE A.37 SUMMARY OF RESULTS, TEST BBCT-2

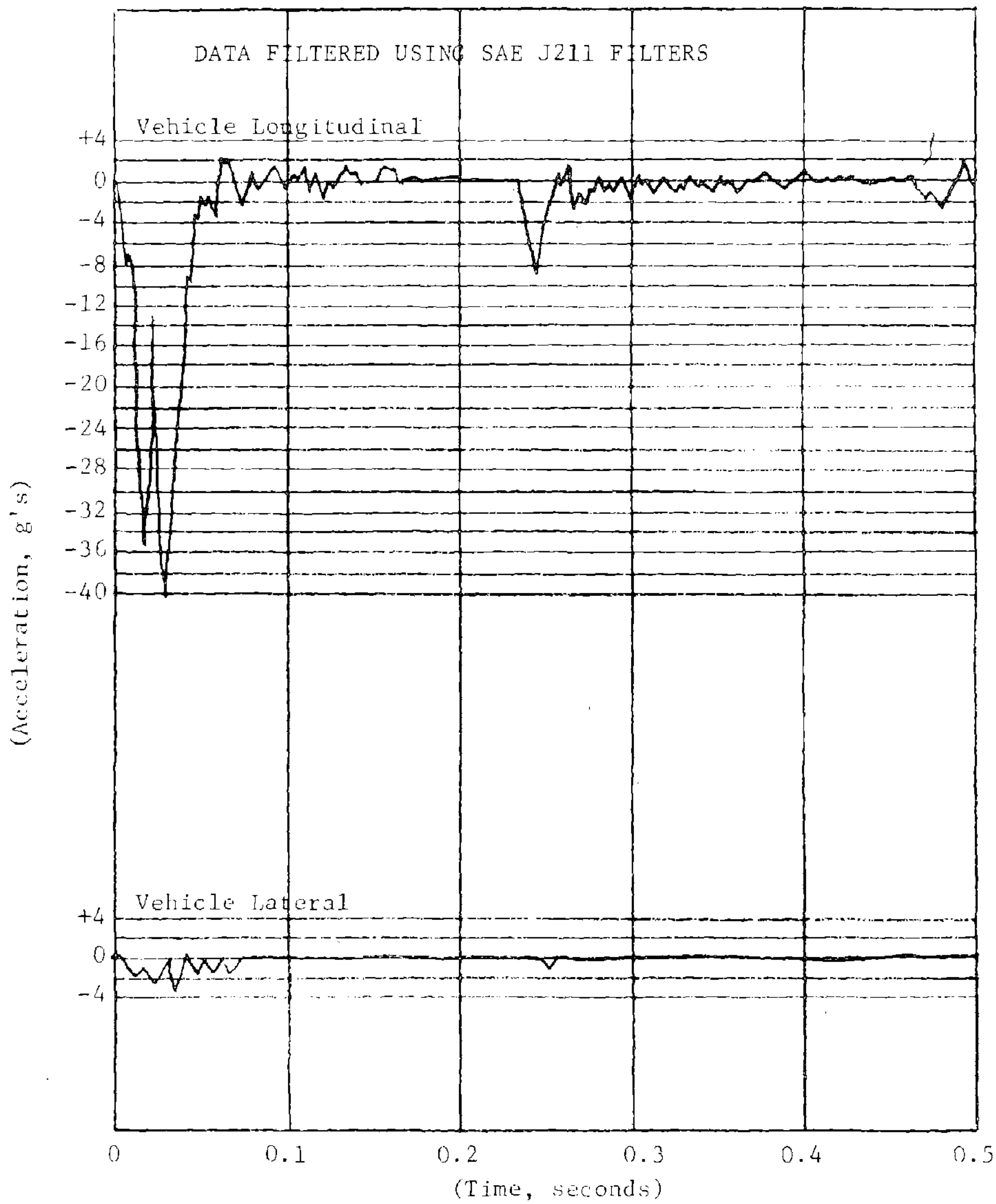


FIGURE A.38 ACCELEROMETER DATA, TEST BBCT-2

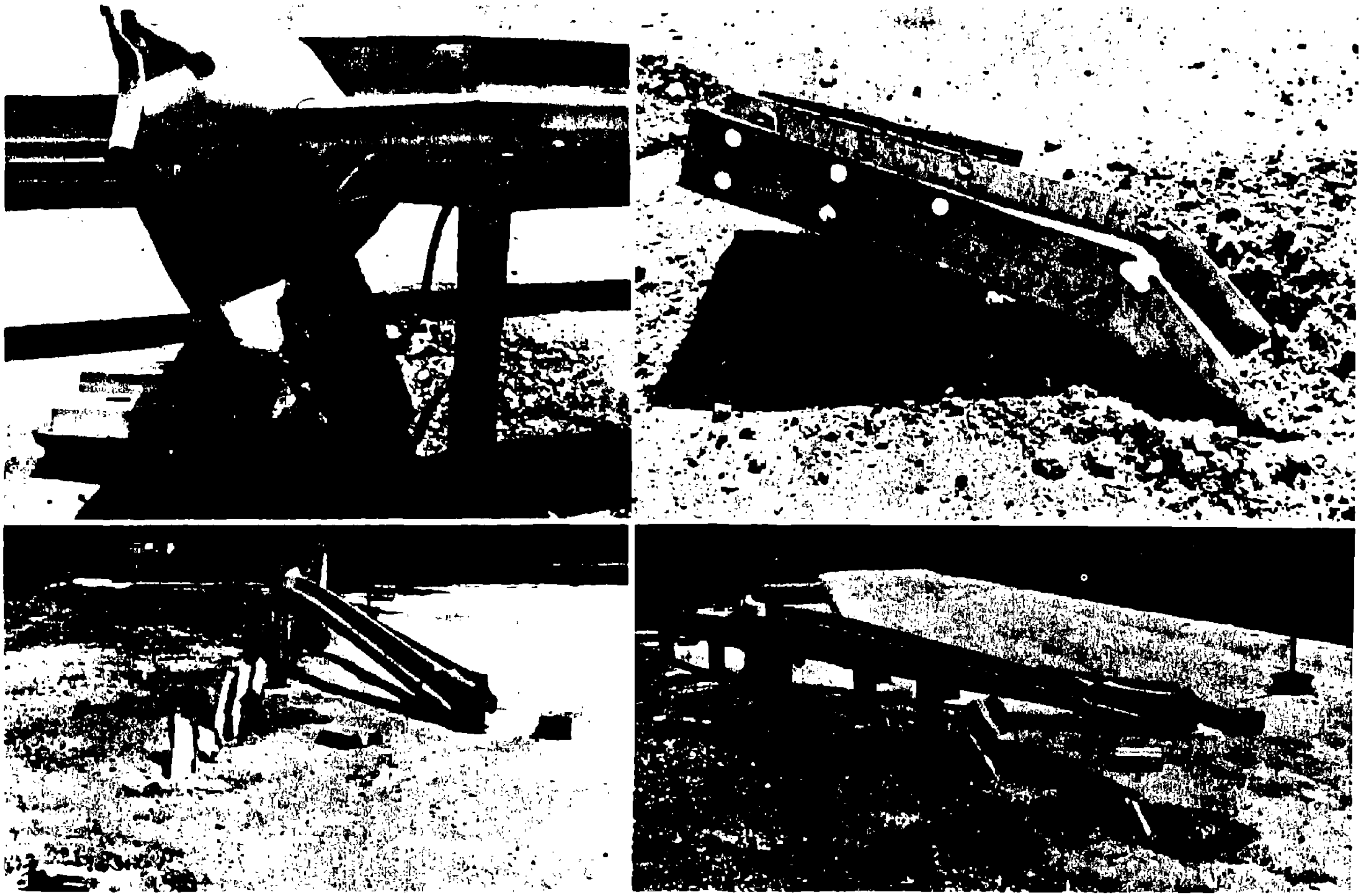


FIGURE A.39 BARRIER DAMAGE, TEST BBCT-2

TABLE A.9

FILM ANALYSIS DATA, TEST BBCT-2

SUMMARY OF VEHICLE KINEMATIC AND DYNAMIC DATA   BOGIE BCT TEST BBCT-2   2/24/81

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	-12.67	4.77	-.88	86.18	-2.80	-2.86	.05	0.00	0.00	5313.	-159.
.010	-12.01	4.73	-.87	85.03	-1.82	-4.25	.42	0.00	0.00	7837.	-496.
.020	-11.17	4.70	-.82	83.46	-1.57	-5.44	.75	0.00	0.00	10018.	-1542.
.030	-10.34	4.68	-.83	81.55	-1.27	-6.40	1.02	-5.71	.83	11780.	-2079.
.040	-9.54	4.65	-.88	79.37	-.95	-7.13	1.24	-6.55	1.08	13122.	-2499.
.050	-8.76	4.63	-.81	76.99	-.63	-7.62	1.41	-7.17	1.28	14034.	-2801.
.060	-8.00	4.62	-.68	74.48	-.34	-7.89	1.53	-7.56	1.42	14532.	-2988.
.070	-7.27	4.61	-.48	71.93	-.08	-7.95	1.60	-7.74	1.53	14665.	-3069.
.080	-6.56	4.60	-.23	69.38	.13	-7.81	1.62	-7.72	1.56	14412.	-3056.
.090	-5.88	4.60	.09	66.91	.27	-7.52	1.62	-7.52	1.60	13880.	-2962.
.100	-5.22	4.61	.46	64.56	.36	-7.08	1.58	-7.18	1.59	13099.	-2803.
.110	-4.59	4.62	.90	62.37	.37	-6.54	1.51	-6.72	1.55	12121.	-2592.
.120	-3.98	4.64	1.39	60.36	.32	-5.92	1.41	-6.17	1.47	10997.	-2346.
.130	-3.38	4.66	1.93	58.56	.20	-5.26	1.30	-5.55	1.38	9777.	-2078.
.140	-2.80	4.68	2.51	56.98	.01	-4.56	1.18	-4.89	1.26	8507.	-1799.
.150	-2.24	4.71	3.14	55.62	-.25	-3.87	1.04	-4.21	1.14	7230.	-1523.
.160	-1.69	4.74	3.80	54.48	-.58	-3.19	.89	-3.54	1.00	5982.	-1258.
.170	-1.15	4.77	4.49	53.55	-.97	-2.55	.75	-2.90	.86	4796.	-1012.
.180	-.62	4.80	5.21	52.81	-1.41	-1.96	.61	-2.29	.71	3698.	-792.
.190	-.10	4.84	5.94	52.25	-1.91	-1.43	.48	-1.74	.58	2709.	-601.
.200	.42	4.87	6.68	51.84	-2.45	-.96	.35	-1.25	.45	1843.	-442.
.210	.94	4.91	7.43	51.56	-3.02	-.57	.25	-.83	.33	1110.	-316.
.220	1.45	4.94	8.17	51.38	-3.63	-.26	.16	-.48	.23	515.	-223.
.230	1.97	4.98	8.91	51.29	-4.25	-.02	.09	-.20	.15	56.	-162.
.240	2.48	5.02	9.63	51.26	-4.87	.16	.04	.01	.09	-269.	-128.
.250	2.99	5.06	10.34	51.26	-5.50	.26	.02	.15	.05	-470.	-120.
.260	3.51	5.10	11.03	51.29	-6.11	.31	.01	.24	.03	-558.	-133.
.270	4.02	5.13	11.69	51.31	-6.70	.31	.03	.27	.03	-565.	-161.
.280	4.54	5.17	12.33	51.33	-7.25	.26	.05	.25	.05	-448.	-201.
.290	5.06	5.21	12.93	51.32	-7.77	.18	.10	.19	.08	-284.	-247.
.300	5.57	5.25	13.50	51.28	-8.24	.07	.15	.11	.13	-68.	-296.
.310	6.09	5.29	14.04	51.21	-8.67	-.05	.20	-.00	.18	182.	-341.
.320	6.61	5.33	14.55	51.09	-9.04	-.18	.26	-.12	.23	448.	-341.
.330	7.13	5.37	15.01	50.93	-9.37	-.32	.32	-.25	.28	717.	-412.
.340	7.64	5.41	15.45	50.74	-9.64	-.45	.36	-.37	.33	972.	-430.
.350	8.16	5.46	15.84	50.51	-9.87	-.56	.40	-.49	.38	1203.	-436.
.360	8.67	5.50	16.20	50.25	-10.05	-.66	.43	-.59	.41	1398.	-427.
.370	9.18	5.54	16.52	49.97	-10.19	-.74	.45	-.68	.43	1551.	-405.
.380	9.68	5.59	16.81	49.66	-10.29	-.80	.45	-.75	.44	1654.	-371.
.390	10.19	5.63	17.07	49.35	-10.37	-.83	.44	-.79	.44	1706.	-326.
.400	10.69	5.68	17.30	49.04	-10.43	-.84	.42	-.81	.42	1707.	-272.
.410	11.19	5.73	17.49	48.74	-10.47	-.82	.38	-.81	.39	1658.	-214.
.420	11.68	5.77	17.66	48.45	-10.49	-.78	.34	-.76	.35	1563.	-156.
.430	12.17	5.82	17.80	48.18	-10.51	-.72	.29	-.73	.31	1431.	-101.
.440	12.66	5.87	17.92	47.94	-10.53	-.64	.24	-.67	.27	1268.	-54.
.450	13.15	5.92	18.02	47.73	-10.54	-.56	.19	-.59	.22	1086.	-21.
.460	13.64	5.96	18.09	47.55	-10.55	-.46	.15	-.50	.18	895.	-4.
.470	14.12	6.01	18.15	47.41	-10.55	-.36	.12	-.41	.15	707.	-10.
.480	14.60	6.06	18.20	47.30	-10.55	-.27	.11	-.32	.13	534.	-41.
.490	15.08	6.11	18.22	47.22	-10.54	-.18	.12	-.24	.13	388.	-100.

TABLE A.9 (Cont'd)

.500	15.57	6.15	18.24	47.17	-10.51	-.11	.14	-.16	.15	280.	-199.
.510	16.05	6.20	18.25	47.14	-10.46	-.06	.20	-.10	.19	218.	-309.
.520	16.53	6.25	18.25	47.13	-10.38	-.03	.27	-.07	.26	211.	-460.
.530	17.01	6.30	18.24	47.12	-10.27	-.03	.37	-.05	.34	264.	-639.
.540	17.49	6.35	18.23	47.11	-10.13	-.05	.50	-.07	.46	379.	-843.
.550	17.96	6.40	18.21	47.09	-9.93	-.10	.64	-.10	.59	555.	-1067.
.560	18.44	6.46	18.19	47.05	-9.68	-.18	.80	-.17	.74	788.	-1303.
.570	18.92	6.51	18.18	46.98	-9.38	-.29	.97	-.26	.89	1069.	-1543.
.580	19.39	6.57	18.15	46.87	-9.02	-.41	1.15	-.37	1.06	1348.	-1776.
.590	19.87	6.63	18.13	46.71	-8.61	-.55	1.32	-.49	1.22	1727.	-1992.
.600	20.33	6.70	18.11	46.52	-8.14	-.70	1.47	-.63	1.37	2069.	-2177.
.610	20.80	6.77	18.09	46.27	-7.62	-.84	1.60	-.76	1.50	2391.	-2317.
.620	21.26	6.84	18.06	45.98	-7.07	-.97	1.68	-.89	1.60	2667.	-2399.
.630	21.72	6.92	18.03	45.66	-6.50	-1.08	1.72	-1.00	1.65	2872.	-2409.
.640	22.17	7.00	17.99	45.30	-5.92	-1.14	1.70	-1.07	1.65	2979.	-2335.
.650	22.62	7.08	17.94	44.93	-5.34	-1.16	1.61	-1.11	1.59	2961.	-2166.
.660	23.06	7.17	17.88	44.57	-4.81	-1.13	1.44	-1.09	1.45	2795.	-1894.
.670	23.49	7.27	17.81	44.23	-4.32	-1.02	1.19	-1.01	1.24	2463.	-1516.
.680	23.93	7.36	17.73	43.93	-3.93	-.84	.86	-.86	.95	1954.	-1034.
.690	24.36	7.46	17.62	43.71	-3.63	-.58	.44	-.64	.58	1267.	-457.

TEST WBCT-4

Purpose: Purpose of this test was to evaluate the performance of the wood post BCT which has been modified to reduce its end-on impact resistance. This was accomplished by a 2170-lb (984-kg) mini-compact automobile impacting the buffer end at 60 mph and a 0-deg angle.

Test Installation: The test installation was the same as that of Test BBCT-2 except that the wood blockout assembly inside the buffer end section was slightly wider - 12 in. (305 mm) instead of 8 in. (203 mm). Photographs of the vehicle and test installation are shown in Figure A.40.

Test Vehicle: A 1975 Honda Civic sedan was the test vehicle and it contained two 50th percentile anthropomorphic dummies in the driver and front passenger seating positions. The driver dummy was restrained by a lap and shoulder belt whereas the passenger dummy was unrestrained. Total weight of the vehicle, dummies and instrumentation was 2170 lb (984 kg). Target impact location was 15 in. (381 mm) to the left of vehicle centerline.

Performance: Impact conditions were 59.4 mph (95.6 kmph) and a 0.6-deg angle. As shown in the impact sequence of Figure 15 the vehicle impacted the buffer end (with wood spacer inside), fracturing the first post and causing the W-beam rail to translate away from the posts. The vehicle began to yaw as it continued its trajectory during which it fractured the second post and overrode Posts 3 and 4. As it overrode these posts the vehicle was launched slightly and began to reverse its yaw direction with the result that the front of the vehicle nosed down into the ground as the rear pitched upward. The rear returned to the ground and the vehicle finally stopped 16 ft (4.9 m) behind Post 10 in a position opposite to its original impact direction. Maximum 50 millisecond average accelerations measured during the impact were -10.0 g/-16.4 g (film analysis/accelerometer) in the longitudinal direction and 1.6 g/6.0 g (film analysis/accelerometer) in the lateral direction. A summary of test results is contained in Figure 16 and results of high-speed film analysis are tabulated in Table A.10. Data from vehicle and driver dummy transducers are shown in Table A.11 and plotted in Figures A.41 thru A.44; an electronic malfunction caused data from the passenger dummy transducers to be lost.

Barrier Damage: As shown in Figure A.45 barrier damage consisted of two fractured wood posts, two bent steel posts, two bent rail sections, and a damaged buffer end section/spacer assembly. In addition, Posts 8 thru 18 were twisted slightly as the W-beam rail translated toward the downstream end.

Vehicle Damage: The test vehicle, as shown in Figure A.45, was heavily damaged. The entire front section was deformed by the end-on impact, the right front wheel and hood were torn off, and the windsheild shattered on the right side by impact of the dummy's head. Additional damage was sustained by the passenger door and sill when contact occurred with the steel posts.

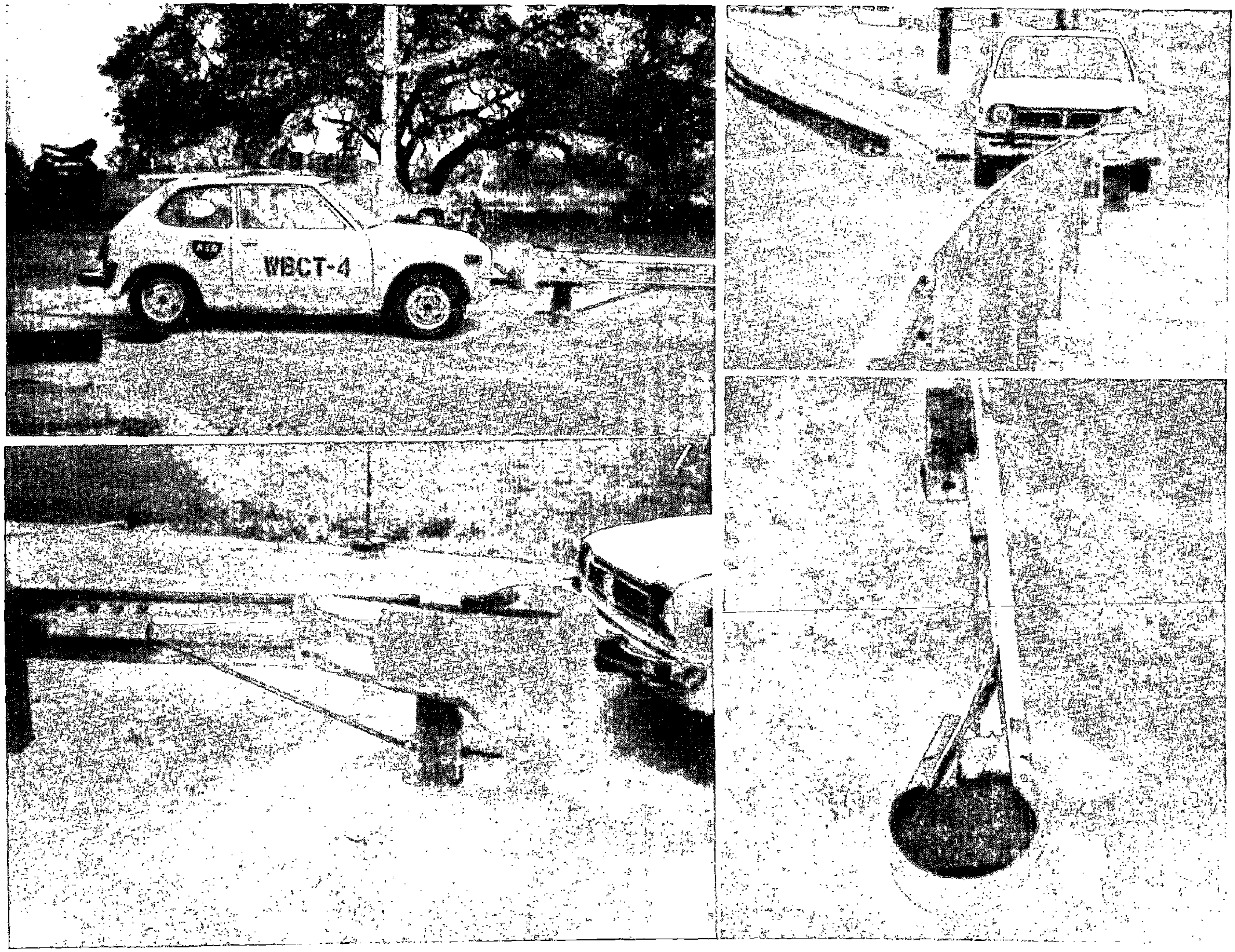
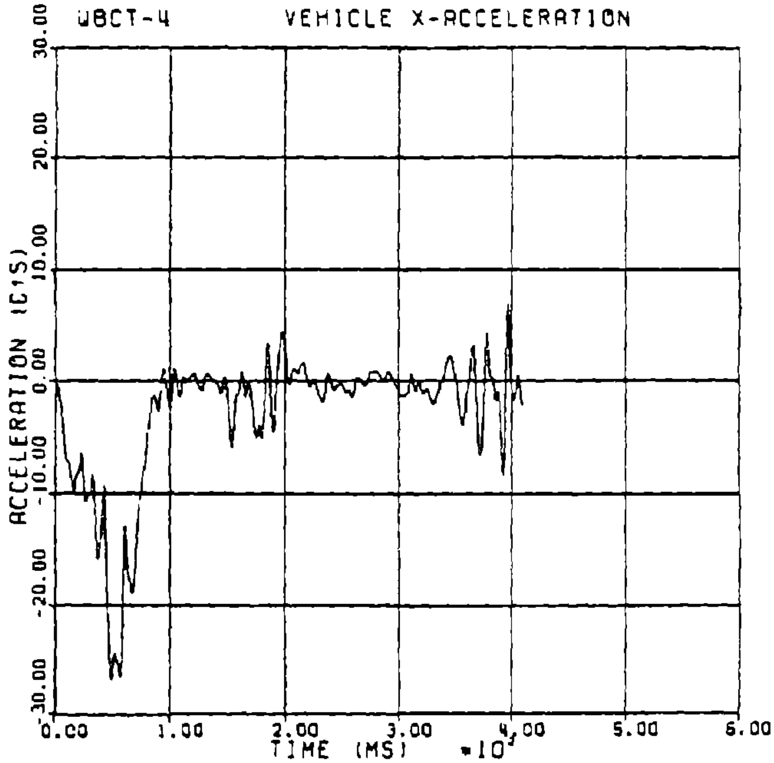


FIGURE A.40 PRETEST PHOTOGRAPHS, TEST WBCT-4



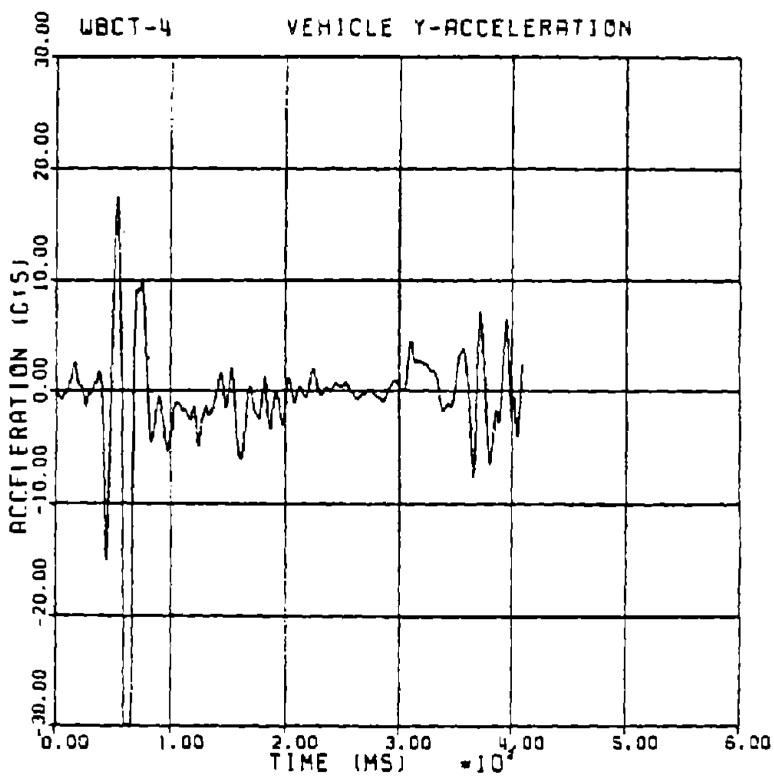


FIGURE A.41 VEHICLE ACCELERATION PLOTS, TEST WBCT-4

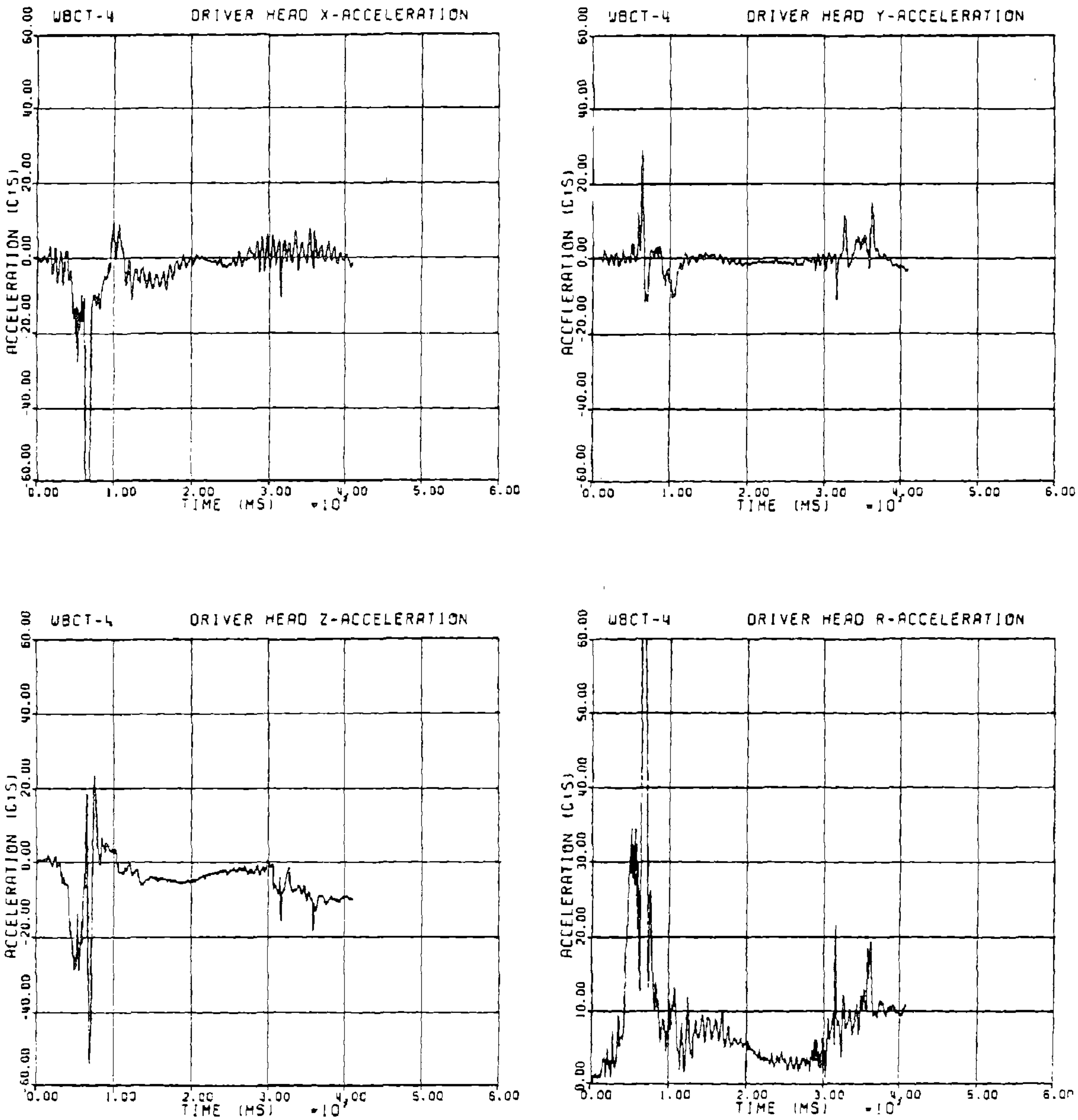


FIGURE A.42 DRIVER DUMMY HEAD ACCELERATION PLOTS, TEST WBCT-4

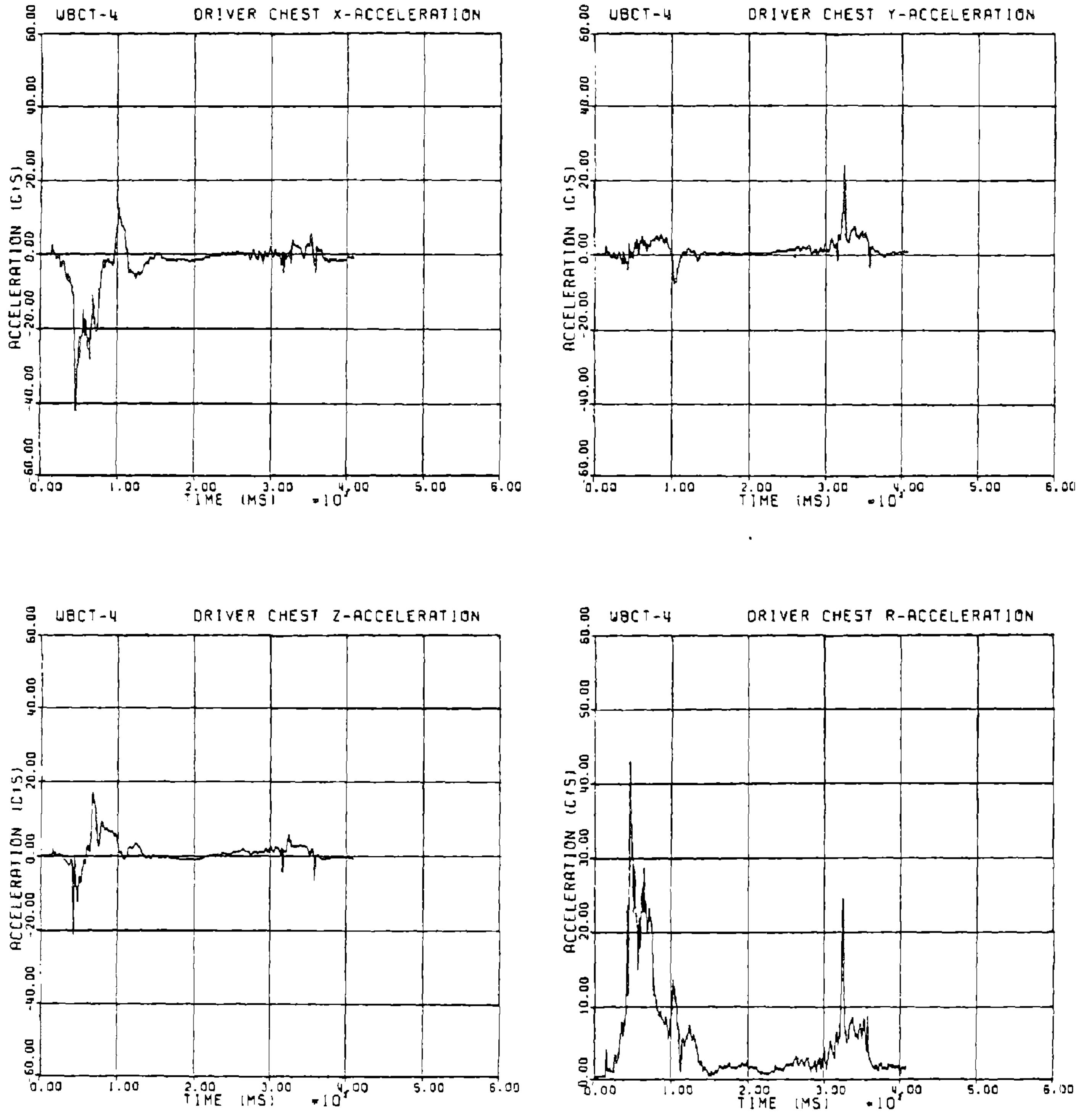
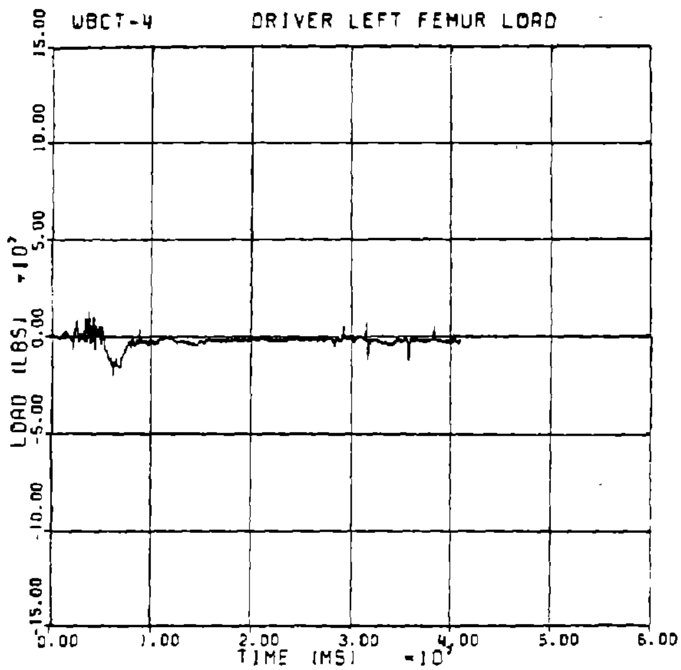


FIGURE A.43 DRIVER DUMMY CHEST ACCELERATION PLOTS, TEST WBCT-4



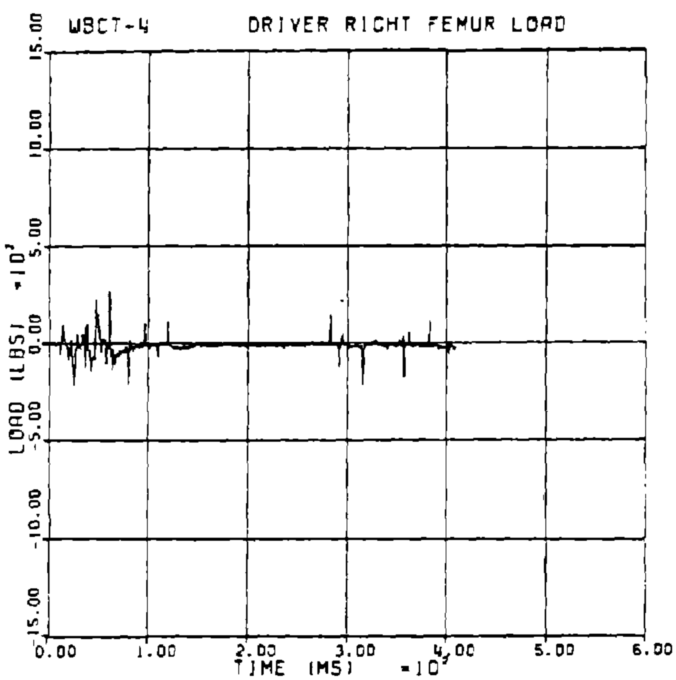


FIGURE A.44 DRIVER DUMMY FEMUR LOAD PLOTS, TEST WBCT-4

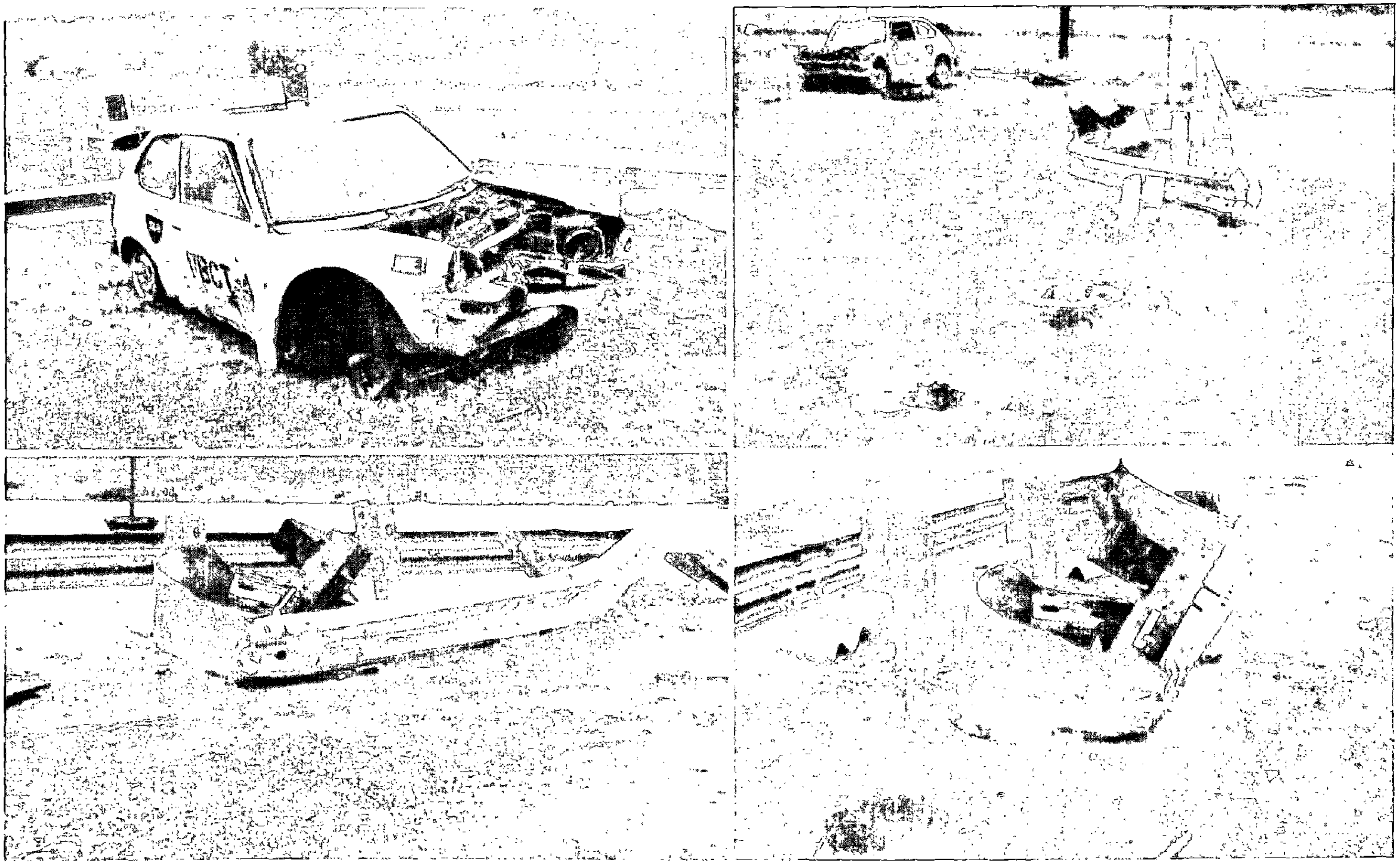


FIGURE A.45 BARRIER AND VEHICLE DAMAGE, TEST WBCT-4

TABLE A.10

FILM ANALYSIS DATA, TEST WBCT-4

SUMMARY OF VEHICLE KINEMATIC AND DYNAMIC DATA WOOD POST BCT TEST WBCT-4 4/8/81

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	-7.96	2.97	.63	87.12	.27	-6.25	.64	0.00	0.00	13579.	-1248.
.010	-7.10	2.99	.95	84.86	-.04	-7.73	.43	0.00	0.00	16798.	-655.
.020	-6.26	3.00	1.41	82.17	-.60	-8.95	.29	0.00	0.00	19425.	-142.
.030	-5.46	3.02	2.03	79.12	-1.39	-9.83	.23	-9.07	.35	21332.	251.
.040	-4.68	3.03	2.81	75.84	-2.36	-10.34	.28	-9.75	.37	22450.	500.
.050	-3.94	3.04	3.75	72.43	-3.46	-10.49	.41	-10.08	.47	22768.	601.
.060	-3.23	3.06	4.83	69.00	-4.64	-10.27	.61	-10.07	.64	22320.	560.
.070	-2.56	3.07	6.04	65.66	-5.83	-9.73	.85	-9.72	.85	21185.	397.
.080	-1.91	3.08	7.37	62.51	-7.00	-8.91	1.09	-9.09	1.08	19474.	141.
.090	-1.30	3.09	8.78	59.61	-8.12	-7.87	1.30	-8.22	1.30	17318.	-175.
.100	-.71	3.10	10.26	57.04	-9.18	-6.70	1.45	-7.17	1.46	14861.	-512.
.110	-.14	3.11	11.78	54.83	-10.18	-5.45	1.53	-6.02	1.56	12252.	-835.
.120	.41	3.12	13.31	52.99	-11.12	-4.20	1.52	-4.83	1.58	9629.	-1111.
.130	.94	3.14	14.94	51.52	-12.04	-3.02	1.43	-3.66	1.51	7122.	-1312.
.140	1.47	3.16	16.35	50.40	-12.95	-1.95	1.25	-2.58	1.37	4835.	-1419.
.150	1.98	3.17	17.83	49.57	-13.87	-1.05	1.03	-1.63	1.17	2852.	-1421.
.160	2.50	3.19	19.27	48.99	-14.82	-.33	.76	-.84	.92	1227.	-1316.
.170	3.01	3.22	20.66	48.60	-15.81	.19	.48	-.23	.65	-12.	-1115.
.180	3.52	3.24	22.02	48.33	-16.85	.51	.21	.20	.37	-868.	-835.
.190	4.03	3.27	23.34	48.13	-17.93	.67	-.04	.46	.12	-1364.	-502.
.200	4.54	3.29	24.62	47.93	-19.05	.68	-.23	.56	-.09	-1548.	-149.
.210	5.06	3.32	25.89	47.70	-20.21	.58	-.38	.55	-.26	-1481.	188.
.220	5.58	3.35	27.15	47.41	-21.39	.41	-.45	.45	-.36	-1232.	470.
.230	6.10	3.37	28.40	47.03	-22.57	.21	-.46	.29	-.40	-874.	661.
.240	6.62	3.40	29.65	46.56	-23.73	.02	-.40	.13	-.38	-471.	730.
.250	7.14	3.42	30.91	46.00	-24.86	-.13	-.28	-.02	-.29	-73.	654.
.260	7.67	3.44	32.18	45.39	-25.93	-.22	-.09	-.13	-.14	289.	420.
.270	8.19	3.46	33.45	44.72	-26.93	-.24	.14	-.19	.07	610.	29.
.280	8.71	3.49	34.72	44.04	-27.82	-.21	.43	-.20	.33	912.	-503.
.290	9.23	3.51	35.99	43.36	-28.60	-.16	.76	-.19	.64	1248.	-1140.
.300	9.75	3.53	37.24	42.68	-29.23	-.11	1.15	-.17	1.00	1695.	-1834.
.310	10.26	3.56	38.47	42.01	-29.70	-.12	1.58	-.20	1.41	2345.	-2520.
.320	10.77	3.59	39.68	41.33	-29.99	-.25	2.08	-.31	1.88	3294.	-3120.
.330	11.28	3.63	40.85	40.59	-30.08	-.54	2.63	-.55	2.39	4618.	-3552.
.340	11.78	3.67	42.01	39.74	-29.94	-1.02	3.24	-.95	2.95	6346.	-3735.
.350	12.27	3.71	43.16	38.71	-29.59	-1.70	3.86	-1.49	3.52	8421.	-3599.
.360	12.75	3.77	44.33	37.44	-29.02	-2.51	4.45	-2.15	4.05	10651.	-3105.
.370	13.21	3.82	45.53	35.89	-28.28	-3.34	4.89	-2.80	4.43	12654.	-2256.
.380	13.65	3.88	46.80	34.09	-27.45	-3.97	4.98	-3.24	4.47	13775.	-1122.
.390	14.08	3.94	48.15	32.14	-26.70	-4.04	4.43	-3.17	3.92	13010.	129.
.400	14.49	4.00	49.59	30.29	-26.29	-3.08	2.76	-2.14	2.32	8892.	1204.
.410	14.87	4.06	51.09	28.98	-26.67	-.41	-.70	.45	-.93	-627.	1646.

TABLE A.11

TEST WBCT-4 TRANSDUCER DATA

TEST ID ------ WBCT-4
TEST DATE ---- 04-08-81
VEHICLE TYPE - MINI-SIZE
IMPACT ANGLE - 0.00 DEGREES
IMPACT SPEED - 84.77 FPS

HIGHEST 50.0-MS AVG. ACCEL.

	G'S	TIME (SEC) START	END
LONG.	-16.35	.025	.075
LAT.	-6.00	.058	.108

VEHICLE KINETICS SUMMARY
NOTE: VALUES ARE INSTANTANEOUS AT TIME

TIME (S)	VEH. ACCEL.(G'S) LONG.	LAT.	VEH. VEL.(FPS) LONG.	LAT.	VEH. DISP.(F) LONG.	LAT.
0.000	-.09	-.16	84.77	0.00	0.00	0.00
.010	-7.04	.12	83.89	-.13	.83	-.00
.020	-8.12	.48	81.24	.32	1.64	-.00
.030	-9.72	-.16	78.22	.20	2.49	.00
.040	-12.30	-1.61	74.33	.48	3.24	.01
.050	-25.44	8.36	68.63	-1.76	3.95	-.00
.060	-13.00	-40.82	61.02	-.02	4.59	-.00
.070	-15.73	9.14	55.79	-8.39	5.16	-.06
.080	-4.74	-1.61	52.39	-5.81	5.74	-.13
.090	-2.25	-.65	51.63	-6.68	6.25	-.19
.100	-2.21	-4.11	51.46	-7.85	6.75	-.26
.110	-.42	-1.81	51.31	-8.43	7.26	-.34
.120	.61	-1.45	51.36	-9.10	7.76	-.43
.130	.33	-1.37	51.32	-10.11	8.31	-.53
.140	-.09	0.00	51.43	-10.62	8.82	-.63
.150	-1.22	-.56	51.32	-10.58	9.32	-.74
.160	-.99	-6.21	50.29	-10.89	9.82	-.84
.170	-.56	.32	50.20	-11.95	10.31	-.96
.180	-5.07	.20	48.98	-12.49	10.84	-1.09
.190	-4.46	-.81	48.74	-12.86	11.32	-1.21
.200	2.85	-1.53	49.09	-13.34	11.80	-1.34
.210	.93	-.65	49.36	-13.38	12.28	-1.47
.220	-.23	.24	49.73	-13.44	12.81	-1.61
.230	-1.36	-.40	49.61	-13.11	13.30	-1.74
.240	.05	-.04	49.39	-13.12	13.79	-1.87
.250	-.23	.36	49.25	-12.98	14.27	-2.00
.260	-1.31	-.16	48.97	-12.86	14.75	-2.12
.270	-.42	-.24	48.90	-13.03	15.27	-2.26
.280	.89	-.52	49.04	-13.06	15.76	-2.39
.290	.70	0.00	49.16	-13.28	16.24	-2.52
.300	-1.13	.32	49.19	-13.08	16.72	-2.65
.310	-.05	4.34	48.81	-12.81	17.20	-2.78
.320	-1.08	2.49	48.74	-11.73	17.72	-2.91
.330	-2.11	1.81	48.37	-11.04	18.20	-3.02
.340	.51	-1.77	48.08	-11.04	18.67	-3.13
.350	.33	.64	48.58	-11.41	19.15	-3.24
.360	-1.27	1.97	47.86	-10.49	19.62	-3.35
.370	-5.49	6.15	47.95	-11.40	20.13	-3.46
.380	1.45	-6.74	47.41	-10.82	20.60	-3.57
.390	-4.08	-1.21	47.21	-12.01	21.06	-3.68
.400	-.99	-1.90	46.88	-11.23	21.52	-3.79

TABLE A.11 (Cont'd)

TEST ID ------ WBCT-4
TEST DATE ---- 04-08-81
VEHICLE TYPE - MINI-SIZE

VEHICLE MASS = 2170. LBS.
IMPACT SPEED = 57.8 MPH
IMPACT ANGLE = 0.0 DEG.

OCCUPANT - DRIVER
572-50% MALE DUMMY
RESTRAINTS - LAB + SHOULDER BELTS

TIME (SEC)	RESULTANT (G'S) HEAD	CHEST	-------SI------- HEAD	CHEST	FEMUR LOADS (LBS) LEFT	RIGHT
0.000	.1	.2	0.0	0.0	0.0	-3.2
.010	1.1	.5	.0	.0	5.6	-3.2
.020	4.8	1.5	.1	.0	-24.4	-51.7
.030	2.8	2.7	.4	.1	-8.9	-12.1
.040	7.9	9.8	1.5	1.4	13.3	-51.7
.050	34.6	22.7	28.8	47.7	11.1	23.4
.060	18.9	21.0	73.0	68.5	-148.6	-23.6
.070	49.2	21.4	686.1	94.9	-110.9	-70.9
.080	10.0	9.6	712.2	108.6	-17.7	-82.4
.090	8.7	7.5	715.5	110.9	-33.3	-13.4
.100	8.1	8.8	717.4	112.4	-31.0	-.6
.110	5.2	4.4	720.5	115.8	4.4	-69.6
.120	1.8	5.7	721.1	116.2	-8.9	-7.0
.130	4.4	5.5	722.5	117.3	-26.6	-21.1
.140	7.3	2.0	723.8	117.5	-38.8	-24.9
.150	9.2	.5	725.6	117.5	-26.6	-3.2
.160	8.8	.9	727.4	117.5	-17.7	-13.4
.170	7.8	2.0	729.2	117.6	-22.2	-13.4
.180	5.5	1.6	730.3	117.6	-17.7	-10.9
.190	5.5	1.9	731.1	117.6	-11.1	-8.3
.200	5.5	2.0	731.8	117.7	-11.1	-18.5
.210	4.0	1.6	732.4	117.7	-8.9	-18.5
.220	3.6	.8	732.7	117.7	-8.9	-10.9
.230	2.6	1.1	732.9	117.8	-16.6	-3.2
.240	3.8	1.2	733.1	117.8	-13.3	-13.4
.250	2.9	1.9	733.3	117.8	-4.4	-13.4
.260	2.4	1.9	733.5	117.9	-8.9	-.6
.270	2.8	2.8	733.6	118.0	-8.9	-3.2
.280	3.3	1.9	733.8	118.1	-26.6	-8.3
.290	3.1	1.0	734.1	118.1	-4.4	-3.2
.300	1.5	4.5	734.5	118.2	-17.7	-8.3
.310	7.2	4.8	735.2	118.5	-4.4	-16.0
.320	8.6	6.3	739.9	119.0	-22.2	-5.7
.330	8.2	5.0	742.0	126.9	-37.7	-3.2
.340	8.2	6.5	744.1	128.3	-41.0	-17.2
.350	10.2	5.6	747.0	129.3	-33.3	-22.3
.360	15.9	2.9	753.3	130.2	-8.9	-3.2
.370	9.2	1.2	760.2	130.2	-26.6	-8.3
.380	9.7	1.7	763.9	130.3	-15.5	-8.3
.390	10.9	1.6	767.2	130.3	-25.5	-10.9
.400	9.7	.7	770.3	130.3	-26.6	-18.5

MAXIMUM VALUES AND TIME OF OCCURANCE

	X/LT	---SEC	Y/RT	---SEC	Z	----SEC	R	----SEC
HEAD (G'S)	-119.3	.065	29.2	.063	-54.0	.068	123.6	.065
CHEST (G'S)	-42.1	.046	24.1	.324	-21.0	.041	42.9	.046
FEMUR LOAD (LBS)	-202.	.061	0.	.409				

CUMULATIVE PERIOD FOR 60-G LEVEL = .007 SEC.

HIC = 588.1 DURING T = .063 TO .070 SEC.

TEST WBCT-5

Purpose: Purpose of this test was to evaluate the performance of the wood post BCT which had been further modified (from that of Test WBCT-4) to reduce its end-on impact resistance. This was accomplished by a 2170-lb (984-kg) minicompact automobile impacting the buffer end at 60 mph and a 0-deg angle.

Test Installation: The test installation of WBCT-4 was further modified by redesigning the wood spacer blockout assembly inside the buffer end, and making three sawcuts in the W-beam rail to allow hinges to be formed quicker and at desired locations. As shown in Figure A.46 the spacer blockout was lengthened downward to further distribute the impact loading over a larger area of the front section of the vehicle, particularly to the vehicle lower crossmember structure. W-beam sawcuts were located approximately 1 ft (0.3 m) downstream of Posts 3 and 4 and 1.5 ft (0.5 m) upstream of Post 6. Sawcuts were 1.75 in. (45 mm) deep into the face of the rail and were terminated with a 0.5-in. (13-mm) dia. hole at each end.

Test Vehicle: A 1977 Honda Civic sedan was the test vehicle and it contained two 50th percentile anthropomorphic dummies in the driver and front passenger seating positions. The driver dummy was restrained by a lap and shoulder belt whereas the passenger dummy was unrestrained. Total weight of the vehicle, dummies and instrumentation was 2170 lb (984 kg). Target impact location was 15 in. (381 mm) to the left of vehicle centerline.

Performance: Impact conditions were 56.8 mph (91.4 kmph) and a 0-deg angle. As shown in the impact sequence of Figure 19 the vehicle impacted the buffer end (and wood spacer) fracturing the first post and causing the rail to translate away from the remaining posts. As the vehicle began to yaw it fractured the second post and overrode Posts 3, 4 and 5 causing the rear of the vehicle to pitch upward as the front nosed downward. The rear then came back down and the vehicle stopped in an upright position normal to the rail approximately 19 ft (5.8 m) behind it and adjacent to Post 12. A camera malfunction resulted in film analysis not being performed and acceleration data shown in the summary of results of Figure 20 were taken from accelerometers only.

Results of analog to digital conversion of vehicle and dummy transducer data is shown in Table A.12 and plotted in Figures A.47 thru A.53.

Barrier Damage: As shown in Figure A.54 barrier damage consisted of two fractured wood posts, three bent rail sections, three bent steel posts and a damaged buffer end/wood spacer assembly.

Vehicle Damage: The front section of the vehicle, as shown in Figure A.54, was heavily damaged from impact with the end of the barrier. In addition, the lower portion of the right door and the area just aft of it were damaged by contact with the steel posts. Although the windshield was impacted and almost knocked out by the unrestrained passenger dummy it remained with the vehicle.

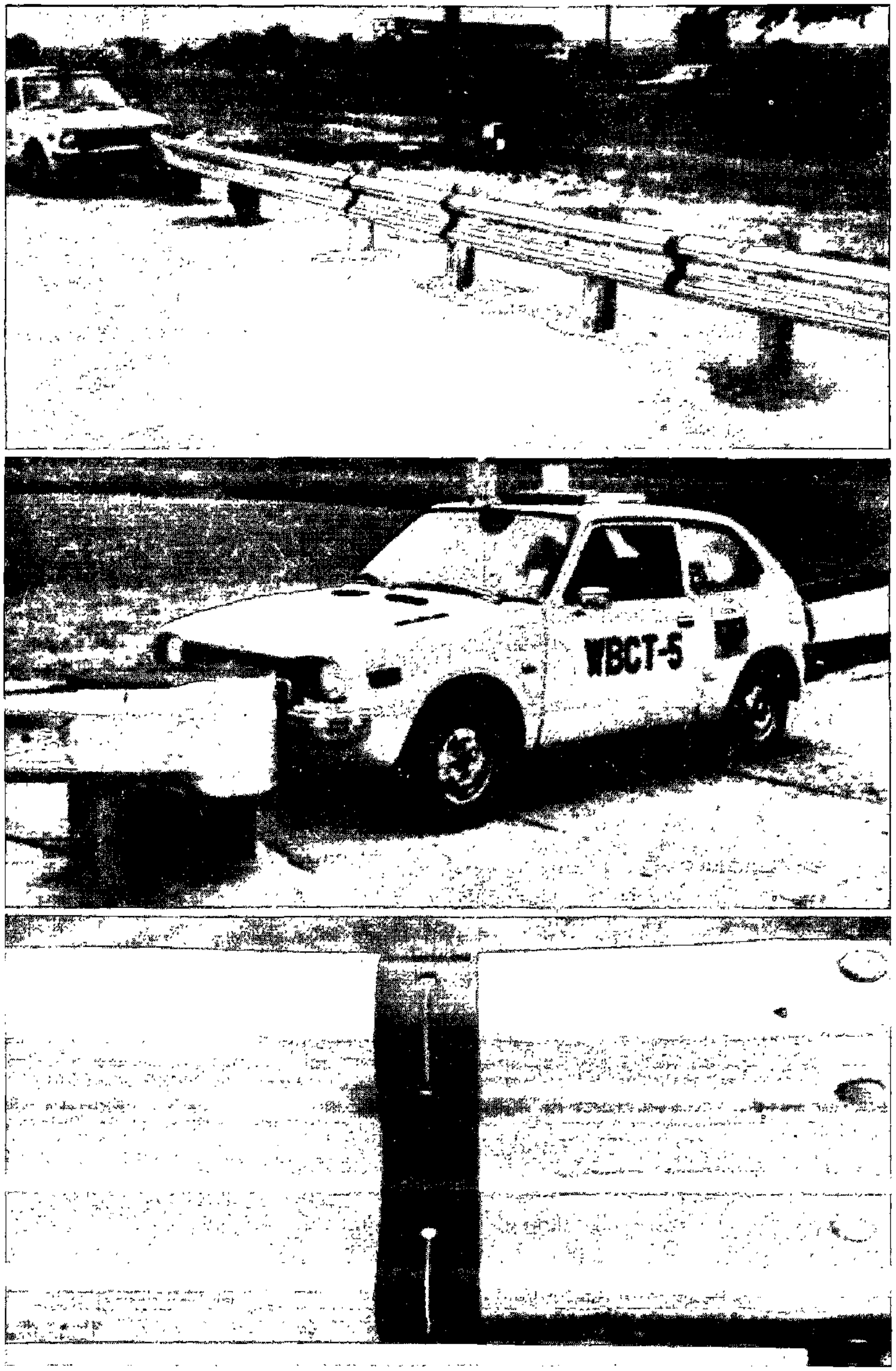
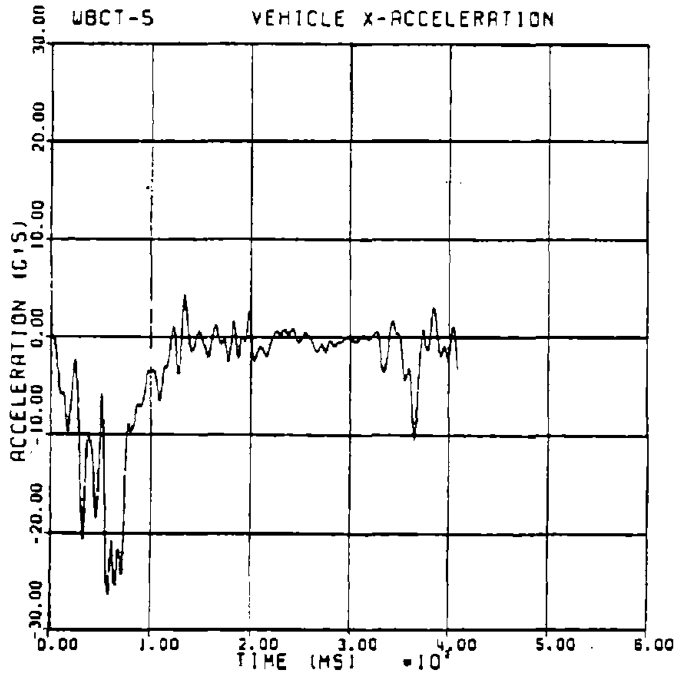


FIGURE A.46 WBCT-5 TEST INSTALLATION



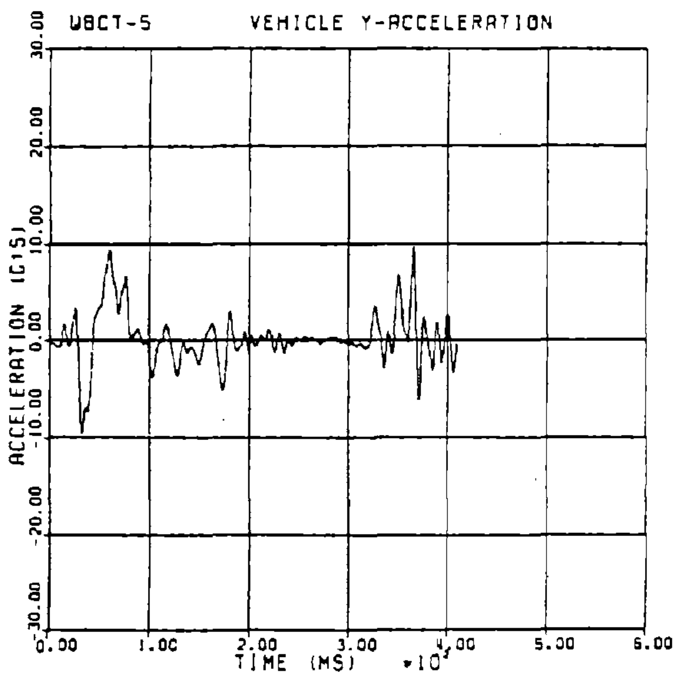


FIGURE A.47 VEHICLE ACCELERATION PLOTS, TEST WBCT-5

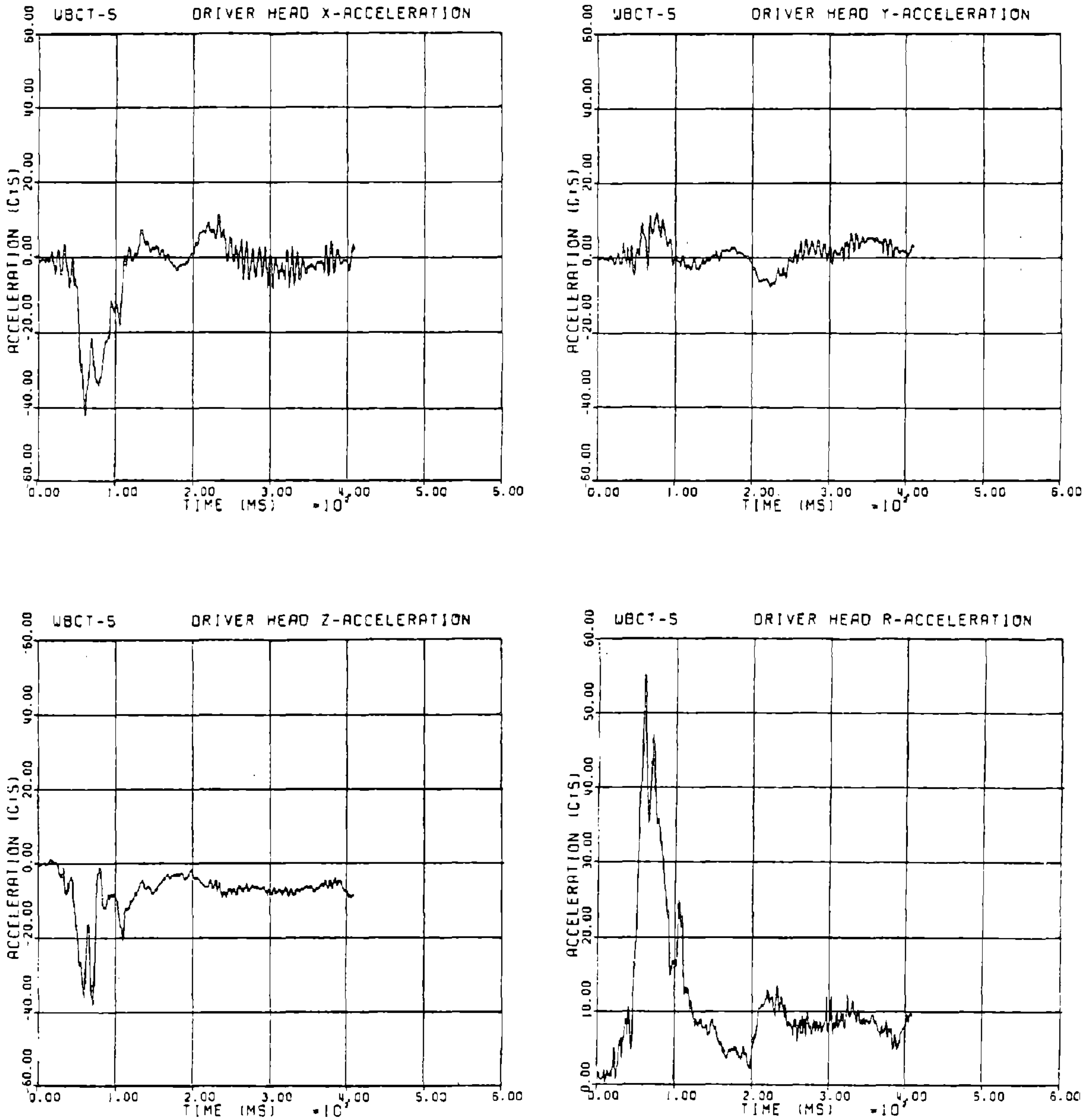


FIGURE A.48 DRIVER DUMMY HEAD ACCELERATION PLOTS, TEST WBCT-5

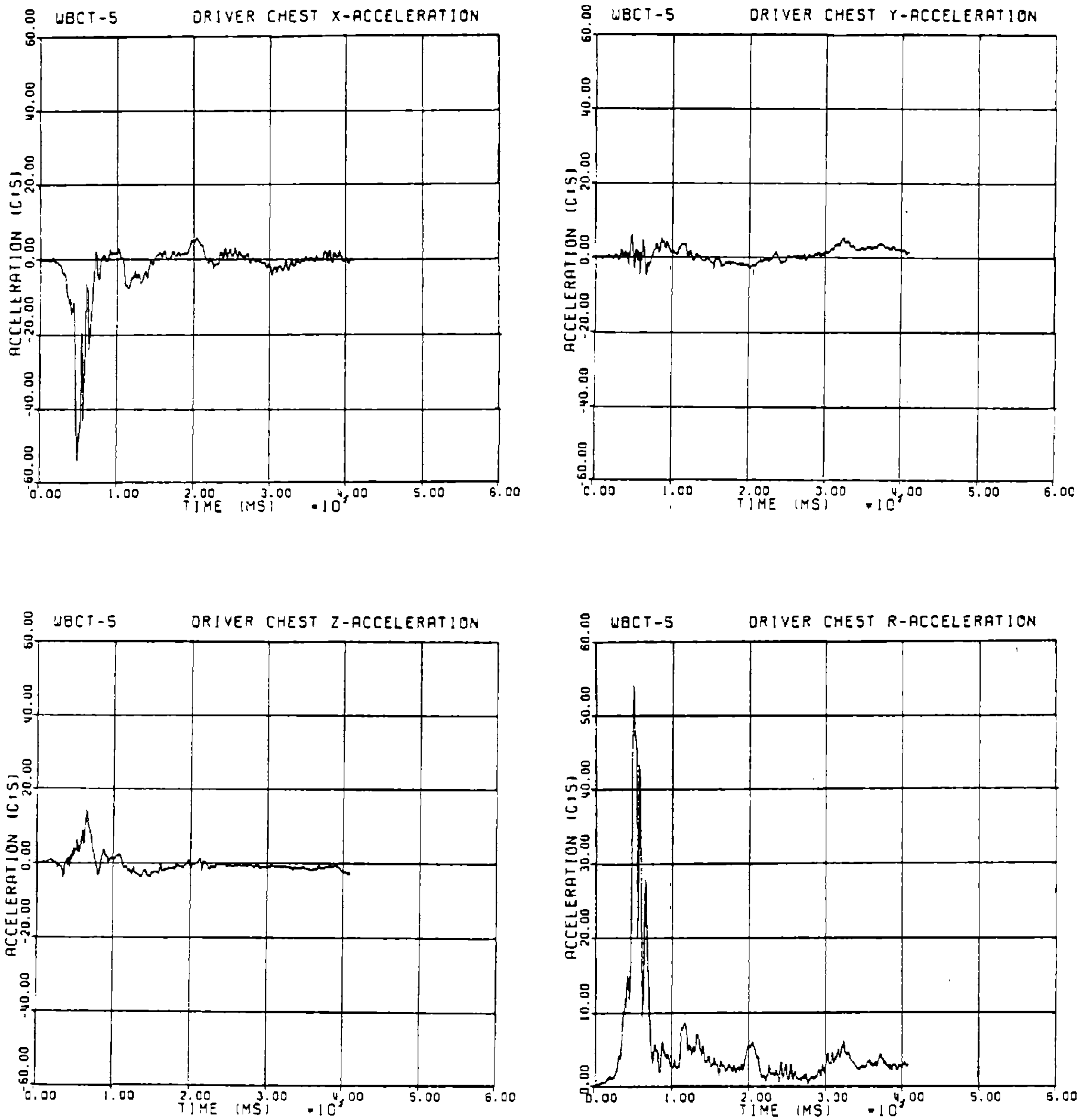
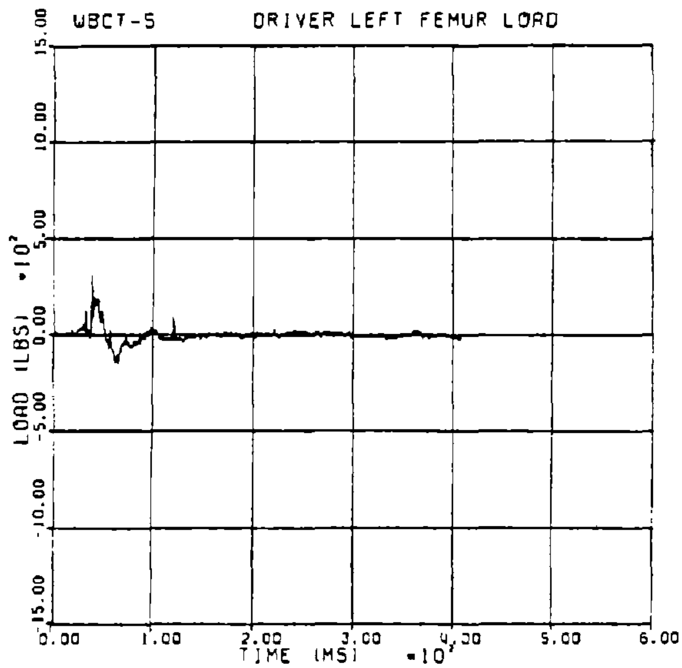


FIGURE A.49 DRIVER DUMMY CHEST ACCELERATION PLOTS, TEST WBCT-5



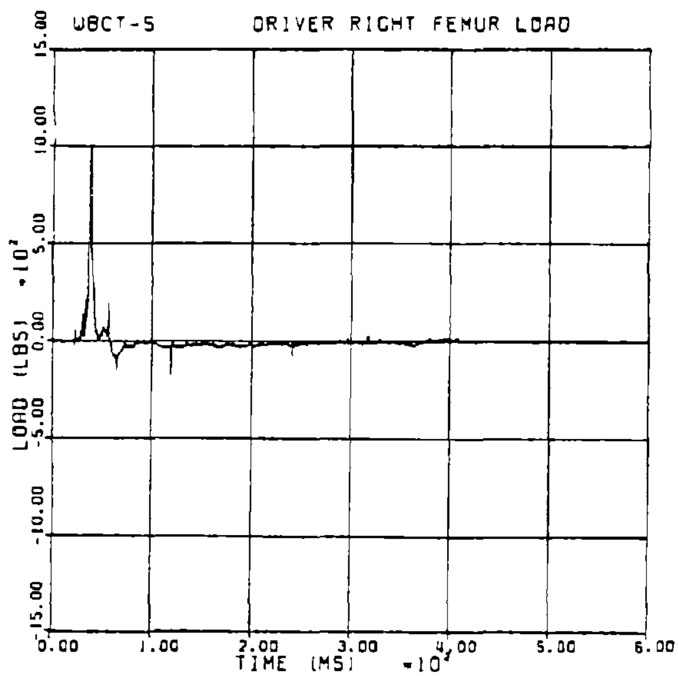


FIGURE A.50 DRIVER DUMMY FEMUR LOAD PLOTS, TEST WBCT-5

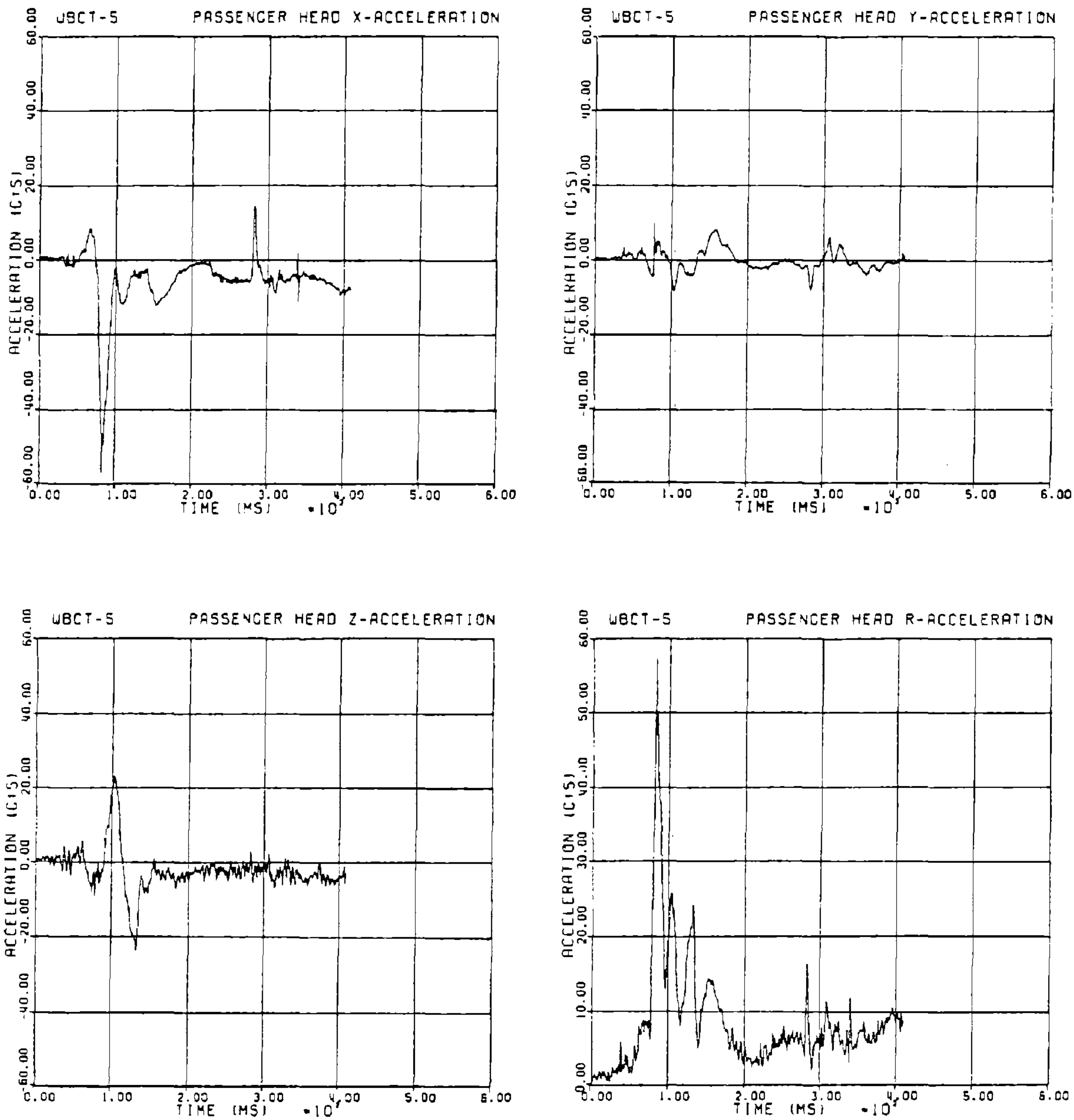


FIGURE A.51 PASSENGER DUMMY HEAD ACCELERATION PLOTS, TEST WBCT-5

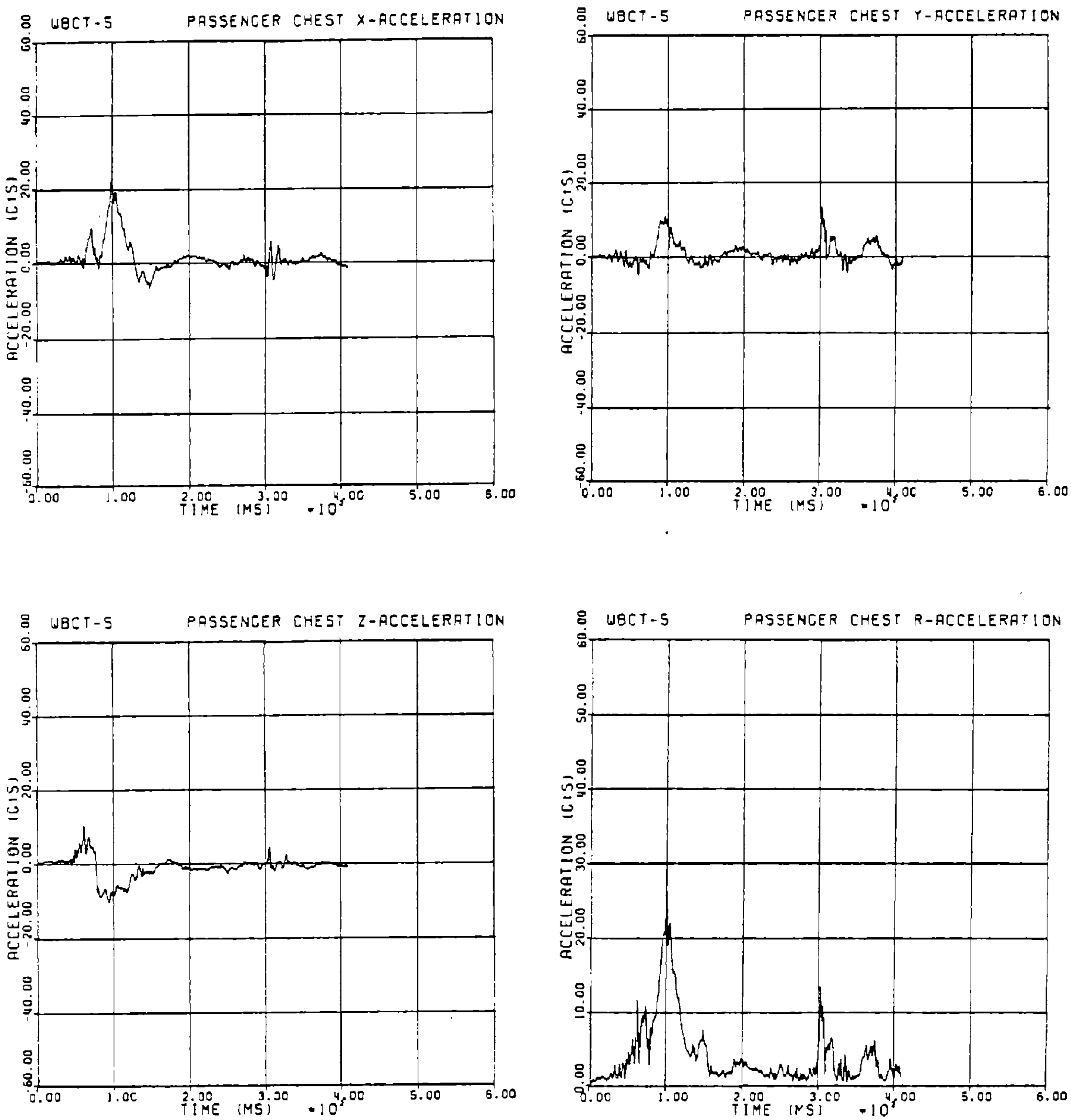
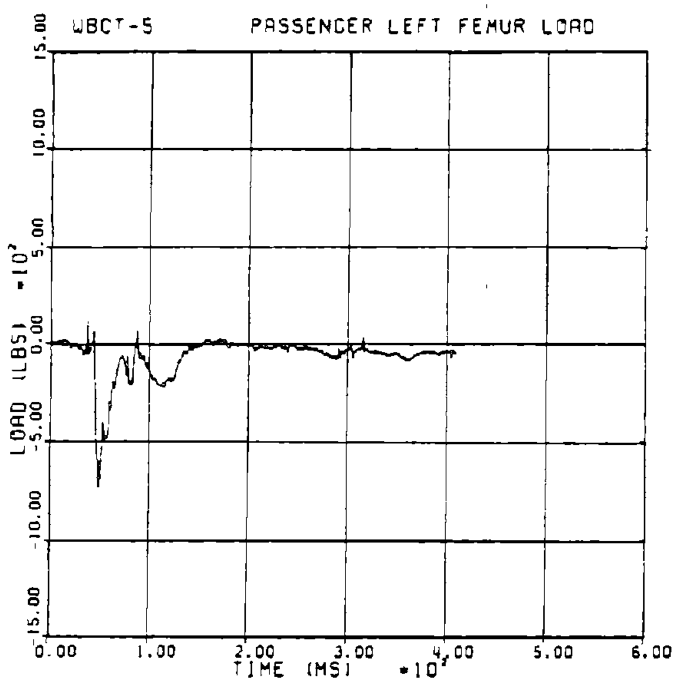


FIGURE A.52 PASSENGER DUMMY CHEST ACCELERATION PLOTS, TEST WBCT-5



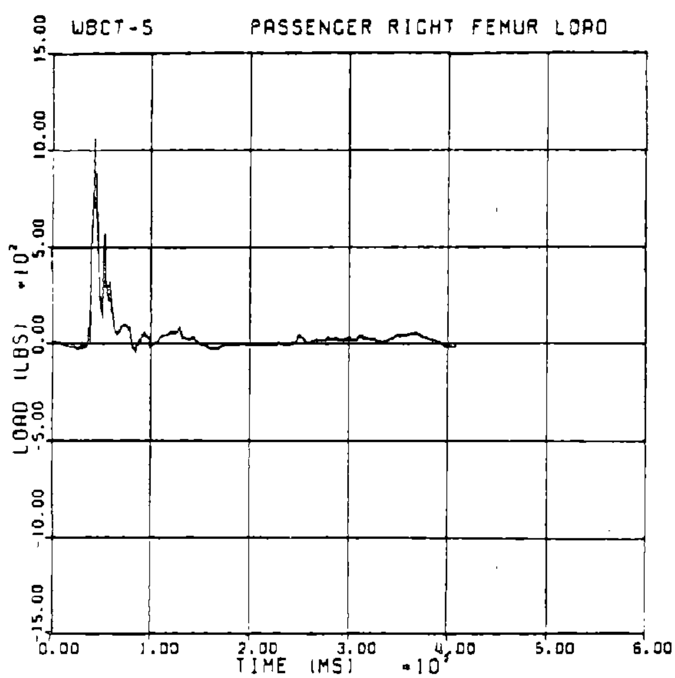


FIGURE A.53 PASSENGER DUMMY FEMUR LOAD PLOTS, TEST WBCT-5

FIGURE A.54 BARRIER AND VEHICLE DAMAGE TEST WBCT-5

TABLE A.12

TEST WBCT-5 TRANSDUCER DATA

TEST ID ------ WBCT-5
TEST DATE ---- 05-08-81
VEHICLE TYPE - MINI-SIZE
IMPACT ANGLE - 0.00 DEGREES
IMPACT SPEED - 83.31 FPS

HIGHEST 50.0-MS AVG. ACCEL.

	G'S	TIME (SEC) START	TIME (SEC) END
LONG.	-16.94	.028	.078
LAT.	3.86	.043	.093

VEHICLE KINETICS SUMMARY
NOTE: VALUES ARE INSTANTANEOUS AT TIME

TIME (S)	VEH. ACCEL.(G'S) LONG.	VEH. ACCEL.(G'S) LAT.	VEH. VEL.(FPS) LONG.	VEH. VEL.(FPS) LAT.	VEH. DISP.(F) LONG.	VEH. DISP.(F) LAT.
0.000	.10	-.13	83.31	0.00	0.00	0.00
.010	-5.80	-.63	82.74	-.14	.82	-.00
.020	-7.16	-.59	80.40	-.01	1.62	-.00
.030	-18.56	-8.05	78.23	.21	2.47	.00
.040	-11.06	-4.70	73.70	-2.25	3.21	-.01
.050	-7.12	3.52	69.08	-1.95	3.91	-.03
.060	-21.81	9.37	63.55	-.01	4.57	-.04
.070	-23.43	2.99	56.34	1.91	5.16	-.03
.080	-9.66	.28	51.22	3.51	5.73	-.00
.090	-7.12	.70	48.68	3.71	6.22	.03
.100	-3.56	-2.59	47.08	3.60	6.69	.07
.110	-6.06	-.23	45.64	2.91	7.14	.10
.120	-.27	.50	44.57	3.15	7.59	.13
.130	.21	-2.03	44.20	2.44	8.06	.16
.140	-1.44	-.82	44.79	2.16	8.50	.18
.150	.14	-2.36	44.67	1.70	8.94	.20
.160	-.84	1.20	44.31	1.61	9.37	.22
.170	-.71	-3.35	44.43	1.76	9.81	.23
.180	-.12	2.97	44.05	.82	10.28	.25
.190	-.36	-.71	43.97	.95	10.72	.26
.200	1.38	-1.02	44.17	.89	11.15	.26
.210	-.93	.15	43.75	.80	11.58	.27
.220	-.49	1.19	43.26	.94	12.04	.28
.230	.25	.68	43.33	.89	12.47	.29
.240	.59	-.10	43.49	.77	12.90	.30
.250	-.36	.02	43.57	.72	13.32	.31
.260	-.05	.08	43.62	.77	13.75	.31
.270	-.80	-.42	43.29	.80	14.21	.32
.280	-.32	.16	42.99	.78	14.64	.33
.290	-.54	-.21	42.79	.83	15.06	.34
.300	.19	-.44	42.72	.76	15.48	.35
.310	-.19	-.52	42.64	.61	15.90	.35
.320	-.05	-.52	42.63	.40	16.35	.36
.330	-1.44	1.54	42.71	.98	16.77	.36
.340	.72	.76	41.94	.78	17.19	.37
.350	.21	6.71	42.23	1.12	17.60	.38
.360	-3.26	-.19	41.34	2.07	18.01	.40
.370	-2.38	-6.06	38.99	3.28	18.44	.43
.380	-.63	-.40	38.79	3.03	18.82	.46
.390	-1.63	1.61	39.21	2.71	19.21	.48
.400	-2.29	2.68	38.70	2.65	19.59	.51

TABLE A.12 (Cont'd)

TEST ID ------ UBCT-5
TEST DATE ---- 05-08-81
VEHICLE TYPE - MINI-SIZE

VEHICLE MASS = 2170. LBS.
IMPACT SPEED = 56.8 MPH
IMPACT ANGLE = 0.0 DEG.

OCCUPANT - DRIVER
572-50% MALE DUMMY
RESTRAINTS - LAB + SHOULDER BELTS

TIME	RESULTANT (G'S)		-------SI-------		FEMUR LOADS (LBS)	
(SEC)	HEAD	CHEST	HEAD	CHEST	LEFT	RIGHT
0.000	.6	.2	0.0	0.0	4.7	-1.6
.010	.9	.5	.0	.0	-5.9	-7.8
.020	2.3	.9	.0	.0	-8.6	-4.7
.030	6.3	4.2	.4	.1	26.4	33.1
.040	9.4	15.0	2.1	3.1	159.0	321.1
.050	21.8	48.0	8.5	73.2	38.6	56.7
.060	53.9	9.5	124.2	152.4	-114.1	-57.4
.070	46.3	9.6	235.3	167.7	-56.1	-48.1
.080	32.3	4.2	334.2	168.4	-29.7	-26.4
.090	23.5	4.3	375.8	168.8	12.9	-4.7
.100	16.2	2.5	388.5	169.0	18.3	-1.6
.110	19.1	5.6	408.3	169.2	-29.7	-32.6
.120	11.4	4.9	414.4	170.8	-21.8	-29.5
.130	8.1	5.9	417.2	171.5	-27.0	-31.0
.140	8.1	4.8	419.0	172.3	-8.6	-26.4
.150	7.9	2.8	420.7	172.5	-.7	-10.9
.160	5.5	1.4	421.8	172.6	6.1	-18.6
.170	4.3	2.3	422.2	172.8	12.9	-29.5
.180	3.9	2.6	422.7	172.9	-5.9	-26.4
.190	4.7	2.8	423.0	173.0	-3.3	-24.8
.200	4.1	5.7	423.3	173.3	-19.1	-10.9
.210	10.3	3.8	424.8	174.0	-8.6	-10.9
.220	12.8	1.0	429.3	174.1	31.8	-1.6
.230	9.4	1.8	433.5	174.1	-7.3	-17.1
.240	10.8	2.0	437.9	174.2	23.7	-15.5
.250	8.3	1.1	440.4	174.2	4.7	-10.9
.260	5.8	1.9	442.1	174.3	12.9	-6.2
.270	6.5	1.1	444.0	174.3	12.9	-14.0
.280	8.6	1.1	445.8	174.3	-8.6	-7.8
.290	8.4	2.2	447.6	174.3	-5.9	-6.2
.300	8.0	2.9	449.7	174.4	-8.6	-10.9
.310	8.6	3.8	452.0	174.7	-8.6	-14.0
.320	7.6	4.8	454.4	175.1	-8.6	-10.9
.330	10.9	4.7	457.4	175.6	-.7	4.7
.340	8.8	2.7	460.4	175.9	-8.6	-6.2
.350	8.8	2.4	462.5	176.0	-3.3	-7.8
.360	8.7	2.9	464.8	176.2	4.7	-17.1
.370	7.7	3.8	466.6	176.3	-7.3	-9.3
.380	7.3	2.9	468.1	176.6	-13.8	14.2
.390	5.5	3.0	469.1	176.7	-.7	7.9
.400	7.9	2.6	470.3	176.9	-5.9	14.2

MAXIMUM VALUES AND TIME OF OCCURANCE

	X/LT---SEC		Y/RT---SEC		Z----SEC		R----SEC	
HEAD (G'S)	-42.2	.060	12.0	.076	-38.1	.070	55.1	.059
CHEST (G'S)	-53.9	.048	6.0	.047	14.2	.064	54.0	.048
FEMUR LOAD (LBS)	304.	.038	0.	.409				

CUMULATIVE PERIOD FOR 60-G LEVEL = 0.000 SEC.

HIC = 339.2 DURING T = .051 TO .092 SEC.

TABLE A.12 (Cont'd)

TEST ID ------ WBCT-5
TEST DATE ---- 05-08-81
VEHICLE TYPE - MINI-SIZE

VEHICLE MASS = 2170. LBS.
IMPACT SPEED = 56.8 MPH
IMPACT ANGLE = 0.0 DEG.

OCCUPANT - PASSENGER
572-50% MALE DUMMY
RESTRAINTS - NONE

TIME (SEC)	RESULTANT (G'S) HEAD	CHEST	-------SI------- HEAD	CHEST	FEMUR LOADS (LBS) LEFT	RIGHT
0.000	.2	.2	0.0	0.0	-4.1	0.0
.010	1.6	1.1	.0	.0	9.5	0.0
.020	.6	.9	.0	.0	-23.1	-12.6
.030	1.8	1.6	.1	.0	-31.3	-25.2
.040	2.7	1.0	.2	.1	-27.2	574.2
.050	2.4	4.4	.3	.2	-686.9	133.3
.060	4.4	7.5	.6	.7	-338.7	161.5
.070	8.7	8.7	2.2	2.6	-83.0	89.7
.080	39.7	7.2	19.7	4.3	-213.6	-10.1
.090	27.4	14.9	139.5	8.1	-51.7	48.7
.100	21.3	22.4	155.2	27.9	-148.3	-10.1
.110	14.6	15.3	178.5	42.5	-213.6	35.9
.120	11.1	7.9	182.2	47.2	-178.2	51.3
.130	22.1	3.8	197.3	48.1	-92.5	43.6
.140	5.5	4.0	207.3	48.5	-28.6	33.3
.150	13.5	5.7	211.1	49.3	-17.7	-5.0
.160	13.1	2.0	218.3	49.6	14.9	-27.7
.170	10.4	1.4	222.5	49.6	17.6	-15.1
.180	4.8	1.7	224.3	49.7	-23.1	-5.0
.190	5.6	3.0	225.1	49.8	-1.4	0.0
.200	4.6	3.4	225.5	49.9	-4.1	-6.3
.210	2.4	2.4	225.8	50.1	-23.1	0.0
.220	4.0	2.0	226.0	50.1	-28.6	-7.6
.230	3.7	1.0	226.4	50.2	4.1	2.6
.240	6.3	1.7	226.9	50.2	-8.2	-7.6
.250	5.7	3.0	227.7	50.2	-17.7	43.6
.260	5.4	2.6	228.7	50.3	-25.8	7.7
.270	6.6	1.2	229.9	50.3	-39.4	10.3
.280	6.7	1.0	230.7	50.4	-58.5	20.5
.290	4.7	1.6	233.7	50.4	-25.8	20.5
.300	4.8	4.4	234.5	50.5	-28.6	33.3
.310	10.6	2.8	236.3	52.8	-28.6	38.5
.320	7.5	2.4	238.0	53.5	-39.4	28.2
.330	6.2	3.6	239.2	53.6	-50.3	2.6
.340	8.3	2.1	240.2	53.7	-61.2	20.5
.350	6.0	1.1	241.0	53.7	-51.7	41.0
.360	6.0	3.8	242.4	53.8	-80.3	46.1
.370	7.3	4.8	243.5	54.3	-50.3	48.7
.380	7.7	2.1	244.8	54.7	-35.4	28.2
.390	9.3	.7	246.8	54.7	-55.8	7.7
.400	8.9	1.0	249.6	54.8	-39.4	-8.8

MAXIMUM VALUES AND TIME OF OCCURANCE

	X/LT	---SEC	Y/RT	---SEC	Z	----SEC	R	----SEC
HEAD (G'S)	-57.0	.082	9.9	.077	-23.5	.132	57.2	.082
CHEST (G'S)	23.1	.098	13.3	.301	-10.4	.093	26.0	.098
FEMUR LOAD (LBS)	-730.	.048	0.	.409				

CUMULATIVE PERIOD FOR 60-G LEVEL = 0.000 SEC.

HIC = 138.7 DURING T = .077 TO .135 SEC.

TEST WBCT-6

Purpose: Purpose of this test was to evaluate the performance of the wood post BCT which had been further modified to reduce its end-on impact resistance. This was accomplished by a 2124-lb (963-kg) minicompact automobile impacting the buffer end at 60 mph and a 0-deg angle.

Test Installation: The test installation of WBCT-5 was modified slightly by relocating the first two sawcuts to 3 ft (0.9 m) downstream of Post 1 and 1 ft (0.3 m) downstream of Post 3, the last sawcut remaining 1.5 ft (0.5 m) upstream of Post 6. These cuts were made to further reduce impact loading caused by the W-beam rail.

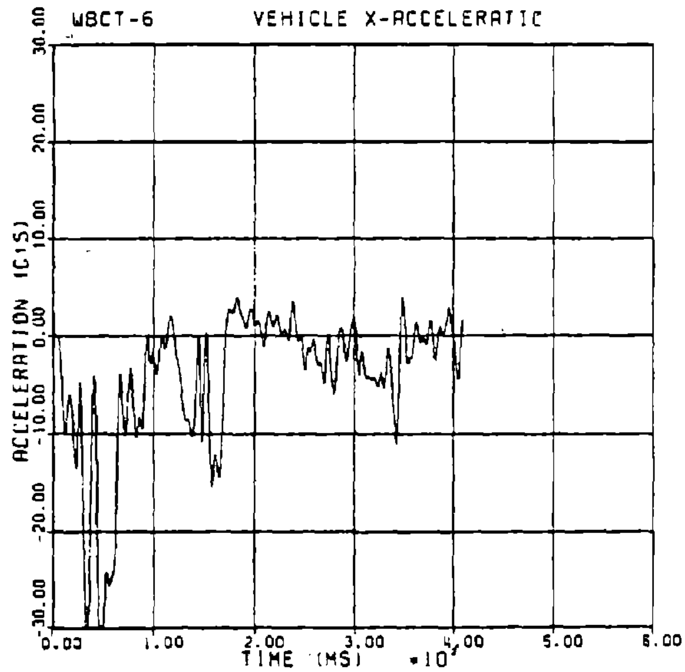
Test Vehicle: A 1974 Honda Civic sedan was the test vehicle, and it contained two 50th percentile anthropomorphic dummies in the driver and front passenger seating positions. The driver dummy was restrained by a lap and shoulder belt whereas the passenger dummy was unrestrained. Total weight of the vehicle, dummies, and instrumentation was 2124 lb (963 kg). Target impact location was 15 in. (381 mm) to the left of vehicle centerline.

Performance: Impact conditions were 60.4 mph (97.2 kmph) and a 0-deg angle. As shown in the impact sequence of Figure 21 the vehicle impacted the buffer end (and wood spacer) fracturing the first post and causing hinges to form at the first two sawcuts as the rail translated away from the posts. As the vehicle began to yaw it fractured the second post and the rail at the first two sawcuts. As it continued its trajectory the vehicle overrode Posts 3, 4 and 5 causing the rear to pitch upward as the front nosed downward. This pitching continued until the vehicle "stood" on its front section and then rolled onto its left side. It came to a stop approximately 11 ft (3.4 m) behind Post 10. Maximum 50 msec average vehicle accelerations measured during the impact were -11.2 g (cine) and -18.7 g (accelerometer) in the longitudinal direction, and 4.2 g (cine) and 3.5 g (accelerometer) in the lateral direction. Test results are summarized in Figure 22 and results of high-speed film analysis are contained in Table A.13. Results of analog to digital conversion of vehicle and dummy transducers are tabulated in Table A.14 and plotted in Figures A.55 thru A.61.

Barrier Damage: Two wood posts were fractured, three steel posts were bent, and three rail sections and the buffer end/wood spacer assembly damaged by impact. Barrier damage is shown in Figure A.62.

Vehicle Damage: Vehicle damage, also shown in Figure A.62, was extensive. The front section was heavily damaged from impacting the end of the barrier. The right side and bottom sheet metal had indentations from steel post contact. The right front wheel MacPherson strut was fractured. The windshield was shattered and knocked out by the unrestrained passenger dummy.

Comment: As determined using the ENDON program it is desirable to achieve a ΔV = 12.2 ft/sec (3.7 m/sec) (using a Honda impacting at 60 mph, 0°, 15 in. offset) in the first 12 ft (3.7 m) in order to achieve gating through the BCT. By comparison the velocity change (taken from film analysis data) for this test was approximately 44 ft/sec (13.4 m/sec) in the time interval from impact to 0.195 sec.



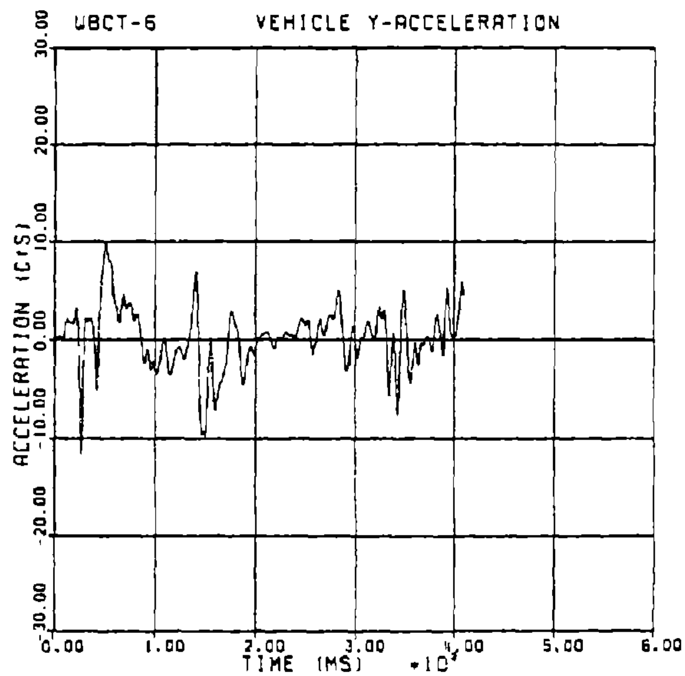


FIGURE A.55 VEHICLE ACCELERATION PLOTS, TEST WBCT-6

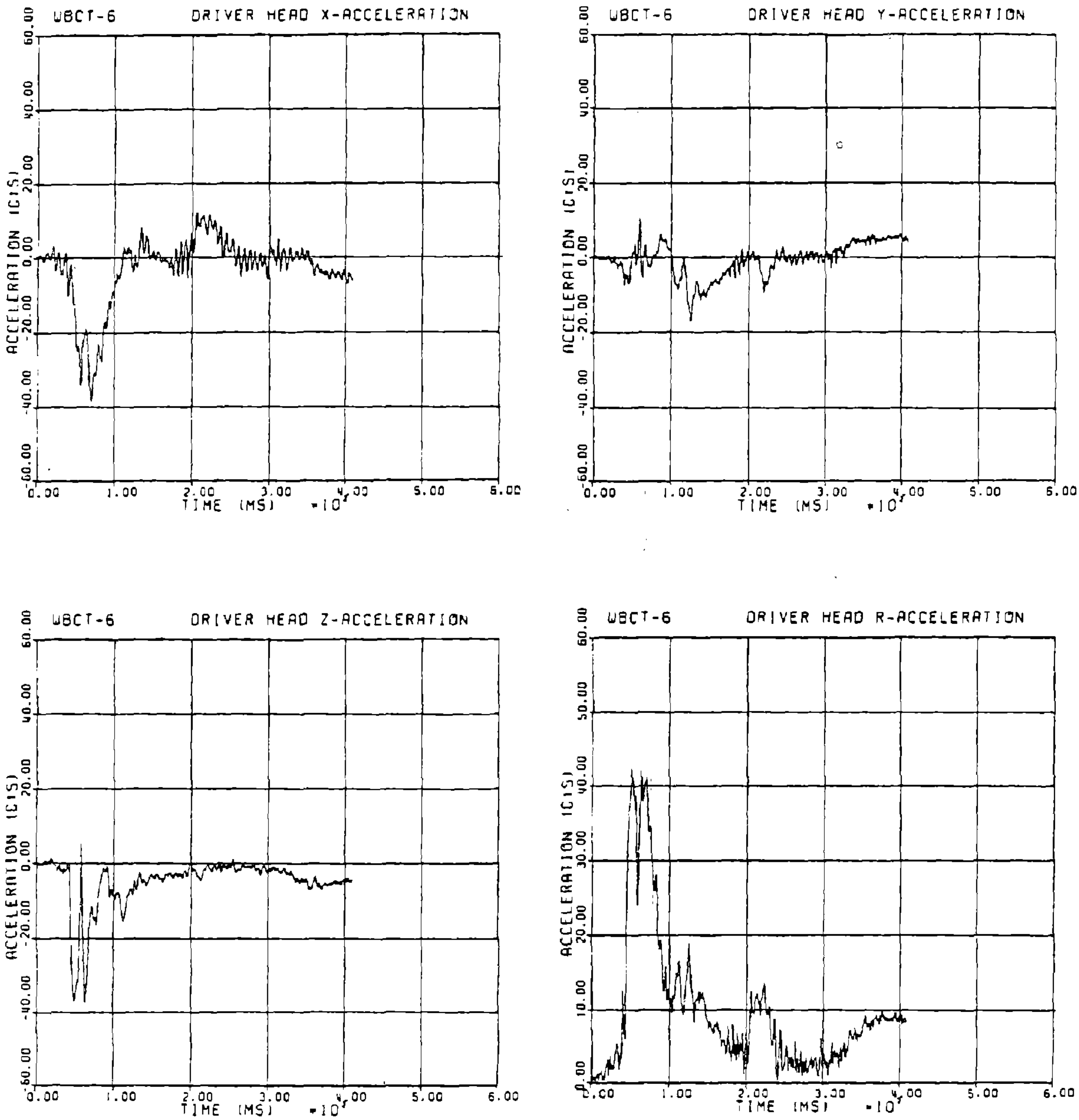


FIGURE A.56 DRIVER DUMMY HEAD ACCELERATION PLOTS, TEST WBCT-6

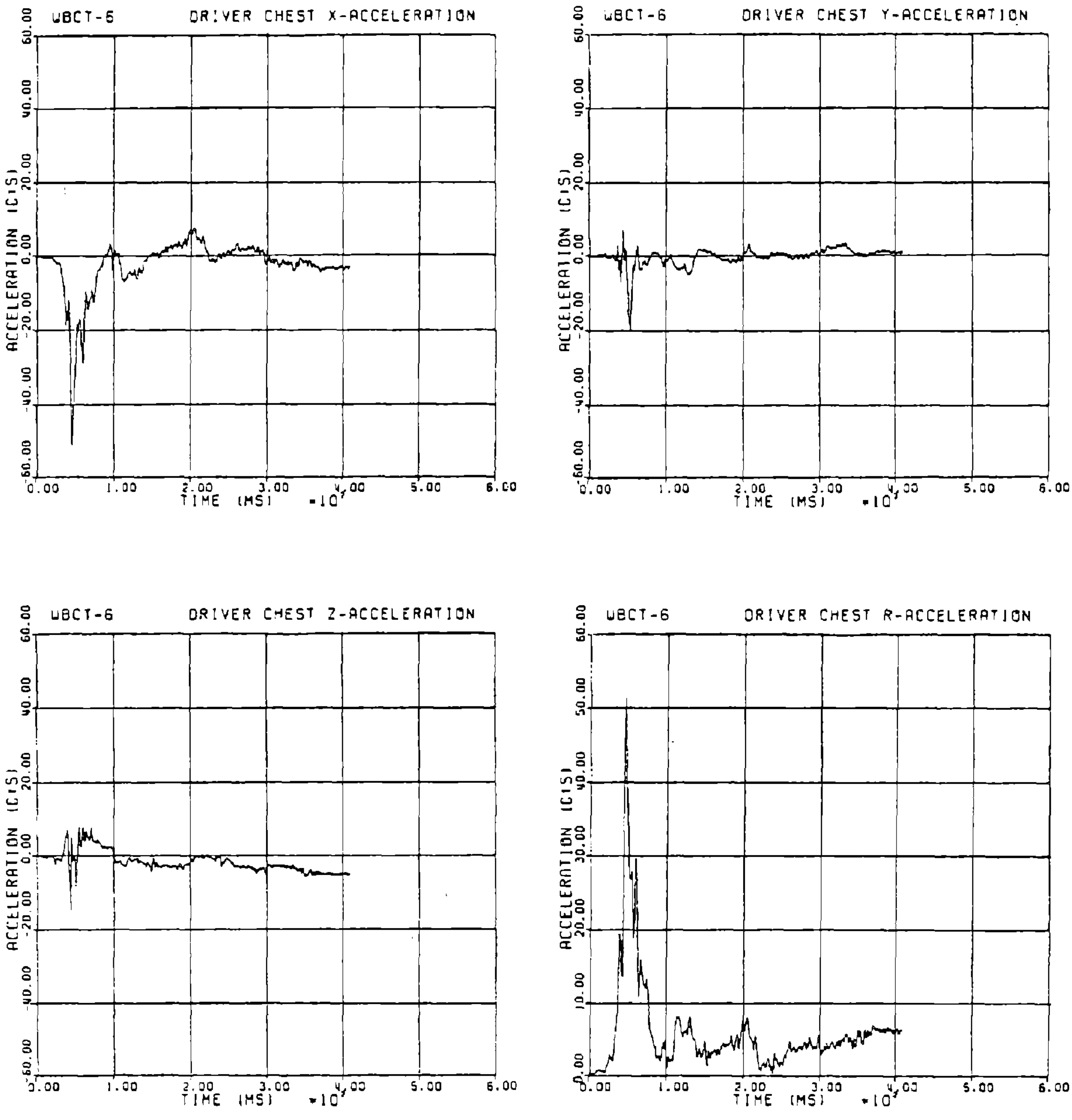
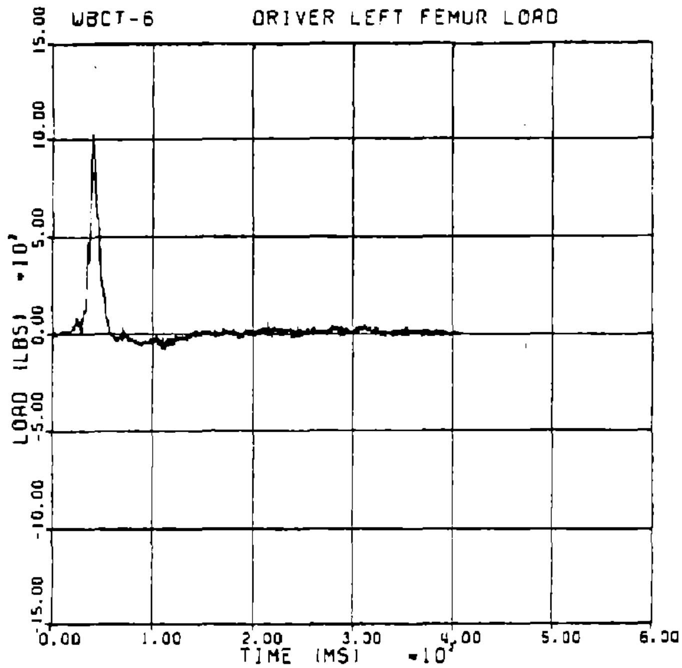


FIGURE A.57 DRIVER DUMMY CHEST ACCELERATION PLOTS, TEST WBCT-6



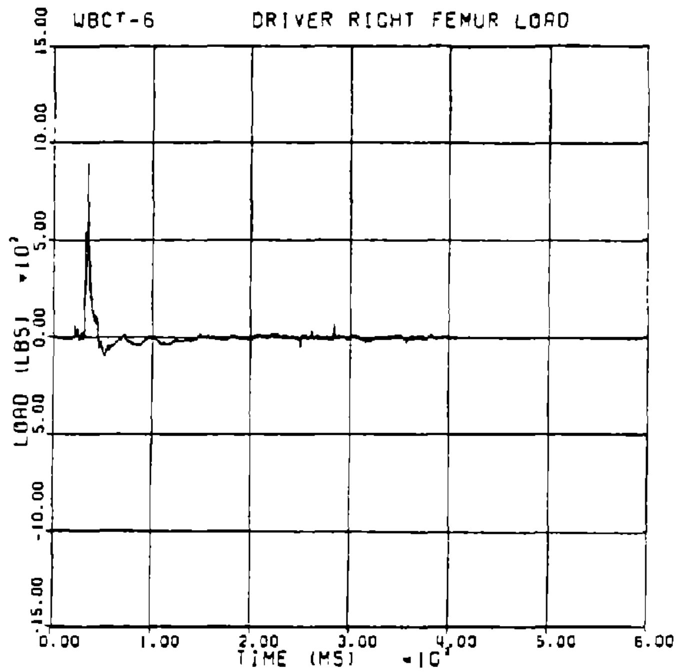


FIGURE A.58 DRIVER DUMMY FEMUR LOAD PLOTS, TEST WBCT-6

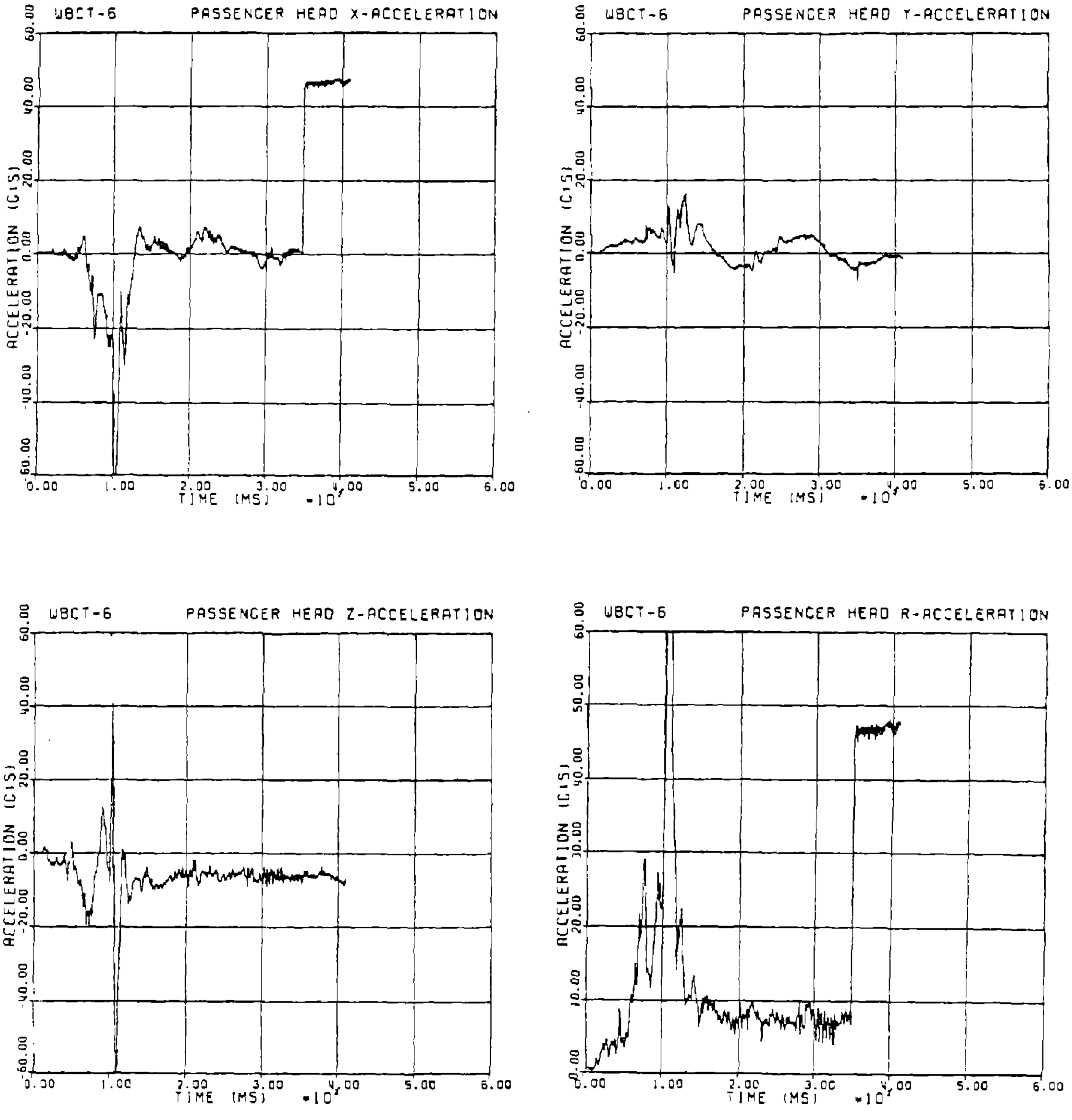


FIGURE A.59 PASSENGER DUMMY HEAD ACCELERATION PLOTS, TEST WBCT-6

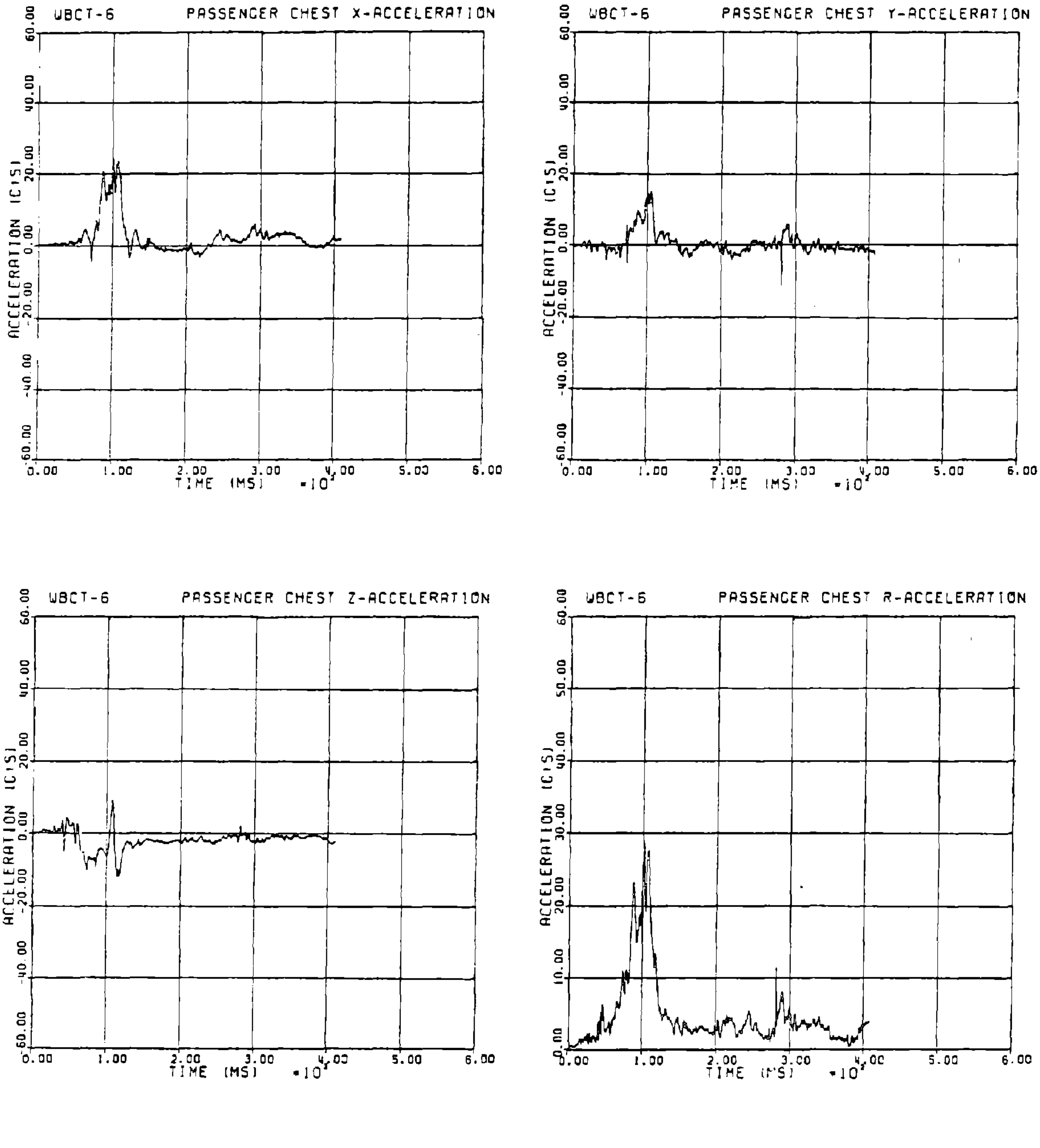
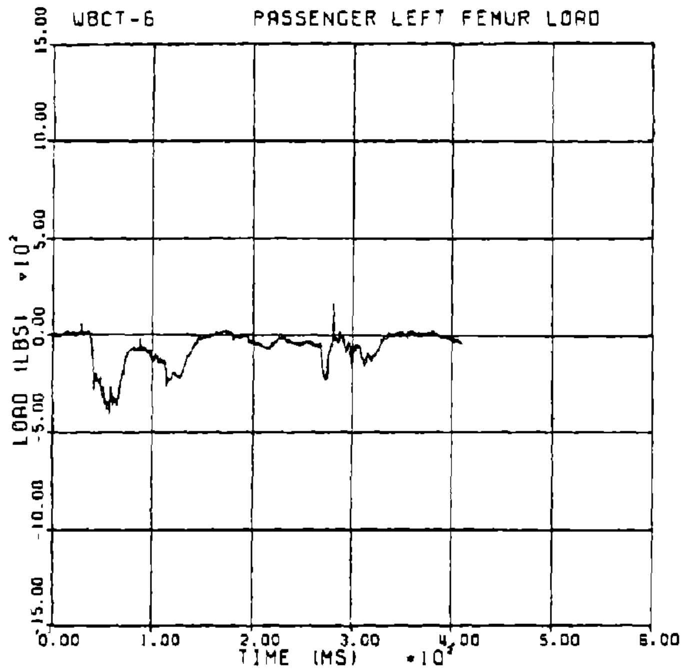


FIGURE A.60 PASSENGER DUMMY CHEST ACCELERATION PLOTS, TEST WBCT-6



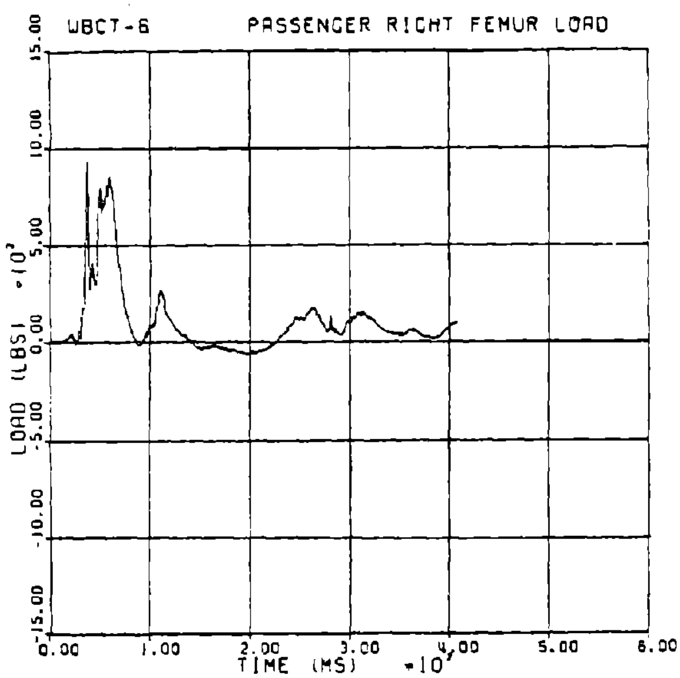


FIGURE A.61 PASSENGER DUMMY FEMUR LOAD PLOTS, TEST WBCT-6

FIGURE A.62 BARRIER AND VEHICLE DAMAGE, TEST WBCT-6

TABLE A.13

FILM ANALYSIS DATA, TEST WBCT-6

SUMMARY OF VEHICLE KINEMATIC AND DYNAMIC DATA   4000 PCST BCT TEST WBCT-6   5/22/81

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	-6.87	3.16	.01	89.59	-1.62	-4.45	.41	0.00	0.00	9449.	-874.
.010	-6.00	3.15	.07	86.87	-1.71	-6.24	.79	0.00	0.00	13246.	-1653.
.020	-5.15	3.13	.36	84.59	-1.83	-7.91	1.15	0.00	0.00	16816.	-2341.
.030	-4.31	3.12	.91	81.77	-2.20	-9.37	1.52	-8.41	1.32	19950.	-2911.
.040	-3.50	3.11	1.75	78.52	-2.83	-10.53	1.90	-9.65	1.71	22476.	-3343.
.050	-2.74	3.11	2.89	74.93	-3.68	-11.32	2.28	-10.57	2.11	24262.	-3624.
.060	-2.00	3.12	4.31	71.10	-4.69	-11.71	2.65	-11.13	2.52	25222.	-3753.
.070	-1.31	3.13	5.99	67.17	-5.80	-11.67	2.99	-11.29	2.89	25315.	-3732.
.080	-.66	3.14	7.89	63.27	-6.95	-11.22	3.25	-11.04	3.21	24548.	-3573.
.090	-.04	3.16	9.95	59.51	-8.09	-10.38	3.40	-10.42	3.42	22969.	-3292.
.100	.55	3.19	12.14	56.01	-9.20	-9.22	3.38	-9.47	3.49	20665.	-2900.
.110	1.10	3.22	14.39	52.38	-10.27	-7.81	3.19	-8.24	3.38	17760.	-2444.
.120	1.62	3.25	16.65	50.19	-11.33	-6.24	2.81	-6.81	3.09	14402.	-1924.
.130	2.13	3.29	18.88	47.99	-12.41	-4.59	2.25	-5.28	2.61	10761.	-1172.
.140	2.61	3.33	20.79	46.30	-13.55	-2.95	1.54	-3.72	1.98	7019.	-612.
.150	3.09	3.37	23.01	45.10	-14.78	-1.41	.73	-2.21	1.23	3361.	-203.
.160	3.56	3.41	24.87	44.37	-16.14	-.03	-.11	-.64	.42	-31.	290.
.170	4.03	3.45	26.59	44.05	-17.63	1.11	-.92	.35	-.39	-2989.	695.
.180	4.51	3.48	28.15	44.05	-19.24	1.95	-1.64	1.31	-1.14	-5369.	1031.
.190	4.99	3.52	29.56	44.30	-20.96	2.57	-2.21	2.00	-1.76	-7053.	1317.
.200	5.49	3.56	30.65	44.69	-22.73	2.83	-2.57	2.40	-2.21	-7961.	1604.
.210	5.99	3.59	32.03	45.11	-24.51	2.76	-2.70	2.51	-2.45	-8055.	1720.
.220	6.51	3.62	33.15	45.47	-26.25	2.44	-2.58	2.33	-2.45	-7341.	1750.
.230	7.04	3.65	34.21	45.66	-27.68	1.84	-2.21	1.89	-2.22	-5876.	1639.
.240	7.58	3.67	35.27	45.60	-29.34	1.03	-1.61	1.24	-1.76	-3765.	1531.
.250	8.12	3.69	36.34	45.22	-30.58	.06	-.81	.43	-1.09	-1159.	1236.
.260	8.67	3.72	37.44	44.49	-31.56	-.93	.14	-.47	-.26	1745.	750.
.270	9.21	3.73	38.58	43.39	-32.22	-1.90	1.18	-1.37	.67	4717.	561.
.280	9.75	3.75	39.76	41.97	-32.55	-2.74	2.22	-2.19	1.65	7501.	99.
.290	10.27	3.77	40.97	40.29	-32.55	-3.37	3.18	-2.83	2.58	9832.	-417.
.300	10.78	3.79	42.20	38.45	-32.24	-3.69	3.96	-3.22	3.35	11452.	-975.
.310	11.27	3.81	43.42	36.58	-31.67	-3.64	4.46	-3.30	3.96	12133.	-1551.
.320	11.75	3.83	44.61	34.82	-30.94	-3.21	4.59	-3.03	4.22	11706.	-2153.
.330	12.20	3.86	45.71	33.31	-30.16	-2.39	4.30	-2.42	4.12	10609.	-2740.
.340	12.65	3.89	46.77	32.13	-29.46	-1.24	3.58	-1.50	3.63	7332.	-3273.
.350	13.08	3.92	47.70	31.52	-29.01	.15	2.46	-.35	2.79	3654.	-3700.
.360	13.50	3.97	48.53	31.39	-28.85	1.66	1.10	.86	1.70	-505.	-4032.
.370	13.91	4.01	49.27	31.74	-29.17	2.66	-.28	1.92	.33	-4428.	-4217.
.380	14.16	4.07	49.74	32.45	-29.82	3.59	-1.32	2.52	-.23	-7655.	-4036.
.390	14.30	4.11	50.55	33.26	-30.57	[illegible]	-1.49	2.22	-.30	-6916.	-3416.

TABLE A.14

TEST ID ------ WBCT-6
TEST DATE ---- 05-22-81
VEHICLE TYPE - MINI-SIZE
IMPACT ANGLE - 0.00 DEGREES
IMPACT SPEED - 88.44 FPS

HIGHEST 50.0-MS AVG. ACCEL.

	G'S	TIME (SEC) START	TIME (SEC) END
LONG.	-18.74	.015	.065
LAT.	3.50	.034	.084

VEHICLE KINETICS SUMMARY
NOTE: VALUES ARE INSTANTANEOUS AT TIME

TIME (S)	VEH. ACCEL.(G'S) LONG.	VEH. ACCEL.(G'S) LAT.	VEH. VEL.(FPS) LONG.	VEH. VEL.(FPS) LAT.	VEH. DISP.(F) LONG.	VEH. DISP.(F) LAT.
0.000	.08	-.16	88.44	0.00	0.00	0.00
.010	-8.02	.75	88.02	.06	.87	.00
.020	-10.13	2.22	85.58	.61	1.72	.00
.030	-23.24	1.98	82.03	-.40	2.61	.01
.040	-4.11	-3.67	75.21	.09	3.38	.01
.050	-29.34	9.79	67.34	.68	4.09	.01
.060	-23.90	3.72	59.32	3.11	4.71	.03
.070	-8.81	3.88	55.62	4.09	5.27	.06
.080	-8.05	2.01	53.36	5.18	5.85	.11
.090	-5.96	-1.77	50.47	5.35	6.36	.16
.100	-2.00	-2.81	49.84	4.69	6.85	.21
.110	-.73	-.04	49.23	4.12	7.34	.26
.120	.62	-1.51	49.39	3.35	7.82	.29
.130	-8.44	-1.43	48.21	2.92	8.34	.33
.140	-9.02	6.93	45.31	3.35	8.80	.36
.150	-4.11	-9.72	43.46	2.33	9.24	.39
.160	-12.56	-7.21	41.07	.94	9.66	.40
.170	-3.95	-2.98	37.22	-.63	10.04	.41
.180	2.83	1.58	37.69	-.34	10.44	.40
.190	1.27	-3.42	38.61	-.86	10.82	.39
.200	1.44	-1.18	39.18	-1.33	11.20	.38
.210	-.89	.70	39.41	-1.31	11.59	.37
.220	1.37	-.49	39.85	-1.30	12.01	.36
.230	.56	.76	40.19	-1.25	12.40	.34
.240	2.56	.03	40.59	-1.10	12.80	.33
.250	-3.24	1.36	40.58	-.66	13.20	.32
.260	-.46	-.41	40.01	-.51	13.59	.32
.270	-4.06	.94	39.84	-.22	14.01	.31
.280	-5.64	3.29	38.18	.43	14.39	.32
.290	-1.52	-3.02	37.78	1.22	14.77	.32
.300	1.57	-.14	37.61	.90	15.13	.33
.310	-2.84	.59	37.05	.75	15.50	.34
.320	-4.32	.32	35.62	1.08	15.89	.35
.330	-5.17	2.22	34.16	1.82	16.23	.37
.340	-8.55	-1.67	32.98	1.25	16.56	.38
.350	2.66	3.85	31.63	.84	16.88	.39
.360	-.46	-.29	31.20	.36	17.19	.39
.370	-.57	.03	31.27	.03	17.52	.40
.380	-1.52	.94	31.34	-.06	17.83	.40
.390	.25	1.53	31.15	.19	18.13	.40
.400	-.52	.40	31.60	.93	18.44	.41

TEST ID ------ WBCT-6
TEST DATE ---- 05-22-81
VEHICLE TYPE - MINI-SIZE

VEHICLE MASS = 2124. LBS.
IMPACT SPEED = 60.3 MPH
IMPACT ANGLE = 0.0 DEG.

OCCUPANT - DRIVER
572-50% MALE DUMMY
RESTRAINTS - LAB + SHOULDER BELTS

TIME (SEC)	RESULTANT (G'S) HEAD	CHEST	-------SI------- HEAD	CHEST	FEMUR LOADS (LBS) LEFT	RIGHT
0.000	.6	.1	0.0	0.0	5.1	3.0
.010	.9	.6	.0	.0	12.8	-6.0
.020	3.3	.7	.0	.0	20.5	-3.0
.030	5.4	2.9	.2	.1	69.2	-15.0
.040	8.2	14.8	1.4	6.5	1007.8	108.2
.050	42.1	29.0	49.3	91.7	259.0	-87.0
.060	30.2	26.4	122.9	124.7	-12.7	-42.0
.070	40.4	12.4	218.5	133.5	30.8	6.1
.080	27.1	5.5	284.1	137.0	-35.7	-31.5
.090	15.5	2.1	308.0	137.2	-43.3	-27.0
.100	10.4	1.9	314.2	137.5	-17.8	6.1
.110	14.5	6.4	319.5	137.6	-75.2	-42.0
.120	11.5	5.7	325.6	139.1	-35.7	-30.0
.130	11.5	8.0	334.8	140.3	-28.0	-24.0
.140	12.6	3.3	338.8	140.9	10.3	-18.0
.150	8.1	3.9	342.6	141.1	12.8	1.5
.160	8.1	3.0	344.3	141.2	0.0	1.5
.170	6.2	3.2	345.5	141.4	32.1	-12.0
.180	2.3	4.2	346.2	141.8	-7.6	6.1
.190	3.6	5.2	346.9	142.2	11.5	-6.0
.200	5.1	6.9	347.4	143.0	12.8	-3.0
.210	9.0	5.1	349.5	144.1	-2.5	6.1
.220	11.8	1.0	353.7	144.5	38.5	18.3
.230	9.3	2.2	357.9	144.5	-2.5	0.0
.240	1.8	3.2	358.9	144.5	-19.1	3.0
.250	2.7	1.5	359.2	144.6	10.3	7.6
.260	3.4	4.6	359.5	144.8	35.9	12.2
.270	4.7	3.7	359.6	145.0	20.5	-9.0
.280	1.5	4.4	359.8	145.3	18.0	-6.0
.290	3.5	4.0	359.9	145.8	3.8	6.1
.300	2.7	3.8	360.1	146.2	2.6	6.1
.310	2.5	4.3	360.2	146.4	38.5	-3.0
.320	1.9	3.8	360.4	146.8	30.8	-24.0
.330	4.4	5.3	360.7	147.3	18.0	-6.0
.340	6.3	5.5	361.5	147.9	-10.2	-3.0
.350	6.4	6.4	362.5	148.4	18.0	0.0
.360	8.0	6.2	364.3	149.1	18.0	0.0
.370	9.0	6.7	366.3	150.1	-10.2	6.1
.380	8.8	6.1	368.5	151.1	-8.9	-3.0
.390	8.3	6.7	370.6	152.1	-7.6	6.1
.400	9.0	6.4	372.9	153.1	7.7	-6.0

MAXIMUM VALUES AND TIME OF OCCURANCE

	X/LT	SEC	Y/RT	SEC	Z	SEC	R	SEC
HEAD (G'S)	-38.6	.069	-17.0	.124	-37.1	.062	42.3	.062
CHEST (G'S)	-50.8	.045	-20.2	.053	-14.8	.043	51.1	.045
FEMUR LOAD (LBS)	0.	.409	893.	.034				

CUMULATIVE PERIOD FOR 60-G LEVEL = 0.000 SEC.

HIC = 282.8 DURING T = .044 TO .085 SEC.

TABLE A.14 (Cont'd)

TEST ID ------ WBCT-6
TEST DATE ---- 05-22-81
VEHICLE TYPE - MINI-SIZE

VEHICLE MASS = 2124. LBS.
IMPACT SPEED = 60.3 MPH
IMPACT ANGLE = 0.0 DEG.

OCCUPANT - PASSENGER
572-50% MALE DUMMY
RESTRAINTS - NONE

TIME (SEC)	RESULTANT (G'S) HEAD	CHEST	-------SI------- HEAD	CHEST	FEMUR LOADS (LBS) LEFT	RIGHT
0.000	.4	.3	0.0	0.0	-1.3	2.7
.010	.3	.6	.0	.0	1.3	4.1
.020	2.7	1.0	.0	.0	9.4	34.1
.030	2.3	.8	.3	.0	-4.0	20.5
.040	3.4	1.2	.5	.1	-175.8	271.4
.050	3.5	2.3	1.2	.4	-261.8	797.9
.060	10.0	4.4	2.6	.6	-363.8	852.5
.070	18.5	7.8	10.6	1.4	-208.1	375.1
.080	14.4	9.4	35.0	4.6	-57.7	72.3
.090	20.5	16.3	44.7	19.5	-63.1	-12.0
.100	26.3	29.0	73.3	36.8	-138.3	83.2
.110	44.3	18.3	555.2	65.2	-132.9	252.3
.120	20.0	8.6	609.2	71.5	-194.6	118.7
.130	9.1	5.6	622.6	72.2	-183.9	34.1
.140	13.4	3.3	626.2	72.6	-60.4	1.4
.150	7.9	3.1	629.6	72.8	-16.1	-36.1
.160	8.7	3.5	632.3	73.0	1.3	-20.1
.170	8.3	2.8	634.8	73.1	13.5	-28.1
.180	8.0	3.2	636.6	73.2	-30.9	-49.5
.190	5.9	2.2	638.3	73.4	4.0	-44.2
.200	6.2	2.8	639.5	73.5	-43.0	-54.9
.210	7.8	4.0	641.2	73.6	-59.1	-41.5
.220	9.1	4.0	643.7	74.0	-47.0	-14.7
.230	4.3	2.2	645.4	74.1	-20.1	34.1
.240	6.4	3.7	646.5	74.3	-44.3	85.9
.250	7.3	2.7	648.2	74.6	-44.3	118.7
.260	7.5	2.2	649.7	74.8	-52.4	156.9
.270	6.9	1.4	651.1	74.8	-192.0	118.7
.280	9.9	3.3	652.5	74.9	161.5	66.8
.290	8.8	7.4	654.1	75.9	-28.2	42.3
.300	8.9	5.3	656.4	76.5	-130.2	115.9
.310	8.4	2.8	657.7	76.9	-119.5	151.4
.320	4.8	4.0	658.9	77.1	-108.7	126.9
.330	7.3	3.4	660.1	77.3	-22.8	77.7
.340	8.0	4.5	661.5	77.6	-4.0	49.1
.350	45.8	3.0	677.5	77.8	10.8	46.4
.360	47.2	1.9	822.6	77.9	20.2	58.7
.370	46.5	1.2	980.9	77.9	6.7	34.1
.380	47.0	1.3	1127.3	77.9	25.6	23.2
.390	47.6	1.6	1275.4	77.9	-17.5	25.9
.400	46.1	3.4	1428.0	78.1	-20.1	77.7

MAXIMUM VALUES AND TIME OF OCCURANCE

	X/LT	---SEC	Y/RT	---SEC	Z	----SEC	R	----SEC
HEAD (G'S)	-93.5	.103	16.3	.124	-69.3	.108	102.5	.102
CHEST (G'S)	24.4	.100	15.0	.104	-11.8	.116	29.0	.100
FEMUR LOAD (LBS)	-404.	.056	0.	.409				

CUMULATIVE PERIOD FOR 60-G LEVEL = .008 SEC.

HIC = 912.5 DURING T = .349 TO .409 SEC.

Purpose: Purpose of this test was to evaluate the performance of the wood post BCT which had been modified to reduce its end-on impact resistance. This was accomplished by a 2120-lb (962-kg) mini-compact automobile impacting the buffer end at 60 mph (96.6 kmph) and a 0-deg angle. The vehicle was offset such that impact occurred 15 in. (381 mm) to the left of its centerline.

Test Installation: The test installation was similar to that of WBCT-6, the difference being that a V-notch was cut in the back of the W-beam rail (away from the traffic side) at each of the three locations where frontal sawcuts were made previously. An additional V-notch was cut 1 ft (0.3 m) upstream of Post 7. These cuts (shown in Figure A.63) were made to reduce impact loading caused by the W-beam rail.

Test Vehicle: A 1975 Honda Civic was the test vehicle, and it contained two 50th percentile anthropomorphic dummies in the drive and front passenger seating positions. The driver dummy was restrained by a lap and shoulder belt whereas the passenger dummy was unrestrained. Total weight of the vehicle, dummies and instrumentation was 2120 lb (962 kg).

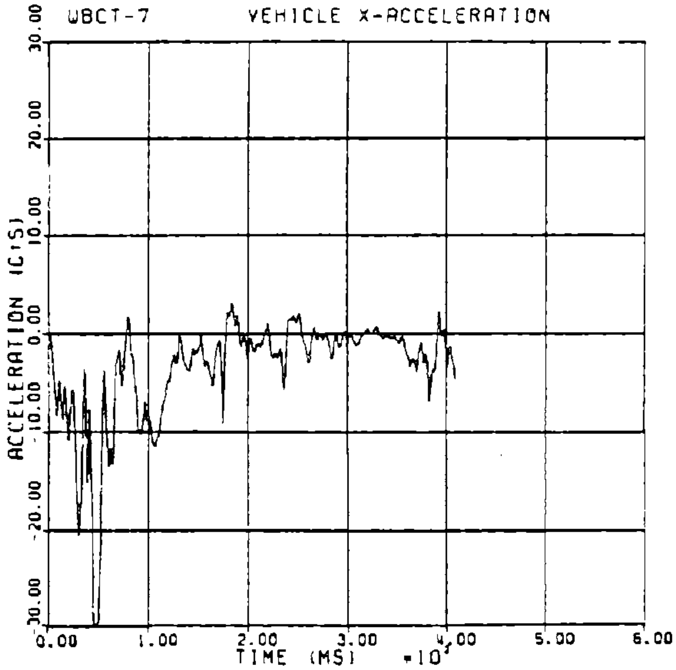
Performance: Impact conditions were 59.2 mph (95.3 kmph) and a 0.2-deg angle. As shown in the impact sequence of Figure 24 the vehicle impacted the buffer end (and wood spacer) fracturing the first post and causing the rail to translate away from the remaining posts. As the vehicle began to yaw it fractured the second post and overrode Posts 3, 4 and 5 causing the rear of the vehicle to pitch upward and the entire vehicle to roll toward the right side. The rear then came back down and the vehicle slid to a stop in an upright position approximately 27 ft (8.2 m) behind Post 14. Maximum 50 msec average accelerations measured during the impact sequence were 3.1 g (cine) and 4.5 g (accelerometer) in the lateral direction, and -8.8 g (cine and -14.1 g (accelerometer) in the longitudinal direction. A summary of test results is shown in Figure 25, and data from high-speed film analysis are contained in Table A.15. Results of analog to digital conversion of vehicle and dummy transducers are tabulated in Table A.16 and plotted in Figures A.64 thru A.70.

Barrier Damage: As shown in Figure A.71 barrier damage consisted of two fractured wood posts, three bent rail sections, three bent steel posts, and a damaged buffer end/wood spacer assembly.

Vehicle Damage: The front section of the vehicle, as shown in Figure A.71, was heavily damaged from impact with the end of the barrier. Additional damage was sustained by the right door and area just aft of it due to contact with the steel posts. Although the head of the unrestrained passenger dummy impacted the right side of the windshield causing it to shatter, the windshield did remain with the vehicle.

Comment: Although the V-notches in the W-beam rail did reduce its impact resistance by causing hinges to form, it appears further weakening of the BCT installation is required to reduce the yawing of the vehicle. This will be accomplished by modification to the first post.

FIGURE A.63 PRETEST PHOTOGRAPHS, TEST WBCT-7



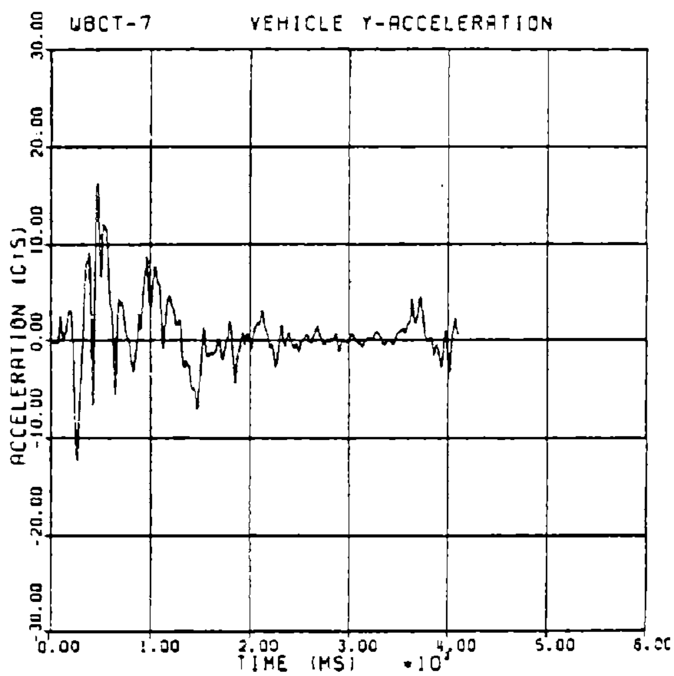


FIGURE A.64 VEHICLE ACCELERATION PLOTS, TEST WBCT-7

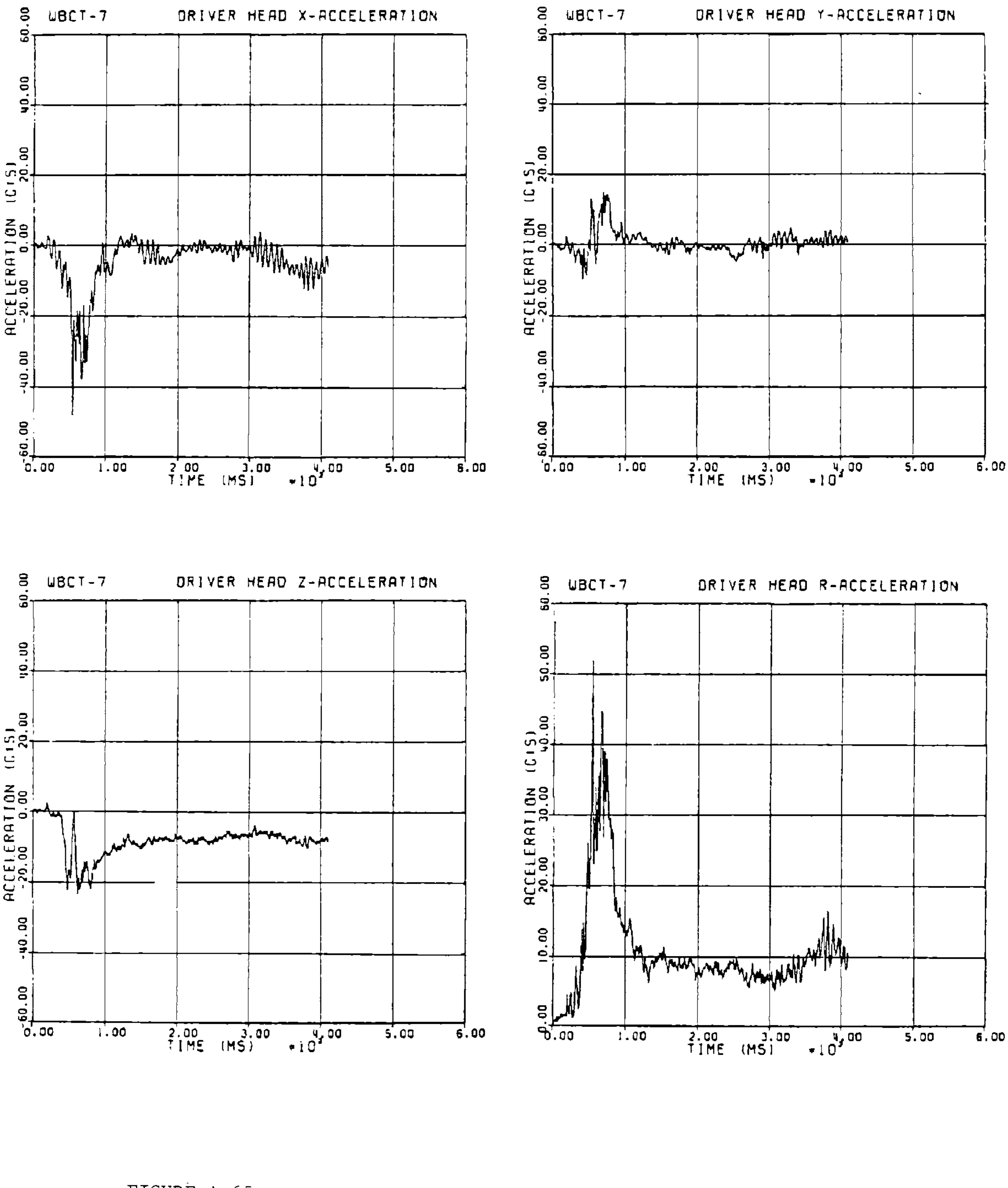


FIGURE A.65 DRIVER DUMMY HEAD ACCELERATION PLOTS, TEST WBCT-7

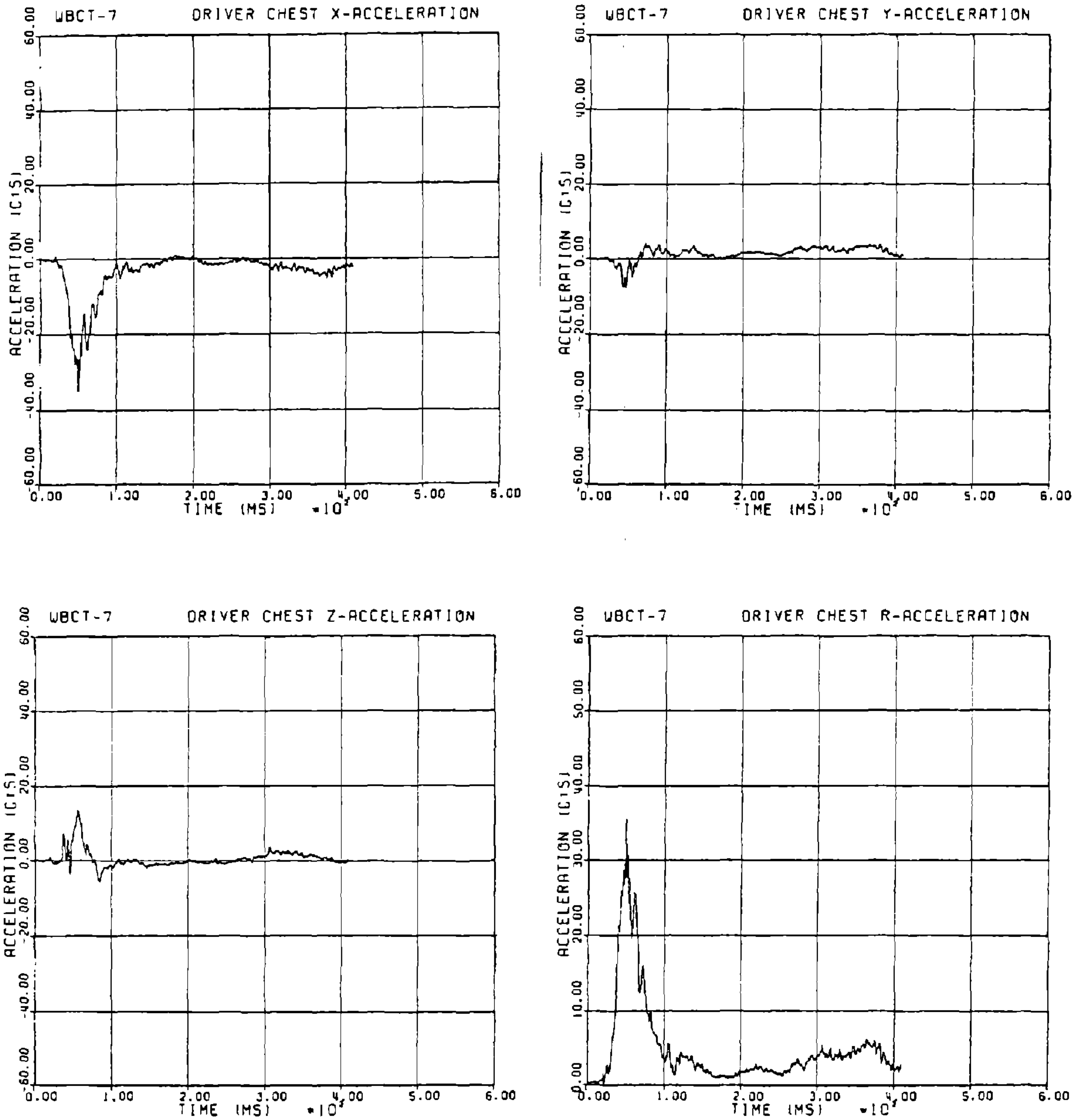
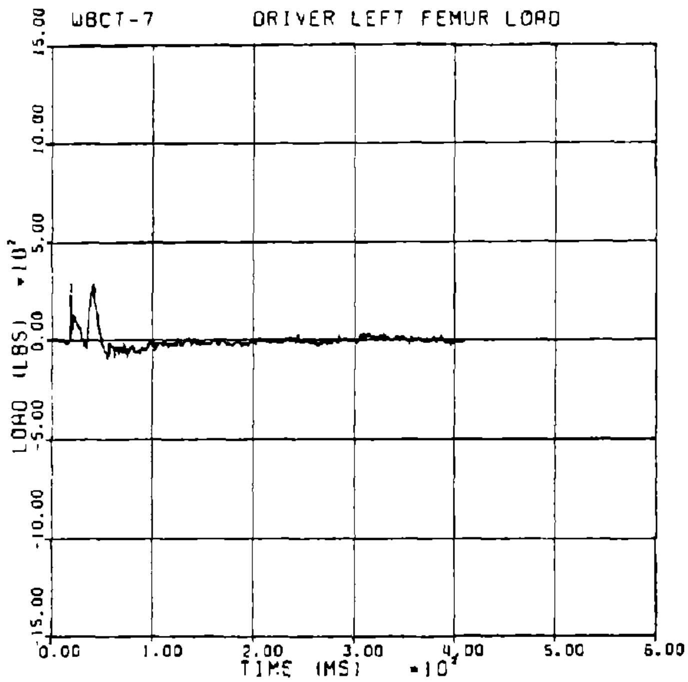


FIGURE A.66 DRIVER DUMMY CHEST ACCELERATION PLOTS, TEST WBCT-7



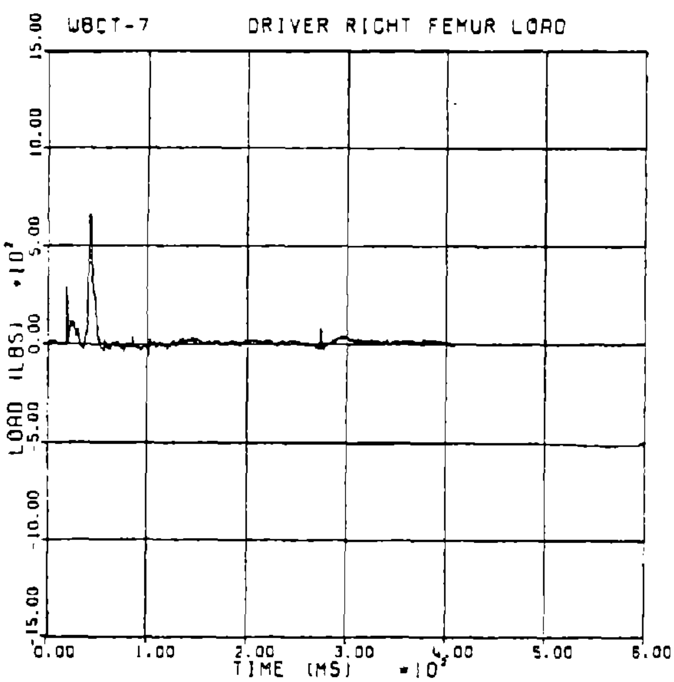


FIGURE A.67 DRIVER DUMMY FEMUR LOAD PLOTS, TEST WBCT-7

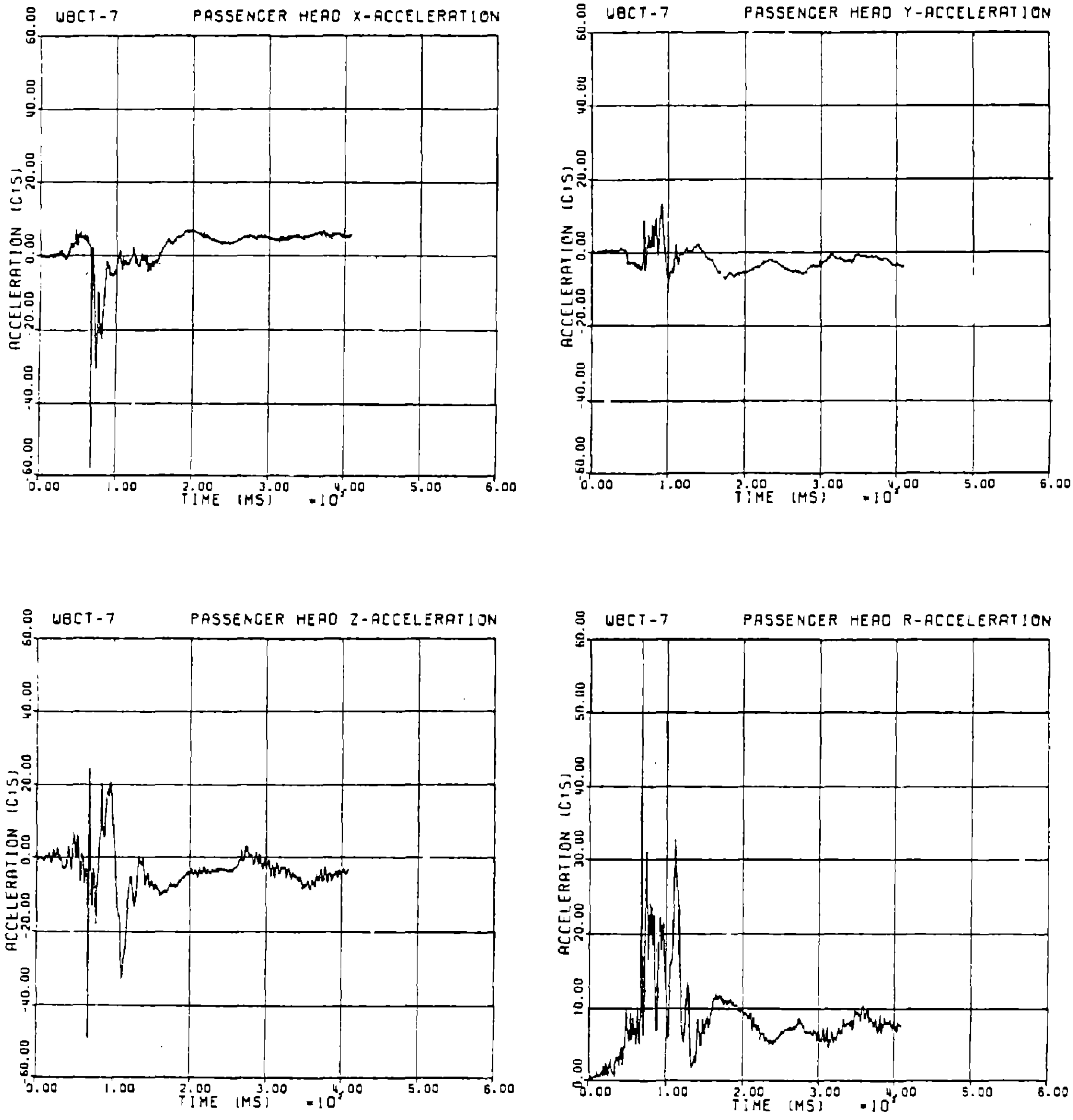


FIGURE A.68 PASSENGER DUMMY HEAD ACCELERATION PLOTS, TEST WBCT-7

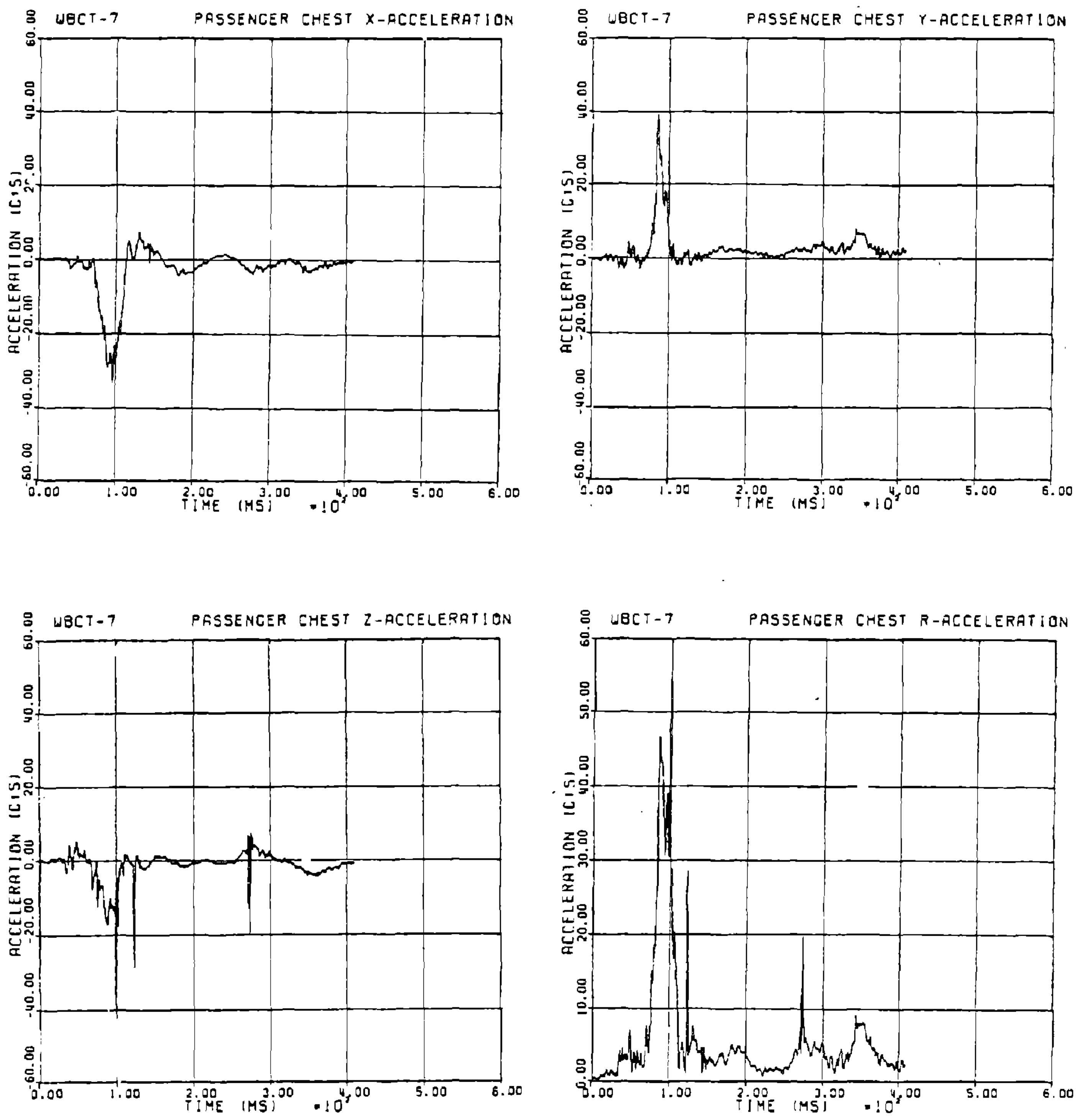


FIGURE A.69 PASSENGER DUMMY CHEST ACCELERATION PLOTS, TEST WBCT-7

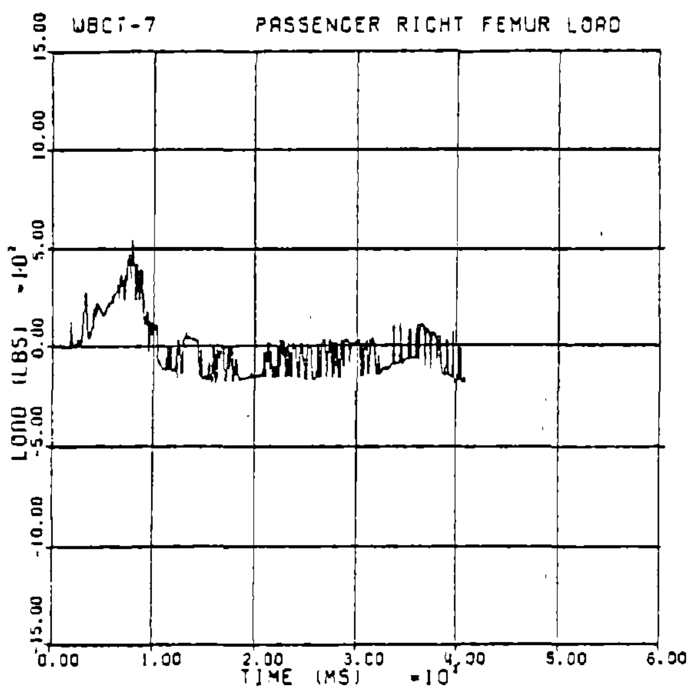


FIGURE A.70 PASSENGER DUMMY FEMUR LOAD PLOTS, TEST WBCT-7

FIGURE A.71   BARRIER AND VEHICLE DAMAGE, TEST WBCT-7

TABLE A.15

FILM ANALYSIS DATA, TEST WBCT-7

SUMMARY OF VEHICLE KINEMATIC AND DYNAMIC DATA   ACCO POST ACT TEST WBCT-7   6/25/81

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 OVER .05 SEC. LONG	VEHICLE ACCELERATION (G'S) AVERAGE OVER .05 SEC. LAT	APPROX. BARRIER FORCES (LB) X	APPROX. BARRIER FORCES (LB) Y
0.000	-7.06	2.94	.21	86.84	-.55	-5.25	-.91	0.00	0.00	11131.	1972.
.010	-6.20	2.93	.19	84.96	-1.46	-6.38	-.59	0.00	0.00	13520.	1353.
.020	-5.37	2.92	.20	82.73	-2.05	-7.36	-.22	0.00	0.00	15589.	661.
.030	-4.55	2.91	1.16	80.22	-2.70	-8.14	.20	-7.56	.62	17256.	-71.
.040	-3.76	2.90	1.77	77.47	-3.41	-8.70	.65	-8.22	.46	18473.	-809.
.050	-3.00	2.89	2.54	74.56	-4.15	-9.07	1.12	-8.64	.92	19203.	-1522.
.060	-2.27	2.88	3.48	71.56	-4.90	-9.05	1.58	-8.84	1.39	19442.	-2184.
.070	-1.57	2.88	4.56	68.55	-5.65	-8.53	2.02	-8.80	1.84	19203.	-2773.
.080	-.85	2.88	5.79	65.61	-6.37	-8.54	2.42	-8.53	2.26	18519.	-3271.
.090	-.25	2.88	7.14	62.79	-7.05	-7.55	2.74	-8.06	2.61	17439.	-3665.
.100	.37	2.89	8.60	60.16	-7.69	-7.20	2.97	-7.42	2.89	16025.	-3947.
.110	.97	2.91	10.14	57.77	-8.29	-6.32	3.10	-6.63	3.07	14347.	-4115.
.120	1.54	2.93	11.74	55.64	-8.87	-5.38	3.12	-5.74	3.14	12461.	-4170.
.130	2.09	2.96	13.38	53.81	-9.44	-4.37	3.04	-4.80	3.11	10509.	-4118.
.140	2.63	3.00	15.03	52.28	-10.02	-3.39	2.85	-3.85	2.97	8509.	-3968.
.150	3.16	3.04	16.68	51.05	-10.63	-2.46	2.57	-2.93	2.74	6557.	-3733.
.160	3.67	3.09	18.30	50.09	-11.26	-1.61	2.23	-2.06	2.43	4723.	-3429.
.170	4.18	3.14	19.87	49.37	-11.59	-.87	1.85	-1.30	2.08	3067.	-3072.
.180	4.68	3.20	21.39	48.87	-12.76	-.26	1.46	-.64	1.70	1643.	-2661.
.190	5.18	3.26	22.85	48.53	-13.59	.21	1.08	-.12	1.32	488.	-2279.
.200	5.68	3.32	24.23	48.31	-14.47	.52	.74	.26	.96	-371.	-1880.
.210	6.18	3.39	25.54	48.17	-15.38	.70	.45	.51	.66	-922.	-1505.
.220	6.68	3.46	26.78	48.06	-16.31	.74	.25	.62	.42	-1163.	-1169.
.230	7.19	3.53	27.96	47.94	-17.24	.66	.12	.61	.26	-1110.	-838.
.240	7.69	3.61	29.08	47.78	-18.14	.48	.10	.49	.18	-787.	-673.
.250	8.20	3.68	30.15	47.55	-19.00	.22	.16	.29	.20	-232.	-532.
.260	8.71	3.76	31.18	47.22	-19.78	-.09	.31	.03	.30	509.	-472.
.270	9.21	3.83	32.20	46.78	-20.47	-.43	.54	-.28	.48	1385.	-491.
.280	9.72	3.91	33.19	46.23	-21.06	-.77	.84	-.60	.73	2138.	-588.
.290	10.22	3.99	34.19	45.56	-21.54	-1.09	1.17	-.90	1.03	3307.	-753.
.300	10.71	4.06	35.19	44.78	-21.89	-1.37	1.53	-1.18	1.36	4234.	-976.
.310	11.20	4.14	36.20	43.91	-22.13	-1.58	1.88	-1.41	1.70	5064.	-1240.
.320	11.68	4.23	37.23	42.98	-22.25	-1.72	2.21	-1.58	2.02	5747.	-1524.
.330	12.15	4.31	38.28	42.01	-22.26	-1.78	2.49	-1.67	2.31	6244.	-1805.
.340	12.62	4.40	39.33	41.03	-22.16	-1.77	2.70	-1.69	2.54	6525.	-2058.
.350	13.07	4.49	40.38	40.06	-22.04	-1.67	2.82	-1.64	2.69	6575.	-2254.
.360	13.51	4.58	41.43	39.15	-21.85	-1.52	2.83	-1.53	2.74	6393.	-2364.
.370	13.94	4.68	42.46	38.30	-21.65	-1.33	2.73	-1.38	2.70	5994.	-2362.
.380	14.37	4.78	43.46	37.52	-21.46	-1.13	2.51	-1.20	2.54	5409.	-2220.
.390	14.78	4.88	44.40	36.84	-21.31	-.94	2.19	-1.03	2.28	4680.	-1918.
.400	15.19	4.99	45.29	36.23	-21.24	-.80	1.77	-.89	1.92	3864.	-1438.
.410	15.60	5.10	46.10	35.69	-21.25	-.73	1.28	-.81	1.48	3026.	-773.
.420	16.00	5.21	46.83	35.18	-21.37	-.75	.74	-.80	.99	2231.	75.
.430	16.39	5.32	47.47	34.68	-21.62	-.87	.19	-.89	.47	1542.	1040.
.440	16.78	5.43	48.02	34.18	-21.98	-1.10	-.35	-1.07	-.06	1007.	2240.
.450	17.17	5.53	48.50	33.57	-22.45	-1.43	-.86	-1.33	-.56	648.	3472.
.460	17.56	5.63	48.91	32.88	-23.04	-1.81	-1.30	-1.64	-1.02	448.	4711.
.470	17.95	5.72	45.27	32.09	-23.73	-2.15	-1.68	-1.95	-1.44	332.	5854.
.480	18.34	5.81	45.59	31.20	-24.50	-2.48	-2.02	-2.18	-1.82	151.	6767.
.490	18.73	5.88	45.90	30.25	-25.37	-2.52	-2.34	-2.19	-2.20	-348.	7279.

TABLE A.16

TEST WBCT-7 TRANSDUCER DATA

TEST ID ------ WBCT-7
TEST DATE ---- 06-29-81
VEHICLE TYPE - MINI-SIZE
IMPACT ANGLE - 0.00 DEGREES
IMPACT SPEED - 86.97 FPS

HIGHEST 50.0-MS AVG. ACCEL.

	G'S	TIME (SEC) START	TIME (SEC) END
LONG.	-14.06	.016	.066
LAT.	4.47	.031	.081

VEHICLE KINETICS SUMMARY
NOTE: VALUES ARE INSTANTANEOUS AT TIME

TIME (S)	VEH. ACCEL.(G'S) LONG.	VEH. ACCEL.(G'S) LAT.	VEH. VEL.(FPS) LONG.	VEH. VEL.(FPS) LAT.	VEH. DISP.(F) LONG.	VEH. DISP.(F) LAT.
0.000	.05	-.08	86.97	0.00	0.00	0.00
.010	-6.10	2.55	85.77	.08	.85	-.00
.020	-10.86	3.12	83.55	.59	1.68	.00
.030	-20.12	-3.15	79.82	-1.32	2.56	.00
.040	-7.65	-.70	76.06	.29	3.32	-.01
.050	-27.22	6.62	68.18	2.14	4.04	.00
.060	-13.43	3.36	64.29	5.07	4.69	.04
.070	-2.06	3.77	61.42	5.31	5.30	.09
.080	1.56	-1.91	60.74	5.85	5.95	.15
.090	-9.99	1.16	59.55	5.61	6.54	.20
.100	-8.27	3.52	56.76	7.34	7.11	.27
.110	-10.43	4.32	53.50	9.24	7.66	.35
.120	-4.72	4.62	51.12	9.94	8.17	.44
.130	-.76	1.08	50.00	10.88	8.71	.55
.140	-3.71	-4.12	49.37	10.24	9.20	.66
.150	-1.65	-3.33	48.61	8.53	9.68	.75
.160	-3.07	-1.39	48.02	8.27	10.15	.83
.170	-.07	-.38	46.86	7.99	10.62	.91
.180	1.88	1.89	45.92	7.84	11.11	1.00
.190	1.74	-.58	46.53	7.32	11.57	1.07
.200	-2.75	-.48	46.34	7.40	12.02	1.14
.210	-.96	1.92	45.90	7.63	12.48	1.22
.220	.85	-.82	45.75	8.13	12.96	1.30
.230	-2.25	.92	45.23	7.70	13.41	1.38
.240	1.28	.41	44.29	7.86	13.85	1.46
.250	1.79	-.94	44.76	7.70	14.29	1.53
.260	-2.48	-.04	44.80	7.73	14.73	1.61
.270	-.41	.47	44.50	7.94	15.20	1.69
.280	-.57	-.18	44.42	7.92	15.64	1.77
.290	-.64	-1.06	44.03	7.93	16.08	1.85
.300	-.53	.18	43.86	7.87	16.51	1.92
.310	-1.15	-.26	43.69	7.94	16.94	2.00
.320	.50	.26	43.58	7.87	17.40	2.09
.330	.50	.61	43.67	8.02	17.83	2.16
.340	-.18	.06	43.62	8.00	18.26	2.24
.350	-.69	.90	43.51	8.01	18.69	2.32
.360	-2.11	1.81	43.24	8.37	19.11	2.40
.370	-3.53	4.05	42.26	9.27	19.57	2.50
.380	-2.52	-.10	41.58	9.94	19.98	2.59
.390	-.87	-1.18	40.21	9.78	20.38	2.69
.400	-3.16	-2.71	40.30	9.43	20.78	2.78

TEST ID ------ WBCT-7
TEST DATE ---- 06-29-81
VEHICLE TYPE - MINI-SIZE

VEHICLE MASS = 2120. LBS.
IMPACT SPEED = 59.3 MPH
IMPACT ANGLE = 0.0 DEG.

OCCUPANT - DRIVER
572-50% MALE DUMMY
RESTRAINTS - LAB + SHOULDER BELTS

TIME (SEC)	RESULTANT (G'S) HEAD	CHEST	-------SI------- HEAD	CHEST	FEMUR LOADS (LBS) LEFT	RIGHT
0.000	.4	.4	0.0	0.0	-6.9	5.5
.010	1.3	.4	.0	.0	-6.9	-5.5
.020	2.1	1.5	.1	.0	45.5	1.8
.030	6.5	4.6	.2	.1	-3.5	42.4
.040	8.0	20.4	2.0	7.3	269.4	418.1
.050	19.6	29.0	15.7	45.1	-24.2	12.9
.060	24.9	24.8	71.4	74.6	-29.4	-16.4
.070	37.2	13.6	145.6	91.4	-69.3	-5.5
.080	26.9	10.0	211.4	97.2	-31.2	-16.4
.090	15.6	5.9	230.3	98.8	-45.0	-12.7
.100	13.7	3.0	238.4	99.2	-3.5	-67.4
.110	11.6	2.6	245.4	99.5	-38.1	-9.1
.120	11.6	2.7	249.1	99.6	-24.2	-16.4
.130	7.4	3.6	252.0	100.0	-13.9	5.5
.140	8.8	1.9	254.0	100.1	7.0	23.9
.150	9.5	2.1	257.0	100.3	-6.9	23.9
.160	8.3	1.8	259.9	100.3	3.5	1.8
.170	9.1	1.0	262.3	100.3	-3.5	1.8
.180	8.4	1.1	264.8	100.3	-12.1	1.8
.190	9.7	1.0	267.2	100.3	-17.3	5.5
.200	7.9	1.5	269.3	100.4	-10.4	9.2
.210	8.6	1.7	271.0	100.4	-3.5	1.8
.220	7.9	2.4	273.3	100.5	3.5	5.5
.230	7.7	1.7	275.3	100.6	-1.7	-9.1
.240	8.4	1.8	276.9	100.6	7.0	5.5
.250	9.8	1.4	279.3	100.6	-19.1	5.5
.260	8.1	1.8	281.5	100.7	-24.2	-7.3
.270	6.4	3.0	283.1	100.8	-13.9	-31.0
.280	7.5	2.5	284.5	100.9	-3.5	-1.8
.290	6.8	3.4	285.9	101.1	8.7	23.9
.300	6.0	4.0	287.1	101.3	-10.4	23.9
.310	7.9	3.7	288.2	101.7	17.5	16.6
.320	6.9	3.3	289.7	102.1	-10.4	12.9
.330	8.1	4.5	291.4	102.4	-3.5	-1.8
.340	10.3	4.4	293.3	102.7	10.5	9.2
.350	9.3	4.1	295.5	103.2	3.5	16.6
.360	9.6	5.5	298.8	103.7	7.0	12.9
.370	10.4	5.1	303.0	104.5	10.5	-1.8
.380	13.4	5.2	307.7	105.1	7.0	12.9
.390	12.0	2.6	313.1	105.4	-13.9	1.8
.400	8.7	2.2	317.3	105.5	5.2	-1.8

MAXIMUM VALUES AND TIME OF OCCURANCE

	X/LT	---SEC	Y/RT	---SEC	Z	----SEC	R	----SEC
HEAD (G'S)	-48.1	.053	14.8	.070	-23.4	.061	51.8	.053
CHEST (G'S)	-35.0	.049	-7.8	.047	13.4	.056	35.5	.049
FEMUR LOAD (LBS)	290.	.019	0.	.409				

CUMULATIVE PERIOD FOR 60-G LEVEL = 0.000 SEC.

HIC = 201.5 DURING T = .046 TO .084 SEC.

TABLE A.16 (Cont'd)

TEST ID ------ WBCT-7
TEST DATE ---- 06-29-81
VEHICLE TYPE - MINI-SIZE

VEHICLE MASS = 2120. LBS.
IMPACT SPEED = 59.3 MPH
IMPACT ANGLE = 0.0 DEG.

OCCUPANT - PASSENGER
572-50% MALE DUMMY
RESTRAINTS - NONE

TIME	RESULTANT (G'S)		-------SI-------		FEMUR LOADS (LBS)	
(SEC)	HEAD	CHEST	HEAD	CHEST	LEFT	RIGHT
0.000	.4	.4	0.0	0.0	0.0	1.0
.010	.9	.4	.0	.0	0.0	-6.1
.020	.7	.4	.0	.0	0.0	21.9
.030	1.0	1.0	.1	.0	0.0	168.1
.040	4.5	2.9	.2	.2	0.0	95.0
.050	6.9	1.9	1.1	.5	0.0	155.6
.060	5.9	2.5	2.4	.7	0.0	232.9
.070	5.6	5.9	33.1	1.0	0.0	337.3
.080	20.3	18.5	55.6	7.1	0.0	429.2
.090	19.5	38.3	67.5	97.6	0.0	122.2
.100	10.7	25.2	82.9	173.1	0.0	95.0
.110	28.5	8.9	92.8	189.5	0.0	-115.0
.120	9.1	2.6	123.6	189.9	0.0	-116.7
.130	8.0	6.6	126.7	192.7	0.0	42.8
.140	6.7	4.0	127.0	193.3	0.0	36.6
.150	6.5	2.4	128.3	193.4	0.0	-165.9
.160	10.2	2.2	130.4	193.6	0.0	-51.8
.170	11.7	3.8	134.8	193.8	0.0	-155.4
.180	11.0	5.1	139.3	194.0	0.0	-132.6
.190	10.3	4.6	143.1	194.4	0.0	-158.9
.200	9.8	3.5	146.1	194.7	0.0	-153.6
.210	9.4	2.1	148.7	194.8	0.0	-77.2
.220	8.0	1.4	150.5	194.9	0.0	-141.3
.230	5.9	1.6	151.6	194.9	0.0	-146.6
.240	5.3	2.0	152.4	194.9	0.0	-6.1
.250	6.6	1.5	153.2	195.0	0.0	-165.9
.260	7.4	2.7	154.5	195.0	0.0	-161.5
.270	7.7	17.6	156.1	195.8	0.0	-144.8
.280	7.8	5.2	157.9	197.3	0.0	-34.2
.290	6.8	5.2	159.1	197.7	0.0	40.7
.300	7.5	5.3	160.3	198.2	0.0	26.1
.310	6.1	2.0	161.3	198.4	0.0	8.4
.320	5.9	3.3	162.2	198.5	0.0	-137.8
.330	6.7	2.9	163.3	198.7	0.0	-102.7
.340	8.1	5.6	165.0	199.0	0.0	-85.1
.350	9.4	8.0	167.2	200.6	0.0	-60.6
.360	9.4	5.1	169.9	201.9	0.0	109.7
.370	8.6	3.6	172.6	202.4	0.0	86.7
.380	8.6	3.0	174.2	202.6	0.0	-39.5
.390	8.3	2.1	176.0	202.7	0.0	-7.9
.400	7.1	1.5	177.7	202.8	0.0	-171.2

MAXIMUM VALUES AND TIME OF OCCURANCE

	X/LT	---SEC	Y/RT	---SEC	Z	----SEC	R	----SEC
HEAD (G'S)	-56.1	.067	15.5	.067	-57.6	.067	81.9	.067
CHEST (G'S)	-33.1	.095	38.8	.084	-45.6	.098	54.7	.098
FEMUR LOAD (LBS)	0.	.409	540.	.079				

CUMULATIVE PERIOD FOR 60-G LEVEL = 0.000 SEC.

HIC = 100.7 DURING T = .047 TO .409 SEC.

PENDULUM TESTS OF MODIFIED WOOD POSTS FOR BREAKAWAY CABLE TERMINAL

Background

During the performance of full-scale tests of the BCT Guardrail System with minicompact automobiles, it became apparent that too high a force level was required to fracture the first post of the system. This resulted in excessive vehicle damage and induced greater vehicle yawing which, in turn, prevented it from "gating" behind the terminal. Therefore, it became necessary to undertake a subtask to modify the post to enhance its breakaway characteristics for end-on impacts without comprising its capability as a cable anchorage for mid-span impacts. This was accomplished by pendulum testing.

Test Procedures

The test was setup, as shown in Figure A.72 using the wood post as an anchorage. It was installed against a concrete wall of the pendulum facility with the anchor cable, bearing plate, and nut assembled in the normal position. A brace against the bottom portion of the post provided lower moment reaction. A hook was installed on the other end of the cable (away from the post) to engage a loop on the back of the 4000-lb. (1814-kg) pendulum mass when it was dropped from a 10-ft. (3-m) height. This provided dynamic loading of the cable and post.

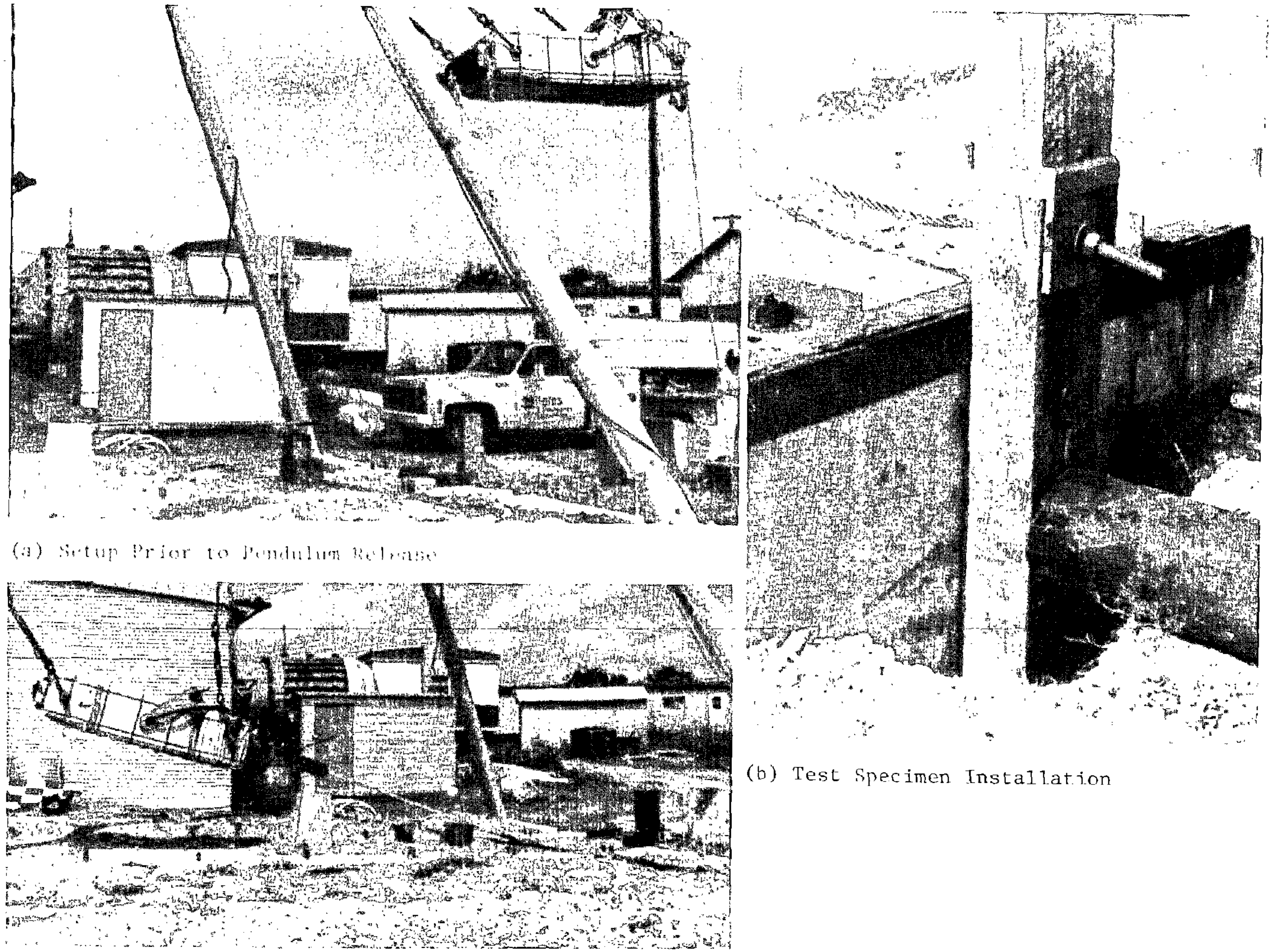
Test Specimen

Four tests with two wood post configurations were performed. The first test was with an unmodified post to provide a baseline for evaluation. The remaining tests utilized a post which was sawcut across the anchor cable hole to a depth equal to half the post width (the steel pipe section through the anchor cable hole was unmodified). Photographs of each of the test specimens are shown in Figure A.73.

Results

Force-time curves from the tests are shown in Figure A.74. Test EX-1 was with the unmodified post in which a 43-kip (181-kN) maximum load was measured with no post fracture. The modified configuration post was then tested, but in the initial test the lower post brace released and the post rotated about the concrete after only a low load level was reached.

Therefore, that test was undesignated and the post reused for the succeeding test (EX-2). The specimen apparently did receive some damage in the unreported test because it fractured during EX-2 not only at a slightly lower level (and much sooner) than EX-1, but also failed at grade instead of through the sawcut. For that reason an additional modified post test (EX-3) was performed, and as seen in Figure A.74 developed a 47-kip (209-kN) maximum load without fracturing. This was slightly higher than the 43-kip (191-kN) of EX-1. Thus the sawcut modification to enhance post breakaway does not adversely affect its anchorage capacity.

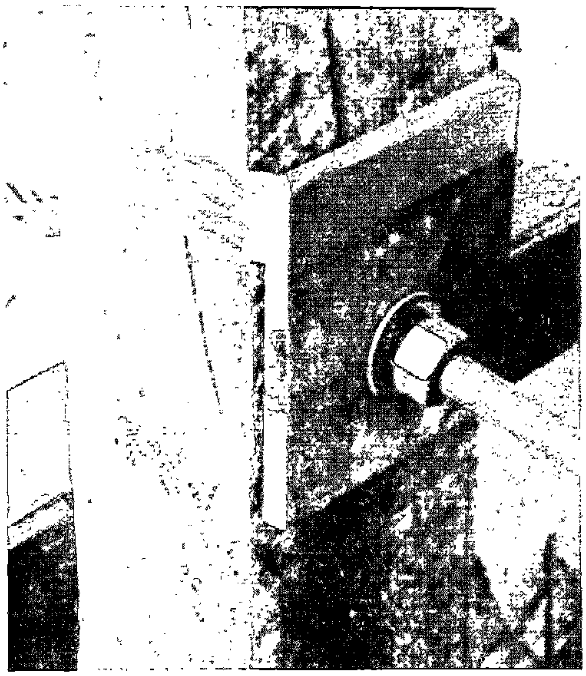


(a) Setup Prior to Pendulum Release

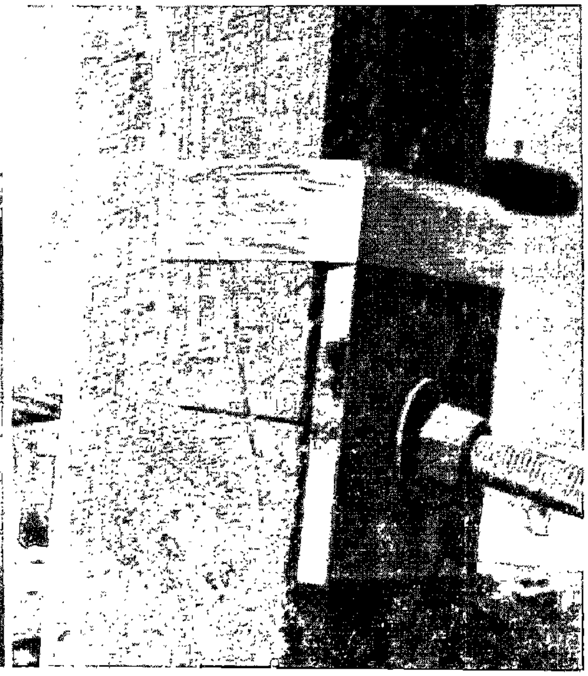
(b) Test Specimen Installation

(c) View Immediately After Maximum Load Obtained - Pendulum Mass Rebounding

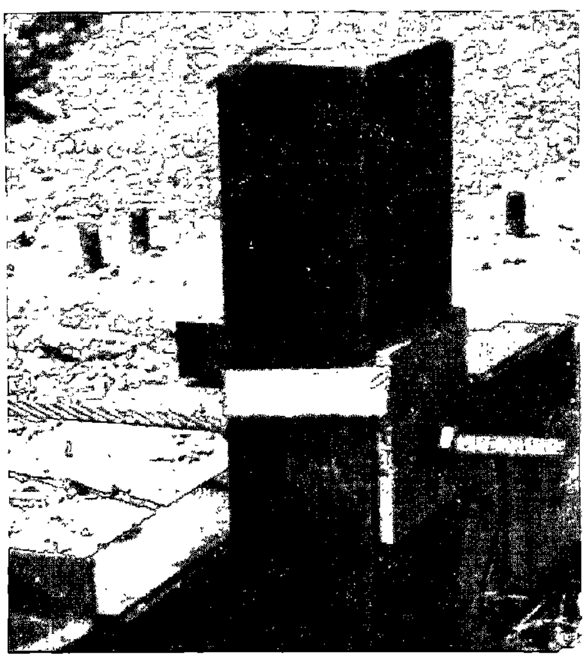
FIGURE A.80 PENDULUM TEST SETUP



(a) Test EX-1 Unmodified Post



(b) Test EX-2 Modified Post



(c) Test EX-3 Modified Post

(d) EX-3 Post After Test

FIGURE A.81 ANCHORAGE TEST SPECIMENS

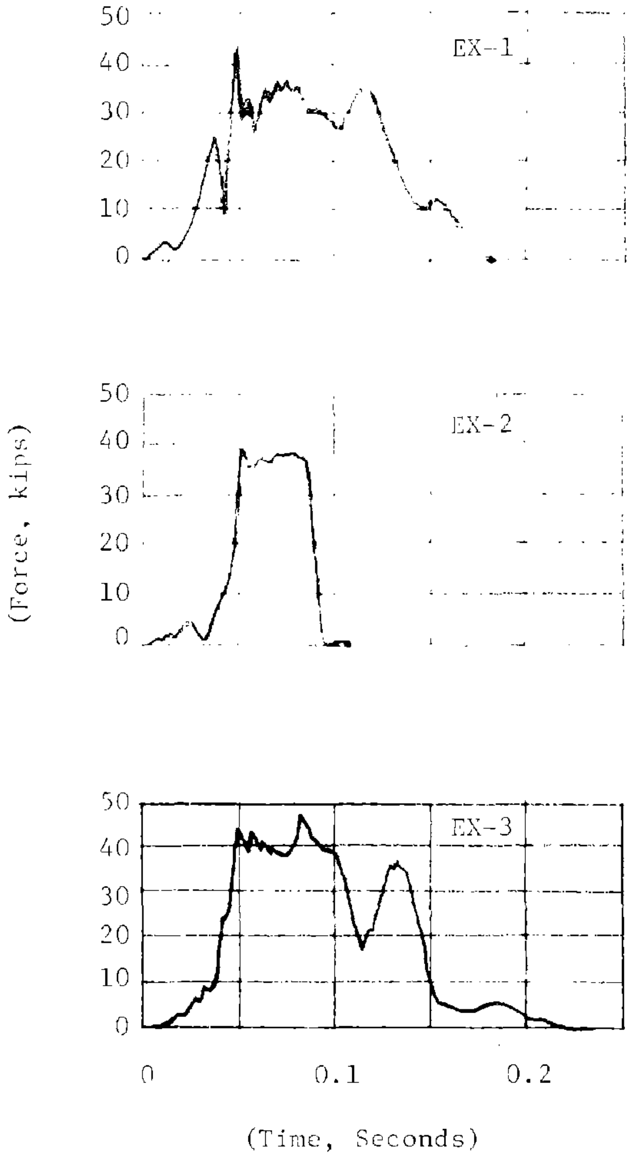


FIGURE A.74 BCT ANCHORAGE TEST TRACES

TEST WBCT-8

Purpose: Purpose of this test was to evaluate the performance of the wood post BCT which had been modified to reduce its end-on impact resistance. This was accomplished by a 2014-lb (914-kg) minicompact automobile impacting the buffer end at 60 mph (96.6 kmph) and a 0-deg angle. The vehicle was offset such that impact occurred 15 in. (381 mm) to the left of its centerline.

Test Installation: The test installation was similar to that of WBCT-7 with two additional features shown in Figure A.75 (1) an additional V-notch was cut in each of the corrugations of the W-beam rail on the traffic side 2 ft (0.71 m) downstream of Post 1; and (2) the first wood post was sawcut halfway through (in the 6 in. (152 mm) direction). Thus, there were a total of 5 notched locations in the rail and these, in conjunction with the sawcut post, were made to reduce impact loading.

Test Vehicle: A 1975 Honda Civic was the test vehicle, and it contained two 50th percentile anthropomorphic dummies in the driver and front passenger seating positions. The driver dummy was restrained by a lap and shoulder belt whereas the passenger dummy was unrestrained. Total weight of the vehicle, dummies, and instrumentation was 2014 lb (914 kg).

Performance: Impact conditions were 59.3 mph (95.4 kmph) and a 0.2-deg angle. As shown in the impact sequence of Figure A.76, the vehicle impacted the buffer end containing the wood spacer and fractured the first post. The W-beam also fractured at the first notch allowing the rail in the flared length to drop to grade. This allowed the vehicle to climb on top of the rail initiating a launching trajectory. When the vehicle reached the sedond post its elevated position caused the post to rotate in a bending mode rather than inducing a shear type fracture, and this contributed to further launching of the vehicle. The result was that the vehicle pitched front upward, rolled onto its left side, then rolled completely over landing in an upright position at an angle approximately normal to the barrier 13 ft (4.0 m) behind Post 13. Maximum 50-msec average accelerations measured during the impact sequence were 4.1 g (cine) and 2.7 g (accelerometer) in the lateral direction and -7.6 g (cine) and -8.3 g (accelerometer) in the longitudinal direction. A summary of test results is shown in Figure 27 and data from high-speed film analysis are contained in Table A.17. Results of analog to digital conversion of vehicle and dummy transducers are shown in Table A.18 and plotted in Figures A.77 thru A.83.

Barrier Damage: As shown in Figure A.84, barrier damage consisted of two broken wood posts, three bent rail sections, and a damaged buffer end/wood spacer assembly.

Vehicle Damage: The front section of the vehicle, the top, and left side were severely damaged by the impact as shown in Figure A.84. Although the windshield was shattered by impact of the passenger dummy's head, it was not thrown out until the rollover occurred.

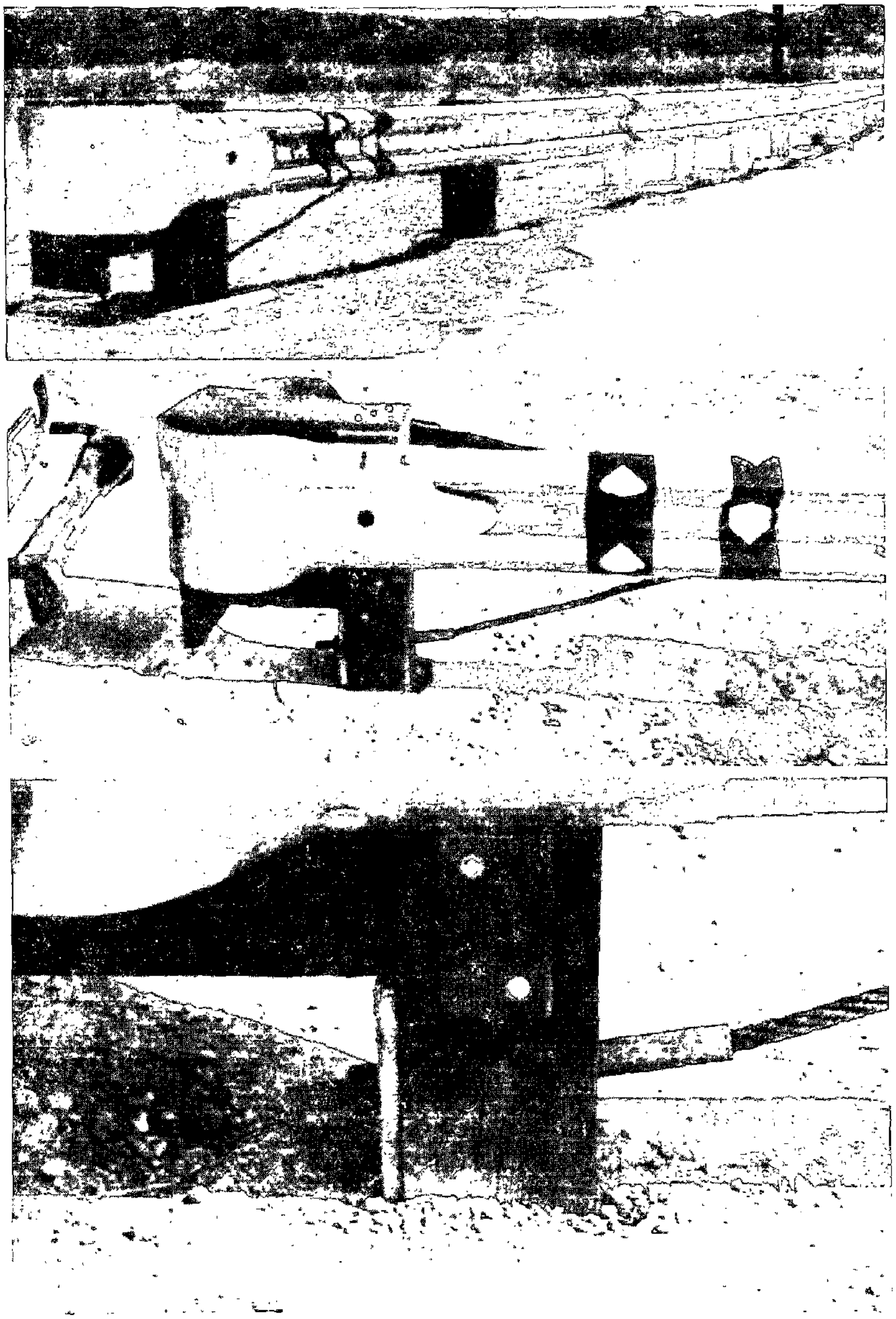


FIGURE A.83 PRE-TEST PHOTOGRAPHS TEST WBCT-8

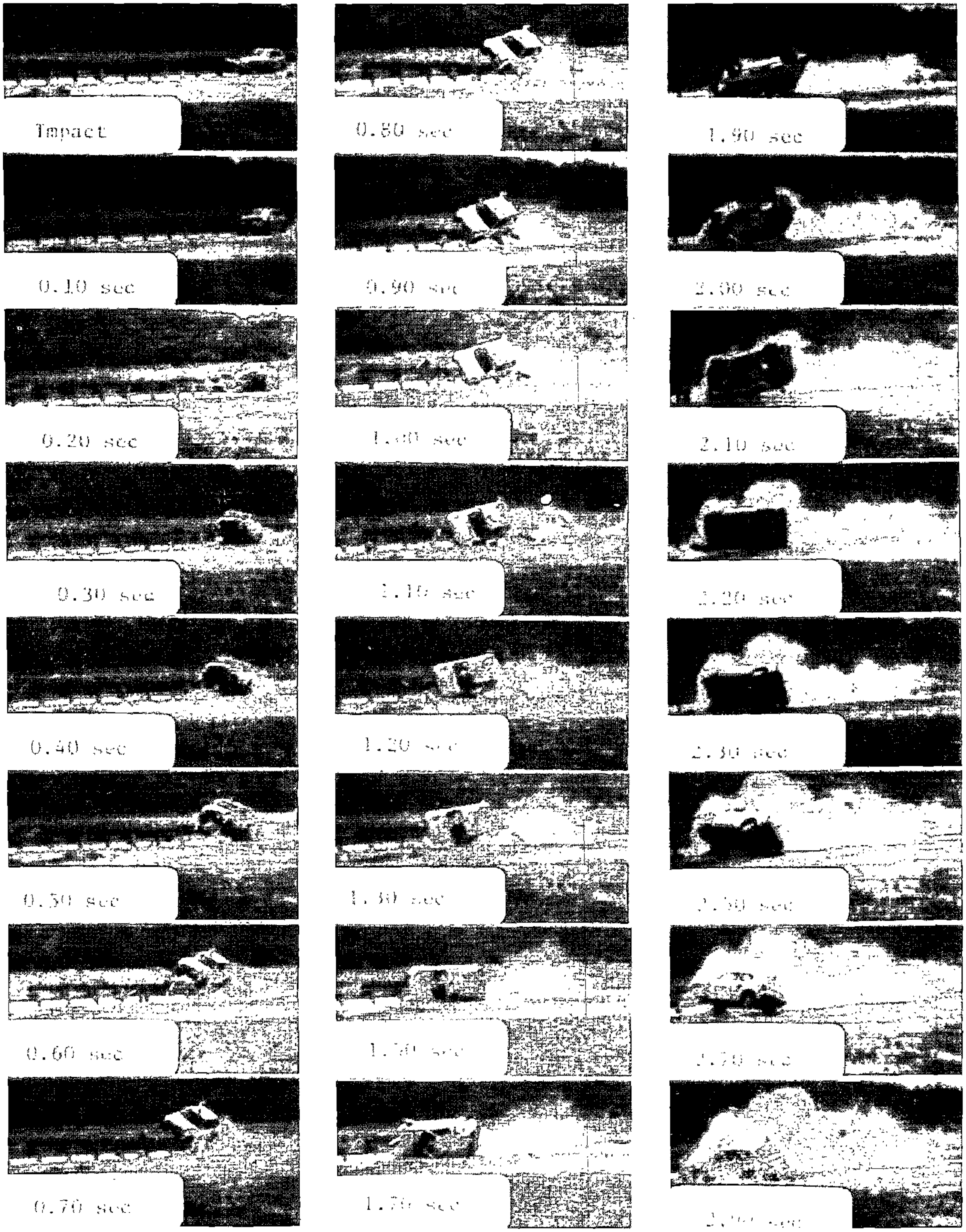
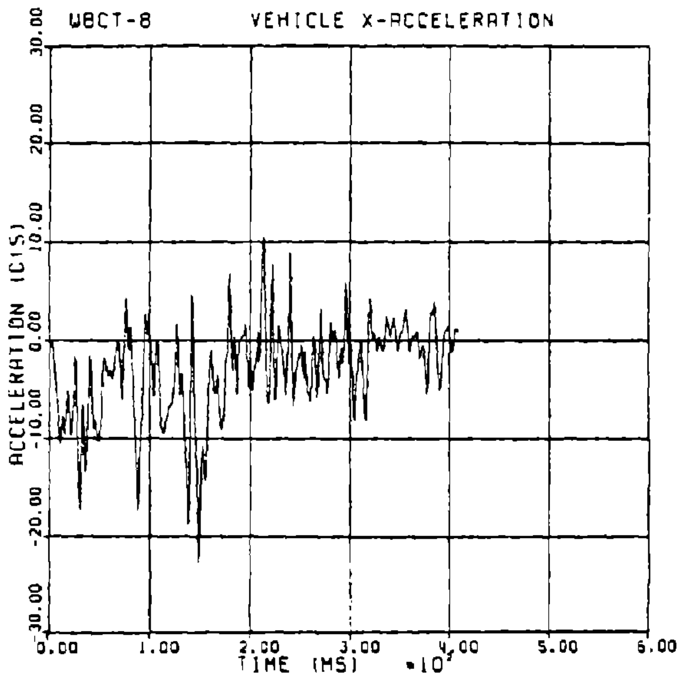


FIGURE A.84 TEST WBCT-8 IMPACT SEQUENCE



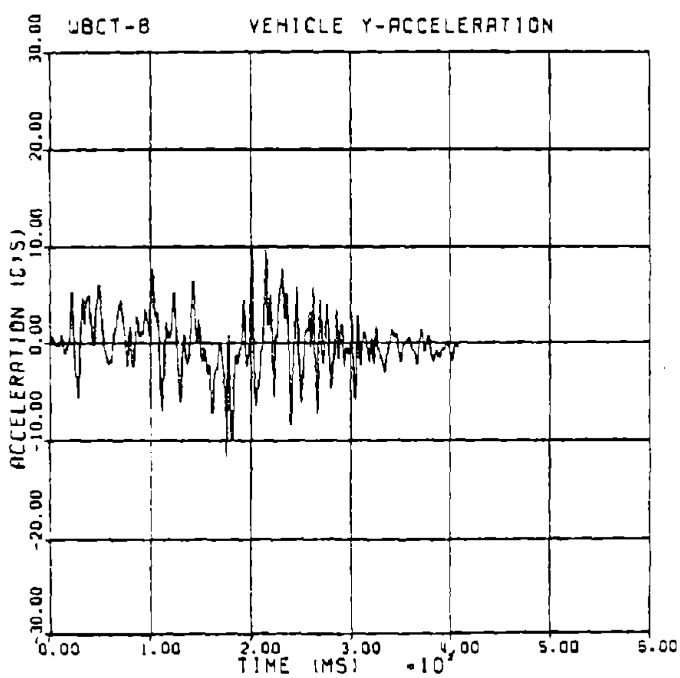


FIGURE A.77 VEHICLE ACCELERATION PLOTS, TEST WBCT-8

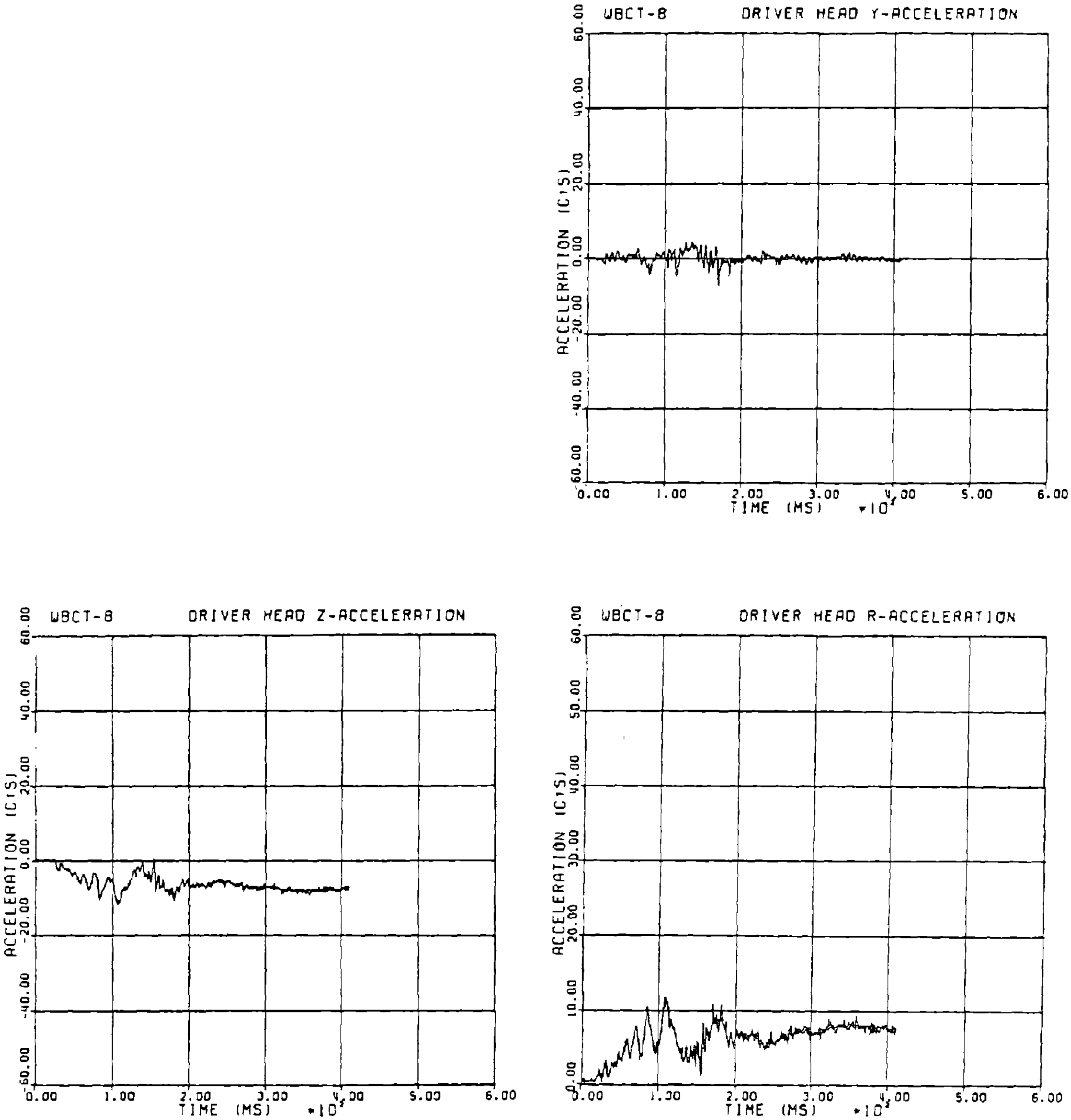


FIGURE A.78 DRIVER DUMMY HEAD ACCELERATION PLOTS, TEST WBCT-8

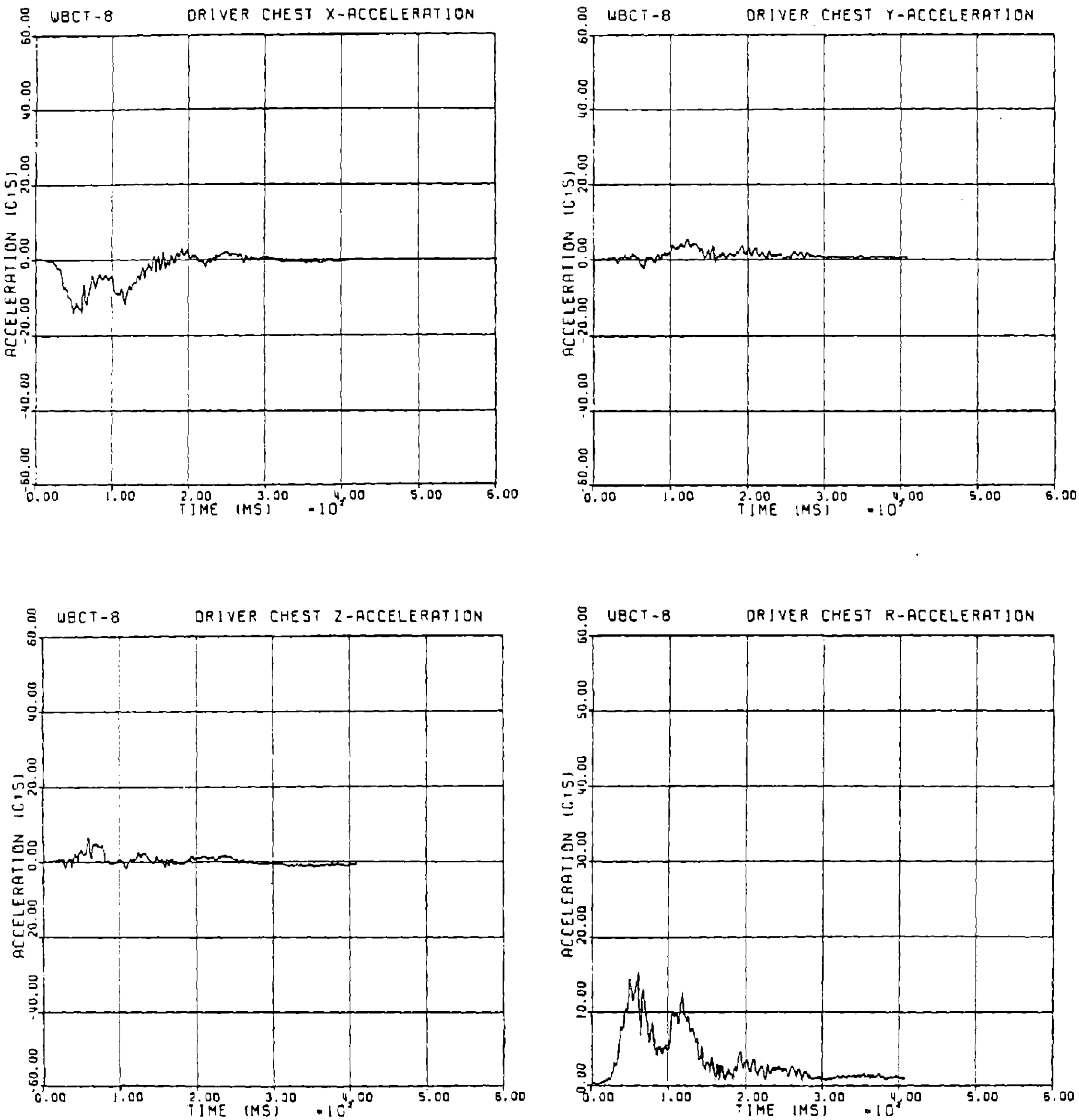
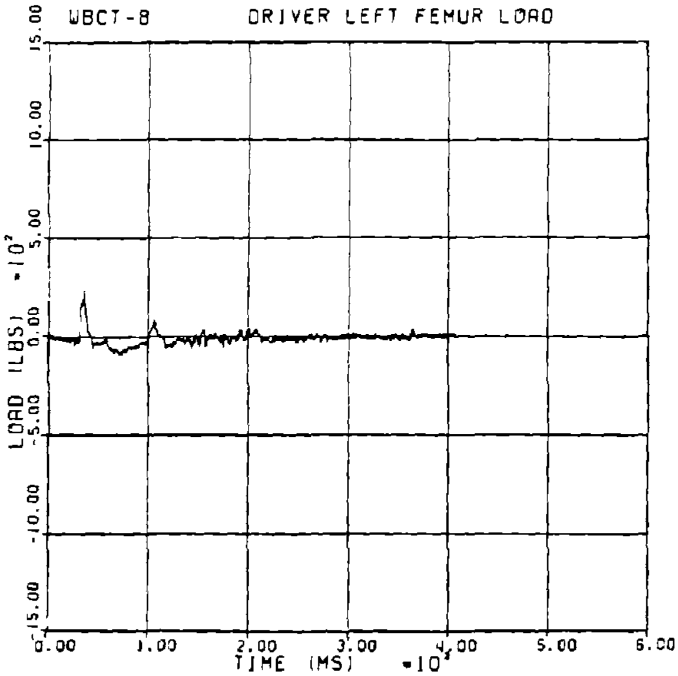


FIGURE A.79 DRIVER DUMMY CHEST ACCELERATION PLOTS, TEST WBCT-8



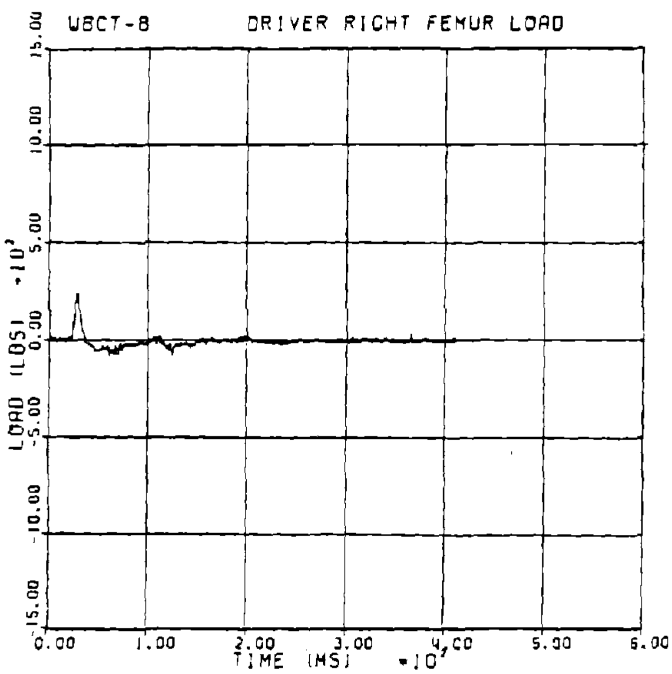


FIGURE A.80 DRIVER DUMMY FEMUR LOAD PLOTS, TEST WBCT-8

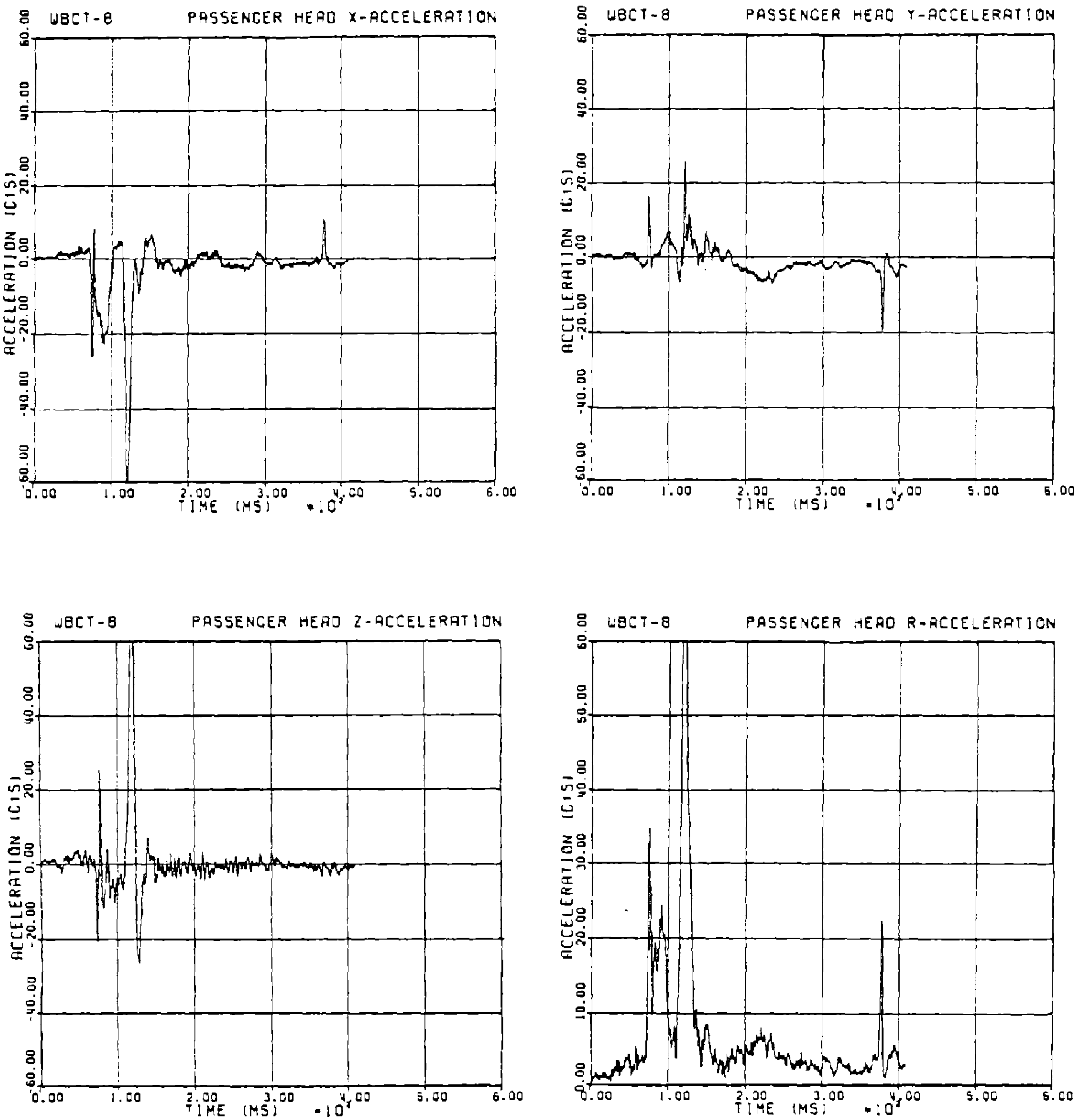


FIGURE A.81 PASSENGER DUMMY HEAD ACCELERATION PLOTS, TEST WBCT-8

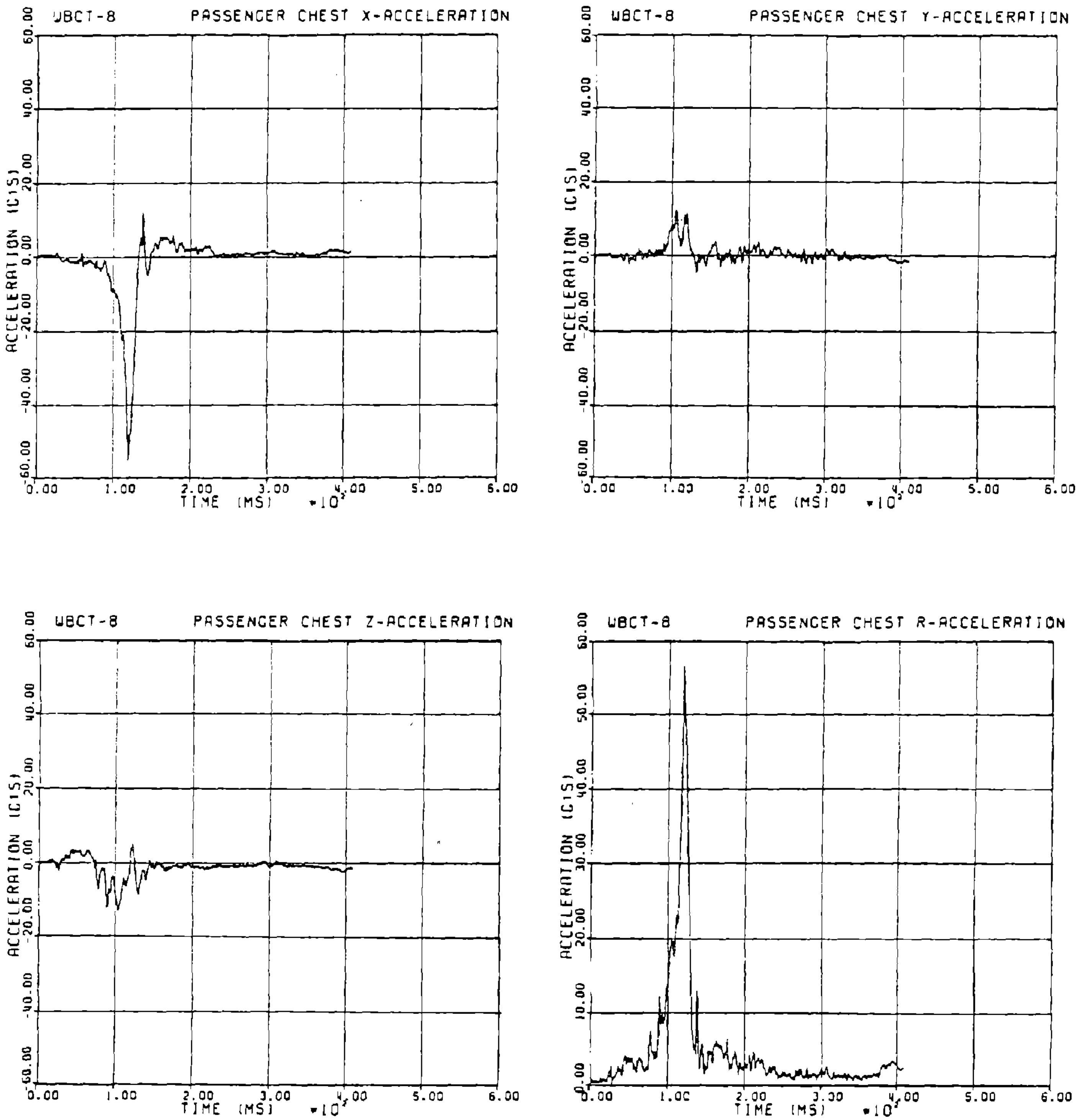


FIGURE A.82 PASSENGER DUMMY CHEST ACCELERATION PLOTS, TEST WBCT-8

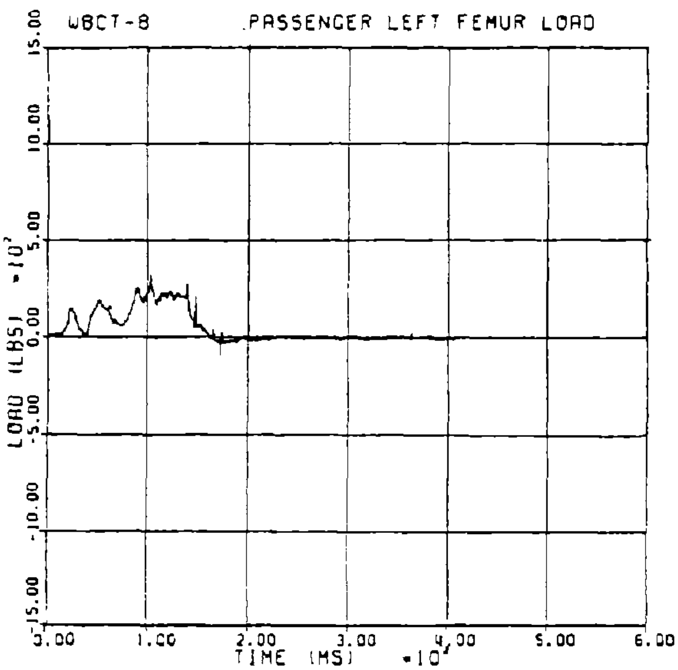


FIGURE A.83 PASENGER DUMMY FEMUR LOAD PLOTS, TEST WBCT-8

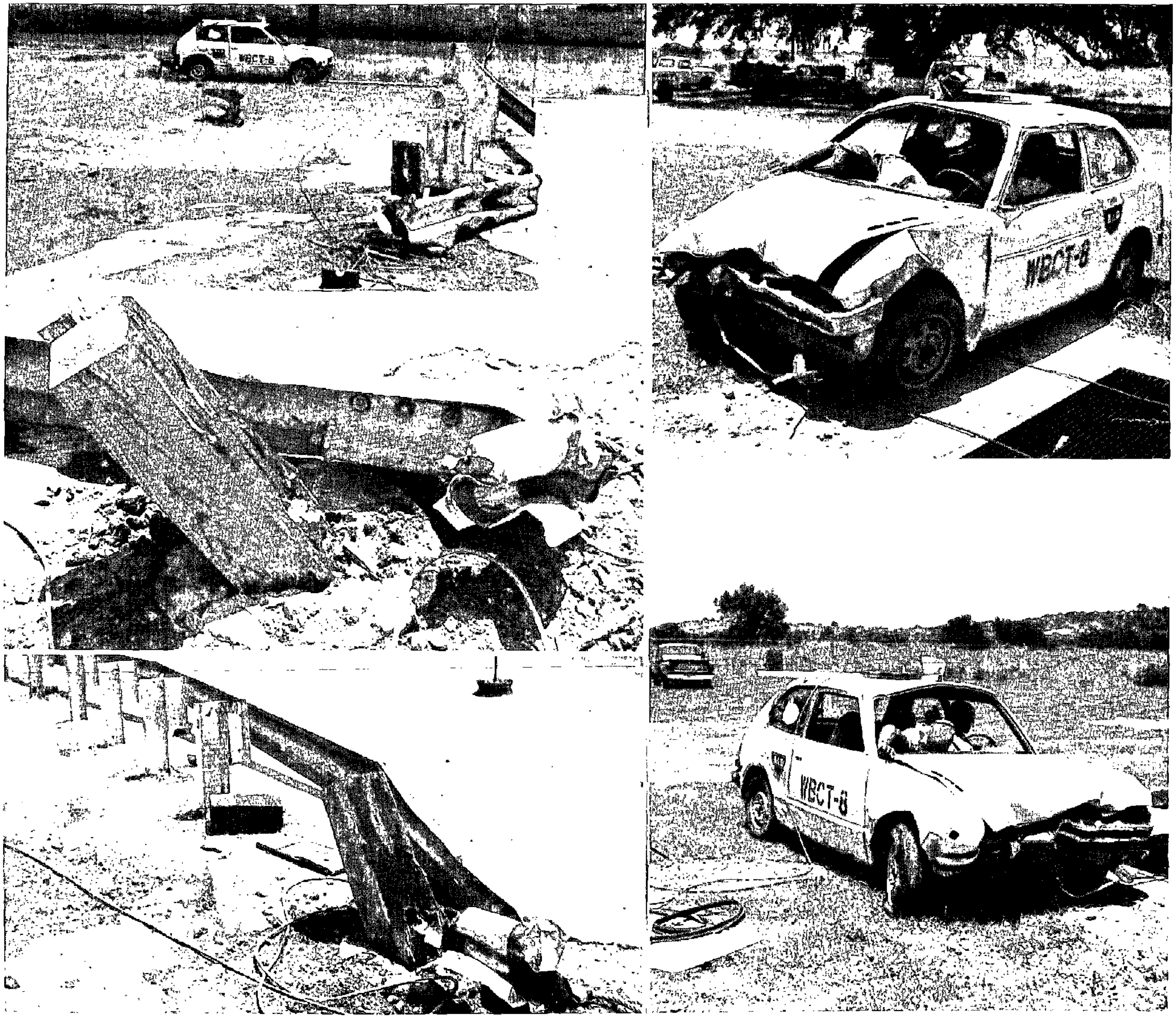


FIGURE A.93 BARRIER AND VEHICLE DAMAGE, TEST WBCT-8

TABLE A.17

RESULTS FROM HIGH-SPEED FILM ANALYSIS, TEST WBCT-8

SUMMARY OF VEHICLE KINEMATIC AND DYNAMIC DATA WOOD POST BCT TEST WBCT-8 8/7/81

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	-6.89	2.65	.21	86.99	.02	-6.60	-.22	0.00	0.00	13298.	482.
.010	-6.03	2.65	.50	84.78	-.51	-7.11	-.34	0.00	0.00	14305.	818.
.020	-5.20	2.65	.76	82.43	-1.30	-7.43	-.41	0.00	0.00	14942.	1086.
.030	-4.39	2.65	1.57	79.99	-2.30	-7.61	-.39	-7.40	-.29	15292.	1205.
.040	-3.60	2.65	2.31	77.49	-3.42	-7.68	-.25	-7.56	-.17	15432.	1118.
.050	-2.83	2.65	3.15	74.95	-4.57	-7.67	.03	-7.61	.05	15427.	797.
.060	-2.10	2.64	4.05	72.41	-5.67	-7.60	.42	-7.59	.38	15327.	245.
.070	-1.38	2.64	4.98	69.88	-6.62	-7.46	.91	-7.50	.80	15165.	-512.
.080	-.69	2.63	5.92	67.39	-7.35	-7.31	1.47	-7.36	1.30	14956.	-1424.
.090	-.03	2.63	6.82	64.94	-7.63	-7.10	2.06	-7.17	1.84	14701.	-2424.
.100	.62	2.63	7.67	62.58	-8.01	-6.85	2.64	-6.93	2.39	14390.	-3437.
.110	1.24	2.64	8.45	60.31	-7.91	-6.56	3.17	-6.65	2.90	14003.	-4382.
.120	1.83	2.65	9.14	58.16	-7.53	-6.22	3.61	-6.33	3.34	13517.	-5184.
.130	2.41	2.68	9.73	56.14	-6.91	-5.83	3.91	-5.97	3.67	12912.	-5774.
.140	2.96	2.71	10.24	54.27	-6.11	-5.41	4.05	-5.56	3.87	12167.	-6098.
.150	3.50	2.75	10.65	52.57	-5.18	-4.94	4.02	-5.12	3.91	11272.	-6123.
.160	4.02	2.80	10.97	51.03	-4.21	-4.43	3.81	-4.64	3.78	10225.	-5833.
.170	4.52	2.86	11.20	49.67	-3.25	-3.90	3.42	-4.12	3.49	9035.	-5237.
.180	5.00	2.93	11.36	48.50	-2.37	-3.33	2.88	-3.59	3.04	7725.	-4367.
.190	5.48	3.00	11.46	47.52	-1.62	-2.76	2.22	-3.03	2.46	6328.	-3274.
.200	5.94	3.08	11.49	46.72	-1.05	-2.18	1.47	-2.47	1.80	4890.	-2029.
.210	6.40	3.17	11.47	46.11	-.69	-1.61	.69	-1.92	1.08	3463.	-719.
.220	6.85	3.25	11.39	45.68	-.53	-1.08	-.07	-1.39	.35	2107.	564.
.230	7.30	3.34	11.26	45.41	-.56	-.60	-.75	-.89	-.32	882.	1722.
.240	7.74	3.42	11.09	45.29	-.76	-.18	-1.31	-.46	-.90	-154.	2664.
.250	8.19	3.50	10.87	45.29	-1.07	.15	-1.70	-.10	-1.34	-949.	3308.
.260	8.64	3.57	10.60	45.39	-1.44	.39	-1.89	.18	-1.60	-1465.	3593.
.270	9.09	3.64	10.28	45.55	-1.80	.51	-1.85	.35	-1.67	-1681.	3435.
.280	9.54	3.70	9.92	45.73	-2.07	.53	-1.59	.43	-1.53	-1597.	2981.
.290	10.00	3.75	9.51	45.90	-2.19	.43	-1.14	.40	-1.20	-1236.	2115.
.300	10.45	3.81	9.07	46.03	-2.11	.24	-.52	.28	-.71	-650.	962.
.310	10.91	3.86	8.60	46.08	-1.79	-.01	.19	.08	-.12	83.	-366.
.320	11.37	3.91	8.11	46.04	-1.22	-.30	.91	-.15	.51	859.	-1719.
.330	11.83	3.96	7.61	45.91	-.42	-.57	1.54	-.39	1.10	1556.	-2920.
.340	12.28	4.02	7.11	45.69	.56	-.77	1.99	-.58	1.55	2038.	-3778.
.350	12.73	4.09	6.62	45.42	1.62	-.84	2.15	-.66	1.77	2171.	-4103.
.360	13.18	4.16	6.15	45.14	2.66	-.71	1.94	-.59	1.69	1838.	-3736.
.370	13.62	4.24	5.69	44.94	3.56	-.35	1.32	-.33	1.26	962.	-2583.
.380	14.07	4.32	5.26	44.89	4.17	.26	.30	.14	.49	-464.	-632.
.390	14.51	4.40	4.83	45.07	4.40	1.08	-1.03	.79	-.55	-2343.	1889.
.400	14.96	4.48	4.33	45.54	4.18	2.01	-2.47	1.53	-1.67	-4427.	4651.
.410	15.41	4.55	3.93	46.30	3.55	2.87	-3.65	2.19	-2.55	-6266.	6946.
.420	15.88	4.61	3.42	47.20	2.70	3.31	-4.03	2.47	-2.69	-7146.	7698.

TABLE A.18

TEST WBCT-8 TRANSDUCER DATA

TEST ID ------ WBCT-8
TEST DATE ---- 08-07-81
VEHICLE TYPE - MINI-SIZE
IMPACT ANGLE - 0.00 DEGREES
IMPACT SPEED - 86.97 FPS

HIGHEST 50.0-MS AVG. ACCEL.

	G'S	TIME (SEC) START	END
LONG.	-8.32	.109	.159
LAT.	-2.66	.149	.199

VEHICLE KINETICS SUMMARY
NOTE: VALUES ARE INSTANTANEOUS AT TIME

TIME (S)	VEH. ACCEL.(G'S) LONG.	LAT.	VEH. VEL.(FPS) LONG.	LAT.	VEH. DISP.(F) LONG.	LAT.
0.000	.09	.31	86.97	0.00	0.00	0.00
.010	-10.06	.19	86.06	.05	.85	.00
.020	-7.78	1.74	83.45	.01	1.68	.00
.030	-17.23	1.64	80.72	-.23	2.56	.00
.040	-1.58	2.63	77.61	.97	3.34	.01
.050	-9.78	5.07	75.21	1.80	4.09	.02
.060	-2.98	-2.00	73.93	1.83	4.82	.04
.070	-1.40	4.57	73.25	2.14	5.54	.06
.080	1.12	.39	72.93	2.53	6.32	.08
.090	-10.01	.97	70.30	2.59	7.03	.11
.100	.28	3.58	69.68	3.20	7.71	.13
.110	-5.96	-5.67	69.02	4.24	8.39	.17
.120	-6.61	.92	66.39	3.71	9.06	.21
.130	-5.26	-5.15	65.17	3.79	9.76	.25
.140	-7.08	2.13	61.86	3.41	10.39	.29
.150	-16.85	-.91	59.08	4.33	10.99	.33
.160	-1.68	-6.29	55.64	3.68	11.55	.37
.170	-8.29	-.14	54.41	2.58	12.09	.40
.180	3.82	-9.87	53.08	1.18	12.66	.42
.190	.09	-.48	52.60	-.07	13.18	.42
.200	-1.79	8.02	52.42	.13	13.69	.42
.210	-1.40	-1.19	51.67	-.03	14.21	.43
.220	-.98	3.53	51.99	1.10	14.76	.43
.230	-.23	7.15	52.00	1.37	15.27	.44
.240	8.62	-8.44	51.70	2.14	15.78	.46
.250	-1.02	-6.20	51.20	1.88	16.29	.48
.260	-6.15	-.33	50.26	1.69	16.79	.49
.270	3.17	2.32	49.43	1.75	17.32	.51
.280	1.82	-4.67	48.65	1.82	17.80	.53
.290	-1.40	1.74	48.45	1.65	18.28	.55
.300	-.84	2.37	48.54	1.53	18.76	.56
.310	-.09	-2.24	47.32	1.31	19.23	.58
.320	3.73	.43	46.37	1.15	19.73	.59
.330	-.05	-1.67	46.51	1.06	20.18	.60
.340	.42	1.16	46.66	.58	20.64	.61
.350	.47	-2.05	46.86	.70	21.10	.61
.360	-1.16	.07	47.30	.63	21.56	.62
.370	-1.77	1.21	47.28	.37	22.07	.63
.380	1.40	-.29	46.55	.45	22.53	.63
.390	-5.05	-1.31	46.90	.05	22.99	.63
.400	.91	-.86	46.61	-.09	23.45	.63

TEST ID ------ UBCT-8
TEST DATE ---- 08-07-81
VEHICLE TYPE - MINI-SIZE

VEHICLE MASS = 2014. LBS.
IMPACT SPEED = 59.3 MPH
IMPACT ANGLE = 0.0 DEG.

OCCUPANT - DRIVER
572-50% MALE DUMMY
RESTRAINTS - LAB + SHOULDER BELTS

TIME	RESULTANT (G'S)		-------SI-------		FEMUR LOADS (LBS)	
(SEC)	HEAD	CHEST	HEAD	CHEST	LEFT	RIGHT
0.000	.5	.3	0.0	0.0	-14.4	-3.0
.010	.6	.2	.0	.0	-14.4	3.1
.020	1.4	.5	.0	.0	-14.4	15.4
.030	2.9	2.6	.0	.1	-31.7	175.8
.040	2.4	8.0	.1	1.0	14.6	-15.2
.050	3.3	13.0	.3	5.3	-40.3	-57.9
.060	5.0	15.4	.8	11.5	-60.4	-57.9
.070	8.3	9.7	1.5	15.3	-83.5	-70.0
.080	6.3	5.4	2.3	16.9	-54.7	-33.5
.090	6.4	4.1	4.4	17.4	-54.7	-21.3
.100	5.6	5.2	5.0	17.9	8.8	-9.1
.110	11.3	9.8	7.9	20.3	-2.9	18.5
.120	7.6	9.7	10.2	23.7	-48.9	-51.8
.130	4.8	7.8	10.9	26.0	-14.4	-33.5
.140	3.1	3.7	11.1	26.8	-14.4	-27.4
.150	6.3	3.1	11.5	27.0	-20.1	-6.1
.160	4.3	.6	12.2	27.1	-14.4	-3.0
.170	10.9	2.6	13.5	27.2	-8.6	-15.2
.180	8.3	1.3	15.9	27.2	-31.7	-3.0
.190	6.2	3.3	17.8	27.3	-14.4	15.4
.200	6.6	3.2	18.7	27.5	14.6	15.4
.210	6.7	3.2	19.9	27.6	14.6	-9.1
.220	6.3	2.4	21.0	27.7	-25.9	-9.1
.230	6.0	1.6	22.2	27.8	-25.9	-15.2
.240	5.9	2.3	22.8	27.8	-14.4	-15.2
.250	5.7	2.1	23.6	27.9	-8.6	-3.0
.260	6.4	2.3	24.5	27.9	-2.9	-3.0
.270	6.7	1.9	25.6	28.0	-2.9	0.0
.280	7.2	1.3	27.0	28.0	-14.4	-3.0
.290	7.3	.9	28.4	28.0	-8.6	3.1
.300	6.9	.8	29.9	28.0	-14.4	3.1
.310	7.7	.9	31.1	28.1	0.0	3.1
.320	7.7	1.3	32.7	28.1	-14.4	3.1
.330	8.0	1.2	34.3	28.1	-8.6	-3.0
.340	8.3	1.2	36.1	28.1	-14.4	3.1
.350	8.0	1.2	37.8	28.1	-14.4	-9.1
.360	8.6	1.4	39.7	28.1	-25.9	0.0
.370	8.2	1.3	41.6	28.2	8.8	-12.2
.380	8.2	1.0	43.3	28.2	-8.6	-3.0
.390	8.0	1.1	44.9	28.2	-8.6	-12.2
.400	7.7	1.0	46.6	28.2	0.0	3.1

MAXIMUM VALUES AND TIME OF OCCURANCE

	X/LT	---SEC	Y/RT	---SEC	Z	----SEC	R	----SEC
HEAD (G'S)	0.0	.409	-7.2	.170	-11.5	.108	11.7	.106
CHEST (G'S)	-14.1	.060	5.5	.122	6.6	.059	15.4	.060
FEMUR LOAD (LBS)	0.	.409	238.	.029				

CUMULATIVE PERIOD FOR 60-G LEVEL = 0.000 SEC.

HIC = 43.5 DURING T = .054 TO .409 SEC.

TEST ID ------ WBCT-8
TEST DATE ---- 08-07-81
VEHICLE TYPE - MINI-SIZE

VEHICLE MASS = 2014. LBS.
IMPACT SPEED = 59.3 MPH
IMPACT ANGLE = 0.0 DEG.

OCCUPANT - PASSENGER
572-50% MALE DUMMY
RESTRAINTS - NONE

TIME (SEC)	RESULTANT (G'S) HEAD	CHEST	--------SI-------- HEAD	CHEST	FEMUR LOADS (LBS) LEFT	RIGHT
0.000	.7	.9	0.0	0.0	-3.4	0.0
.010	.6	.3	.0	.0	8.1	-5.7
.020	.8	.4	.0	.0	58.9	62.4
.030	2.1	1.1	.0	.0	47.3	6.8
.040	2.5	1.8	.1	.1	42.7	70.3
.050	3.2	3.0	.3	.3	185.9	176.9
.060	3.1	3.3	.5	.4	138.6	111.1
.070	3.5	1.9	.7	.6	64.7	86.2
.080	16.8	4.0	19.9	1.1	102.8	167.8
.090	24.4	8.4	35.0	2.6	252.9	254.0
.100	9.1	15.0	48.8	6.7	225.2	502.3
.110	3.8	22.7	50.0	22.0	185.9	195.0
.120	121.8	53.8	281.1	106.4	222.9	165.5
.130	16.7	9.3	795.0	195.2	225.2	173.5
.140	6.6	2.3	798.3	196.8	130.5	77.1
.150	8.0	2.1	799.2	197.0	47.3	15.9
.160	4.0	5.6	800.0	197.4	12.7	6.8
.170	1.9	4.9	800.2	198.1	-26.3	0.0
.180	4.2	2.0	800.3	198.5	-24.0	6.8
.190	5.5	2.7	800.7	198.7	-17.2	-10.5
.200	2.9	2.5	801.1	198.8	-10.3	-5.7
.210	4.2	3.0	801.6	198.9	-13.7	9.1
.220	8.0	3.0	802.7	199.2	-14.9	18.1
.230	6.1	1.5	803.5	199.3	10.4	-91.3
.240	3.9	2.3	804.3	199.3	1.2	13.6
.250	3.7	2.0	804.6	199.4	-5.7	6.8
.260	2.7	1.6	804.9	199.4	-1.1	4.5
.270	2.6	2.1	805.0	199.4	1.2	9.1
.280	2.7	1.1	805.2	199.4	-1.1	-1.9
.290	2.9	1.6	805.3	199.5	-3.4	1.1
.300	3.2	2.1	805.4	199.5	-3.4	1.1
.310	3.4	1.5	805.7	199.6	-9.2	-1.9
.320	3.9	1.0	805.7	199.6	-14.9	-5.7
.330	2.8	1.2	805.9	199.6	-3.4	-1.9
.340	1.7	1.0	806.0	199.6	1.2	-1.9
.350	1.9	1.0	806.0	199.6	-5.7	-1.9
.360	2.0	1.1	806.1	199.6	1.2	1.1
.370	4.1	1.6	806.3	199.7	-3.4	6.8
.380	1.4	2.6	811.3	199.7	1.2	6.8
.390	3.7	2.8	811.4	199.8	-9.2	0.0
.400	3.2	2.8	811.9	200.0	-5.7	-1.9

MAXIMUM VALUES AND TIME OF OCCURANCE

	X/LT	---SEC	Y/RT	---SEC	Z	----SEC	R	----SEC
HEAD (G'S)	-98.9	.120	25.7	.120	98.2	.120	141.7	.120
CHEST (G'S)	-55.2	.119	12.2	.105	-13.1	.102	56.5	.119
FEMUR LOAD (LBS)	318.	.102	0.	.409				

CUMULATIVE PERIOD FOR 60-G LEVEL = .006 SEC.

HIC = 599.0 DURING T = .117 TO .123 SEC.

TEST WBCT-9

Purpose: Purpose of this test was to evaluate the performance of the wood post BCT which had been modified to reduce its end-on impact resistance. This was accomplished by a 2040-lb (925-kg) minicompact automobile impacting the buffer end at 60 mph (96.6 kmph) and a 0-deg angle. The vehicle was offset such that impact occurred 15 in. (381 mm) to the left of its centerline.

Test Installation: The test installation was the same as that of WBCT-8 except the first notch in the W-beam rail (2 ft (0.61 m) from Post 1) was deleted. This left 4 notched locations in the rail to form hinges and these in conjunction with the sawcut first post were retrofitted to reduce impact loading.

Test Vehicle: A 1975 Honda Civic was the test vehicle; it contained two 50th percentile anthropomorphic dummies in the driver and front passenger seating positions. The driver dummy was restrained by a lap and shoulder belt whereas the passenger dummy was unrestrained. Total weight of the vehicle, dummies, and instrumentation was 2040 lb (925 kg).

Performance: Impact conditions were 59.3 mph (95.4 kmph) and a -1.3-deg angle. As shown in the impact sequence of Figure A.85, the vehicle impacted the buffer end containing the wood spacer and fractured the first post. As it continued the vehicle began to yaw counterclockwise and the right front section of the vehicle impacted the second post fracturing it also. Vehicle yawing continued until Post 3 (the first steel post) was contacted by the lower portion of the right door. Impact with this post and Posts 4 and 5 caused the vehicle to reverse its yaw direction, and also to pitch nose upward at the same time. When the vehicle returned to grade its trajectory was approximately parallel to that prior to impact, and it rolled to a stop 2 ft (0.6 m) behind Post 14. Maximum 50 msec average accelerations measured during the impact sequence were -3.3 g in the lateral direction and -12.2 g in the longitudinal direction. These were measured from accelerometer traces as a malfunction (broken film) caused data from one camera to be lost, and film analysis could not be performed. A summary of test results is shown in Figure 30.

Results of analog to digital conversion of vehicle and dummy transducer data is contained in Table A.19 and plotted in Figures A.86 thru A.92.

Barrier Damage: As shown in Figure A.93, barrier damage consisted of two broken wood posts, three bent steel posts, three bent rail sections, and a damaged buffer end/wood spacer assembly.

Vehicle Damage: As is also shown in Figure A.93, damage to the vehicle front end was severe. Major structural and suspension damage were sustained in addition to the extensive sheet metal deformation. Contact with the steel posts caused some deformation to the lower portion of the right door. Although it remained with the vehicle, the windshield was shattered and partially dislodged by impact of the passenger dummy's head.

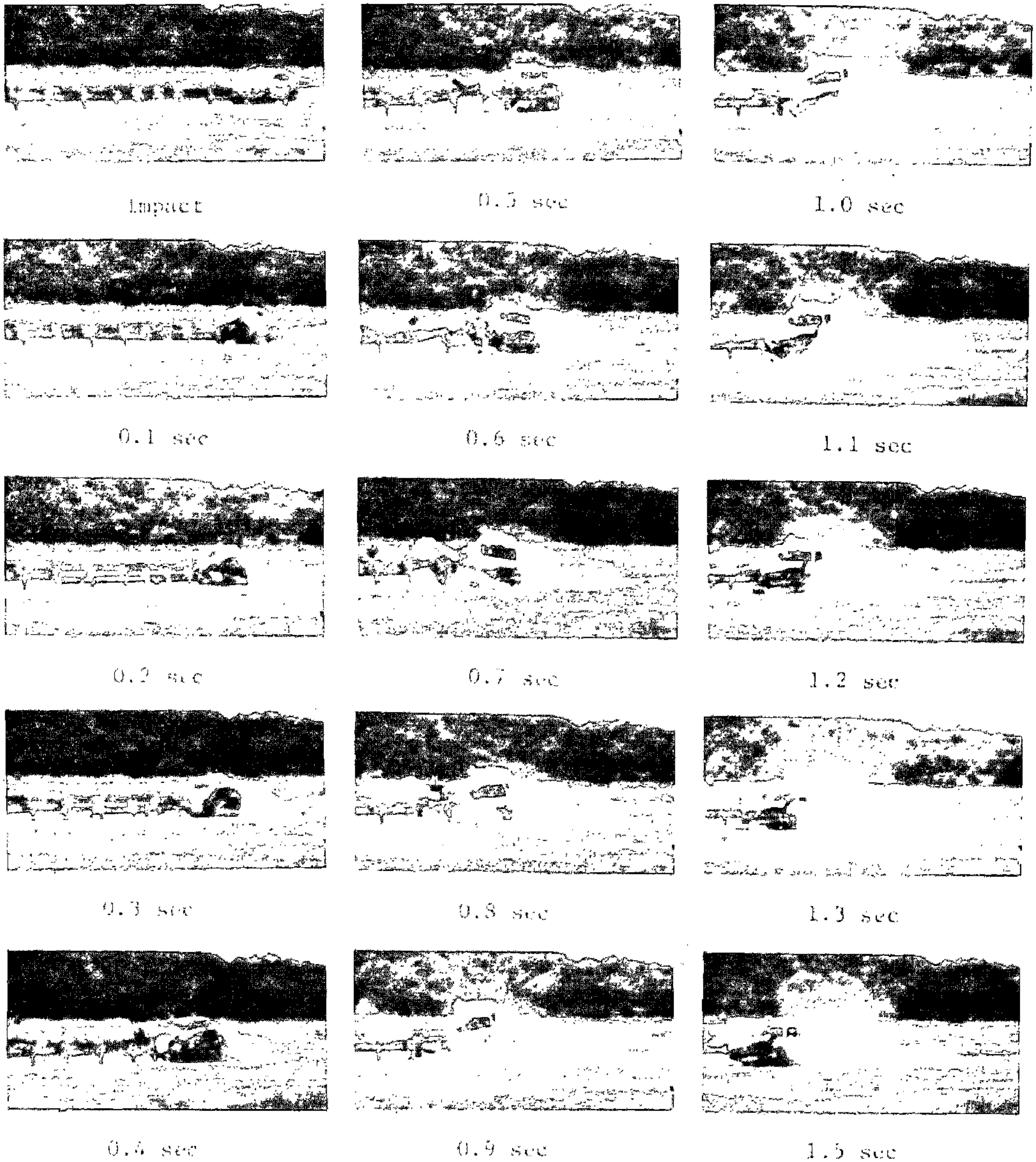
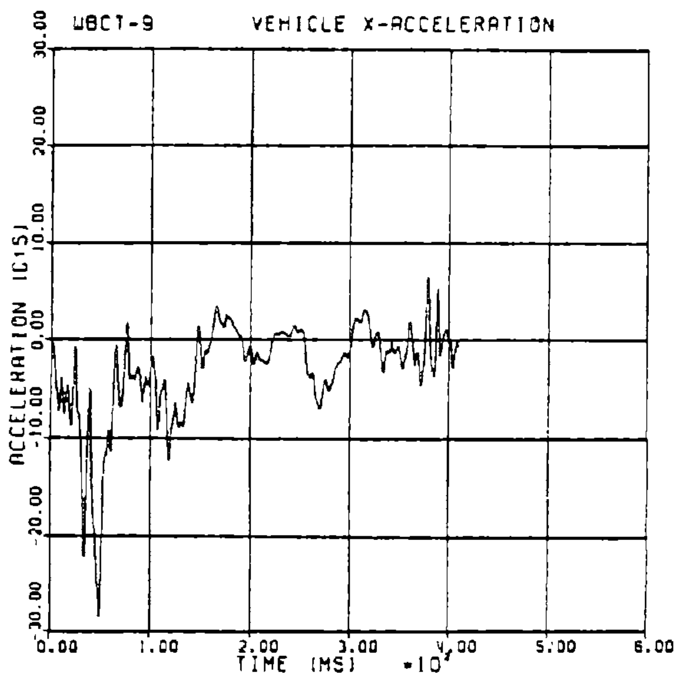


FIGURE A.94 TEST WBCT-9 IMPACT SEQUENCE



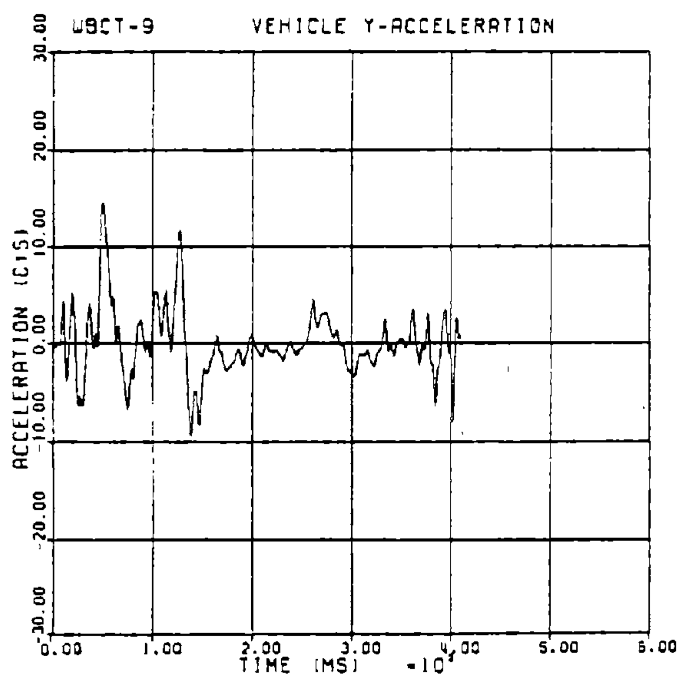


FIGURE A.86 VEHICLE ACCELERATION PLOTS, TEST WBCT-9

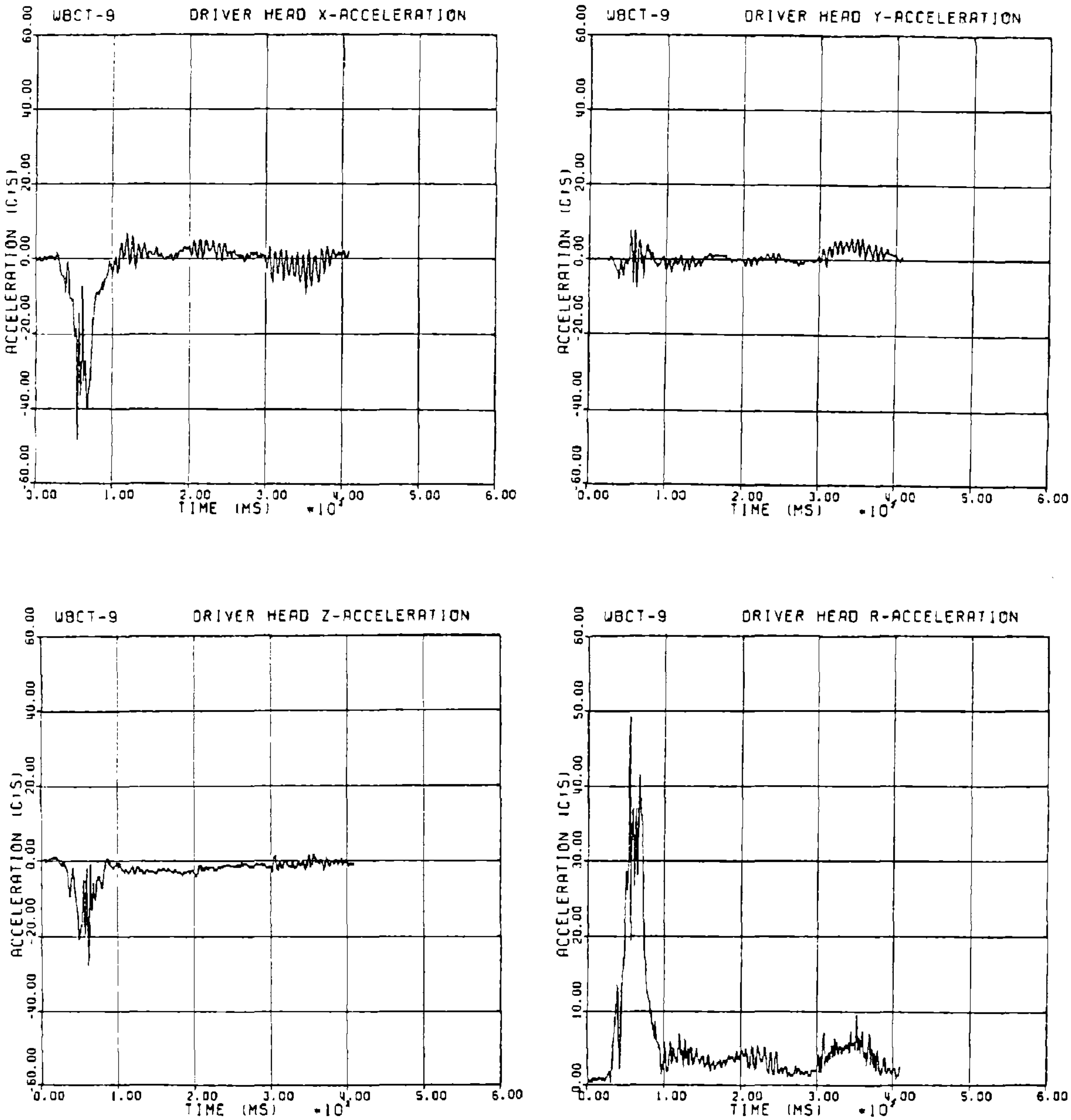


FIGURE A.87 DRIVER DUMMY HEAD ACCELERATION PLOTS, TEST WBCT-9

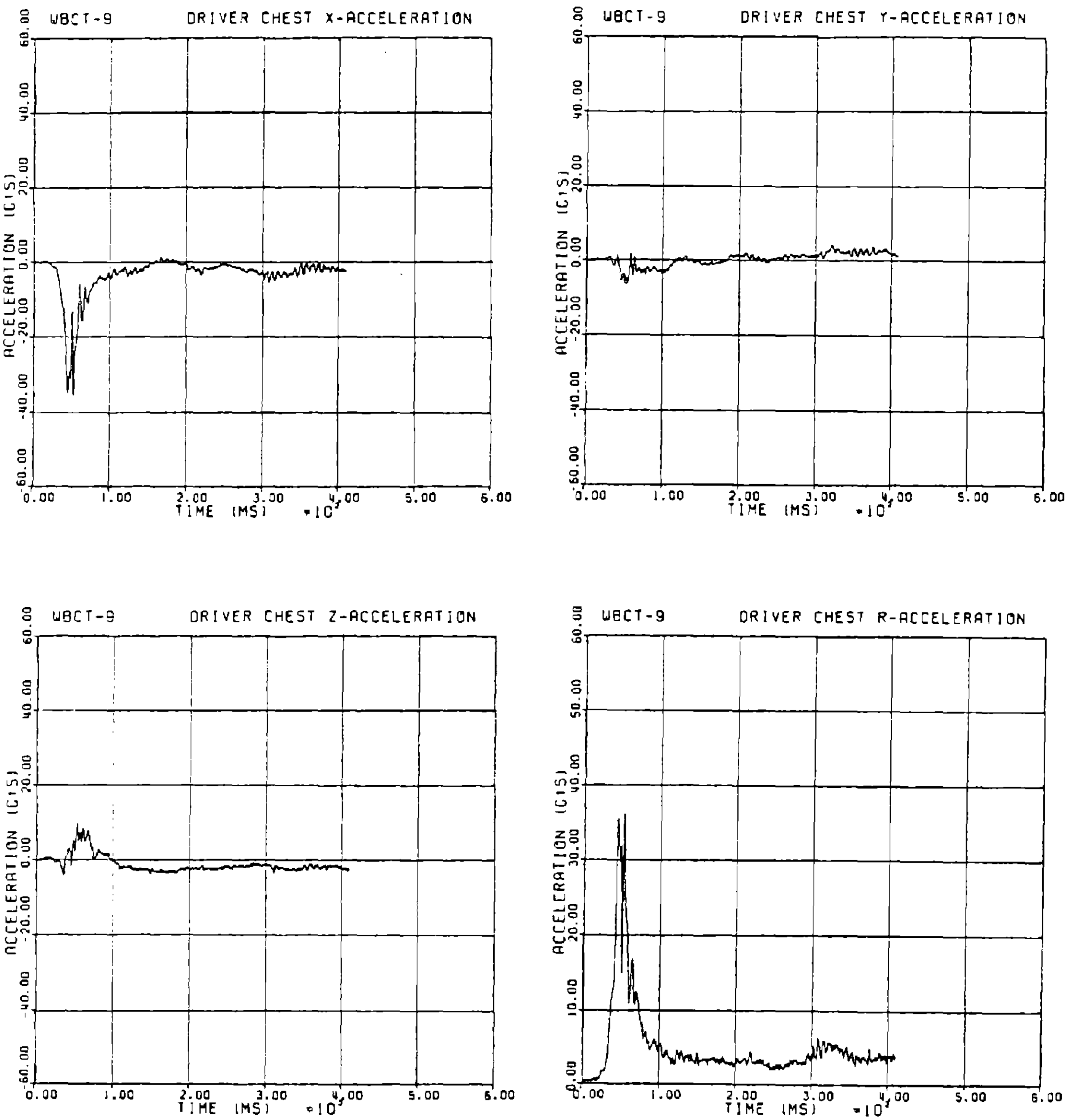
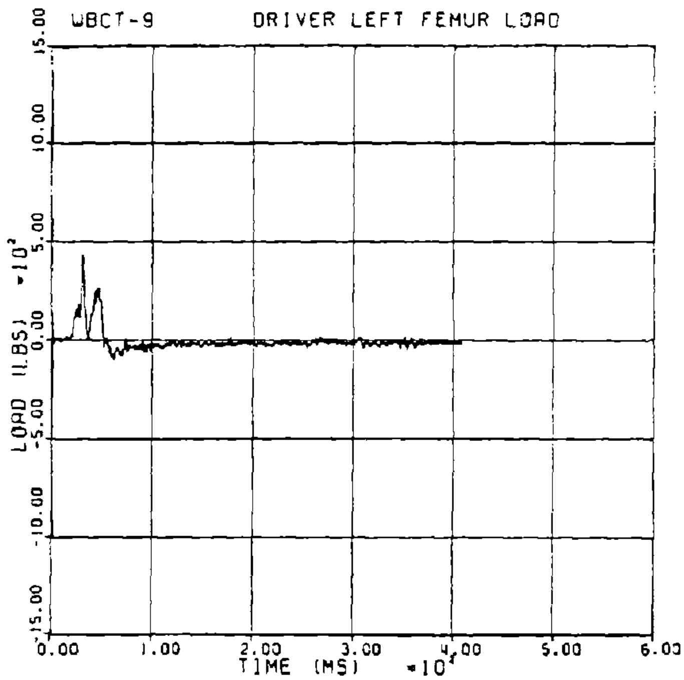


FIGURE A.88 DRIVER DUMMY CHEST ACCELERATION PLOTS, TEST WBCT-9



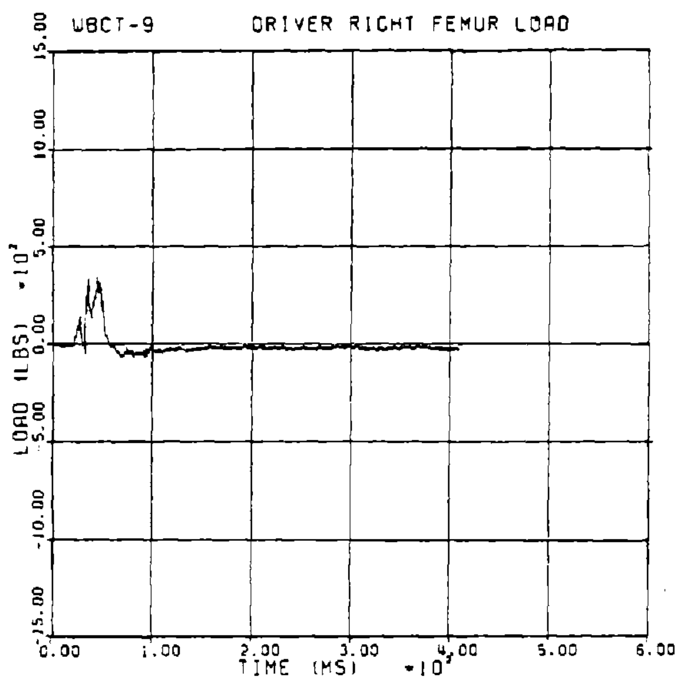


FIGURE A.89 DRIVER DUMMY FEMUR LOAD PLOTS, TEST WBCT-9

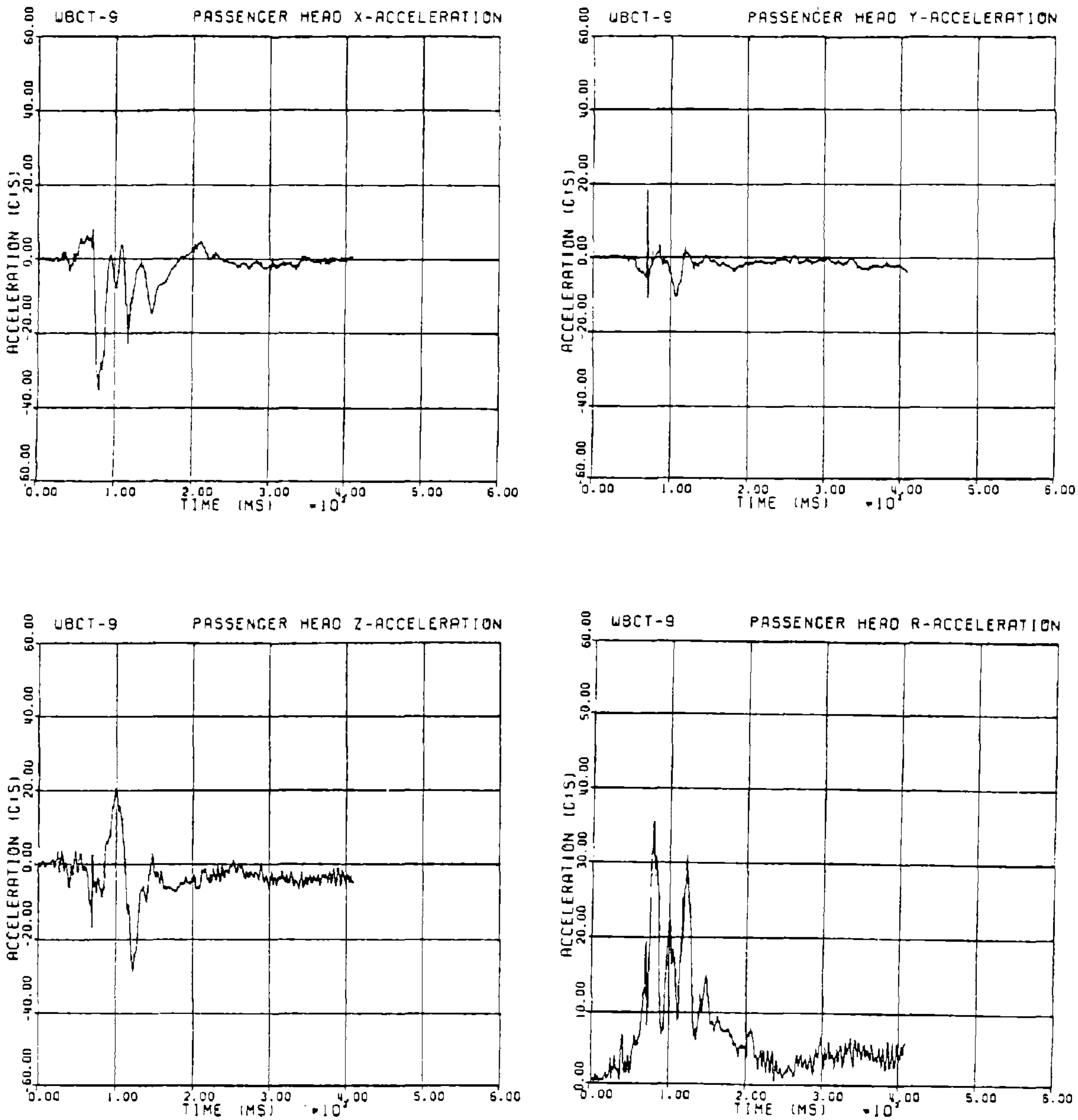


FIGURE A.90 PASSENGER DUMMY HEAD ACCELERATION PLOTS, TEST WBCT-9

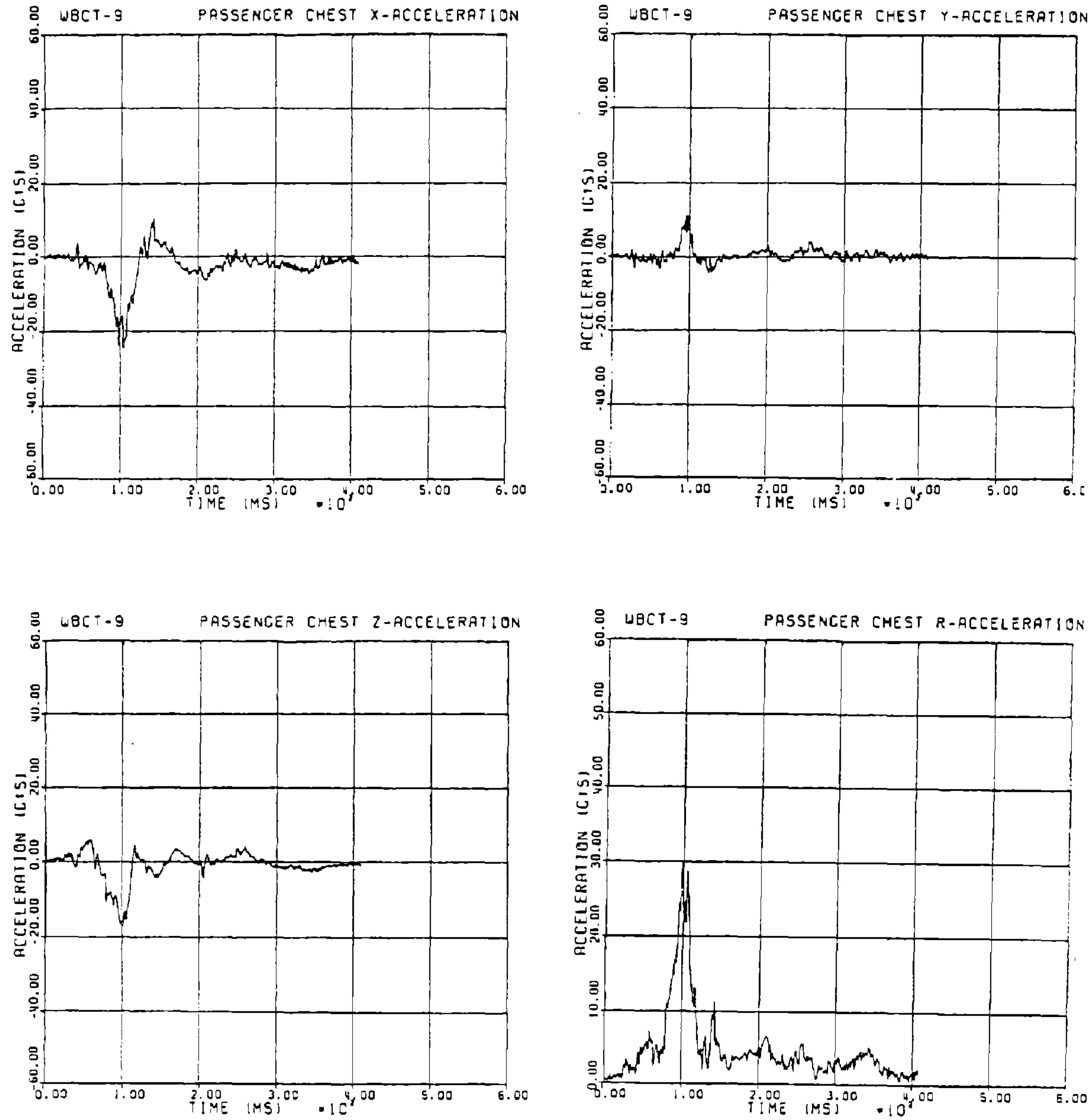
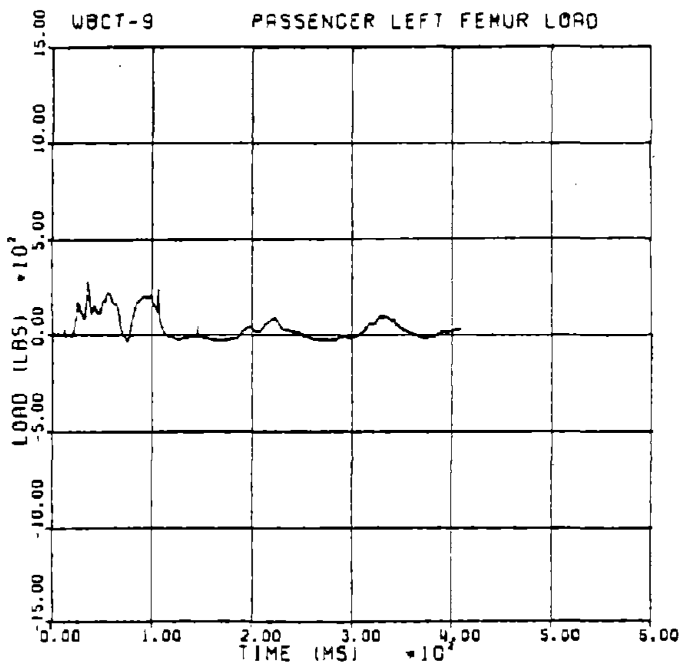


FIGURE A.91 PASSENGER DUMMY CHEST ACCELERATION PLOTS, TEST WBCT-9



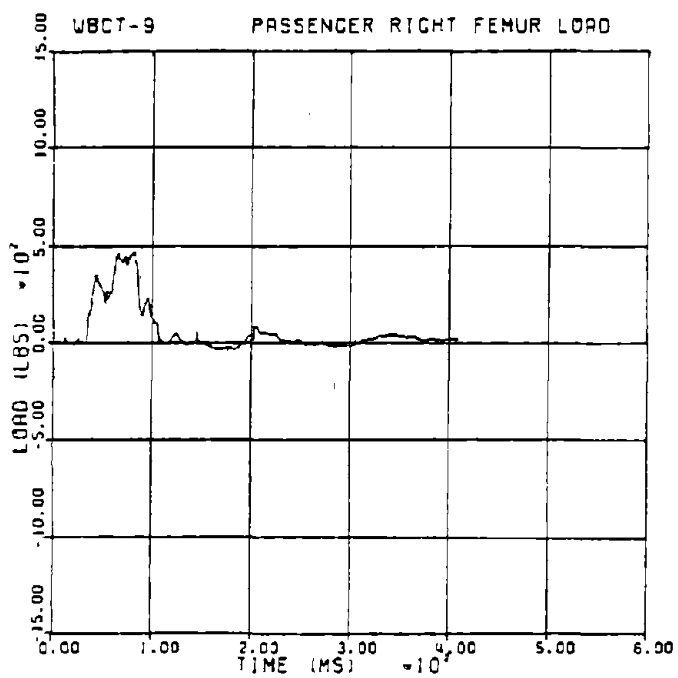


FIGURE A.92 PASSENGER DUMMY FEMUR LOAD PLOTS, TEST WBCT-9

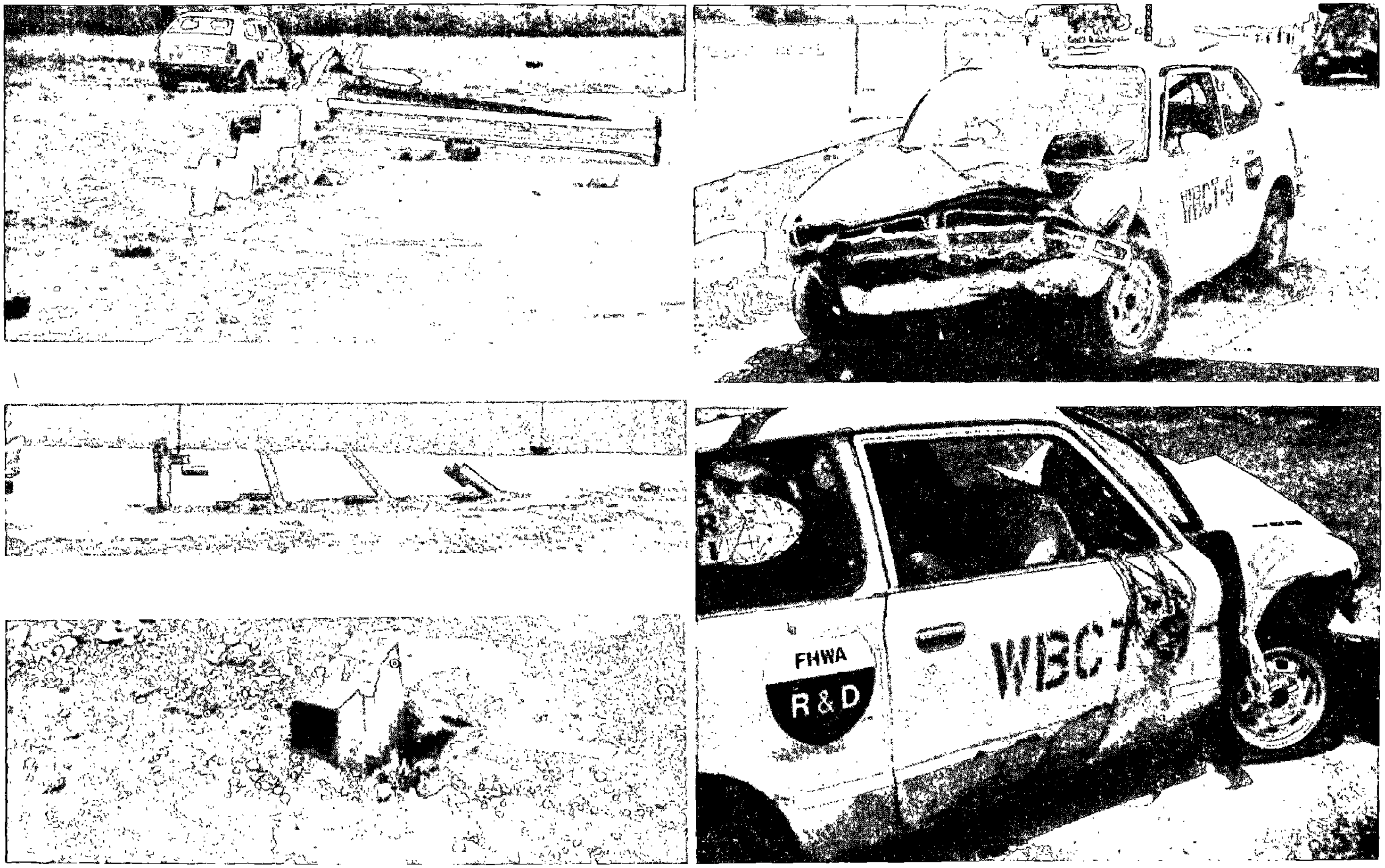


FIGURE A.103 BARRIER AND VEHICLE DAMAGE, TEST WBCT-9

TABLE A.19

TEST WBCT-9 TRANSDUCER DATA

TEST ID ------ WBCT-9
TEST DATE ---- 08-24-81
VEHICLE TYPE - MINI-SIZE
IMPACT ANGLE - 0.00 DEGREES
IMPACT SPEED - 86.97 FPS

HIGHEST 50.0-MS AVG. ACCEL.

	G'S	TIME (SEC) START	END
LONG.	-12.19	.013	.063
LAT.	-3.25	.134	.184

VEHICLE KINETICS SUMMARY
NOTE: VALUES ARE INSTANTANEOUS AT TIME

TIME	VEH. ACCEL.(G'S)		VEH. VEL.(FPS)		VEH. DISP.(F)	
(S)	LONG.	LAT.	LONG.	LAT.	LONG.	LAT.
0.000	-.08	-.26	86.97	0.00	0.00	0.00
.010	-5.24	4.42	85.87	.13	.85	-.00
.020	-8.72	4.70	84.06	.38	1.69	.00
.030	-10.84	-5.58	82.14	-.70	2.57	.00
.040	-9.06	-.49	77.81	-.54	3.35	-.00
.050	-25.80	14.62	71.16	.83	4.09	-.01
.060	-11.24	4.85	66.78	3.63	4.77	.02
.070	-6.94	-2.64	65.11	3.95	5.41	.06
.080	-3.89	-3.56	64.11	2.45	6.10	.09
.090	-5.09	.68	62.98	2.64	6.72	.11
.100	-2.93	2.63	61.45	2.53	7.33	.14
.110	-5.75	1.74	59.88	3.63	7.93	.17
.120	-10.95	.64	57.71	4.39	8.51	.21
.130	-8.41	4.92	54.85	6.87	9.11	.27
.140	-5.75	-6.85	52.71	5.79	9.64	.33
.150	-.93	-3.43	51.86	3.82	10.15	.38
.160	-.12	-1.32	51.36	3.01	10.66	.42
.170	1.80	-1.24	52.01	2.90	11.16	.44
.180	2.13	-1.99	52.68	2.10	11.72	.47
.190	.35	-2.25	53.05	1.70	12.24	.49
.200	-.67	.72	52.70	1.49	12.76	.50
.210	-2.16	-1.44	52.16	1.35	13.28	.52
.220	-.96	-.92	51.42	1.12	13.83	.53
.230	.77	-1.84	51.51	.80	14.33	.54
.240	.43	-.43	51.70	.60	14.84	.55
.250	1.04	-.46	52.02	.36	15.35	.55
.260	-3.89	4.11	51.72	.58	15.86	.56
.270	-6.98	3.03	49.95	1.54	16.40	.57
.280	-4.82	.68	48.31	2.33	16.89	.59
.290	-2.24	-.09	47.25	2.51	17.35	.61
.300	-.73	-3.31	46.72	1.93	17.82	.63
.310	1.82	-1.16	47.16	1.17	18.28	.65
.320	.66	-2.15	47.98	.74	18.78	.66
.330	-.50	.06	48.03	.30	19.25	.66
.340	-1.20	-.55	47.44	.49	19.72	.67
.350	-.96	.40	47.18	.36	20.19	.67
.360	1.70	2.92	46.68	.42	20.65	.68
.370	-4.13	-.28	46.41	.61	21.15	.68
.380	2.86	-2.24	46.43	.72	21.60	.69
.390	-.08	.19	46.38	-.32	22.05	.69
.400	-.35	-2.08	46.40	.12	22.51	.69

TEST ID ------ WBCT-9
TEST DATE ---- 08-24-81
VEHICLE TYPE - MINI-SIZE

VEHICLE MASS = 2040. LBS.
IMPACT SPEED = 59.3 MPH
IMPACT ANGLE = 0.0 DEG.

OCCUPANT - DRIVER
572-50% MALE DUMMY
RESTRAINTS - LAB + SHOULDER BELTS

TIME (SEC)	RESULTANT (G'S) HEAD	CHEST	SI HEAD	CHEST	FEMUR LOADS (LBS) LEFT	RIGHT
0.000	.4	.2	0.0	0.0	17.9	1.8
.010	.8	.4	.0	.0	-3.5	-14.3
.020	1.0	.6	.0	.0	25.1	-3.6
.030	2.4	3.1	.0	.0	429.6	-10.7
.040	3.9	17.7	2.3	3.7	125.3	213.8
.050	28.7	14.8	14.7	48.3	39.4	157.7
.060	26.6	11.2	80.0	75.2	-74.0	-10.7
.070	36.1	12.2	149.2	81.8	-88.1	-66.3
.080	11.3	6.4	170.1	84.3	-38.8	-75.2
.090	5.8	5.3	172.0	85.0	-3.5	-39.4
.100	5.9	5.4	172.4	85.7	-38.8	-28.7
.110	3.0	4.3	172.7	86.1	-49.3	-35.8
.120	6.4	2.6	173.2	86.3	-10.6	-25.1
.130	4.9	3.8	173.6	86.6	-10.6	-28.7
.140	3.8	3.2	173.9	86.8	-24.7	-35.8
.150	4.0	3.9	174.2	87.0	-28.2	-28.7
.160	1.9	3.4	174.4	87.2	-10.6	-21.5
.170	3.0	3.6	174.5	87.4	-10.6	-7.2
.180	2.6	3.5	174.7	87.6	-24.7	-21.5
.190	3.5	2.7	174.9	87.8	-3.5	-19.7
.200	4.4	2.8	175.2	87.9	-8.8	-10.7
.210	2.9	3.2	175.5	88.1	-24.7	-25.1
.220	3.4	4.0	175.8	88.3	-22.9	-25.1
.230	4.1	3.0	176.1	88.5	-7.0	-7.2
.240	4.1	2.8	176.4	88.6	-17.6	-35.8
.250	1.5	2.4	176.6	88.7	-21.1	-25.1
.260	2.6	2.8	176.6	88.8	-10.6	-32.2
.270	1.6	2.9	176.6	88.9	-10.6	-25.1
.280	2.0	3.2	176.7	89.1	-10.6	-10.7
.290	1.3	3.0	176.7	89.2	-10.6	-21.5
.300	2.6	3.8	176.8	89.5	-17.6	-21.5
.310	7.0	5.2	177.1	89.9	-45.8	-32.2
.320	5.2	5.2	177.5	90.5	-3.5	-32.2
.330	5.3	4.8	178.1	91.2	-14.1	-21.5
.340	5.0	4.9	178.6	91.7	-3.5	-17.9
.350	5.9	3.9	179.4	92.1	-17.6	-21.5
.360	7.3	4.0	180.4	92.3	-17.6	-25.1
.370	6.0	3.5	181.0	92.6	-28.2	-21.5
.380	4.7	3.2	181.3	92.8	-10.6	-25.1
.390	2.1	4.0	181.4	93.1	-10.6	-21.5
.400	1.9	3.9	181.5	93.3	-10.6	-25.1

MAXIMUM VALUES AND TIME OF OCCURANCE

	X/LT	SEC	Y/RT	SEC	Z	SEC	R	SEC
HEAD (G'S)	-48.1	.054	-7.7	.062	-27.7	.061	49.1	.054
CHEST (G'S)	-35.3	.052	-6.4	.052	9.7	.053	36.1	.052
FEMUR LOAD (LBS)	430.	.030	0.	.409				

CUMULATIVE PERIOD FOR 60-G LEVEL = 0.000 SEC.

HIC = 148.1 DURING T = .048 TO .073 SEC.

TABLE A.19 (Cont'd)

TEST ID ------ WBCT-9
TEST DATE ---- 08-24-81
VEHICLE TYPE - MINI-SIZE

VEHICLE MASS = 2040. LBS.
IMPACT SPEED = 59.3 MPH
IMPACT ANGLE = 0.0 DEG.

OCCUPANT - PASSENGER
572-50% MALE DUMMY
RESTRAINTS - NONE

TIME (SEC)	RESULTANT (G'S) HEAD	CHEST	-------SI------- HEAD	CHEST	FEMUR LOADS (LBS) LEFT	RIGHT
0.000	.4	.4	0.0	0.0	4.8	4.1
.010	.3	.6	.0	.0	1.0	-3.5
.020	.7	.6	.0	.0	-5.7	-3.5
.030	3.9	2.5	.1	.1	94.6	-1.7
.040	5.8	1.2	.4	.1	129.0	260.2
.050	1.5	4.2	.5	.4	180.5	270.6
.060	5.8	5.4	1.2	1.2	171.0	289.2
.070	19.5	4.3	5.6	1.7	18.2	415.2
.080	30.2	10.3	41.4	2.9	96.5	462.7
.090	6.9	16.4	68.9	10.1	201.6	138.4
.100	22.2	23.7	78.0	37.7	167.2	121.9
.110	10.2	15.7	91.1	63.5	33.4	-1.7
.120	26.6	5.7	105.9	68.0	-6.7	26.9
.130	11.7	6.5	137.6	68.5	-17.1	8.3
.140	12.6	9.1	139.7	69.4	-8.6	-3.5
.150	13.5	4.1	145.6	70.7	-10.5	2.1
.160	8.2	2.1	148.4	70.9	-27.6	-25.9
.170	7.6	3.4	150.5	71.0	-27.6	-32.9
.180	6.5	3.9	152.1	71.3	-19.0	-29.4
.190	4.0	4.6	153.0	71.7	27.7	-6.9
.200	5.4	5.3	153.5	72.1	33.4	36.1
.210	6.6	6.7	154.6	72.8	39.2	51.6
.220	4.9	3.6	155.1	73.3	86.0	39.2
.230	4.9	3.9	155.3	73.5	28.7	12.4
.240	3.0	2.5	155.5	73.6	16.2	4.1
.250	.9	3.9	155.6	73.9	-4.8	10.3
.260	1.9	4.0	155.6	74.3	-20.0	-8.6
.270	3.0	3.0	155.8	74.6	-29.5	0.0
.280	2.3	2.0	156.0	74.6	-25.7	-8.6
.290	2.4	1.5	156.1	74.7	-10.5	-12.1
.300	5.3	3.4	156.6	74.8	-10.5	-8.6
.310	5.5	2.0	157.0	75.0	12.4	4.1
.320	5.1	2.5	157.4	75.1	57.3	18.6
.330	5.4	3.5	157.8	75.3	85.0	37.2
.340	3.3	4.3	158.4	75.7	75.5	41.3
.350	5.1	4.0	159.0	76.1	35.3	35.1
.360	4.8	2.0	159.4	76.2	12.4	31.0
.370	3.7	1.9	159.9	76.3	-12.4	16.5
.380	5.3	1.4	160.2	76.3	-6.7	19.6
.390	2.7	1.1	160.5	76.4	12.4	12.4
.400	4.1	1.6	160.9	76.4	20.1	18.6

MAXIMUM VALUES AND TIME OF OCCURANCE

	X/LT	---SEC	Y/RT	---SEC	Z	----SEC	R	----SEC
HEAD (G'S)	-35.4	.078	18.8	.070	-28.6	.122	35.6	.078
CHEST (G'S)	-24.3	.104	11.1	.094	-17.1	.099	30.1	.097
FEMUR LOAD (LBS)	278.	.035	0.	.409				

CUMULATIVE PERIOD FOR 60-G LEVEL = 0.000 SEC.

HIC = 106.0 DURING T = .066 TO .131 SEC.

TEST WBCT-10

Purpose: Purpose of this test was to determine whether modifications to the wood post BCT to reduce its end-on impact resistance had compromised the system's ability to perform as a longitudinal traffic barrier when impacted downstream of the terminal. This was accomplished by a structural adequacy impact test using a 4500-lb (2041-kg) automobile at 60 mph and a 25-deg angle. Target impact point was the third post (the first steel post) of the installation.

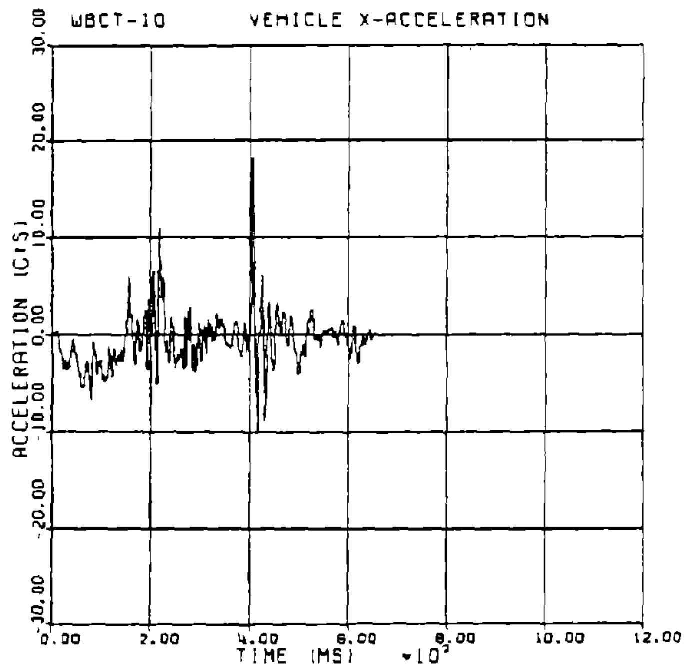
Test Installation: The configuration of the installation was the same as that used for Test WBCT-9. It was, however, re-oriented such that the straight portion of the barrier was at a 25-deg angle to the vehicle track.

Test Vehicle: A 1978 Ford LTD was the test vehicle, and it contained two 50th percentile anthropomorphic dummies in the driver and right front passenger seating positions. The driver dummy was restrained by a lap and shoulder belt whereas the passenger dummy was unrestrained. Total weight of the vehicle, dummies and instrumentation was 4500 lb (2041 kg).

Performance: Impact conditions were 58.1 mph (93.5 kmph) and a 24.9-deg angle. As shown in the sequential photographs of Figure 31, the vehicle impacted the installation at Post 3 and was redirected slightly before the W-beam rail fractured at the third notch location (between Posts 5 and 6). The vehicle then overrode Posts 4 thru 7 and continued in a trajectory approximately parallel to and behind the barrier, stopping 37 ft (11 m) past the end. Maximum 50 msec average accelerations measured during the event were -3.2 g (accelerometer) and -4.6 g (film) in the lateral direction, and -5.2 g (accelerometer) and -4.8 g (film) in the longitudinal direction. A summary of test results is contained in Figure 31; high-speed film analysis is shown in Table A.20. Results of analog to digital conversion of vehicle and dummy transducers is contained in Table A.21 and plotted in Figures A.94 thru A.100.

Barrier Damage: As shown in Figure A.101, barrier damage consisted of one fractured rail section, two bent rail sections, and six bent or twisted steel posts. In addition, the concrete footing of Post 1 was cracked and rotated slightly in the soil.

Vehicle Damage: Most of the deformation of the vehicle occurred in the area forward of the front wheels (bumper, grill, and forward portion of the fenders) as shown in Figure A.101. Both front tires were cut and the rims bent by contact with steel posts and blockouts. In addition, the windshield was cracked from impact by the unrestrained passenger dummy's head.



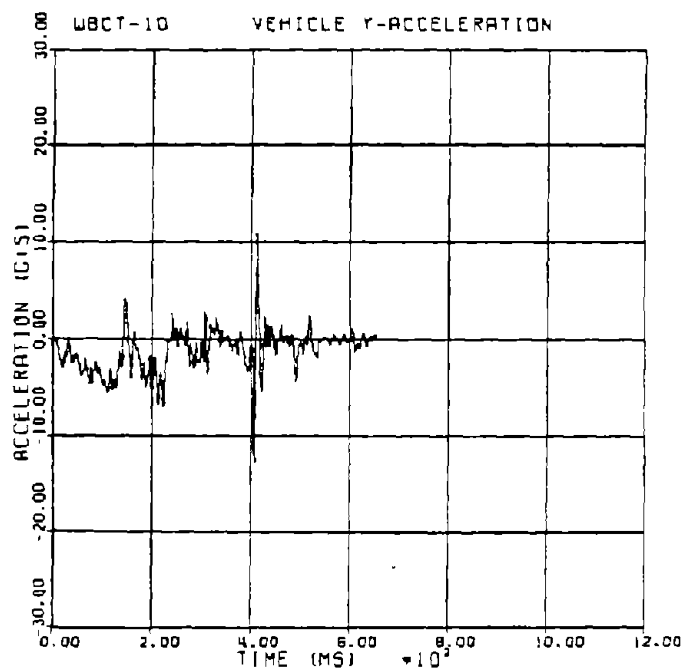


FIGURE A.94 VEHICLE ACCELERATION PLOTS, TEST WBCT-10

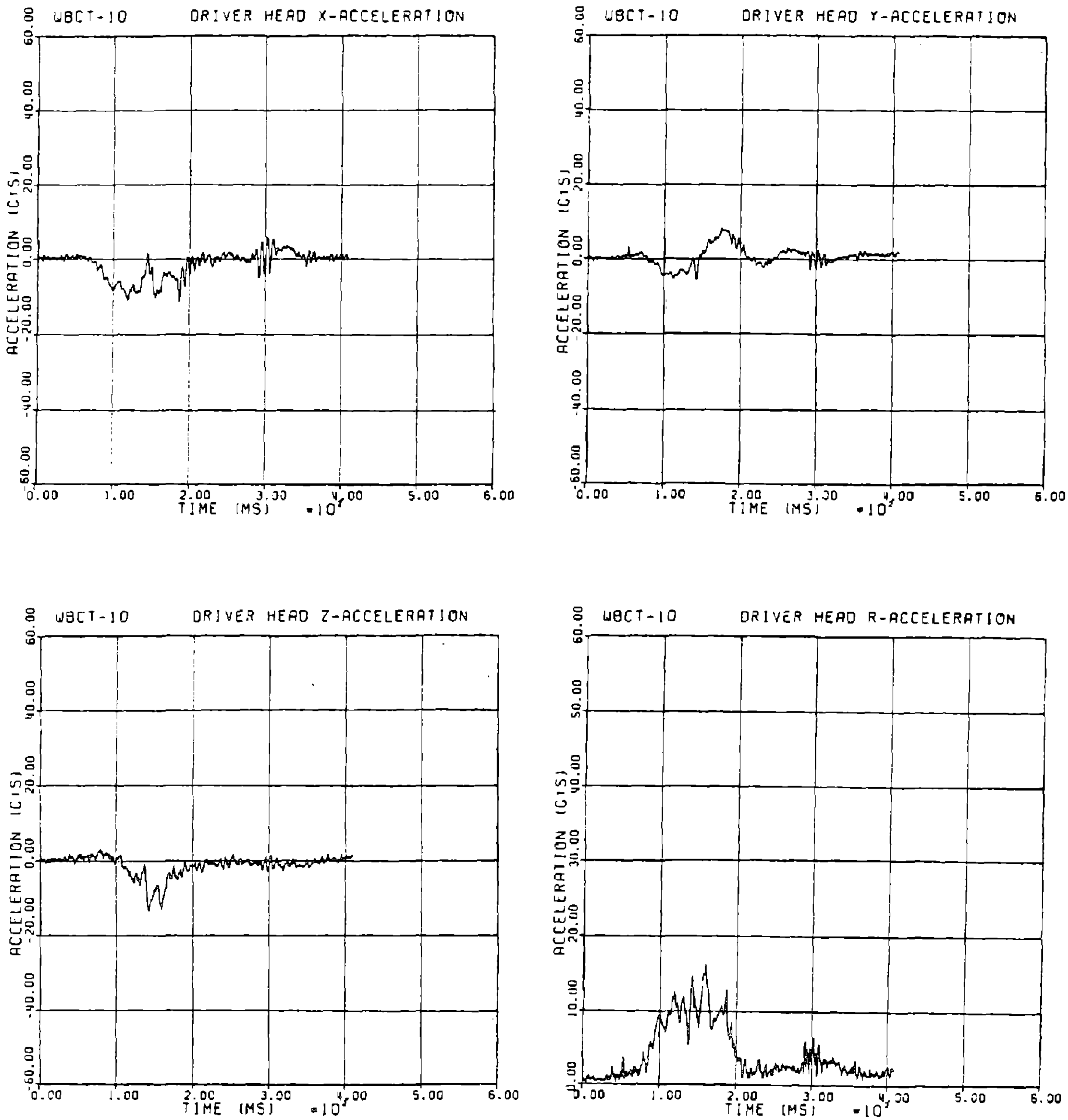


FIGURE A.95 DRIVER DUMMY HEAD ACCELERATION PLOTS, TEST WBCT-10

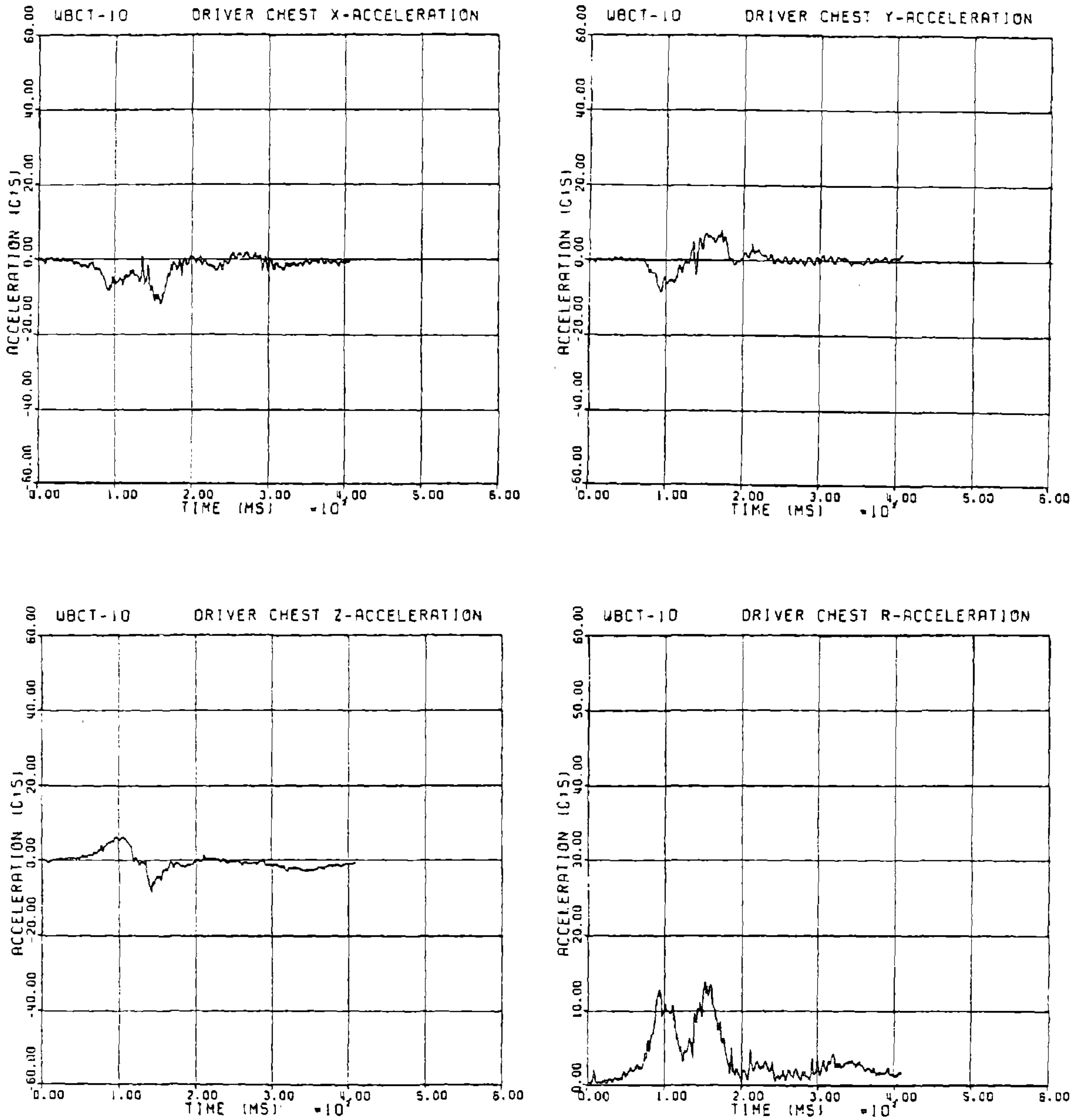
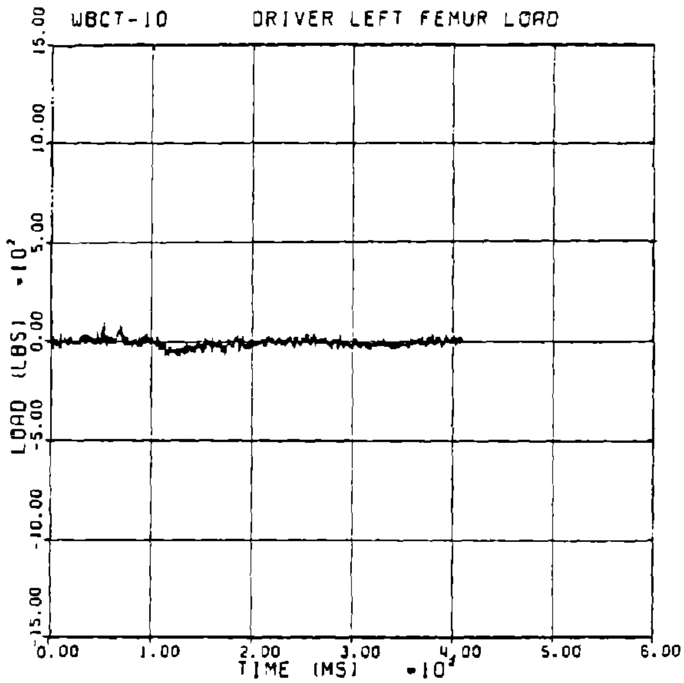


FIGURE A.96 DRIVER DUMMY CHEST ACCELERATION PLOTS, TEST WBCT-10



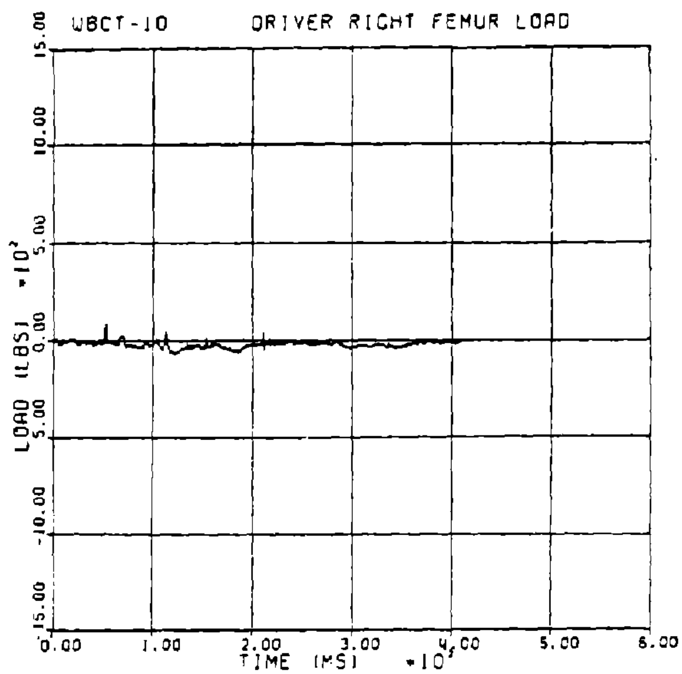


FIGURE A.97 DRIVER DUMMY FEMUR LOAD PLOTS, TEST WBCT-10

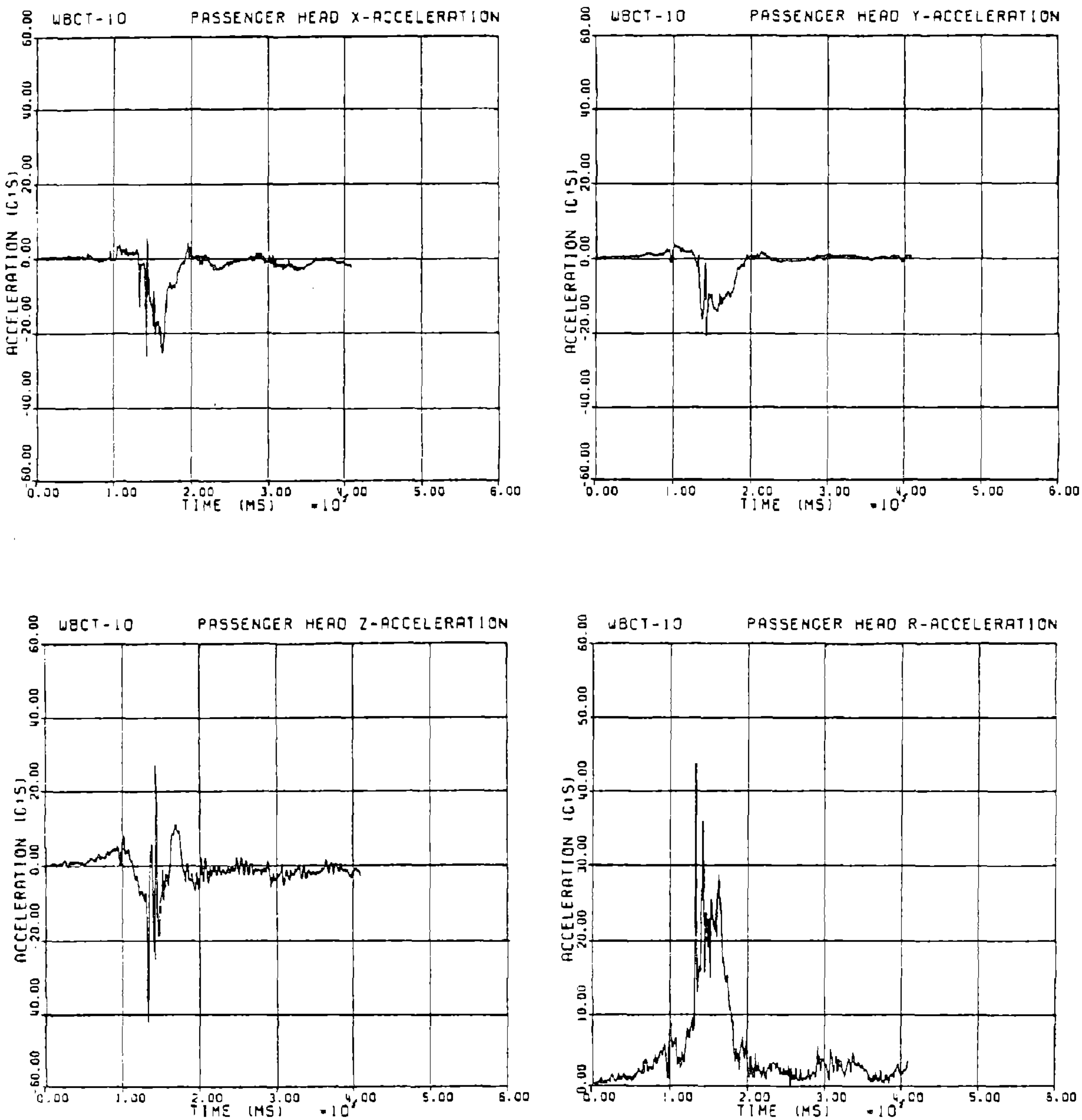


FIGURE A.98 PASSENGER DUMMY HEAD ACCELERATION PLOTS, TEST WBCT-10

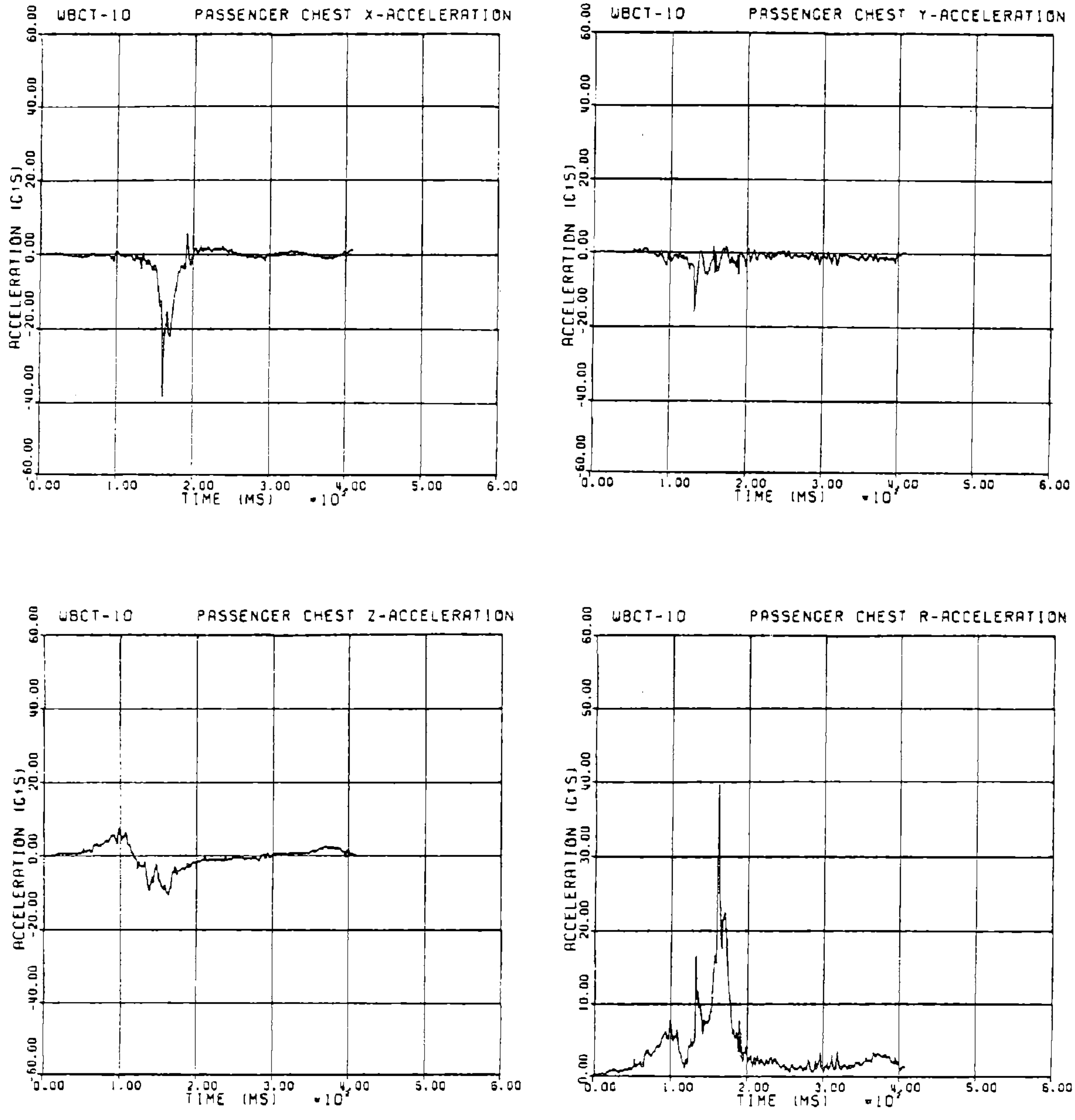
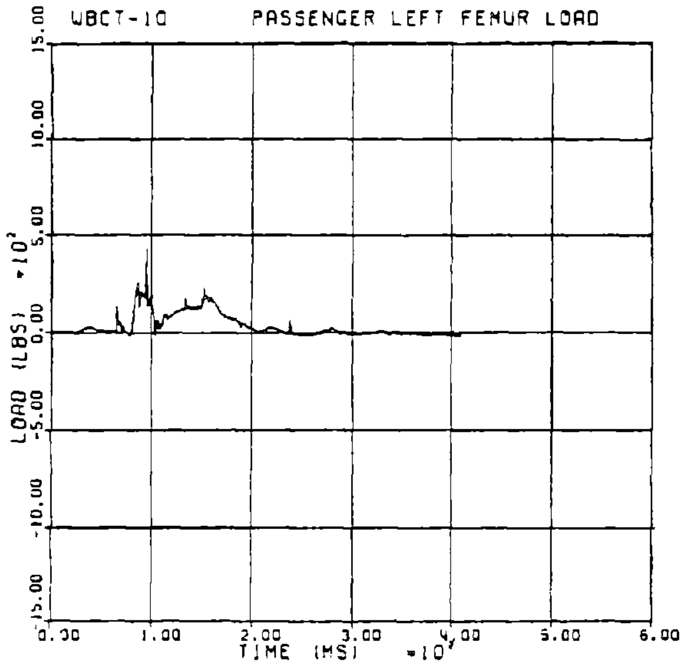


FIGURE A.99 PASSENGER DUMMY CHEST ACCELERATION PLOTS, TEST WBCT-10



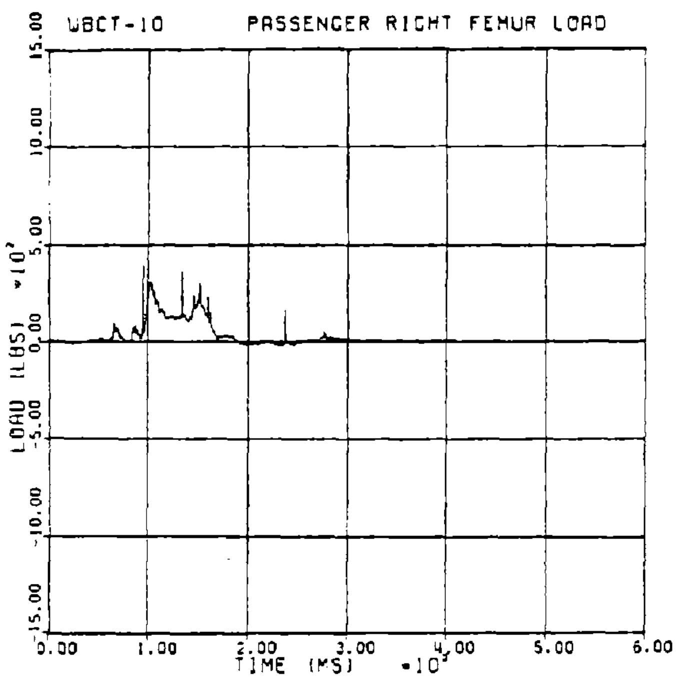


FIGURE A.100 PASSENGER DUMMY FEMUR LOAD PLOTS, TEST WBCT-10

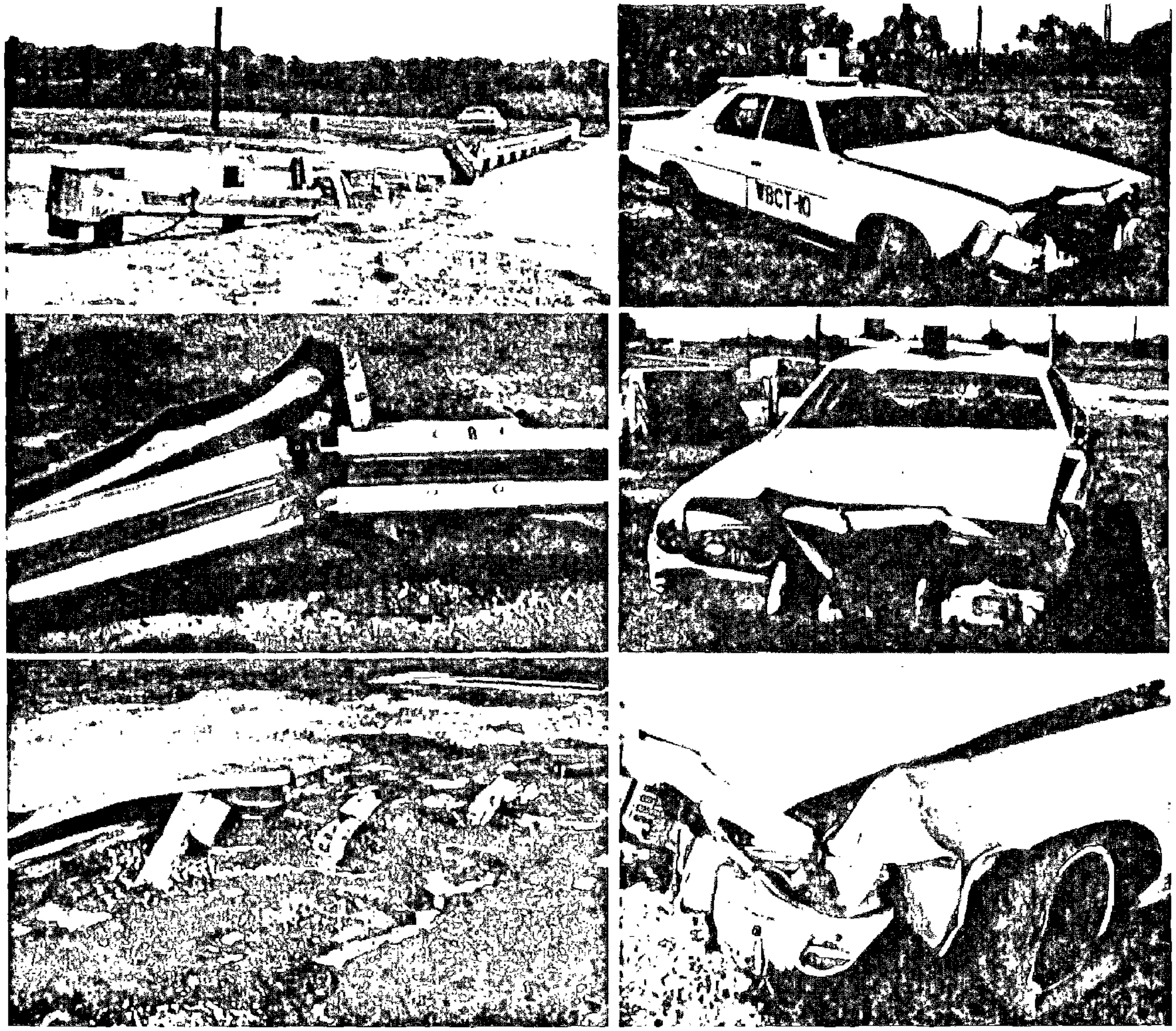


FIGURE A.101 BARRIER AND VEHICLE DAMAGE, TEST WBCT-10

TABLE A.20

RESULTS FROM HIGH-SPEED FILM ANALYSIS, TEST WBCT-10

SUMMARY OF VEHICLE KINEMATIC AND DYNAMIC DATA   WOOD POST BCT TEST WBCT-10   9/18/81

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	-6.33	-4.82	24.89	85.77	.83	-1.58	-.94	0.00	0.00	4652.	6632.
.010	-5.56	-4.46	25.04	85.17	.18	-2.17	-1.79	0.00	0.00	5447.	[illegible]
.020	-4.79	-4.10	25.11	84.37	-.64	-2.76	-2.59	0.00	0.00	6306.	[illegible]
.030	-4.02	-3.75	25.09	83.39	-1.57	-3.33	-3.32	-3.01	-2.35	7219.	[illegible]
.040	-3.26	-3.42	24.96	82.24	-2.55	-3.84	-3.94	-3.52	-3.50	8167.	23332.
.050	-2.51	-3.11	24.70	80.95	-3.52	-4.26	-4.40	-3.97	-4.02	9136.	[illegible]
.060	-1.76	-2.81	24.30	79.55	-4.43	-4.59	-4.70	-4.33	-4.39	10108.	27731.
.070	-1.02	-2.53	23.76	78.08	-5.22	-4.80	-4.81	-4.59	[illegible]	11054.	[illegible]
.080	-.29	-2.28	23.08	76.58	-5.85	-4.91	-4.74	-4.74	-4.62	11986.	28271.
.090	.43	-2.04	22.27	75.08	-6.27	-4.92	-4.48	-4.80	-4.47	12955.	[illegible]
.100	1.14	-1.82	21.35	73.61	-6.45	-4.84	-4.06	-4.77	-4.16	13652.	[illegible]
.110	1.85	-1.62	20.34	72.18	-6.39	-4.70	-3.49	-4.67	-3.70	14359.	22073.
.120	2.54	-1.44	19.26	70.82	-6.06	-4.50	-2.81	-4.51	-3.11	14960.	[illegible]
.130	3.22	-1.27	18.14	69.52	-5.48	-4.28	-2.05	-4.32	-2.42	15441.	14743.
.140	3.90	-1.11	17.02	68.28	-4.65	-4.05	-1.24	-4.11	-1.67	15787.	[illegible]
.150	4.56	-.96	15.90	67.09	-3.60	-3.82	-.42	-3.87	-.89	15990.	6332.
.160	5.21	-.81	14.83	65.95	-2.36	-3.59	.35	-3.68	-.13	16040.	[illegible]
.170	5.85	-.66	13.82	64.86	-.99	-3.39	1.05	-3.49	.57	15934.	-945.
.180	6.47	-.52	12.90	63.80	.49	-3.20	1.63	-3.30	1.19	15559.	[illegible]
.190	7.09	-.37	12.07	62.79	2.00	-3.02	2.07	-3.12	1.68	15246.	[illegible]
.200	7.69	-.22	11.35	61.80	3.50	-2.86	2.34	-2.95	2.02	14671.	-7337.
.210	8.29	-.06	10.73	60.87	4.94	-2.70	2.43	-2.79	2.20	13953.	[illegible]
.220	8.87	.11	10.21	59.97	6.26	-2.54	2.34	-2.63	2.21	13104.	-8347.
.230	9.44	.28	9.78	59.13	7.42	-2.38	2.08	-2.47	2.04	12137.	-7355.
.240	10.01	.45	9.43	58.34	8.39	-2.22	1.66	-2.31	1.73	11078.	-5720.
.250	10.57	.63	9.13	57.61	9.14	-2.06	1.12	-2.15	1.29	9943.	[illegible]
.260	11.12	.82	8.86	56.92	9.67	-1.89	.50	-1.98	.75	8759.	[illegible]
.270	11.66	1.00	8.59	56.30	9.99	-1.72	-.15	-1.81	.17	7556.	[illegible]
.280	12.20	1.18	8.30	55.72	10.12	-1.54	-.77	-1.63	-.41	6362.	4474.
.290	12.74	1.36	7.97	55.20	10.11	-1.35	-1.29	-1.44	-.92	[illegible]	[illegible]
.300	13.27	1.54	7.59	54.73	10.01	-1.15	-1.66	-1.24	-1.11	4130.	[illegible]
.310	13.80	1.70	7.11	54.31	9.89	-.93	-1.81	-1.03	-1.52	3156.	[illegible]
.320	14.32	1.87	6.55	53.95	9.84	-.71	-1.69	-.82	-1.49	2320.	[illegible]
.330	14.85	2.02	5.92	53.64	9.95	-.50	-1.20	-.60	-1.20	1650.	3331.
.340	15.37	2.18	5.22	53.37	10.32	-.31	-.52	-.41	-.52	1171.	[illegible]
.350	15.89	2.33	4.46	53.19	11.01	-.16	.52	-.26	.23	910.	-2232.
.360	16.41	2.48	3.67	52.99	12.09	-.08	1.80	-.15	1.11	377.	[illegible]
.370	16.93	2.64	2.94	52.79	13.59	-.08	3.20	-.14	2.52	1062.	-15551.
.380	17.45	2.81	2.24	52.59	15.48	-.16	4.55	-.19	3.70	1525.	[illegible]
.390	17.97	2.97	1.64	52.33	17.68	-.33	5.60	[illegible]	4.53	2191.	-25142.
.400	18.49	3.19	1.15	52.03	20.01	-.56	6.00	-.52	[illegible]	3057.	-25753.
.410	19.00	3.41	.81	51.68	22.19	-.73	5.32	-.76	[illegible]	[illegible]	[illegible]
.420	19.51	3.65	.57	51.27	23.79	-1.12	2.97	[illegible]	[illegible]	[illegible]	[illegible]

TABLE A.21

TEST WBCT-10 TRANSDUCER DATA

TEST ID ------ WBCT-10
TEST DATE ---- 09-18-81
VEHICLE TYPE - FULL SIZE
IMPACT ANGLE - 25.00 DEGREES
IMPACT SPEED - 88.00 FPS

HIGHEST 50.0-MS AVG. ACCEL.

	G'S	TIME (SEC) START	TIME (SEC) END
LONG.	-3.96	.037	.107
LAT.	[illegible]	.176	.226

VEHICLE KINETICS SUMMARY
NOTE: VALUES ARE INSTANTANEOUS AT TIME

TIME (S)	VEH. ACCEL.(G'S) LONG.	VEH. ACCEL.(G'S) LAT.	VEH. VEL.(FPS) LONG.	VEH. VEL.(FPS) LAT.	VEH. DISP.(F) LONG.	VEH. DISP.(F) LAT.
0.000	-.11	-.06	88.00	0.00	0.00	0.00
.010	.33	-1.03	88.04	-.08	.88	-.00
.020	-3.20	-2.77	87.79	-.30	1.73	-.00
.030	-3.46	.27	86.71	-1.36	2.65	-.02
.040	-1.03	-2.46	85.88	-1.73	3.51	-.03
.050	-2.71	-2.06	85.45	-2.37	4.35	-.05
.060	-5.46	-3.43	84.16	-3.39	5.19	-.08
.070	-2.71	-3.59	82.69	-4.27	6.00	-.12
.080	-5.78	-4.40	81.17	-5.67	6.83	-.17
.090	-4.14	-3.52	80.30	-6.66	7.67	-.23
.100	-3.92	-4.73	79.28	-7.83	8.45	-.30
.110	-4.60	-5.49	77.84	-9.36	9.22	-.39
.120	-3.48	-5.22	77.00	-10.72	9.99	-.48
.130	-2.73	-3.60	76.01	-12.34	10.30	-.61
.140	-1.58	-1.92	75.25	-13.10	11.54	-.73
.150	-.18	1.64	74.73	-12.35	12.29	-.86
.160	1.38	-1.12	75.61	-12.89	13.02	-.98
.170	-1.21	-1.03	75.39	-12.99	13.76	-1.11
.180	-1.47	-4.05	75.35	-13.90	14.56	-1.25
.190	1.51	-4.12	75.42	-14.95	15.30	-1.39
.200	-.04	-4.72	75.63	-16.11	16.04	-1.54
.210	-2.37	-5.46	76.55	-17.25	16.79	-1.71
.220	6.38	-4.65	77.42	-18.75	17.60	-1.90
.230	-1.91	-1.33	78.72	-20.32	18.37	-2.10
.240	1.29	2.59	78.79	-20.26	19.14	-2.30
.250	-2.93	.09	78.06	-20.02	19.91	-2.49
.260	-1.58	0.00	77.26	-19.95	20.68	-2.69
.270	-2.05	1.73	76.20	-19.96	21.30	-2.90
.280	2.77	-1.37	76.83	-20.20	22.25	-3.10
.290	-3.67	-1.63	76.31	-20.84	23.00	-3.30
.300	-1.85	-.43	75.84	-21.50	23.75	-3.51
.310	.41	-3.66	75.60	-21.69	24.49	-3.72
.320	-.37	1.03	75.60	-21.92	25.30	-3.96
.330	-.31	1.76	75.38	-21.59	26.04	-4.17
.340	1.07	.32	75.93	-21.46	26.78	-4.38
.350	-.55	.21	75.24	-21.47	27.53	-4.59
.360	-1.39	-.69	75.71	-21.55	28.28	-4.80
.370	1.22	-.71	75.70	-21.80	29.09	-5.03
.380	-2.09	-.09	75.81	-21.90	29.83	-5.25
.390	1.07	-3.03	75.48	-22.36	30.57	-5.47
.400	-.29	-.36	75.30	-23.15	31.31	-5.69
.410	-.95	7.49	77.47	-24.61	32.12	-5.74
.420	.18	-5.45	75.87	-23.71	32.88	-6.18
.430	-7.52	-.63	76.72	-24.10	33.63	-6.41
.440	3.21	1.10	75.76	-24.07	34.37	-6.65
.450	-2.72	-1.87	75.33	-24.07	35.12	-6.89
.460	.87	1.46	75.78	-24.08	35.92	-7.14
.470	2.32	.21	76.12	-24.01	36.67	-7.38
.480	.15	.12	76.14	-24.38	37.42	-7.62
.490	-1.14	-4.09	76.45	-24.33	38.17	-7.85
.500	-4.30	-.40	75.59	-24.98	38.91	-8.10
.510	-1.43	.12	74.84	-25.16	39.71	-8.36
.520	1.51	.94	74.69	-24.39	40.43	-8.61
.530	.72	-1.46	75.31	-25.12	41.16	-8.86
.540	-.11	-.17	75.26	-25.51	41.92	-9.10
.550	.41	.09	75.26	-25.51	42.66	-9.36
.560	.52	-.60	75.15	-25.57	43.46	-9.63
.570	-.29	.33	75.23	-25.82	44.20	-9.88
.580	-1.03	-.54	75.17	-25.56	44.74	-10.13
.590	1.14	.15	75.33	-25.55	45.68	-10.38
.600	-1.43	.21	75.32	-25.61	46.42	-10.63

TEST ID ------ WBCT-10
TEST DATE ---- 09-18-81
VEHICLE TYPE - FULL-SIZE

VEHICLE MASS = 4500. LBS. OCCUPANT - DRIVER
IMPACT SPEED = 60.0 MPH 572-50% MALE DUMMY
IMPACT ANGLE = 25.0 DEG. RESTRAINTS - LAB + SHOULDER BELTS

TIME	RESULTANT (G'S)		-------SI-------		FEMUR LOADS (LBS)	
(SEC)	HEAD	CHEST	HEAD	CHEST	LEFT	RIGHT
0.000	.4	.0	0.0	0.0	20.1	1.8
.010	.7	.3	.0	.0	34.7	-19.3
.020	.4	.2	.0	.0	23.8	5.3
.030	1.1	.3	.0	.0	-1.8	-8.8
.040	.8	.6	.0	.0	16.5	-33.3
.050	.9	1.2	.0	.0	20.1	-1.8
.060	1.3	1.9	.1	.1	14.6	-8.8
.070	2.1	2.3	.1	.2	65.8	24.9
.080	3.2	5.2	.2	.6	-32.5	-33.3
.090	5.4	12.0	.6	2.8	-16.3	-40.3
.100	9.4	10.9	2.2	6.9	1.8	-15.8
.110	9.2	10.7	4.1	10.0	-38.0	-40.3
.120	11.9	4.4	7.8	11.4	-56.1	-64.8
.130	11.9	5.4	11.5	11.9	-54.2	-36.8
.140	12.1	9.0	14.1	13.0	-59.7	-26.3
.150	8.7	12.3	18.8	16.2	-59.7	-29.8
.160	15.5	13.3	24.8	22.1	-56.1	-22.8
.170	7.6	7.5	28.7	25.3	-27.1	-36.8
.180	10.7	4.0	31.5	26.4	-19.9	-57.8
.190	6.6	1.8	34.8	26.6	-23.5	-45.5
.200	5.2	.7	35.7	26.6	-9.0	-26.3
.210	1.2	1.9	35.9	26.6	-1.8	-24.5
.220	2.4	3.2	36.0	26.8	12.8	-15.8
.230	3.6	3.2	36.0	26.9	1.8	-8.8
.240	2.9	3.2	36.1	27.0	-30.7	-1.8
.250	2.1	.8	36.1	27.0	12.8	-8.8
.260	2.1	1.3	36.2	27.0	20.1	-8.8
.270	2.6	2.2	36.3	27.1	-12.7	-19.3
.280	1.7	1.8	36.4	27.1	7.3	-15.8
.290	3.9	.7	36.5	27.1	-27.1	-33.3
.300	2.7	2.3	36.8	27.2	-27.1	-36.8
.310	5.6	2.3	37.2	27.3	-9.0	-36.8
.320	2.4	4.1	37.4	27.5	-16.3	-24.5
.330	3.0	2.5	37.6	27.6	-23.5	-26.3
.340	1.9	3.1	37.7	27.8	-23.5	-29.8
.350	1.6	2.8	37.8	27.9	-16.3	-33.3
.360	1.3	2.4	37.9	28.0	-1.8	-19.3
.370	1.6	1.7	37.9	28.1	-21.7	-15.8
.380	1.7	1.5	37.9	28.2	-23.5	-5.3
.390	1.3	2.2	38.0	28.2	-19.9	-5.3
.400	2.0	1.1	38.0	28.2	-1.8	-19.3

MAXIMUM VALUES AND TIME OF OCCURANCE

	X/LT---SEC		Y/RT---SEC		Z----SEC		R----SEC	
HEAD (G'S)	-11.5	.187	8.1	.175	-13.6	.143	16.3	.159
CHEST (G'S)	-11.8	.160	-8.6	.093	-8.7	.143	13.9	.152
FEMUR LOAD (LBS)	93.	.052	0.	.409				

CUMULATIVE PERIOD FOR 60-G LEVEL = 0.000 SEC.

HIC = 31.8 DURING T = .093 TO .196 SEC.

TEST ID ------ WBCT-10
TEST DATE ---- 09-18-81
VEHICLE TYPE - FULL-SIZE

VEHICLE MASS = 4500. LBS.
IMPACT SPEED = 60.0 MPH
IMPACT ANGLE = 25.0 DEG.

OCCUPANT - PASSENGER
572-50% MALE DUMMY
RESTRAINTS - NONE

TIME (SEC)	RESULTANT (G'S) HEAD	CHEST	-------SI------- HEAD	CHEST	FEMUR LOADS (LBS) LEFT	RIGHT
0.000	.3	.1	0.0	0.0	0.0	.8
.010	.8	.4	.0	.0	0.0	4.0
.020	.9	.8	.0	.0	0.0	-2.0
.030	.5	.6	.0	.0	8.7	-2.0
.040	1.5	.9	.0	.0	26.2	4.0
.050	.6	1.1	.1	.0	0.0	4.0
.060	2.2	2.0	.1	.0	2.9	-10.0
.070	3.8	3.2	.2	.2	35.0	48.5
.080	4.4	4.0	.3	.4	52.4	7.2
.090	4.4	5.6	.7	.8	190.9	34.2
.100	8.7	6.2	1.3	1.8	147.1	269.8
.110	3.1	3.5	2.3	2.4	40.8	180.7
.120	4.9	1.8	2.6	2.5	87.4	125.0
.130	8.1	4.7	4.4	2.9	122.4	132.9
.140	25.1	7.1	25.6	6.2	125.3	109.0
.150	19.9	8.4	56.4	7.6	147.1	217.3
.160	20.5	36.0	79.4	18.1	176.3	233.2
.170	16.0	22.4	105.7	50.3	96.2	19.9
.180	9.1	5.9	112.4	58.6	75.8	29.4
.190	2.7	2.7	113.0	59.2	51.0	.8
.200	4.6	1.9	113.7	59.5	23.3	-8.7
.210	2.3	2.6	113.8	59.6	-2.9	-15.4
.220	2.2	1.9	113.9	59.6	23.3	-3.3
.230	2.0	2.6	114.0	59.7	2.9	-15.4
.240	2.8	1.8	114.1	59.7	0.0	-2.0
.250	1.6	.8	114.2	59.8	-2.9	-3.3
.260	1.5	1.5	114.2	59.8	-2.9	7.2
.270	1.2	1.3	114.3	59.8	4.4	-2.0
.280	1.5	2.3	114.3	59.8	20.4	13.5
.290	2.1	2.2	114.3	59.8	2.9	19.9
.300	3.4	.4	114.6	59.9	2.9	7.2
.310	4.4	1.6	114.7	59.9	0.0	4.0
.320	3.1	1.7	114.9	60.0	2.9	2.4
.330	2.7	1.2	115.0	60.0	5.8	2.4
.340	3.2	1.2	115.2	60.0	0.0	-4.7
.350	3.0	1.6	115.4	60.0	0.0	.8
.360	1.2	2.2	115.5	60.1	-2.9	-4.7
.370	.6	2.8	115.5	60.2	-8.8	-2.0
.380	1.4	2.9	115.5	60.4	-2.9	-2.0
.390	2.0	1.9	115.5	60.5	-5.9	-2.0
.400	2.2	1.3	115.6	60.5	-11.7	-2.0

MAXIMUM VALUES AND TIME OF OCCURANCE

	X/LT	---SEC	Y/RT	---SEC	Z	----SEC	R	----SEC
HEAD (G'S)	-26.0	.142	-20.7	.143	-41.7	.133	43.7	.133
CHEST (G'S)	-38.3	.161	-15.9	.132	-10.6	.162	39.7	.161
FEMUR LOAD (LBS)	431.	.094	0.	.409				

CUMULATIVE PERIOD FOR 60-G LEVEL = 0.000 SEC.

HIC = 94.6 DURING T = .132 TO .176 SEC.

TEST RBCT-1

Purpose: Purpose of this test was to verify the anchorage capability of the wood post BCT after modifications had been incorporated to reduce its end-on impact resistance. This was to be accomplished by impacting the barrier with a 4700-lb vehicle at 60 mph and a 25-deg angle. However, impact speed was only 50.5 mph (81.3 kmph) necessitating a test rerun. For this reason only a minimum of data is presented.

Test Installation: Total length of the installation was 100 ft (30 m) with a 37.5-ft (11.4-m) flared BCT system at the upstream end. This transitioned into a standard G4S (steel post) guardrail system which was anchored at the downstream end. Retrofit modifications which had been incorporated to reduce the end-on impact resistance of the BCT included: (1) sawcut midway through the first wood post; (2) notches in the W-beam rail at locations 3 ft (0.9 m), 11 ft (3.3 m), 23 ft (7.0 m), and 36 ft (11.0 m) from the first post; (3) a wood spacer located inside the buffer end. These modifications were developed in a previous FHWA program and are shown in Figure A.102. In addition, two wire ropes were nested in the corrugations behind the W-beam rail from just upstream of Post 3 to just downstream of Post 8. These were attached to the W-beam using special brackets as shown in Figure A.102. The wire ropes were utilized to provide additional support of the notched rail for impacts downstream of the terminal in which the rail must function as a tension member.

Test Vehicle: The test vehicle was a 1978 Ford LTD with a test inertia weight of 4535 lb (2057 kg). A 50th percentile male dummy was placed in the driver's position and restrained with lap and shoulder belts. Gross test weight was 4700 lb (2132 kg).

Performance: Impact conditions were 50.5 mph (81.3 kmph) and a 25-deg angle. As shown in the sequential photographs of Figure A.103 the vehicle impacted the barrier at Post 3, deflected it rearward and was then redirected, losing contact with the rail 2 ft (0.6 m) downstream of Post 8. The vehicle then continued in a trajectory away from the barrier for a short distance, then it swerved back into it, making slight contact and finally stopping adjacent to Post 14. Due to the vehicle being underspeed and a retest required, high-speed film analysis and analog to digital conversion of accelerometer data were not performed.

Barrier Damage: As shown in Figure A.104 the barrier between Posts 3 and 8 was deflected rearward and requires replacement prior to retest. The concrete footing of Post 1 rotated in the soil and will require realignment and retamping. Although the vehicle made secondary contact with the barrier near Post 14 no damage resulted from it.

Vehicle Damage: Vehicle damage, also shown in Figure A.104 consisted mostly of sheet metal distortion and suspension damage in the left front quadrant. In addition, the left rear tire deflated during the impact sequence.

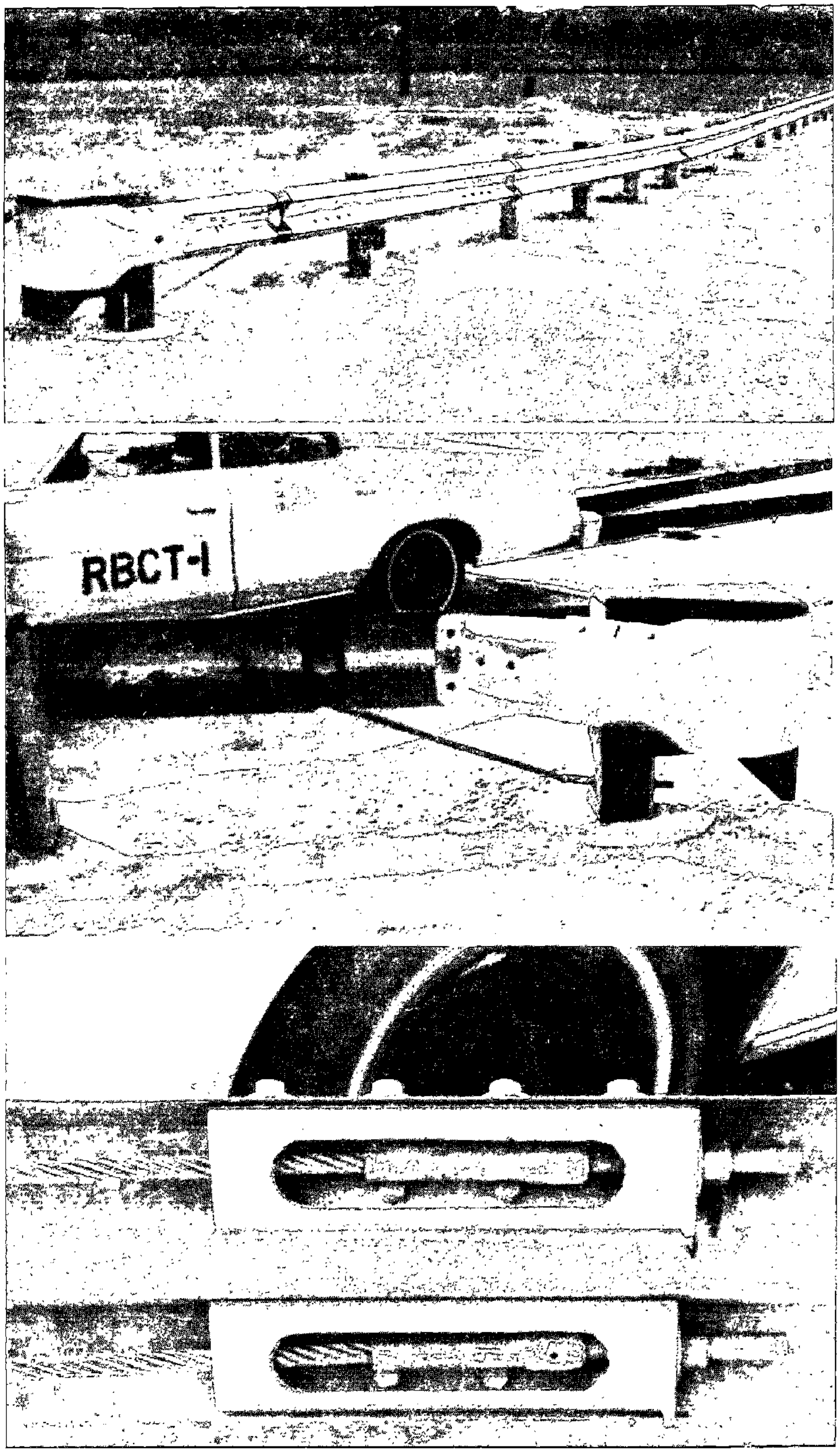


FIGURE A.102 RETROFIT BCT TEST INSTALLATION

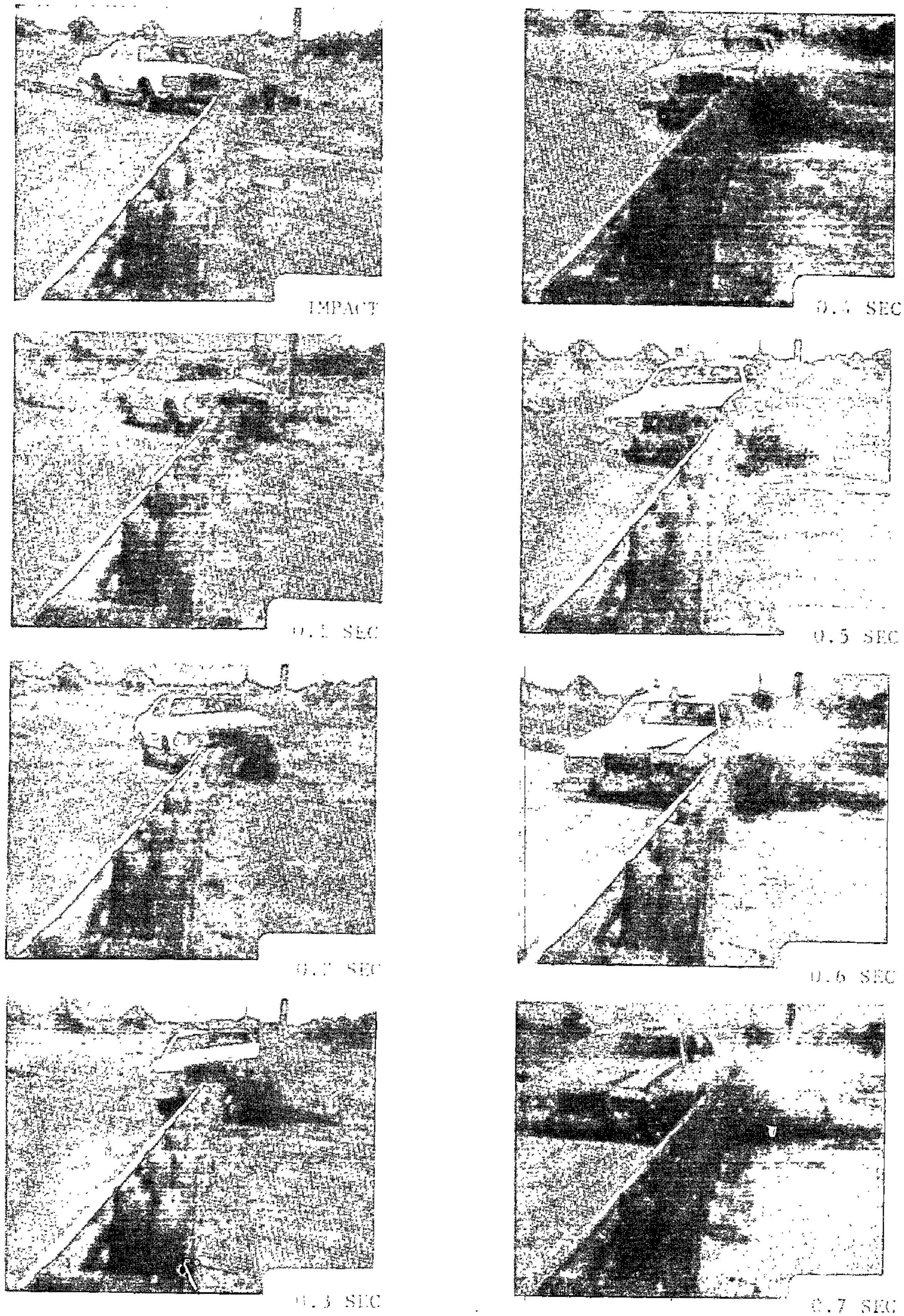


FIGURE A.103 TEST RBCT-1 IMPACT SEQUENCE

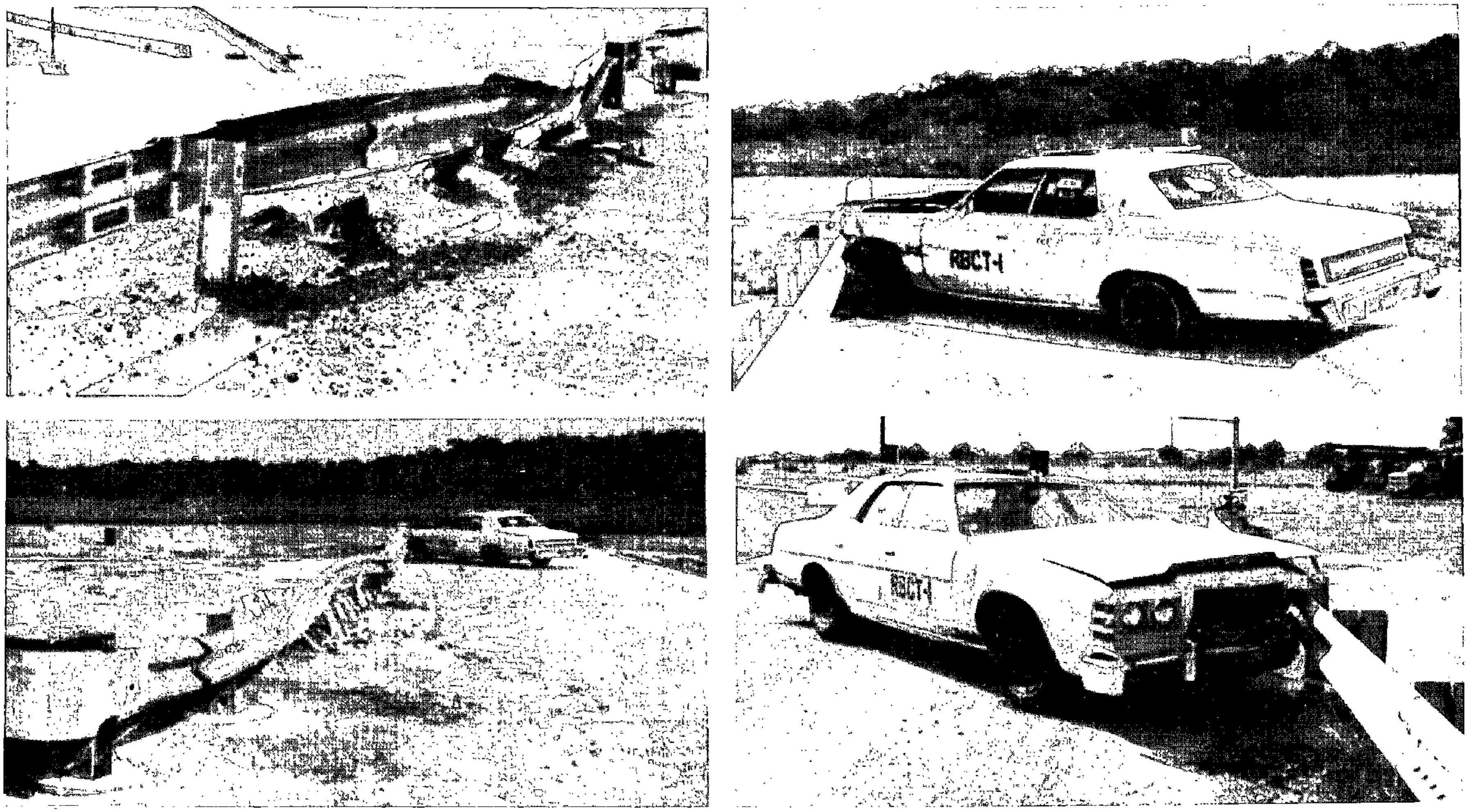


FIGURE A.104 BARRIER AND VEHICLE DAMAGE, TEST RBCT-1

TEST RBCT-2

Purpose: Purpose of this test was to verify the anchorage capability of the wood post BCT after modifications had been incorporated to reduce its end-on impact resistance. This was a repeat of Test RBCT-1 in which the impact speed was only 50.5 MPH (81.3 kmph) instead of the desired 60 MPH (96.6 kmph).

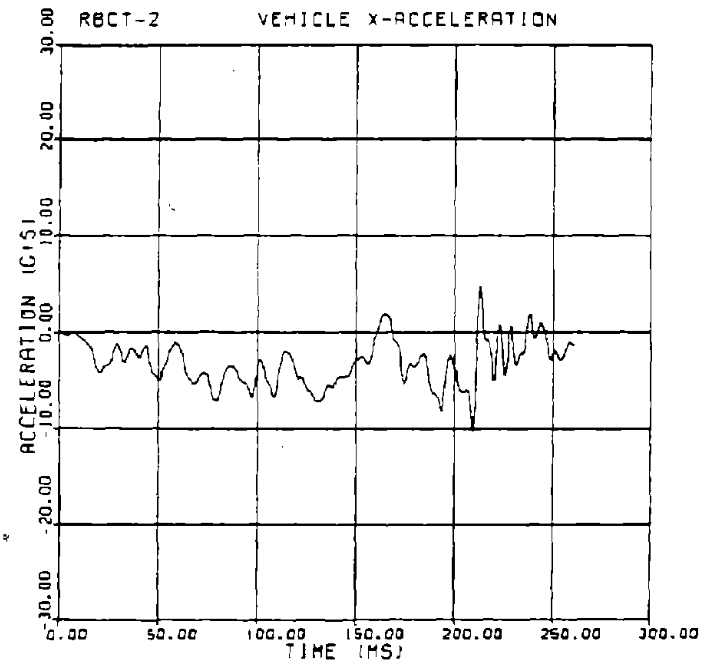
Test Installation: The configuration of the test insta-lation was the same as that of Test RBCT-1. Barrier Damage sustained in that test was repaired.

Test Vehicle: A 1978 Ford LTD was the test vehicle. Inertia weight of the vehicle and instrumentation was 4555 Lb (2066 kg). A 50th percentile male dummy was placed in the driver's position and restrained with lap and shoulder belts. Gross test weight was 4720 Lb (2141 kg).

Performance: Impact conditions were 58.7 MPH (94.5 kmph) and 26.8 deg. As shown in the sequential photographs of Figure 34, the vehicle impacted the installation at Post 3, deflected it rearward and pocketed causing rail fracture at the notch between Posts 5 and 6 and post fracture at Posts 1 and 2. The vehicle then overode Posts 4, 5, and 6 and continued behind the barrier where it impacted a camera stand and stopped approximately normal to the barrier 40 ft (12M) past the downstream end. Maximum 50 MSEC average vehicle accelerations taken from high-speed film analysis were -4.7 g's in the longitudinal direction and -3.7 g's in the lateral direction. A summary of test results is contained in Figure 35 and Table A.22 contains film analysis data. Analog to digital conversion of accelerometer data is contained in Table A.23 and plotted in Figures A.105 thru A.108.

Barrier Damage: As shown in Figure A.109, the entire barrier up to Post 8 was damaged and required replacement. The footings at Posts 1 and 2 were rotated slightly in the soil and required realignment and retamping.

Vehicle Damage: Vehicle damage, as shown in Figure A.110 was confined mostly to the structure forward of the front wheels, and some suspension damage. Sheet metal deformation on the right front corner of the vehicle was caused by the secondary impact with the camera stand and should be disregarded.



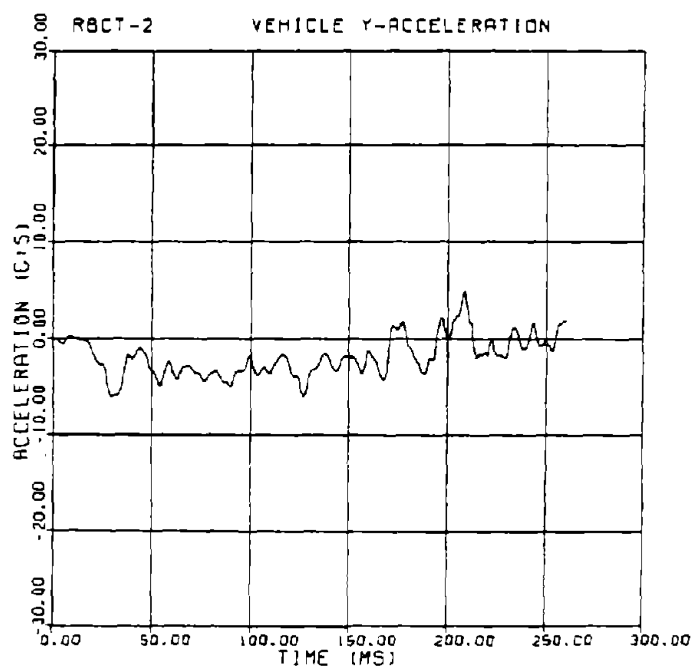
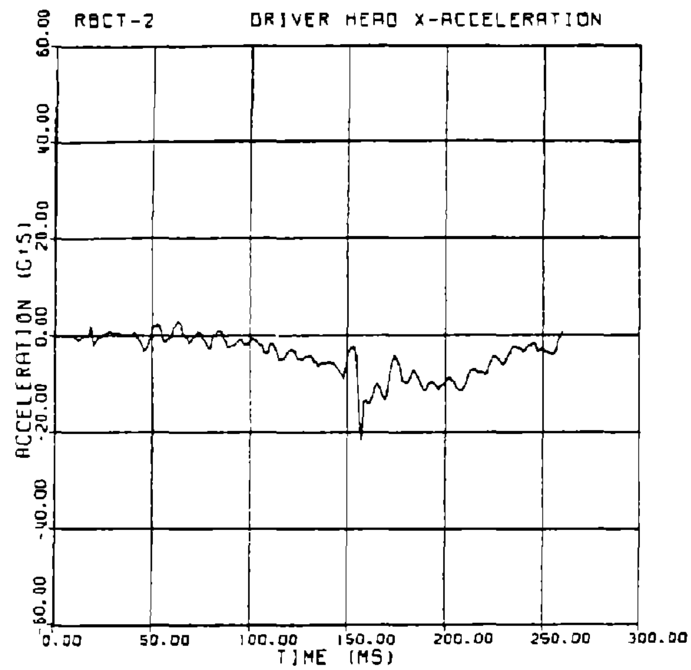
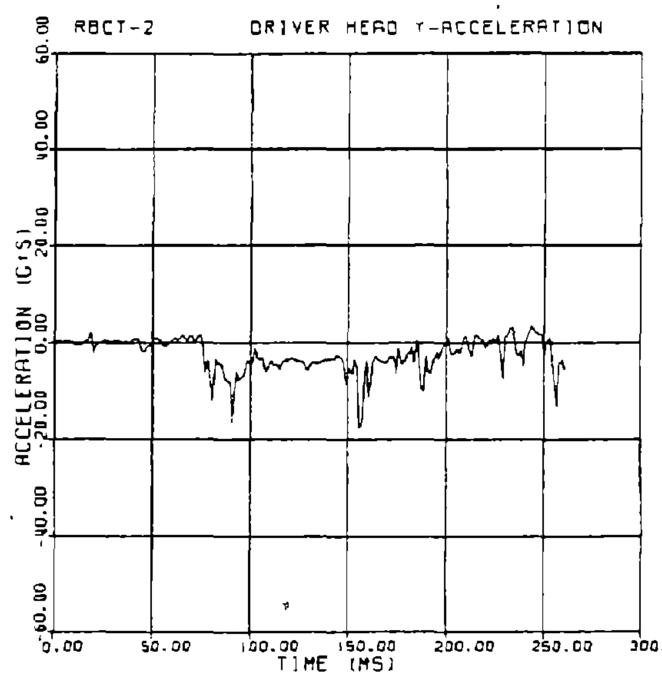


FIGURE A.105 VEHICLE ACCELERATION PLOTS, TEST RBCT-2





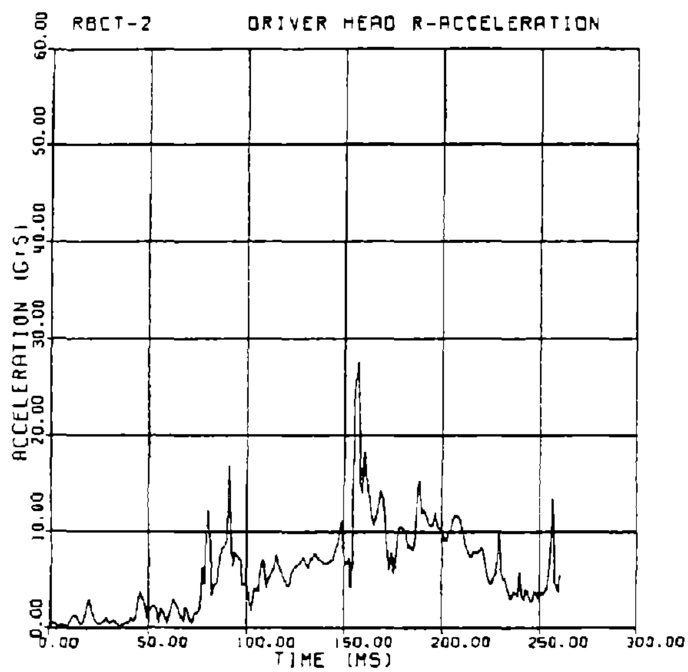


FIGURE A.106 DRIVER DUMMY HEAD ACCELERATION PLOTS, TEST RBCT-2

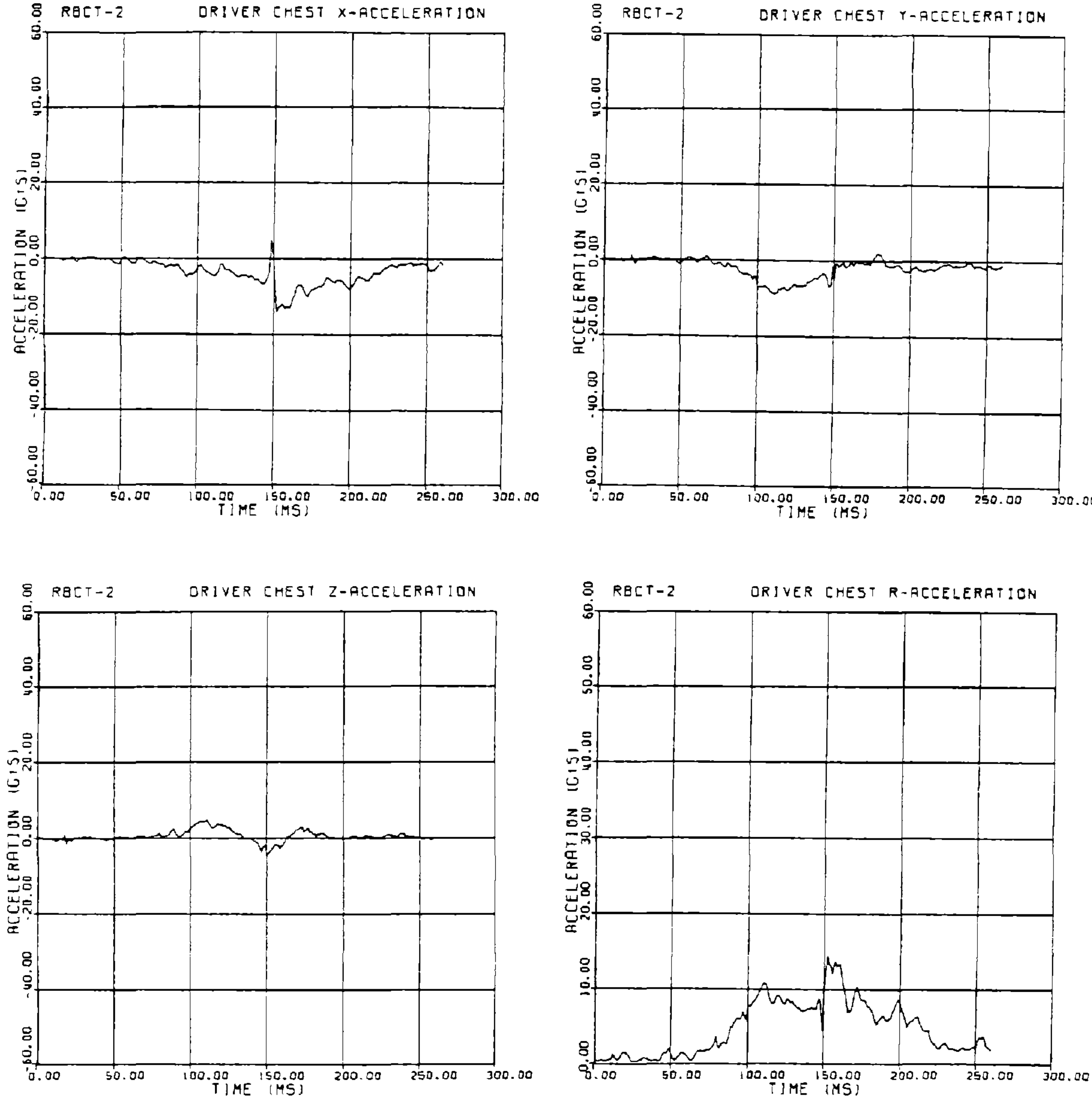
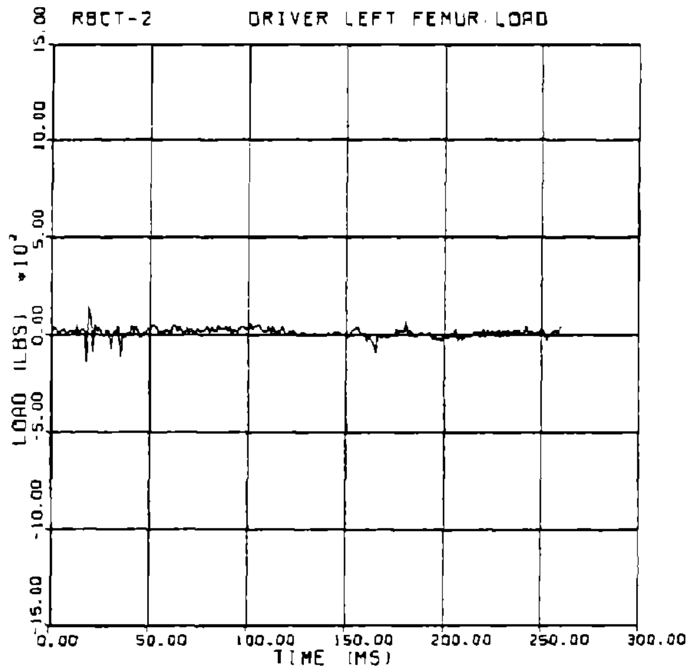


FIGURE A.107 DRIVER DUMMY CHEST ACCELERATION PLOTS, TEST RBCT-2



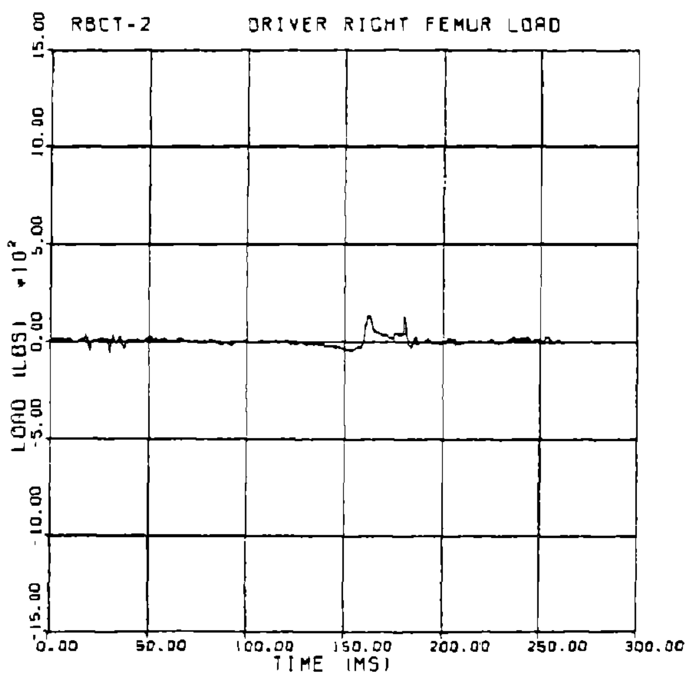


FIGURE A.108 DRIVER DUMMY FEMUR LOAD PLOTS

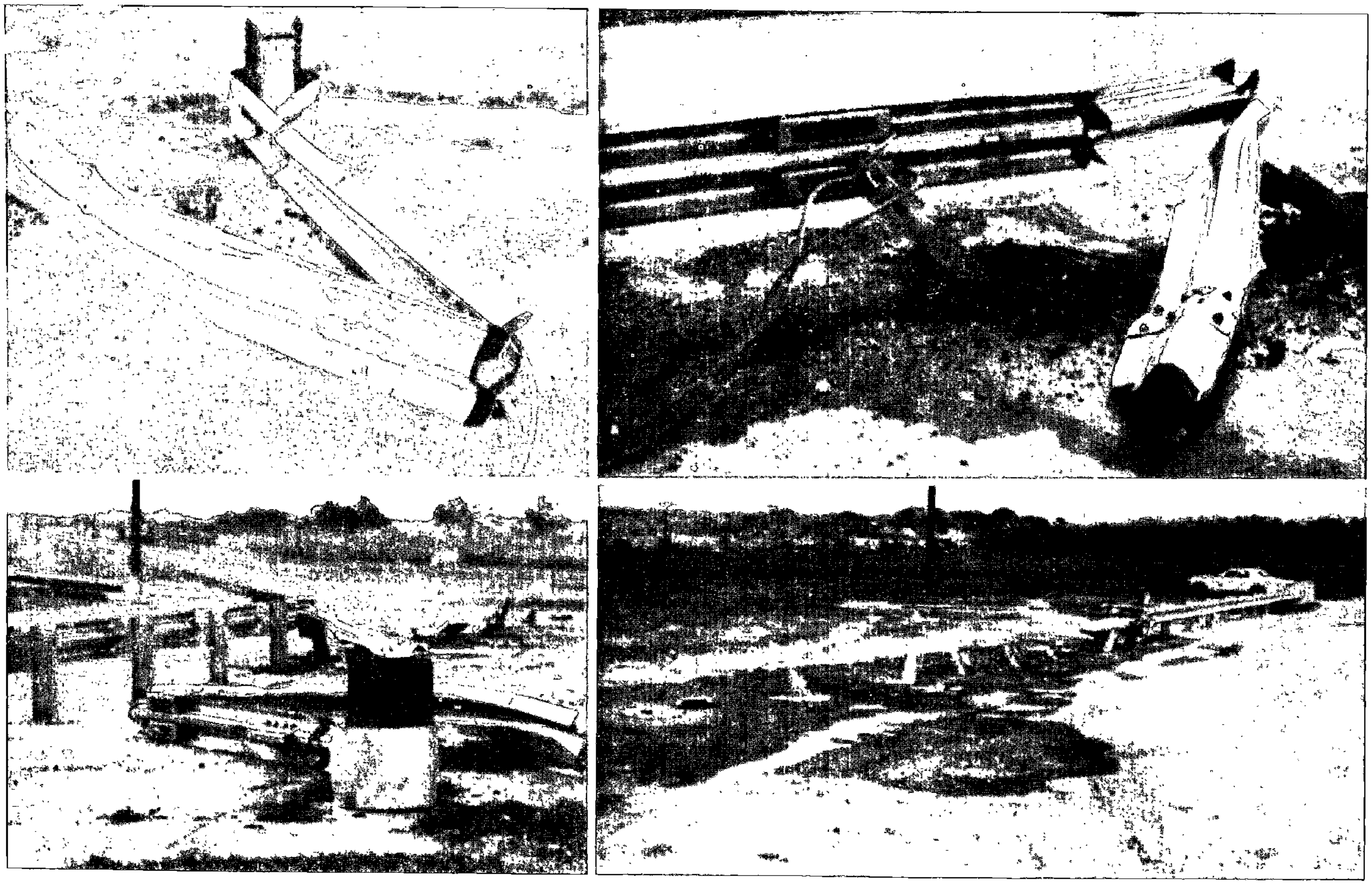


FIGURE A.109 BARRIER DAMAGE, TEST RBCT-2

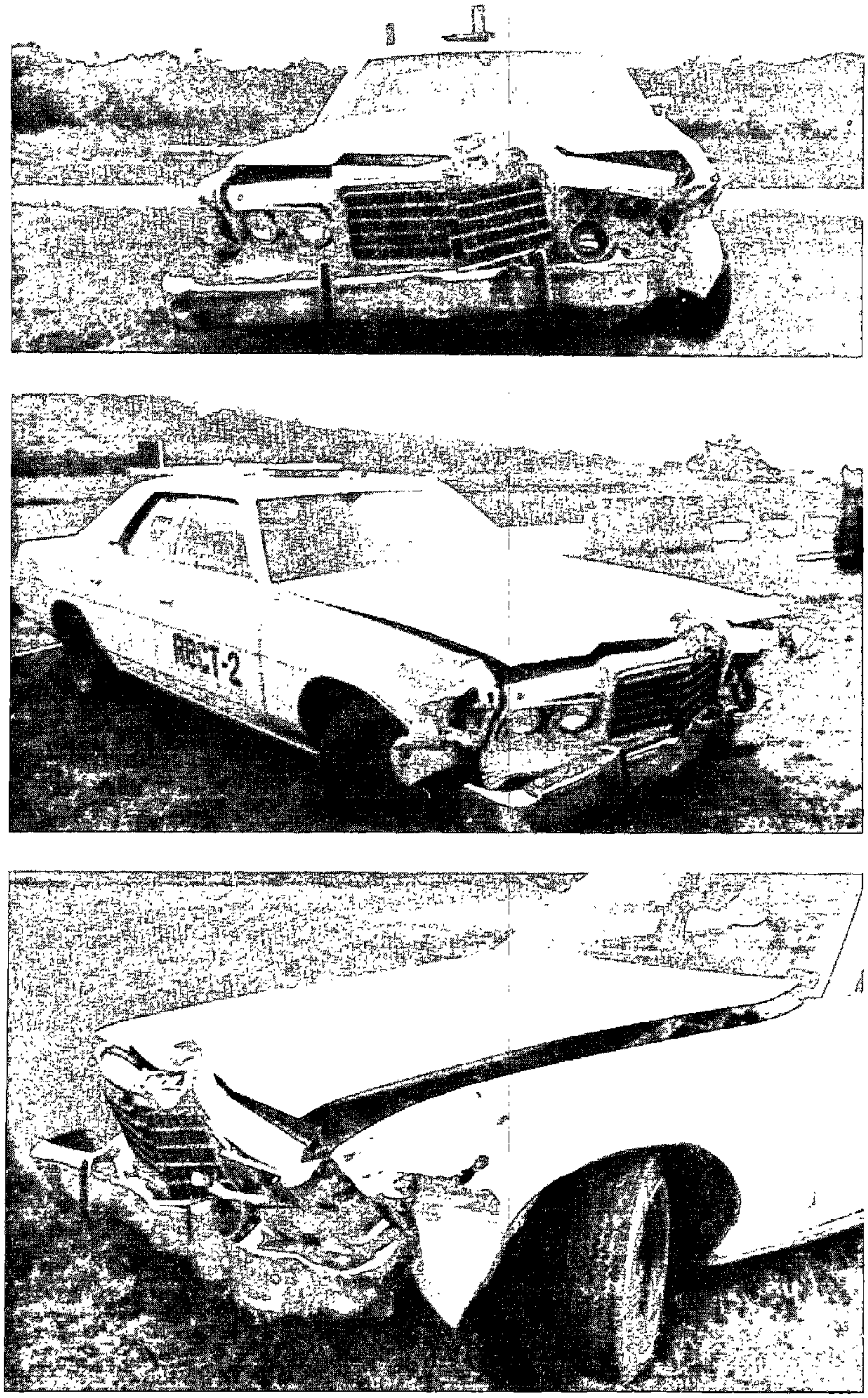


FIGURE A.110 VEHICLE DAMAGE, TEST RBCT-2

TABLE A.22

HIGH-SPEED FILM ANALYSIS, TEST RBCT-2

SUMMARY OF VEHICLE KINEMATIC AND DYNAMIC DATA　　　　RETROFIT BCT TEST RBCT-2　　11/13/81

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	-7.55	-4.52	26.80	86.11	-.97	-1.08	.21	0.00	0.00	4984.	1414.
.010	-6.78	-4.14	26.89	85.67	-1.11	-1.67	-.25	0.00	0.00	6514.	4626.
.020	-6.01	-3.76	26.93	85.03	-1.35	-2.30	-.81	0.00	0.00	7960.	8344.
.030	-5.25	-3.39	26.92	84.18	-1.68	-2.93	-1.42	-2.59	-1.13	9277.	12234.
.040	-4.50	-3.03	26.82	83.15	-2.10	-3.50	-2.03	-3.16	-1.70	10432.	15994.
.050	-3.75	-2.69	26.63	81.95	-2.56	-4.00	-2.58	-3.67	-2.24	11400.	19365.
.060	-3.01	-2.34	26.33	80.61	-3.05	-4.39	-3.06	-4.10	-2.74	12170.	22144.
.070	-2.28	-2.02	25.92	79.17	-3.53	-4.67	-3.43	-4.42	-3.14	12736.	24190.
.080	-1.55	-1.72	25.39	77.68	-3.95	-4.82	-3.68	-4.62	-3.45	13099.	25420.
.090	-.84	-1.43	24.74	76.16	-4.28	-4.84	-3.79	-4.71	-3.63	13268.	25811.
.100	-.13	-1.16	23.98	74.67	-4.50	-4.75	-3.77	-4.68	-3.69	13257.	25389.
.110	.56	-.90	23.11	73.24	-4.58	-4.56	-3.63	-4.55	-3.63	13084.	24279.
.120	1.25	-.67	22.16	71.89	-4.51	-4.30	-3.38	-4.34	-3.45	12771.	22439.
.130	1.93	-.44	21.13	70.63	-4.26	-3.98	-3.04	-4.06	-3.18	12342.	20153.
.140	2.60	-.24	20.04	69.49	-3.85	-3.63	-2.63	-3.74	-2.83	11822.	17522.
.150	3.26	-.04	18.92	68.45	-3.27	-3.26	-2.17	-3.40	-2.42	11239.	14703.
.160	3.91	.15	17.78	67.51	-2.54	-2.91	-1.70	-3.06	-1.98	10620.	11850.
.170	4.56	.33	16.63	66.67	-1.67	-2.58	-1.24	-2.74	-1.53	9990.	9104.
.180	5.20	.50	15.50	65.91	-.69	-2.29	-.81	-2.44	-1.10	9376.	6587.
.190	5.83	.66	14.41	65.22	.36	-2.04	-.44	-2.18	-.71	8799.	4398.
.200	6.46	.83	13.36	64.58	1.46	-1.83	-.13	-1.96	-.38	8281.	2605.
.210	7.08	.99	12.36	63.98	2.57	-1.68	.10	-1.79	-.11	7838.	1243.
.220	7.70	1.15	11.43	63.41	3.66	-1.57	.25	-1.66	.08	7483.	318.
.230	8.31	1.32	10.57	62.86	4.70	-1.50	.32	-1.57	.21	7227.	-199.
.240	8.92	1.48	9.78	62.31	5.68	-1.46	.33	-1.51	.26	7074.	-365.
.250	9.52	1.64	9.04	61.76	6.57	-1.46	.29	-1.49	.26	7025.	-260.
.260	10.12	1.80	8.37	61.20	7.38	-1.48	.22	-1.50	.22	7075.	14.
.270	10.71	1.96	7.75	60.64	8.10	-1.52	.13	-1.52	.17	7216.	348.
.280	11.30	2.12	7.16	60.05	8.75	-1.58	.06	-1.56	.11	7432.	626.
.290	11.88	2.29	6.61	59.44	9.34	-1.64	.03	-1.61	.08	7707.	739.
.300	12.46	2.45	6.07	58.82	9.91	-1.70	.05	-1.67	.09	8017.	594.
.310	13.03	2.61	5.53	58.16	10.49	-1.76	.15	-1.72	.16	8336.	119.
.320	13.60	2.77	4.99	57.49	11.10	-1.81	.31	-1.77	.29	8634.	-722.
.330	14.16	2.93	4.43	56.79	11.80	-1.84	.55	-1.81	.49	8880.	-1928.
.340	14.71	3.09	3.85	56.06	12.60	-1.86	.86	-1.83	.75	9039.	-3452.
.350	15.26	3.26	3.24	55.33	13.52	-1.86	1.21	-1.84	1.05	9079.	-5197.
.360	15.80	3.42	2.59	54.57	14.59	-1.83	1.57	-1.82	1.37	8965.	-7020.
.370	16.33	3.60	1.92	53.81	15.79	-1.77	1.91	-1.77	1.68	8669.	-8732.
.380	16.86	3.78	1.22	53.05	17.10	-1.68	2.18	-1.70	1.94	8163.	-10106.
.390	17.39	3.96	.49	52.31	18.50	-1.55	2.32	-1.59	2.10	7428.	-10897.
.400	17.91	4.16	-.26	51.58	19.93	-1.38	2.29	-1.43	2.12	6452.	-10856.
.410	18.42	4.36	-1.02	50.90	21.31	-1.15	2.05	-1.23	1.94	5233.	-9760.
.420	18.93	4.56	-1.79	50.28	22.58	-.85	1.55	-.96	1.56	3784.	-7451.
.430	19.44	4.78	-2.56	49.75	23.64	-.49	.80	-.64	.95	2135.	-3882.
.440	19.95	4.99	-3.33	49.34	24.41	-.06	-.18	-.25	.13	333.	830.
.450	20.46	5.20	-4.10	49.07	24.83	.42	-1.31	.19	-.82	-1548.	6320.
.460	20.96	5.41	-4.87	48.95	24.88	.93	-2.46	.66	-1.79	-3410.	11941.
.470	21.47	5.62	-5.66	48.99	24.61	1.43	-3.39	1.12	-2.56	-5122.	16577.
.480	21.99	5.81	-6.49	49.17	24.14	1.82	-3.76	1.48	-2.83	-6516.	18617.
.490	22.51	5.78	-7.35	49.42	23.74	1.98	-3.12	1.64	-2.18	-7184.	15704.

TABLE A.23

TEST RBCT-2 TRANSDUCER DATA

TEST ID ------ RBCT-2
TEST DATE ---- 11-03-81
VEHICLE TYPE - FULL SIZE
IMPACT ANGLE - 25.00 DEGREES
IMPACT SPEED - 86.09 FPS

HIGHEST 50.0-MS AVG. ACCEL.

	G'S	TIME (SEC) START	TIME (SEC) END
LONG.	-5.12	.091	.141
LAT.	-3.74	.048	.098

VEHICLE KINETICS SUMMARY
NOTE: VALUES ARE INSTANTANEOUS AT TIME

TIME (S)	VEH. ACCEL.(G'S) LONG.	VEH. ACCEL.(G'S) LAT.	VEH. VEL.(FPS) LONG.	VEH. VEL.(FPS) LAT.	VEH. DISP.(F) LONG.	VEH. DISP.(F) LAT.
0.000	-.16	-.08	86.09	0.00	0.00	0.00
.010	-.53	.05	86.01	-.06	.85	-.00
.020	-4.23	-1.51	85.44	-.15	1.69	-.00
.030	-1.75	-6.00	84.40	-1.22	2.59	-.01
.040	-2.70	-2.15	83.66	-2.61	3.42	-.03
.050	-5.08	-3.42	82.68	-3.20	4.24	-.06
.060	-1.48	-2.96	81.76	-4.39	5.04	-.09
.070	-3.02	-3.01	80.33	-5.47	5.84	-.14
.080	-6.73	-3.65	78.66	-6.78	6.69	-.21
.090	-4.39	-4.73	77.24	-8.10	7.46	-.28
.100	-3.75	-2.05	75.49	-9.16	8.21	-.37
.110	-5.92	-3.68	73.96	-10.19	8.94	-.46
.120	-4.60	-2.71	72.96	-10.94	9.66	-.57
.130	-7.35	-3.47	71.02	-12.49	10.43	-.69
.140	-4.77	-2.45	69.32	-13.28	11.12	-.82
.150	-3.07	-2.02	67.62	-14.10	11.79	-.95
.160	-.63	-1.36	66.76	-14.91	12.45	-1.09
.170	-.90	-2.30	67.05	-15.81	13.11	-1.24
.180	-3.60	-.87	65.92	-15.60	13.82	-1.41
.190	-6.45	-2.56	64.73	-16.39	14.46	-1.57
.200	-3.49	-.31	62.96	-16.49	15.08	-1.73
.210	-10.31	3.77	61.04	-15.62	15.70	-1.89
.220	-4.97	-1.71	60.56	-15.92	16.34	-2.06
.230	-1.30	-1.97	59.99	-16.39	16.93	-2.22
.240	.05	-1.20	59.56	-16.46	17.52	-2.38
.250	-2.57	-.47	59.39	-16.47	18.11	-2.54
.260	-1.32	1.39	58.70	-16.46	18.69	-2.70

TABLE A.23 (Cont'd)

TEST ID ------ 43CT-2
TEST DATE ---- 11-03-81
VEHICLE TYPE - FULL SIZE
IMPACT ANGLE - 25.00 DEGREES
IMPACT SPEED - 88.09 FPS

OCCUP. RISK FACTORS		TIME(S)	VELOCITY-(FPS) TEST	NORMALIZED
LONG. VEL. AFTER 2.0 FT. DISP.	--	.194	22.15	N/A
LAT. VEL. AFTER 1.0 FT. DISP.	--	.133	14.38	N/A

MAX. ACCEL. AFTER OCCUPANT IMPACT		TIME(S)	ACC.(G'S)
LONG. ACCELERATION	--	.210	-6.07
LAT. ACCELERATION	--	.170	-2.84

OCCUPANT RISK SUMMARY
NOTE: AVG. ACCEL. FOR PRIOR .010 SEC. CALCULATED
FROM VEHICLE VELOCITY CHANGE

TIME (S)	OCCUP. ACCEL.(G'S) LONG.	OCCUP. ACCEL.(G'S) LAT.	OCCUP. VEL.(FPS) LONG.	OCCUP. VEL.(FPS) LAT.	OCCUP. DISP.(F) LONG.	OCCUP. DISP.(F) LAT.
0.000	0.00	0.00	0.00	0.00	0.00	0.00
.010	-.26	-.18	.08	.06	.00	.00
.020	-1.79	-.31	.65	.15	.00	.00
.030	-3.02	-3.39	1.49	1.32	.02	.01
.040	-2.34	-4.10	2.43	2.61	.04	.03
.050	-3.11	-1.84	3.41	3.20	.07	.06
.060	-2.91	-3.78	4.33	4.39	.10	.09
.070	-3.88	-3.41	5.36	5.47	.15	.14
.080	-5.39	-3.64	7.41	6.78	.22	.21
.090	-4.54	-4.15	8.35	8.10	.30	.28
.100	-3.53	-5.34	10.60	9.16	.40	.37
.110	-4.65	-3.27	12.13	10.19	.51	.46
.120	-3.14	-2.38	13.13	10.94	.63	.56
.130	-5.66	-4.51	15.07	12.49	.78	.69
.140	-6.34	-2.51	17.07	13.28	.94	.82
.150	-4.42	-2.57	18.47	14.10*	1.11	.95*
.160	-2.71	-2.57	19.33	14.91	1.30	1.09
.170	.92	-2.84*	19.04	15.61	1.49	1.24
.180	-3.29	.60	20.17	15.60	1.70	1.41
.190	-3.77	-2.49	21.36+	16.39	1.90+	1.57
.200	-5.58	-.31	23.13	16.49	2.12	1.73
.210	-6.07+	2.10	25.05	15.82	2.36	1.89
.220	-1.42	-.29	25.53	15.92	2.63	2.06
.230	-1.30	-1.47	26.10	16.39	2.88	2.22
.240	-1.34	-.23	26.53	16.46	3.14	2.38
.250	-.55	-.04	26.70	16.47	3.40	2.54
.260	-2.17	.06	27.39	16.46	3.67	2.70

TABLE A.23 (Cont'd)

TEST ID ------ RBCT-2
TEST DATE ---- 11-03-81
VEHICLE TYPE - FULL SIZE

VEHICLE MASS = 4720. LBS.
IMPACT SPEED = 58.7 MPH
IMPACT ANGLE = 25.0 DEG.

OCCUPANT - DRIVER
572-50% MALE DUMMY
RESTRAINTS - SHOULDER + LAP BELTS

TIME	-----HEAD (G'S)------			-----CHEST (G'S)------			FEMUR LOADS (LBS)		RESULTANT (G'S)		-------SI-------	
(SEC)	X	Y	Z	X	Y	Z	LEFT	RIGHT	HEAD	CHEST	HEAD	CHEST
0.000	-.1	0.0	0.0	.1	.3	-.5	22.0	16.2	.1	.6	0.0	0.0
.010	-.6	-.4	0.0	-.1	-.2	-.5	20.3	16.2	.7	.5	.0	.0
.020	-1.9	-1.9	-.2	-.7	-1.2	-.2	74.9	-49.5	2.7	1.1	.0	.0
.030	.7	0.0	-.2	.2	.3	.3	9.7	10.3	.8	.6	.0	.0
.040	-.1	.2	0.0	-.4	-.1	-.3	-6.1	10.5	.3	.5	.0	.0
.050	1.2	.6	0.0	-.5	-.9	0.0	22.0	21.9	1.3	1.0	.1	.0
.060	-.3	.2	-.2	-1.0	-.5	.3	15.0	-.9	.4	1.2	.2	.0
.070	-1.3	1.2	0.0	-1.5	-.6	.4	4.4	1.0	1.8	1.6	.2	.1
.080	-2.8	-8.0	0.0	-2.7	-2.0	1.4	43.2	1.0	8.5	3.6	.4	.1
.090	-2.6	-8.9	-.2	-3.0	-3.2	1.9	10.5	-8.4	9.2	4.8	2.2	.3
.100	-1.3	-4.2	-.2	-2.2	-6.9	2.7	23.3	-.9	4.4	7.7	4.7	1.3
.110	-3.4	-4.9	0.0	-4.5	-8.4	4.4	15.0	-11.0	6.0	10.5	5.2	3.5
.120	-3.4	-3.7	0.0	-2.8	-8.1	3.7	-.9	6.7	5.1	9.3	6.1	6.4
.130	-4.5	-5.7	-.2	-4.6	-6.9	1.4	-9.5	-12.1	7.5	8.4	6.9	8.3
.140	-5.9	-3.6	0.0	-5.7	-4.8	-.1	-4.3	-29.0	6.9	7.5	8.4	10.0
.150	-3.6	-5.2	-.2	-3.8	-5.4	-4.8	9.7	-38.3	6.4	8.2	10.5	11.5
.160	-13.5	-3.9	0.0	-13.0	-1.3	-2.2	7.9	-.9	14.0	13.3	19.6	17.1
.170	-12.8	-4.4	0.0	-8.9	-1.1	2.2	-2.6	33.4	13.5	9.3	27.1	20.4
.180	-9.9	-4.1	-.2	-7.5	1.6	1.5	15.0	37.2	10.7	7.8	29.3	22.7
.190	-11.6	-3.1	-.2	-6.3	-1.3	.3	-2.6	-4.7	12.0	6.4	33.5	23.9
.200	-9.9	.2	0.0	-7.5	-2.7	-.3	[illegible]	-8.4	9.9	8.3	37.9	25.2
.210	-11.3	1.2	0.0	-5.6	-2.5	-.1	-28.6	-14.0	11.4	6.2	41.2	26.1
.220	-8.3	-1.1	0.0	-3.3	-1.3	.3	29.1	-.9	8.3	3.5	43.4	26.8
.230	-6.1	-7.2	0.0	-2.2	-1.4	1.1	-14.7	-14.0	9.4	2.8	44.4	26.9
.240	-3.5	-4.9	-.2	-1.1	-.7	1.3	-.9	18.1	6.0	1.8	44.9	27.0
.250	-2.9	-3.1	0.0	-1.9	-1.3	.2	29.1	1.0	4.2	2.4	45.2	27.1
.260	-.1	-3.9	-.2	-1.0	-1.6	-.1	36.1	10.5	3.9	1.9	46.4	27.2

MAXIMUM VALUES AND TIME OF OCCURANCE

	X/LT---SEC		Y/RT---SEC		Z----SEC		R----SEC	
HEAD (G'S)	-21.3	.157	-17.8	.156	-.2	.259	27.1	.157
CHEST (G'S)	-14.0	.152	-8.9	.110	-4.8	.150	14.5	.152
FEMUR LOAD (LBS)	0.	.261	138.	.162				

CUMULATIVE PERIOD FOR 60-G LEVEL = 0.000 SEC.

HIC = 33.0 DURING T = .077 TO .231 SEC.

TEST RBCT-3

Purpose: Purpose of this test was to verify the anchorage capability of the wood post BCT after modifications had been incorporated to reduce its end-on resistance. This was accomplished by impacting the barrier with a 4500 lb (2041 kg) vehicle at 60 mph (96.6 kmph) and a 25 deg angle.

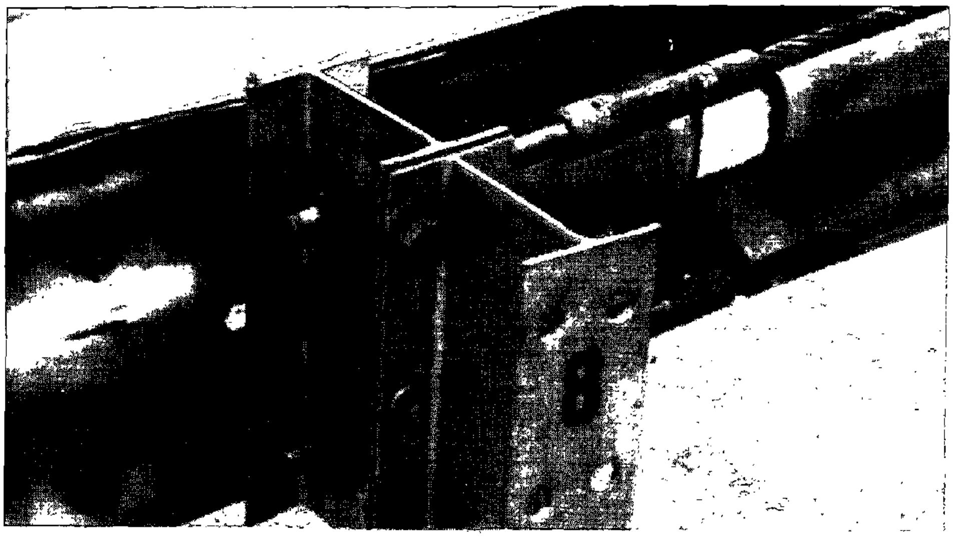
Test Installation: The test installation of RBCT-2 was repaired and used for this test except that the anchorage of the two backup wire ropes was strengthened to reduce barrier deflection. As shown in Figure A.111, the upstream ends attached to a flat plate bracket mounted near grade on Post 2, whereas the downstream ends were connected to the blockout of Post 8. In addition, the wire ropes were attached with U-Bolts to the blockout of each interim post.

Test Vehicle: A 1978 Ford LTD with test inertia weight of 4527 lb (2053 kg) was the test vehicle. A 50th percentile male dummy was placed in the driver's position and restrained with lap and shoulder belts. Gross test weight was 4692 lb (2128 kg).

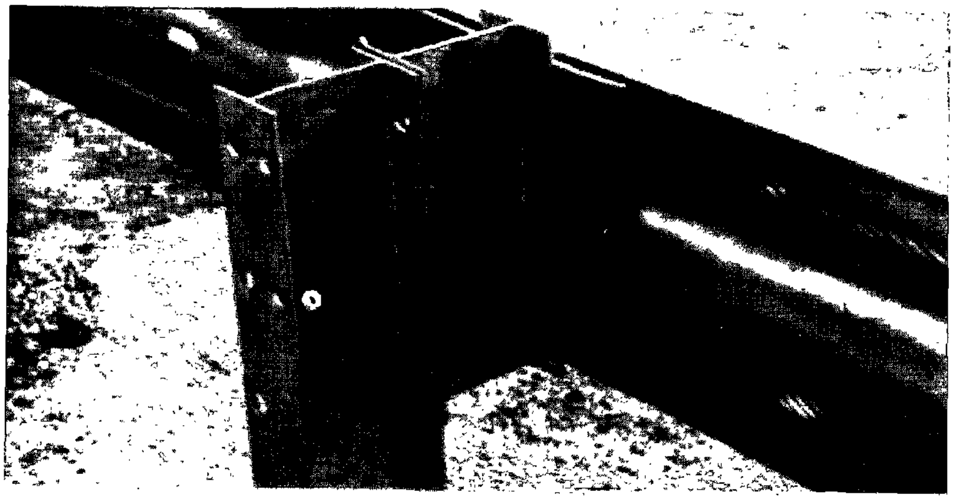
Performance: Impact conditions were 55.9 mph (89.9 kmph) and a 24.9 deg angle. As shown in the photo of Figure 37, the vehicle impacted the installation at Post 3, deflected it rearward and was redirected approximately parallel to the barrier. During the sequence, the vehicle rolled (away from the barrier) and pitched such that it lost contact with the W-Beam rail, but made secondary contact on top of the barrier after being airborne for 26.2 ft (8m). The vehicle then slid to a stop 44 ft (13m) past the end of the installation in an attitude approximately parallel to the straight portion of it. Maximum 50 msec average accelerations taken from high-speed film analysis were - 4.9g in the lateral direction and - 7.5g in the longitudinal direction. A summary of test results is shown in Figure 38 and Table A.24 contains film analysis data. Analog to digital conversion of transducer data is tabulated in Table A.25 and plotted in Figures A.112 thru A.115.

Barrier Damage: As shown in Figure A.116 the posts blockouts and W-Beam rail between Posts 3 thru 7 was damaged and required replacement, and the footing at Post 2 rotated in the soil slightly and required realignment and retamping. In addition, Post 12 and its blockout were damaged when the vehicle made secondary contact with the installation. Barrier Deflection measurements are contained in Table A.26.

Vehicle Damage: As shown in Figure A.117 most of the vehicle damage occurred at the left front corner. In addition to the deformation of the fender, hood, and grille, considerable suspension damage was sustained by the left front wheel. Also both left side tires were deflated during either initial or secondary contact with the barrier.



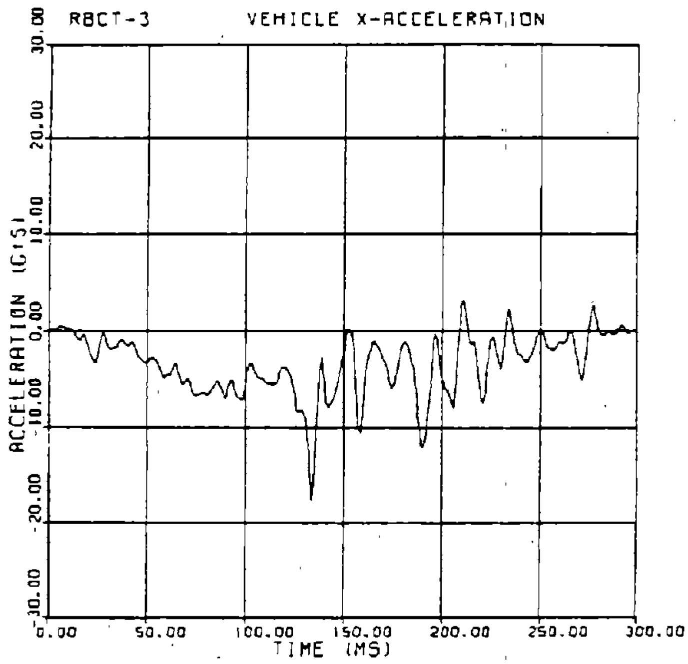
DOWNSTREAM END



TYPICAL INTERIM POST

UPSTREAM END

FIGURE A.111 WIRE ROPE ANCHORAGE MODIFICATIONS, TEST RBCT-3



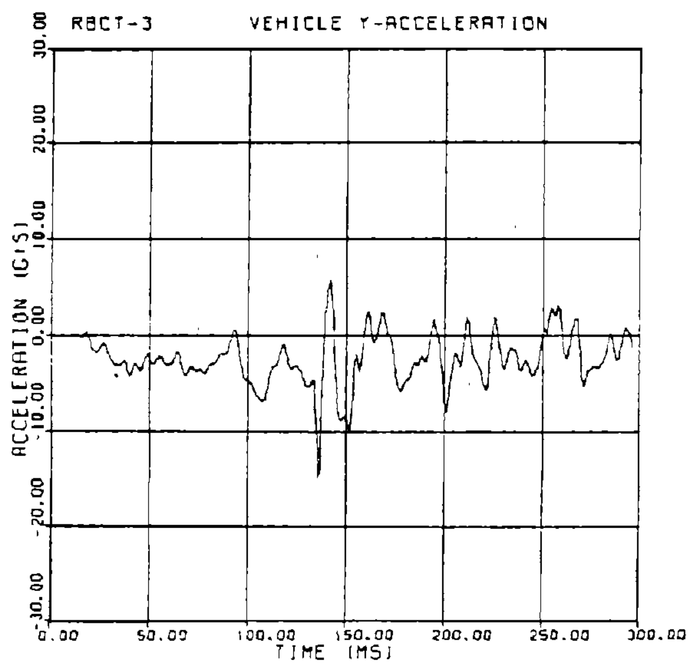


FIGURE A.112 VEHICLE ACCELERATION PLOTS, TEST RBCT-3

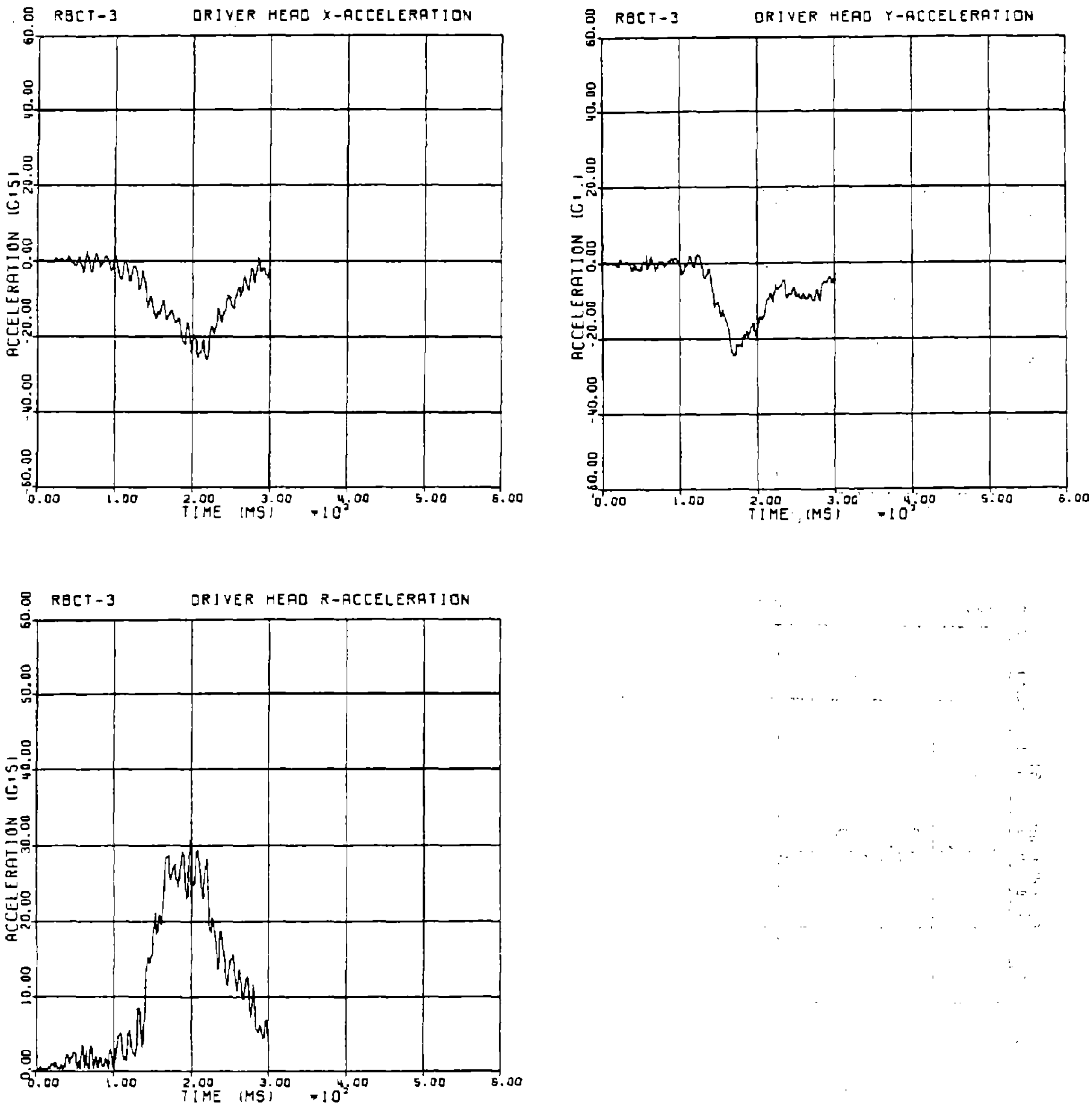


FIGURE A.113 DRIVER DUMMY HEAD ACCELERATION PLOTS, TEST RBCT-3

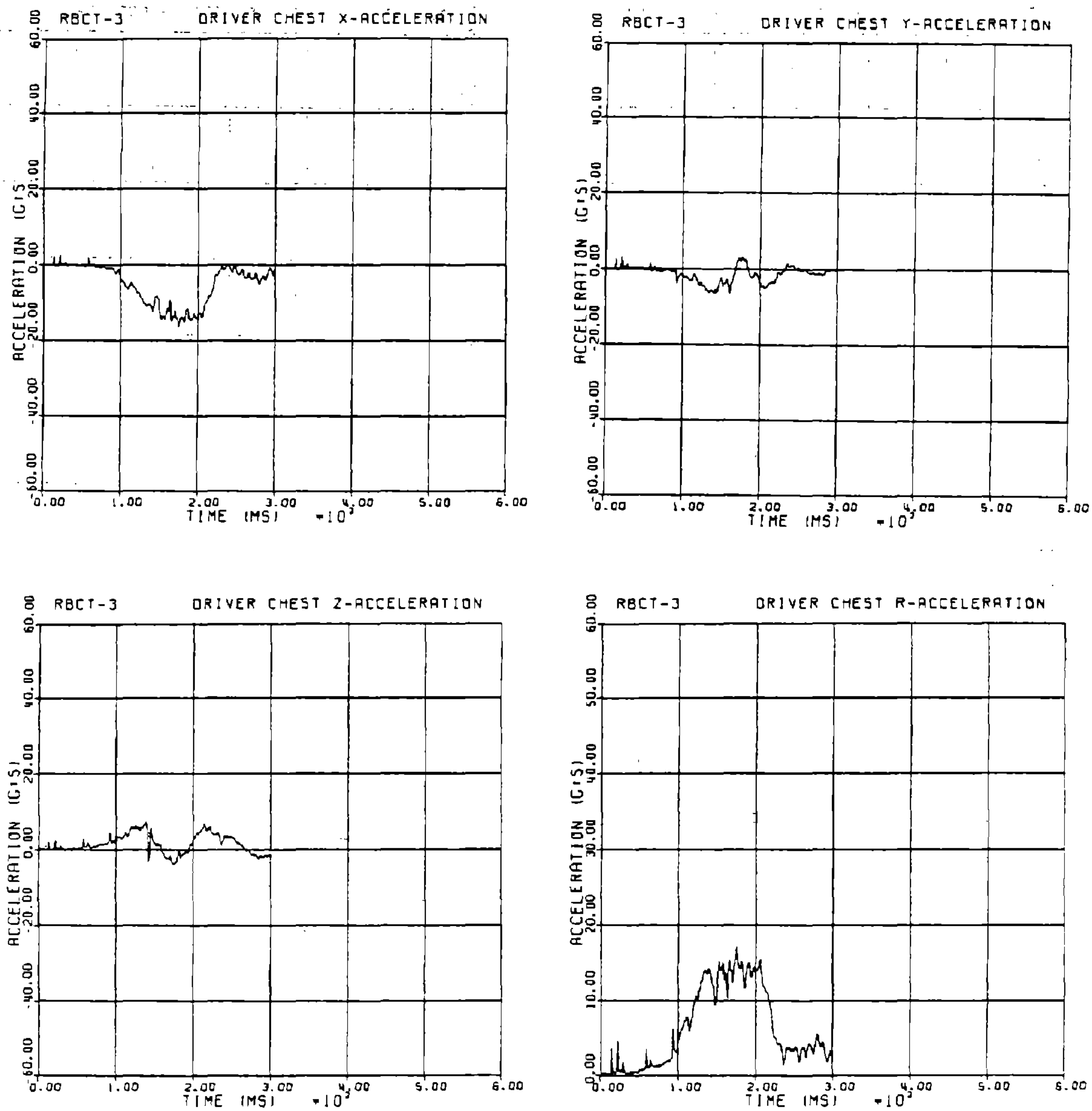
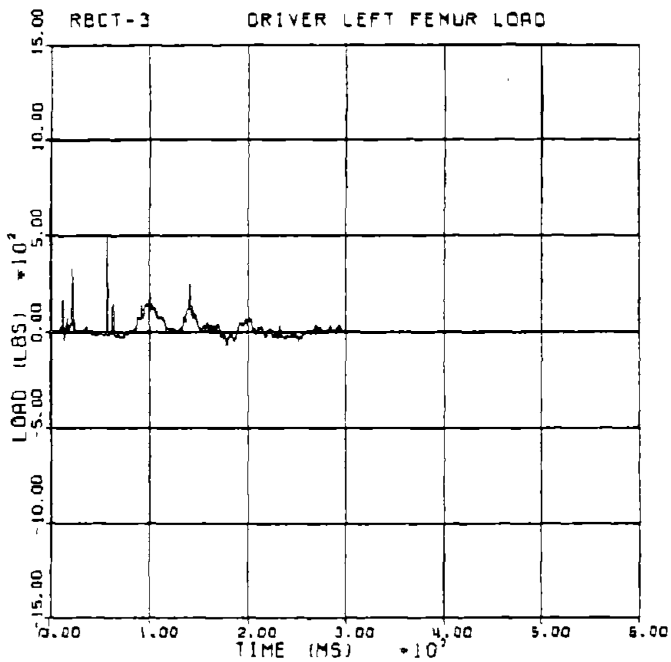


FIGURE A.114 DRIVER DUMMY CHEST ACCELERATION PLOTS, TEST RBCT-3



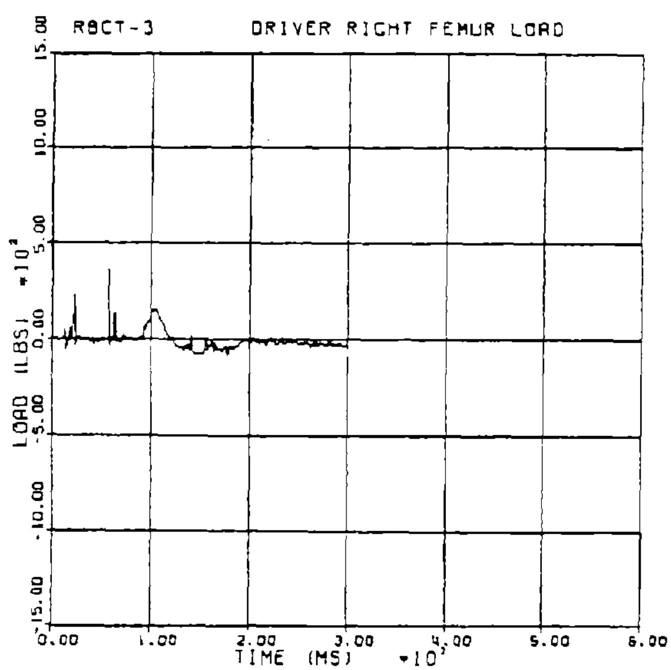


FIGURE A.115 DRIVER DUMMY FEMUR LOAD PLOTS, TEST RBCT-3

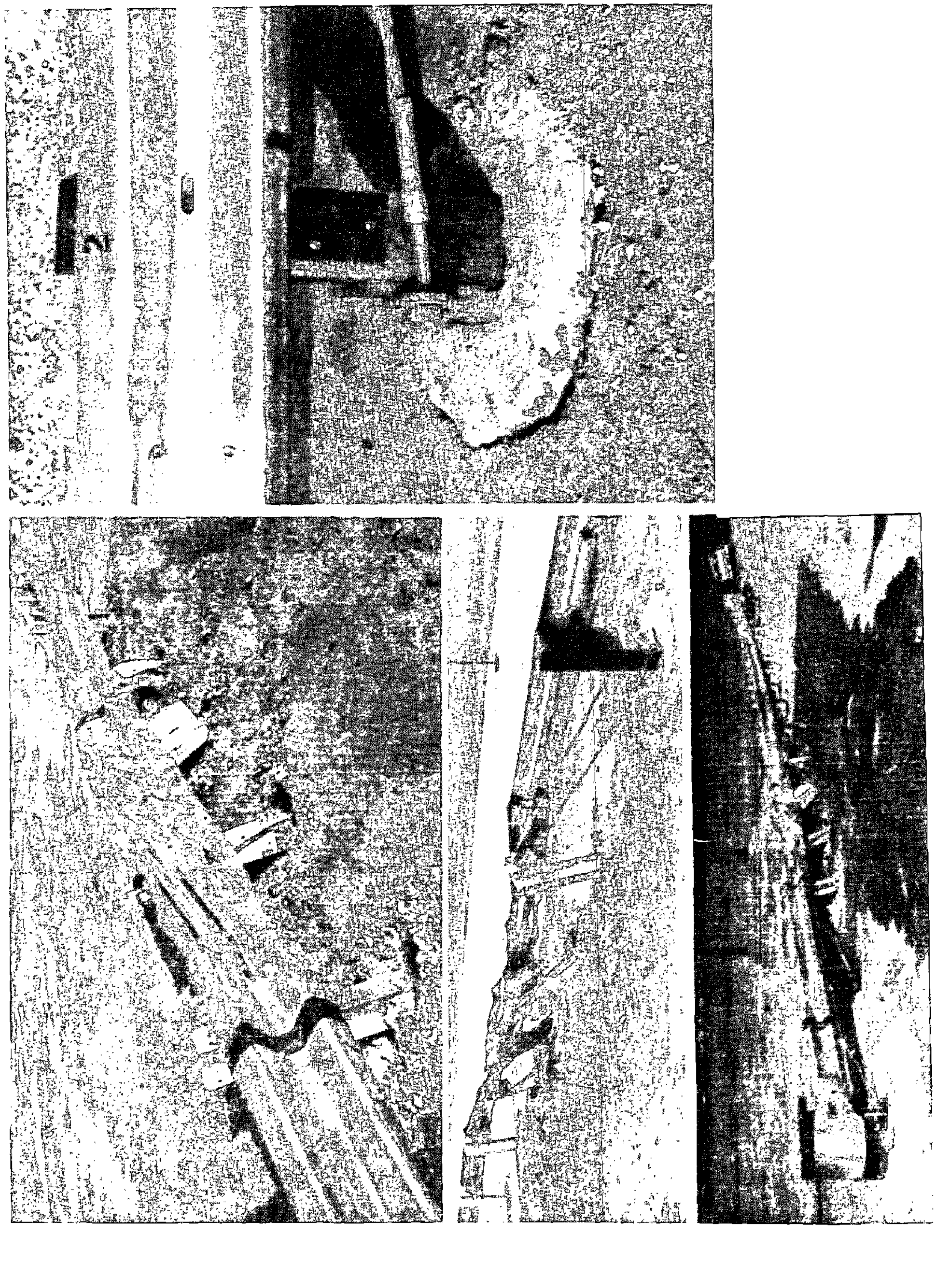


FIGURE A.116 BARRIER DAMAGE, TEST RBCT-3

FIGURE A.117 VEHICLE DAMAGE, TEST RBCT-3

TABLE A.24
HIGH-SPEED FILM ANALYSIS
TEST RBCT-3

SUMMARY OF VEHICLE KINEMATIC AND DYNAMIC DATA   WOOD POST BCT TEST RBCT-3 12/10/81

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	-2.00	-5.60	24.87	81.92	-1.19	-2.43	-2.30	0.00	0.00	5620.	14074.
.010	-1.26	-5.28	24.67	81.00	-1.75	-3.34	-2.85	0.00	0.00	8369.	18046.
.020	-.52	-4.96	24.41	79.78	-2.38	-4.23	-3.35	0.00	0.00	11177.	21749.
.030	.22	-4.66	24.07	78.30	-3.07	-5.07	-3.80	-4.59	-3.52	13934.	25061.
.040	.94	-4.38	23.66	76.57	-3.80	-5.82	-4.17	-5.35	-3.92	16534.	27881.
.050	1.65	-4.12	23.18	74.63	-4.56	-6.46	-4.48	-6.02	-4.26	18890.	30134.
.060	2.35	-3.87	22.63	72.51	-5.33	-6.97	-4.70	-6.58	-4.53	20927.	31771.
.070	3.03	-3.66	22.02	70.26	-6.10	-7.34	-4.84	-7.00	-4.72	22586.	32767.
.080	3.69	-3.46	21.33	67.94	-6.85	-7.56	-4.90	-7.29	-4.83	23827.	33118.
.090	4.34	-3.29	20.59	65.58	-7.56	-7.64	-4.88	-7.44	-4.86	24623.	32844.
.100	4.97	-3.14	19.79	63.23	-8.22	-7.58	-4.78	-7.45	-4.81	24967.	31983.
.110	5.59	-3.02	18.95	60.95	-8.82	-7.39	-4.61	-7.33	-4.68	24864.	30589.
.120	6.18	-2.91	18.05	58.76	-9.33	-7.08	-4.37	-7.09	-4.49	24334.	28730.
.130	6.76	-2.83	17.12	56.70	-9.75	-6.66	-4.07	-6.74	-4.23	23409.	26484.
.140	7.33	-2.76	16.16	54.79	-10.07	-6.17	-3.72	-6.30	-3.92	22130.	23938.
.150	7.87	-2.72	15.17	53.07	-10.28	-5.61	-3.33	-5.79	-3.56	20548.	21180.
.160	8.40	-2.68	14.17	51.55	-10.37	-5.00	-2.91	-5.23	-3.16	18718.	18304.
.170	8.92	-2.66	13.15	50.22	-10.33	-4.37	-2.47	-4.63	-2.74	16700.	15397.
.180	9.43	-2.66	12.14	49.10	-10.18	-3.73	-2.03	-4.01	-2.31	14556.	12547.
.190	9.93	-2.66	11.12	48.18	-9.90	-3.10	-1.61	-3.39	-1.89	12349.	9833.
.200	10.41	-2.66	10.12	47.45	-9.52	-2.49	-1.20	-2.79	-1.47	10138.	7321.
.210	10.89	-2.68	9.13	46.90	-9.03	-1.92	-.83	-2.22	-1.09	7980.	5079.
.220	11.37	-2.69	8.18	46.52	-8.46	-1.39	-.50	-1.68	-.74	5927.	3147.
.230	11.84	-2.71	7.25	46.28	-7.83	-.93	-.23	-1.20	-.44	4025.	1563.
.240	12.31	-2.73	6.36	46.16	-7.15	-.52	-.02	-.77	-.20	2311.	348.
.250	12.77	-2.75	5.51	46.16	-6.44	-.17	.13	-.40	-.02	816.	-493.
.260	13.24	-2.77	4.71	46.23	-5.74	.11	.20	-.08	.10	-438.	-965.
.270	13.71	-2.79	3.96	46.38	-5.07	.33	.22	.17	.15	-1441.	-1088.
.280	14.17	-2.81	3.26	46.57	-4.44	.49	.17	.36	.14	-2180.	-896.
.290	14.64	-2.83	2.63	46.79	-3.88	.60	.07	.49	.07	-2684.	-431.
.300	15.11	-2.84	2.05	47.03	-3.41	.65	-.08	.57	-.04	-2944.	254.
.310	15.58	-2.86	1.53	47.27	-3.04	.65	-.26	.61	-.19	-2988.	1099.
.320	16.06	-2.88	1.08	47.50	-2.78	.62	-.46	.60	-.37	-2843.	2038.
.330	16.53	-2.90	.68	47.71	-2.63	.55	-.67	.56	-.56	-2543.	3004.
.340	17.01	-2.92	.33	47.89	-2.59	.46	-.87	.49	-.75	-2124.	3928.
.350	17.49	-2.94	.04	48.04	-2.66	.36	-1.05	.40	-.93	-1626.	4747.
.360	17.97	-2.97	-.20	48.14	-2.82	.24	-1.19	.30	-1.08	-1087.	5398.
.370	18.45	-3.00	-.39	48.21	-3.06	.13	-1.29	.19	-1.19	-548.	5833.
.380	18.94	-3.04	-.55	48.25	-3.35	.02	-1.33	.09	-1.25	-45.	6008.
.390	19.42	-3.08	-.67	48.25	-3.67	-.07	-1.30	-.01	-1.26	390.	5898.
.400	19.90	-3.12	-.77	48.22	-3.99	-.15	-1.21	-.09	-1.20	732.	5409.
.410	20.38	-3.17	-.85	48.17	-4.29	-.20	-1.06	-.15	-1.08	960.	4787.
.420	20.86	-3.22	-.92	48.11	-4.54	-.22	-.85	-.18	-.90	1066.	3816.
.430	21.34	-3.28	-.99	48.04	-4.71	-.22	-.58	-.20	-.67	1048.	2616.
.440	21.82	-3.34	-1.06	47.98	-4.80	-.20	-.28	-.19	-.40	915.	1248.
.450	22.30	-3.39	-1.14	47.93	-4.77	-.15	.04	-.16	-.11	689.	-209.
.460	22.78	-3.45	-1.23	47.89	-4.62	-.10	.37	-.12	.19	398.	-1663.
.470	23.26	-3.51	-1.35	47.88	-4.36	-.03	.66	-.06	.48	82.	-3007.
.480	23.73	-3.56	-1.48	47.89	-3.99	.02	.91	-.01	.73	-213.	-4128.
.490	24.21	-3.61	-1.64	47.92	-3.53	.07	1.09	.03	.92	-437.	-4913.

TABLE A.24
HIGH SPEED FILM ANALYSIS
TEST RBCT-3 (cont'd)

.500	24.69	-3.66	-1.83	47.95	-3.01	.08	1.16	.04	1.03	-535.	-5252.
.510	25.17	-3.70	-2.03	47.99	-2.47	.06	1.12	.03	1.03	-459.	-5054.
.520	25.65	-3.74	-2.25	48.00	-1.95	.00	.94	-.01	.91	-167.	-4254.
.530	26.13	-3.78	-2.48	48.00	-1.51	-.11	.62	-.10	.66	366.	-2828.
.540	26.60	-3.81	-2.71	47.94	-1.18	-.26	.17	-.23	.28	1145.	-808.
.550	27.08	-3.85	-2.93	47.83	-1.04	-.45	-.40	-.39	-.19	2137.	1694.
.560	27.56	-3.88	-3.13	47.66	-1.10	-.67	-1.03	-.57	-.73	3270.	4473.
.570	28.03	-3.92	-3.30	47.41	-1.39	-.88	-1.64	-.75	-1.27	4409.	7200.
.530	28.50	-3.97	-3.42	47.10	-1.90	-1.06	-2.14	-.90	-1.71	5351.	9397.
.590	28.97	-4.02	-3.49	46.75	-2.58	-1.14	-2.37	-.97	-1.91	5802.	10405.
.600	29.43	-4.07	-3.51	46.39	-3.31	-1.06	-2.13	-.89	-1.70	5359.	9349.
.610	29.89	-4.14	-3.46	46.09	-3.90	-.70	-1.17	-.56	-.83	3487.	5102.
.620	30.35	-4.21	-3.37	45.97	-4.06	.06	.84	.13	.99	-500.	-3762.

TABLE A.25

TEST RBCT-3 TRANSDUCER DATA

TEST ID ------ RBCT-3
TEST DATE ---- 12-10-91
VEHICLE TYPE - FULL SIZE
IMPACT ANGLE - 25.00 DEGREES
IMPACT SPEED - 81.67 FPS

OCCUPANT RISK SUMMARY
NOTE: AVG. ACCEL. FOR PRIOR .010 SEC. CALCULATED
FROM VEHICLE VELOCITY CHANGE

TIME	OCCUP. ACCEL.(G'S)		OCCUP. VEL.(FPS)		OCCUP. DISP.(F)	
(S)	LONG.	LAT.	LONG.	LAT.	LONG.	LAT.
0.000	0.00	0.00	0.00	0.00	0.00	0.00
.010	.27	-.02	-.09	.01	.00	.00
.020	-.51	-.08	.08	.03	.00	.00
.030	-1.82	-1.43	.70	.32	.00	.00
.040	-1.49	-3.08	1.17	1.49	.01	.01
.050	-2.29	-3.12	1.90	2.48	.03	.03
.060	-3.60	-2.75	3.04	3.35	.05	.06
.070	-4.55	-3.00	4.48	4.30	.09	.10
.080	-6.15	-3.65	6.59	5.55	.15	.15
.090	-6.06	-2.42	8.50	6.31	.22	.21
.100	-6.32	-1.86	10.30	6.90	.32	.27
.110	-4.44	-3.95	11.91	8.79	.43	.35
.120	-3.06	-2.80	13.32	9.67	.53	.44
.130	-6.36	-3.62	15.70	10.91	.71	.55
.140	-10.21	-6.57	18.93	12.99	.88	.67
.150	-6.14	-2.50	20.87	13.78	1.07	.80
.160	-4.02	-5.05*	22.14	15.38*	1.28	.94*
.170	-2.95	1.08	23.08	15.04	1.51	1.09
.180	-4.09	-2.66	24.48*	15.75	1.75*	1.26
.190	-4.37	-3.35	26.02	17.01	2.01	1.42
.200	-5.75*	-.89	27.84	17.29	2.27	1.59
.210	-5.47	-4.29	29.57	18.65	2.55	1.77
.220	-1.14	-1.64	29.96	19.21	2.87	1.97
.230	-3.47	-1.85	31.06	19.79	3.17	2.16
.240	-.77	-2.46	31.30	20.57	3.46	2.36
.250	-2.30	-3.32	32.03	21.62	3.79	2.56
.260	-1.29	1.64	32.44	21.10	4.10	2.77
.270	-1.19	-.36	32.64	21.23	4.45	3.00
.280	-1.13	-3.37	33.20	22.45	4.78	3.21
.290	-.28	-1.69	33.29	22.99	5.10	3.44
.300	.24	-.60	33.21	23.17	5.43	3.66

HIGHEST 50.0-MS AVG. ACCEL.

	G'S	TIME (SEC) START	END
LONG.	-6.64	.088	.138
LAT.	-4.56	.104	.154

TABLE A.25 (Cont'd)

TEST ID ------ RBCT-3
TEST DATE ---- 12-10-81
VEHICLE TYPE - FULL SIZE
IMPACT ANGLE - 25.00 DEGREES
IMPACT SPEED - 81.69 FPS

VEHICLE KINETICS SUMMARY
NOTE: VALUES ARE INSTANTANEOUS AT TIME

TIME (S)	VEH. ACCEL.(G'S) LONG.	VEH. ACCEL.(G'S) LAT.	VEH. VEL.(FPS) LONG.	VEH. VEL.(FPS) LAT.	VEH. DISP.(F) LONG.	VEH. DISP.(F) LAT.
0.000	.06	-.01	81.69	0.00	0.00	0.00
.010	.20	-.08	81.78	-.01	.80	-.00
.020	-1.70	-1.12	81.61	-.03	1.61	-.00
.030	-1.82	-2.56	80.99	-.32	2.47	-.00
.040	-1.48	-4.24	80.32	-1.49	3.26	-.01
.050	-3.17	-2.62	79.77	-2.48	4.05	-.03
.060	-4.56	-3.07	78.65	-3.33	4.83	-.06
.070	-5.05	-3.61	77.21	-4.30	5.60	-.10
.080	-6.67	-3.11	75.10	-5.55	6.41	-.15
.090	-6.69	-1.25	73.19	-6.31	7.14	-.21
.100	-5.58	-4.65	71.19	-6.70	7.85	-.27
.110	-5.24	-5.43	69.78	-8.77	8.54	-.35
.120	-3.81	-2.32	68.17	-9.67	9.22	-.44
.130	-9.30	-5.29	65.99	-10.71	9.93	-.55
.140	-5.65	3.36	62.76	-12.99	10.56	-.67
.150	-1.70	-8.82	60.82	-13.78	11.17	-.79
.160	-8.02	1.21	59.35	-15.38	11.77	-.94
.170	-2.39	1.58	58.61	-15.04	12.34	-1.09
.180	-1.30	-4.65	57.21	-15.95	12.96	-1.25
.190	-12.15	-2.87	55.67	-17.01	13.52	-1.42
.200	-4.94	-6.87	53.85	-17.29	14.05	-1.58
.210	2.58	-.99	52.12	-18.65	14.57	-1.76
.220	-7.57	-5.61	51.73	-19.21	15.13	-1.96
.230	-3.89	-3.61	50.63	-19.79	15.63	-2.15
.240	-2.54	-3.47	50.39	-20.57	16.13	-2.35
.250	.02	-.26	49.66	-21.62	16.62	-2.56
.260	-1.22	1.35	49.25	-21.10	17.11	-2.77
.270	-4.26	-4.21	48.85	-21.23	17.63	-3.00
.280	.13	-3.11	48.49	-22.45	18.10	-3.21
.290	.07	-1.67	48.40	-22.99	18.58	-3.44
.300	.04	-.53	48.46	-23.17	19.06	-3.66

OCCUP. RISK FACTORS	TIME(S)	VELOCITY-(FPS) TEST	VELOCITY-(FPS) NORMALIZED
>LONG. VEL. AFTER 2.0 FT. DISP. --	.190	25.93	N/A
>LAT. VEL. AFTER 1.0 FT. DISP. --	.163	15.25	N/A

MAX. ACCEL. AFTER OCCUPANT IMPACT	TIME(S)	ACC.(G'S)
>LONG. ACCELERATION --	.200	-3.75
>LAT. ACCELERATION --	.160	-5.05

TABLE A.25 (Cont'd)

TEST ID ------ RBCT-3
TEST DATE ---- 12-10-81
VEHICLE TYPE - FULL SIZE

VEHICLE MASS = 4692. LBS.
IMPACT SPEED = 55.7 MPH
IMPACT ANGLE = 25.0 DEG.

OCCUPANT - DRIVER
572-50% MALE DUMMY
RESTRAINTS - SHOULDER + LAP BELTS

TIME	-----HEAD (G'S)------			-----CHEST (G'S)-----			FEMUR LOADS (LBS)		RESULTANT (G'S)		-------SI-------	
(SEC)	X	Y	Z	X	Y	Z	LEFT	RIGHT	HEAD	CHEST	HEAD	CHEST
0.000	-.2	-.2	-.1	.0	-.1	.2	-11.6	0.0	.3	.2	0.0	0.0
.010	0.0	.2	.1	.0	.0	.1	25.9	5.2	.2	.1	.0	.0
.020	-.5	-.9	-.1	.2	.4	.3	25.9	83.7	1.0	.6	.0	.0
.030	.3	0.0	.1	.0	.4	.3	-7.0	0.0	.4	.5	.0	.0
.040	1.2	-1.2	.1	-.1	.2	.1	2.4	-10.3	1.7	.3	.0	.0
.050	-.5	-1.2	-.1	-.3	-.5	.2	-18.6	-10.3	1.3	.7	.1	.0
.060	-2.7	-1.1	.1	-.3	-.5	.8	-21.0	5.2	3.1	1.0	.1	.1
.070	-3.1	-1.4	-.1	-.6	-.6	.7	-34.9	-15.4	3.4	1.2	.2	.1
.080	-.2	-.3	-.1	-.5	-.3	1.4	-11.6	5.2	.4	1.5	.2	.1
.090	.9	1.2	-.1	-1.4	-.9	1.6	68.2	10.5	1.5	2.5	.3	.1
.100	1.1	-.9	-.1	-3.6	-1.9	2.5	135.8	146.5	1.4	4.8	.3	.5
.110	-4.3	-.9	.1	-6.6	-2.8	3.4	63.5	104.6	4.4	7.9	.6	1.5
.120	-5.4	-.2	-.1	-6.6	-3.8	5.7	16.5	5.2	5.4	7.6	.8	3.2
.130	-5.5	-1.9	.1	-10.2	-5.7	5.3	7.1	-46.3	5.8	12.8	1.0	6.9
.140	-8.1	-3.8	-.1	-11.1	-6.4	5.9	127.0	-61.7	8.9	14.1	2.3	14.2
.150	-13.6	-11.5	-.1	-12.2	-2.8	1.4	21.2	-77.2	17.8	12.6	10.9	19.6
.160	-13.0	-15.5	-.1	-11.5	-5.6	-.1	44.7	-41.2	20.3	12.8	27.1	26.9
.170	-14.4	-24.7	-.1	-12.2	1.9	-1.6	44.7	-56.6	28.6	12.5	58.3	34.0
.180	-16.1	-22.1	.1	-13.8	2.0	-2.4	-41.9	-41.2	27.3	14.1	92.3	42.4
.190	-22.3	-18.0	-.1	-14.7	-2.2	-.2	-7.0	-25.7	28.7	14.9	130.8	49.9
.200	-21.6	-16.8	.1	-13.3	-3.9	2.6	39.4	-10.3	27.4	14.1	169.5	57.8
.210	-24.5	-13.4	-.1	-10.0	-4.8	4.8	-16.3	-25.7	28.0	12.1	204.2	65.0
.220	-25.9	-10.6	-.1	-6.1	-3.3	5.7	9.4	0.0	28.0	9.0	239.4	69.1
.230	-18.4	-6.3	-.1	-1.4	-.9	3.9	11.6	-25.7	19.4	4.3	258.1	69.9
.240	-14.8	-8.4	-.1	.2	.8	3.2	-21.0	-15.4	17.0	3.3	270.3	70.1
.250	-11.7	-9.1	-.1	-1.5	.4	3.0	-25.6	-30.9	14.8	3.4	277.9	70.4
.260	-7.0	-6.4	-.1	-3.1	.0	1.4	-11.6	-25.7	10.7	3.4	284.4	70.5
.270	-5.9	-9.1	-.1	-4.2	-.9	-.6	-16.3	-30.9	10.8	4.4	289.2	70.8
.280	-5.0	-9.4	-.1	-5.3	-1.3	-1.5	-2.3	-30.9	10.7	5.7	292.4	71.1
.290	-2.7	-5.6	.1	-3.4	-.4	-1.9	-14.0	-36.0	6.2	3.9	294.1	71.6
.300	.3	-2.8	-.1	-.3	-.1	-1.7	7.1	-30.7	2.8	1.7	294.9	71.7

MAXIMUM VALUES AND TIME OF OCCURANCE

	X/LT---SEC		Y/RT---SEC		Z----SEC		R----SEC	
HEAD (G'S)	-26.3	.219	-24.7	.170	-.1	.300	30.6	.170
CHEST (G'S)	-16.5	.179	-6.7	.160	7.3	.138	17.1	.179
FEMUR LOAD (LBS)	506.	.057	0.	.300				

CUMULATIVE PERIOD FOR 60-G LEVEL = 0.000 SEC.

HIC = 252.0 DURING T = .142 TO .257 SEC.

TABLE A.26

BARRIER DEFLECTION - TEST RBCT-3

LOCATION-POST NO.	DEFLECTION* (IN.)
1	0
2	1.00
3	8.63
4	22.13
5	23.63 (MAXIMUM)
6	19.13
7	3.75
8 AND ON	0

*Measured at Top of W-Beam Rail
Metric Conversion: Multiply Inches by 25.4 to Obtain Millimeters

APPENDIX B

AN ALGORITHM FOR SIMULATING VEHICLE-END TREATMENT COLLISION BEHAVIOR

AN ALGORITHM FOR SIMULATING VEHICLE-END TREATMENT COLLISION BEHAVIOR

by

John J. Labra, Ph.D.

Recently at Southwest Research Institute (SwRI) a full-scale crash test involving a mini-car collision with a longitudinal barrier end treatment resulted in a hazardous post impact trajectory; the vehicle rapidly yawing and eventually rolling over. Since the particular end treatment is presently widely used, major concern exists in terms of its ability to perform adequately for the new downgraded sized vehicles. The algorithm (ENDON) presented in this text was developed to gain insight into this problem.

In the algorithm, the vehicle-end treatment interaction is assumed to take place in two phases: (a) the initial impulsive impact with the treatment at a specific eccentricity with respect to the vehicle longitudinal centerline axis and (b) a continuous, nonimpulsive translation and/or yawing motion. Specifically, the ENDON program can monitor the following:

1. The angular orientation of the vehicle after the impact.
2. The trajectory of the vehicle center of gravity (c.g.).
3. The angular and translational velocity components.
4. The vehicle lateral and longitudinal accelerations.

In the algorithm, a vehicle fixed reference frame (R, S) and an inertial reference frame (x, y), as shown in Figure B.1, are used. The inertial reference frame initially coincides with the vehicle system.

To minimize the complexity of the problem and thereby the associated computer costs, certain simplifying assumptions have been made. These include:

1. A three degree of freedom, rigid body representation for the vehicle without separate degrees of freedom for the wheels.
2. A single impact point located a specified distance from the vehicle longitudinal centerline.
3. An instantaneous (impulsive) failure of the end treatment upon impact.

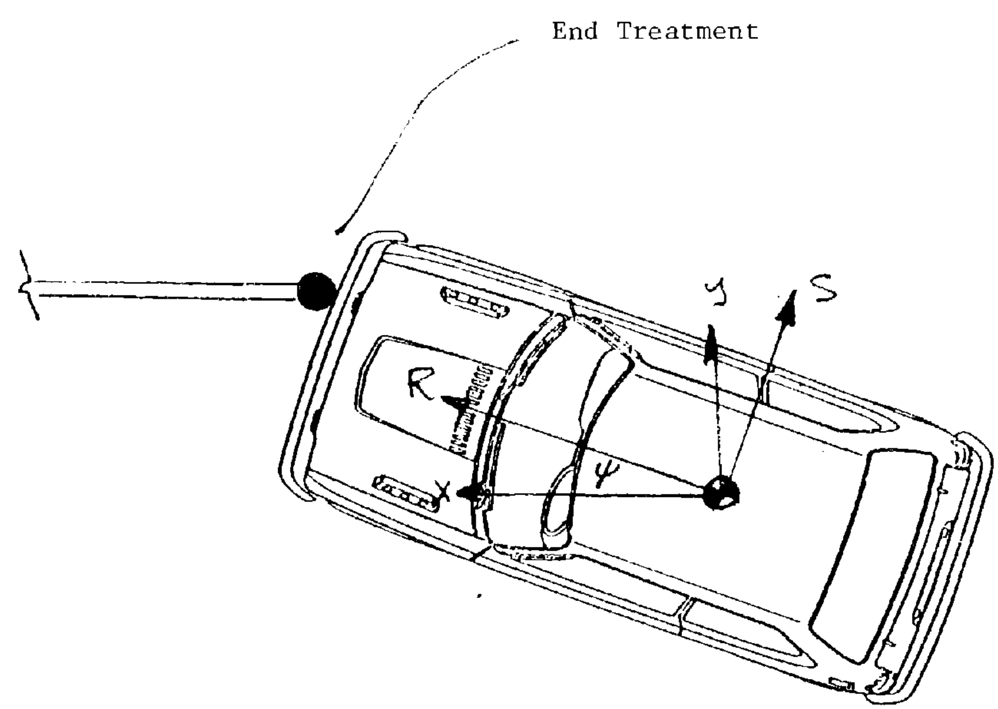


FIGURE B.1 VEHICLE IMPACTING END TREATMENT

With the ENDON program, yawing potential for any single-unit vehicle may be investigated by inserting the relevant weight and geometric parameters. The program was used to investigate impacts of a 1509-lb mini-car with a breakaway end treatment located at various distances from the vehicle longitudinal centerline. Further, the end treatment breakaway property effect on the vehicle yawing tendency was also considered by user input of instantaneous velocity change due to the particular end treatment struck.

A. Impact

In the ENDON program when the vehicle strikes the end treatment, an impulsive situation is assumed to exist. Based on the linear momentum principle during this initial phase, one obtains

$$M(V_R - V_0) = -\hat{P}_R$$

$$MV_S = -\hat{P}_S \qquad (1)$$

where

V_0, 0 = the initial translational velocity of the c.g. before impact in the vehicle fixed (and inertial) longitudinal direction;

V_R, V_S = the c.g. velocity components immediately after impact with respect to the vehicle fixed reference frame;

$\hat{P}_R$, $\hat{P}_S$ = the impulsive force components in the negative vehicle fixed R, S directions; and

M = the vehicle mass.

Based on the angular momentum principle about the vehicle's c.g., the angular or yaw velocity, ω, assumed zero prior to impact, is defined by the following:

$$I_{cg}\omega = \bar{r} \times \hat{P} \qquad (2)$$

where

I_{cg} = the vehicle's yaw moment of inertia about its c.g.,

$\bar{r}$ = the moment arm vector from the vehicle's c.g. to the impact point 0 on the end treatment,

$\hat{P}$ = the impulsive force vector between vehicle and end treatment.

In terms of scalar components, $\overline{r}$ and $\hat{P}$ are defined as

$$\overline{r} = x_F i + Ej$$

$$\hat{P} = -\hat{P}_R i - \hat{P}_S j \qquad (3)$$

where I, j are unit vectors in the longitudinal and lateral directions and x_F and E are the distances from vehicle c.g. to front bumper and eccentricity, respectively. Substitution of (3) into (2) results in

$$I_{cg}\omega = -x_F P_S + EP_R \qquad (4)$$

where ω is positive in the clockwise direction.

It is realized that the resultant impulsive force $\hat{P}$ during a typical impact scenario lies in an undefined direction. It can be safely assumed, however, the largest impulsive force component is directed along the vehicular longitudinal axis, vis.,

$$\hat{P}_R > \hat{P}_S \qquad (5)$$

Noting this, it is assumed that

$$\hat{P}_S = \alpha\hat{P}_R \qquad (6)$$

where α is some small fraction. Substitution of (1) into (6) results in

$$V_S = \alpha(V_R - V_0) \qquad (7)$$

Further, substitution of (1) and (6) into (4) gives

$$I_{cg}\omega = -P_R(x_F\alpha - E)P_R$$

$$= M(V_R - V_0)(\alpha x_F - E)$$

Accordingly, the instantaneous vehicle angular velocity induced by the end treatment can be written as

$$\omega = \frac{M}{I_{cg}}(V_R - V_0)(\alpha x_F - E) \qquad (8)$$

B. Post-Breakaway Trajectory

After the end treatment fails (instantaneous breakaway), the vehicle is assumed to be free of all external forces except those imparted through its tires.

For this two dimensional model, Euler's equations of motion reduce to:

$$M\left(\frac{du}{dt} - v\frac{d\psi}{dt}\right) = \Sigma F_{Ru} \qquad (9)$$

$$M\left(\frac{dv}{dt} + u\frac{d\psi}{dt}\right) = \Sigma F_{Su} \qquad (10)$$

$$I_{cg}\frac{d^2\psi}{dt^2} = \Sigma N_{\psi} \qquad (11)$$

where

u, v = the vehicle's velocity components in the R and S direction, respectively;

$\frac{du}{dt}, \frac{dv}{dt}$ = the corresponding longitudinal and lateral accelerations with respect to the vehicle fixed reference frame;

$\psi, \frac{d\psi}{dt}, \frac{d^2\psi}{dt^2}$ = the vehicle yaw angle, angular velocity, and angular acceleration, respectively;

$\Sigma F_{Ru}, \Sigma F_{Su}$ = the resultant tire-forces on the vehicle imposed through the tires in the vehicle R and S directions, and

ΣN_{ψ} = resulting yaw moment about the vehicle c.g. due to the tire-roadway reaction forces (Attachment A).

The initial value for ψ is zero. The initial values for u and v and $d\psi/dt$ are taken to be those defined for the vehicle immediately after impact when the end terminal has failed, i.e.,

$$u = V_R$$

$$v = V_S = \alpha(V_R - V_0)$$

$$\frac{d\psi}{dt} = \omega \qquad (12)$$

To solve for the vehicular accelerations (Equations 9-11) for each time increment, Δt, values for the velocities and forces from the previous time step are used, i.e.,

$$\left[\frac{du}{dt}\right]_{t+\Delta t} = \left[\frac{1}{M}\,\Sigma F_{Ru} + v\,\frac{d\psi}{dt}\right]_t$$

$$\left[\frac{dv}{dt}\right]_{t+\Delta t} = \left[\frac{1}{M}\,\Sigma F_{Su} - u\,\frac{d\psi}{dt}\right]_t$$

$$\left[\frac{d^2\psi}{dt^2}\right]_{t+\Delta t} = \frac{1}{I_{cg}}\left[\Sigma N_\psi\right]_t \qquad (13)$$

where

$$[u]_t = \left[u + \frac{du}{dt}\,dt\right]_{t-\Delta t}$$

$$[v]_t = \left[v + \frac{du}{dt}\,dt\right]_{t-\Delta t}$$

$$\left[\frac{d\psi}{dt}\right]_t = \left[\frac{d\psi}{dt} + \frac{d^2\psi}{dt^2}\,dt\right]_{t-\Delta t} \qquad (14)$$

A similar procedure is used to determine the trajectory parameters and is valid for small time increments ($t \leq 5$ msec). Repeating this process for each time step ENDON calculates accelerations, velocities, and trajectory data for time t. A simple transformation matrix is then used to transform the trajectory from vehicle to inertial reference frame. The simulation is completed either when the vehicle has yawed 90 degrees from its initial position or if the collision event has exceeded 1 second real time.

C. Implementation of ENDON Program

The foregoing theoretical developments were amalgamated into an algorithm and coded for placement on a CDC 175 system. A user's guide is enclosed in Attachment B. Using the ENDON program, simulations were made for a mini-car (Honda Civic) impacting a breakaway type end treatment. The parameters varied included the resistive properties of the treatment via varying the impulsive velocity change during impact, the impact eccentricity, and the fraction of longitudinal impulsive force imparted in the lateral direction. Over 36 simulations were performed. Results suggest that inducing 10 percent of the longitudinal impulse force in the lateral direction ($\alpha = 0.1$) gives good correlation between simulation results and full-scale test data (BCT end-on impacts @ 60 mph w/Honda). Further, the relationship between impulsive velocity change (ΔV) due to impact, trajectory (ψ/x), and impact eccentricity (E) is mathematically (approximately) defined by

$$\Delta V = \frac{366\ (\psi/x)^{0.70}}{E^{1.20}}$$

where ΔV is in ft/sec, E is in inches, and ψ/x, the ratio of yaw angle to longitudinal (inertial reference frame) trajectory is in deg/ft.

ATTACHMENT A

TIRE-ROADWAY REACTION FORCES

During the time interval after the vehicle has failed the end treatment, the yaw orientation and c.g. trajectory are determined by the vehicle dynamic system. These changes result from the vehicle's initial angular velocity after impact, weight distribution on the four tires, mass moment of inertia (yaw), overall geometry, and the tire-roadway patch reaction forces. Since the model is two dimensional, only the frictional reaction forces are applicable.

The location of each of the tire-road contact points is defined in matrix notation with respect to the inertial reference frame by

$$\begin{pmatrix} x_1 \\ y_1 \end{pmatrix} = \begin{pmatrix} x_{cg} \\ y_{cg} \end{pmatrix} + \|A\| \begin{pmatrix} a \\ T/2 \end{pmatrix} \qquad \text{Right Front (RF)}$$

$$\begin{pmatrix} x_2 \\ y_2 \end{pmatrix} = \begin{pmatrix} x_{cg} \\ y_{cg} \end{pmatrix} + \|A\| \begin{pmatrix} a \\ -T/2 \end{pmatrix} \qquad \text{Left Front (LF)}$$

$$\begin{pmatrix} x_3 \\ y_3 \end{pmatrix} = \begin{pmatrix} x_{cg} \\ y_{cg} \end{pmatrix} + \|A\| \begin{pmatrix} -b \\ T/2 \end{pmatrix} \qquad \text{Right Rear (RR)}$$

$$\begin{pmatrix} x_4 \\ y_4 \end{pmatrix} = \begin{pmatrix} x_{cg} \\ y_{cg} \end{pmatrix} + \|A\| \begin{pmatrix} -b \\ -T/2 \end{pmatrix} \qquad \text{Left Rear (LR)} \qquad (1)$$

where

x_{cg}, y_{cg} = vehicle c.g. location with respect to inertial system,

a, b = distance from c.g. to front and rear axles, respectively, and

T = vehicle track.

The 2 x 2 matrix $||A||$ is the transformation matrix from the vehicle fixed to inertial reference frame, viz.,

$$||A|| = \begin{bmatrix} \cos\psi & -\sin\psi \\ \sin\psi & \cos\psi \end{bmatrix} \quad (2)$$

The forward (longitudinal) velocities for each wheel are

$$u_1 = u - (T/2) \frac{d\psi}{dt} \quad \text{(RF)}$$

$$u_2 = u + (T/2) \frac{d\psi}{dt} \quad \text{(LF)}$$

$$u_3 = u - (T/2) \frac{d\psi}{dt} \quad \text{(RR)}$$

$$u_4 = u + (T/2) \frac{d\psi}{dt} \quad \text{(LR)} \quad (3)$$

The lateral velocities at each wheel contact point are taken as

$$v_1 = v_2 = v + a \frac{d\psi}{dt}$$

$$v_3 = v_4 = v - b \frac{d\psi}{dt} \quad (4)$$

In expressions (3) and (4) u, v are the vehicle c.g. velocities with respect to the vehicle fixed reference frame.

The frictional tire-roadway patch interaction forces developed during braking, traction, or skidding is a function of the normal reaction force at each tire-roadway interface. The normal reaction forces (F_{Ri}) are a function of the weight distribution and are calculated in ENDON by:

$$\mathring{F}_{R1} = F_{R2} = \frac{b}{2(a + b)} W$$

$$F_{R3} = F_{R4} = \frac{a}{2(a + b)} W \quad (5)$$

where subscripts 1-4 represent tire locations (RF, LF, RR, LR) and W is the total vehicle weight.

Using equations (5) the corresponding frictional forces are defined as

$$f_i = \mu F_{Ri} \quad (i = 1, 2, \ldots 4) \tag{6}$$

where μ is the kinetic friction coefficient.

As illustrated in Figure A-1, the tire frictional forces oppose vehicle motion. Since the wheels are in a fixed direction, each frictional force direction is defined in direction of the slip angle where the slip angle at each wheel is evaluated from

$$\beta_i = \tan^{-1} \frac{v_i}{|u_i|} \quad i = 1, 2, \ldots 4 \tag{7}$$

Resolving each tire force into components along the vehicle fixed axes, we obtain

$$\begin{aligned} f_{Rui} &= -F_{Ri} \cos\beta_i \cdot \mu \\ & \qquad\qquad i = 1, 2, \ldots 4 \\ f_{Sui} &= -F_{Ri} \sin\beta_i \cdot \mu \end{aligned} \tag{8}$$

The resultant tire forces in the vehicle longitudinal and lateral directions are then

$$\Sigma F_{Ru} = -\sum_{i=1}^{4} f_{Rui}$$

$$\Sigma F_{Su} = -\sum_{i=1}^{4} f_{Sui} \tag{9}$$

or expanded

$$\Sigma F_{Ru} = -(F_{R1}\cos\beta_1 + F_{R2}\cos\beta_2 + F_{R3}\cos\beta_3 + F_{R4}\cos\beta_4)$$

$$\Sigma F_{Su} = -(F_{R1}\sin\beta_1 + F_{R2}\sin\beta_2 + F_{R3}\sin\beta_3 + F_{R4}\sin\beta_4) \tag{10}$$

The individual moments (positive clockwise direction) about the vehicle c.g. due to these tire-roadway frictional forces is given by

$$N_{\psi i} = f_{Sui}\bar{r}_i - f_{Rui}\bar{s}_i \tag{11}$$

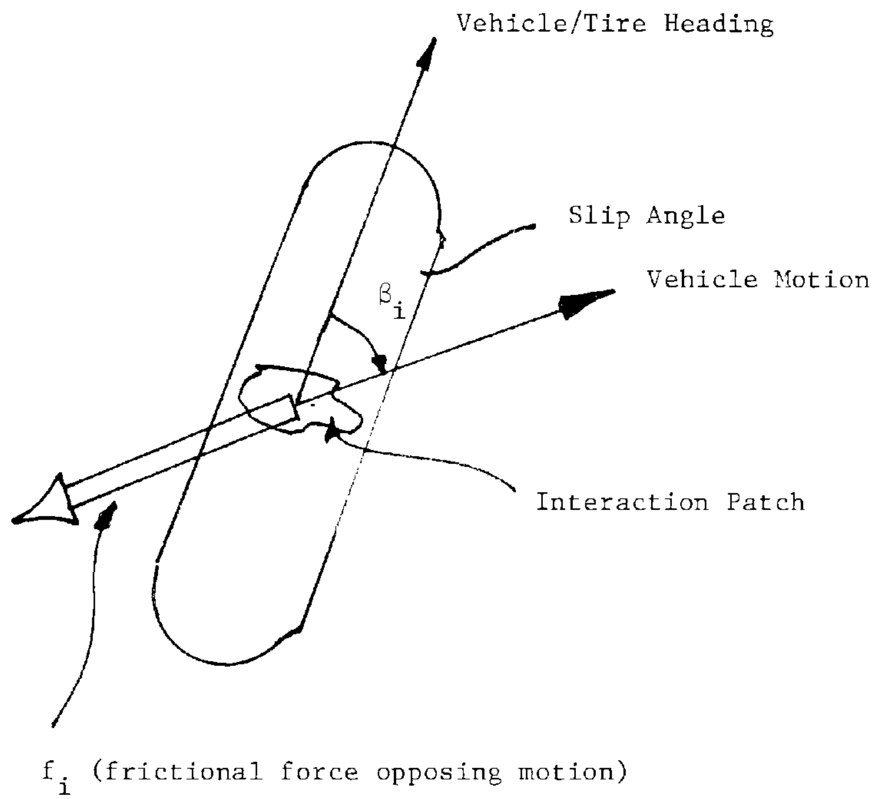


FIGURE A-1. TIRE-ROADWAY REACTION FORCE MODEL or expanded

$$N_{\psi 1} = a\ f_{Su1} - (T/2)\ f_{Ru1}$$

$$N_{\psi 2} = a\ f_{Su2} + (T/2)\ f_{Ru2}$$

$$N_{\psi 3} = -b\ f_{Su3} - (T/2)\ f_{Ru3}$$

$$N_{\psi 4} = -b\ f_{Su4} + (T/2)\ f_{Ru4} \qquad (12)$$

The resultant moment is then

$$\Sigma N_{\psi} = \sum_{i=1}^{4} N_{\psi i} \qquad (13)$$

or

$$\Sigma N_{\psi} = (f_{Su1} + f_{Su2})a - (f_{Su3} + f_{Su4})b$$

$$+ (-f_{Ru1} + f_{Ru2} - f_{Ru3} + f_{Ru4})T/2 \qquad (14)$$

The above defined resultant forces and moment (Equations 10 and 14) are evaluated at each time internal in the ENDON program. Making the a priori assumption of zero, frictional forces would, in essence, simulate a vehicle's trajectory on an ideal smooth surface with no external loads after the failure of the end treatment.

ATTACHMENT B

USER GUIDE FOR PROGRAM ENDON

A simple algorithm has been developed at Southwest Research Institute which models the impact response of a vehicle into a barrier end treatment designed to breakaway. The program's two dimension model consists of a rigid vehicle structure which includes:

- yaw moment of inertia (ZI),
- total weight (W),
- front axle location with respect to center-of-gravity (A),
- rear axle location with respect to center-of-gravity (B),
- wheel track (T).

The collision event is initially modeled as a concentered point loading with a user specified eccentricity (E) with respect to the vehicle longitudinal centerline. This concentrated impulse force is assumed to act in the vehicle longitudinal direction.

A vehicle impact velocity (Vϕ) is specified as well as assumed longitudinal velocity at the instant the end treatment breaks away (VB). Further, the user can specify a fraction of the longitudinal impulse, m(VB - VO), acting in the lateral direction. This is achieved by the imput of a constant (ALPHA) which is less than one. This initial phase of the simulation is handled mathematically by simple linear momentum theory. From this initial impact phase an instantaneous angular velocity is derived.

During the second phase of the accident scenario, the only forces acting on the vehicle are through its tires. The user may specify a coefficient of kinetic friction at the tire/road interface patch, analogous to tire breaking and side forces. These forces are based on the "friction circle" concept which assumes that the maximum force that can be generated by the tire in the plane of the tire-terrain contact patch is equal in all directions. In the algorithm each tire force opposes the vehicle motion and is in a direction based on the program calculated slip angles at wheel (analogous to a locked wheel situation). Specifying a zero or small friction coefficient will allow the user to approximate a "free-rolling" post-impact event.

For each simulation the program runs until the maximum time (TMAX) is exceeded or if the vehicle has rotated 90 degrees from its initial position. A time increment (DELT) of 0.005 sec or less is recommended. Output includes post-impact vehicle c.g. trajectory, acceleration lateral and longitudinal components, angular velocity, speed, lateral and longitudinal velocity components, and vehicle orientation. The simple user input is shown in Table B-1. An example of typical output is illustrated in Table B-2. The program listing is given in Table B-3.

TABLE B-1

ENDON PROGRAM
INPUT PARAMETERS

Card No.	Notation	Input Variable Descriptor
1	W = vehicle weight (lb) A = distance from c.g. to front axle (in.) B = distance from c.g. to rear axle (in.) T = track (in.) XF = c.g. to vehicle front bumper (in.) ZI = yaw moment of inertia (lb-in.-sec^2) MU = tire/terrain patch coefficient of kinetic friction	6F10.0
2	E = lateral distance from vehicle longitudinal centerline to contact pt. with end treatment (in.) Vϕ = vehicle initial velocity (ft/sec) VB = vehicle velocity at instant of end treatment breakaway (ft/sec) ALPHA = fraction of longitudinal impulse in the lateral direction (constant less than 1.0) DELT = simulation time increment (sec) TMAX = total simulation time (sec)	5F10.0

TABLE B-2

P R O G R A M   E N D O N

THIS PROGRAM INVESTIGATES THE VEHICLE IMPACT RESPONSE
DUE TO A COLLISION WITH A BREAKAWAY END TREATMENT

VEHICLE PROPERTIES

WEIGHT(LB.)	1509.
CG TO FRONT AXLE(IN.)	37.25
CG TO REAR AXLE(IN.)	54.89
YAW M. OF INERTIA(LB-IN-SEC2)	4144.00
TIRE/ROAD FRICT.COEFF.	.3000
FRONT/REAR TRACK(IN.)	50.50
CG TO FRONT BUMPER(IN.)	63.23
VEHICLE INITIAL VEL.(FPS)	88.00

END TREATMENT PROPERTIES

IMPACT ECCENTRICITY(IN.)	20.
POST BREAK. VELOCITY	58.0
Y IMPULSE FACTOR	.10

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TIME SEC.	CG ACCEL. G-UNITS LAT	LONG	ANG.VEL DEG/SEC	SPEED FT/SEC	CG POSITION(FT.) XP	YP	ORIENT DEG	VELOCITY(FPS) LAT	LONG
.005	-8.4	-.7	265.7	58.0	.3	-.0	1.3	-4.3	57.9
.010	-8.3	-.9	265.3	58.0	.6	-.0	2.7	-5.7	57.7
.015	-8.3	-1.1	264.9	58.0	.9	-.0	4.0	-7.0	57.6
.020	-8.2	-1.3	264.4	58.0	1.2	-.1	5.3	-8.3	57.4
.025	-8.2	-1.5	264.0	57.9	1.4	-.1	6.6	-9.7	57.1
.030	-8.1	-1.7	263.6	57.9	1.7	-.1	7.9	-11.0	56.8
.035	-8.1	-1.9	263.2	57.9	2.0	-.1	9.3	-12.3	56.5
.040	-8.0	-2.0	262.8	57.8	2.3	-.1	10.6	-13.6	56.2
.045	-8.0	-2.2	262.4	57.8	2.6	-.1	11.9	-14.8	55.9
.050	-7.9	-2.4	262.1	57.8	2.9	-.2	13.2	-16.1	55.5
.055	-7.8	-2.6	261.7	57.7	3.2	-.2	14.5	-17.4	55.1
.060	-7.7	-2.7	261.3	57.7	3.5	-.2	15.8	-18.6	54.6
.065	-7.7	-2.9	260.9	57.7	3.8	-.2	17.1	-19.8	54.2
.070	-7.6	-3.1	260.6	57.6	4.0	-.2	18.4	-21.1	53.7
.075	-7.5	-3.2	260.2	57.6	4.3	-.2	19.7	-22.3	53.1
.080	-7.4	-3.4	259.9	57.6	4.6	-.2	21.0	-23.5	52.6
.085	-7.3	-3.6	259.5	57.5	4.9	-.3	22.3	-24.6	52.0
.090	-7.2	-3.7	259.2	57.5	5.2	-.3	23.6	-25.8	51.4
.095	-7.1	-3.9	258.8	57.5	5.5	-.3	24.9	-26.9	50.8
.100	-7.0	-4.0	258.5	57.5	5.8	-.3	26.2	-28.1	50.1
.105	-6.9	-4.2	258.2	57.4	6.1	-.3	27.5	-29.2	49.5
.110	-6.8	-4.3	257.9	57.4	6.3	-.3	28.8	-30.3	48.8
.115	-6.7	-4.5	257.6	57.4	6.6	-.3	30.1	-31.3	48.0
.120	-6.6	-4.6	257.3	57.3	6.9	-.4	31.3	-32.4	47.3
.125	-6.4	-4.8	257.0	57.3	7.2	-.4	32.6	-33.4	46.5
.130	-6.3	-4.9	256.7	57.3	7.5	-.4	33.9	-34.4	45.7
.135	-6.2	-5.0	256.4	57.2	7.8	-.4	35.2	-35.4	44.9
.140	-6.1	-5.2	256.1	57.2	8.1	-.4	36.5	-36.4	44.1
.145	-5.9	-5.3	255.9	57.2	8.3	-.4	37.8	-37.4	43.3
.150	-5.8	-5.4	255.6	57.1	8.6	-.5	39.0	-38.3	42.4
.155	-5.7	-5.5	255.3	57.1	8.9	-.5	40.3	-39.2	41.5
.160	-5.6	-5.7	255.1	57.1	9.2	-.5	41.6	-40.1	40.6
.165	-5.4	-5.8	254.8	57.0	9.5	-.5	42.9	-41.0	39.7
.170	-5.3	-5.9	254.6	57.0	9.8	-.5	44.1	-41.8	38.7
.175	-5.1	-6.0	254.3	57.0	10.1	-.5	45.4	-42.7	37.7
.180	-5.0	-6.1	254.1	56.9	10.3	-.5	46.7	-43.5	36.8
.185	-4.9	-6.2	253.9	56.9	10.6	-.6	47.9	-44.2	35.8
.190	-4.7	-6.3	253.7	56.9	10.9	-.6	49.2	-45.0	34.8
.195	-4.6	-6.4	253.5	56.8	11.2	-.6	50.5	-45.7	33.7
.200	-4.4	-6.5	253.2	56.8	11.5	-.6	51.8	-46.4	32.7
.205	-4.3	-6.6	253.0	56.8	11.8	-.6	53.0	-47.1	31.6
.210	-4.1	-6.6	252.8	56.7	12.0	-.6	54.3	-47.8	30.6
.215	-3.9	-6.7	252.6	56.7	12.3	-.7	55.5	-48.4	29.5
.220	-3.8	-6.8	252.4	56.7	12.6	-.7	56.8	-49.0	28.4
.225	-3.6	-6.9	252.3	56.6	12.9	-.7	58.1	-49.6	27.3
.230	-3.5	-6.9	252.1	56.6	13.2	-.7	59.3	-50.2	26.2
.235	-3.3	-7.0	251.9	56.6	13.5	-.7	60.6	-50.7	25.1
.240	-3.2	-7.1	251.7	56.5	13.7	-.7	61.8	-51.2	23.9
.245	-3.0	-7.1	251.5	56.5	14.0	-.7	63.1	-51.7	22.8
.250	-2.8	-7.2	251.4	56.5	14.3	-.8	64.4	-52.2	21.6

TABLE B-2 (Cont'd)

TIME SEC.	CG ACCEL. G-UNITS LAT	CG ACCEL. G-UNITS LONG	ANG.VEL DEG/SEC	SPEED FT/SEC	CG POSITION(FT.) XP	CG POSITION(FT.) YP	ORIENT DEG	VELOCITY(FPS) LAT	VELOCITY(FPS) LONG
.255	-2.7	-7.2	251.2	56.4	14.6	-.8	65.6	-52.6	20.5
.260	-2.5	-7.3	251.0	56.4	14.9	-.8	66.9	-53.0	19.3
.265	-2.4	-7.3	250.8	56.4	15.1	-.8	68.1	-53.4	18.1
.270	-2.2	-7.4	250.7	56.3	15.4	-.8	69.4	-53.7	16.9
.275	-2.0	-7.4	250.5	56.3	15.7	-.8	70.6	-54.1	15.7
.280	-1.9	-7.4	250.4	56.3	16.0	-.9	71.9	-54.4	14.5
.285	-1.7	-7.5	250.2	56.2	16.3	-.9	73.1	-54.6	13.3
.290	-1.5	-7.5	250.1	56.2	16.5	-.9	74.4	-54.9	12.1
.295	-1.4	-7.5	249.9	56.2	16.8	-.9	75.6	-55.1	10.9
.300	-1.2	-7.5	249.7	56.1	17.1	-.9	76.9	-55.3	9.7
.305	-1.0	-7.5	249.6	56.1	17.4	-.9	78.1	-55.4	8.5
.310	-.9	-7.6	249.5	56.1	17.7	-.9	79.4	-55.6	7.3
.315	-.7	-7.6	249.3	56.0	17.9	-1.0	80.6	-55.7	6.1
.320	-.5	-7.6	249.2	56.0	18.2	-1.0	81.9	-55.8	4.8
.325	-.4	-7.6	249.1	56.0	18.5	-1.0	83.1	-55.8	3.6
.330	-.2	-7.6	249.1	55.9	18.8	-1.0	84.4	-55.9	2.4
.335	-.0	-7.6	249.0	55.9	19.1	-1.0	85.6	-55.9	1.2
.340	.1	-7.6	249.0	55.9	19.3	-1.0	86.9	-55.9	-.0
.345	.3	-7.6	249.0	55.8	19.6	-1.1	88.1	-55.8	-1.3
.350	.5	-7.6	249.0	55.8	19.9	-1.1	89.3	-55.7	-2.5

TABLE B-3

```
 80/11/13. 14.45.43.
PROGRAM    ENDON

      PROGRAM ENDON(INPUT,OUTPUT)
C     TO INVESTIGATE POST IMPACT TRAJECTORY OF ERRANT VEHICLE AFTER
C     STRIKING MEDIAN BARRIER TERMINAL
C
      DIMENSION XTP(4),YTP(4),UT(4),VT(4)
C     READ IN VEHICLE PROPERTIES
C     TOTAL WEIGHT(W)-LBS.
C     LONG. DIST. FROM C.G. TO FRONT AXLE
C     LONG. DIST. FROM C.G. TO REAR AXLE(IN.)
C     FRONT AND REAR TRACK(IN.)
C     YAW MOMENT OF INERTIA(LB-IN-SEC2)
C     READ IN INITIAL CONDITIONS
C     ECCENTRICITY OF POST POSITION WRT CAR CENTERLINE(IN.)
C     INITIAL VELOCITY(V0)-FPS
C     POST BREAKAWAY VELOCITY(VB)-FPS
      REAL OMEG,MU,MOM
      READ 10,W,A,B,T,XF,ZI,MU
C     INITIAL IMPACT PHASE
      WM=W/32.17
      READ 10,E,V0,VB,ALPHA,DELT,TMAX
      OMEG=WM*(VB-V0)*(-E+ALPHA*XF)/ZI
C     INITIALIZE CONDITIONS
      PSI=0.
      X=0.
      Y=0.
      XP=0.
      YP=0.
      U=VB
      V=ALPHA*(VB-V0)
      TM=0.
      KK=0
      PSIDOT=OMEG
      UDOT=0.
      VDOT=0.
      PRINT 50,W,E,A,VB,ALPHA,B,ZI,MU,T,XF,V0
      PRINT 25
      CALL AMAT(X,Y,PSI,XP,YP)
      CALL TRAN(T,A,B,PSI,XP,YP,XTP,YTP)
  1   CALL TIRE(A,B,T,PSIDOT,MU,W,U,V,FX,FY,MOM,UT,VT)
      CALL ACCEL(WM,U,V,PSIDOT,ZI,FX,FY,MOM,UDOT,VDOT,PSDD)
      U=U+UDOT*DELT
      V=V+VDOT*DELT
      PSIDOT=PSIDOT+PSDD*DELT
      X=X+U*DELT
      Y=Y+V*DELT
      PSI=PSI+PSIDOT*DELT
```

```
      TM=TM+DELT
      XX=U◆DELT
      YY=V◆DELT
      CALL AMAT(U,V,PSI,UP,VP)
      CALL AMAT(XX,YY,PSI,XXP,YYP)
      XP=XP+XXP
      YP=YP+YYP
      CALL TRAN(T,A,B,PSI,XP,YP,XTP,YTP)
      IF(KK.NE.0) GO TO 5
      PRINT 100
 5    CONTINUE
      KK=KK+1
      IF(KK.EQ.50)KK=0
      IF(TM.GT.TMAX) GO TO 1000
      ALAT=VDOT/32.17
      ALONG=UDOT/32.17
      ANGV=PSIDOT◆180./3.141592654
      SPEED=SQRT(U◆◆2.+V◆◆2.)
      ANG=PSI◆180./3.141592654
      IF(ABS(ANG).GT.90.) GO TO 1000
      PRINT 200,TM,ALAT,ALONG,ANGV,SPEED,XP,YP,ANG,V,U
      GO TO 1
 1000 PRINT 1001
      STOP
1001  FORMAT(1H1/5X,◆END OF RUN◆//)
10    FORMAT(8F10.0)
 100  FORMAT(1H1/T6,◆TIME◆,T20,◆CG ACCEL.◆,T40,◆ANG.VEL◆,T60,◆SPEED◆,
     1T80,◆CG POSITION(FT.)◆,T100,◆ORIENT◆,T117,◆VELOCITY(FPS)◆/
     2T6,◆SEC.◆,T21,◆G-UNITS◆,T40,◆DEG/SEC◆,T60,◆FT/SEC◆,T83,◆XP◆,
     3T93,◆YP◆,T102,◆DEG◆,T118,◆LAT◆,T125,◆LONG◆/
     4T15,◆LAT◆,T23,◆LONG◆//)
 200  FORMAT(T4,F6.3,T13,F7.1,T23,F7.1,T39,F8.1,T56,F8.1,T78,F8.1
     1,T90,F8.1,T101,F5.1,T112,F8.1,T122,F8.1)
 50   FORMAT(1H1/T53,◆P R O G R A M   E N D O N◆///
     1T39,◆THIS PROGRAM INVESTIGATES THE VEHICLE IMPACT RESPONSE◆/
     2T41,◆DUE TO A COLLISION WITH A BREAKAWAY END TREATMENT◆///
     3T40,◆VEHICLE PROPERTIES◆,T90,◆END TREATMENT PROPERTIES◆//
     4T30,◆WEIGHT(LB.)◆,T60,F8.0,T90,◆IMPACT ECCENTRICITY(IN.)◆,T110,
     5F5.0,/T30,◆CG TO FRONT AXLE(IN.)◆,T60,F8.2,T90,◆POST BREAK. VEL◆
     6◆OCITY◆,T110,F5.1/T90,◆Y IMPULSE FACTOR◆,T110,F4.2/
     7T30,◆CG TO REAR AXLE(IN.)◆,T60,F8.2/
     8T30,◆YAW M. OF INERTIA(LB-IN-SEC2)◆,T60,F8.2/
     9T30,◆TIRE/ROAD FRICT.COEFF.◆,T60,F8.4/
     3T30,◆FRONT/REAR TRACK(IN.)◆,T60,F8.2/
     6T30,◆CG TO FRONT BUMPER(IN.)◆,T60,F8.2/
     7T30,◆VEHICLE INITIAL VEL.(FPS)◆,T60,F8.2/)
  25  FORMAT(///T53,◆SOUTHWEST RESEARCH INSTITUTE◆/
     1T61,◆PO BOX 28510◆/T55,◆SAN ANTONIO,TX. 78284◆//
     2T52,◆DR.JOHN J.LABRA,(512) 684-5111◆)
      END
```

TABLE B-3 (Cont'd)

```
SUBROUTINE TIRE(A,B,T,PSIDOT,[illegible],FY,MOM,UT,VT)
REAL MU,MOM
DIMENSION UT(4),VT(4)
F1=MU*B*W/(2.*(A+B))
F2=F1
F3=F1*A/B
F4=F3
TIRE VELOCITIES
U1=U-T*PSIDOT/24.
U3=U1
U2=U+T*PSIDOT/24.
U4=U2
V1=V+A*PSIDOT/12.
V2=V1
V3=V-PSIDOT*B/12.
V4=V3
UT(1)=U1
UT(2)=U2
UT(3)=U3
UT(4)=U4
VT(1)=V1
VT(2)=V2
VT(3)=V3
VT(4)=V4
SLIP ANGLES
B1=ATAN(V1/ABS(U1))
B2=ATAN(V2/ABS(U2))
B3=ATAN(V3/ABS(U3))
B4=ATAN(V4/ABS(U4))
TRANSLATIONAL TIRE FORCES
FX1=-F1*COS(B1)
FX2=-F2*COS(B2)
FX3=-F3*COS(B3)
FX4=-F4*COS(B4)
FX=FX1+FX2+FX3+FX4
FY1=-F1*SIN(B1)
FY2=-F2*SIN(B2)
FY3=-F3*SIN(B3)
FY4=-F4*SIN(B4)
FY=FY1+FY2+FY3+FY4
TIRE MOMENTS
TM1=A*FY1-T*FX1/2.
TM2=A*FY2+T*FX2/2.
TM3=-B*FY3-T*FX3/2.
TM4=-B*FY4+T*FX4/2.
MOM=TM1+TM2+TM3+TM4
MOMENT IN (LB-IN)
RETURN
END
```

TABLE B-3 (Cont'd)

```
SUBROUTINE ACCEL(WM,U,V,PSIDOT,ZI,FX,FY,MOM,UDOT,VDOT,PSDD)
PER. MOM
T. ACCEL. IN FT./SEC2
UDOT=(FX+WM*V*PSIDOT)/WM
VDOT=(FY-WM*U*PSIDOT)/WM
PSDD=MOM/ZI
RETURN
END
SUBROUTINE AMAT(R,S,PSI,RP,SP)
CS=COS(PSI)
SN=SIN(PSI)
RP=R*CS-S*SN
SP=R*SN+S*CS
RETURN
END
SUBROUTINE TRAN(T,A,B,XP,YP,PSI,XTP,YTP)
DIMENSION XTP(4),YTP(4)
CS=COS(PSI)
SN=SIN(PSI)
XP=XP*12.
YP=YP*12.
XTP(1)=XP+A*CS-T*SN/2.
XTP(2)=XP+A*CS+T*SN/2.
XTP(3)=XP-B*CS-T*SN/2.
XTP(4)=XP-B*CS+T*SN/2.
YTP(1)=YP+A*SN+T*CS/2.
YTP(2)=YP+A*SN-T*CS/2.
YTP(3)=YP-B*SN+T*CS/2.
YTP(4)=YP-B*SN-T*CS/2.
XP=XP/12.
YP=YP/12.
RETURN
END
```

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FEDERALLY COORDINATED PROGRAM (FCP) OF HIGHWAY RESEARCH AND DEVELOPMENT

The Offices of Research and Development (R&D) of the Federal Highway Administration (FHWA) are responsible for a broad program of staff and contract research and development and a Federal-aid program, conducted by or through the State highway transportation agencies, that includes the Highway Planning and Research (HP&R) program and the National Cooperative Highway Research Program (NCHRP) managed by the Transportation Research Board. The FCP is a carefully selected group of projects that uses research and development resources to obtain timely solutions to urgent national highway engineering problems.*

The diagonal double stripe on the cover of this report represents a highway and is color-coded to identify the FCP category that the report falls under. A red stripe is used for category 1, dark blue for category 2, light blue for category 3, brown for category 4, gray for category 5, green for categories 6 and 7, and an orange stripe identifies category 0.

FCP Category Descriptions

1. **Improved Highway Design and Operation for Safety**

   Safety R&D addresses problems associated with the responsibilities of the FHWA under the Highway Safety Act and includes investigation of appropriate design standards, roadside hardware, signing, and physical and scientific data for the formulation of improved safety regulations.

2. **Reduction of Traffic Congestion, and Improved Operational Efficiency**

   Traffic R&D is concerned with increasing the operational efficiency of existing highways by advancing technology, by improving designs for existing as well as new facilities, and by balancing the demand-capacity relationship through traffic management techniques such as bus and carpool preferential treatment, motorist information, and rerouting of traffic.

3. **Environmental Considerations in Highway Design, Location, Construction, and Operation**

   Environmental R&D is directed toward identifying and evaluating highway elements that affect the quality of the human environment. The goals are reduction of adverse highway and traffic impacts, and protection and enhancement of the environment.

4. **Improved Materials Utilization and Durability**

   Materials R&D is concerned with expanding the knowledge and technology of materials properties, using available natural materials, improving structural foundation materials, recycling highway materials, converting industrial wastes into useful highway products, developing extender or substitute materials for those in short supply, and developing more rapid and reliable testing procedures. The goals are lower highway construction costs and extended maintenance-free operation.

5. **Improved Design to Reduce Costs, Extend Life Expectancy, and Insure Structural Safety**

   Structural R&D is concerned with furthering the latest technological advances in structural and hydraulic designs, fabrication processes, and construction techniques to provide safe, efficient highways at reasonable costs.

6. **Improved Technology for Highway Construction**

   This category is concerned with the research, development, and implementation of highway construction technology to increase productivity, reduce energy consumption, conserve dwindling resources, and reduce costs while improving the quality and methods of construction.

7. **Improved Technology for Highway Maintenance**

   This category addresses problems in preserving the Nation's highways and includes activities in physical maintenance, traffic services, management, and equipment. The goal is to maximize operational efficiency and safety to the traveling public while conserving resources.

0. **Other New Studies**

   This category, not included in the seven-volume official statement of the FCP, is concerned with HP&R and NCHRP studies not specifically related to FCP projects. These studies involve R&D support of other FHWA program office research.

* The complete seven-volume official statement of the FCP is available from the National Technical Information Service, Springfield, Va. 22161. Single copies of the introductory volume are available without charge from Program Analysis (HRD-3), Offices of Research and Development, Federal Highway Administration, Washington, D.C. 20590.