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Final Report

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**BASIC RESEARCH IN CRASHWORTHINESS II ---
INCORPORATION OF A MODIFIED FRONT STRUCTURE
INTO OPERATIONAL AUTOMOBILES**

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16. Abstract A front structural modification utilizing the engine deflection concept developed on another phase of the Basic Research in Crashworthiness II project was refined and incorporated into a series of fully operational automobiles. The structure was adapted to conventional 1972 full size Ford sedans. The structural modification did not have a significant effect on the handling characteristics of the modified automobile when compared to similar data for the conventional automobile. Three different operational automobiles were developed and crash tested into both flat and pole barriers at speeds ranging from 40 MPH to just under 60 MPH. In addition, to provide comparative data, a conventional 1972 Ford was impacted into the pole barrier at 57.8 MPH. Results of the study demonstrate the feasibility of significantly improving front structural crash performance using conventional automotive technology.			
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FOREWORD

This interim report presents the results of a research effort to incorporate structural modifications into fully operational automobiles. The structure was developed under another phase of the overall project and changes were limited to those necessary to accommodate normal operational requirements. Both vehicle handling and crash tests were performed with both modified and conventional 1972 full size Ford automobiles. Complete results for these series of tests are presented.

This report is submitted in partial fulfillment of a program of research conducted by Calspan Corporation for the National Highway Traffic Safety Administration under Contract No. FH-11-7622. Contract Technical Manager for this project is Mr. Glen Brammeier of NHTSA.

The opinions and findings expressed in this publication are those of the author and not necessarily those of the National Highway Traffic Safety Administration.

This report has been reviewed and is approved by:



Edwin A. Kidd, Head
Transportation Research Department

PREFACE

This report is one of a series of interim reports describing the research efforts being conducted under the "Basic Research in Crash-worthiness II" program. These interim reports represent the effort and conclusions in a particular area associated with the overall crashworthiness program. While the conclusions may not be final and the data presented may not be all of the data to be collected in the particular area being reported, it is felt that these reports may be useful in:

- (1) providing a focus for the objective of the overall program, and
- (2) providing a convenient means for presentation of the program results in a measured fashion rather than in a voluminous final report.

It is anticipated that the final report will present any additional pertinent data collected and fully integrate these interim reports with the overall program objectives and conclusions. In the meantime, a brief discussion of the program objectives and the overall scope of the effort is presented to provide perspective for these interim reports.

The objective of this research program is to obtain experimental and analytical data that will establish the feasibility of designing automobile structures to dissipate energy at a controlled rate during collisions and prevent intrusion into the passenger compartment. The problem has been attacked from three separate and initially distinct aspects, namely,

- to determine structural performance characteristics of current automobiles through a wide range of test conditions, i. e., vehicle size, impact speed, impact conditions, etc. (so-called base line tests),
- to consider structural modifications required of the front of a vehicle to improve its structural performance in frontal impacts,
- to consider structural modifications required of the side elements (i. e., doors, door pillars, roof) of the vehicle to improve its structural performance in side impacts.

Each of these areas has involved a concern for the performance of unmodified and modified vehicles in impact situations with

- fixed pole and flat barriers, and
- in vehicle-to-vehicle impacts, including impacts between two unmodified vehicles, two fully modified vehicles and one unmodified and one modified vehicle.

The effort also encompasses a concern for the impact behavior between vehicles of

- different weight classifications,
- different structural characteristics, i. e., frame-compartment type vs. unitized type, and
- different impact conditions, namely compatibility in front/side impacts.

The modifications are not restricted to the vehicle exterior. A task concerned with desirable interior modifications, e.g., steering columns, piggyback testing of advanced restraint systems, interior modifications (padding, seats, etc.) is also a part of the program. A natural outgrowth of the overall concern for improving the crashworthiness of the vehicle is the concern for the production feasibility of the recommended structural design modifications made for full size automobiles. A separate task addresses itself to this aspect of the crashworthiness program.

Finally, a substantial analytical treatment of the problem of a frame-compartment type of automobile impacting a rigid obstacle is under development. The objective of the effort is to allow prediction and hence evaluation of the behavior of frame type structures.

Conclusion of the program is anticipated by May 1973.

ACKNOWLEDGMENTS

The author wishes to acknowledge a number of Calspan Corporation personnel who contributed to the research described in this report. Particularly important were the engineering recommendations and the vehicle handling investigation performed by Mr. James E. Greene. Mr. Donald Lombard made significant contributions while translating structural criteria into the final design. Others made contributions in the following areas:

- Vehicle Preparation, Instrumentation and Crash Testing

Donald A. Alianello
Walter A. Stahl
Jerold F. Cory
Norman E. Schweitzer
Frank A. DuWaldt

- Photography

Ralph L. Jones
Richard G. Matthies
Frederick Thornton
Robert E. Scott
Shirley Mandel

- Data Reduction

Robert F. Wantuck

- Report Preparation

Ross H. Ramsey
Alesia E. Kudela

The vehicles were fabricated by Pioneer Engineering and Manufacturing Company, Warren, Michigan. Messrs. Norman Ludtke and Charles Rondeau were responsible for the PEM effort.

Suggestions and recommendations of various NHTSA technical personnel, particularly Messrs. Glen Brammeier and James Hofferberth were timely and helpful to the performance of this study.

SUMMARY

A front structural modification utilizing the engine deflection concept developed on another phase of the Basic Research in Crashworthiness II project was refined and incorporated into a series of fully operational automobiles. The structure was adapted to conventional 1972 full size Ford sedans. The structural modification did not have a significant effect on the handling characteristics of the modified automobile when compared to similar data for the conventional automobile. Three different operational automobiles were developed and crash tested into both flat and pole barriers at speeds ranging from 40 MPH to just under 60 MPH. In addition, to provide comparative data, a conventional 1972 Ford was impacted into the pole barrier at 57.8 MPH. Results of the study demonstrate the feasibility of significantly improving front structural crash performance using conventional automotive technology.

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1. INTRODUCTION

Presented in this report are the results of an effort to integrate the engine deflection concept into a fully operational automobile. The basic technique of deflecting the engine relative to the passenger compartment (a combination of downward engine and upward passenger compartment movements) has been under investigation for a number of years. The scheme was initially investigated in the Basic Research in Crashworthiness I program (Contract No. FH-11-6918) performed by Calspan Corporation for the National Highway Traffic Safety Administration. In that program, modifications were made to 1966 Ford sedans which were tested against fixed objects at impact speeds between 40 MPH and 60 MPH (Refs. 1, 2 and 3).

Although the terminology "engine deflection" has been used extensively to describe the concept, the basic effort is essentially related to modifying the structure to provide for better control of the kinetic energy absorption (dissipation) during vehicular collapse as a result of frontal collisions. Therefore, important changes are made to various vehicle structural components (e. g., frame, hood, fenders, etc.). With these modified full size vehicles, substantial engine movement occurs only during fixed object tests at speeds somewhat above 45 MPH. Thus, only in these more severe cases is it imperative that some means be undertaken to insure that excessive intrusion of the engine into the passenger compartment does not take place.

For various reasons, the vehicle alterations as initially developed in the Crashworthiness I program (Contract No. FH-11-6918) were not suitable for incorporation into operational vehicles. Furthermore, the modified structures generally employed materials and metal gauge thicknesses not normally used in automobile structures. Consequently, a major effort on the Basic Research in Crashworthiness II project was directed towards refinement of the concept to make it more consistent with these automobile requirements. This effort is reported in a companion report (Ref. 4).

Therefore, the reader should consult the cited references to gain complete understanding of the background research that preceded (and in certain instances paralleled) the activities considered in this report.

Within this phase of the study, front structural modifications were incorporated into three 1972 Ford sedans.* These vehicles, designated OV-I, OV-II and OV-III, were completely operational. The first vehicle, OV-I, did not incorporate all aspects of the eventual design and did not employ prototype tooling methods. The latter vehicles, OV-II and OV-III, were identical and prototype tooling was employed while fabricating the frame. In addition, all materials added to the structure were within typical automotive gauge requirements. With the exception of the fire wall sub-assembly, all other structural components added to the production automobile could be manufactured using conventional automotive technology.

To provide base line information on the conventional, unmodified automobile, a 1972 Ford was impacted at 57.8 MPH** into a rigid pole barrier. This test condition represents an extremely severe test both in terms of impact speed and obstacle. The first modified vehicle, OV-I, was impacted at 58.7 MPH into a flat barrier. Because this was a developmental vehicle, the flat barrier was used to determine structural response (primarily that of the frame) during impact with a flat surface obstacle. The test on the OV-II was meant to be identical with that imposed on the conventional 1972 Ford (i. e., high speed impact with the pole barrier). Unfortunately, due to two consecutive system malfunctions, the vehicle impacted the pole obstacle at 40 MPH. The vehicle was, however, eventually repaired (designated OV-II R) and then impacted into the pole barrier at 56.8 MPH. Primarily to determine the performance of the system throughout a wider range of

* All vehicle fabrication was performed by Pioneer Engineering and Manufacturing Company, Warren, Michigan under subcontract to Calspan Corporation.

** For these high speed tests, speed tolerance was set at 57.5 $\pm$ 2.5 MPH.

conditions, the OV-III vehicle was crash tested at 49.9 MPH into a flat barrier.*

Generally, greatly improved structural performance was exhibited between the modified and conventional automobiles. This is particularly evident in the greater passenger compartment structural integrity (occupant survival space) exhibited by the modified vehicles when compared to that of the conventional automobile. It should be noted, however, that passive air bag restraints were employed in the front seat positions in three of the modified vehicle tests. These devices were conventional, 30 MPH systems, and no effort other than the installation of a frame mounted sensor,** was made in an attempt to upgrade their performance. With the possible exception of the driver response during the 40 MPH impact, these systems did not provide adequate occupant protection during these severe exposures.

It was believed that this test series would permit an economical means of determining the performance of state-of-the-art inflatable restraint systems under conditions much more adverse than that of their present design criteria. Such information might be useful in future attempts to upgrade performance to be compatible with high speed, severe impact conditions.

Limited handling tests were performed with the OV-I and the conventional 1972 Ford. Both automobiles were found to generally respond in the same manner during these various maneuvers. Measured differences in performance were extremely small and probably would be undetectable during normal vehicle operation.

Conclusions and recommendations derived in this study are provided in the next section. This is followed by a brief description of the vehicle modifications, a summary of test results and general discussion of the overall effort. Complete results for all handling and crash tests are fully documented in Appendices A and B, respectively.

* target speed of 50 ± 2 MPH

** Mounting the sensor on the first frame cross member frame resulted in a 0.006 sec. crash detection time period for the inflatable system (see Ref. 4 for details).

2. CONCLUSIONS AND RECOMMENDATIONS

General conclusions and recommendations derived as a result of the study are provided in this section. Further details on the basis for these are provided in the Summary of Test Results and Discussion Sections. In addition, because the structure considered here is essentially identical to that developed in Reference 4, Conclusions and Recommendations of that report also apply to this study.

2.1 Conclusions

- Structural modifications developed to improve full size vehicle crashworthiness have little effect on handling performance. The modifications increased the gross vehicle weight by about 400 lbs. Both steady state and transient response handling tests were performed with modified and conventional automobiles. Comparison of steady state results indicated a small increase in the understeer characteristics of the modified vehicle when compared to the conventional vehicle. Otherwise, test results from both vehicles were virtually identical.

- A significant improvement in full size automobile front structural performance is possible utilizing existing automotive technology. A front structural modification compatible with conventional automotive technology has been developed and tested under a wide range of test conditions. The modified vehicle utilized materials and gauge thickness consistent with conventional automotive fabrication. Test results indicate that reasonable passenger compartment decelerations and survival space (compartment integrity) can be maintained during fixed object collisions up to speeds approaching 60 MPH. The only part of the structure which departs considerably from current automotive fabrication is the fire wall and engine transmission deflector. These elements are needed, however, only during fixed object collisions at speeds greater than 45 MPH.

- The structure develops similar crash performance during pole and flat barrier fixed object collisions. To reduce added weight, the structure was designed to collapse in different manners during pole and flat barrier collisions. That is, the face bar (front bumper system) is not intended to remain rigid during pole barrier collision. Yet, through special design of the frame structure, essentially identical passenger compartment responses occur during pole and flat barrier collisions at similar impact speeds.

2.2 Recommendations

- Further refinement of the engine deflector and fire wall structures is needed. Nearly one-half of the total weight increase is related to these two components. Furthermore, engine/fire wall contact results in deceleration levels somewhat higher than is desirable. Thus, refinement of these components has the potential of reducing added weight while at the same time improving vehicle crash performance.

- Trade-off studies between maximum fixed object impact speed protection and structural requirements should be made. For example, a major portion of the added weight associated with the structural design is necessary to provide performance during fixed object impacts at speeds greater than 50 MPH. Based on data developed in this study, it should be possible to provide reasonable estimates of structural weight increments as a function of maximum impact speed for full size automobiles.

- Vehicles with structures modified for multiple collision modes should be developed. Efficient crashworthy structures require that many structural components serve different functions during various types of collisions. For example, door beams which are primarily required for lateral strength during side collisions can also serve a dual role of providing increased longitudinal passenger compartment strength during frontal collisions. Thus, efficient structural designs can be developed and evaluated only if the entire vehicle structural system is considered.

3. STRUCTURAL MODIFICATIONS

The front structural modifications incorporated into operational vehicles, particularly OV-II and OV-III, did not substantially differ from those for a series of non-operational vehicles developed within a different phase of the overall program. Because the design is described in considerable detail in Reference 4, only a limited review of basic rationale behind the various structural changes is presented in this report.

The modifications conformed to the overall geometric and frame chassis scheme of a full size 1972 Ford sedan. Major structural modifications were made to both the frame and passenger compartment. The objectives behind these changes were, (1) to increase the energy dissipation capacity of the vehicle structure as a function of vehicle collapse distance (primarily during the initial portion of structural deformation), and (2) to provide for improved passenger compartment integrity (occupant survival space) during severe frontal collisions. Schematic illustrations of the modified frame and body are shown in Figures 3-1 and 3-2, respectively. The underlying rationale for these structural changes is briefly discussed in the following:

- Bumper System - A face bar with upper and lower closed sections containing an energy absorbing polyurethane foam was developed. This bar is attached with C-shaped brackets to the first frame cross member. The urethane will absorb (dissipate) all energy associated with collisions involving fixed objects at speeds slightly in excess of 8 MPH. The face bar made from high strength steel (150,000 psi, static ultimate stress) is intended to remain elastic (no permanent deformations) only during low speed collisions.

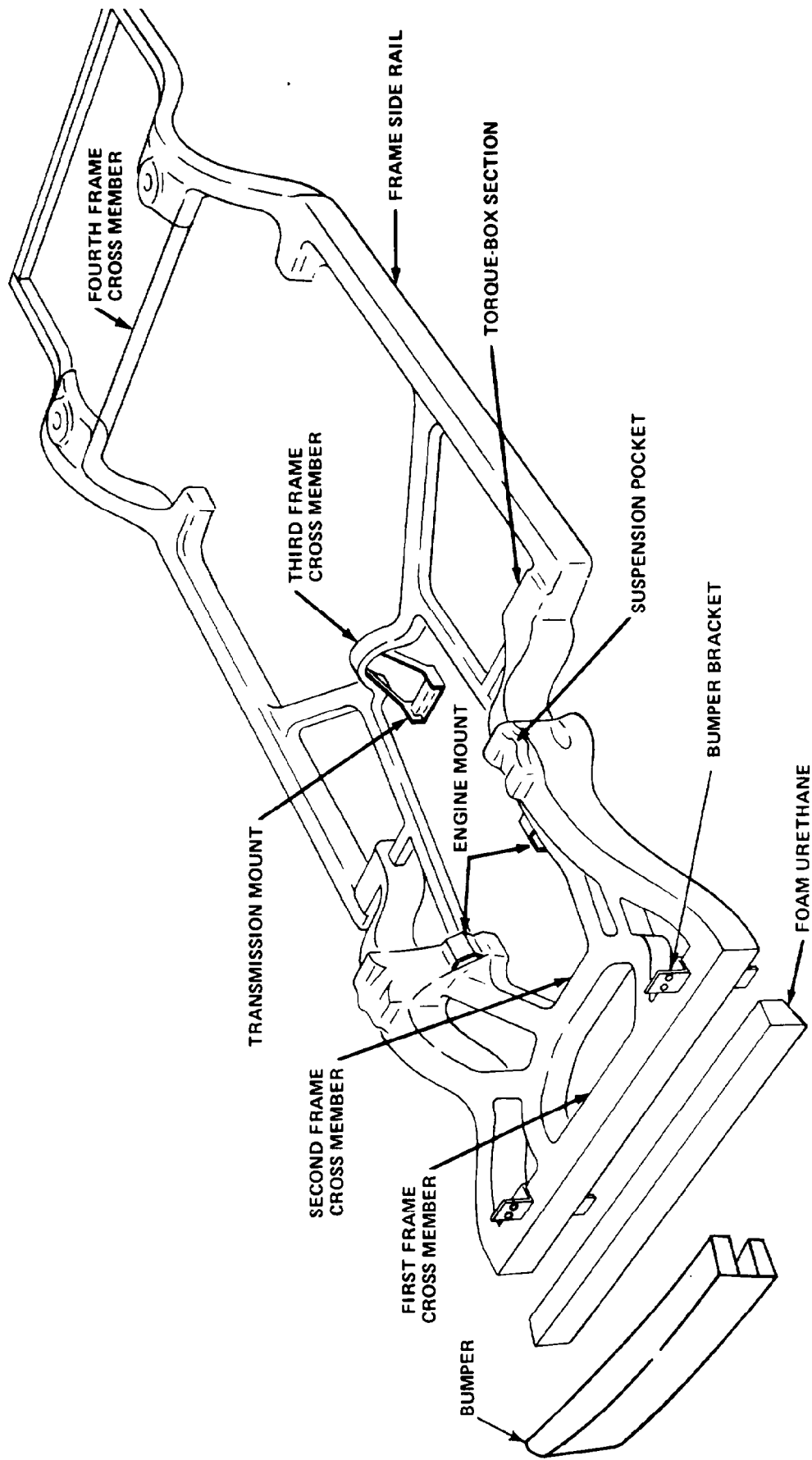


Figure 3-1 SCHEMATIC ILLUSTRATION OF FRAME/BUMPER STRUCTURE

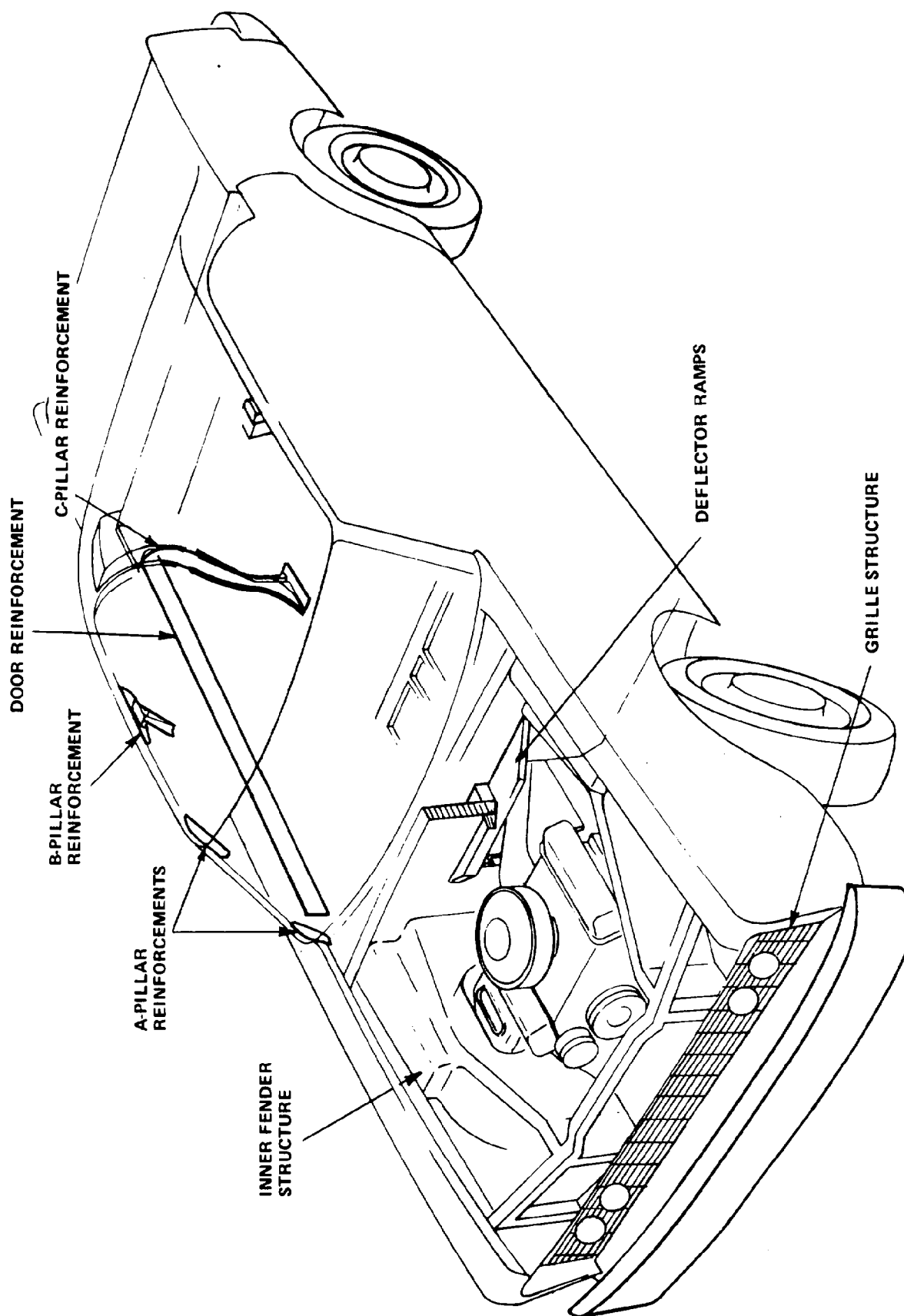
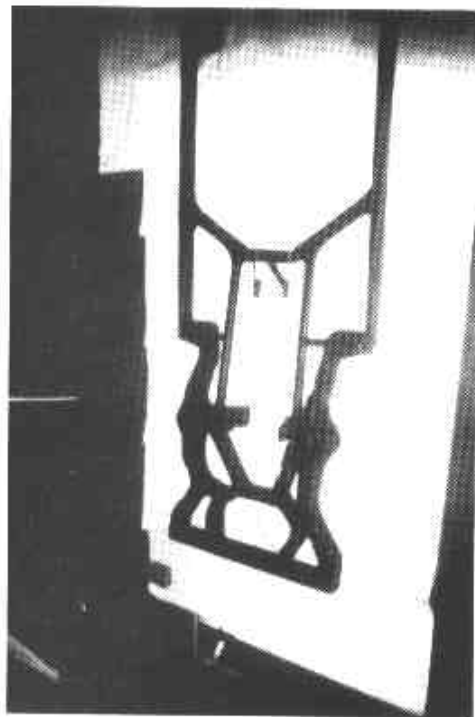


Figure 3-2 SCHEMATIC ILLUSTRATIONS OF MODIFICATIONS TO PASSENGER COMPARTMENT

- Frame - Modifications to the conventional 1972 Ford frame are primarily restricted to first, second and third frame cross members. The outside frame side rails were left unchanged except for small forward extensions to the four S-frame rails. The original first and second frame cross members have increased section properties and have been moved forward from their original locations. Furthermore, these cross members are interconnected through a series of longitudinal members. The third frame cross member was redesigned to span the frame side rails underneath the passenger compartment. This change was made primarily to improve performance during later collisions. However, with the longitudinal struts running from just behind the suspension pockets to the third frame cross member, this element also provides for significant energy absorption during frontal collisions through a small but important spreading of the frame side rails. All frame modifications were fabricated from mild steel having properties equivalent to the original frame material. Photographs of the conventional and modified frames are presented in Figure 3-3.
- Engine Mounting - The engine transmission mounts were unchanged. However, the system is now supported in a cantilever manner with the engine mounts cantilevered from sections remaining from the original second frame cross member and the transmission mount is cantilevered from the third frame cross member. These changes were made to eliminate possible interference with downward motion of the engine during severe frontal collisions.
- Grille - The original plastic grille was replaced with an aluminum grating structure. The purpose of the replacement was to insure that a more uniform loading was imposed on other vehicles during intervehicular collisions. In addition,



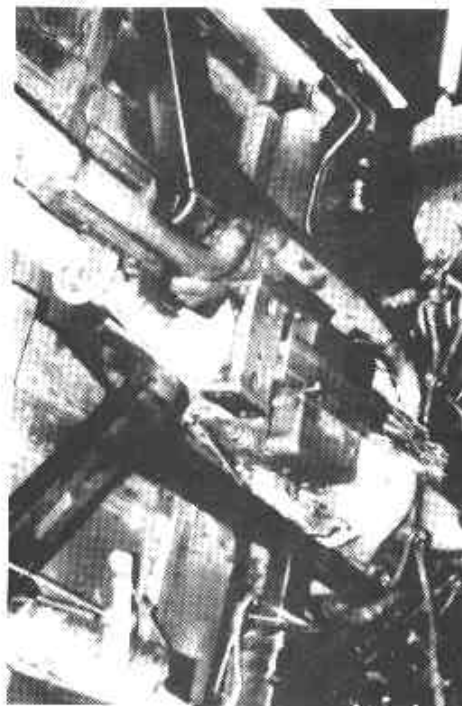
(a) CONVENTIONAL



(b) MODIFIED



(c) FRAME/ENGINE



(d) INSTALLATION

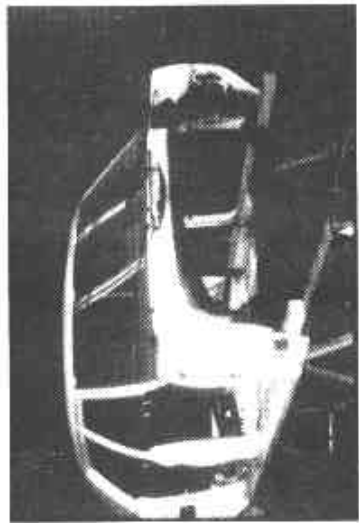
Figure 3-3 CONVENTIONAL AND MODIFIED FRAME

all styling protrusions (i. e., bumper, fender and hood prows) were eliminated. Effort on other phases of the overall program indicated that these protrusions result in excessive side wall intrusions in the struck vehicle during front-to-side collisions.

- Fenders and Hood - Mild steel reinforcement channels were placed on the inner fenders which were welded directly to the fire wall. This structure was stabilized with the conventional hood bolted to it at strategic locations. The bolts were an expedient means for simulating the effect of multiple latching points. The front fender structure is a prime source for energy dissipation during frontal collisions.
- Fire Wall - Sandwich plate panels were used to replace the existing fire wall. These panels had 0.040" thick steel skins with a 2 inch thick bonded aluminum honeycomb core. The transmission tunnel was reshaped to provide for a deflector surface. A mating deflector ramp was attached to the engine/transmission assembly.
- Passenger Compartment - To improve passenger compartment integrity, A, B and C pillars were reinforced in certain critical areas. In addition, longitudinal stiffeners were placed on the inner door panels. This latter change was meant to simulate the added longitudinal door strength that would result from doors that were modified for side collisions. To accommodate the third frame cross member, the forward section of the floor was raised about one inch from its normal location.

- Body/Frame Mounting - The original mounts located at the front torque-boxes were moved forward to the inner fender in front of the suspension pockets. Substantial mounts were added at the C-pillar locations. Both mounts were found to be necessary in order to properly control the passenger compartment kinematics, particularly pitching during severe frontal collisions.
- Steering Column - To better accommodate a driver restraint system and occupant loading, the angle between the steering column and a horizontal plane was reduced to 18 degrees from 26 degrees. Small knee pads were also added to the lower instrument panel in the front of the driver.

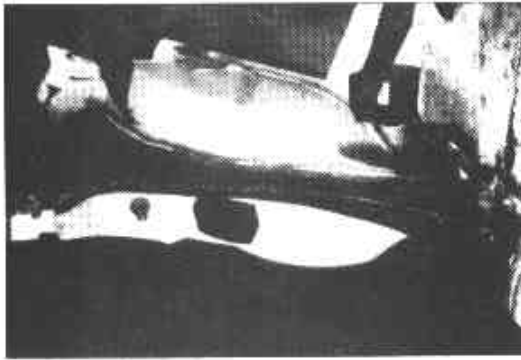
Photographs of some of these passenger compartment modifications are provided in Figure 3-4. Exterior and interior views of the modified completed OV-III vehicle are shown in Figure 3-5.



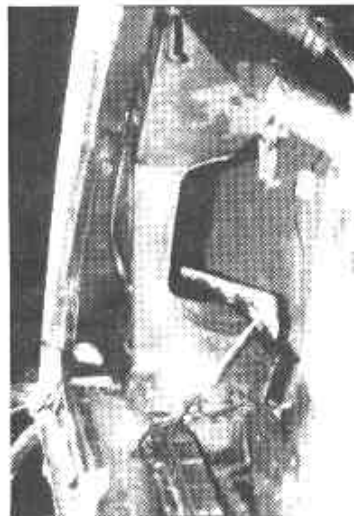
(a) COMPARTMENT



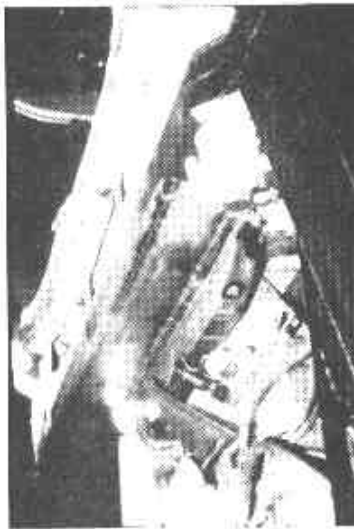
(b) A-PILLAR



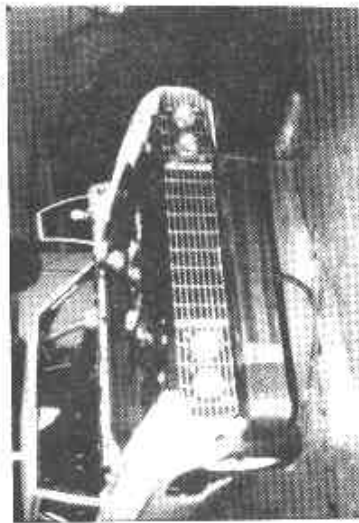
(c) C-PILLAR



(d) INNER FENDER



(e) FIRE WALL AND DEFLECTOR



(f) FRONT FENDERS

Figure 3-4 PASSENGER COMPARTMENT MODIFICATIONS



(a)



(b)

Figure 3-5 EXTERIOR AND INTERIOR VIEWS OF MODIFIED VEHICLE (OV-III)

4. SUMMARY OF TEST RESULTS

Although the major emphasis in the study was placed on the crash performance of the modified automobiles, both vehicle handling and crash tests were performed. Complete results from both of these two test series are presented and fully documented in Appendices A and B, respectively.

The purpose of the handling tests was to determine if the structural modifications, which essentially constitute an increase in the overall weight of the vehicle, would result in significant changes in vehicle performance. Both steady state and transient response tests were conducted with a conventional 1972 Ford and the first modified vehicle, designated OV-I. The modified vehicle demonstrated slightly greater understeer than the conventional automobile. In all other respects, differences in handling characteristics between the modified and conventional vehicles were virtually undetectable.

The results of the handling tests will not be further reviewed in this section and the reader should consult Appendix A for complete details. In the following, results from the five frontal crash tests are presented.

4.1 Instrumentation and Data Processing

The Calspan experimental test facility and data system are described in detail in Reference 5. Because the tests performed within this study did not deviate from conventional procedures, the test methodology employed will not be reviewed here and the interested reader should consult the cited reference.

Vehicle passenger compartment triaxial accelerometer packages were mounted on the floor at five different locations. These were four corner locations, numbered consecutively beginning at the left front corner in a clockwise direction and a tunnel location near the front seat inboard

seat belt anchor points. Engine accelerometers were embedded in the intake throat of the engine block.

Sierra 50th percentile, model 850 dummies were installed in the outboard front seat positions in most of the tests. Dummy positions are labeled one through four in the same sequence as used for the passenger compartment corner accelerometers. For example, the driver is dummy (1), right front passenger is dummy (2), etc. Triaxial accelerometer packages were located in the dummy head, chest and pelvis components.

All data contained in this report have been processed and filtered according to SAE Recommended Practice J211. A digital filtering technique was used as specified below:

<u>Data Type</u>	<u>SAE J211 Channel Class</u>	<u>Digital Filter Characteristics</u>		
		<u>f_{co}</u>	<u>Δf</u>	<u>N</u>
Vehicle Acceleration Load Measurement	}	60	50	240
Dummy Head Acceleration	1000	1650	3560	20
Dummy Chest Acceleration	}	180	300	650
Dummy Pelvis Acceleration*				

* Not specified in SAE J211

Additional kinematic data (velocity and displacement) were determined for selected acceleration data channels through first and second integrations of the acceleration-time histories. In these instances, initial impact velocity and initial zero displacements were specified, respectively, when determining velocity-time and displacement-time histories.

4.2 Vehicle Crash Test Results

The five crash tests performed within the study are summarized in Table 4-1. The test on the 1972 Ford (Test 71) was performed to establish performance data for the unmodified or conventional vehicle. Modified vehicles, OV-I and OV-III, (Tests 77 and 90) were impacted into a flat barrier to determine the performance of the system under flat barrier impact conditions at speeds of 50 MPH and 60 MPH. The OV-II vehicle (Test 84) was intended to duplicate the test conditions of the conventional car experiment (Test 71). Unfortunately, due to system malfunctions, the vehicle was undertested at 40 MPH. However, the vehicle was repaired and subsequently tested under the desired condition (Test 91 with the OV-II R vehicle). Thus, structural data for pole barrier impacts at two different impact speeds were also developed within the study.

Exterior views of the vehicles before and after test are presented in Figures 4-1 through 4-3. In order to facilitate making appropriate comparisons, the vehicles are arranged in a different sequence than the listing in Table 4-1.

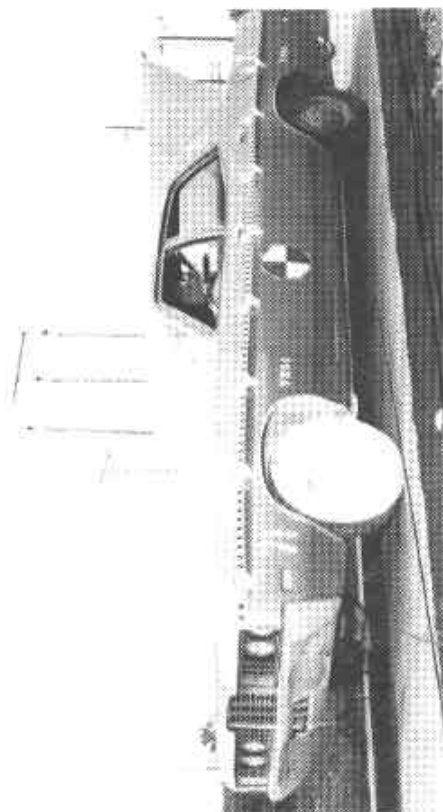
Shown in Figure 4-1 are views of the 1972 Ford (Test 71) and OV-II R (Test 91) automobiles. These two test conditions were nearly identical and the photographs of Figure 4-1 graphically illustrate the difference in structural deformations, particularly preservation of acceptable passenger compartment integrity, which resulted from the modifications to the OV-II R vehicle. The engine in the 1972 Ford was displaced about 3 ft. into the middle of the front seat. On the other hand, the engine of the modified

Table 4-1
GENERAL SUMMARY OF CRASH TESTS

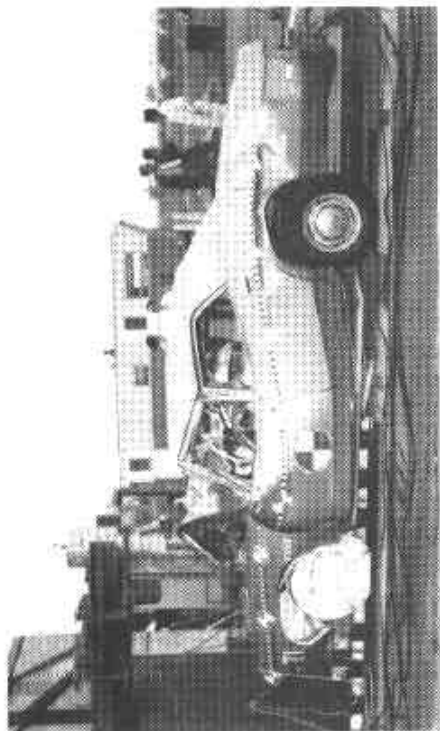
TEST NO.	VEHICLE (WEIGHT-lbs.)	OBSTACLE	IMPACT SPEED (MPH)	MAX COMP. ACCEL.** (G'S)	STATIC CRASH (in.)
71	1972 FORD (4290)	POLE BARRIER	57.8	60	70
77	OV-I (4790)	FLAT BARRIER	58.7	65	41
84	OV-II (4640)	POLE BARRIER	40.0*	45	26
90	OV-III (4560)	FLAT BARRIER	49.9	62	30
91	OV-II R (4020)	POLE BARRIER	56.8	68	38

* VEHICLE UNDER TESTED AS A RESULT OF SYSTEM MALFUNCTIONS

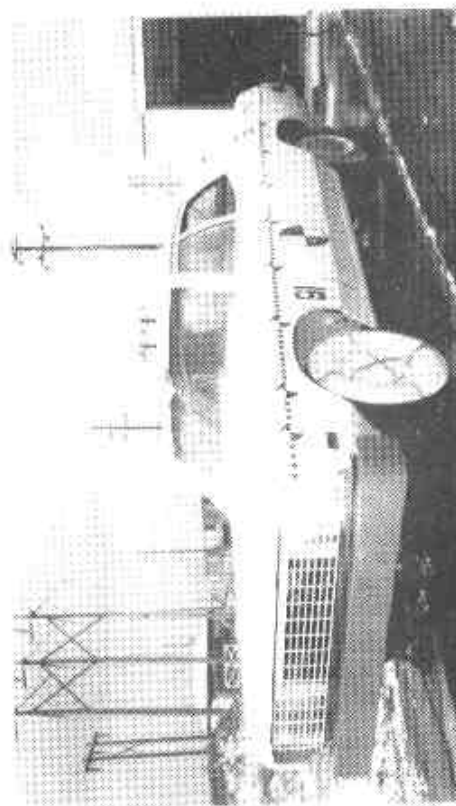
** AVERAGE OF LONGITUDINAL PASSENGER COMPARTMENT ACCELEROMETERS



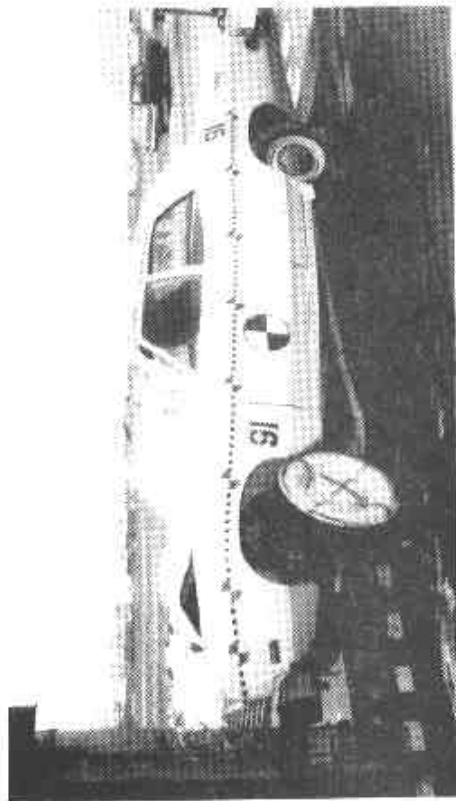
a) 1972 FORD - BEFORE



b) 1972 FORD - AFTER

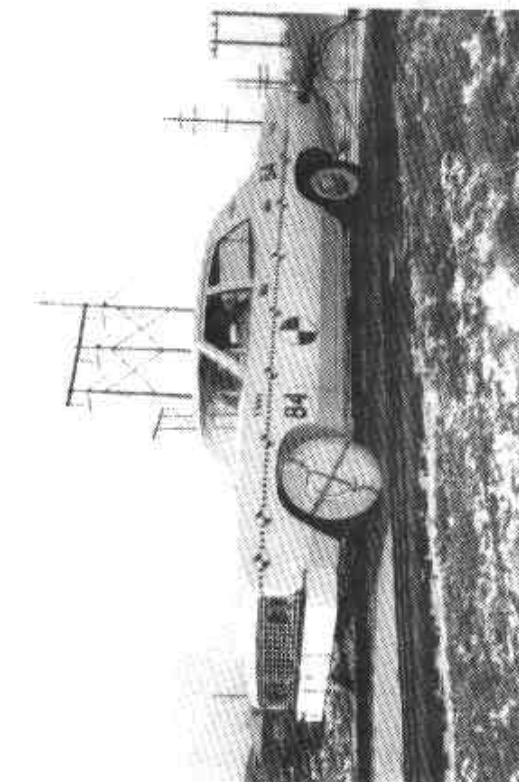


c) OV-II R - BEFORE

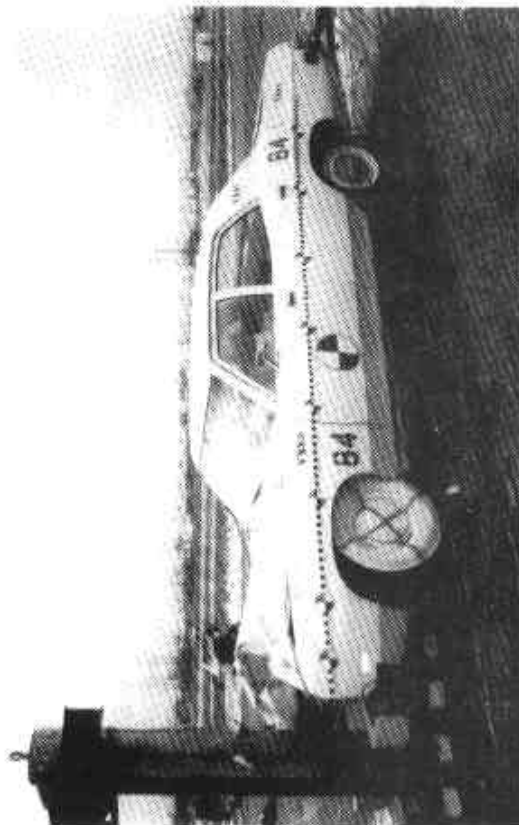


d) OV-II R - AFTER

Figure 4-1 CONVENTIONAL AND MODIFIED VEHICLES BEFORE AND AFTER
HIGH SPEED IMPACT WITH POLE BARRIER

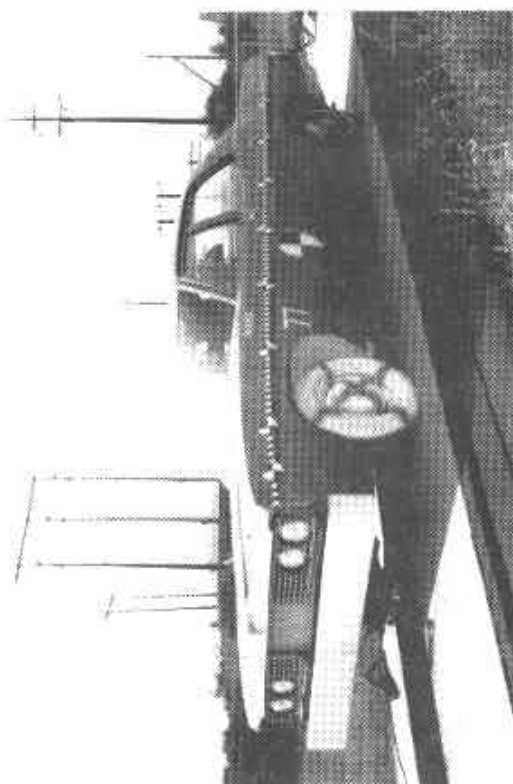


a) OV-II - BEFORE

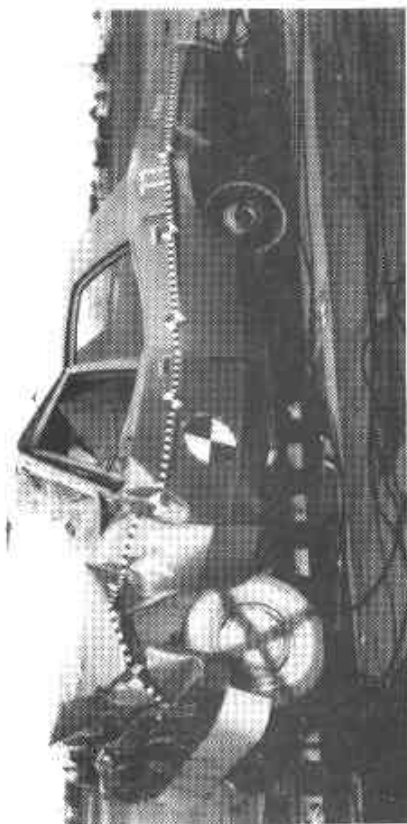


b) OV-II - AFTER

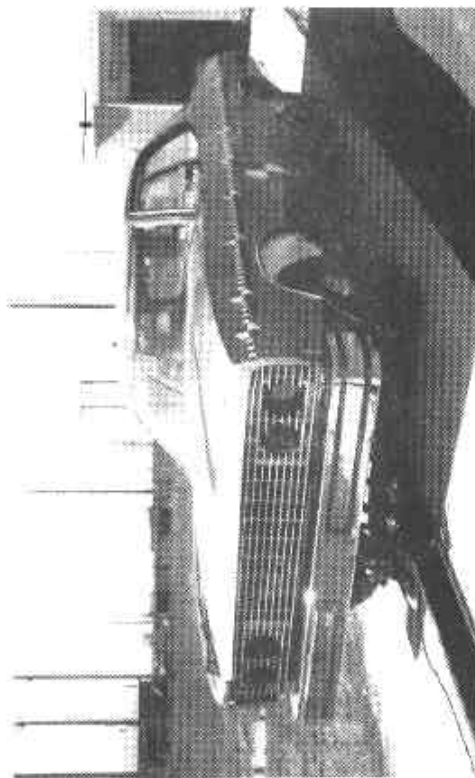
Figure 4-2 MODIFIED VEHICLE BEFORE AND AFTER 40 MPH POLE
BARRIER IMPACT



a) OV-I - BEFORE



b) OV-I - AFTER



c) OV-III - BEFORE



d) OV-III - AFTER

Figure 4-3 MODIFIED VEHICLES BEFORE AND AFTER HIGH SPEED FLAT BARRIER IMPACT

vehicle was deflected relative to the passenger compartment and virtually no intrusion occurred. It should be noted that about one inch of permanent longitudinal compression of the passenger compartment occurred, resulting in the doors being jammed shut. All windows were, however, operable after the test on the modified vehicle.

Photographs of the OV-II vehicle (Test 84) before and after the 40 MPH pole barrier impact are shown in Figure 4-2. As indicated previously, this test was intended to be at nominally 57.5 MPH. The results do, however, provide an indication of the expected vehicle damage during a 40 MPH collision. In this instance the engine just contacted the fire wall. Little apparent passenger compartment permanent deformation occurred. All doors, although apparently experiencing dynamic deflections during the crash, could be manually opened after the impact.

Before and after test photographs of the modified vehicles that were impacted at high speed into a flat SAE barrier are presented in Figure 4-3. The OV-I (Test 77) shown in Figure 4-3 (a) and (b) was impacted at 58.7 MPH. This vehicle, the first in the series, did not incorporate the fire wall and floor modifications of the OV-II and OV-III vehicles. As is apparent in Figure 4-3 (b), rearward displacement of the fire wall instrument panel regions occurred, but total relative displacement was of the order of 3 to 5 inches. The OV-III vehicle is shown in Figure 4-3 (c) and (d). In this case, very minimal permanent passenger compartment deformation is evident. It should be noted that in the latter case, the impact speed was 49.9 MPH.

Shown in Figures 4-4 through 4-8 are average passenger compartment longitudinal kinematic data for all vehicle tests. It should be noted that these curves for acceleration, velocity and displacement represent the averages of the data obtained from the five accelerometer channels located on the passenger compartment floor. An exception is the data for Test 90 (OV-III) where an error is contained in the zero time for the front corner traces (see note accompanying test data in Appendix B). In that case, the

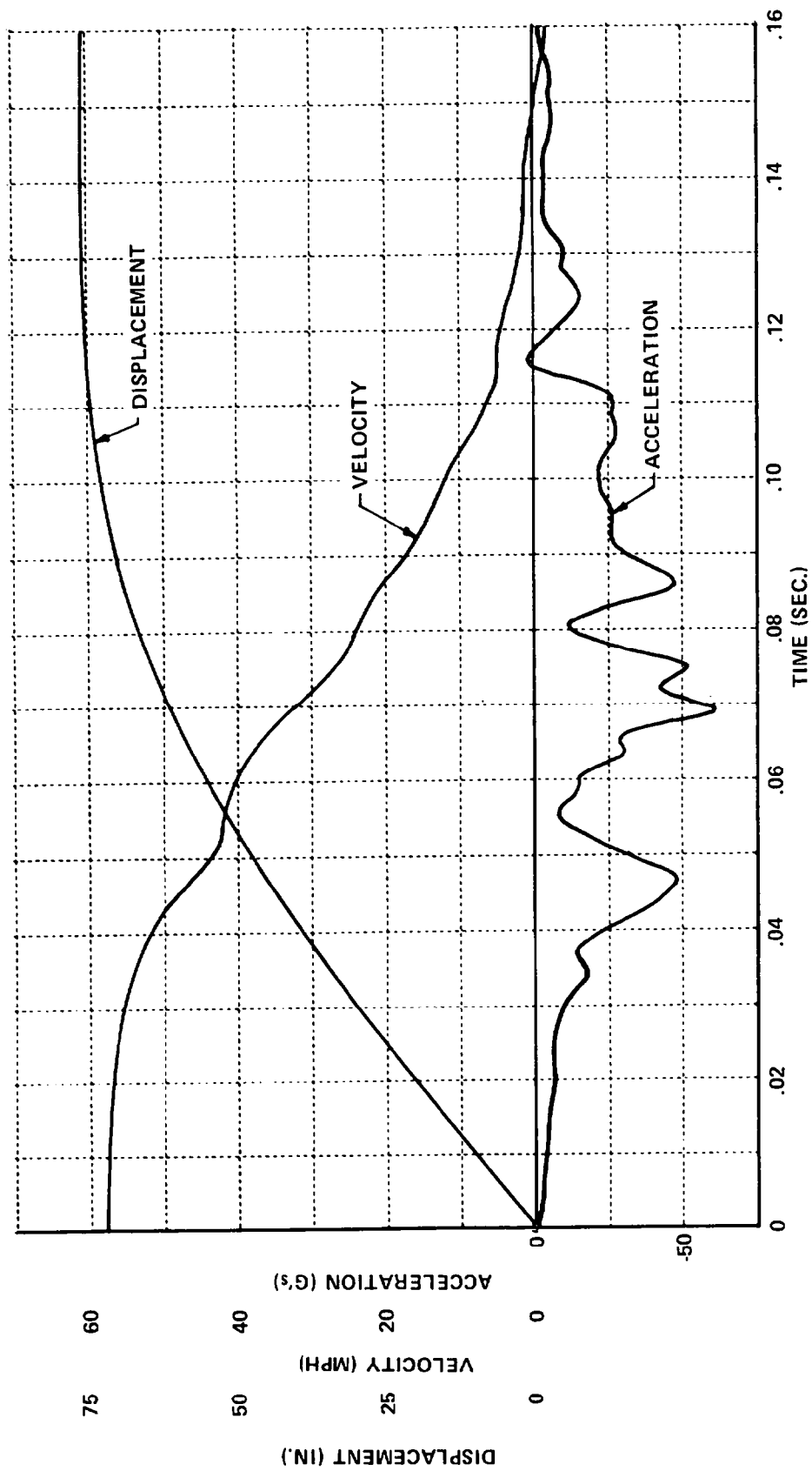


Figure 4-4 AVERAGE PASSENGER COMPARTMENT LONGITUDINAL KINEMATIC DATA,
1972 FORD CAR (TEST 71)

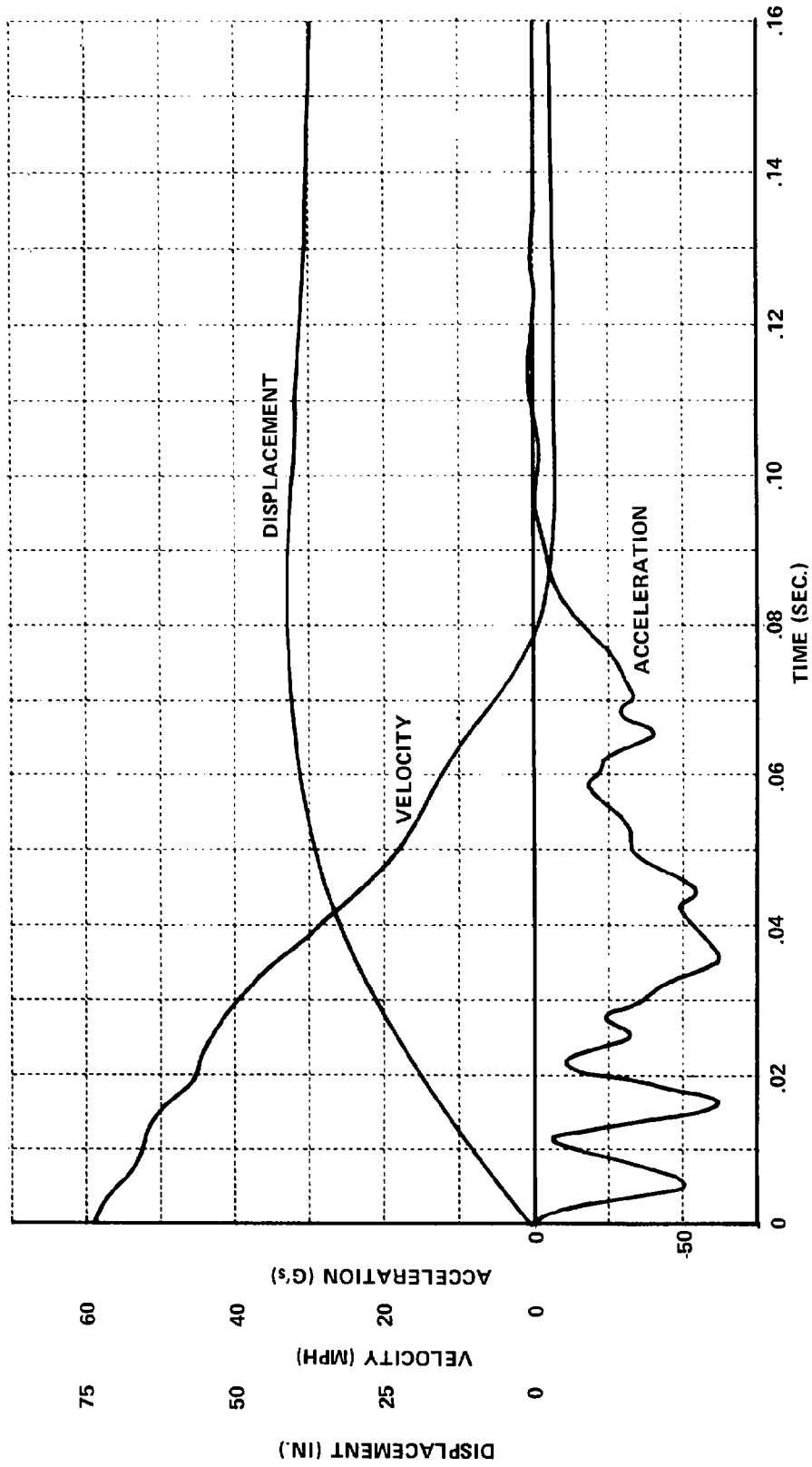


Figure 4-5 AVERAGE PASSENGER COMPARTMENT LONGITUDINAL KINEMATIC DATA,
OV-I CAR (TEST 77)

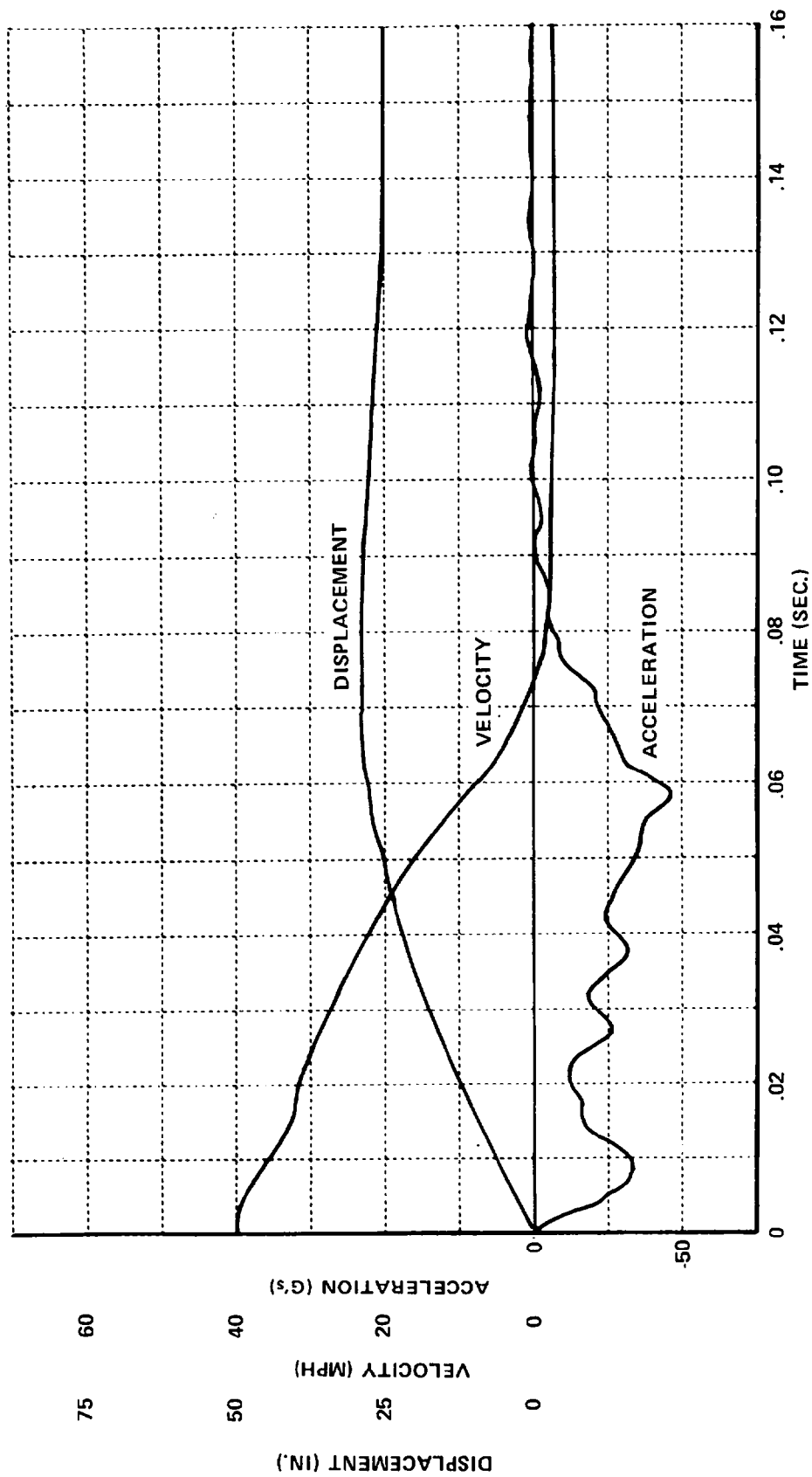


Figure 4-6 AVERAGE PASSENGER COMPARTMENT LONGITUDINAL KINEMATIC DATA,
OV-II CAR (TEST 84)

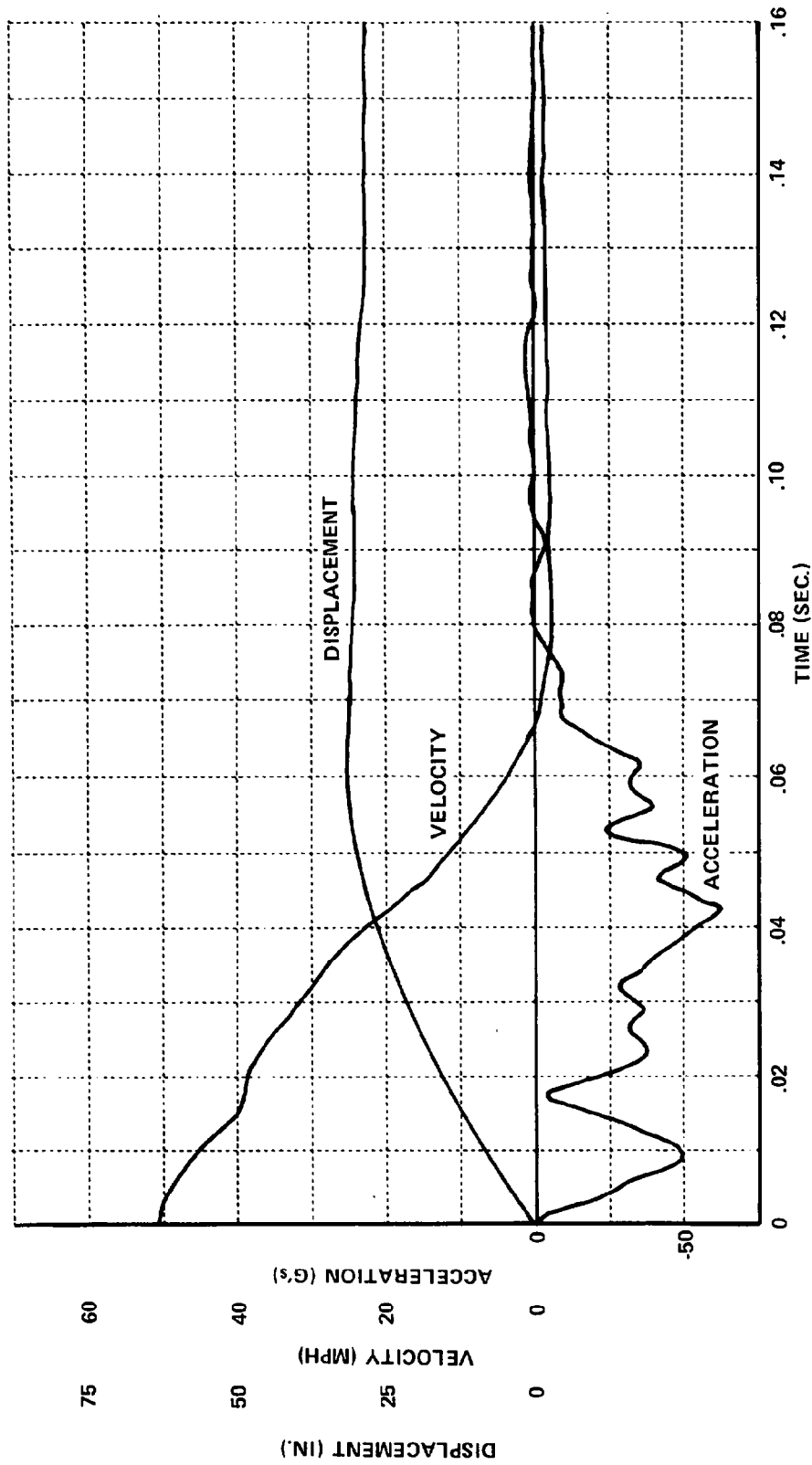


Figure 4-7 AVERAGE PASSENGER COMPARTMENT LONGITUDINAL KINEMATIC DATA, OV-III CAR (TEST 90)

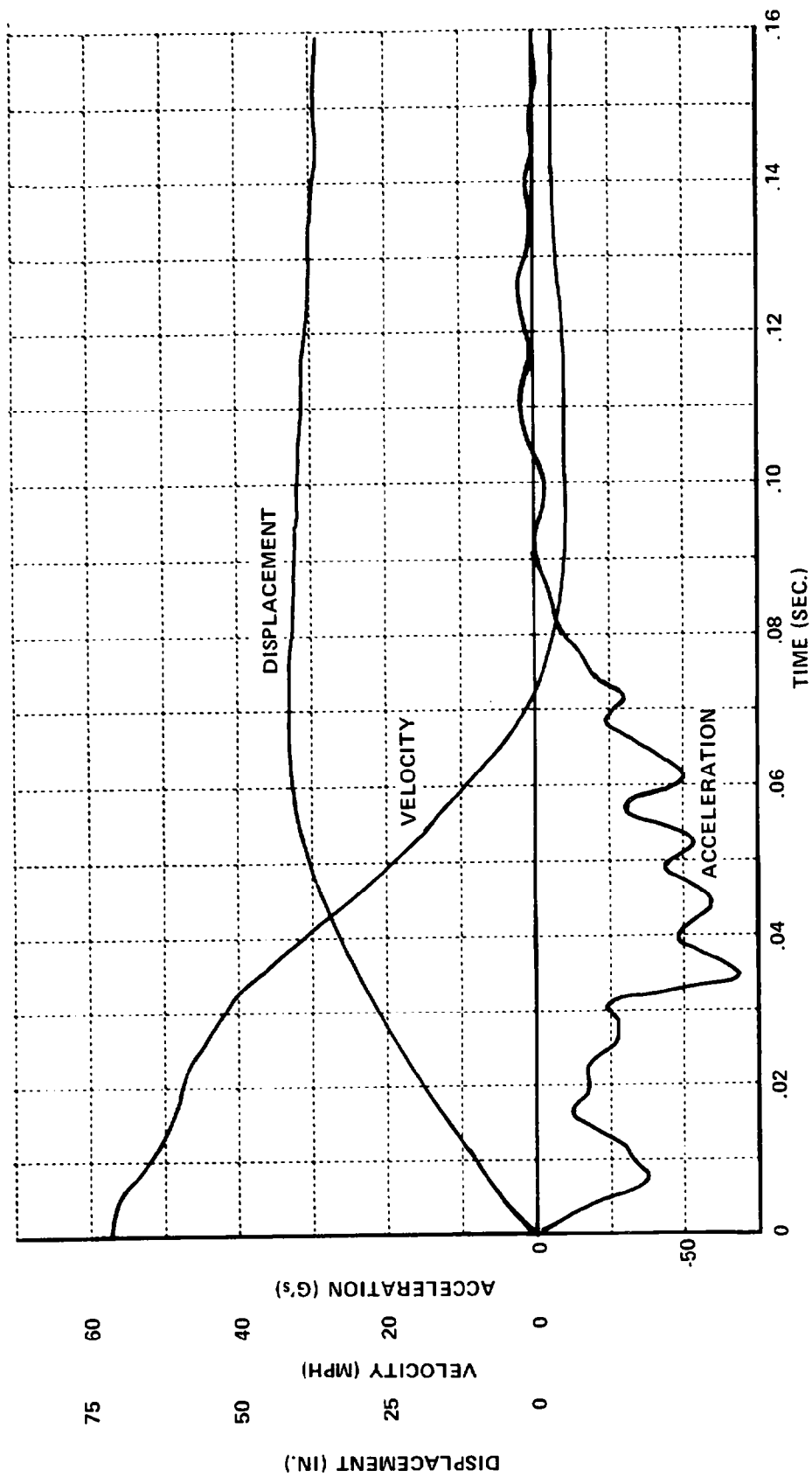


Figure 4-8 AVERAGE PASSENGER COMPARTMENT LONGITUDINAL KINEMATIC DATA, OV-II R CAR (TEST 91)

data presented in Figure 4-7 represents the average from three passenger compartment accelerometers, i. e., the tunnel and two rear corner locations.

Results from all data channels are presented in Appendix B. In addition, longitudinal kinematic data, i. e., first and second integrals of the acceleration-time histories, were determined and are presented for all longitudinal passenger compartment data channels.

4.3 Occupant Crash Test Data

It should be noted that no program effort was directed towards further development of restraint systems. Existing inflatable occupant restraint systems (primarily designed for 30 MPH collisions) were procured and installed in the modified vehicles. In addition, the angle between the steering column and a horizontal plane was changed from 26 degrees to 18 degrees which may have had some effect on the driver dummy performance in the modified vehicles.

The crash sensor which would normally be located in the forward passenger compartment region was, however, installed on the first frame cross member. This installation is shown in Figure 4-9 where the sensor is encased in the section of capped pipe. As a result of this installation, the sensor activated the restraint system at about 0.006 sec. into the crash event. Furthermore, because of the low speed bumper design, the sensor will not activate the system during low speed collisions. Further discussion and test results relative to the bumper system are contained in Reference 4.

Shown in Table 4-2 are summary results from the dummies (Sierra, 850 male, 50th percentile devices) employed in this test series. In the base line vehicle (Test 71), the dummies were restrained with the conventional lap and shoulder belts. The extremely high head accelerations (decelerations) for the dummies in this test were due to contact with the hood which intruded more than 12 inches into the passenger compartment.

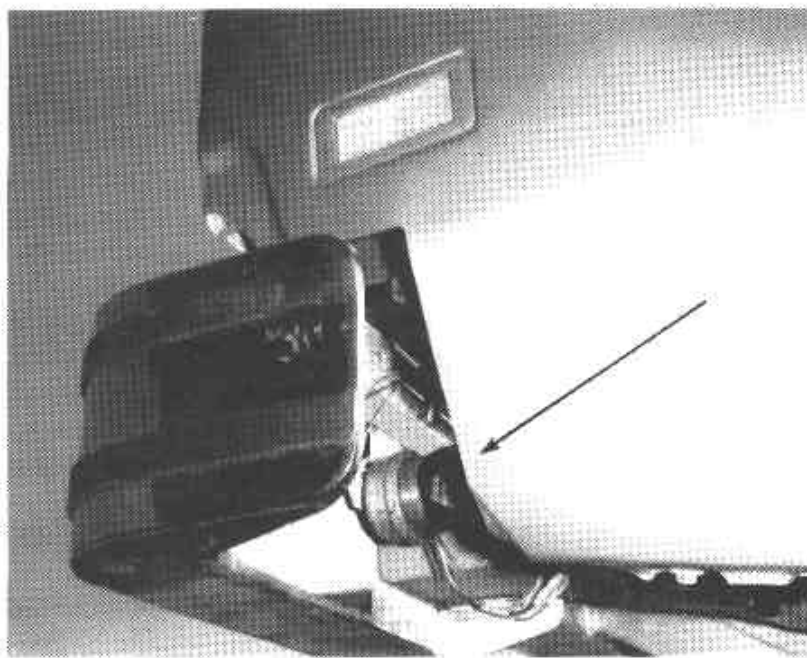


Figure 4-9 CRASH SENSOR FOR INFLATABLE OCCUPANT RESTRAINT SYSTEM

Table 4-2

GENERAL SUMMARY OF OCCUPANT DATA

PARAMETER	TEST			
	71	77	84	90
SPEED (MPH)	57.8	58.7	40.0	49.9
RESTRAINT SYSTEM	LAP & SHOULDER BELTS	EATON AIR CUSHION	OLIN AIR CUSHION	OLIN AIR CUSHION
DRIVER				
HEAD MAX ACCEL. (G's)*	-180	-80	-55	-95
HEAD SEVERITY INDEX	7100	3200	650	2650
CHEST MAX ACCEL. (G's)**	-130	-75	-60	-75
PELVIS MAX. ACCEL. (G's)**	-135	-200	-45	-90
PASSENGER				
HEAD MAX ACCEL. (G's)*	> -250***	-200	-95	-110
HEAD SEVERITY INDEX	—	6500	2200	2300
CHEST MAX. ACCEL. (G's)**	-120	—	-60	-70
PELVIS MAX. ACCEL. (G's)**	-115	-175	-55	-75

* FOR 0.003 SEC. DURATION, SAE J211 CLASS 1000 FILTER

** FOR 0.003 SEC. DURATION, SAE J211 CLASS 180 FILTER

*** EXCEEDED TRANSDUCER RANGE

The data of Table 4-2 for the occupants of the modified vehicles indicate that the severity for the occupants may have been somewhat reduced for the modified vehicles when compared to the conventional car occupant. But, in no instance (with the possible exception of the driver of Test 84) was satisfactory results obtained. Thus, it is clear that improvement in restraint system performance is required before occupants could be expected to benefit from the reduction in passenger compartment intrusion which resulted from the structural modifications.

Further details on the data obtained for the various car occupants are provided in Appendix B.

5. DISCUSSION OF RESULTS

The results of the study are discussed in two parts which consider modified vehicle crash performance and general comments on the overall aspects of the investigation.

5.1 Vehicle Crash Performance

Because of the number of tests performed, it is natural to compare the results from specific crash tests. Comparisons are made relative to (1) the difference between conventional (base line) and modified vehicle performance, (2) the variation in vehicle performance in relation to impact obstacle (i. e., pole or flat barrier), and (3) differences in vehicle performance resulting from variation in impact speed. Finally, it should be recalled that a major objective of the program was to generally preserve the performance demonstrated with a previous vehicle modification (Ref. 3) while at the same time develop a structure suitable for a completely operational automobile. Consequently, comparisons are also made between respective crash performance of the operational vehicle and the non-operational vehicle developed on the predecessor project.

Shown in Figure 5-1 are average longitudinal kinematic data for the conventional 1972 Ford and the OV-II R vehicles. The vehicles were impacted into the pole barrier at the same speed (cf. 57.8 MPH and 56.8 MPH). The modified vehicle (OV-II R) exhibits a much shorter rise time and significantly more energy absorption (dissipation) during the first 0.050 sec. of the collision. As a result, considerably less displacement takes place in the modified vehicle than does with the conventional vehicle. This difference in displacement is directly related to vehicular structural collapse as is graphically illustrated in the photographs of Figure 5-2 where similar views of both structures are presented.

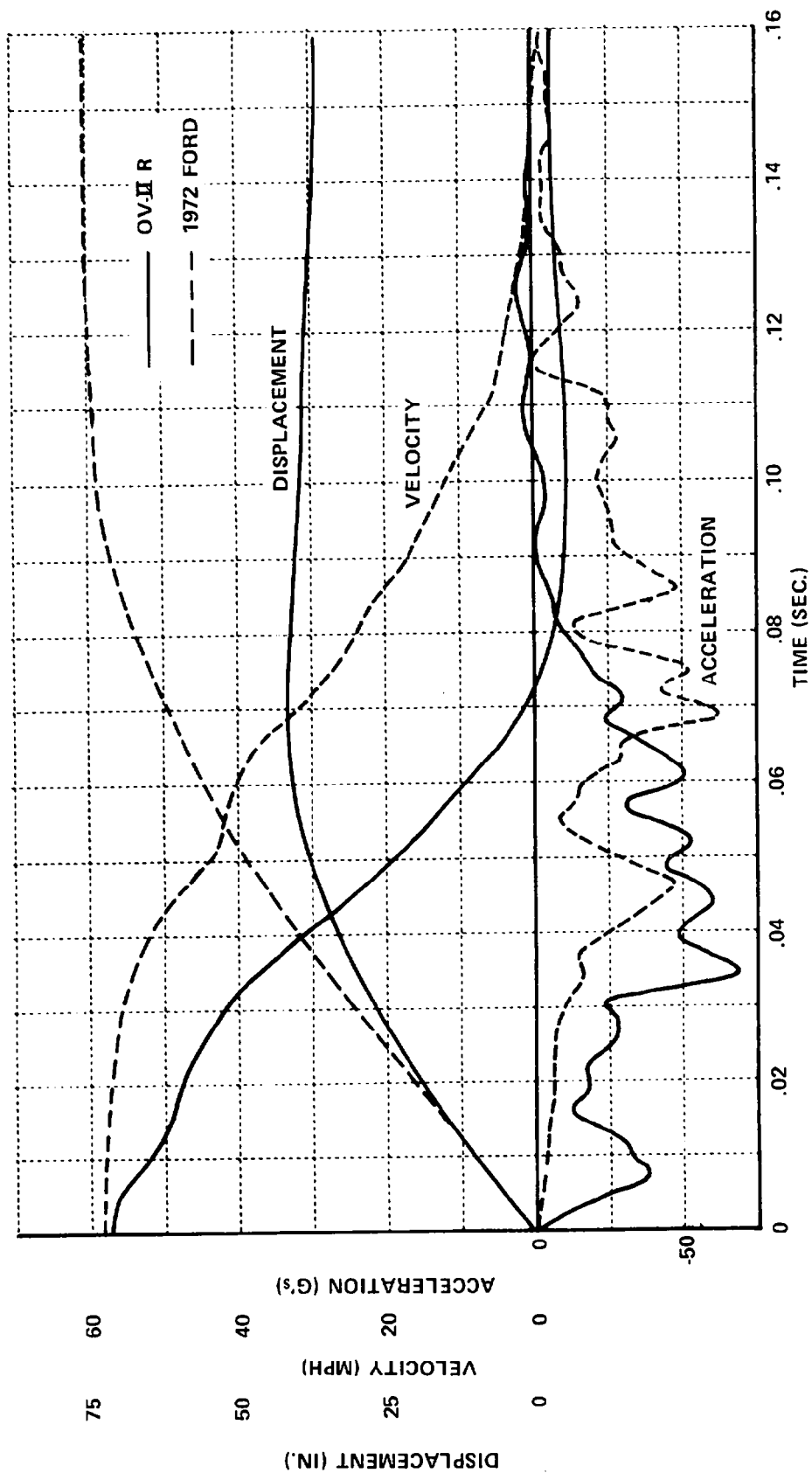
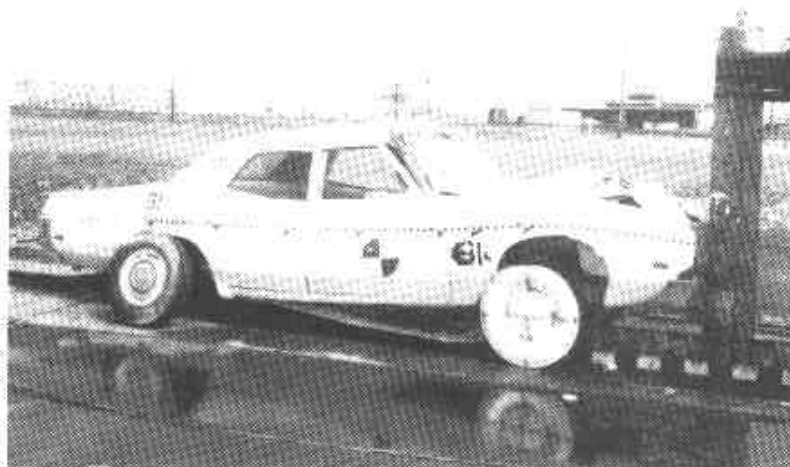


Figure 5-1 COMPARISON OF PASSENGER COMPARTMENT LONGITUDINAL DATA FOR MODIFIED AND CONVENTIONAL VEHICLES IMPACTING POLE BARRIER



a) CONVENTIONAL



b) MODIFIED

Figure 5-2 EXTERIOR VIEWS OF CONVENTIONAL AND MODIFIED FULL SIZE AUTOMOBILES AFTER COMPARABLE HIGH SPEED COLLISIONS WITH POLE BARRIER

From these two figures it is apparent that dramatic improvement in vehicle structural performance has resulted from the modifications. Furthermore, it is noteworthy that the maximum passenger compartment decelerations are comparable (i. e. , near 60 g's) in both vehicle structures.

At Calspan, major reliance has been placed on the pole barrier as a fixed impact obstacle rather than the flat barrier. The reasoning behind this choice is the belief that satisfying the more severe (in terms of structural loading) pole barrier condition, would tend to at the same time satisfy the flat barrier condition. Conversely, it is felt that it is more unlikely that satisfying the flat barrier conditions will tend to result in similar performance with pole barriers. Thus, in this sense, the pole barrier is recognized as a more desirable structural developmental test conditions, but both impact obstacles should be used to compliment each other.

In this study, modified vehicles were impacted into flat and pole barriers at comparable high speeds. Shown in Figure 5-3 are longitudinal passenger compartment kinematic data for the OV-I and OV-II R vehicles which were impacted, respectively, into flat and pole barriers at 58.7 MPH and 56.8 MPH.* Although some localized differences are evident in the acceleration-time histories, velocity-time traces are virtually identical for these two tests, indicating essentially the same overall kinematic performance for the modified vehicle structure when impacting either a pole or flat barrier.

In this regard, it should be noted that the forward part of the frame structure, i. e. , the region in front of the engine, is intended to collapse in a different manner when impacting either a flat or pole barrier. Yet, the

*

It should be noted that the general design incorporated into these vehicles was developed on the basis of four high speed pole barrier collisions (see Ref. 4).

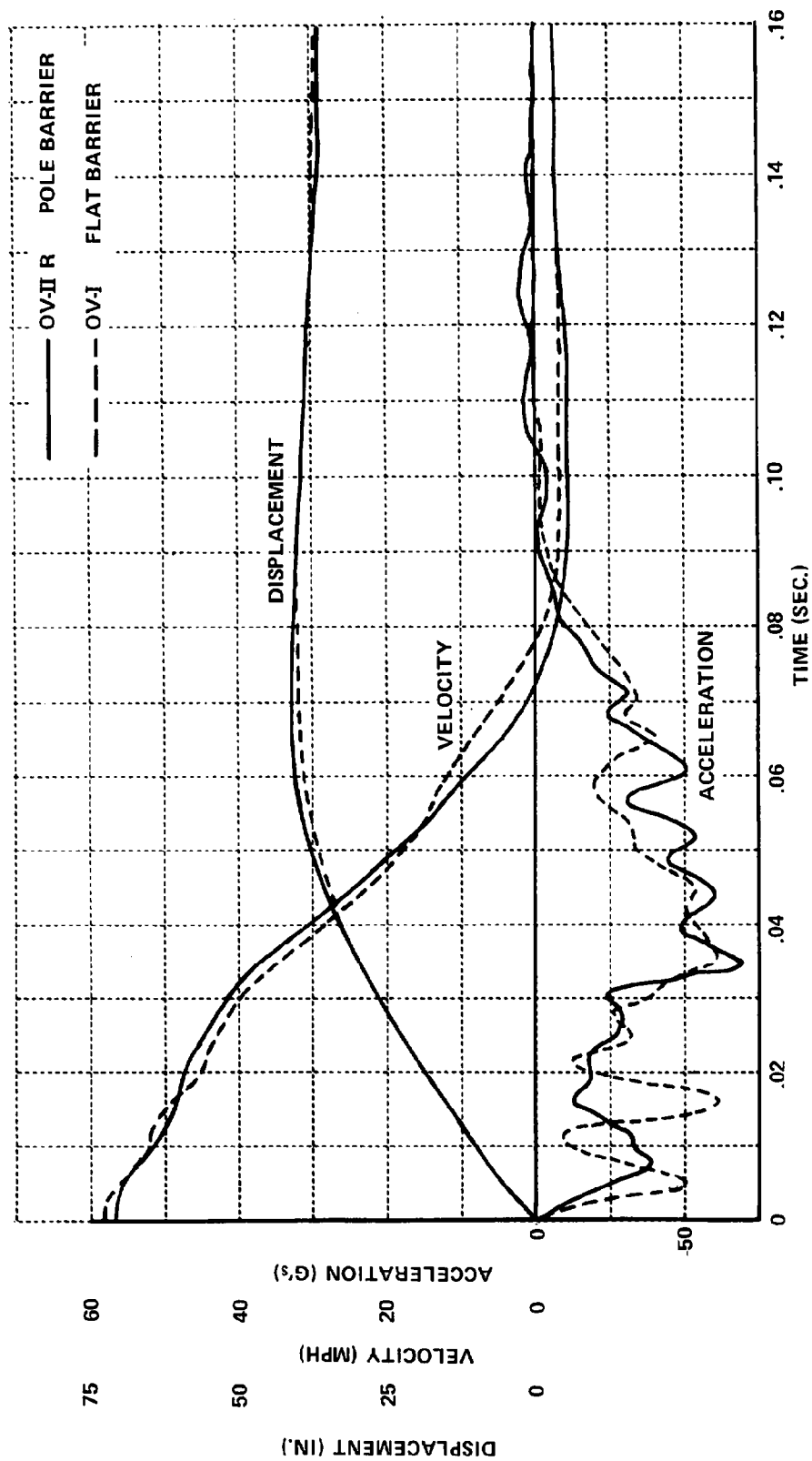


Figure 5-3 COMPARISON OF PASSENGER COMPARTMENT LONGITUDINAL DATA FOR MODIFIED VEHICLES IMPACTING POLE AND FLAT BARRIERS

structure is still designed to provide similar responses during the two different (loadings) collapse mechanisms. This was done to minimize overall weight increase. That is, permitting the bumper and first frame cross member to collapse, rather than remain relatively undeformed, during pole barrier impacts greatly reduces the strength (and weight) of these structural components.

It should be noted that the OV-I vehicle acceleration-time trace in Figure 5-3 has two relative maximum decelerations which occurred before 0.020 sec. into the event compared to only one relative maximum for the OV-II R vehicle during the same time period. This difference is due to small variations in the front structure designs. The OV-I did not incorporate the same fender structure as was used in the latter vehicles (OV-II and OV-III). Indeed, the flat barrier test at 49.9 MPH with the OV-III (see Figure 5-4) resulted in a single relative maximum during the initial time period.

Passenger compartment longitudinal kinematic data for modified vehicles impacting the same obstacle at different impact speeds are presented for flat and pole barriers, respectively, in Figures 5-4 and 5-5. The data for the OV-I and OV-III vehicles which impacted a flat barrier at 58.7 MPH and 49.9 MPH are shown in Figure 5-4. In this instance both vehicles experienced similar maximum acceleration levels. However, in the case of the OV-II and OV-II R impacting the pole barrier at 40 MPH and 56.8 MPH, somewhat different maximum deceleration levels were experienced (see Figure 5-5). This difference is due to the fact that during a 40 MPH collision the engine does not contact and deform the fire wall as is the case in the impacts at or greater than 50 MPH. Thus, it is believed that decidedly different deceleration-time histories will result for these vehicles depending on whether engine/fire wall contact takes place.

The acceleration as a function of displacement is shown in Figure 5-6 for the conventional and last three modified (OV-II, OV-III and OV-II R) vehicles. A highly significant difference between energy dissipation as a

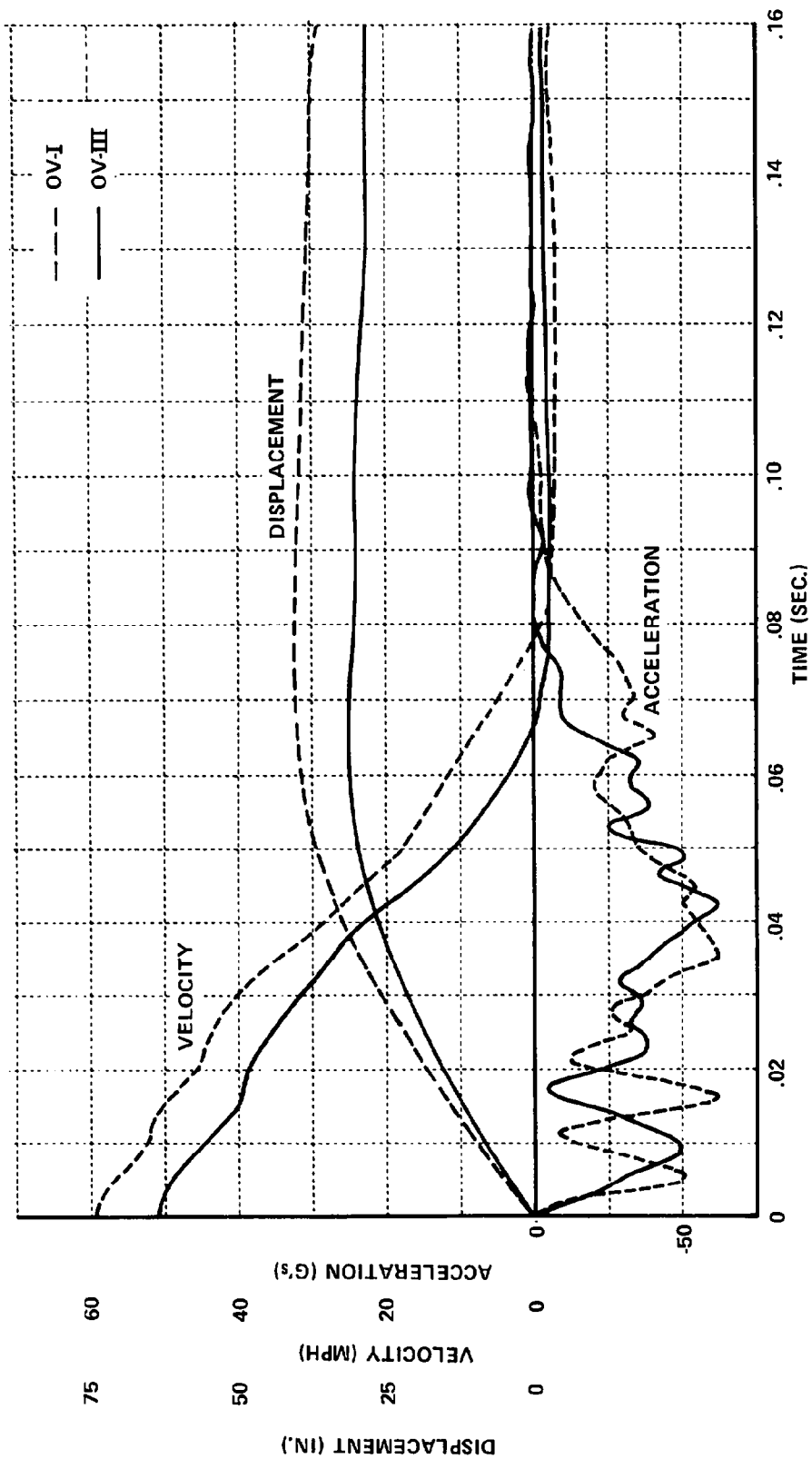


Figure 5-4 COMPARISON OF PASSENGER COMPARTMENT LONGITUDINAL DATA FOR MODIFIED VEHICLES IMPACTING FLAT BARRIER AT DIFFERENT IMPACT SPEEDS

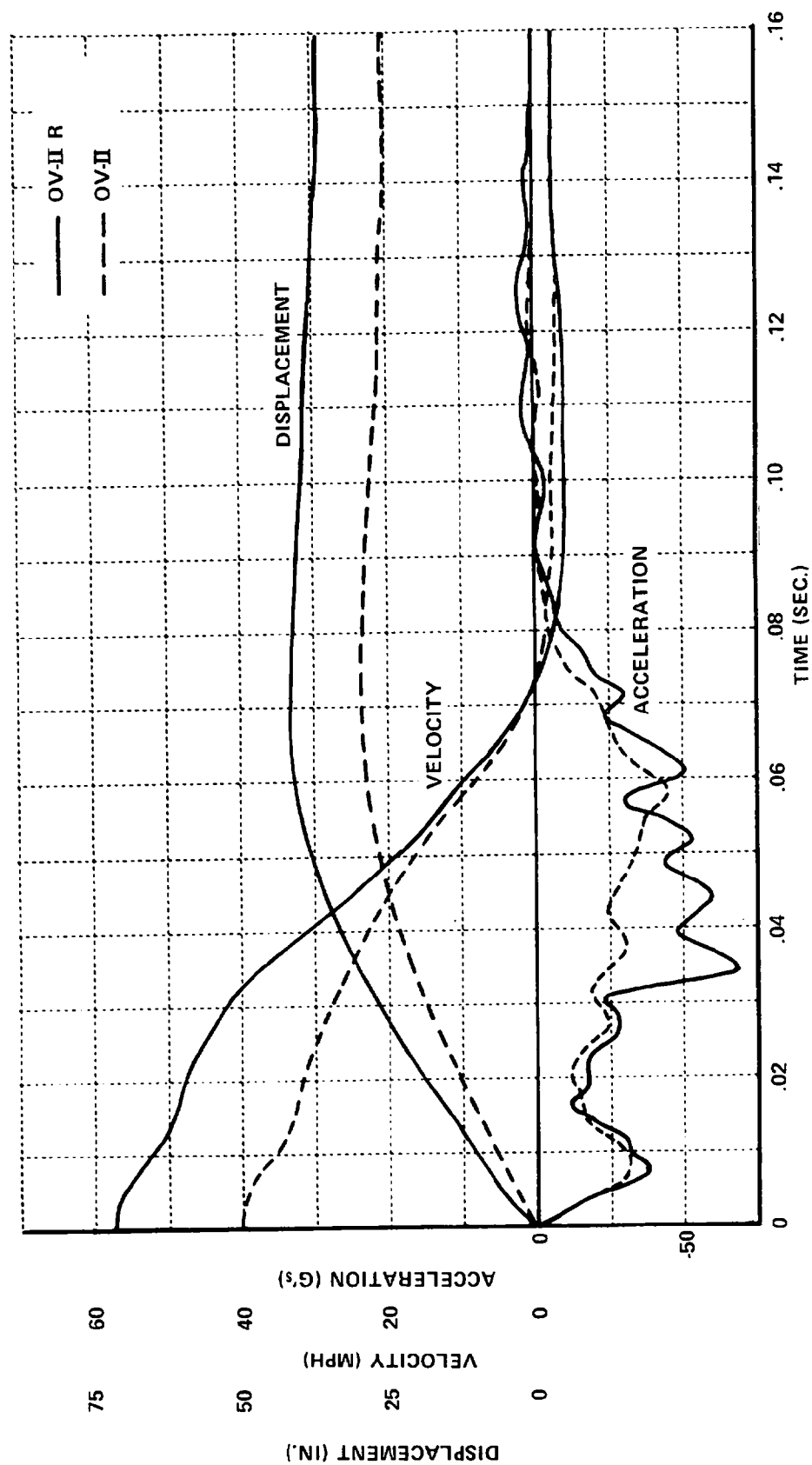


Figure 5-5 COMPARISON OF PASSENGER COMPARTMENT LONGITUDINAL DATA FOR MODIFIED VEHICLES IMPACTING POLE BARRIER AT DIFFERENT IMPACT SPEEDS

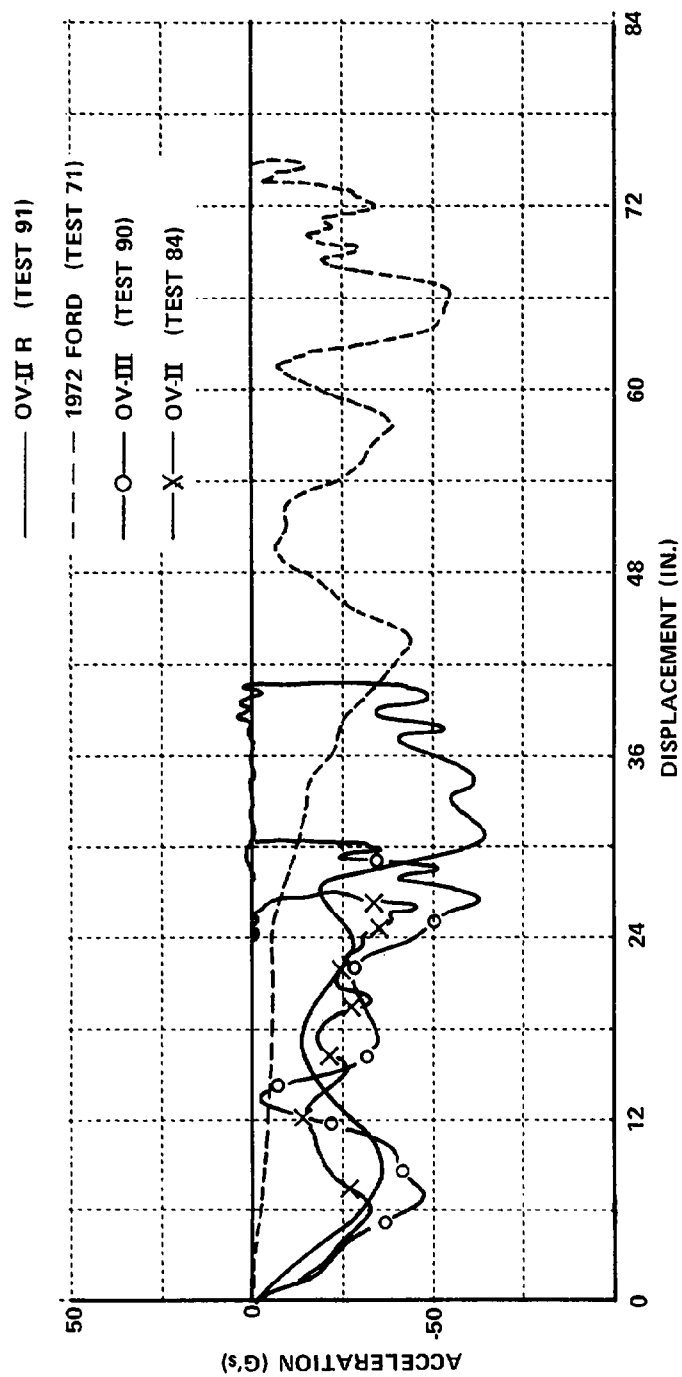


Figure 5-6 ACCELERATION - DISPLACEMENT DATA FOR CONVENTIONAL AND MODIFIED VEHICLES

function of vehicle collapse is illustrated by comparing the OV-II(R) and 1972 Ford curves. Total collapse (displacement) of the 1972 Ford was almost twice that of the OV-II R vehicle (cf. 75 in. to 41 in.). From these curves, it is noteworthy that the acceleration-displacement responses for the modified vehicles tend to follow the same general pattern. These data indicate a relative insensitivity of the structure to impact speed and type of obstacle. Differences in responses for various impact speeds are due, for the most part, to differences in the amount of total structural collapse rather than variation in rate sensitivity of the structural materials.

The results from the OV-II R test are compared to similar data for the non-operational vehicle, designated Mod. 1B2(R) developed on a previous program (Ref. 3) in Figure 5-7. The impact speeds for the two vehicles, OV-II R (56.8 MPH) and the Mod. 1B2(R) (63 MPH), are slightly different but it is evident from these curves that generally the vehicles exhibited similar deceleration-time histories. The only significant difference appears to be near 0.035 sec. into the crash where the engine contacts the fire wall in the OV-II R vehicle. This results in a relatively higher deceleration in the OV-II R vehicle. Otherwise, it appears that the overall performance of the previously modified vehicle, Mod. 1B2(R), has been preserved while developing these operational vehicles.

Data on a conventional 1971 Ford impacting both pole and flat barriers at 50 MPH are contained in Ref. 6. In that study, by the Ford Motor Co., the 1971 Ford served as the basis for development of the Ford ESV. The reader may wish to compare results obtained in this study, particularly the 49.9 MPH, OV-III test results, with those contained in the cited reference.

5.2 General Comments

The results of this study have demonstrated that reasonable passenger compartment acceleration-time histories and integrity (occupant survival space) can be developed for full size automobiles undergoing a wide range of extremely severe impact conditions. Furthermore, that kinetic energy

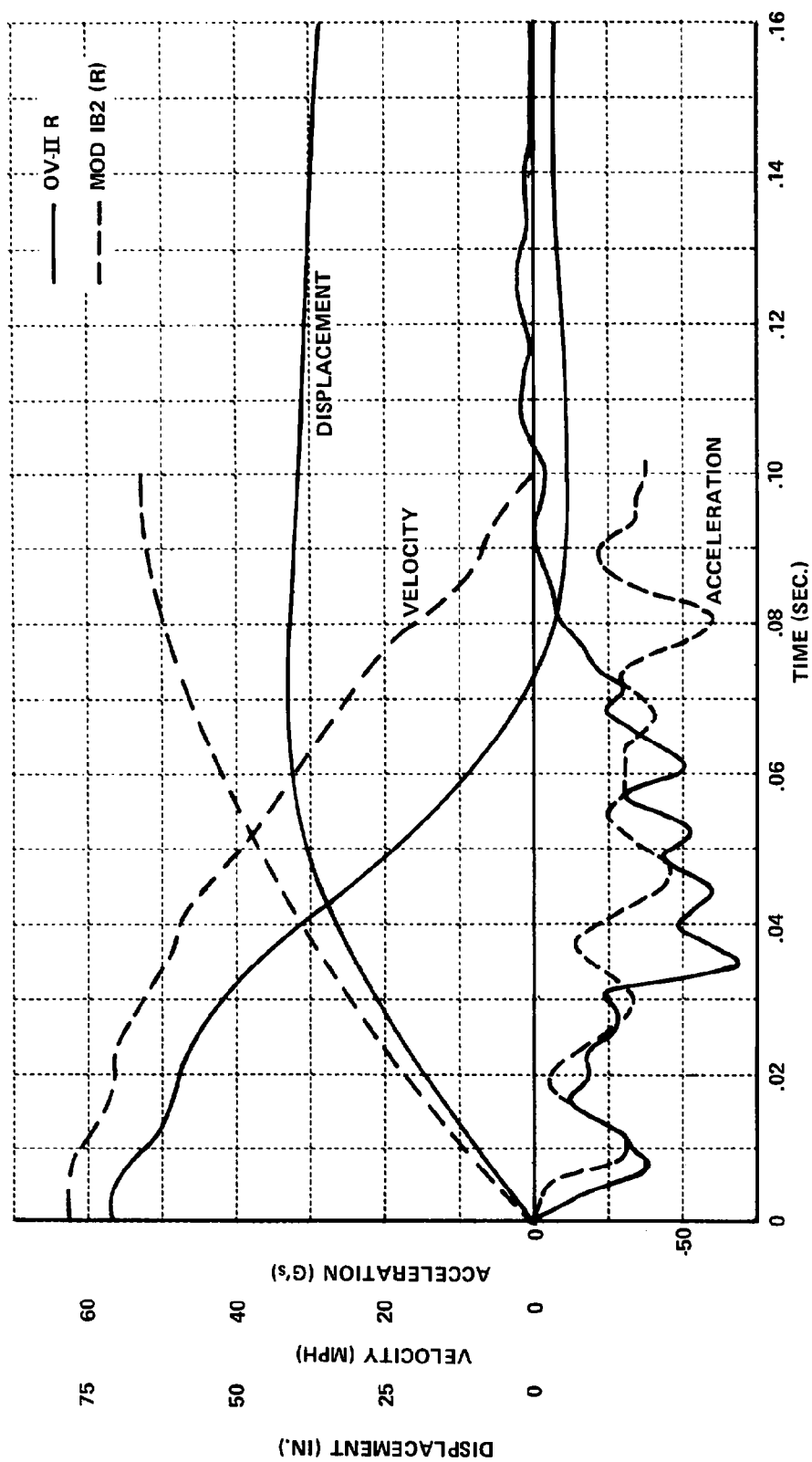


Figure 5-7 COMPARISON OF PASSENGER COMPARTMENT LONGITUDINAL DATA FOR
OV-II AND MOD IB2 R VEHICLES

management is feasible with use of current automotive materials and metal gauge thickness. Therefore, incorporation of such structures into full size automobiles need not have a major impact on current automotive technology.

One exception is the fire wall where a sandwich plate, steel skins bonded to an aluminum honeycomb core, was used. This structure is not at present suitable for automotive manufacturing methods. It should be noted, however, that the fire wall is too strong as indicated by the higher deceleration level which occurs (generally in all tests) when the engine contacts the fire wall deflection ramp and that this structure is needed only during fixed object impacts at speeds above 45 MPH. Thus, if maximum impact speeds were specified near 50 MPH rather than near 60 MPH, then only relatively small changes in the conventional fire wall structure would be needed.

Of critical importance in the study was the weight increase associated with the structural modifications. Because these vehicles were essentially identical (in terms of structure) to those developed under another phase of the overall program, the weight changes were very similar to those given in Reference 4. (The reader may wish to review the Discussion Section in that report.) Shown in Table 5-1 are carefully measured weight increments for various modified (OV-II and OV-III) vehicle structural components.

The bumper constitutes a minor change of 13 lbs. over similar component weight for the conventional 1972 Ford. In this case, high strength steel was used in the face bar, but such material is needed only for low speed impact with pole barrier, no damage performance. In this regard, it should be noted that the bumper system used on these vehicles will not result in any structural damage for all fixed object collisions (both flat and pole barriers), up to speeds slightly in excess of 8 MPH.

The net weight increase to the frame was 113 lbs. Frame modifications constitute use of mild steel having properties and thickness equivalent to

Table 5-1

WEIGHT CHANGES IN MODIFIED STRUCTURAL COMPONENTS (UNITS-LB.)

ITEM	WEIGHT OF REMOVED ITEM	WEIGHT OF ADDED ITEM	NET WEIGHT INCREASE
BUMPER			
FACE BAR	—	58	6
BRACKETS	—	4	—
URETHANE	—	5	5
	<u>56</u>	<u>63</u>	<u>13</u>
FRAME			
1ST X - MEM.	12	28	16
H-SECTION	10	46	36
3RD X-MEM.	15	37	22
S-MEM. EXT.	8	15	7
LONG. STRUTS	—	24	24
MISC.	—	8	8
	<u>45</u>	<u>158</u>	<u>113</u>
FENDERS & GRILLE			
FENDERS	34	75	41
GRILLE	38	53	15
	<u>91</u>	<u>141</u>	<u>56</u>
ENGINE TRANSMISSION			
DEFLECTOR	—	23	23
STIFFENER	—	14	14
		<u>36</u>	<u>37</u>
FIREWALL AND FLOOR			
FRONT SKIN		18	
BACK SKIN		19	
EDGES		6	
FRONT HAT		6	
BACK HAT		19	
INBOARD SKIN		21	
OUTBOARD SKIN		10	
HONEYCOMB & GLUE		20	
FLOOR SKIN		21	
TUNNEL SKIN		9	
STIFFENER		25	
MISC.		44	
	<u>63</u>	<u>218</u>	<u>155</u>
PASSENGER COMPARTMENT			
A-PILLARS	—	25	25
B-PILLARS	—	4	4
C-PILLARS	—	14	14
		<u>43</u>	<u>43</u>
TOTAL NET WEIGHT INCREASE - 417 LBS			

the original frame structural material. Performance has been increased substantially over that of the original frame during both front and side collisions (for side impact data see Ref. 7). Also, the modified frame was fitted within the overall geometry of the 1972 Ford. Other than raising the frontal section of the passenger compartment floor about one inch, no other changes in vehicle structural geometry were made. Thus, if additional changes in vehicle geometry were possible, it is probable that similar frame performance could be maintained for frame structures weighing slightly less than the modified frame.

Front fenders and grille constituted a weight increase of 56 lbs. Most of this increase, of course, is in the addition of the channel members to the inner fenders. Also, the design necessitates that the inner fenders be attached directly to the passenger compartment fire wall.

The major increase in structural weight is in the transmission deflector (37 lbs.) and fire wall (155 lbs.). From the test results it is apparent that the fire wall is over-designed and significant weight reduction should be possible while at the same time improving performance. More importantly, however, is the fact that the deflector mechanism and fire wall becomes necessary only for fixed object collisions greater than approximately 45 MPH. Consequently, if impact speeds near 50 MPH were specified, then most of the 192 lbs. of added weight for these two structural elements could be avoided.

Passenger compartment reinforcements of 43 lbs. were added to the various pillars. High strength steel was used in most of these applications, but it should be recalled that these reinforcements generally were cover plates added to existing metal surfaces. Thus, complete integration of the structural reinforcements into the passenger compartment structure itself would tend to reduce the weight increment. Development of this type of structure would require substantial tooling of passenger compartment structural elements.

Many of the structural modifications adapted to the vehicle would be helpful during side collisions. Also, door beams which would provide longitudinal stiffness in addition to lateral strength are needed with the front structure. (The strength of these members was only simulated in the vehicles developed in this study.) Therefore, the next step in development of full size vehicle crashworthy structures is fabrication of vehicles intended to provide front, side and rollover protection. Such a program is currently underway in the Production Feasibility, Crashworthy Structures - Full Size Cars Project (Contract DOT-HS-053-2-487). Within that program, such completely modified vehicles are being fabricated based, for the most part, on refinements of this front and a compatible side structural (see Ref. 7 for details of side structures) designs. Total weight increase for the complete modification is expected to be less than 10 percent of the gross conventional vehicle weight.

6. REFERENCES

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2. Miller, P. M. and Mayor, R. P., "Basic Research in Automobile Crashworthiness--Summary Report," CAL Report No. YB-2684-V-6, November 1969 (PB #196496).
3. Miller, P. M., Greene, J. E. and Culkowski, P. M., "Basic Research in Automobile Crashworthiness--Additional Evaluation of the Engine Deflection Concept," CAL Report No. YB-2684-V-7, March 1971 (PB #203719).
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5. Trenka, A. R., "Basic Research in Crashworthiness II--Instrumentation and Data Handling Techniques," Calspan Report No. YB-2987-V-5, April 1973.
6. Arning, K. H., Feustel, J. R. and Rhodes, A., "Ford ESV Energy Management System," SAE No. 730074, January 8-12, 1973.
7. Greene, J. E., "Basic Research in Crashworthiness II--Development and Testing of Vehicle Side Structure Modifications," Calspan Report No. YB-2987-V-14, May 1973.

APPENDIX A

Comparative Handling Tests -
Conventional 1972 Ford and OV-I Modified Vehicle

A-1 Objectives

Structural modification of an automobile for improving crashworthiness tends to change vehicle characteristics such as weight, distribution of mass, and stiffness properties. Changes such as these are known to affect handling qualities. It is imperative that normal handling qualities (as well as other performance requirements) not be significantly degraded as a result of the structural modifications.

The objective of this limited test program is to determine if the handling qualities of a specific automobile have been markedly affected by structural modifications for frontal crash protection.* Evaluation of the performance of the modified vehicle is based on comparison with results for the corresponding conventional vehicle (unmodified 1972 Ford). Commonly performed handling tests of a quantitative nature were selected to determine the steady-state steering and certain dynamic response characteristics for each vehicle.

A-2 Description of Vehicles and Test Conditions

The OV-I vehicle is a structurally modified 1972 Ford Custom. Extensive changes are incorporated in the front bumper, frame, firewall and floorpan structures. Except for stiffer front springs, no alteration of handling-related components was introduced to compensate for the change in mass distribution.

Figure A-1 compares the OV-I and conventional 1972 Ford. The difference in frontal appearance reflects the bumper change and the elimination of sheet metal protrusions to allow for a four inch no-damage bumper stroke.

* Operational modified vehicle designated OV-I



(a) OV-I



(b) OV-I AND 1972 FORD

Figure A-1 OV-I AND 1972 FORD TEST VEHICLES

Test weights for the OV-I and 1972 Ford are given in Table A-I.

TABLE A-I - TEST WEIGHTS

<u>LOCATION</u>	<u>TIRE LOAD (LBS.)</u>	
	<u>OV-I</u>	<u>1972 FORD</u>
left front	1370	1160
right front	1390	1150
left rear	1030	960
right rear	980	940
total	4770	4210
weight distribution (% front/% rear)	58/42	55/45

Both vehicle test weights include a payload of 390 lbs., of which 180 lbs. is the weight of the driver and 210 lbs. is the weight of the instrumentation package.

Note that the weight difference between the OV-I and conventional 1972 Ford is 560 lbs. It is estimated that the structural modifications account for approximately 475 lbs., while the other 85 lbs. is due to other differences between the vehicles, e. g., amount of fuel load and cosmetrical variances. The difference in mass distribution indicated in Table A-I represents a 3.6 inch forward shift of the center of gravity.

The standard equipment tire supplied with the 1972 Ford custom is a size F78-15, rated for a maximum load of 1500 lbs. Since the front tire loads for the OV-I are near the maximum rated load (see Table A-I), handling tests were also performed with the OV-I equipped with H70-15 tires, which have a maximum load rating of 1770 lbs.

Throughout the test program, tire inflation pressures were selected in conformance to the manufacturer's recommendations for the 1972 Ford with the particular tire sizes. These are 27/29* psi (cold) for the F78-15 tires and 24/26 psi (cold) for the H70-15 tires.

3.0 Instrumentation

A minimal amount of instrumentation was utilized due to the limited scope of the test program. The physical variables recorded and the corresponding instrumentation are described in Table A-II.

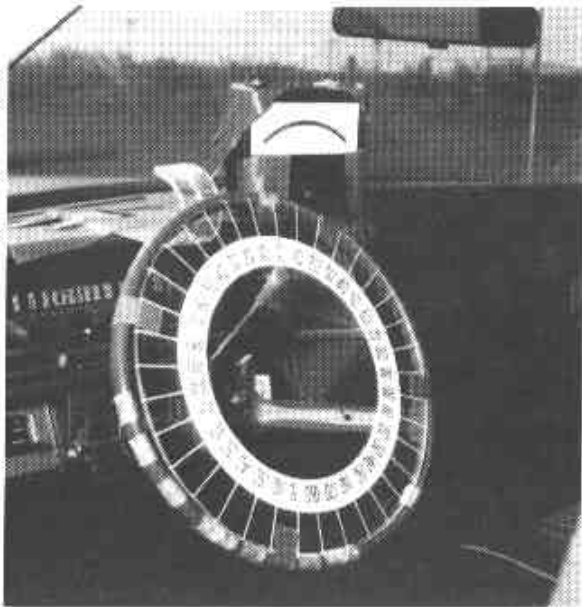
TABLE A-II - INSTRUMENTATION

<u>VARIABLE</u>	<u>MEASURING DEVICE</u>	<u>RANGE</u>
Speed	Lab Equipment Corporation 5th wheel	0-60 MPH
Lateral Acceleration	CEC Accelerometer, Model 4-202-0001	+ - 1 g
Steering Wheel Angle	Beckman Helipot	+ - 360°

Data were recorded on two-channel Brush recorders with signals filtered flat to 6 Hz. In addition to the recorded data, visual readouts of speed and steering wheel angle were available to the driver.

Figure A-2 shows various components of the data acquisition package. The driver's steering wheel angle reference and the 5th wheel unit are shown

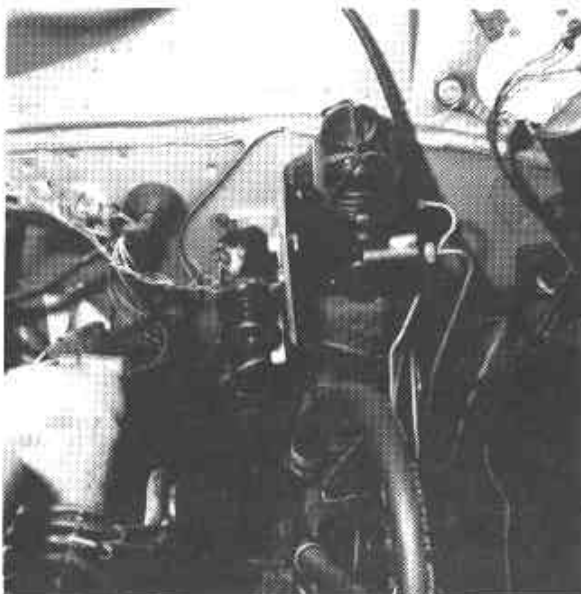
* front tire pressure/rear tire pressure



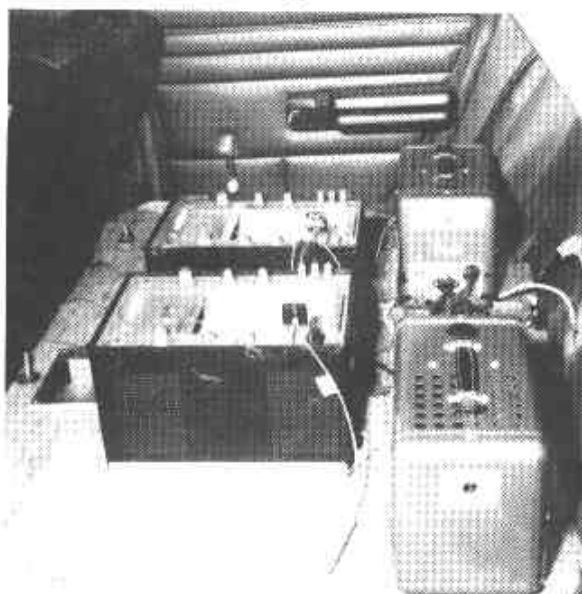
(a)



(b)



(c)



(d)

Figure A-2 INSTRUMENTATION FOR HANDLING TESTS

in Figure A-2 (a) and (b). A rotary potentiometer with a spring-loaded windup for measuring the steering shaft rotation can be seen in Figure A-2 (c). Figure A-2 (d) shows the two recorders and power supply inverters; the lateral accelerometer can also be seen mounted to the plywood board between the front seat back and the Brush recorders.

A-4 Test Methodology and Results

Specific handling tests performed with the OV-I and conventional 1972 Ford were chosen to determine quantitative steady-state cornering characteristics and transient responses to certain steering control inputs. Methodology and results of these tests, which have been commonly performed in other handling studies, are discussed below.

A-4.1 Steady-State Cornering Tests

The steady-state cornering behavior of an automobile can be characterized by determining the front wheel steer angle as a function of lateral acceleration. Using a "constant radius" test technique, wherein a specific circular path is maintained, lateral acceleration is directly related to speed so that either speed or lateral acceleration can be considered an independent variable. For the purpose of this investigation, steering wheel angle was assumed to be directly proportional to front wheel angle and treated as the dependent variable.

Constant radius steady-state cornering tests were performed on the CAL/VERF skid pad using the 100 ft. and 150 ft. path radii denoted in Figure A-3. The test procedure involved obtaining a stable preselected speed on the particular circular path and measuring the associated steering wheel angle and lateral acceleration. Runs were made in both clockwise and counter-clockwise directions and the resulting data were averaged. For the higher speed runs in which stabilizing is difficult, several runs were made to insure meaningful data.

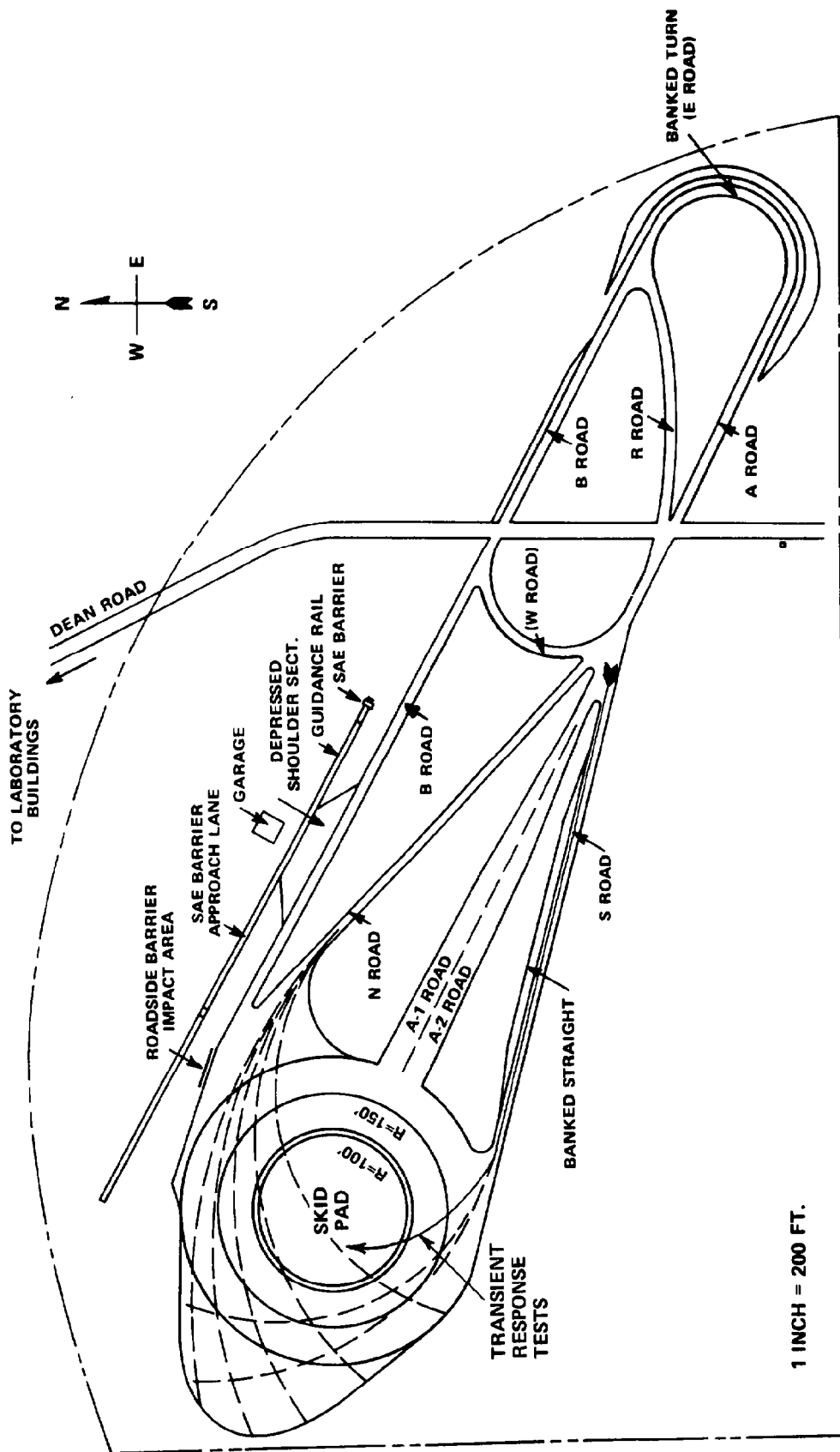


Figure A-3 LOCATIONS FOR PERFORMING STEADY STATE AND TRANSIENT RESPONSE HANDLING TESTS

The averaged steady-state cornering data are contained in Table A-III for each of the speed and path radius combinations. Steering wheel angle data are given for the OV-I vehicle with H70-15 and F78-15 tires, and for the 1972 Ford with standard equipment F78-15 tires (see Section A-2 on Test Conditions). It is inferred in the table that measured lateral acceleration data did not vary significantly between vehicles for a given speed.

It is important to note that the lateral acceleration data given in Table A-III are measured values in a vehicle-fixed reference system. As a result, these data contain a component of gravitational acceleration due to vehicle roll attitude. This roll angle effect is evident in Figure A-4 in which the measured lateral acceleration data points are compared with calculated curves based on vehicle speed and path radius ($A_y = V^2/R$). Although differences are evident, measured data in the vehicle-fixed reference system will be treated as actual lateral acceleration with the understanding that the errors exist. This is not expected to affect conclusions based on a comparative handling evaluation.

In Figure A-4, the numbers associated with each data point correspond to the numbered test configurations defined in Table A-III. Also, it is important to note in Figure A-4 that these test configurations encompass the entire range of vehicle lateral acceleration capability from the "normal" driving range (about 0-0.4 g) to the limit of performance (about 0.8 g).

The steady-state cornering data contained in Table A-III are plotted for each path radius in Figures A-5 and A-6, in which steering wheel angle is given as a function of lateral acceleration (or speed).^{*} It is seen that for each of the vehicle/tire combinations, the steering input must be increased

* The data points corresponding to zero lateral acceleration (Ackermann steer angle) were actually measured at a very low rate of speed (less than 5 MPH).

Table A-III
SUMMARY OF STEADY-STATE CONDITIONS

CONFIGURATION NUMBER	PATH RADIUS (FEET)	SPEED (MPH)	LATERAL ACCELERATION * (g's)	STEERING WHEEL ANGLE ** (DEG)		
				OV-1		
				H70-15	F78-15	1972 FORD F78-15
1	150	15	0.12	105	105	100
2	150	20	0.21	120	120	112
3	150	25	0.32	137	140	125
4	150	30	0.47	170	170	145
5	150	35	0.62	210	200	170
6	150	40	0.75	280	250	190
7	100	10	0.08	147	153	140
8	100	15	0.20	162	165	153
9	100	20	0.34	180	185	165
10	100	25	0.51	215	215	185
11	100	30	0.70	285	280	225

* MEASURED LATERAL ACCELERATION FOR BOTH VEHICLES (CONTAINS ROLL ANGLE COMPONENT).

** AVERAGE OF CLOCKWISE AND COUNTERCLOCKWISE ANGULAR MEASUREMENTS.

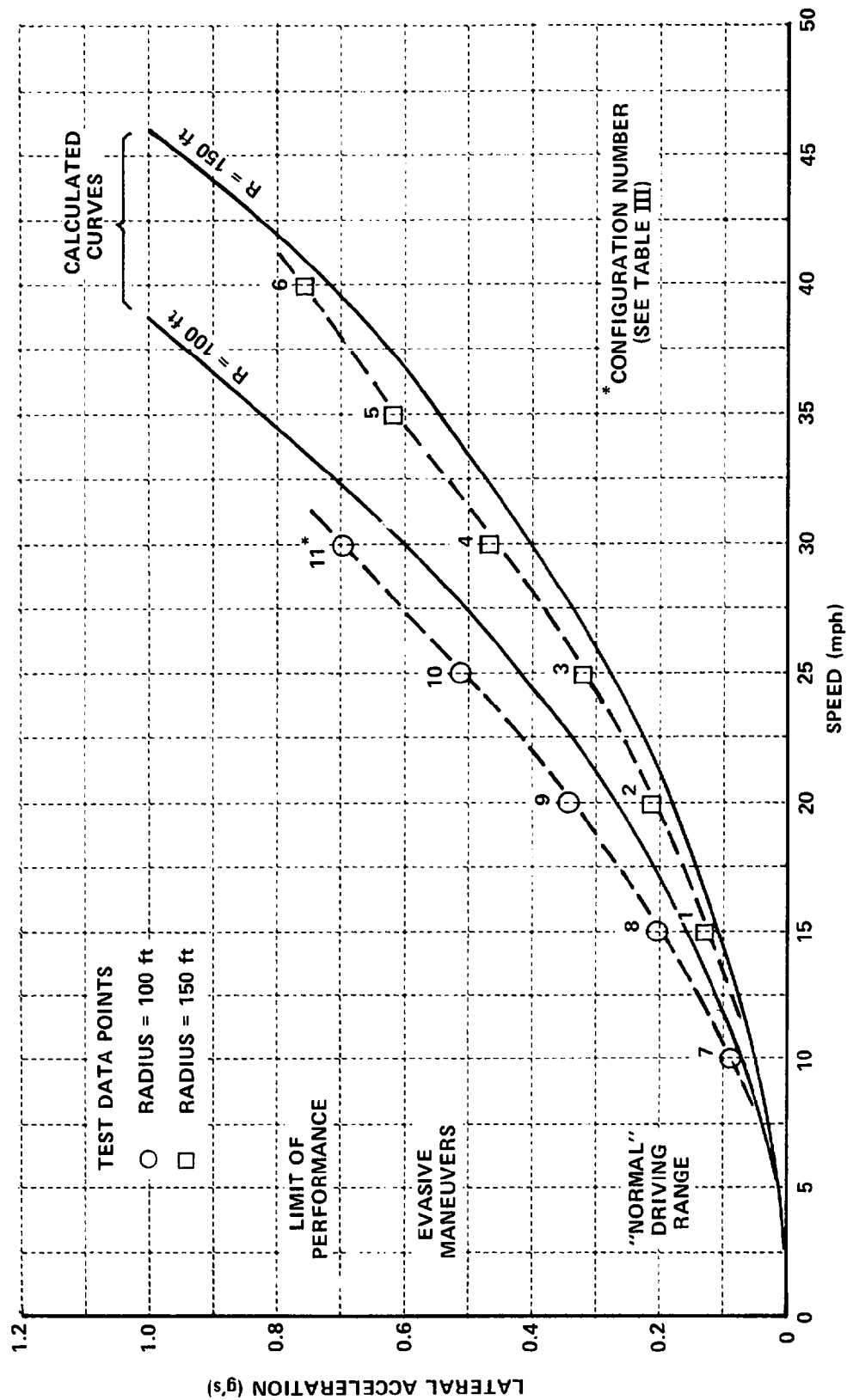


Figure A-4 COMPARISON OF MEASURED AND CALCULATED LATERAL ACCELERATIONS

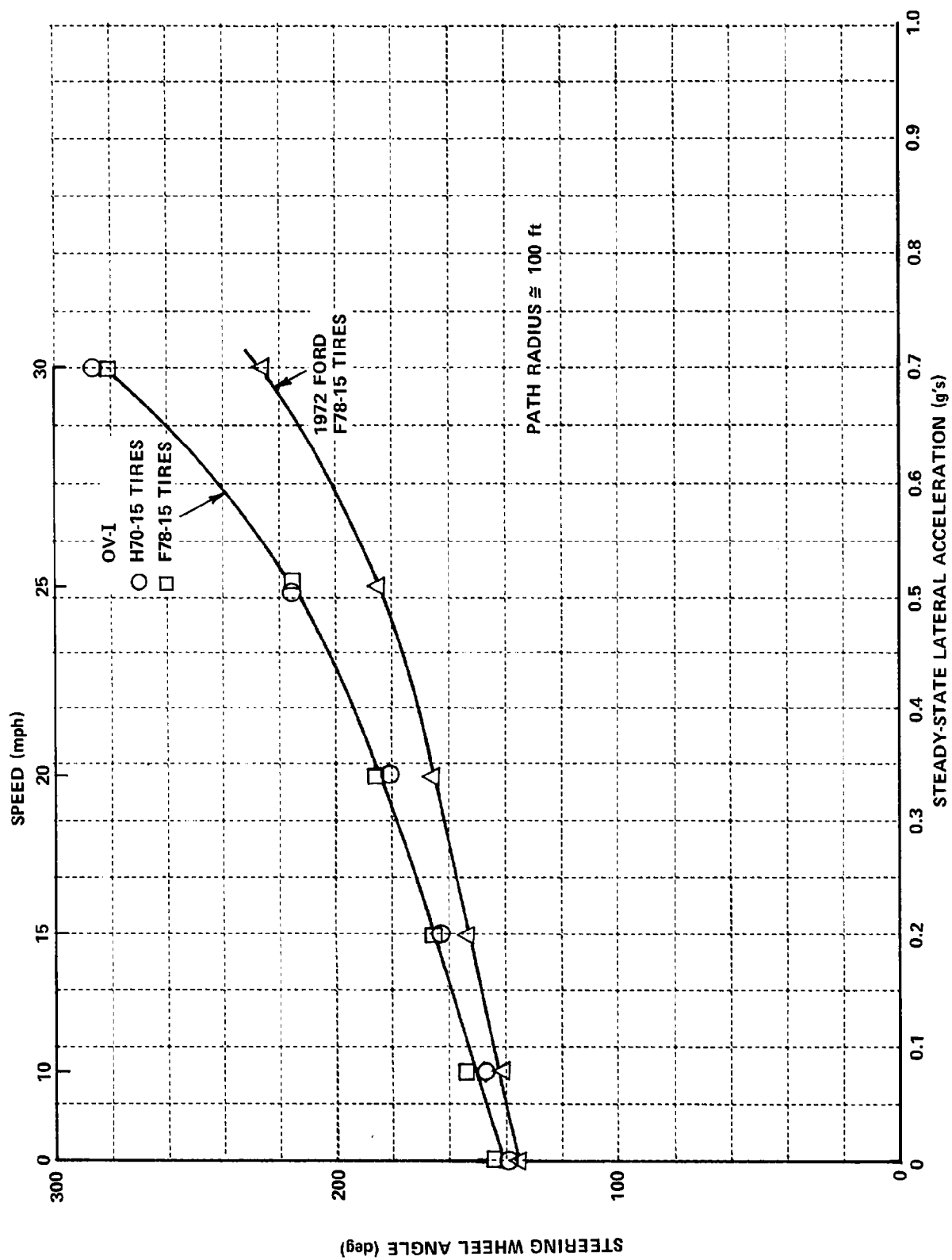


Figure A-5 STEADY-STATE STEERING CHARACTERISTICS FOR 100 FT RADIUS PATH

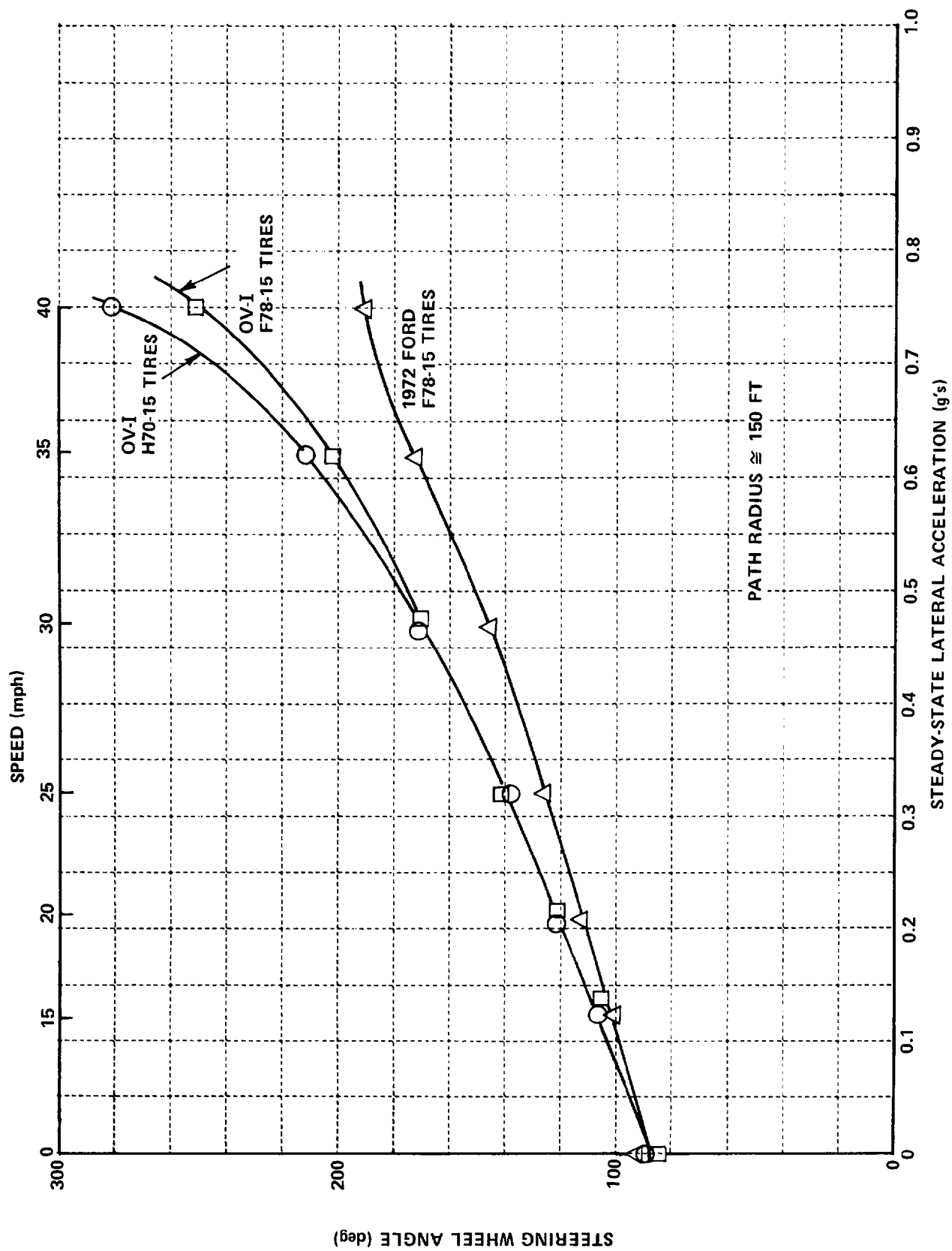


Figure A-6 STEADY-STATE STEERING CHARACTERISTICS FOR 150 FT RADIUS PATH

as lateral acceleration (or speed) increases to maintain the prescribed path radius, i. e., the curves have positive slope. This vehicle cornering behavior is known as "understeer", and is typical of American automobiles.

It is clear that the OV-I is more understeer than the 1972 Ford, particularly for the higher lateral accelerations. It is also noted that changing the tire size on the OV-I did not significantly affect the understeer characteristic, except perhaps for the higher lateral acceleration range at the larger radius (Figure A-6).^{*} Furthermore, for the larger radius path, the conventional automobile approaches a "neutral steer" condition (zero slope) near the limit of performance whereas the OV-I is increasingly understeer.

4.2 Transient Response Tests

Common vehicle handling tests involve evaluating response to a step steer input, and free (hands-off) response from a steady-state cornering condition. Both of these responses can be determined for a specific lateral acceleration condition from a single test run. Figure A-7 illustrates the test procedure by depicting the nature of the important variables and the pertinent response parameters for a hypothetical test.

A test run begins at the desired velocity with the vehicle in a straight-ahead course. Maintaining a constant throttle position, a preselected step change of steering wheel angle is introduced by the driver. After a stable cornering condition is achieved, the steering wheel is released to produce the free response portion of the test. After a stable condition is again achieved (nearly straight-ahead course), the vehicle is stopped and the test run is concluded. In the fixed throttle condition, some reduction of speed will take place during the cornering portion of the test and an average value of the actual speed is taken as the velocity reading.

*

The effect of changing tire pressures from the manufacturer's recommendations was not explored.

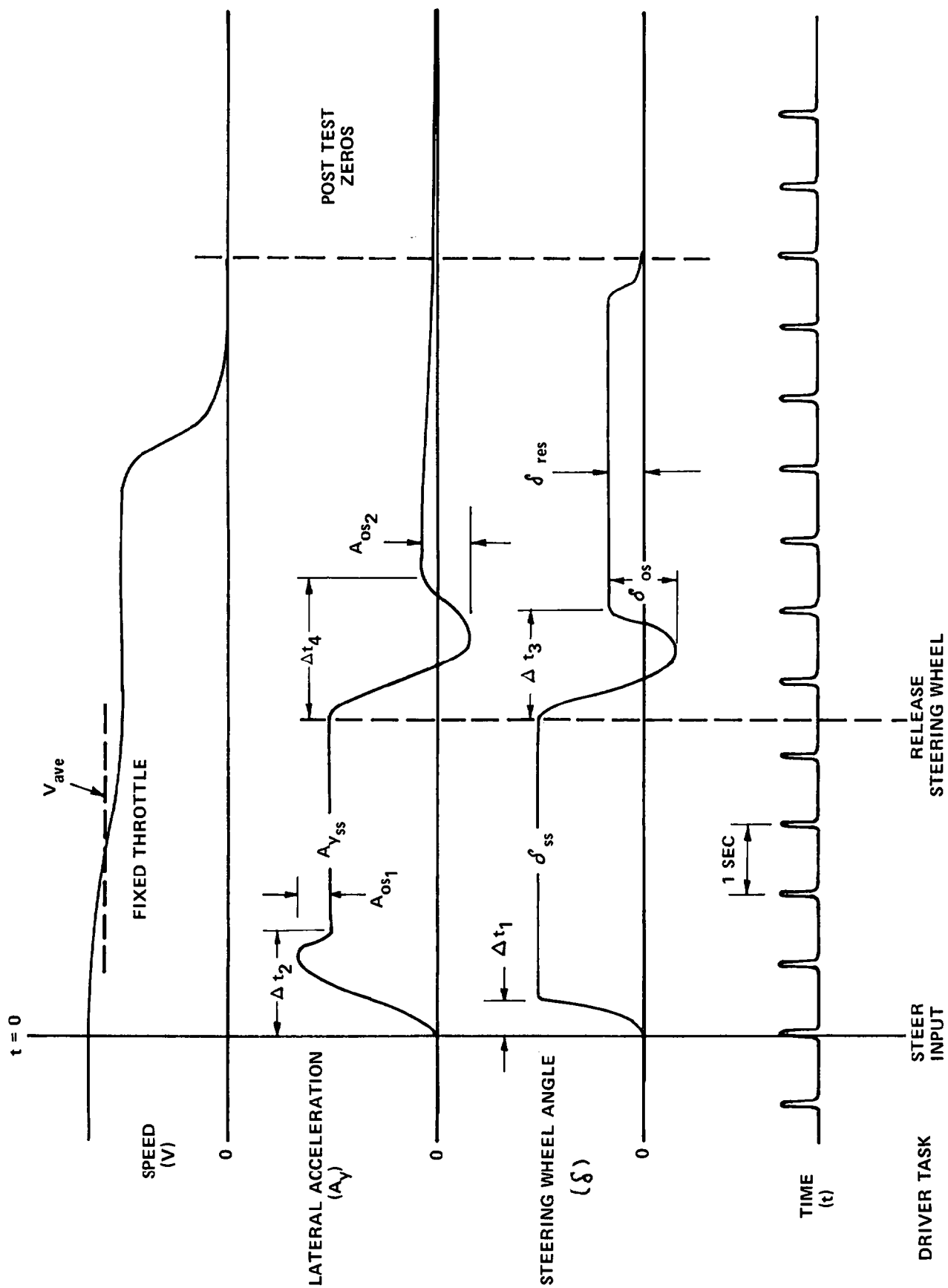


Figure A-7 DEFINITION OF TRANSIENT RESPONSE TEST DATA

It should be noted that the initial speed and steering input for a particular test run is chosen to correspond with one of the steady-state configurations listed in Table A-III. This permits correlation between the steady-state cornering data and the results of the transient response tests, and also accommodates orderly processing and analysis of the data.

Figure A-7 graphically defines the transient response parameters which are used to characterize the directional responsiveness of the vehicles. These parameters are further defined in Table A-IV.

A perfect step steer input is, of course, not possible to obtain; a finite rate of input corresponding to the capability of the driver will exist in an actual test. Figure A-8 is a plot of actual steer angle inputs and corresponding input times for all of the transient response tests performed. The rate of steering input varies between 350 and 700 deg./sec., with a mean rate of about 520 deg./sec. It appears that, for each of the three vehicle/tire combinations, the points are scattered between the lower and upper bound. It is thus assumed that variation in steering input rate will not significantly bias the overall results of the step response tests due to the number of data points obtained.

The time required to achieve a steady-state lateral acceleration condition following a step steer input (Δt_2) is indicated in Figure A-9. Data points for each of the vehicle/tire combinations appear to fall within a rather narrow band throughout the range of lateral acceleration. Similar scatter of data points representing the amount of lateral acceleration overshoot ($Aos_1 / Ay_{ss} \times 100$) following a step steer input is found in Figure A-10. No significant differences are evident between the OV-I and conventional 1972 Ford for those particular response measures.

For the free response portion of the transient response tests, the time required for lateral acceleration to settle to a stable condition following steering wheel release (Δt_4) is plotted in Figure A-11 as a function of pre-release steady-state acceleration. Curves are faired through the data points

Table A-IV
DEFINITION OF RESPONSE PARAMETERS

PARAMETER	DESCRIPTION	UNITS
V^*	SPEED	mph
$A_{y_{ss}}^*$	STEADY-STATE LATERAL ACCELERATION	g's
A_{os1}	LATERAL ACCELERATION OVERSHOOT FOLLOWING STEP INPUT	g's
A_{os2}	LATERAL ACCELERATION OVERSHOOT DURING FREE RESPONSE	g's
δ_{ss}^*	STEADY-STATE STEERING WHEEL ANGLE	deg
δ_{os}	STEERING WHEEL OVERSHOOT DURING FREE RESPONSE	deg
δ_{res}	RESIDUAL STEERING WHEEL ANGLE (DEVIATION FROM STRAIGHT AHEAD)	deg.
Δt_1	TIME FOR STEERING WHEEL INPUT	sec
Δt_2	RESPONSE TIME TO ACHIEVE STEADY-STATE LATERAL ACCELERATION FOLLOWING STEP INPUT	sec
Δt_3	SETTLING TIME FOR STEERING WHEEL MOTION DURING FREE RESPONSE	sec
Δt_4	SETTLING TIME FOR LATERAL ACCELERATION DURING FREE RESPONSE	sec

* VALUES CORRESPOND TO STEADY-STATE CONFIGURATION GIVEN IN TABLE III.

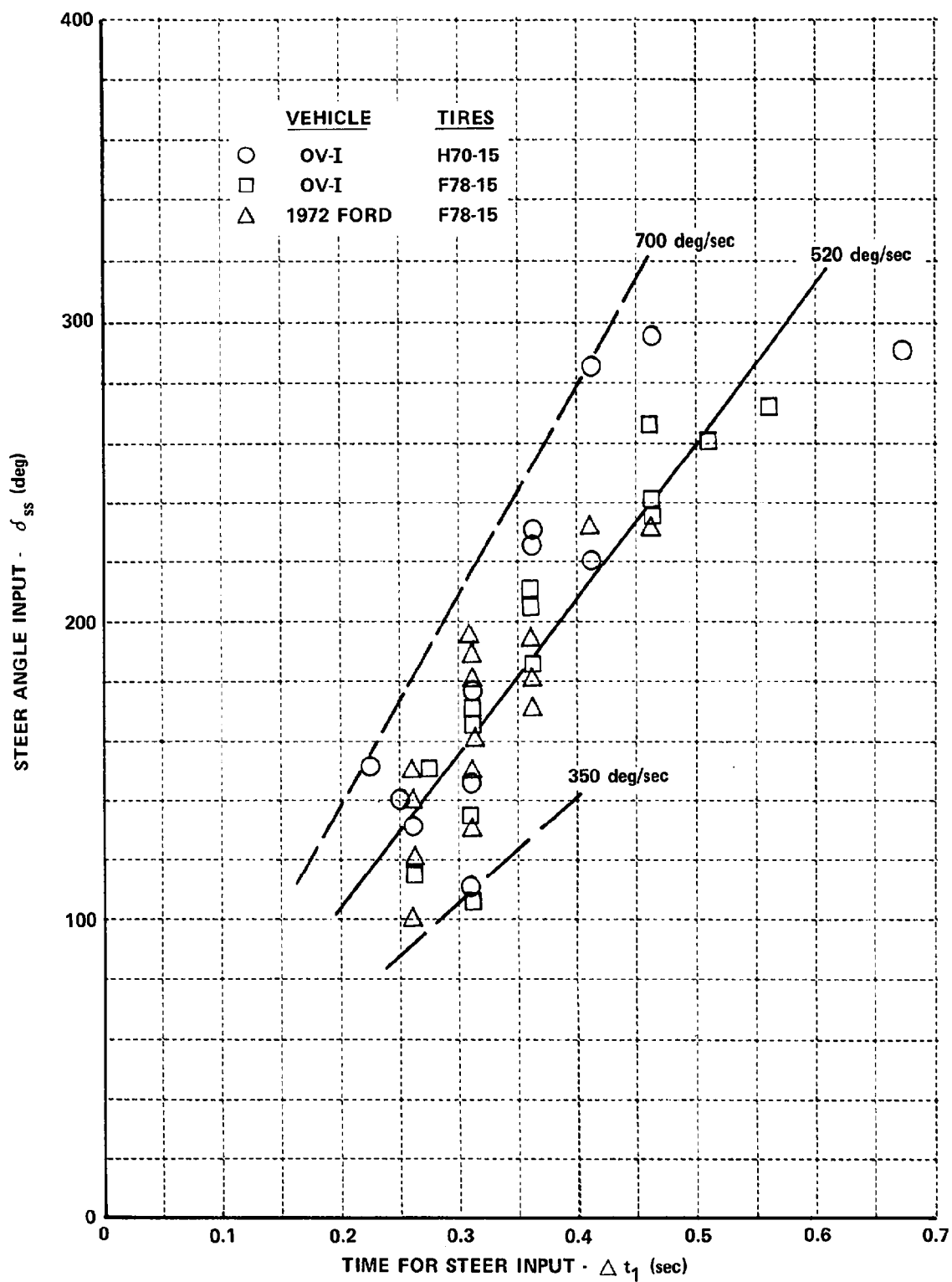


Figure A-8 RATES OF STEP STEER INPUTS



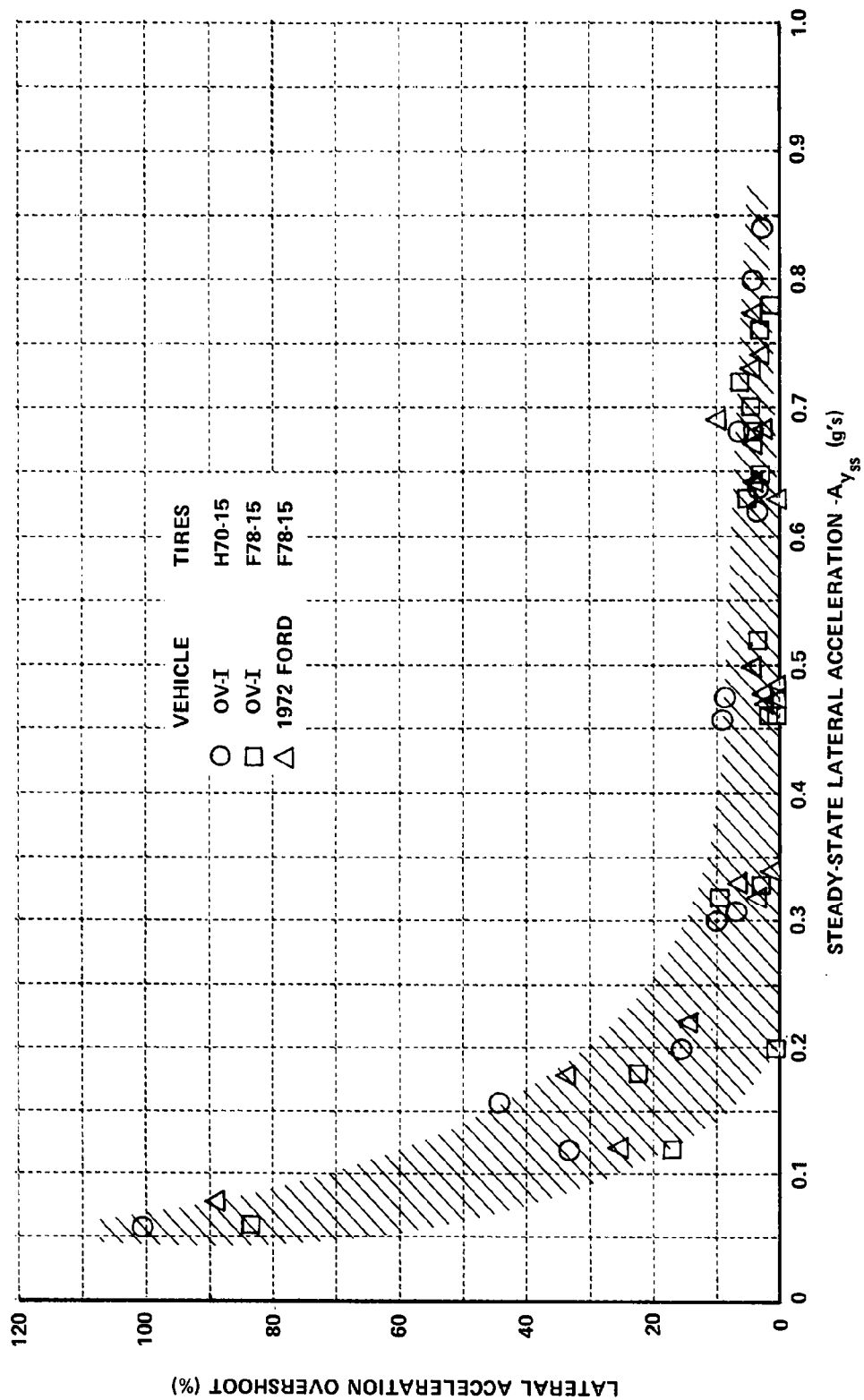


Figure A-10 COMPARISON OF LATERAL ACCELERATION OVERSHOOT AFTER STEP STEER INPUT

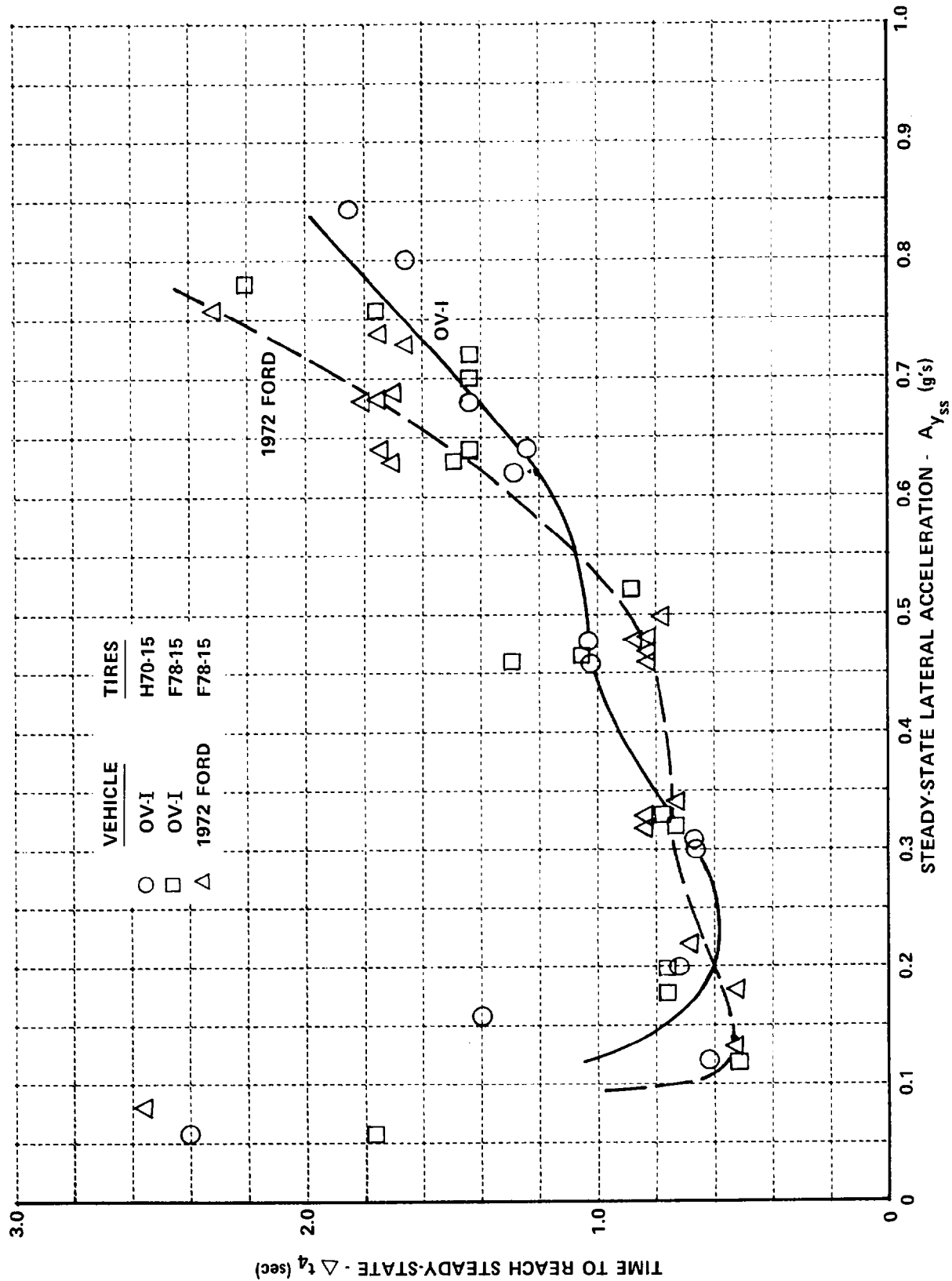


Figure A-11 COMPARISON OF SETTLING TIMES DURING FREE RESPONSE

for the OV-I (includes both tire selections) and for the 1972 Ford. Data points showing very long response times at low levels of lateral acceleration reflect the effect of friction in the steering system for both vehicles that prevents rapid centering of the steering wheel. In the 0.2-0.6 g lateral acceleration range, the differences in settling times for the two vehicles are not particularly significant. However, for initial lateral acceleration greater than 0.6 g, the OV-I appears to respond faster than the conventional vehicle. This occurs because the conventional vehicle tends to double overshoot the straight-ahead position whereas the OV-I exhibits a more critically damped response.

Figure A-12 compares the percentage overshoot of lateral acceleration during free response from a steady-state cornering condition ($A_{os2} / A_{y_{ss}} \times 100$). No meaningful differences between the OV-I and 1972 Ford are evident because the data points are similarly scattered within the data band shown.

The tendency for the steering wheel (or front wheels) to return to a straight-ahead (centered) position is characterized by the amount of residual steering wheel angle present following free response from a particular steady-state lateral acceleration. Substantial differences in the steering wheel returnability between the OV-I and conventional vehicle are evident in Figure A-13, particularly for the higher pre-release lateral accelerations. In the range of normal driving (below about 0.4 g), the overlap of the data bands indicates that neither vehicle tends to return to the centered wheel angle without driver assist, but the OV-I may require more manual return than the conventional vehicle. At higher levels of lateral acceleration, the OV-I consistently undershoots the centering position whereas the conventional vehicle tends to overshoot or return completely.

The differences in steering returnability are probably due to variation in effective steering system damping as a result of the difference in front wheel loads (larger tire footprint for heavier OV-I). It is possible that increasing the front tire pressure for the OV-I would improve its centering behavior. The differences in centering response might also be due to

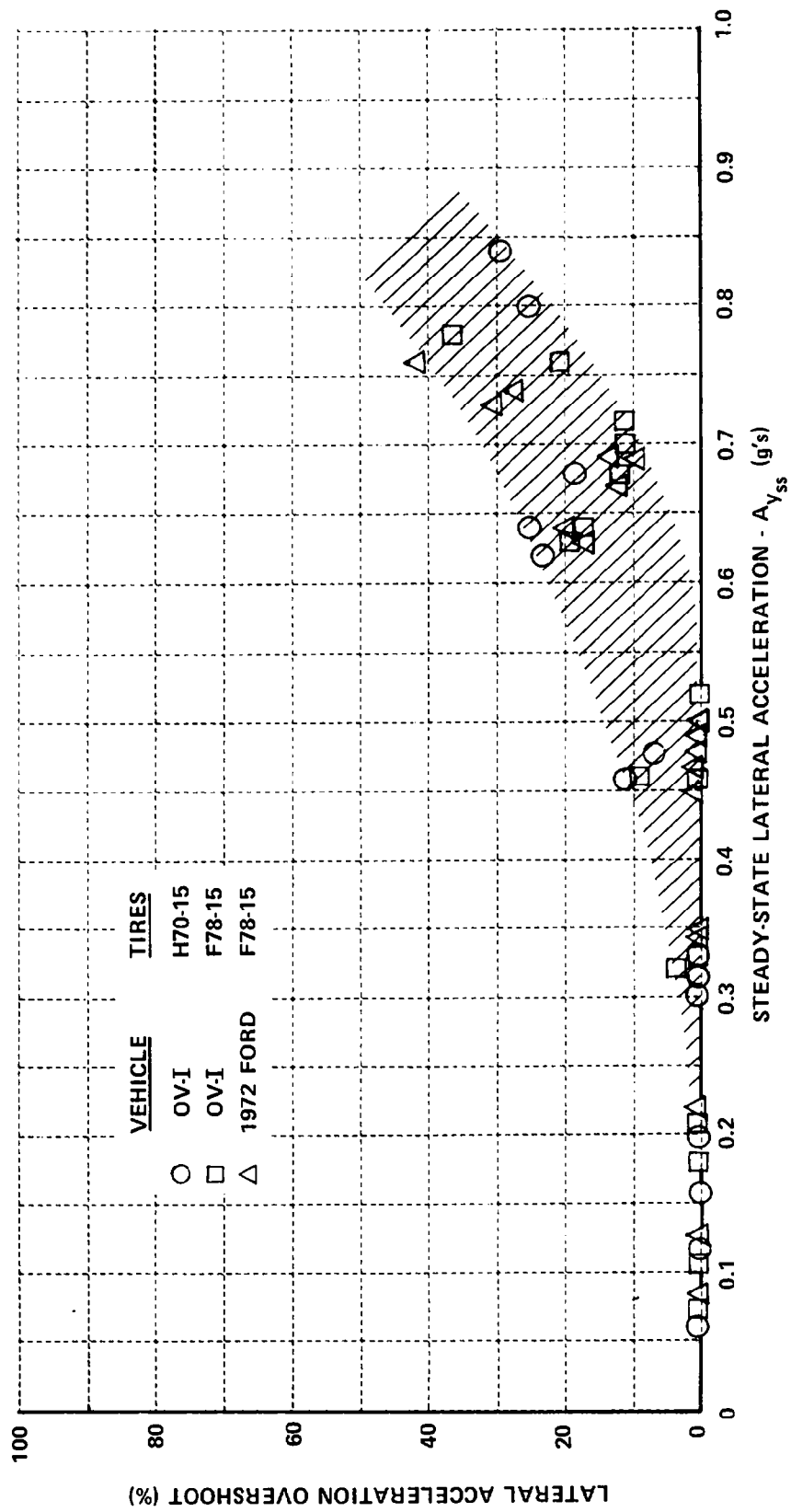


Figure A-12 COMPARISON OF LATERAL ACCELERATION OVERSHOOT DURING FREE RESPONSE

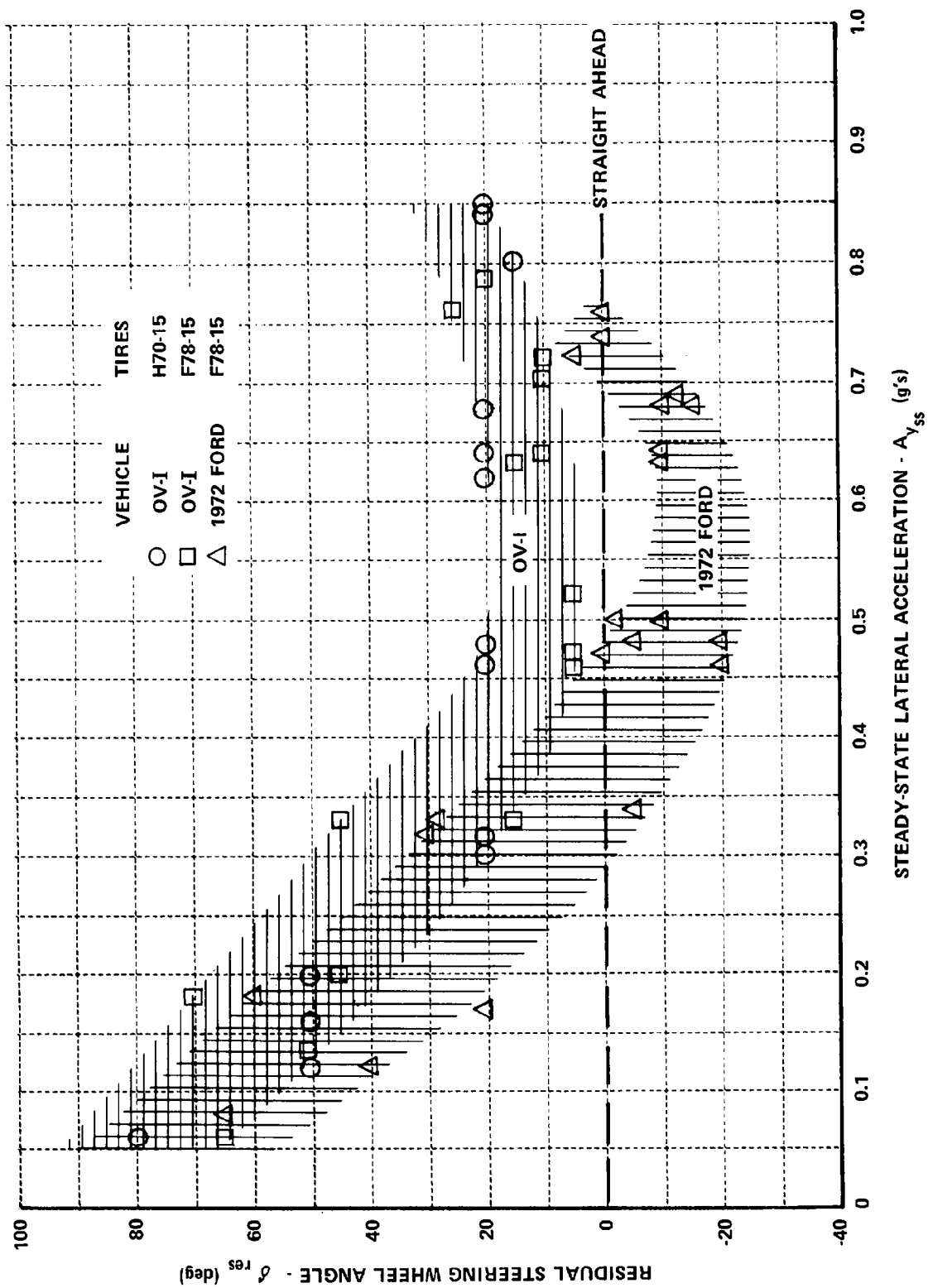


Figure A-13 COMPARISON OF STEERING RETURNABILITY

variations between the steering systems of the two basic vehicles.

To provide a comparison of the directional responsiveness of the OV-I and 1972 Ford near the limit of performance (maximum lateral acceleration), actual data are shown in Figure A-14. These three data records correspond to approximately the same test condition^{*} for the steady-state portion of the test run. Note the similarity in the speed and lateral acceleration time histories for each of the vehicle/tire combinations. The differences in the associated steering input magnitudes reflect the variation in steady-state steering characteristics (varying degrees of understeer).

The striking similarity in dynamic behavior near the limit of performance that is illustrated by Figure A-14 is a strong indication that no major difference in handling behavior exists between the OV-I and corresponding conventional automobile.

A-5 Conclusions

Based on the test results presented and discussed in the previous section, it is concluded that no serious degradation of handling qualities was caused by the front structure modification of the 1972 Ford. However, some differences in steady-state and transient response behavior were observed. In the following, specific results comparing the structurally modified OV-I and conventional automobile are summarized.

- Structural modification of the 1972 Ford Custom (and other small differences) accounted for a weight increase of 560 lbs., and an increase in the proportion of load on the front wheels from 55% to 58% of the total weight. This mass distribution alteration resulted in the OV-I becoming more understeer than the conventional automobile (see Figures A-5 and A-6). However,

*

Configuration No. 6 in Table III, i. e., 40 MPH on a 150 ft. radius path giving 0.75 g lateral acceleration.

since American automobiles tend to be markedly understeer, this change does not produce an unusual or disconcerting change in the basic steering characteristics. Furthermore, it is possible that the understeer difference is sufficiently small so that minor changes in the suspension system or simply varying the tire pressures could significantly reduce or eliminate the difference.

- Transient response to a step steer input corresponding to a particular steady-state lateral acceleration was not significantly influenced by the structural modification (see Figures A-9 and A-10).

- Differences in free response behavior from a steady-state cornering condition were observed. In particular, response time (see Figure A-11) and self-centering tendency (see Figure A-13) were affected, apparently by increased effective steering system damping associated with the OV-I vehicle.

- In the range of lateral acceleration corresponding to "normal" driving (less than 0.4 g), differences in handling characteristics between the OV-I and conventional vehicles are virtually undetectable. For higher lateral accelerations necessary for evasive maneuvers (near the limit of performance), observable differences exist but these are either of a minor nature or do not necessarily represent handling quality degradation. In any event, the variations are not of such a magnitude to indicate that structural modification of the nature incorporated in the OV-I will produce serious or insurmountable handling problems.

APPENDIX B

Crash Test Results

Contained in this Appendix are the data generated during the five crash tests performed during this phase of the program. The vehicles along with test number designations are listed in Table B-1, where it should be noted that impact speeds varied between 40 MPH and 58.7 MPH. Both flat and pole surface barriers were utilized as impact obstacles.

It should be noted that test 84 with the OV-II vehicle was intended to be a higher speed impact (target speed 57.5 ± 2.5 MPH). But, due to malfunctions in the control and abort systems, the test vehicle impacted the pole obstacle at 40.0 MPH. After the test, the vehicle was repaired (designated OV-IIR) and then impacted into the pole barrier at 56.8 MPH, within the speed window. The repaired vehicle was structurally identical to the original OV-II vehicle, except no effort was made to replace operational components such as radiator, battery, etc. Also, no dummies were installed in the vehicle for test 91 and, consequently, the vehicle weight was somewhat less than that for test 84 (original OV-II).

Instrumentation for these vehicles was generally equivalent for all tests. A longitudinal axis accelerometer was embedded in the engine block (carburetor throat location). Triaxial accelerometers were mounted at the four corner and tunnel locations in the passenger compartment floor.

With the exception of test 91, 50th percentile, male Sierra 850 dummies were placed in the two outboard front seat positions of all test vehicles. Triaxial accelerometers were located in the dummy head, chest and pelvis body components. Upper femur forces were measured in some instances. Belt forces were measured in cases where lap and shoulder straps were employed. Complete details on the instrumentation specified for each test can be found in the "Instrumentation Requirements" sheet provided in respective test data sections.

In all instances ground based high speed cameras were used to record the crash event. Camera locations were specified so as to view left, right, upper and lower sides of the vehicle and also dummy movements through side

windows. Copies of all test film have been provided to NHTSA and information relative to camera location and film speeds are contained on the "Test Site Location of Sensors and Cameras" included with the subsequent test data sections for each test.

Table B-1
SUMMARY OF CRASH TESTS

TEST NO.	VEHICLE (WEIGHT-lbs)	IMPACT SPEED (MPH)	OBSTACLE	RESTRAINT SYSTEM	REFER TO PAGES
71	1972 FORD (4290)	57.8	POLE BARRIER	CONVENTIONAL LAP & SHOULDER	B-5
77	OV-I (4790)	58.7	FLAT BARRIER	AIR BAG (EATON)	B-35
84	OV-II (4640)	40.0*	POLE BARRIER	AIR BAG (OLIN)	B-62
90	OV-III (4560)	49.9	FLAT BARRIER	AIR BAG (OLIN)	B-93
91	OV-IIR (4020)	56.8	POLE BARRIER	NONE	B-122

* VEHICLE UNDER TESTED AS A RESULT OF SYSTEM MALFUNCTION

Test No. 71 Data

The following items are included:

1. Instrumentation requirements
2. Test site location of sensors and cameras
3. Before and after test photographs
4. Engine acceleration data
5. Passenger compartment acceleration data
6. Pole barrier loads
7. Driver data
8. Right front passenger data

INSTRUMENTATION REQUIREMENTS

FACILITY TEST NO. 134 PROGRAM TEST NO. 71
 PROGRAM: Crashworthiness II
 TEST DESCRIPTION: Base Line Test, Pole Obstacle
 VEHICLE TYPE: 1972 Ford

VEHICLE DESIGNATION	COM- PONENT	COMPARTMENT			ENGINE	DUMMIES (1, 2)			RESTRAINT *			RECORDER	OTHER
		TUNNEL	(1) (2) CORNERS (4) (3)	REAR DECK		HEAD	CHEST	PELVIS	LAP	SHOULDER	OTHER		
1972 FORD	X	A	1A, 2A, 3A, 4A		A	A	A	A	1, 2 L	1, 2L			POLE X-comp. only
	Y	A	1A, 2A, 3A, 4A			A	A	A					
	Z	A	1A, 2A, 3A, 4A			A	A	A					
	X												
	Y												
	Z												

LEGEND:

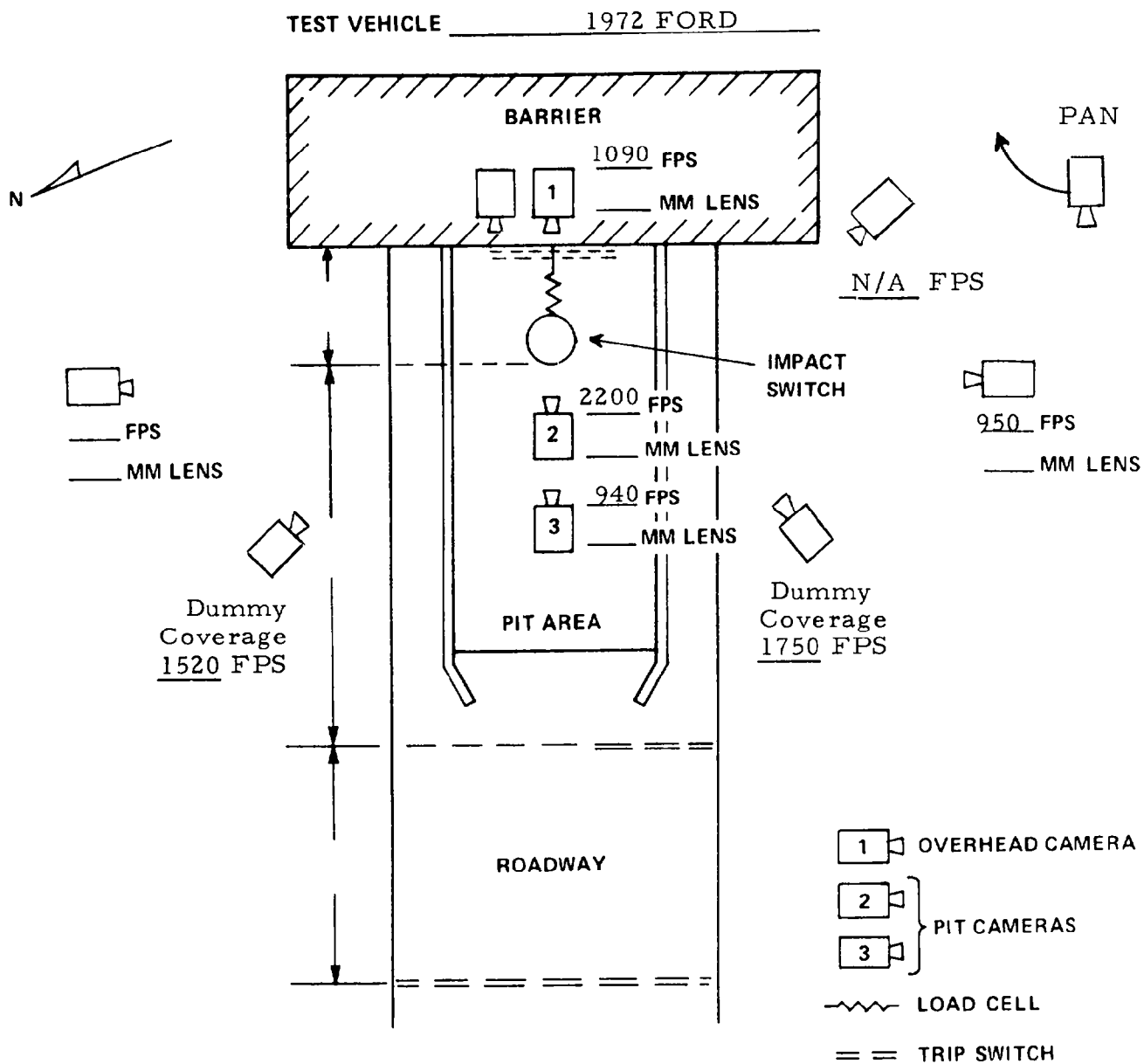
A - ACCELEROMETER
 V - VELOCITY METER
 D - DISPLACEMENT METER
 L - LOAD CELL

MISCELLANEOUS

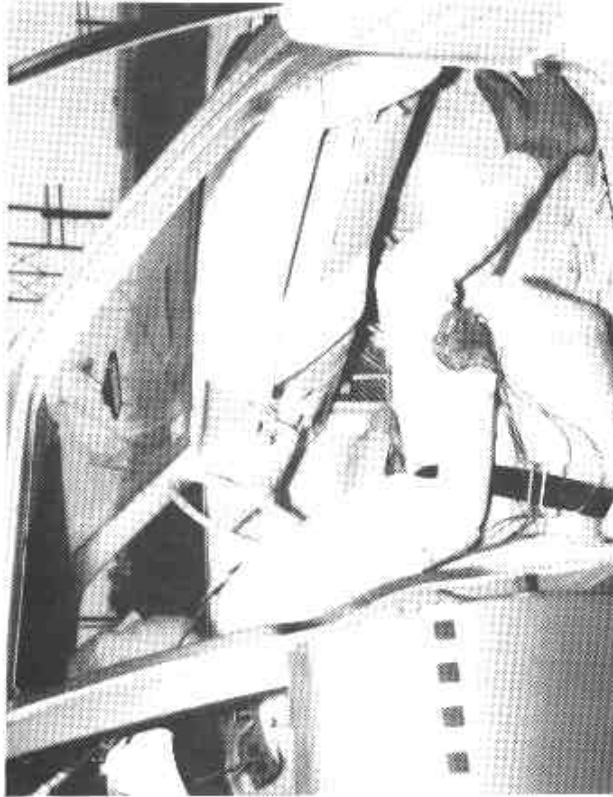
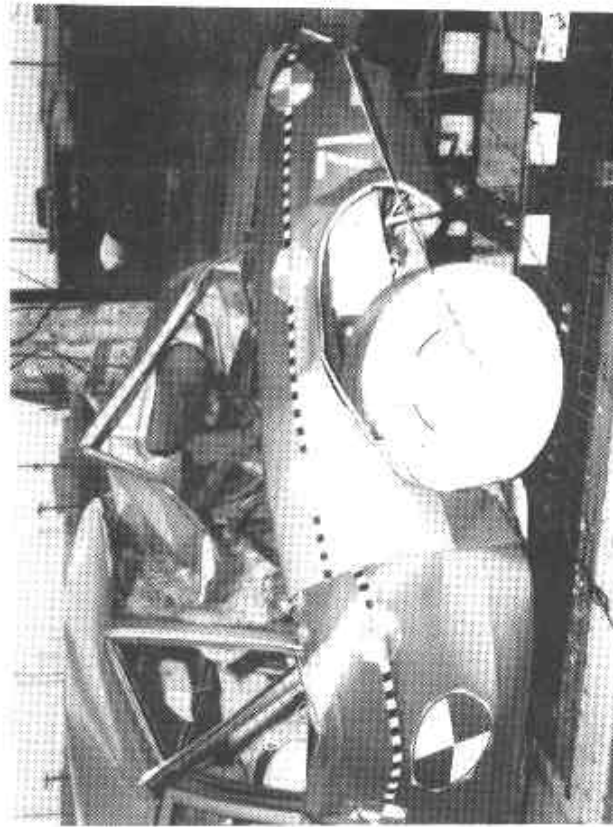
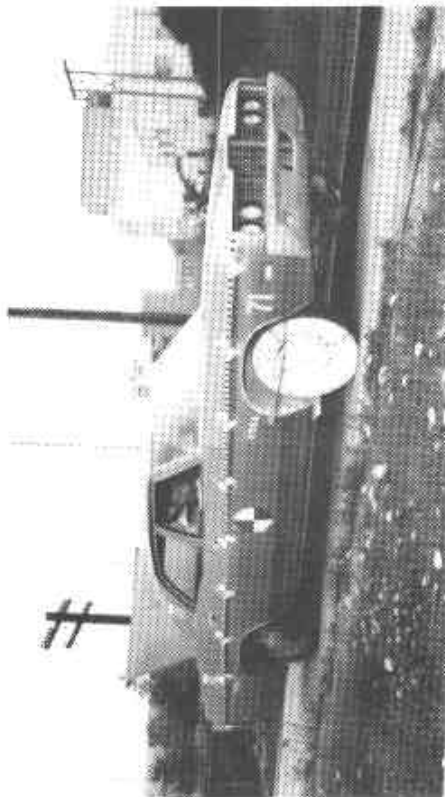
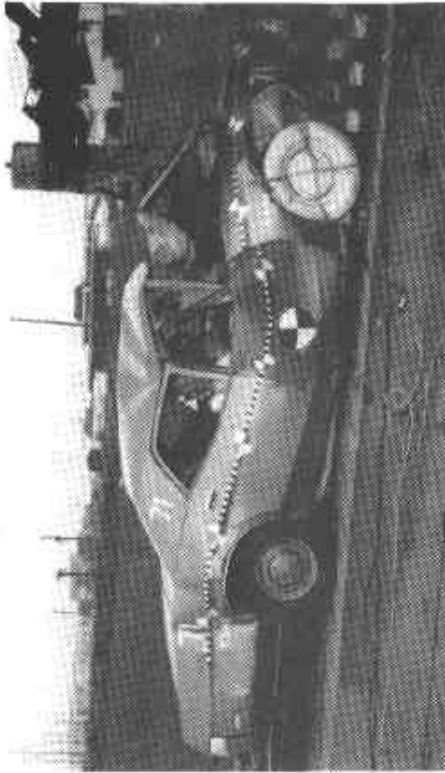
- 1) CONTACT SWITCH/BAR:
- 2) AIR BAG SENSORS:
- 3) POSITION OF CARS:
- 4) SPEED WINDOW: 57.7 ± 2.5 MPH

* Lap and shoulder strap loads

TEST SITE LOCATION OF SENSORS AND CAMERAS



REMARKS:



B-8

YB-2987-V-19

Figure B-1 BEFORE AND AFTER TEST PHOTOGRAPHS OF CONVENTIONAL 1972 FORD (TEST 71)

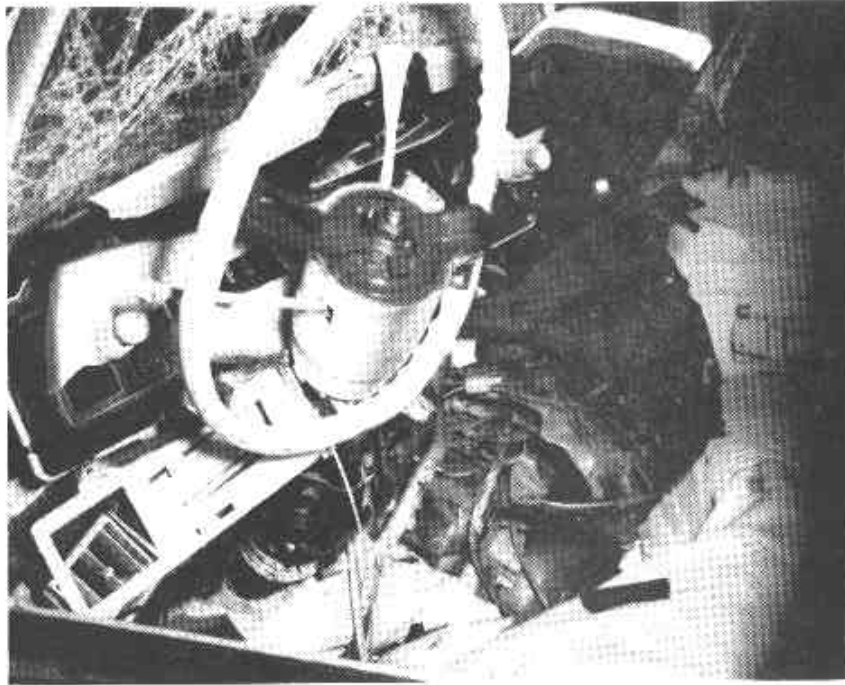


Figure B-2 VEHICLE INTERIOR OF 1972 CONVENTIONAL FORD AFTER 57.8 MPH IMPACT WITH POLE BARRIER (TEST 71)

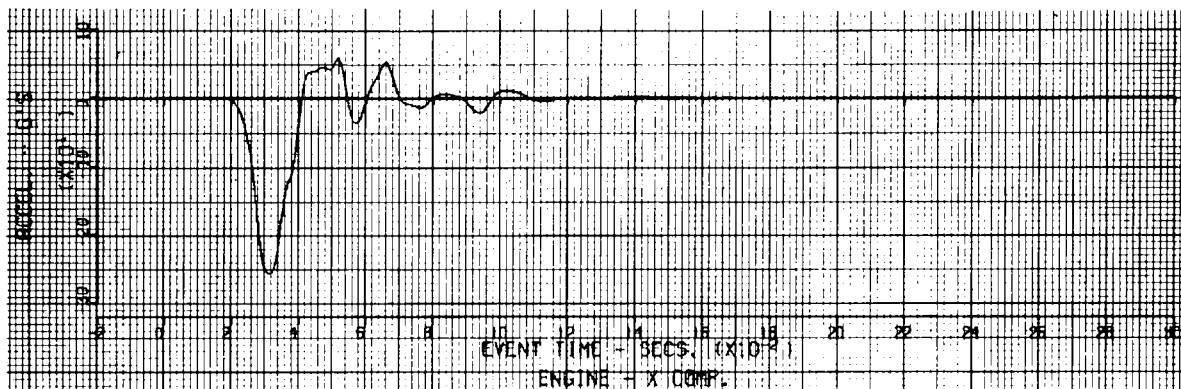


Figure B-3 ENGINE LONGITUDINAL ACCELERATION DATA (TEST 71)

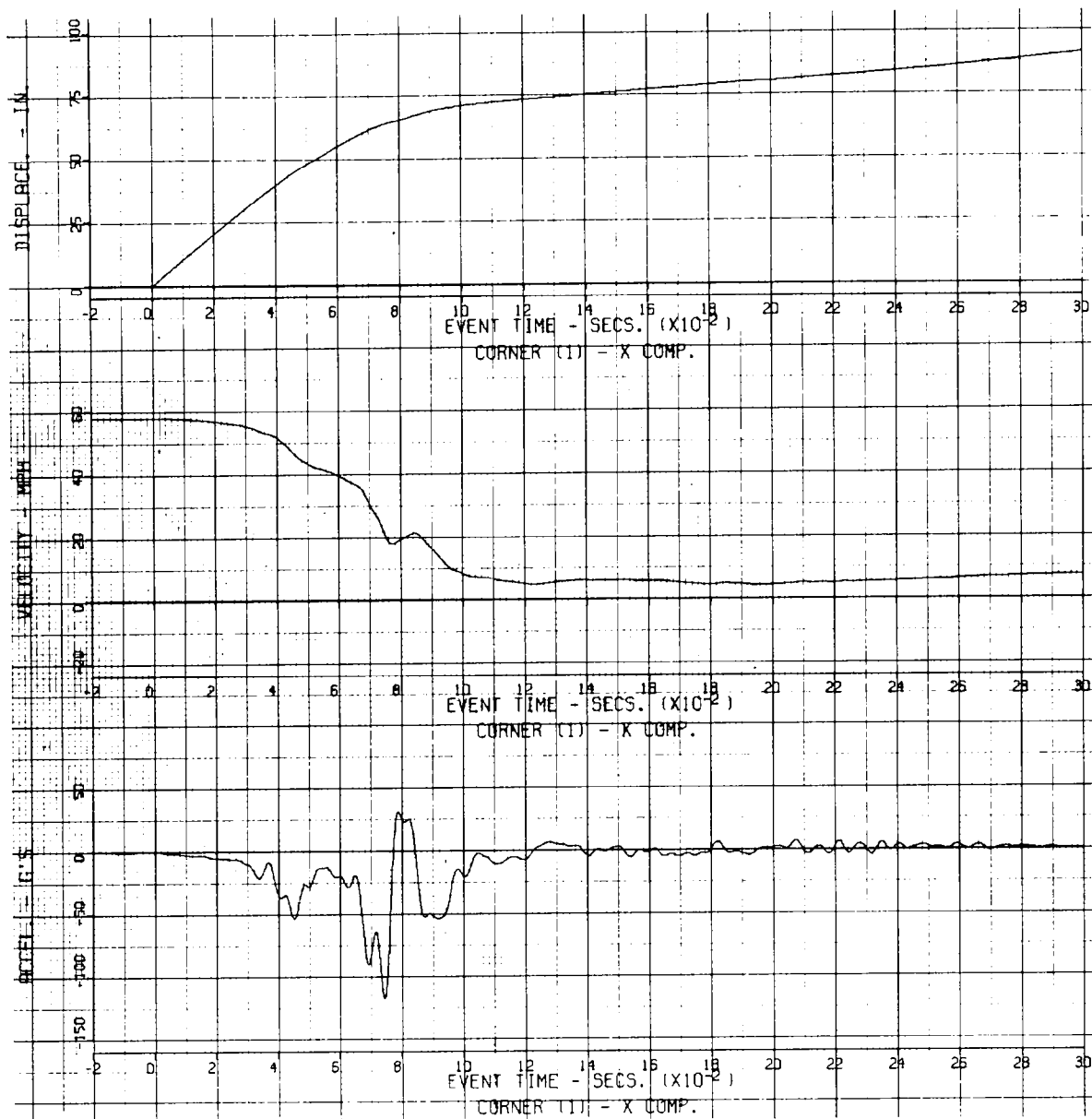


Figure B-4 PASSENGER COMPARTMENT ACCELERATION AND LONGITUDINAL KINEMATIC DATA, LEFT FRONT CORNER LOCATION (TEST 71)

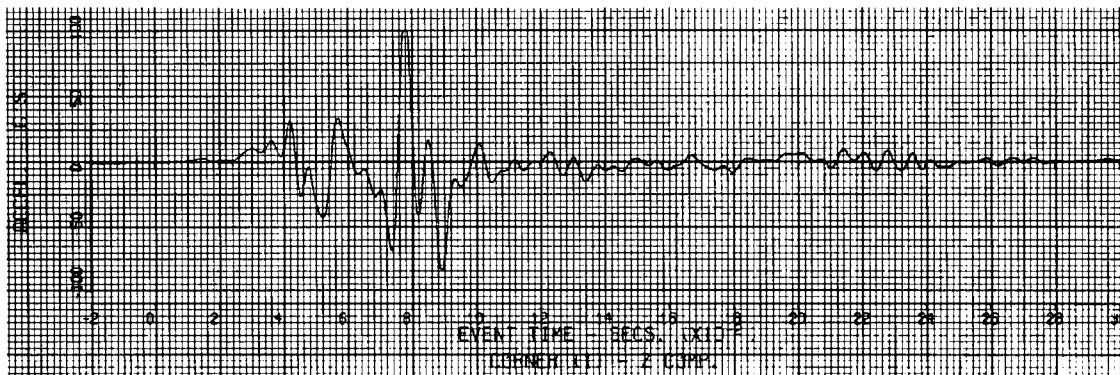
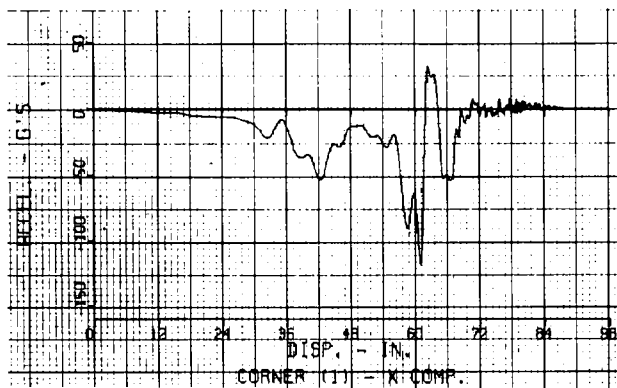


Figure B-4 (cont.) PASSENGER COMPARTMENT ACCELERATION AND LONGITUDINAL KINEMATIC DATA, LEFT FRONT CORNER LOCATION (TEST 71)

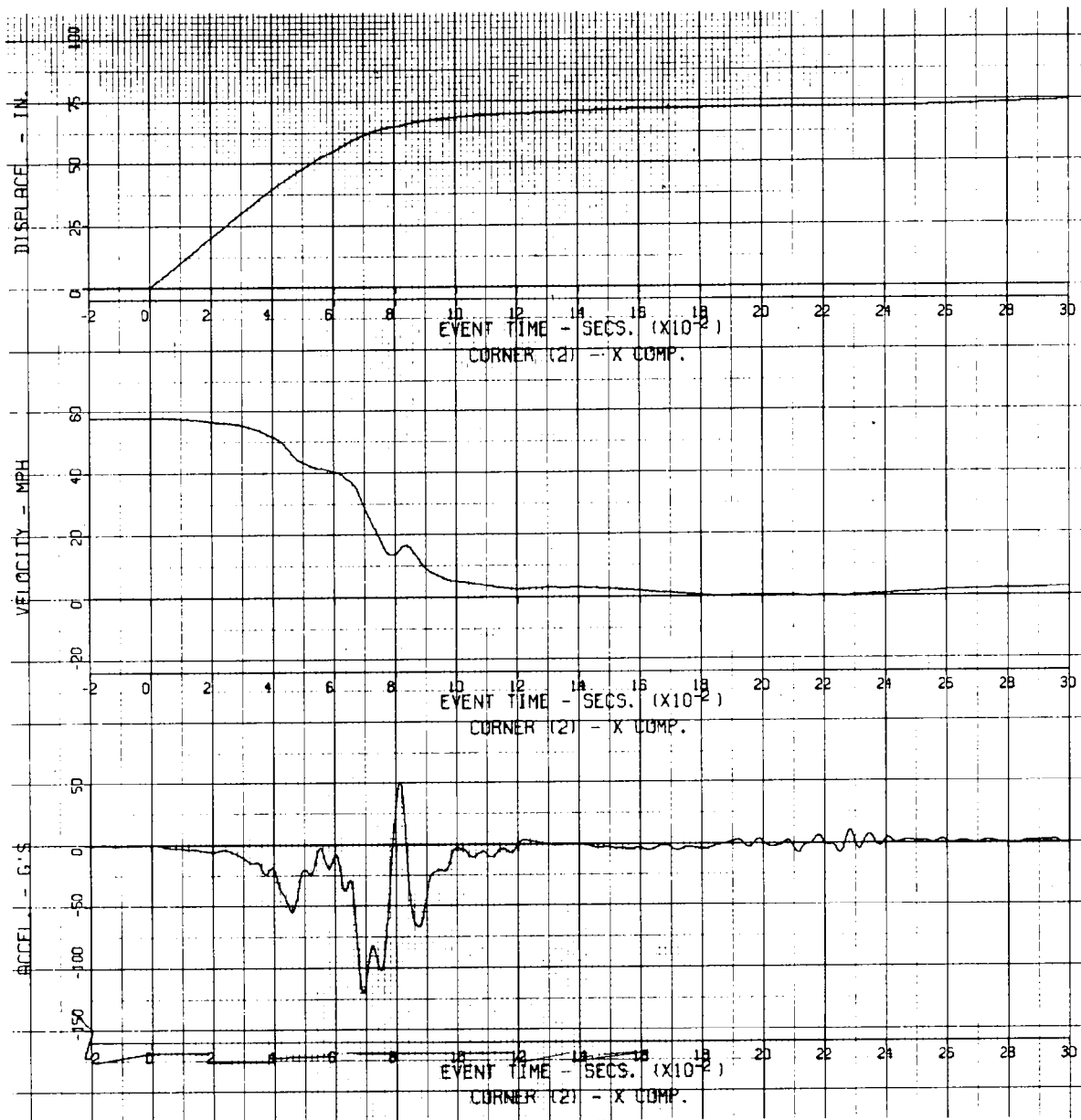


Figure B-5 PASSENGER COMPARTMENT ACCELERATION AND LONGITUDINAL KINEMATIC DATA, RIGHT FRONT CORNER LOCATION (TEST 71)

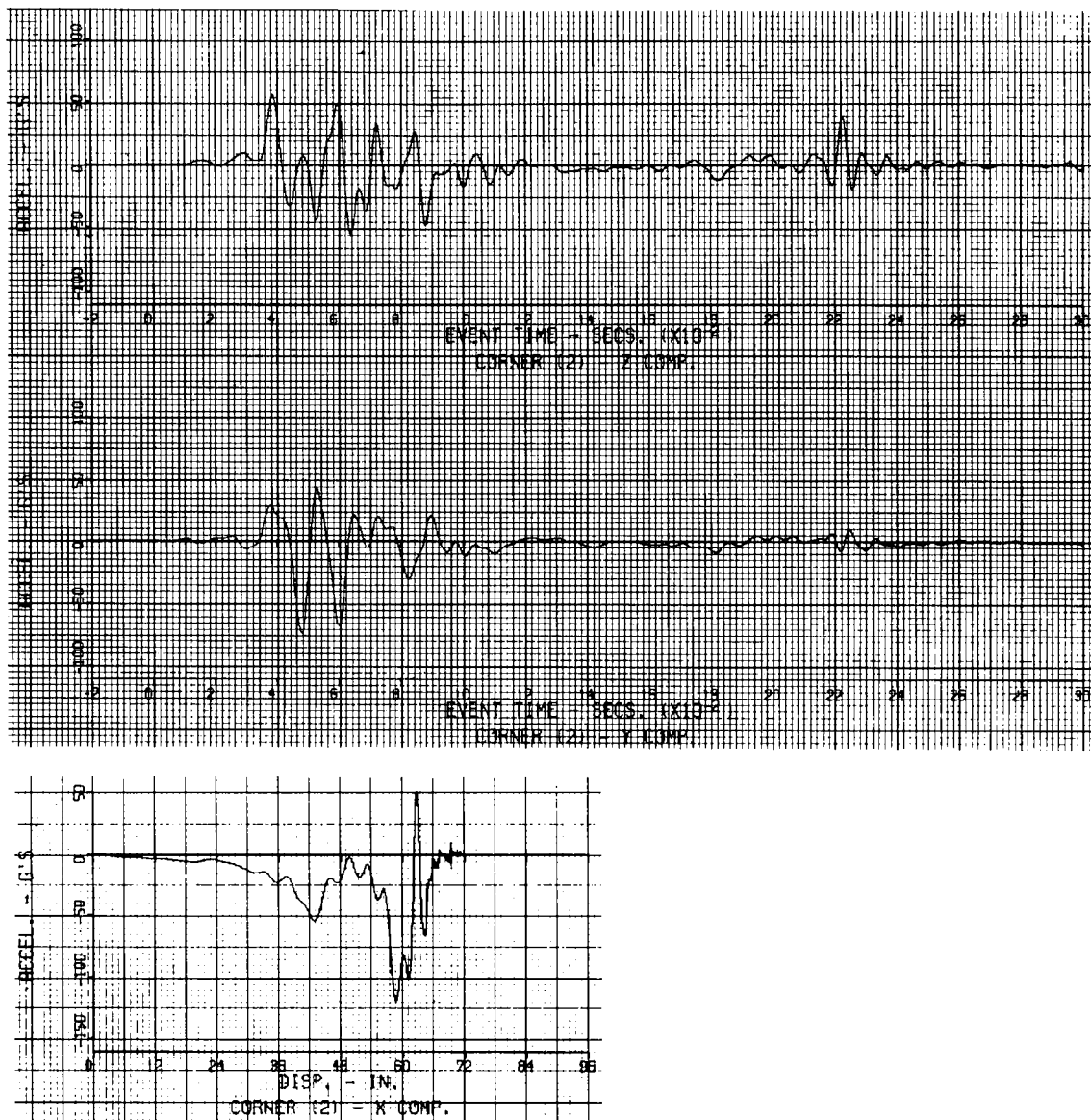


Figure B-5 (cont.) PASSENGER COMPARTMENT ACCELERATION AND LONGITUDINAL KINEMATIC DATA, RIGHT FRONT CORNER LOCATION (TEST 71)

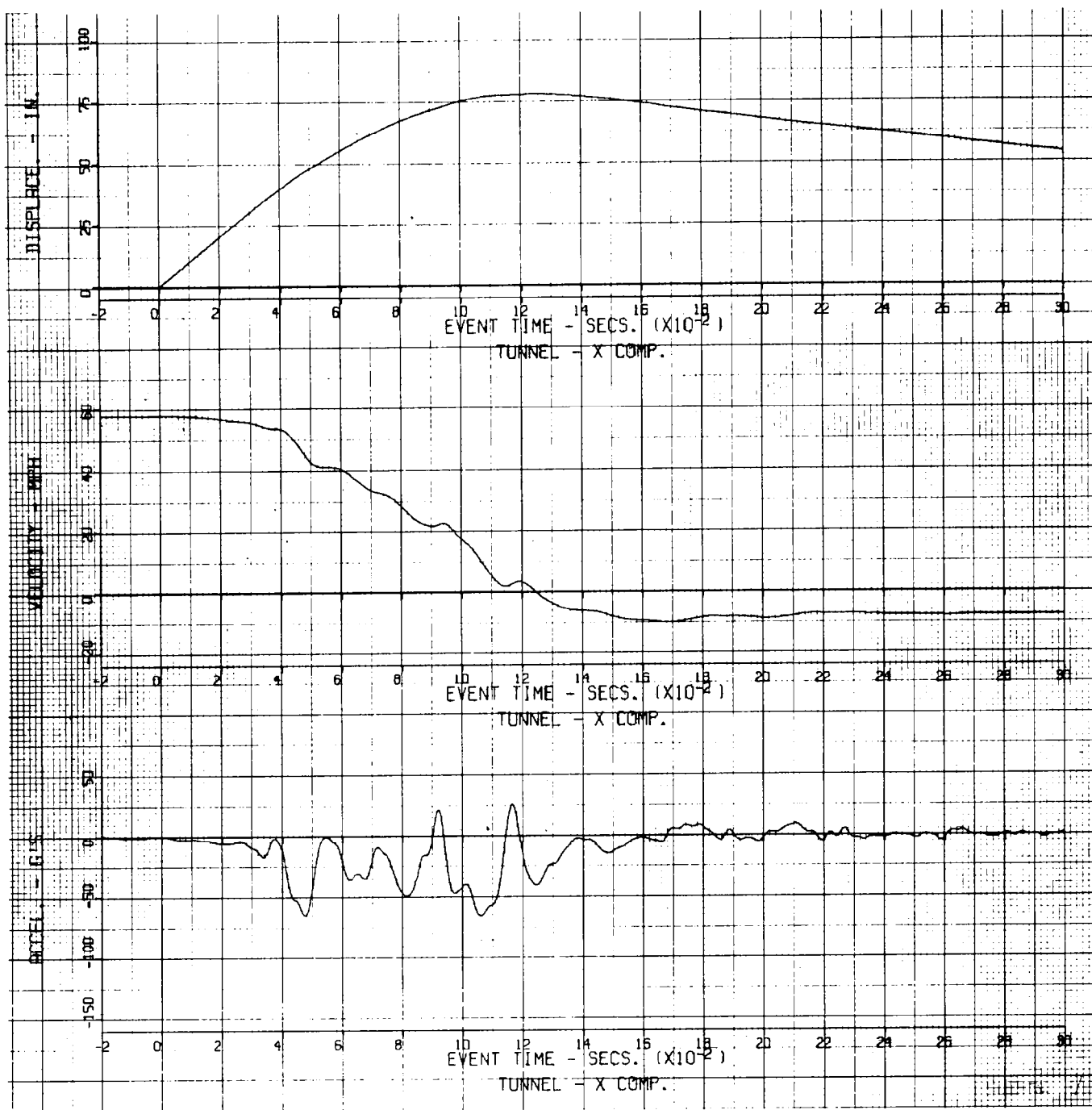


Figure B-6 PASSENGER COMPARTMENT ACCELERATION AND LONGITUDINAL KINEMATIC DATA, TUNNEL LOCATION (TEST 71)

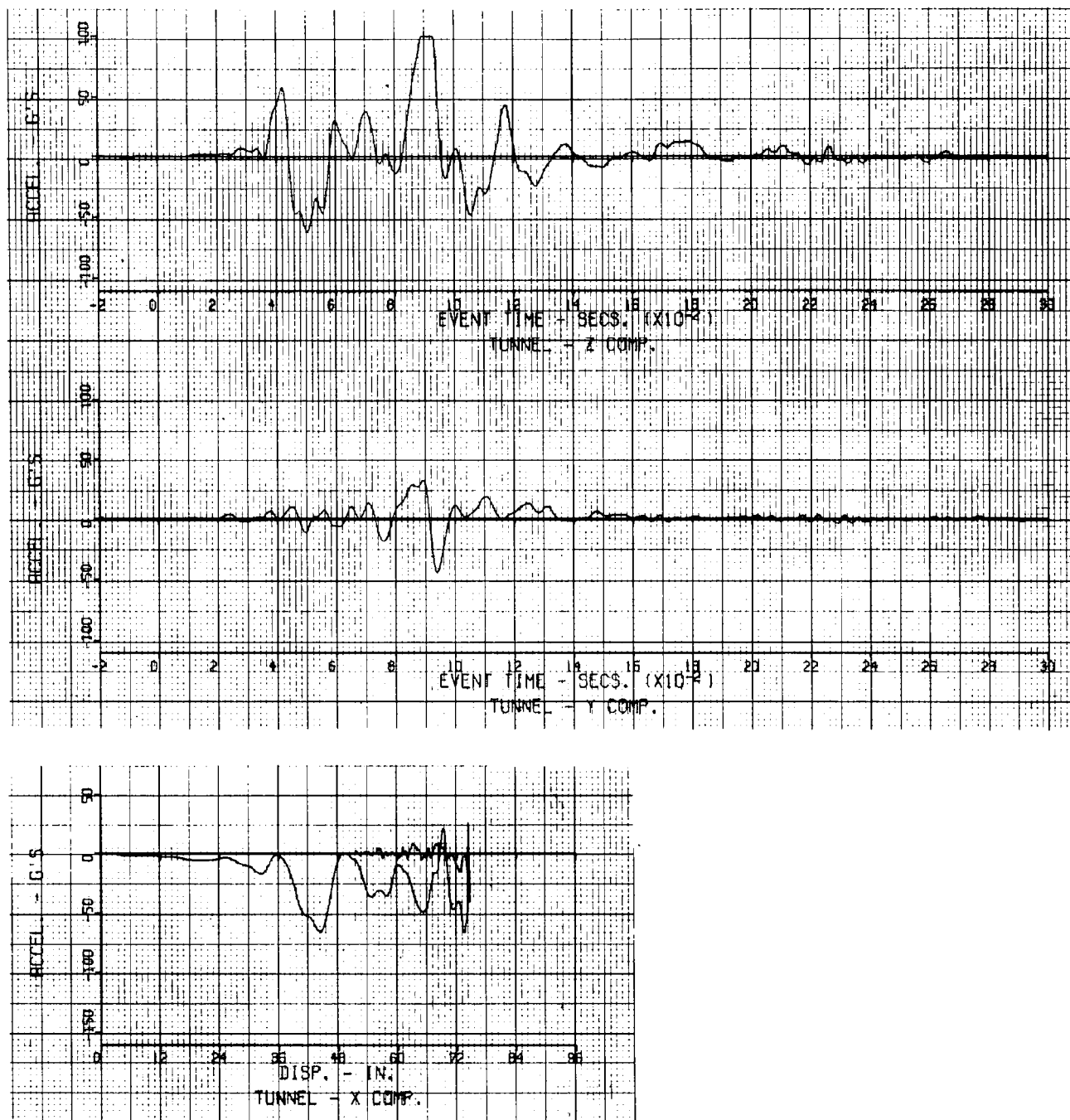


Figure B-6 (cont.) PASSENGER COMPARTMENT ACCELERATION AND LONGITUDINAL KINEMATIC DATA, TUNNEL LOCATION (TEST 71)

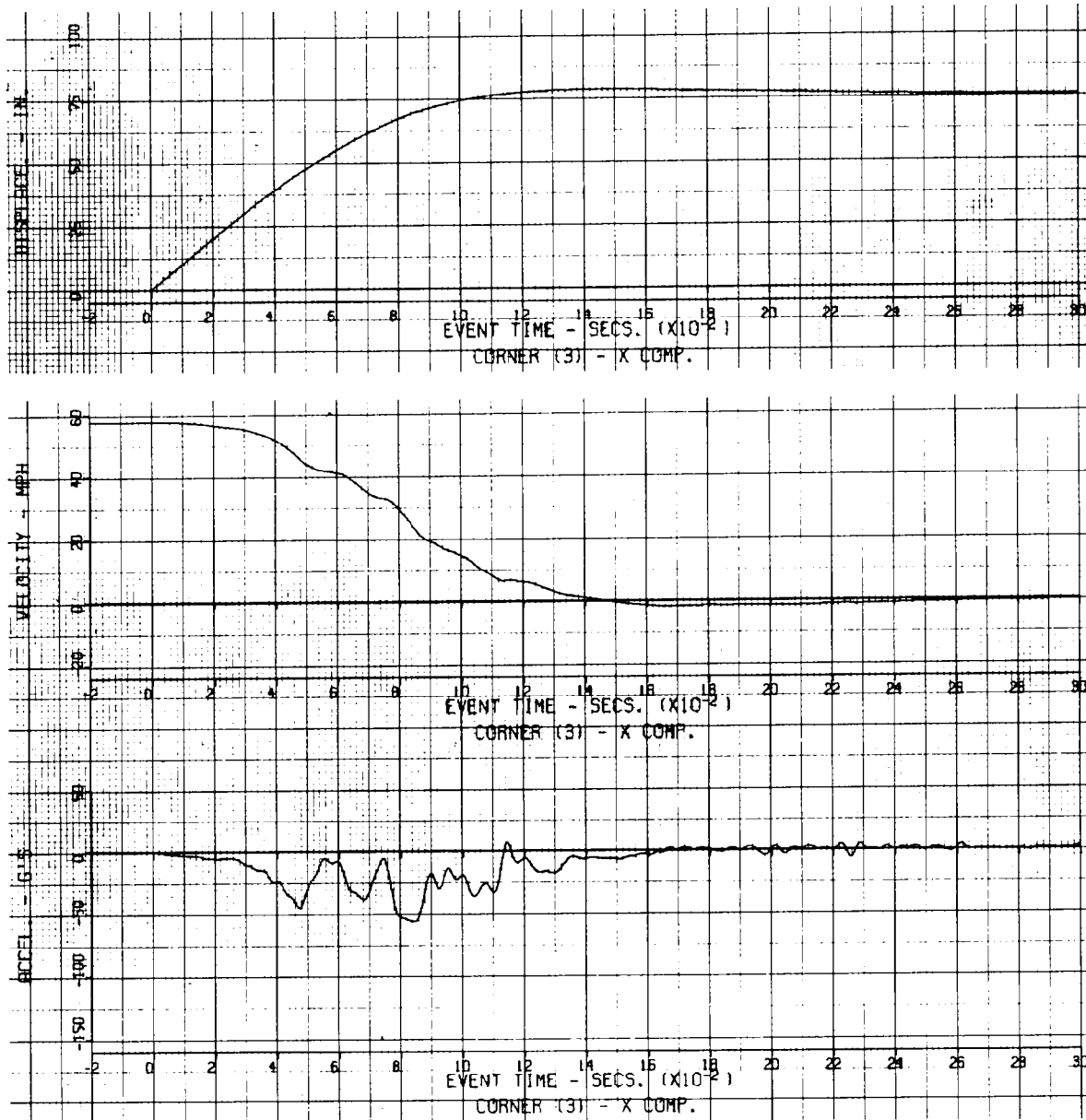


Figure B-7 PASSENGER COMPARTMENT ACCELERATION AND LONGITUDINAL KINEMATIC DATA, RIGHT REAR CORNER (TEST 71)

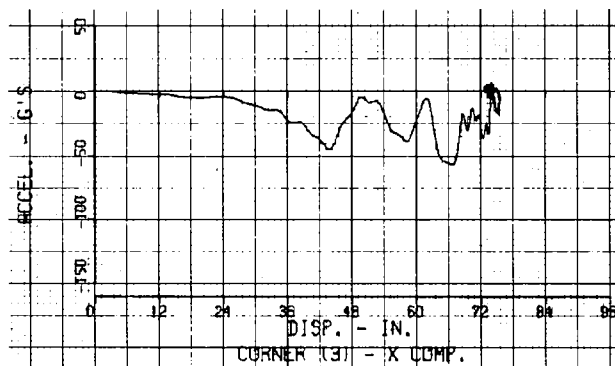
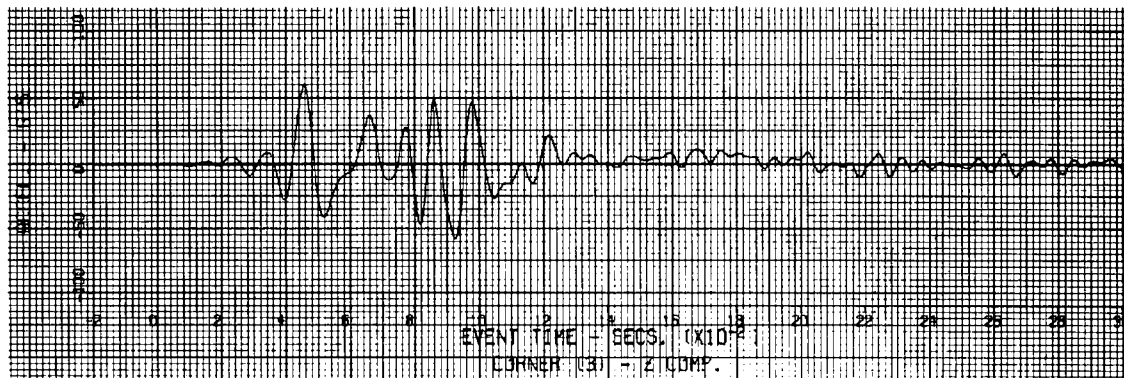
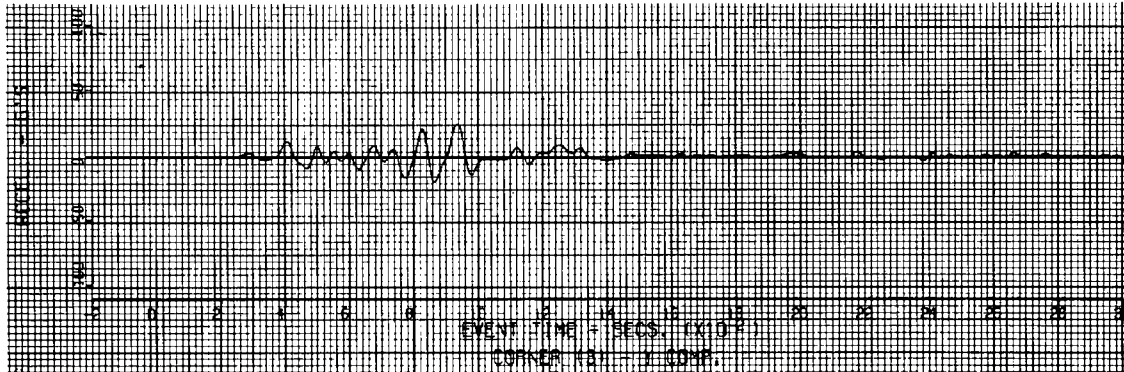


Figure B-7 (cont.) PASSENGER COMPARTMENT ACCELERATION AND LONGITUDINAL KINEMATIC DATA, RIGHT REAR CORNER (TEST 71)

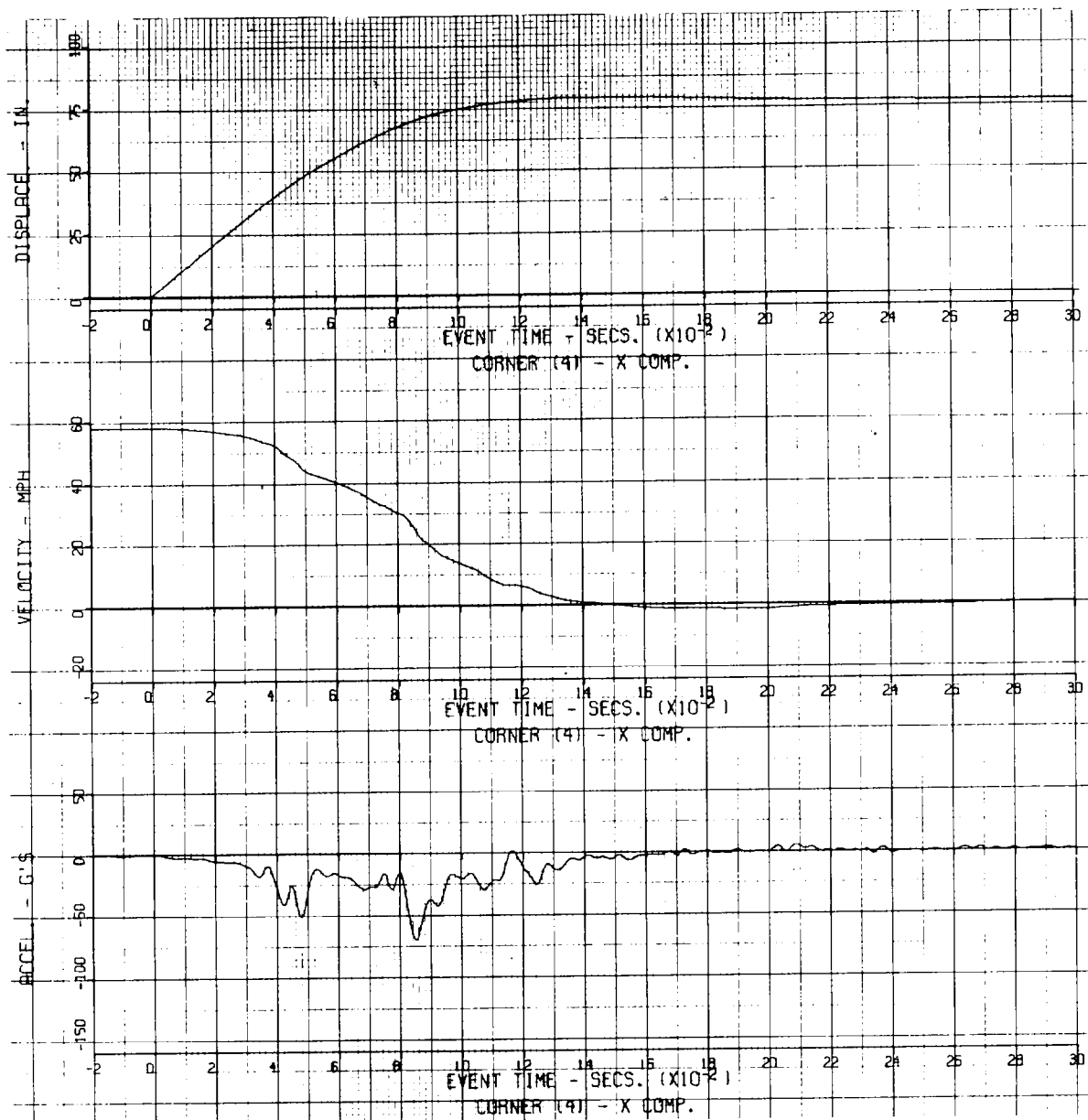


Figure B-8 PASSENGER COMPARTMENT ACCELERATION AND KINEMATIC DATA, LEFT REAR CORNER LOCATION (TEST 71)

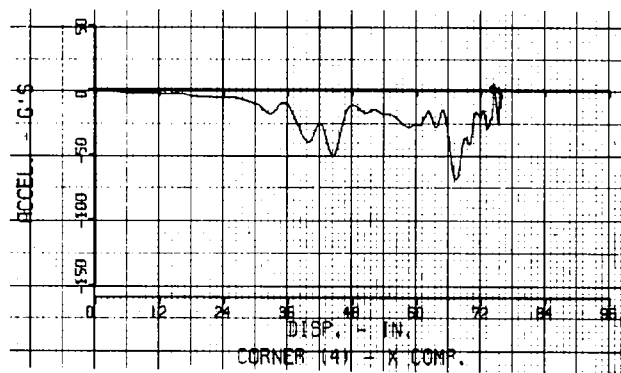
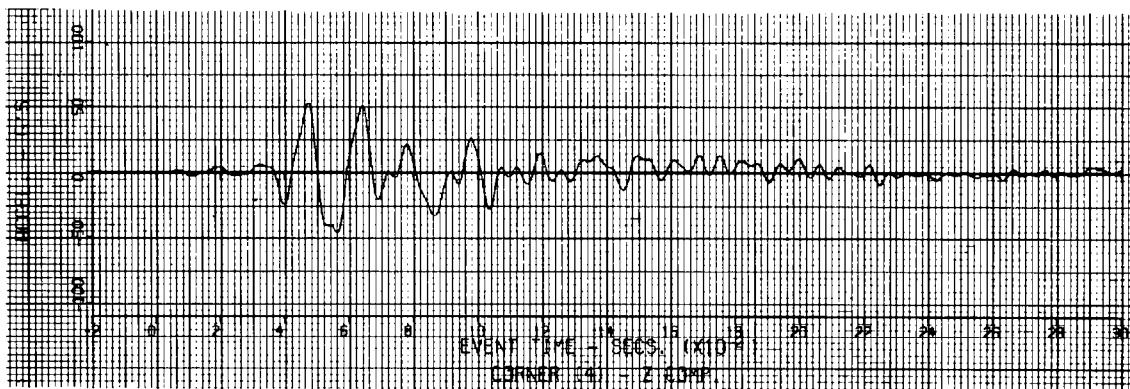
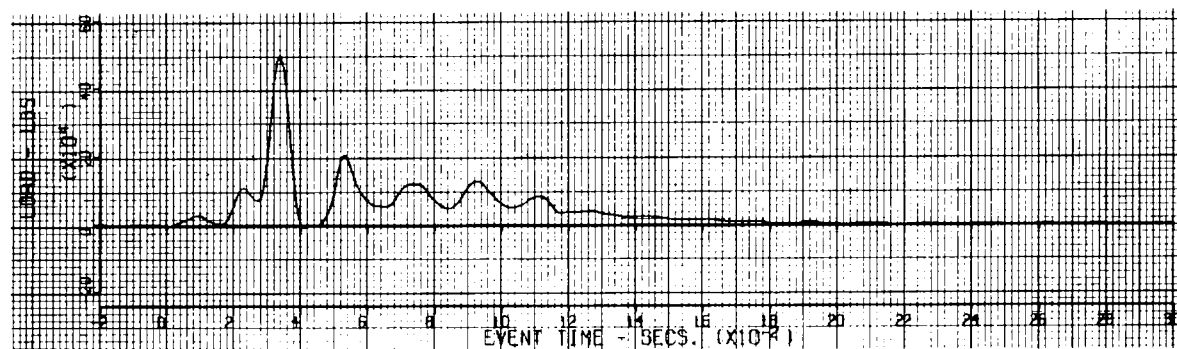
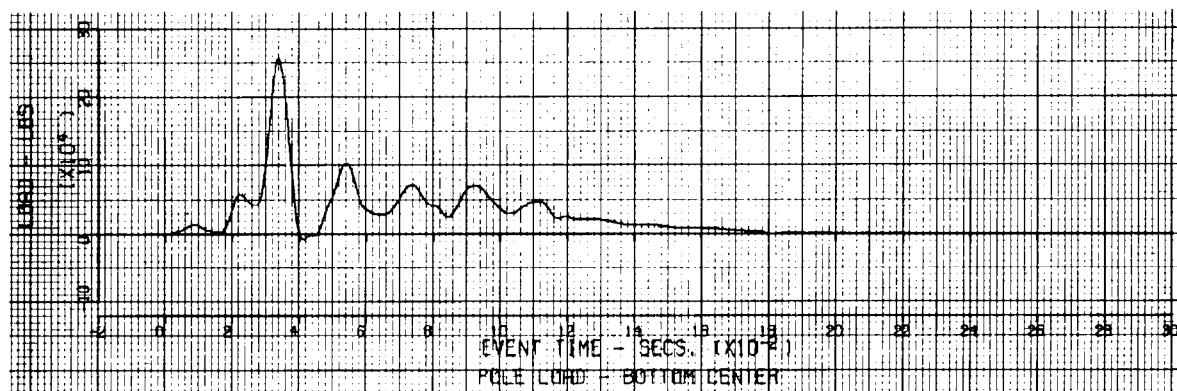
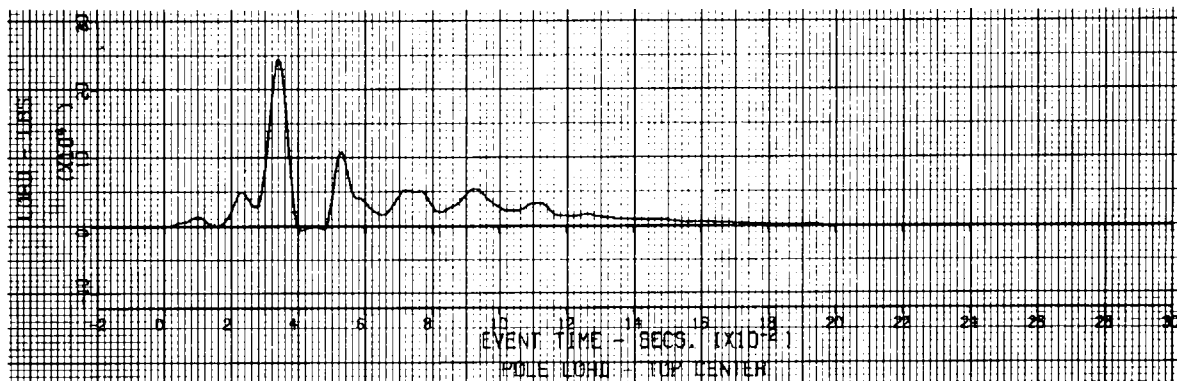


Figure B-8 (cont.) PASSENGER COMPARTMENT ACCELERATIONS AND KINEMATIC DATA, LEFT REAR CORNER LOCATIONS (TEST 71)



SUM OF UPPER AND LOWER LOADS

Figure B-9 LOAD MEASURED ON POLE BARRIER (TEST 71)

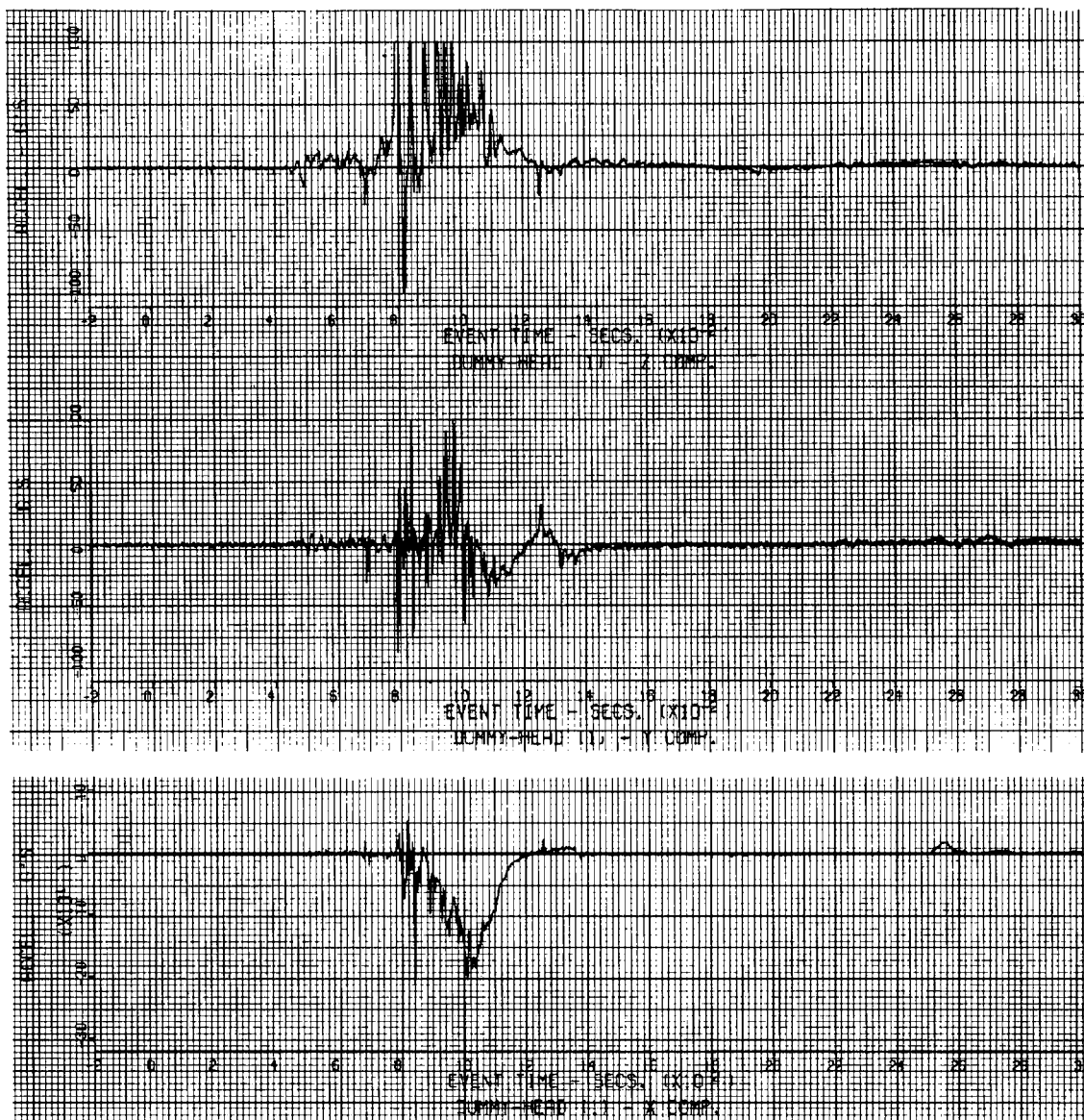


Figure B-10 DRIVER HEAD ACCELERATION DATA (TEST 71)

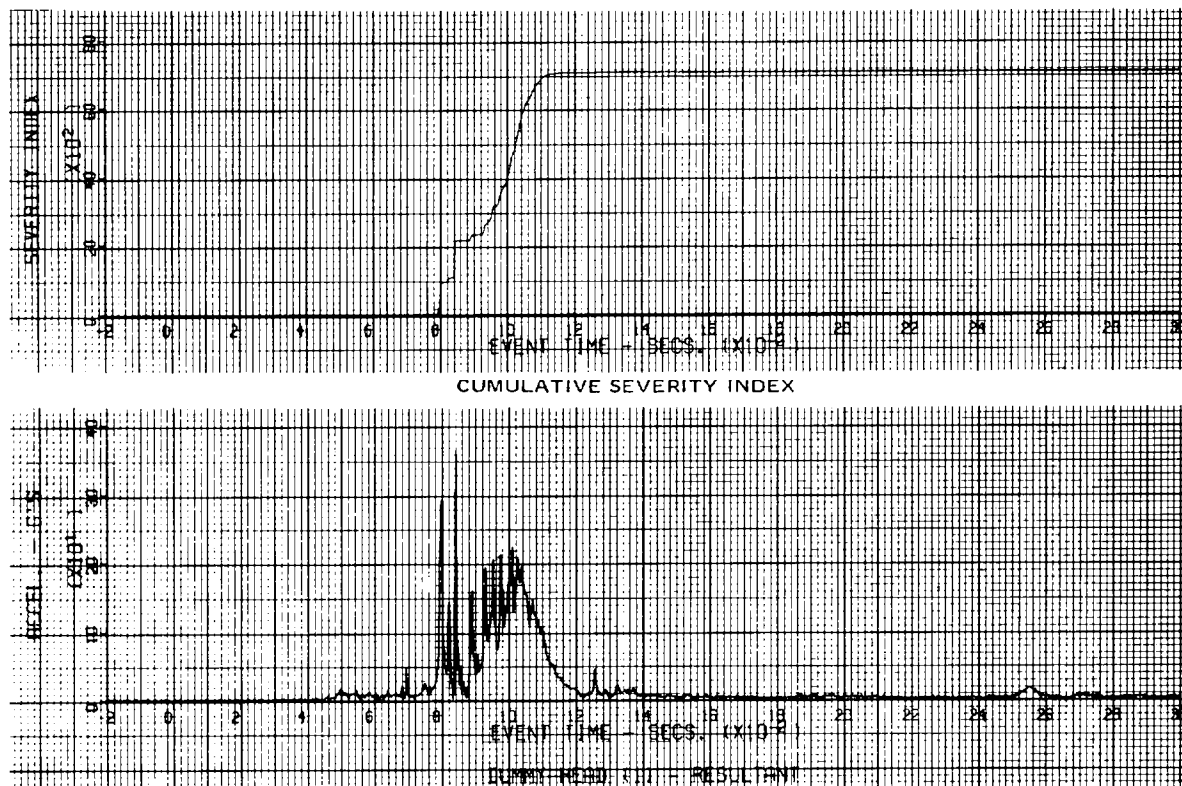


Figure B-10 (cont.) DRIVER HEAD ACCELERATION DATA (TEST 71)

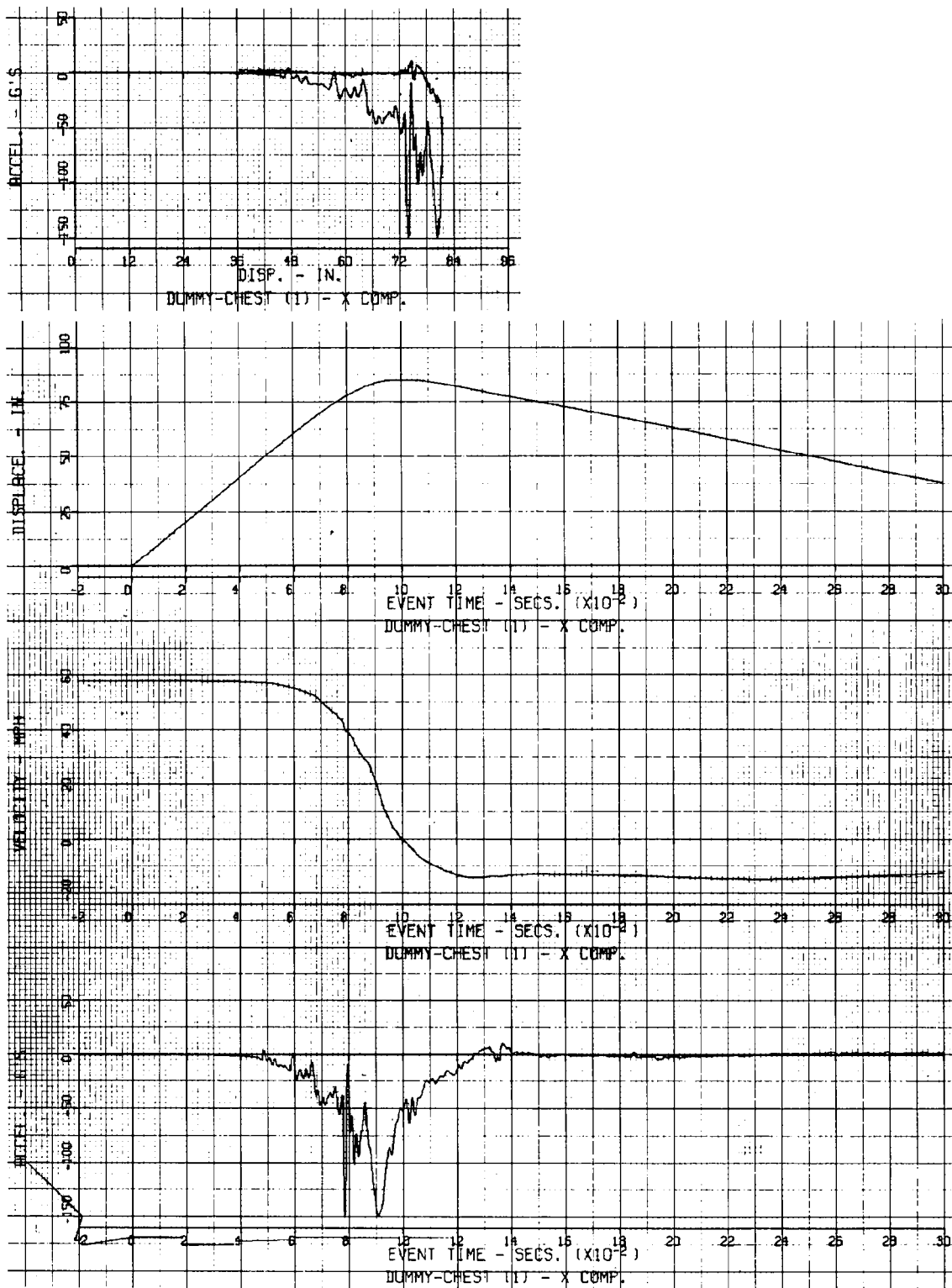


Figure B-11 DRIVER CHEST ACCELERATION AND LONGITUDINAL KINEMATIC DATA (TEST 71)

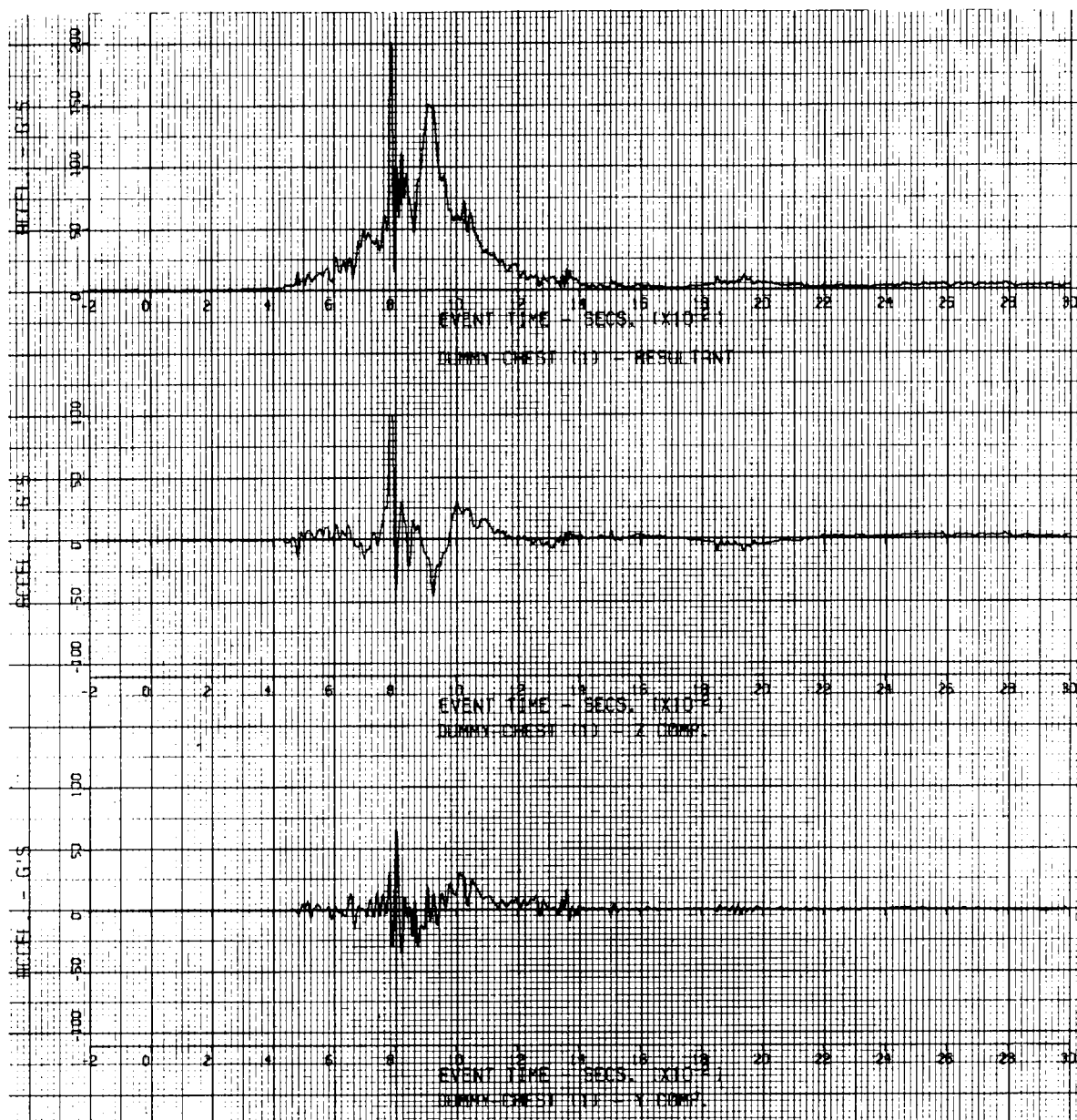


Figure B-11 (cont.) DRIVER CHEST ACCELERATION AND LONGITUDINAL KINEMATIC DATA (TEST 71)

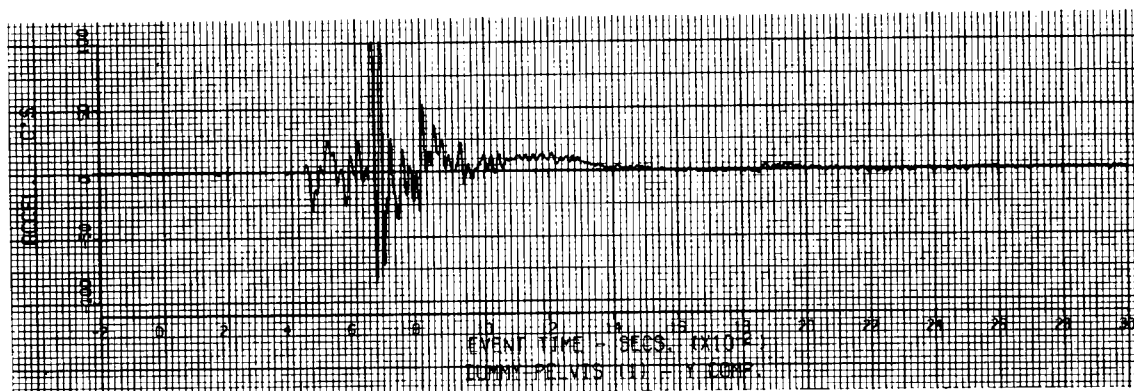
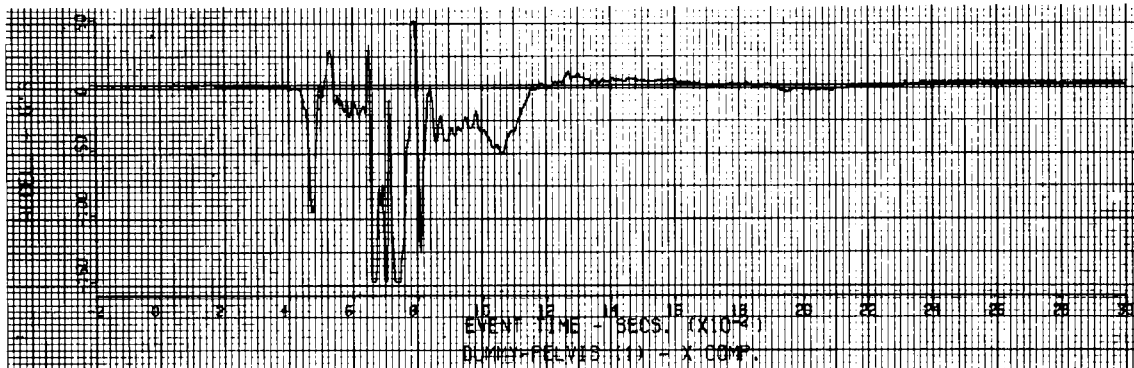


Figure B-12 PELVIS ACCELERATIONS, DRIVER POSITION (TEST 71)

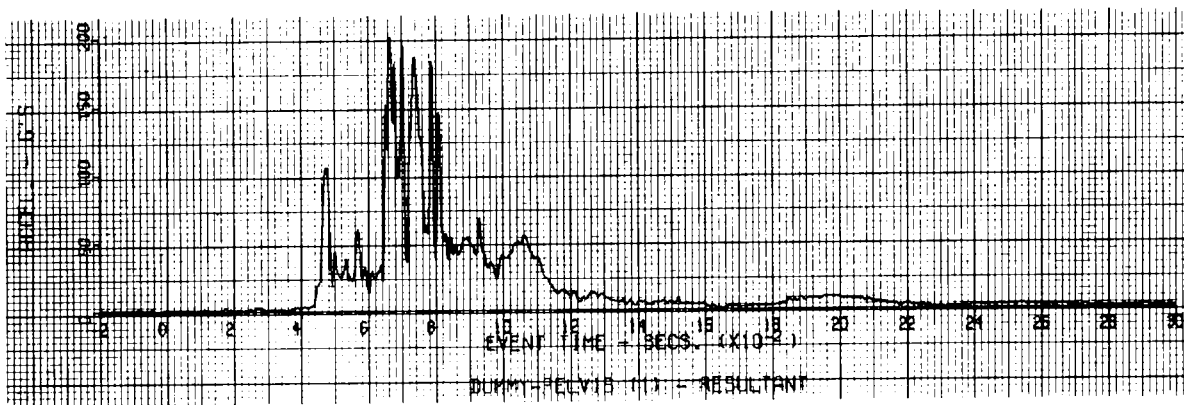
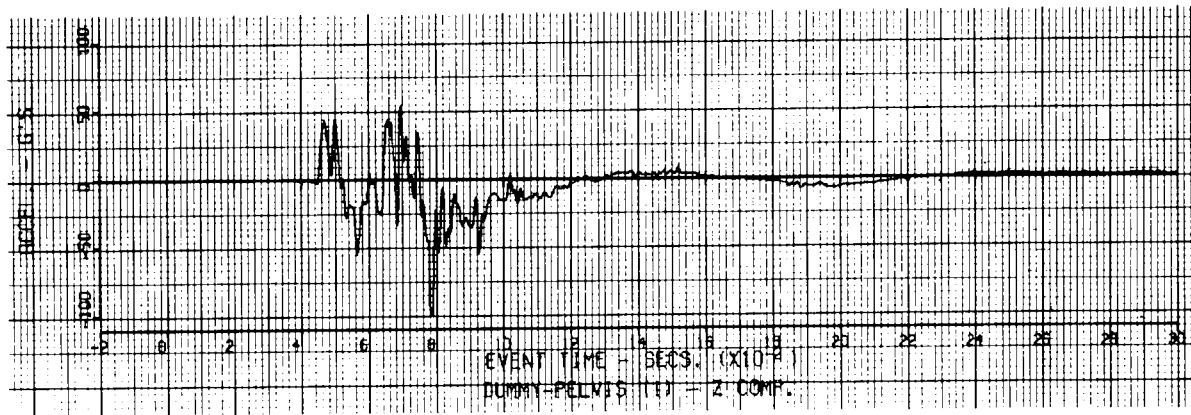


Figure B-12 (cont.) PELVIS ACCELERATIONS, DRIVER POSITION (TEST 71)

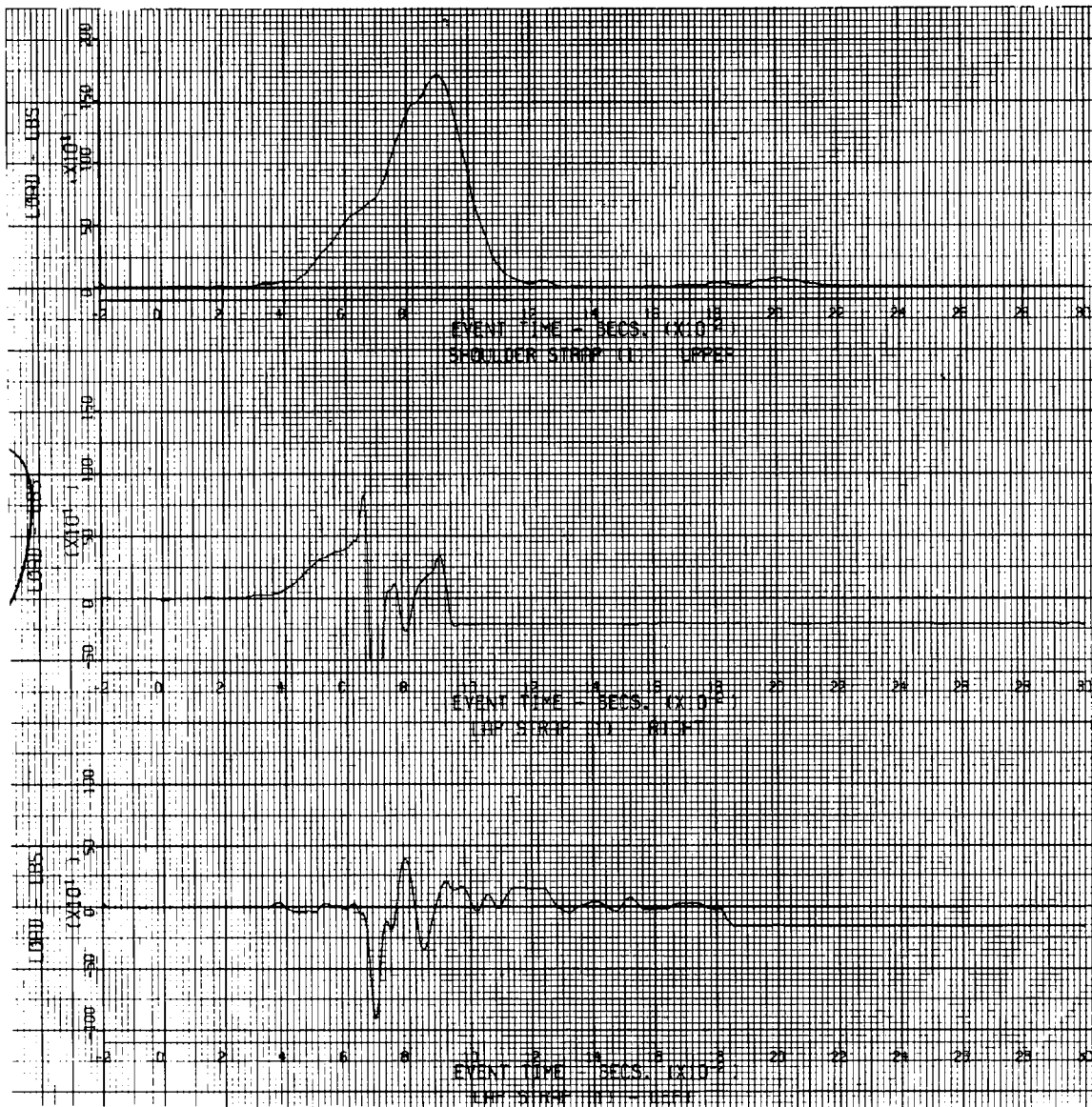


Figure B-13 RESTRAINT SYSTEM LOADS, DRIVER POSITION (TEST 71)

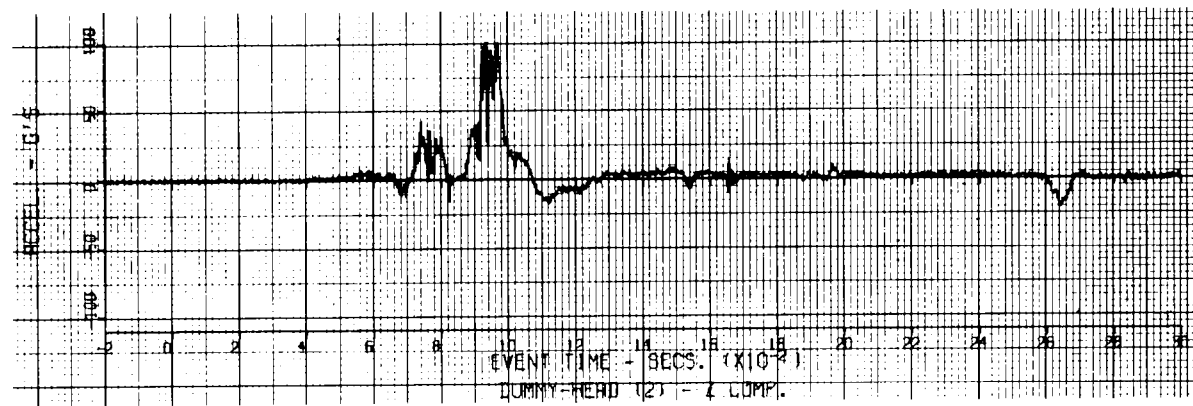
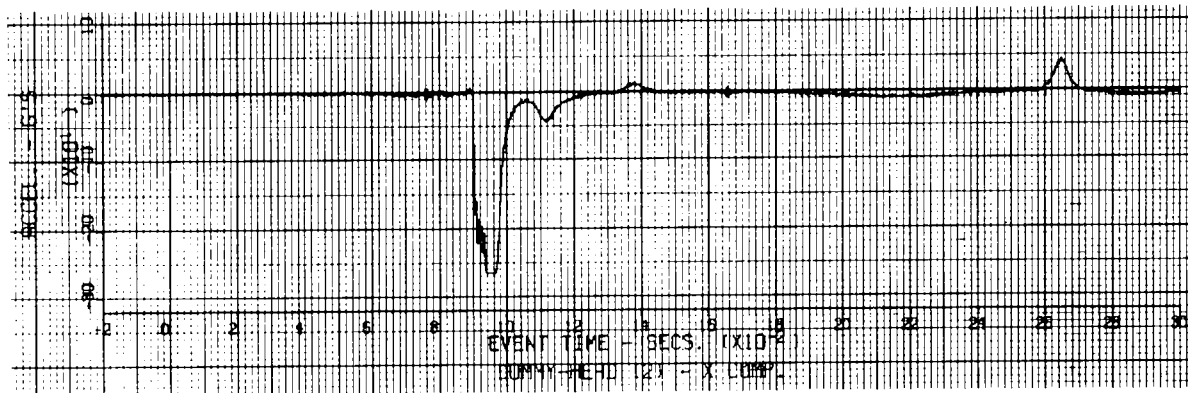


Figure B-14 RIGHT FRONT PASSENGER HEAD ACCELERATION (TEST 71)
(Y-COMPONENT EXCEEDS TRANSDUCER RANGE)

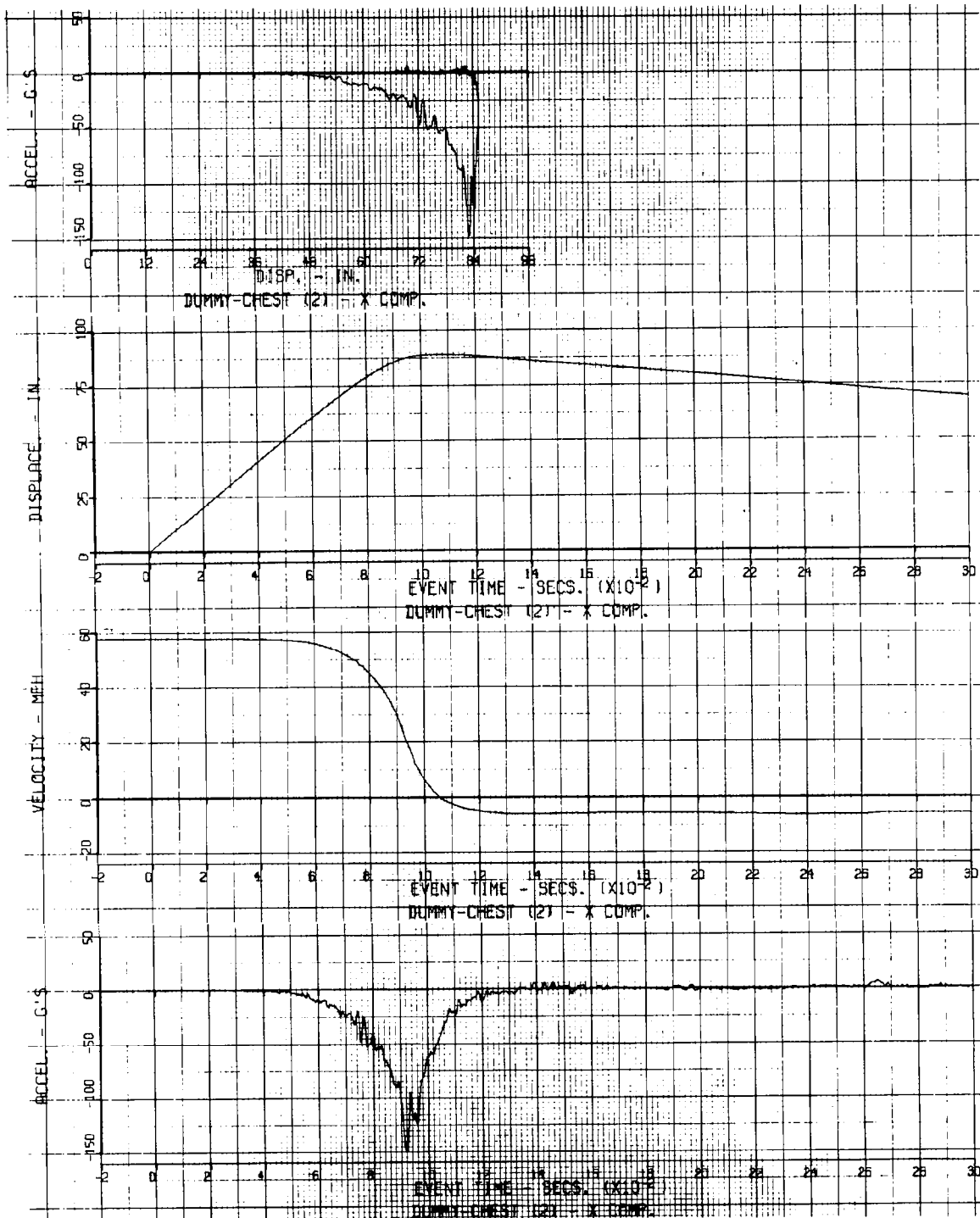


Figure B-15 RIGHT FRONT PASSENGER CHEST ACCELERATION AND LONGITUDINAL KINEMATIC DATA (TEST 71)

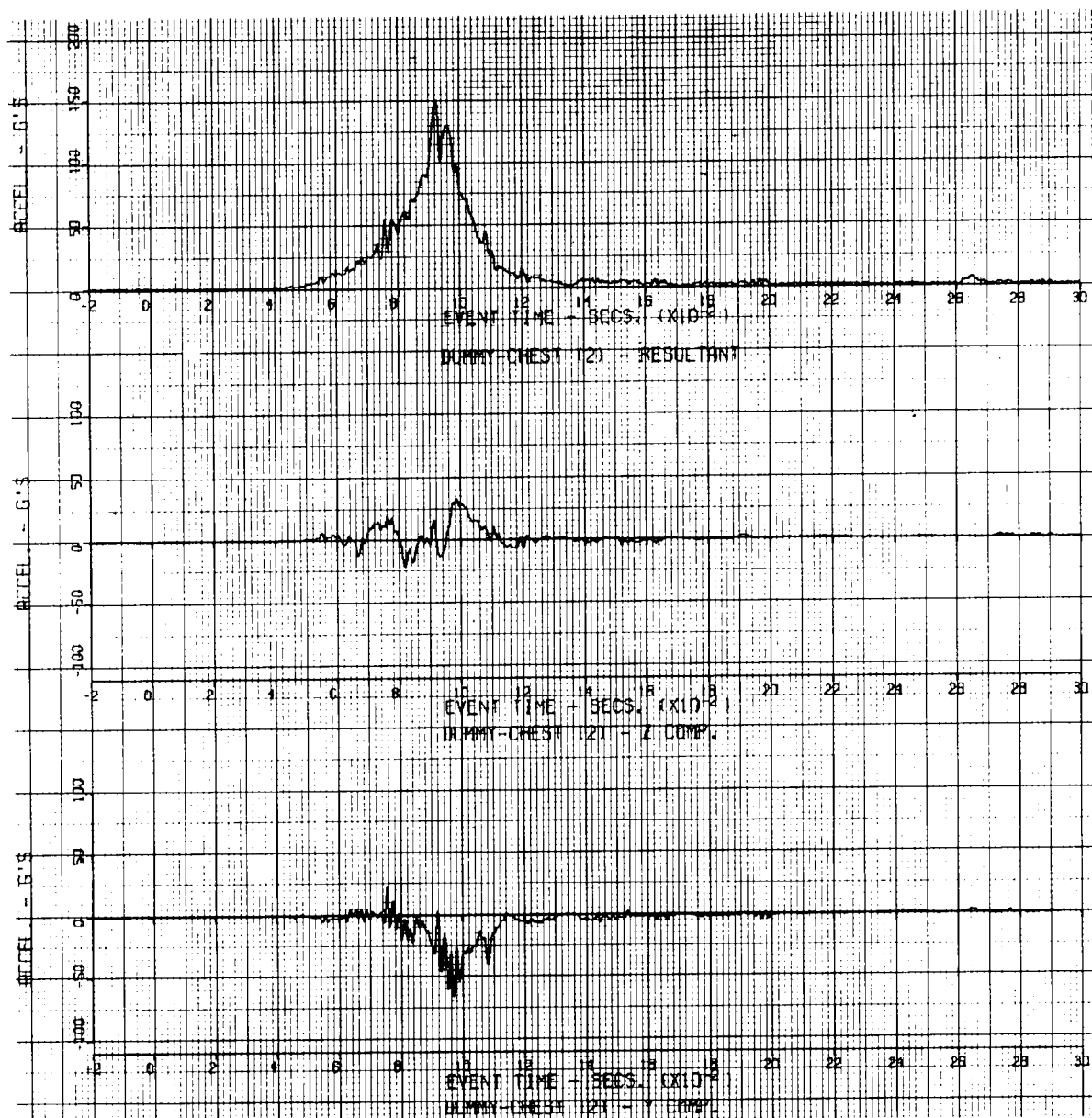


Figure B-15 (cont.) RIGHT FRONT PASSENGER CHEST ACCELERATION AND LONGITUDINAL KINEMATIC DATA (TEST 71)

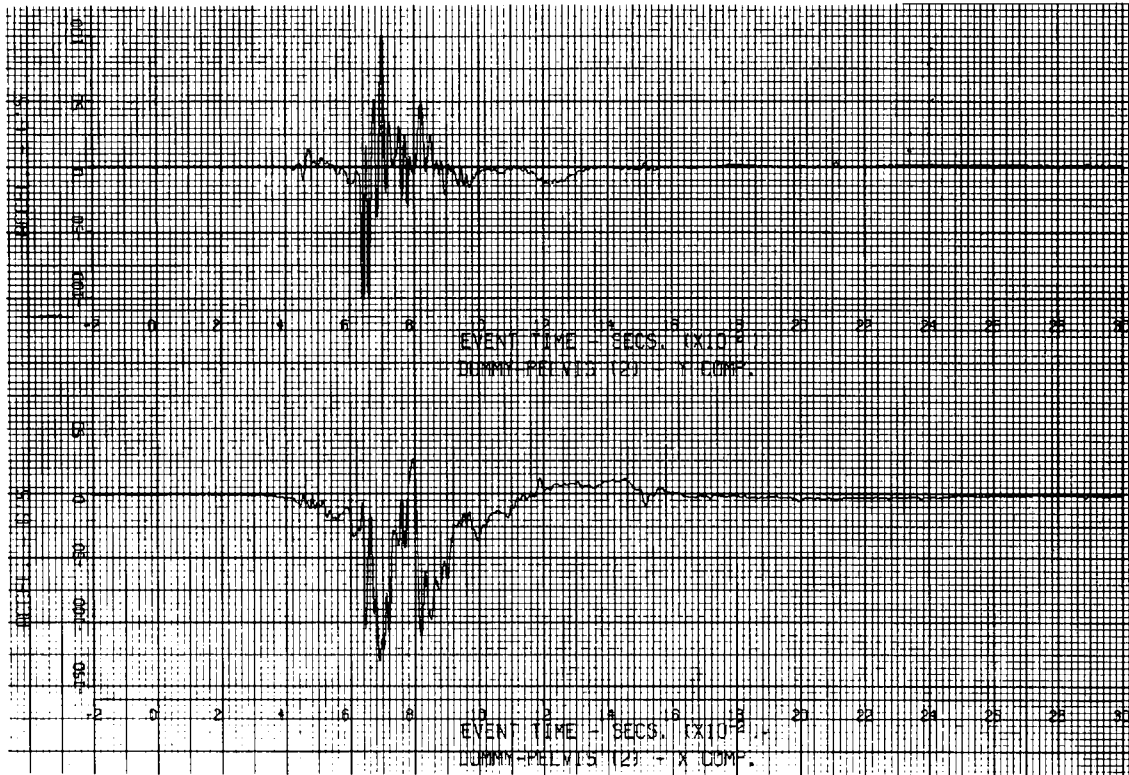


**Figure B-16 PELVIS ACCELERATIONS, RIGHT FRONT PASSENGER POSITION
(TEST 71)**

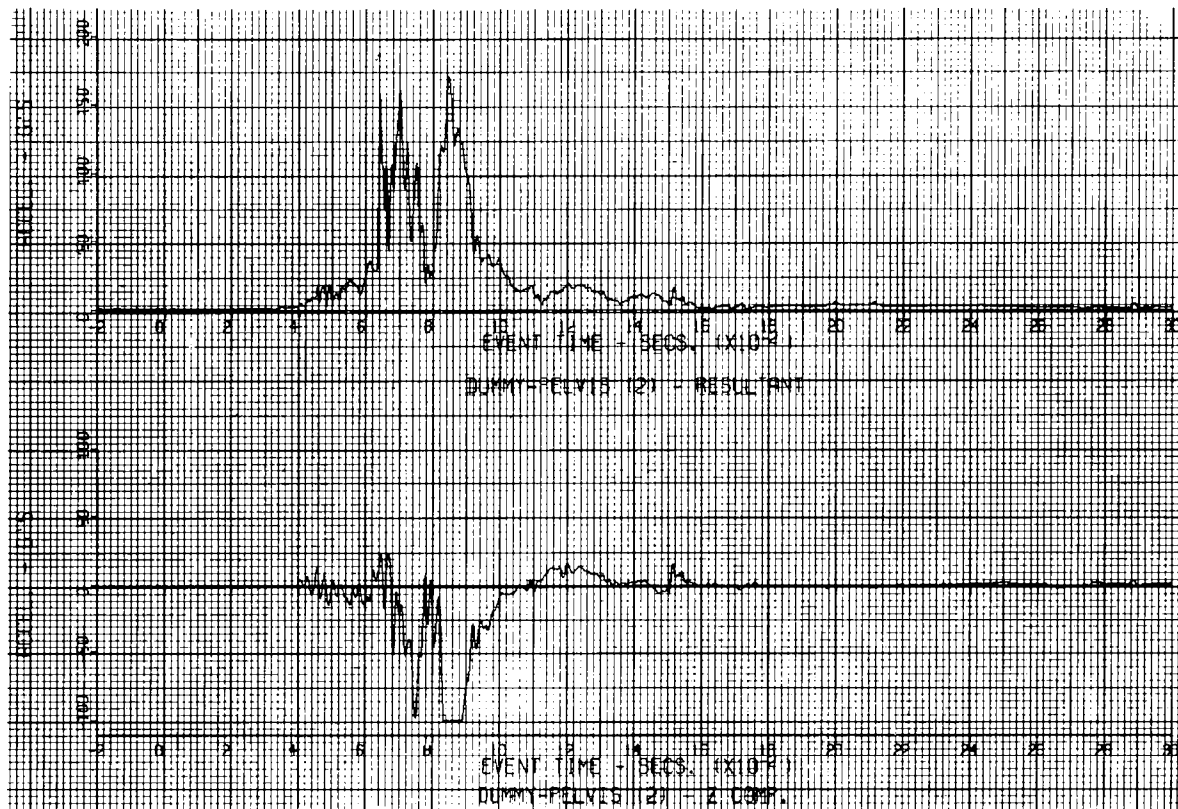


Figure B-16 (cont.) PELVIS ACCELERATIONS, RIGHT FRONT PASSENGER POSITION (TEST 71)

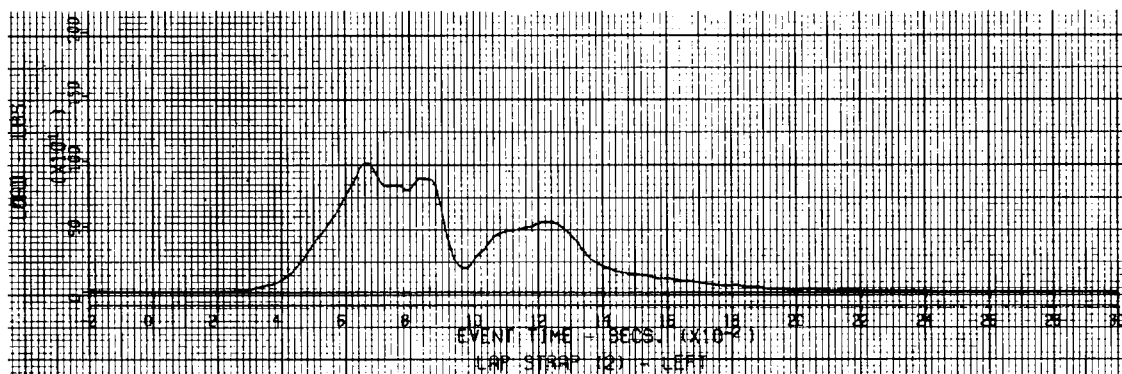
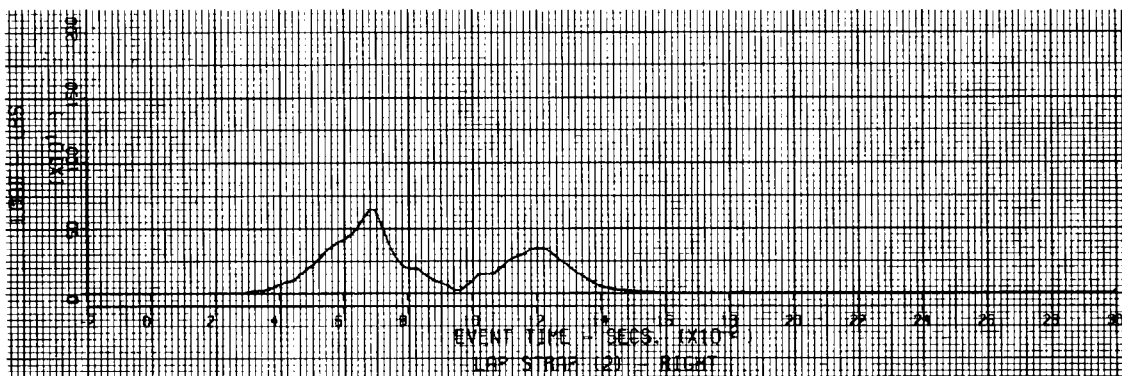
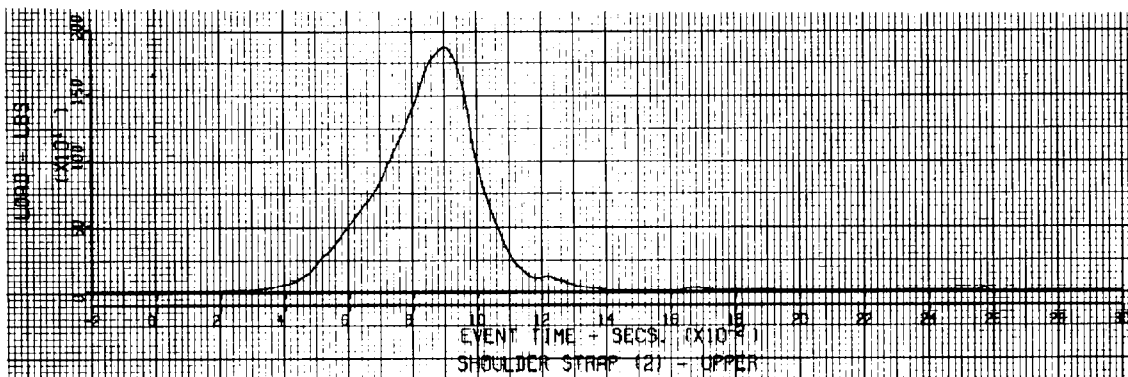


Figure B-17 RESTRAINT SYSTEM LOADS, RIGHT FRONT PASSENGER POSITION (TEST 71)

Test No. 77 Data

The following items are included:

1. Instrumentation requirements
2. Test site location of sensors and cameras
3. Before and after test photographs
4. Engine acceleration data
5. Passenger compartment acceleration data
6. Driver data
7. Passenger data

INSTRUMENTATION REQUIREMENTS

FACILITY TEST NO. 141 PROGRAM TEST NO. 77
 PROGRAM: Crashworthiness II
 TEST DESCRIPTION: OV-I, Flat barrier impact
 VEHICLE TYPE: OV-I

VEHICLE DESIGNATION	COM- PONENT	COMPARTMENT				ENGINE	DUMMIES (1, 2)				RESTRAINT			RECORDER	OTHER
		TUNNEL	(1) (4)	(2) (3)	REAR DECK		OTHER	HEAD	CHEST	PELVIS	LAP	SHOULDER	OTHER		
OV-I	X	A	1A, 2A, 3A, 4A			A	A	A	A				2 air cushions		
	Y	A	1A, 2A, 3A, 4A				A	A	A				1 driver knee bar		
	Z	A	1A, 2A, 3A, 4A				A	A	A						
	X														
	Y														
	Z														

LEGEND:

A - ACCELEROMETER
 V - VELOCITY METER
 D - DISPLACEMENT METER
 L - LOAD CELL

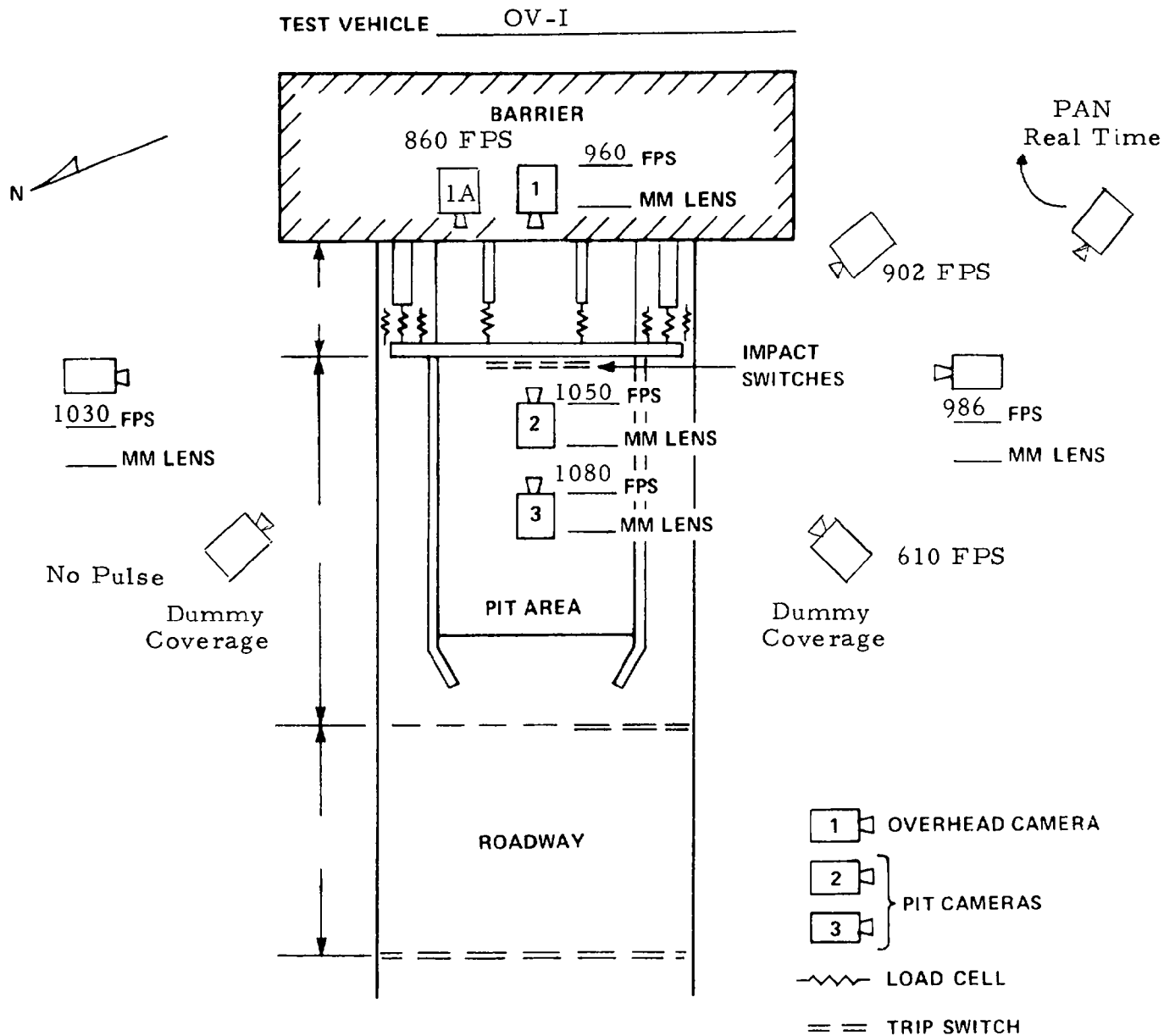
**DESCRIBE "OTHER"

**IF MORE THAN 1 DUMMY, NUMBER
 SEQUENTIALLY IN CLOCKWISE (FROM TOP VIEW)
 DIRECTION (i.e. DRIVER 1, PASS FRONT 2, etc)

MISCELLANEOUS

- 1) CONTACT SWITCH/BAR:
- 2) AIR BAG SENSORS: Parallel, front mounted, Eaton.
- 3) POSITION OF CARS: + 2.5 MPH
- 4) SPEED WINDOW: 57.2 - 2.5 MPH

TEST SITE LOCATION OF SENSORS AND CAMERAS



REMARKS: Load cell barrier not required for this test.

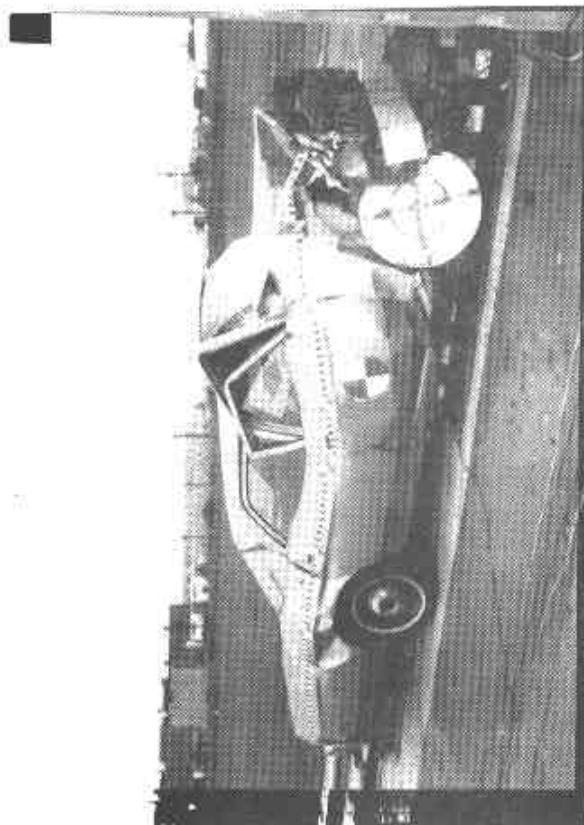
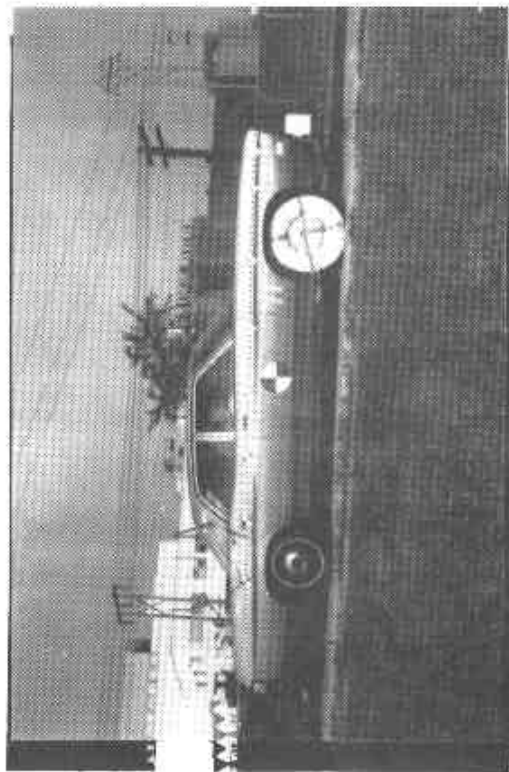
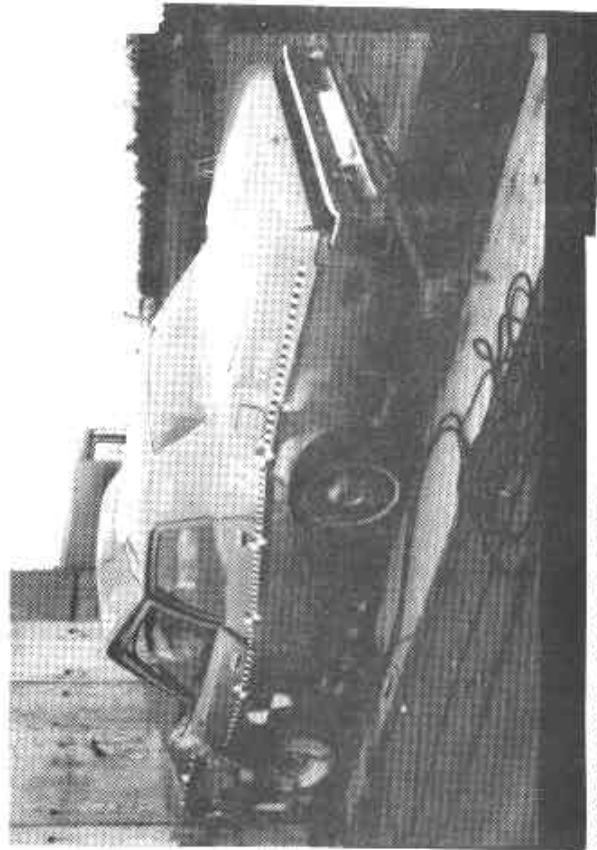
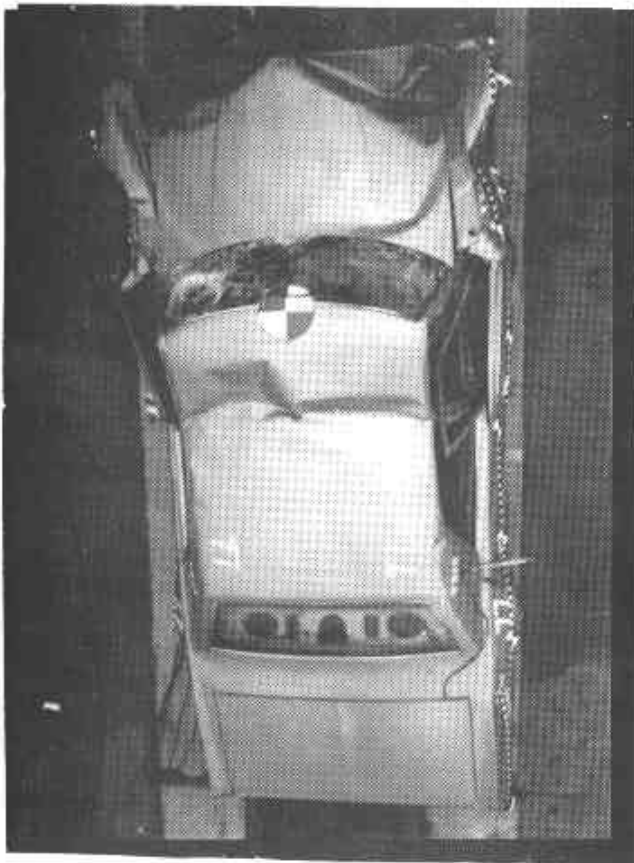


Figure B-18 BEFORE AND AFTER TEST PHOTOGRAPHS OF OV-1 VEHICLE (TEST 77)

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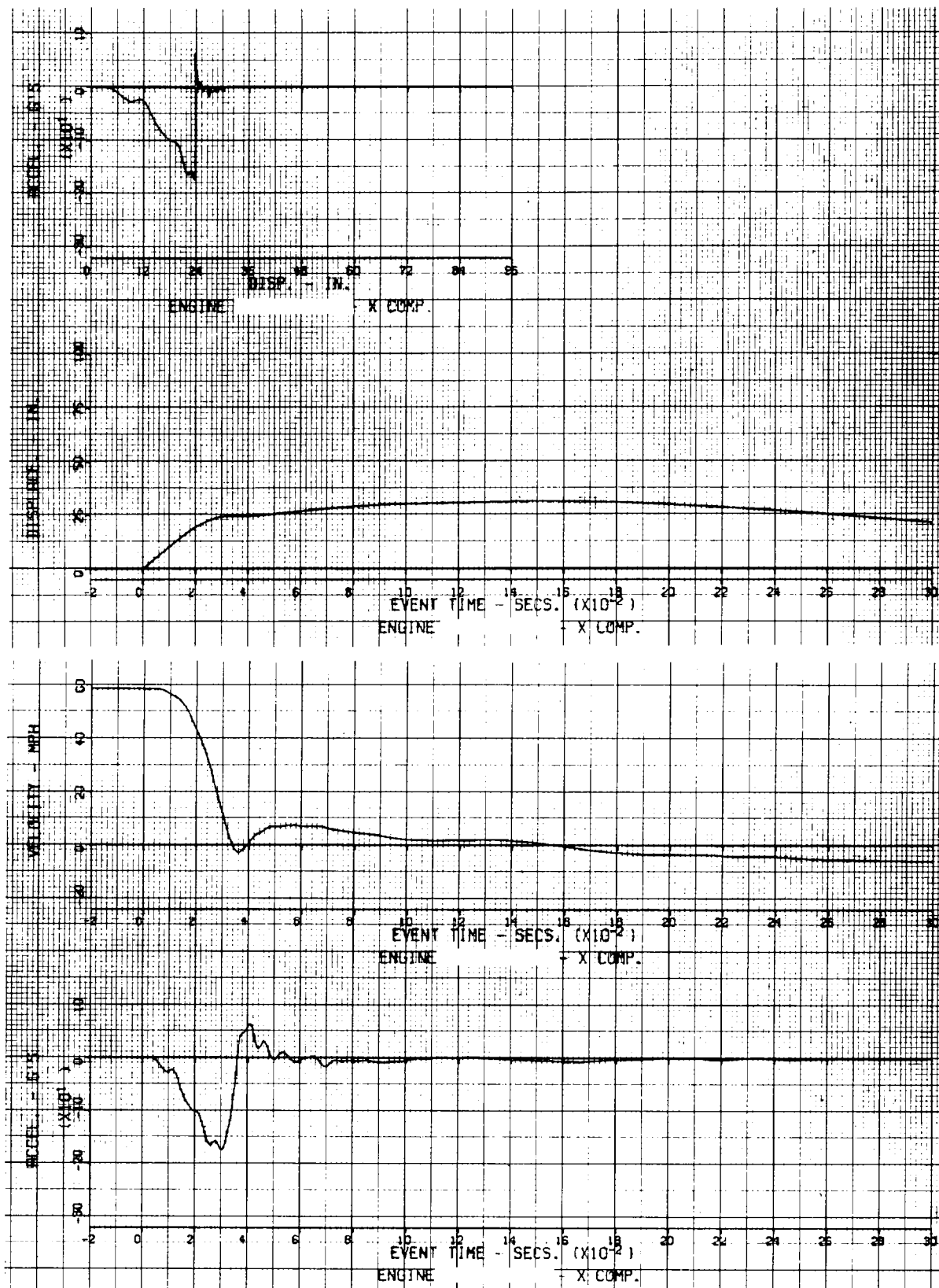


Figure B-19 ENGINE LONGITUDINAL KINEMATIC DATA (TEST 77)

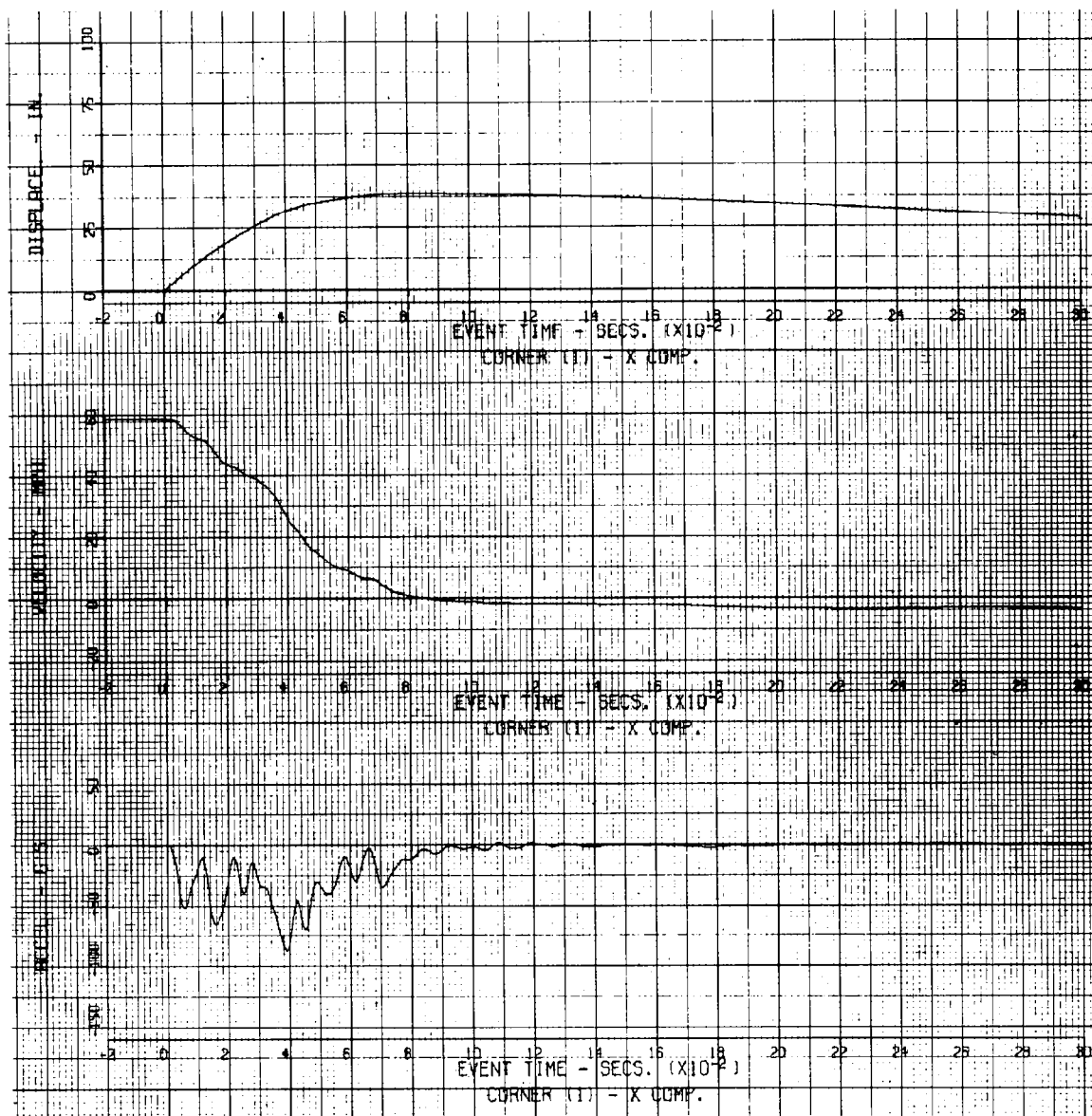


Figure B-20 PASSENGER COMPARTMENT ACCELERATION AND LONGITUDINAL KINEMATIC DATA, LEFT FRONT CORNER LOCATION (TEST 77)

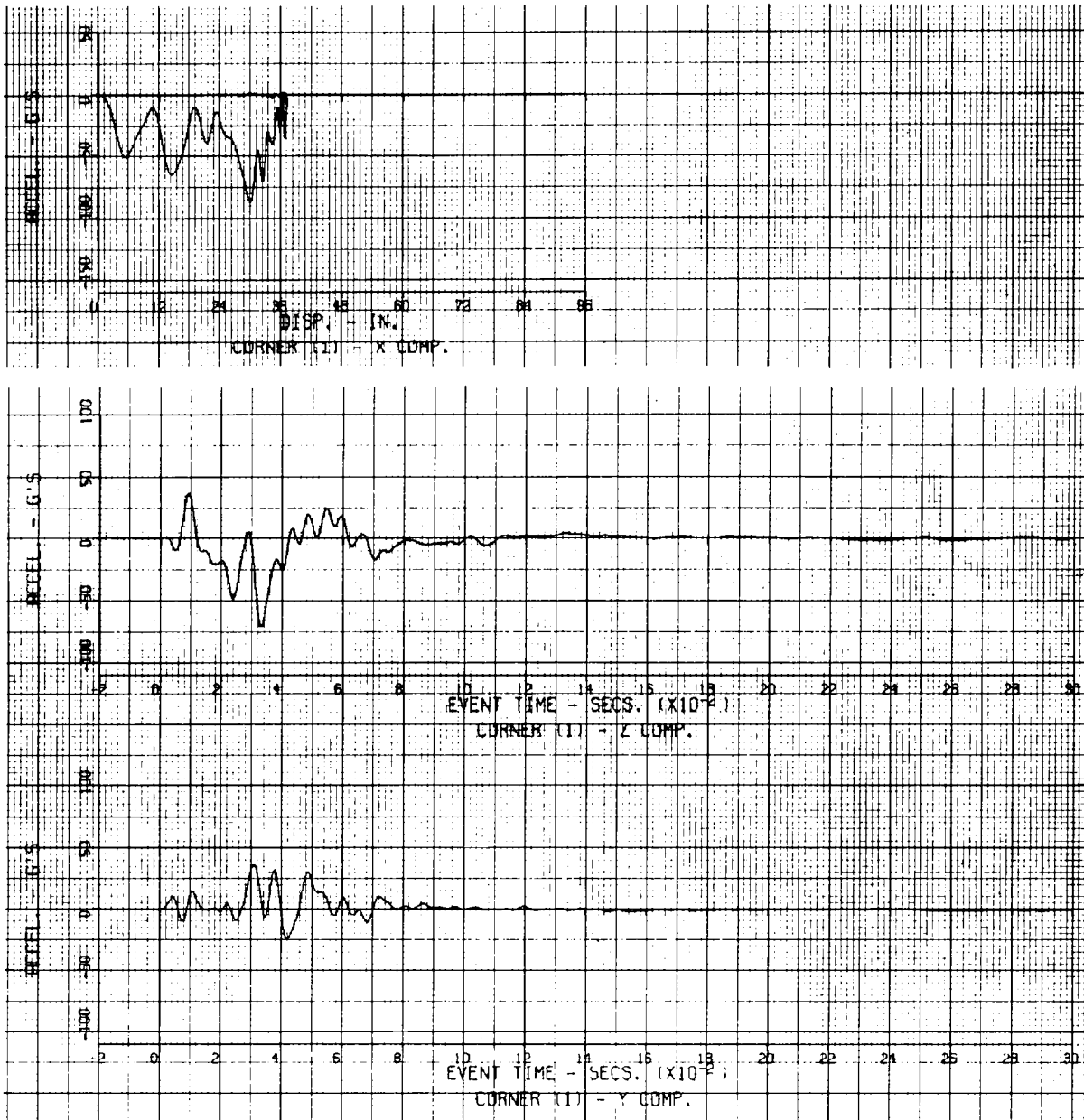


Figure B-20 (Cont.) PASSENGER COMPARTMENT ACCELERATION AND LONGITUDINAL KINEMATIC DATA, LEFT FRONT CORNER LOCATION (TEST 77)

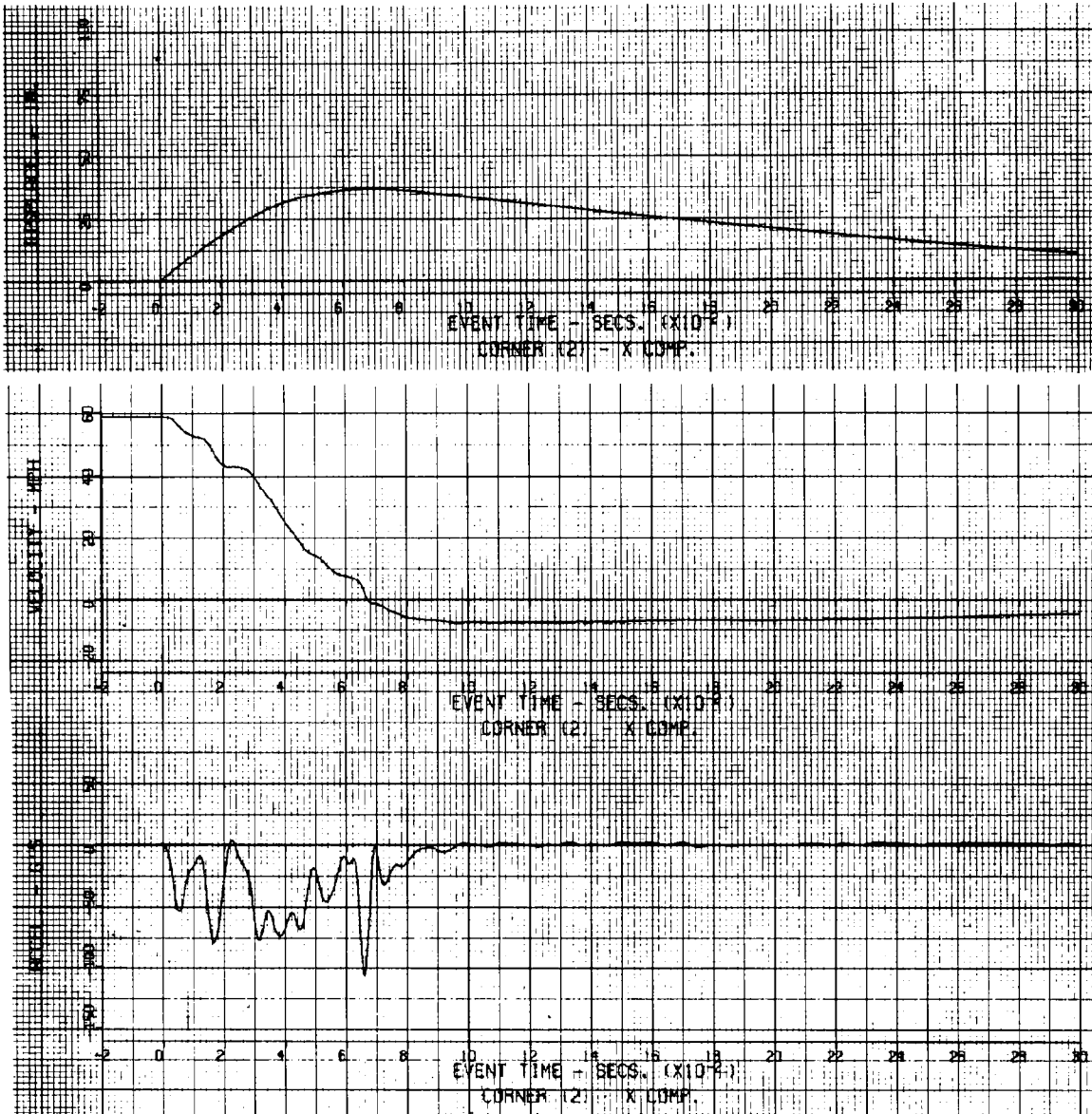


Figure B-21 PASSENGER COMPARTMENT ACCELERATION AND LONGITUDINAL KINEMATIC DATA, RIGHT FRONT CORNER LOCATION (TEST 77)

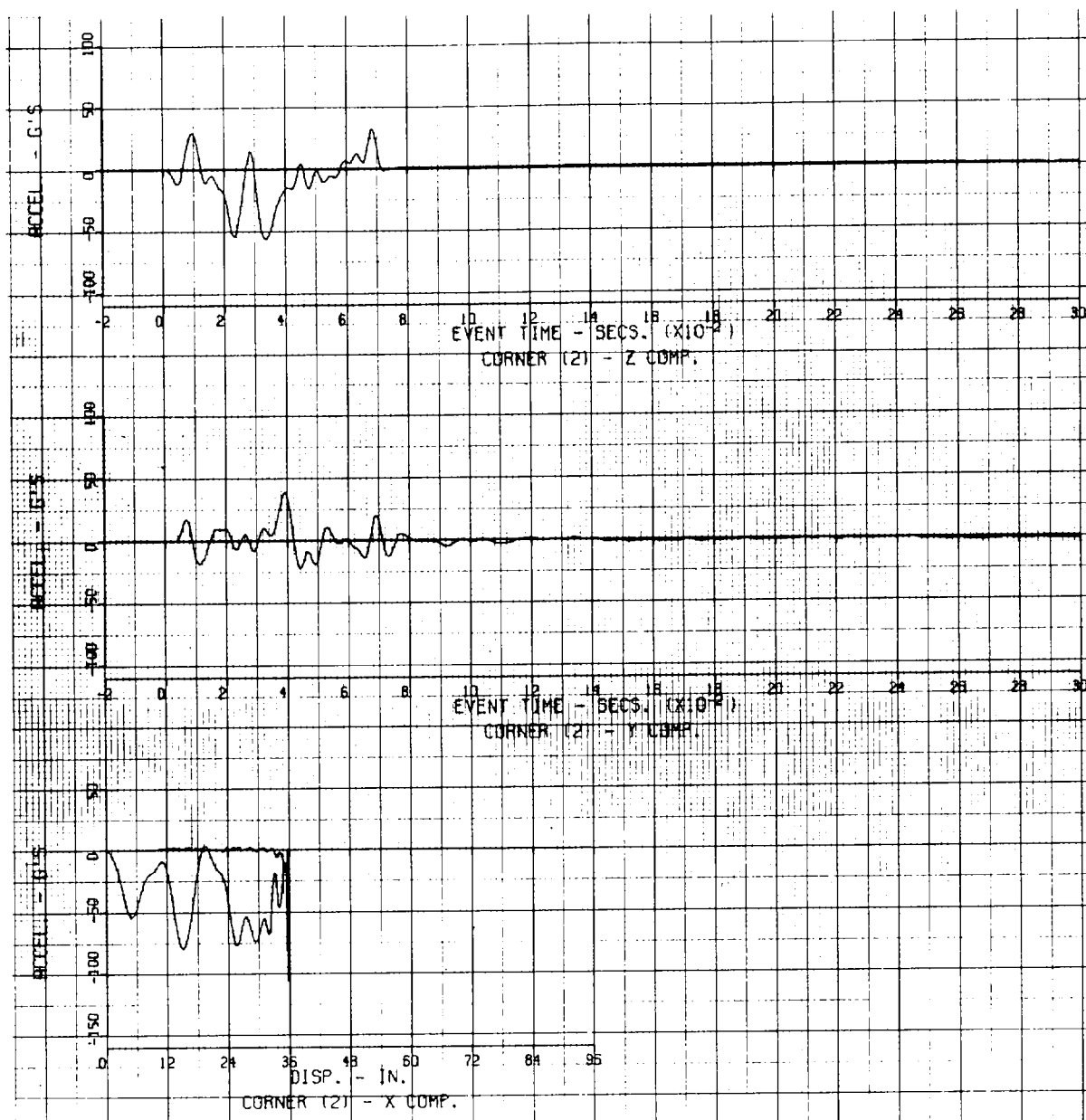


Figure B-21 (Cont.) PASSENGER COMPARTMENT ACCELERATION AND LONGITUDINAL KINEMATIC DATA, RIGHT FRONT CORNER LOCATION (TEST 77)

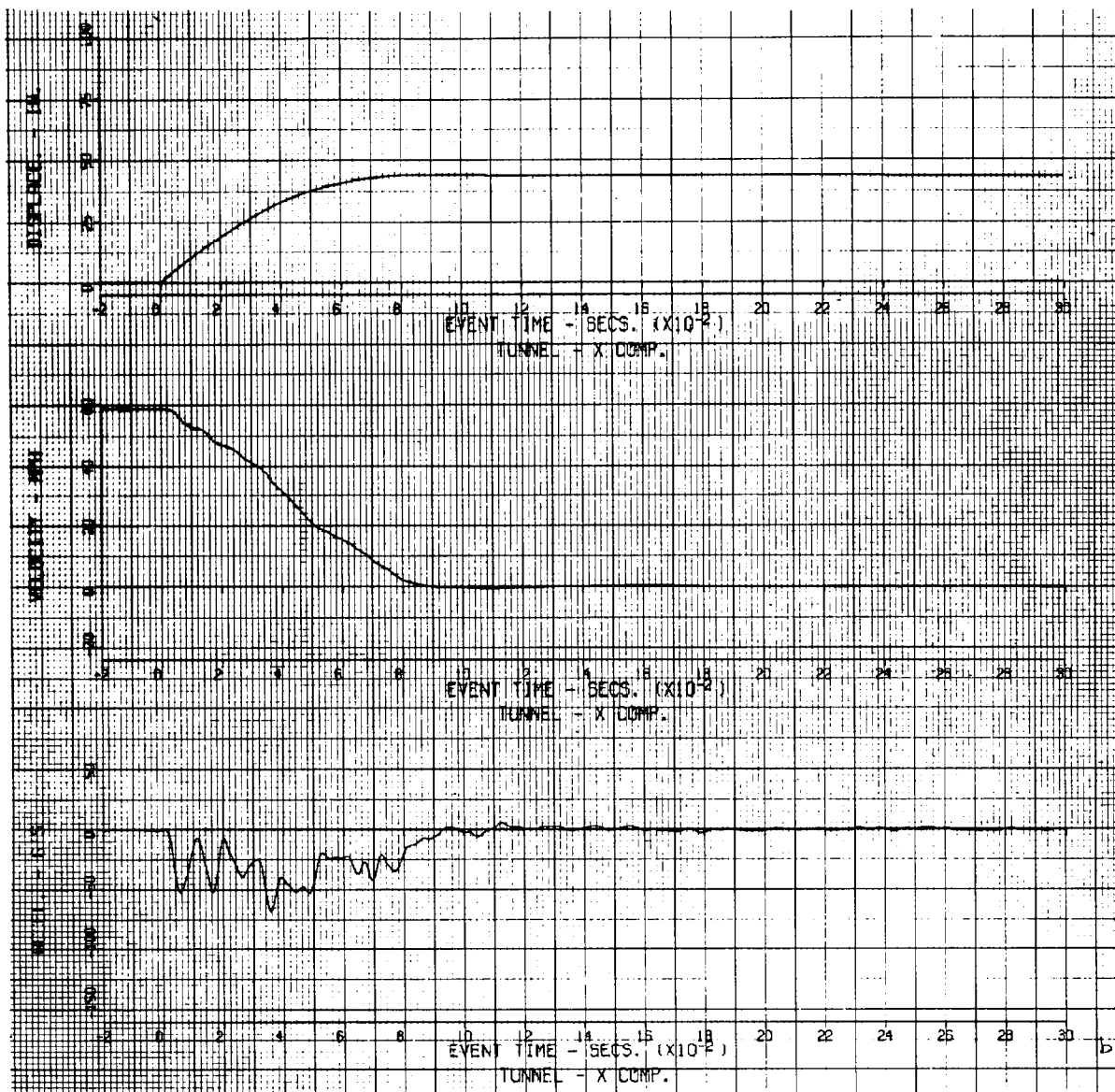


Figure B-22 PASSENGER COMPARTMENT ACCELERATION AND LONGITUDINAL KINEMATIC DATA, TUNNEL LOCATION (TEST 77)

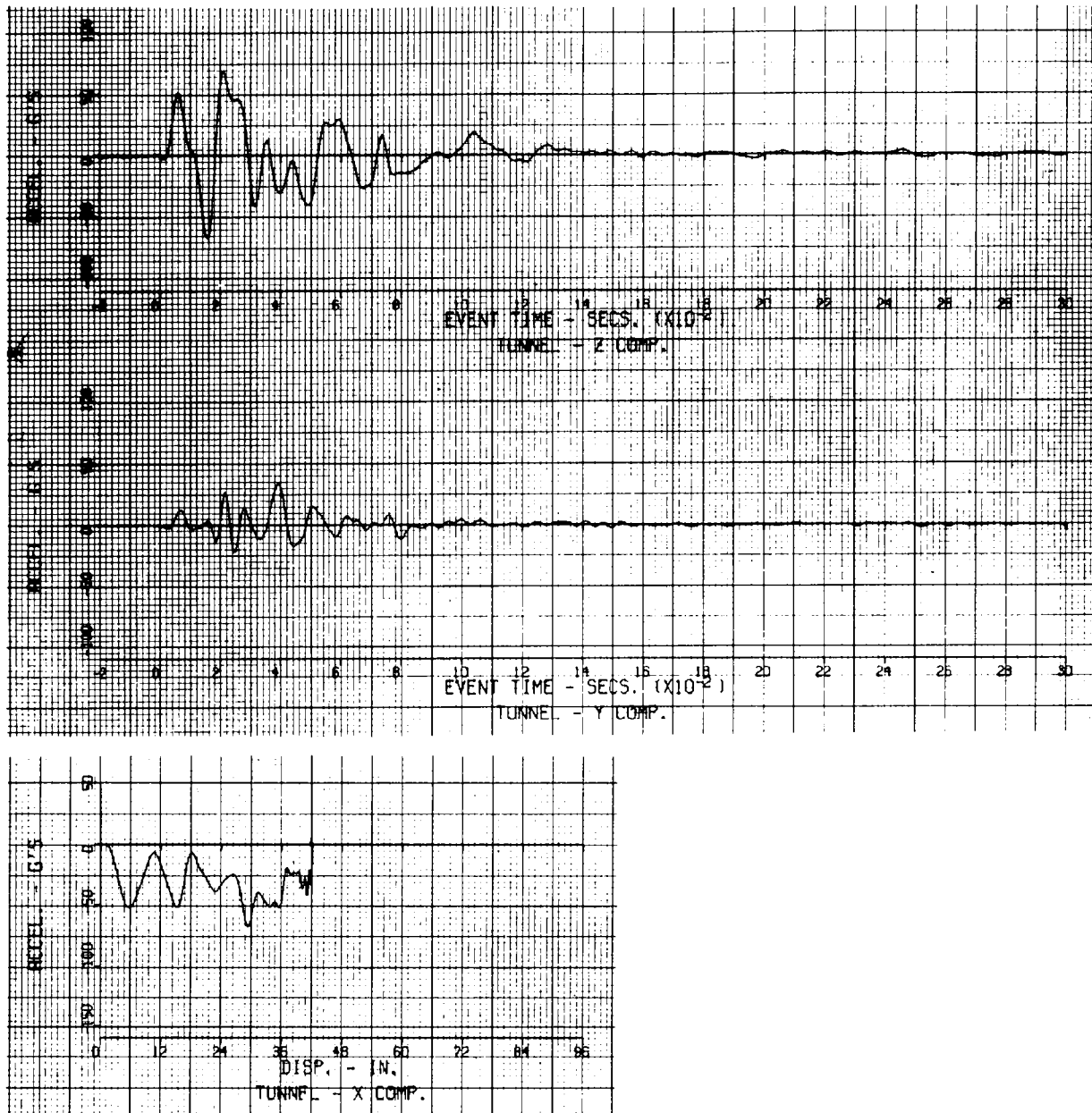


Figure B-22 (Cont.) PASSENGER COMPARTMENT ACCELERATION AND LONGIDUTINAL KINEMATIC DATA, TUNNEL LOCATION (TEST 77)

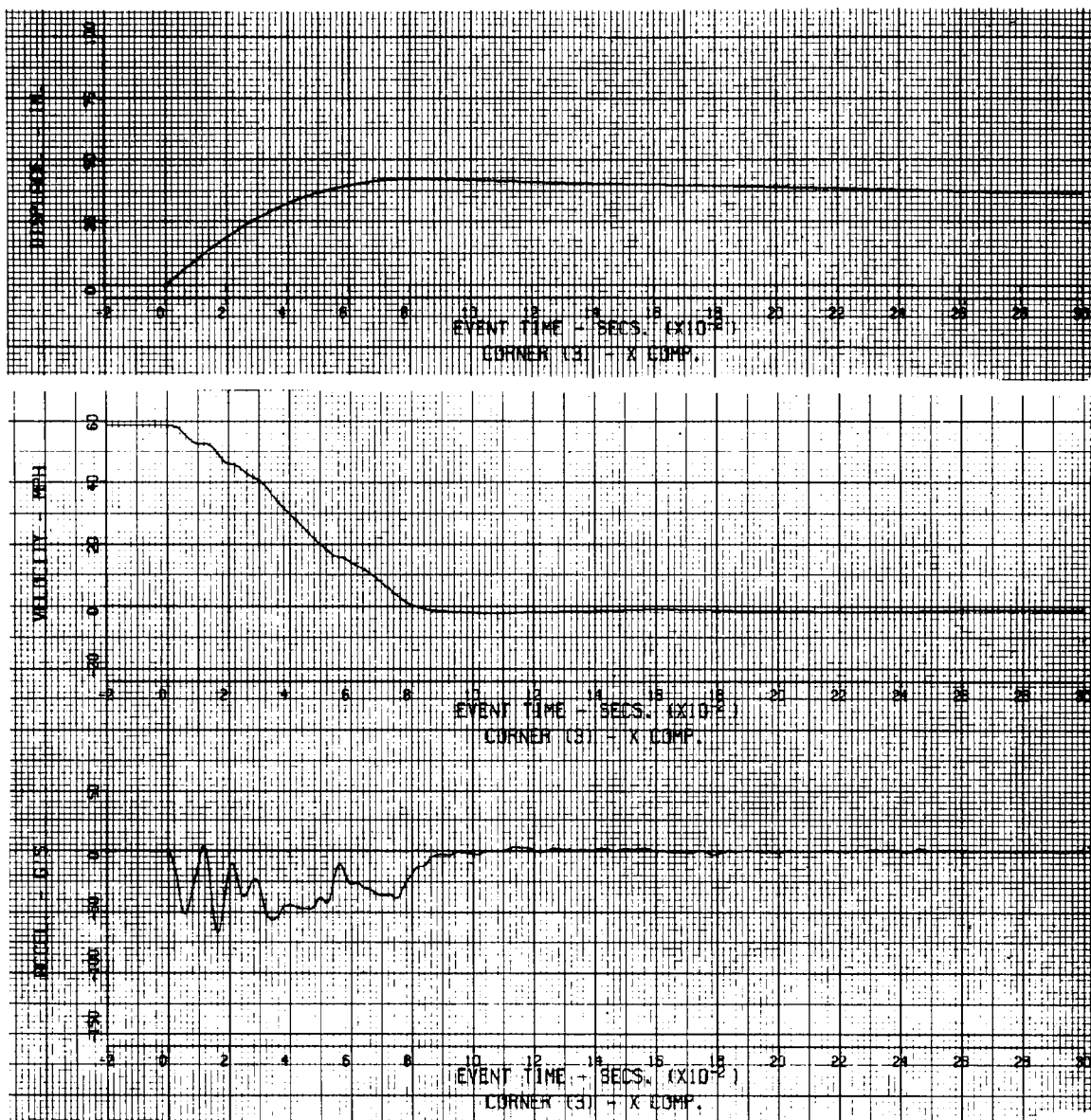


Figure B-23 PASSENGER COMPARTMENT ACCELERATION AND LONGITUDINAL KINEMATIC DATA, RIGHT REAR CORNER LOCATIONS (TEST 77)

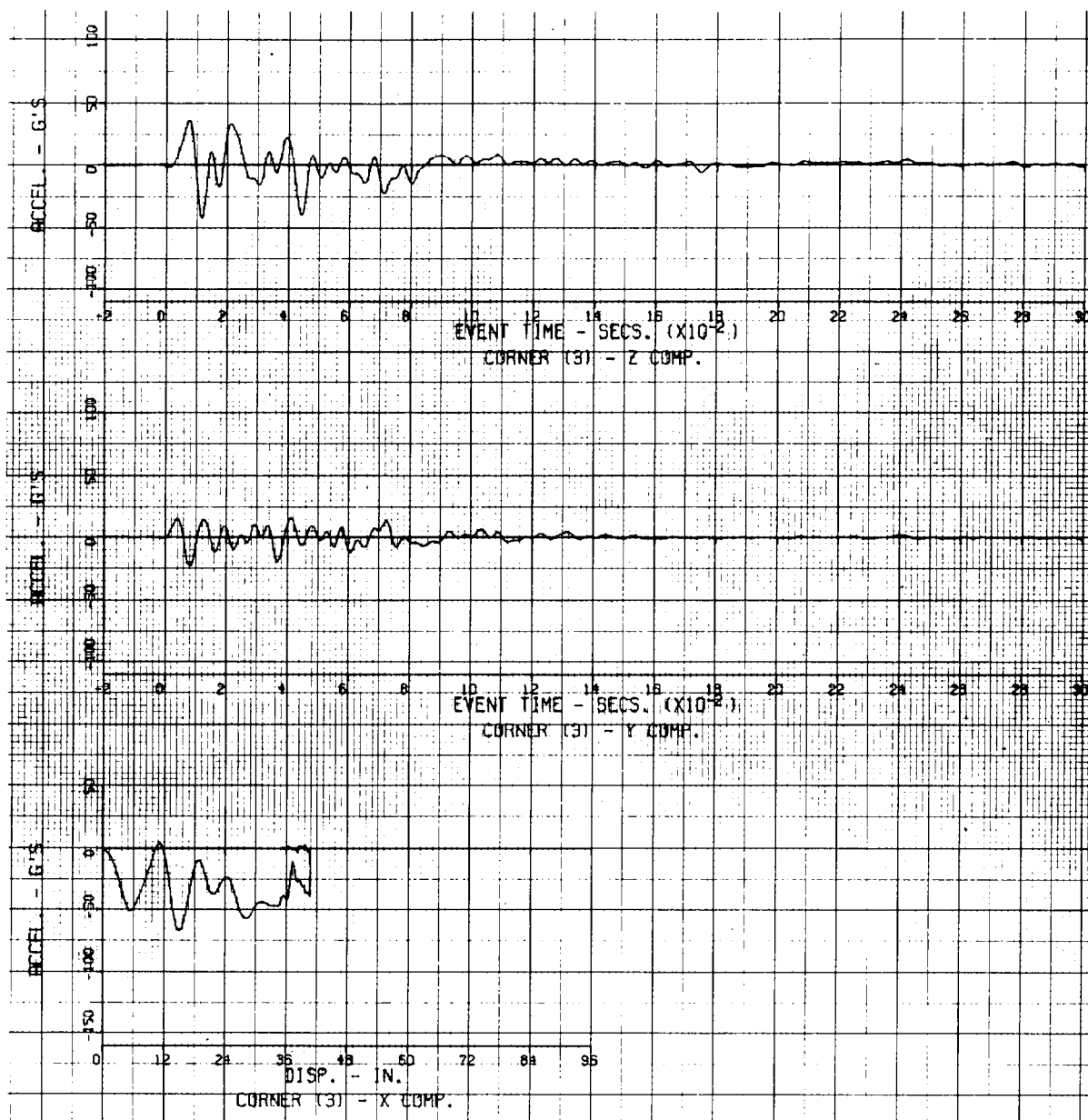


Figure B-23 (Cont.) PASSENGER COMPARTMENT ACCELERATION AND LONGITUDINAL KINEMATIC DATA, RIGHT REAR CORNER LOCATION (TEST 77)

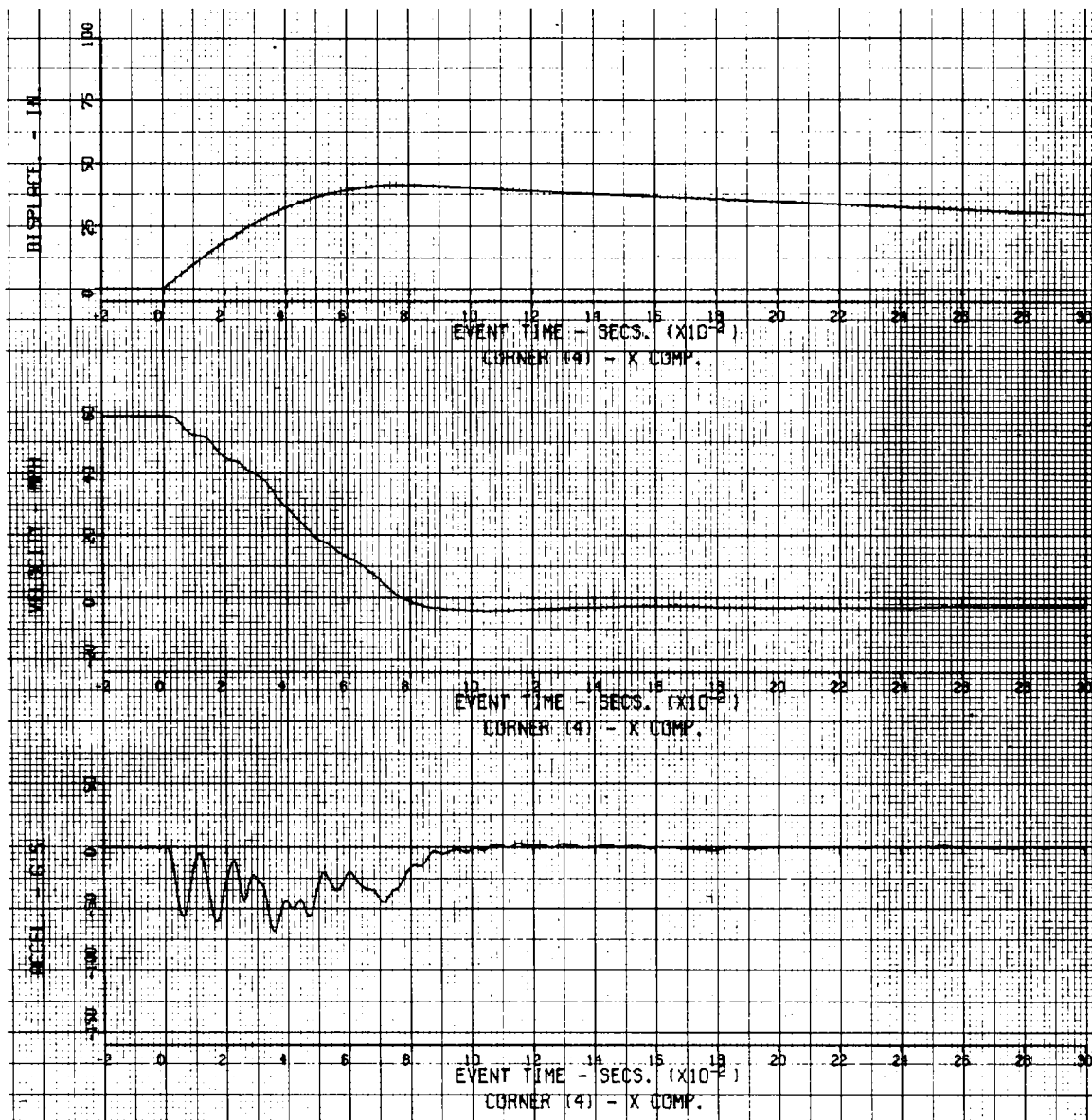


Figure B-24 PASSENGER COMPARTMENT ACCELERATION AND LONGITUDINAL KINEMATIC DATA, LEFT REAR CORNER LOCATION (TEST 77)

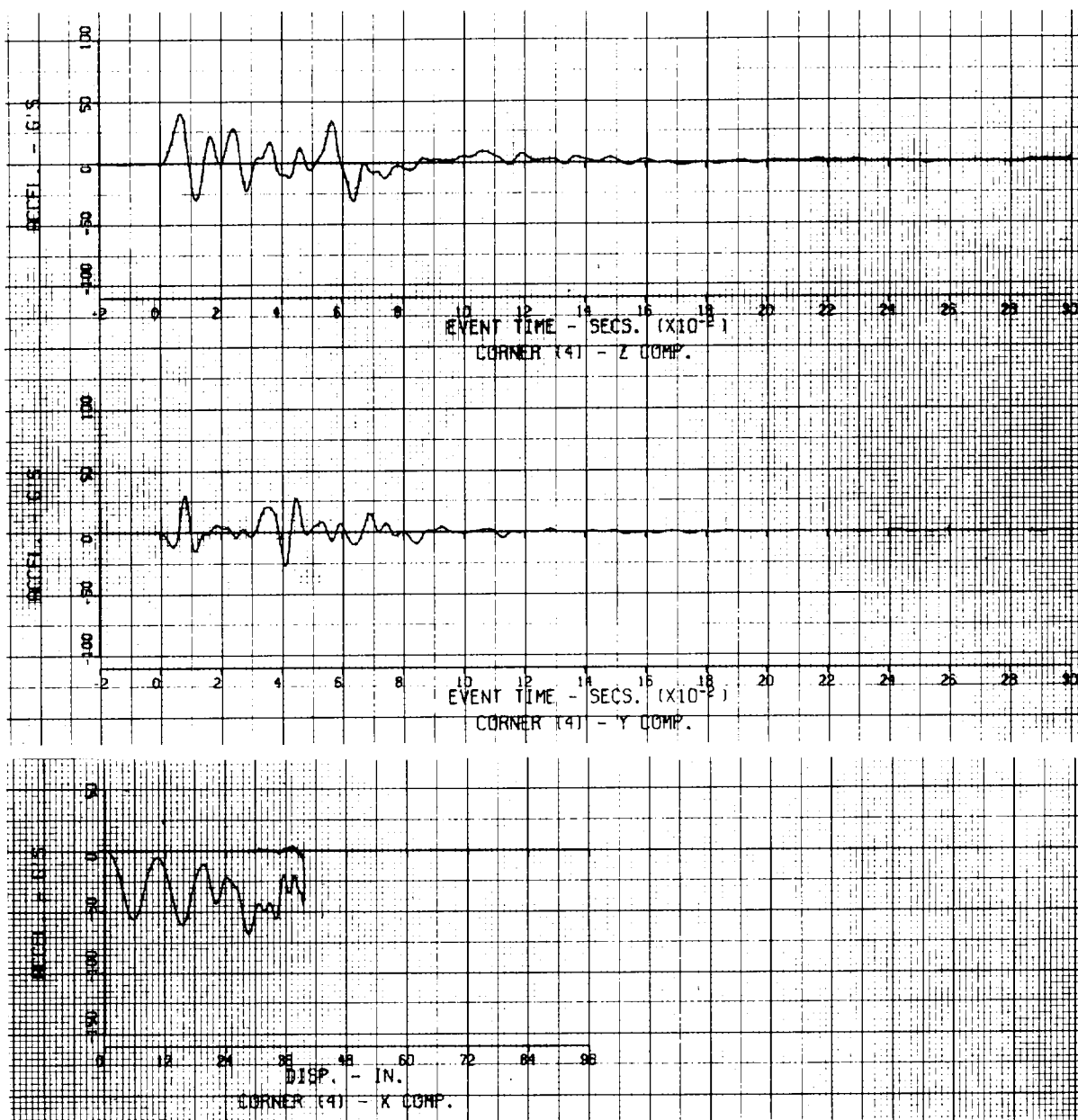


Figure B-24 (Cont.) PASSENGER COMPARTMENT ACCELERATION AND LONGITUDINAL KINEMATIC DATA, LEFT REAR CORNER LOCATION (TEST 77)

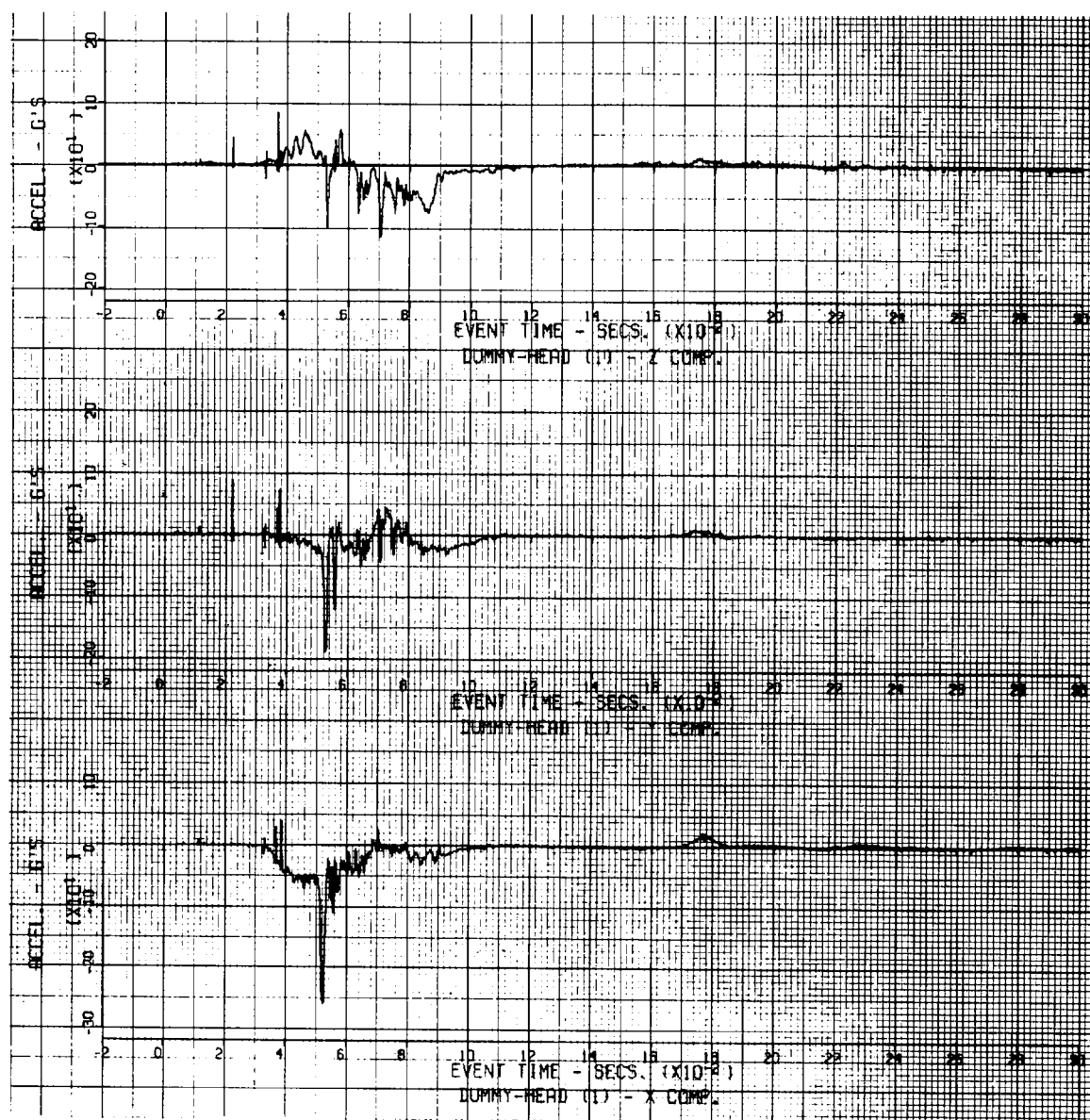


Figure B-25 DRIVER DUMMY HEAD ACCELERATION DATA (TEST 77)

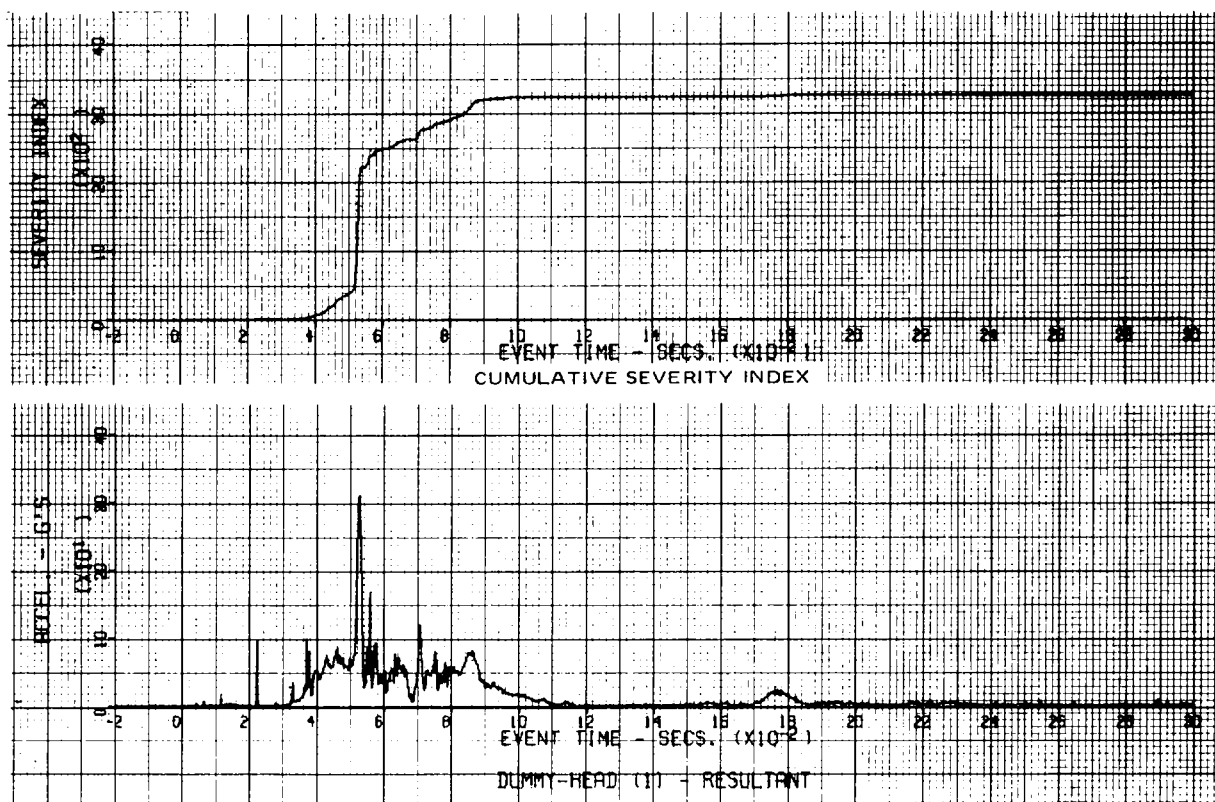


Figure B-25 (Cont.) DRIVER HEAD ACCELERATION DATA (TEST 77)

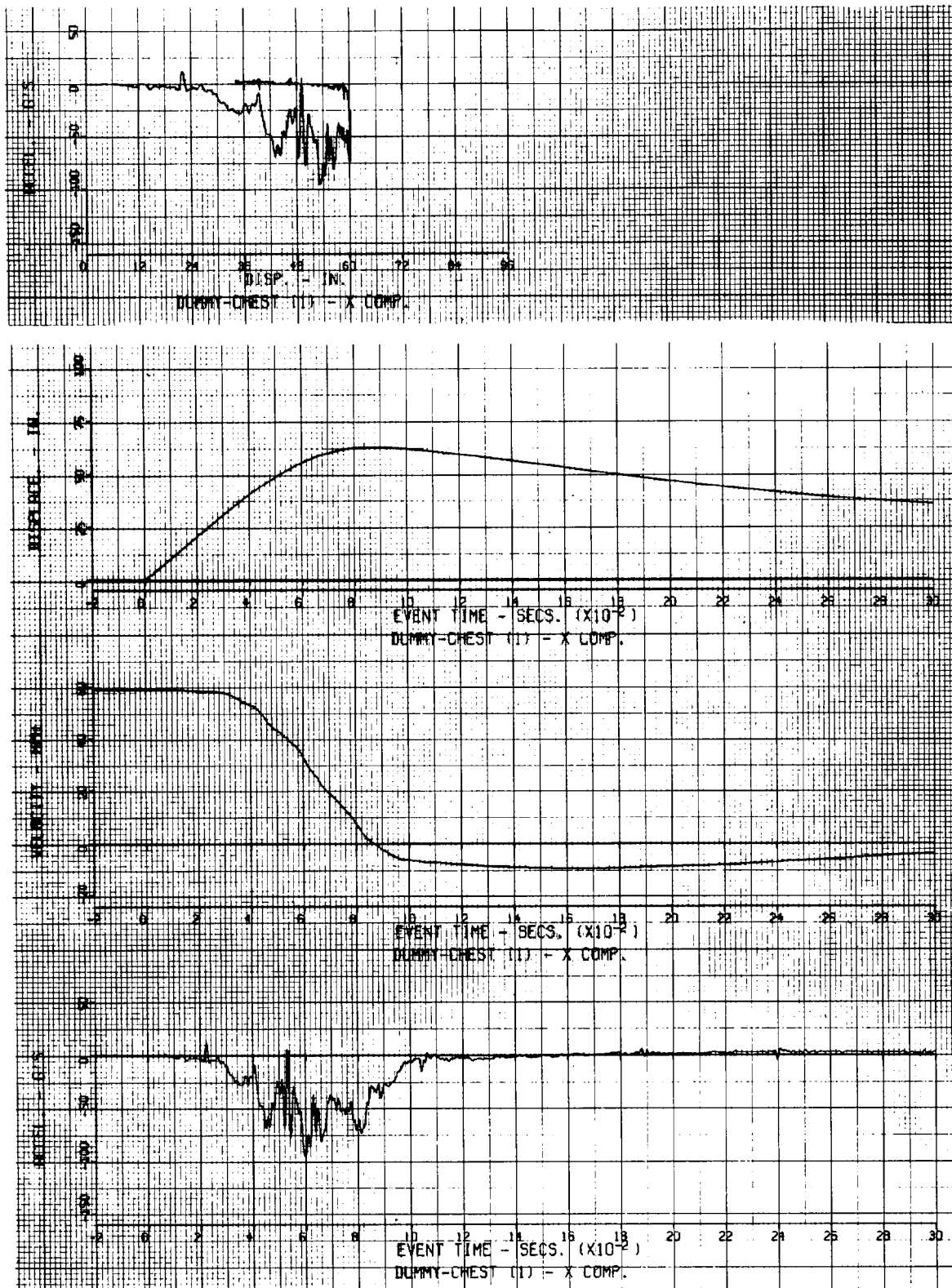


Figure B-26 DRIVER DUMMY CHEST ACCELERATION AND LONGITUDINAL KINEMATIC DATA (TEST 77)

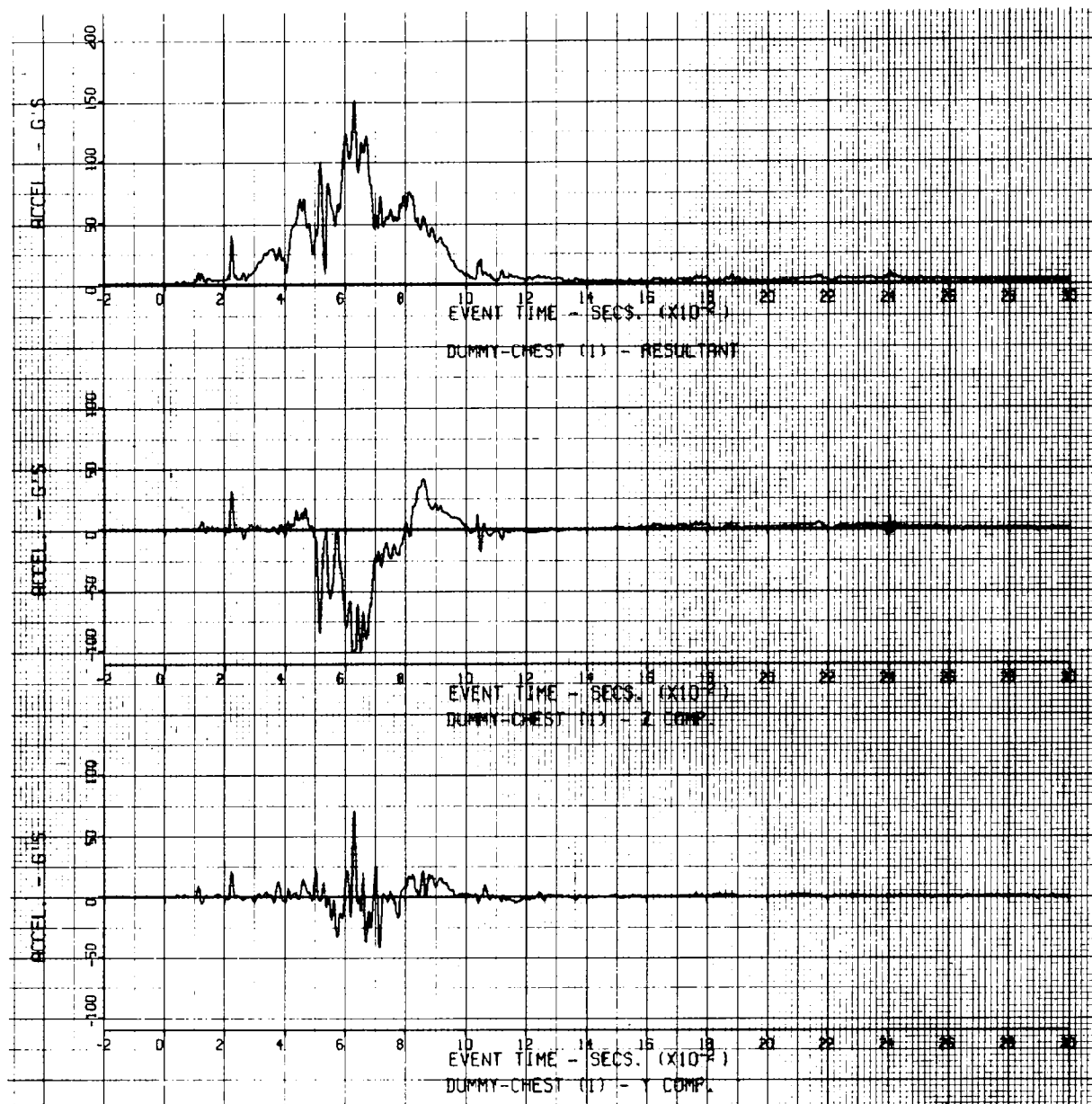


Figure B-26 (Cont.) DRIVER DUMMY CHEST ACCELERATION AND LONGITUDINAL KINEMATIC DATA (TEST 77)

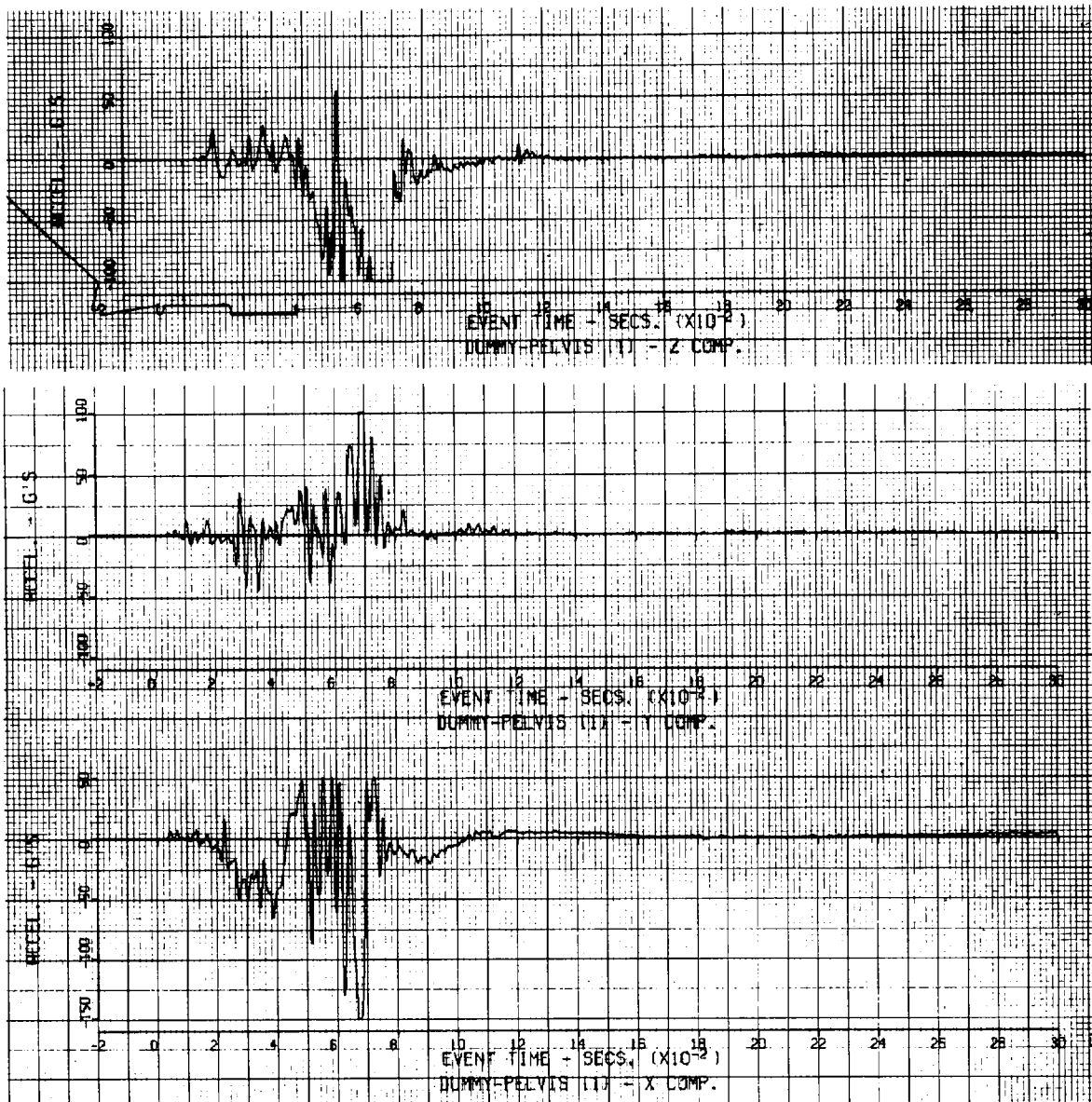


Figure B-27 DRIVER DUMMY PELVIS ACCELERATION AND FEMUR LOAD DATA
(TEST 77)

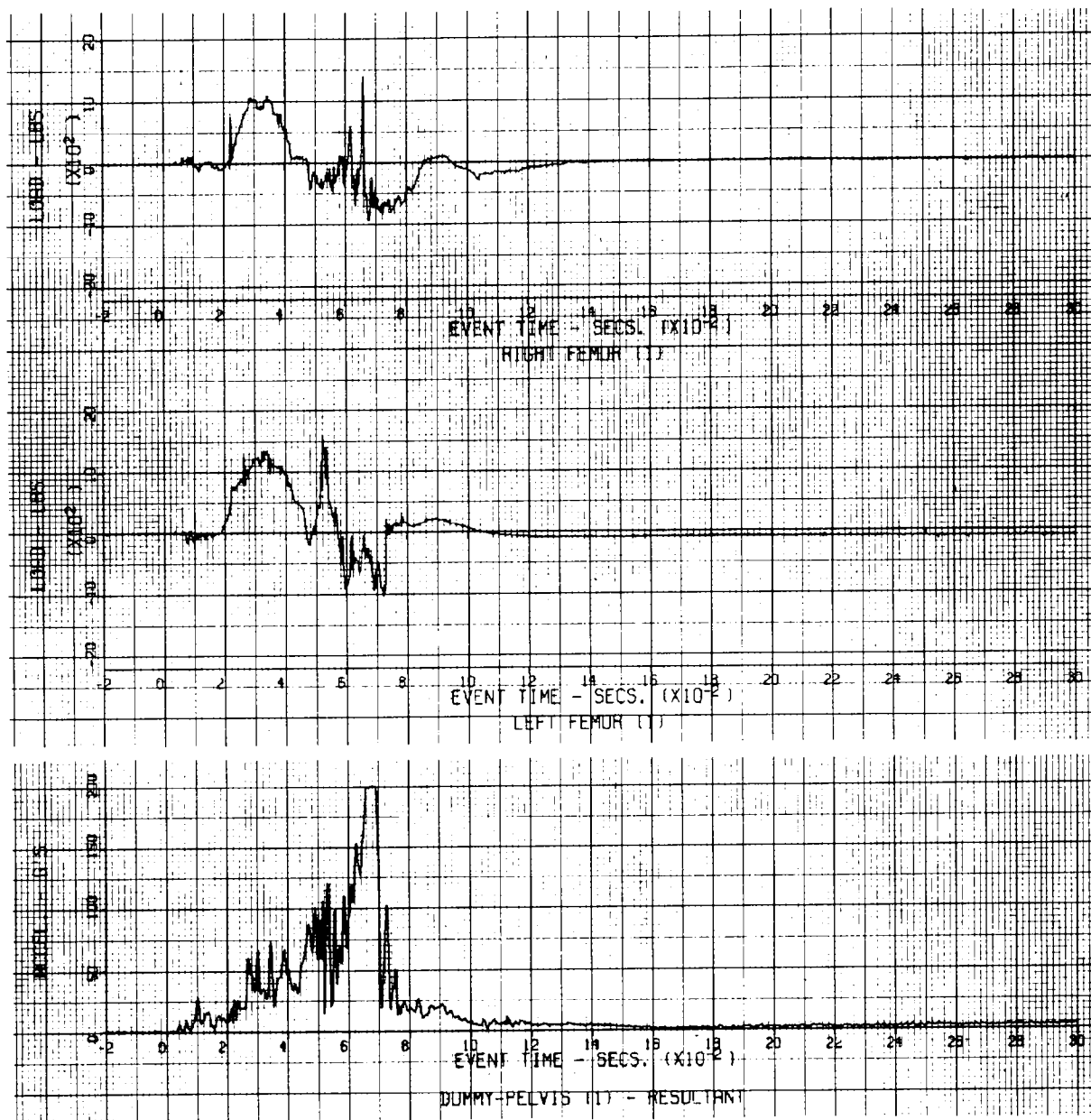


Figure B-27 (Cont.) DRIVER DUMMY PELVIS ACCELERATION AND FEMUR LOAD DATA (TEST 77)

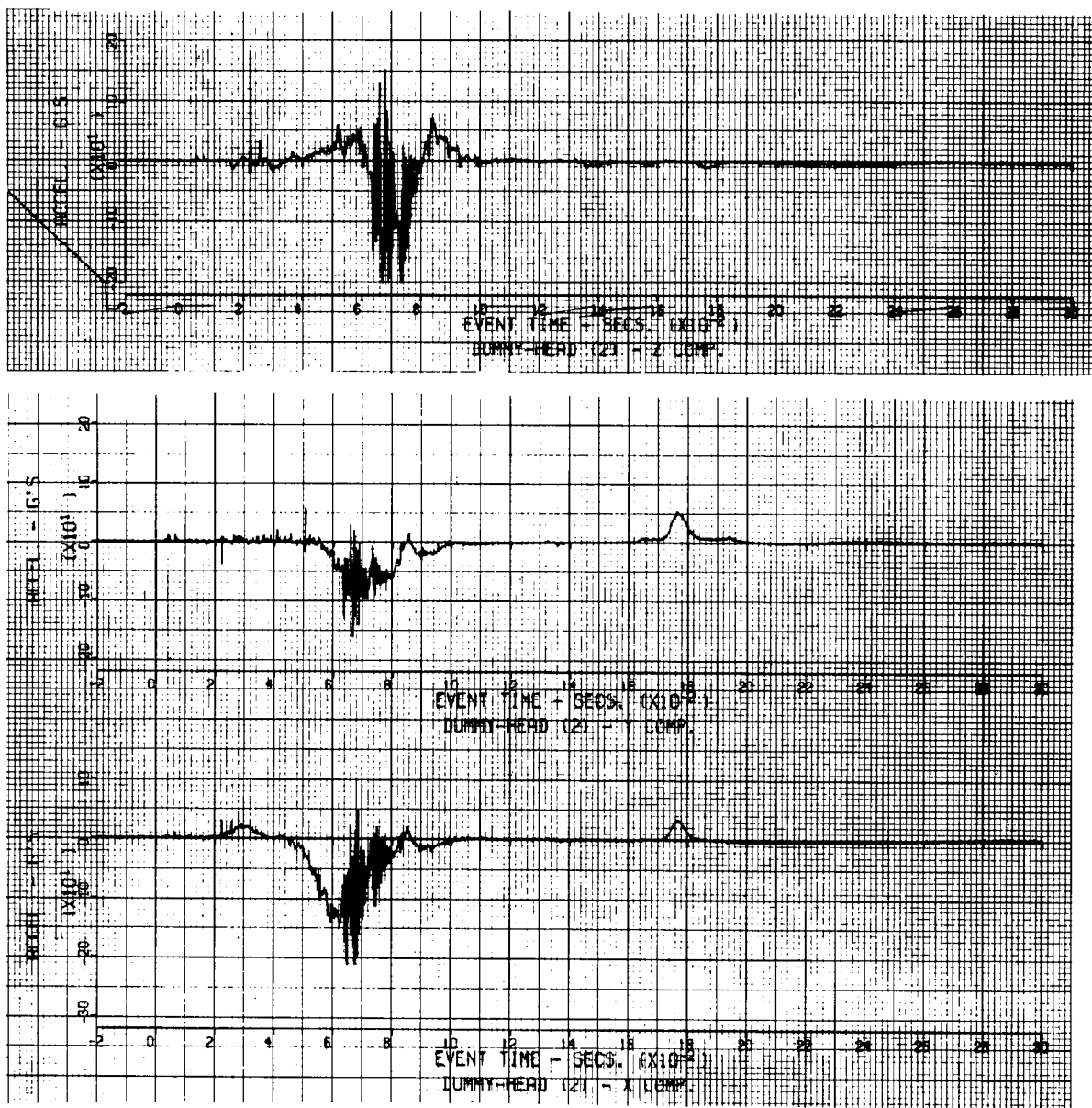


Figure B-28 RIGHT FRONT PASSENGER DUMMY HEAD ACCELERATION DATA (TEST 77)

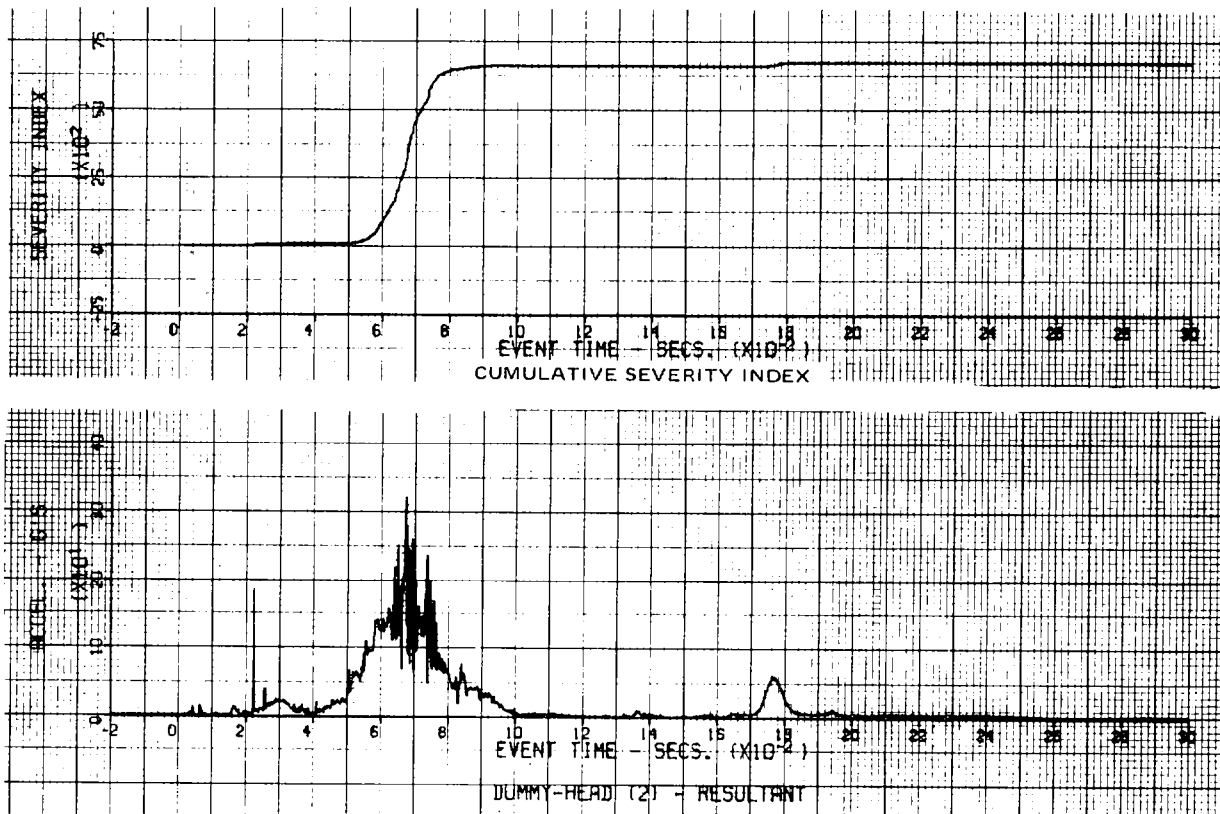


Figure B-28 (cont.) RIGHT FRONT PASSENGER DUMMY HEAD ACCELERATION DATA
(TEST 77)

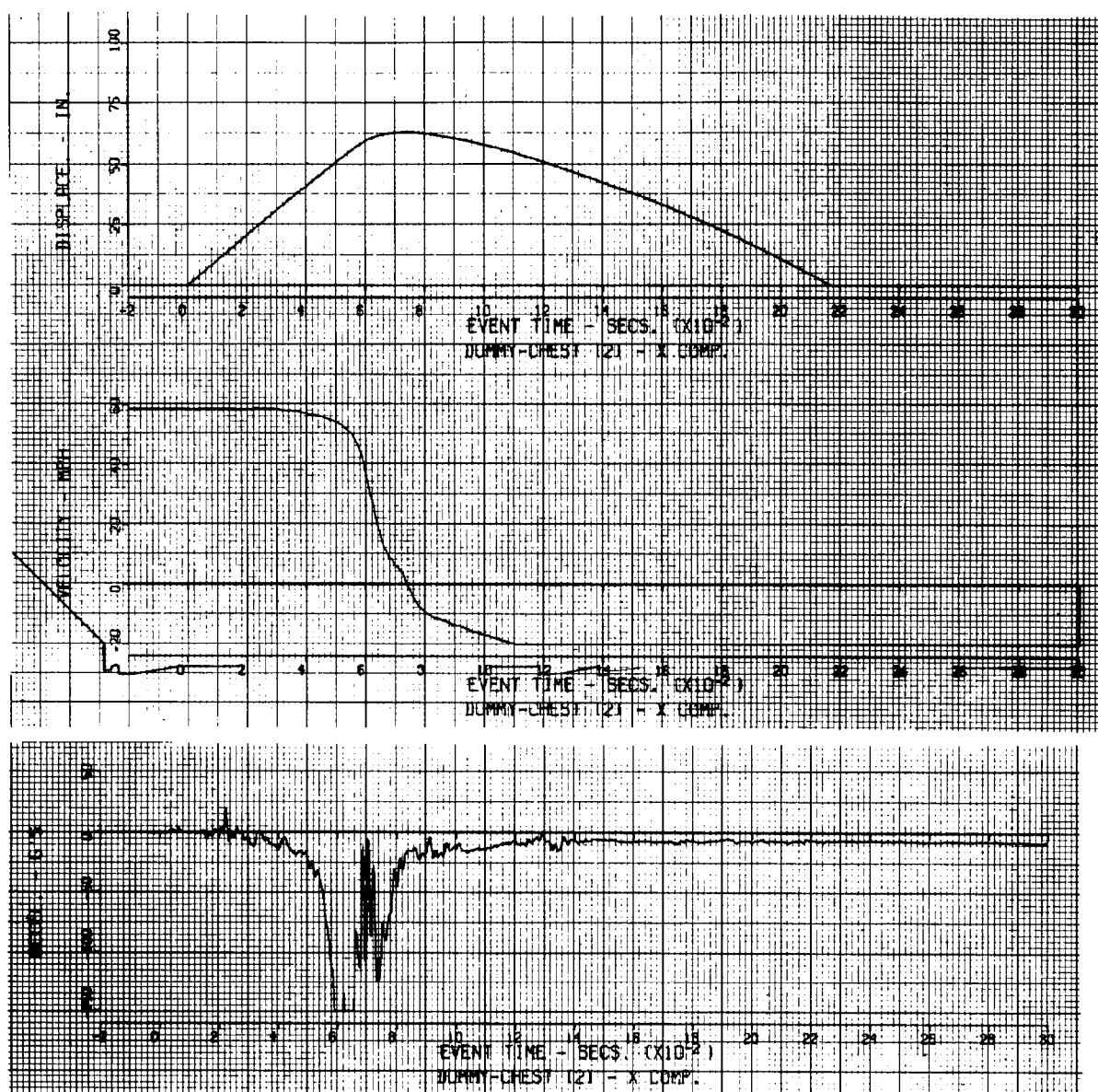


Figure B-29 RIGHT FRONT PASSENGER DUMMY CHEST ACCELERATION AND LONGITUDINAL KINEMATIC DATA (TEST 77)

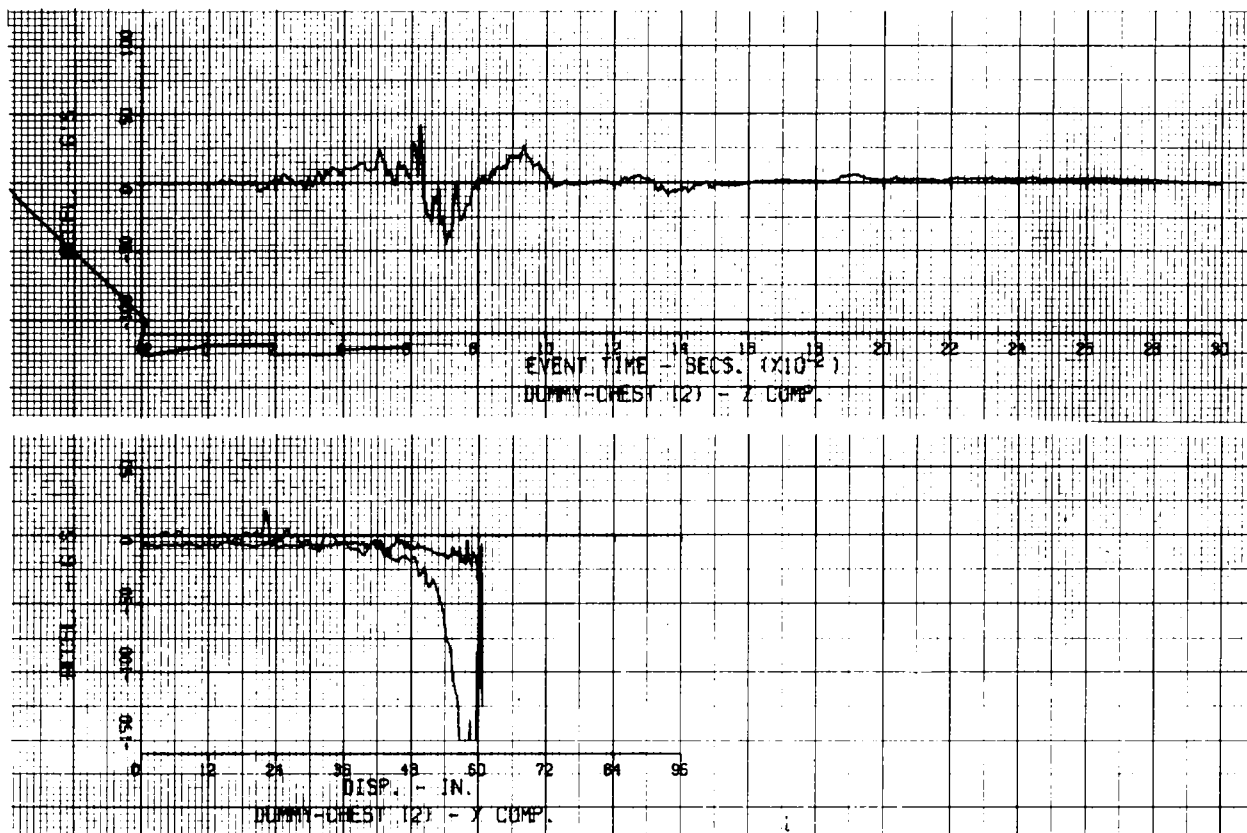


Figure B-29 (Cont.) RIGHT FRONT PASSENGER DUMMY CHEST ACCELERATION
AND LONGITUDINAL KINEMATIC DATA (TEST 77)

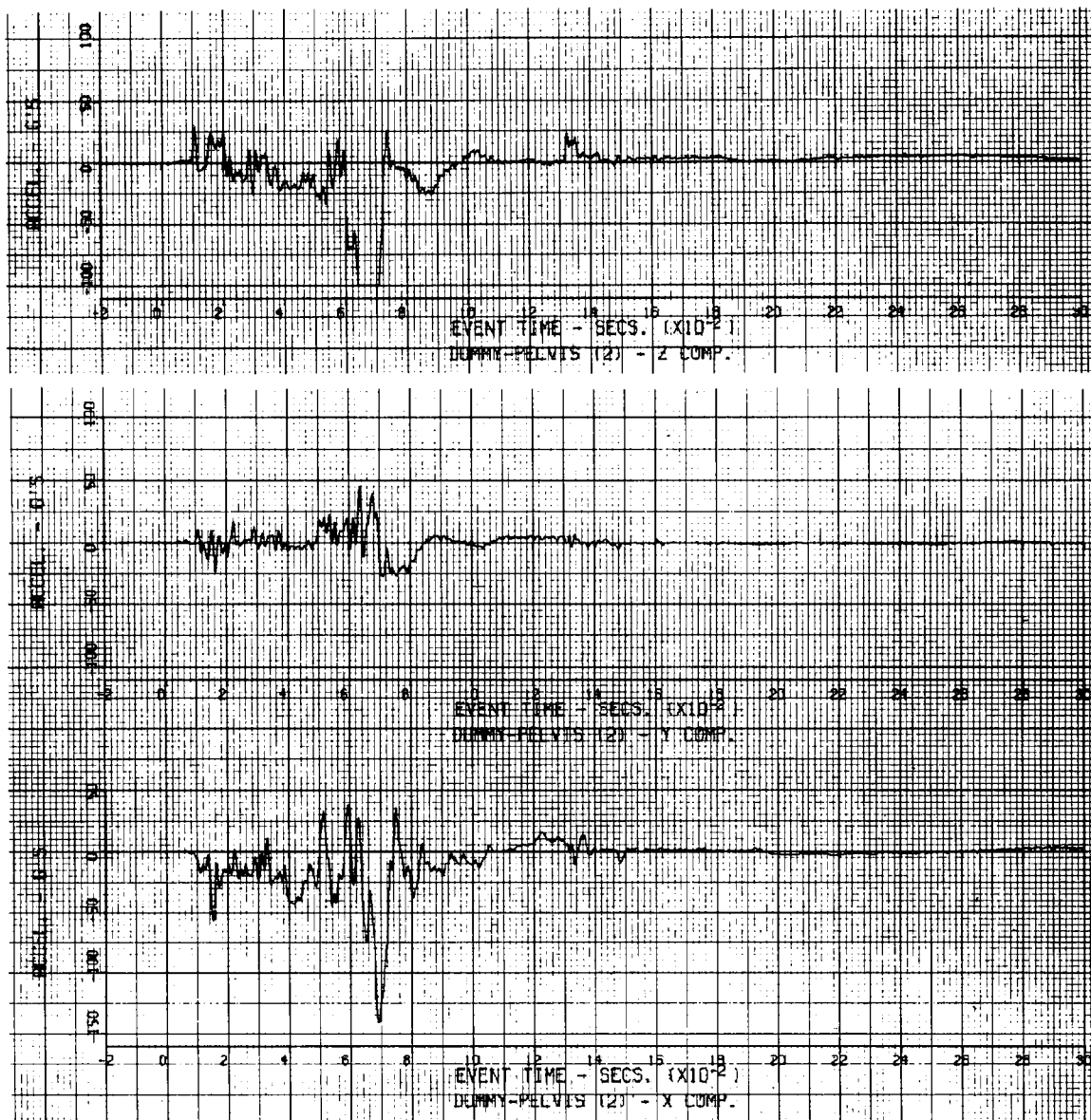


Figure B-30 RIGHT FRONT PASSENGER DUMMY PELVIS ACCELERATION AND FEMUR DATA (TEST 77)

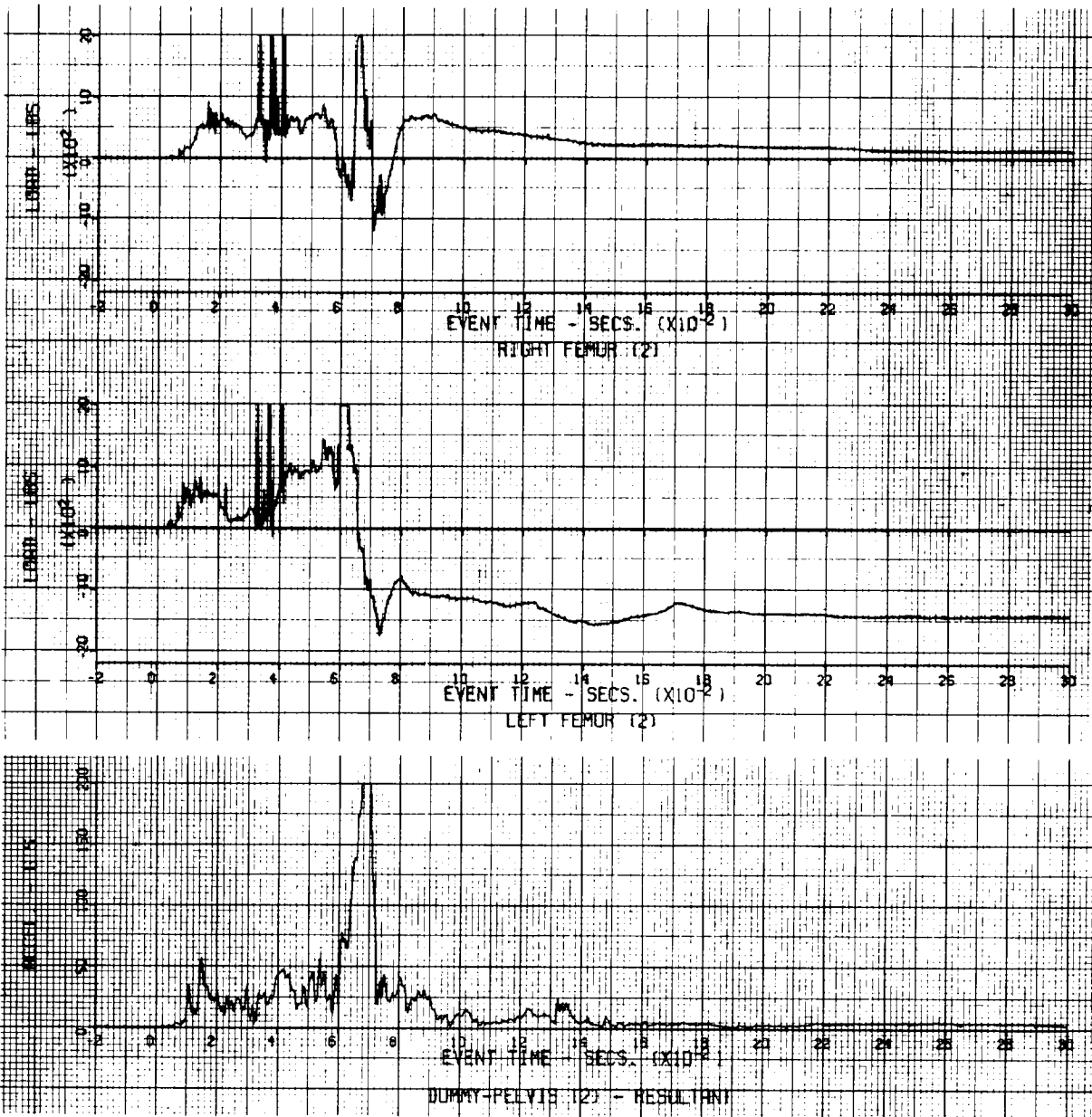


Figure B-30 (Cont.) RIGHT FRONT PASSENGER DUMMY PELVIS ACCELERATION AND FEMUR LOAD DATA (TEST 77)

Test 84 Data

The following items are included:

1. Instrumentation requirements
2. Test site location of sensors and cameras
3. Before and after test photographs
4. Engine acceleration data
5. Passenger compartment acceleration data
6. Pole barrier loads
7. Driver data
8. Right front passenger data

Note: Due to an instrumentation malfunction, an erroneous signal was recorded in all data channels during the time period 0.020 - 0.025 sec. Therefore, linear interpolation was applied to the raw data for all channels during this time period.

INSTRUMENTATION REQUIREMENTS

FACILITY TEST NO. 148 PROGRAM TEST NO. 84
 PROGRAM: Crashworthiness II
 TEST DESCRIPTION: Pole obstacle impact
 VEHICLE TYPE: OV-II

VEHICLE DESIGNATION	COM- PONENT	COMPARTMENT				ENGINE	DUMMIES(1, 2)				RESTRAINT *			RECORDER	OTHER
		TUNNEL	(1) (4)	(2) (3)	REAR DECK		OTHER	HEAD	CHEST	PELVIS	LAP	SHOULDER	OTHER		
OV-II	X	A	1A, 2A, 3A, 4A			A	A	A	A					POLE X-comp. only	
	Y	A	1A, 2A, 3A, 4A				A	A	A						
	Z	A	1A, 2A, 3A, 4A				A	A	A						
	X														
	Y														
	Z														

LEGEND:

A - ACCELEROMETER
 V - VELOCITY METER
 D - DISPLACEMENT METER
 L - LOAD CELL

**DESCRIBE "OTHER"

**IF MORE THAN 1 DUMMY, NUMBER
 SEQUENTIALLY IN CLOCKWISE (FROM TOP VIEW)
 DIRECTION (i.e. DRIVER 1, PASS FRONT 2, etc)

MISCELLANEOUS

1) CONTACT SWITCH/BAR:

2) AIR BAG SENSORS:

3) POSITION OF CARS:

4) SPEED WINDOW: 57.7 ± 2.5 MPH

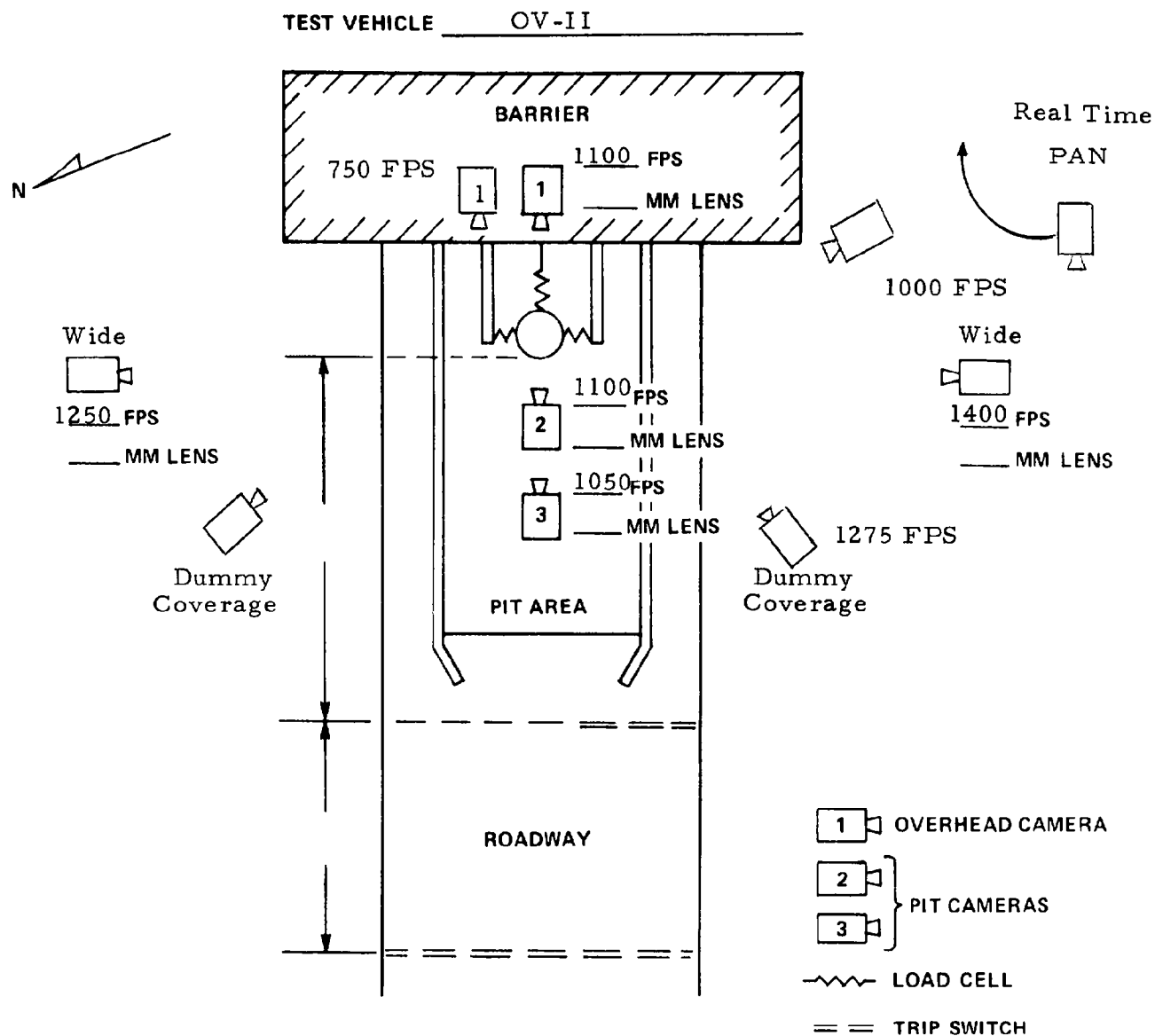
*Olin air bag system

PROJECT: Crashworthiness II

TEST NO: 84

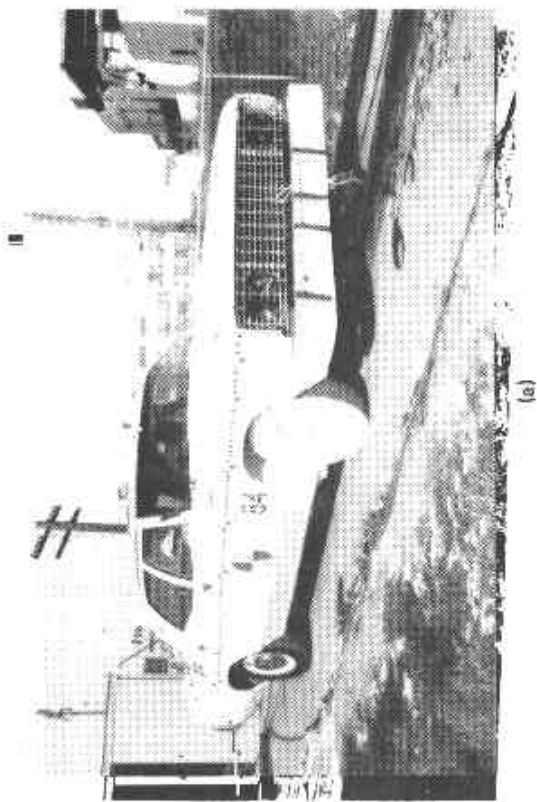
FACILITY TEST NO: 148

TEST SITE LOCATION OF SENSORS AND CAMERAS



REMARKS:

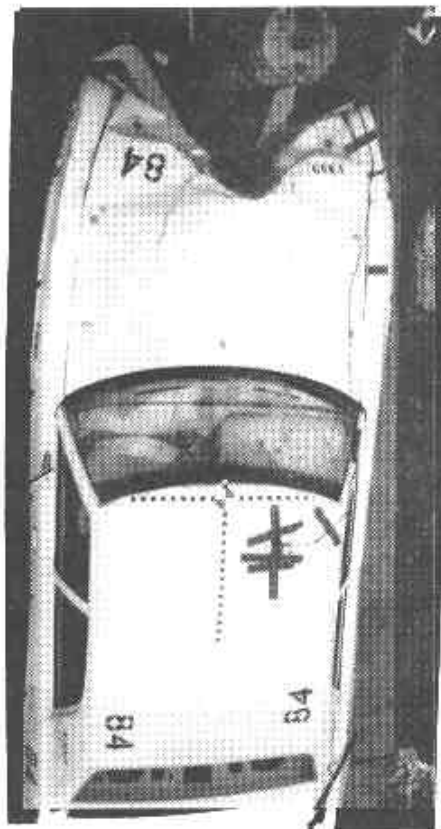
Wide - indicates complete vehicle coverage



(a)



(b)

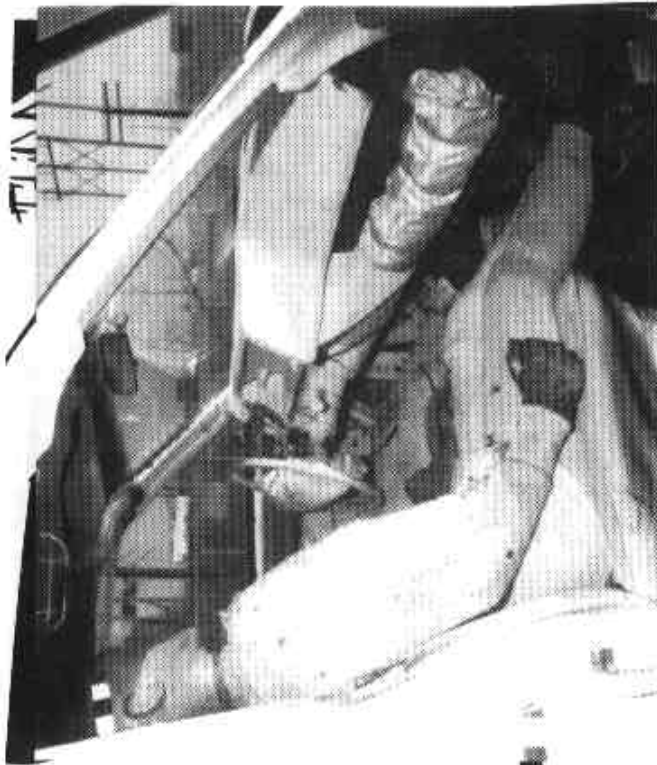


(c)



(d)

Figure B-31 EXTERIOR BEFORE AND AFTER IMPACT VIEWS OF OV-II VEHICLE (TEST 84)

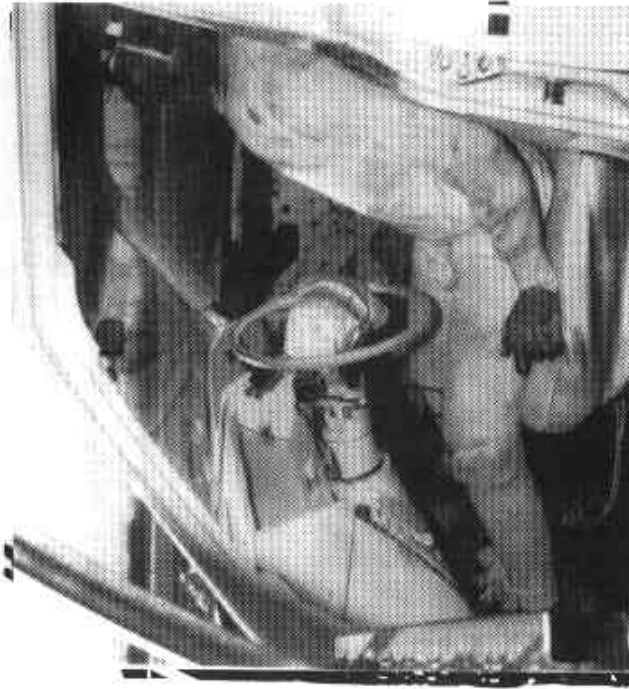


(a)

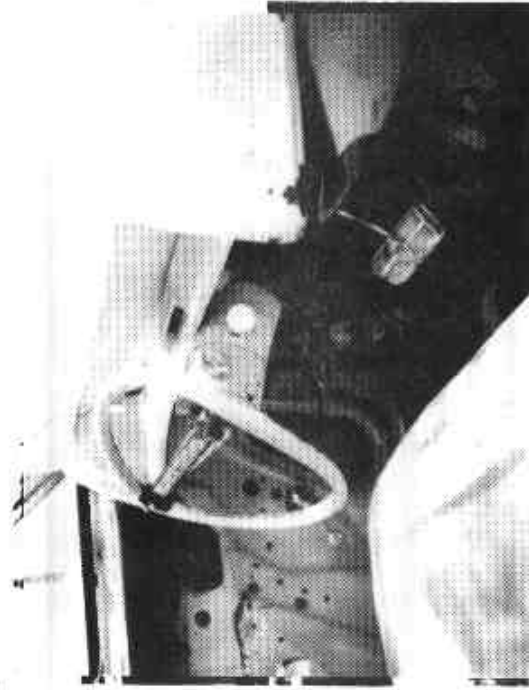
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(c)



(b)



(d)

Figure B-32 INTERIOR BEFORE AND AFTER IMPACT VIEWS OF OV-II VEHICLE (TEST 84)

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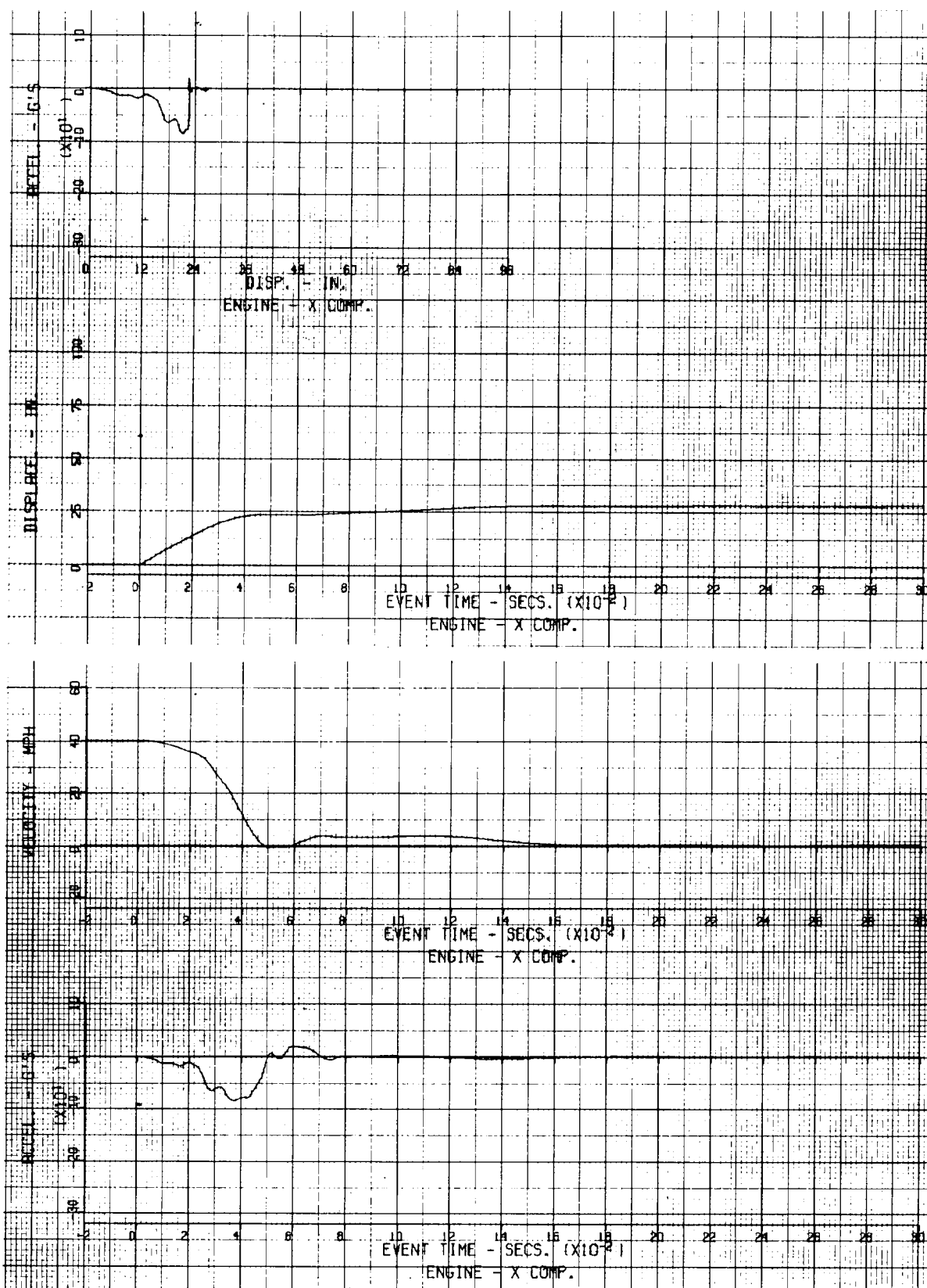


Figure B-33 ENGINE LONGITUDINAL KINEMATIC DATA (TEST 84)

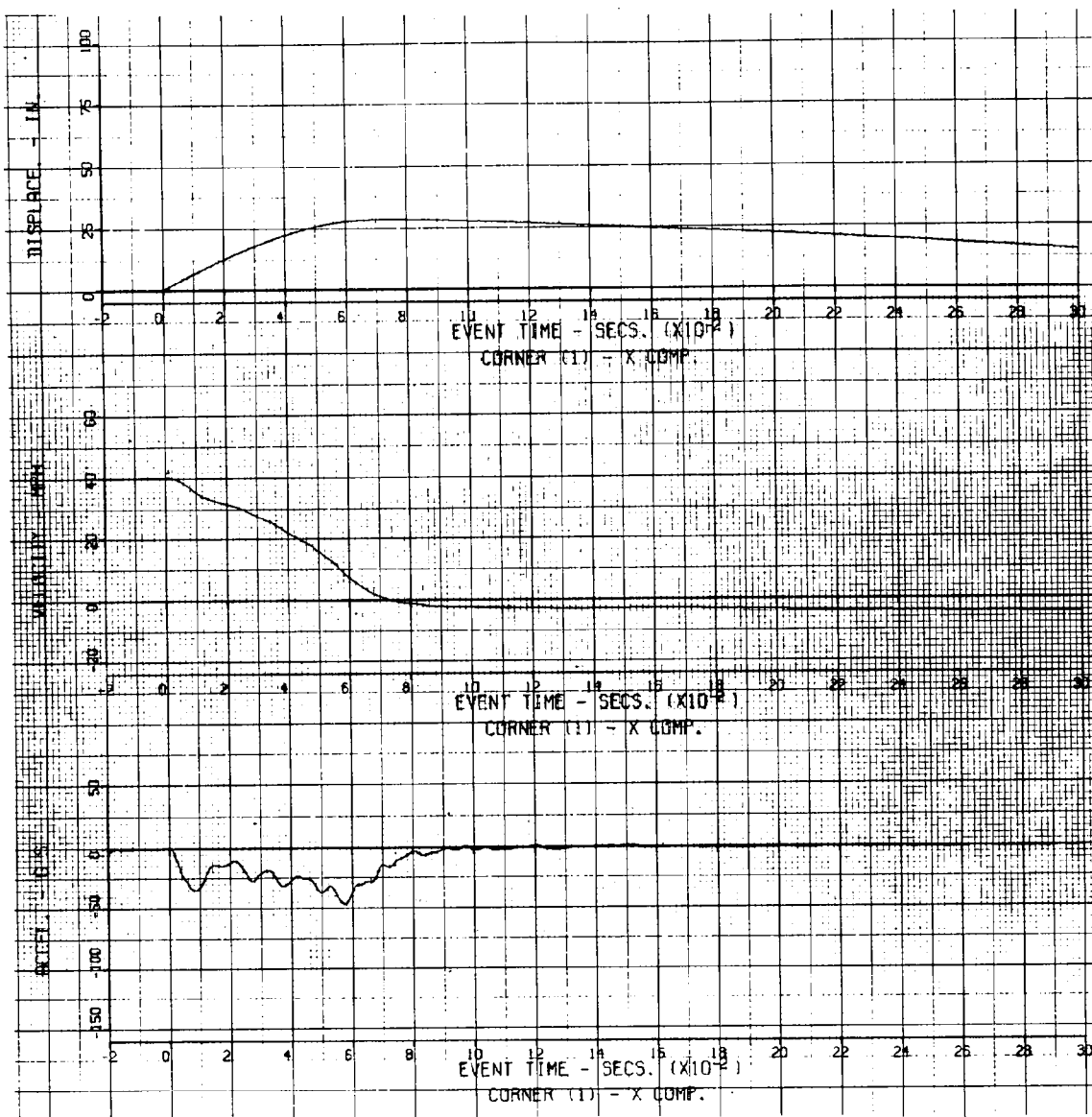


Figure B-34 PASSENGER COMPARTMENT ACCELERATION AND LONGITUDINAL KINEMATIC DATA, LEFT FRONT CORNER LOCATION (TEST 84)

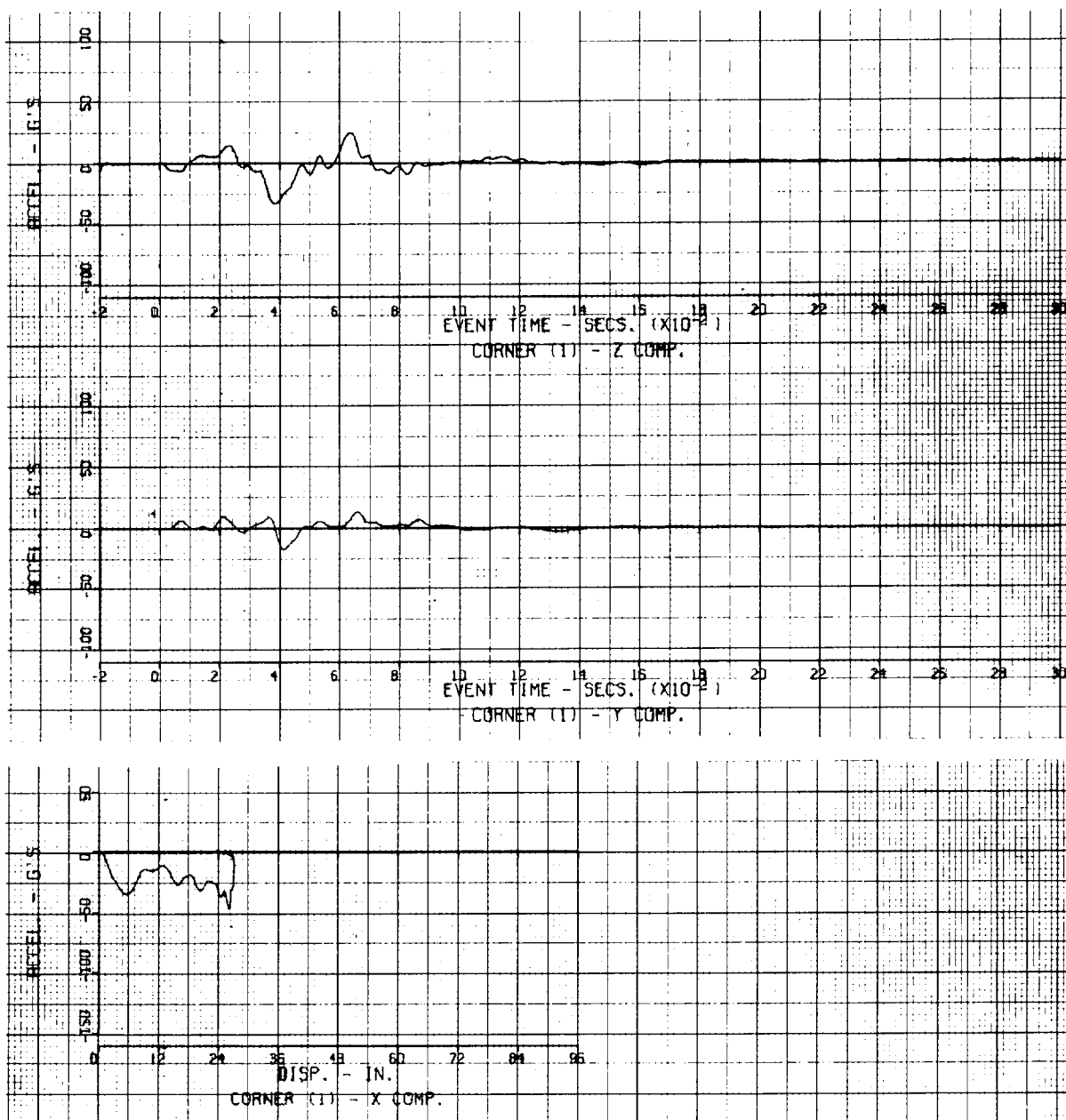


Figure B-34 (Cont.) PASSENGER COMPARTMENT ACCELERATION AND LONGITUDINAL KINEMATIC DATA, LEFT FRONT CORNER LOCATION (TEST 84)

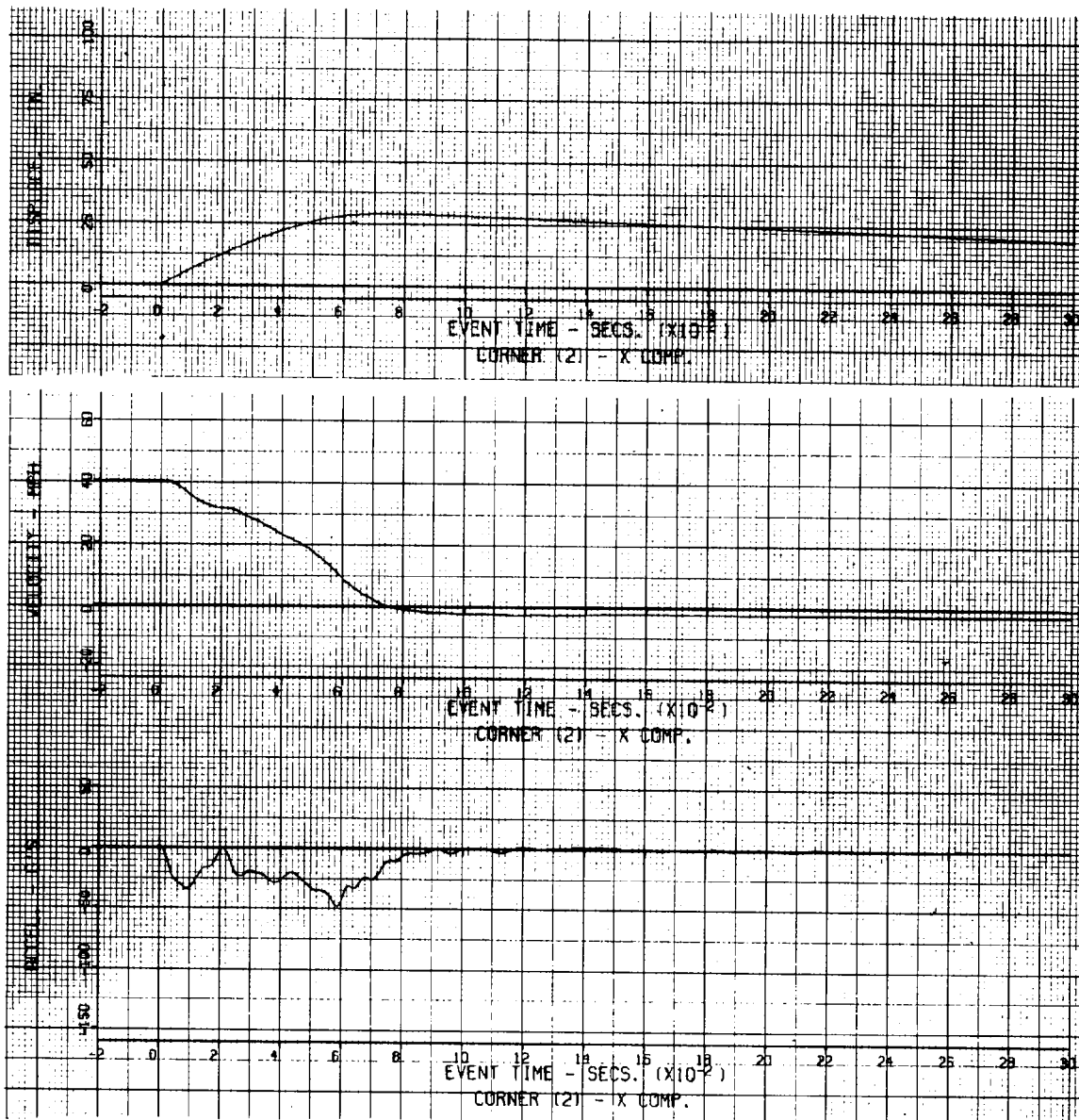


Figure B-35 PASSENGER COMPARTMENT ACCELERATION AND LONGITUDINAL KINEMATIC DATA, RIGHT FRONT CORNER LOCATION (TEST 84)

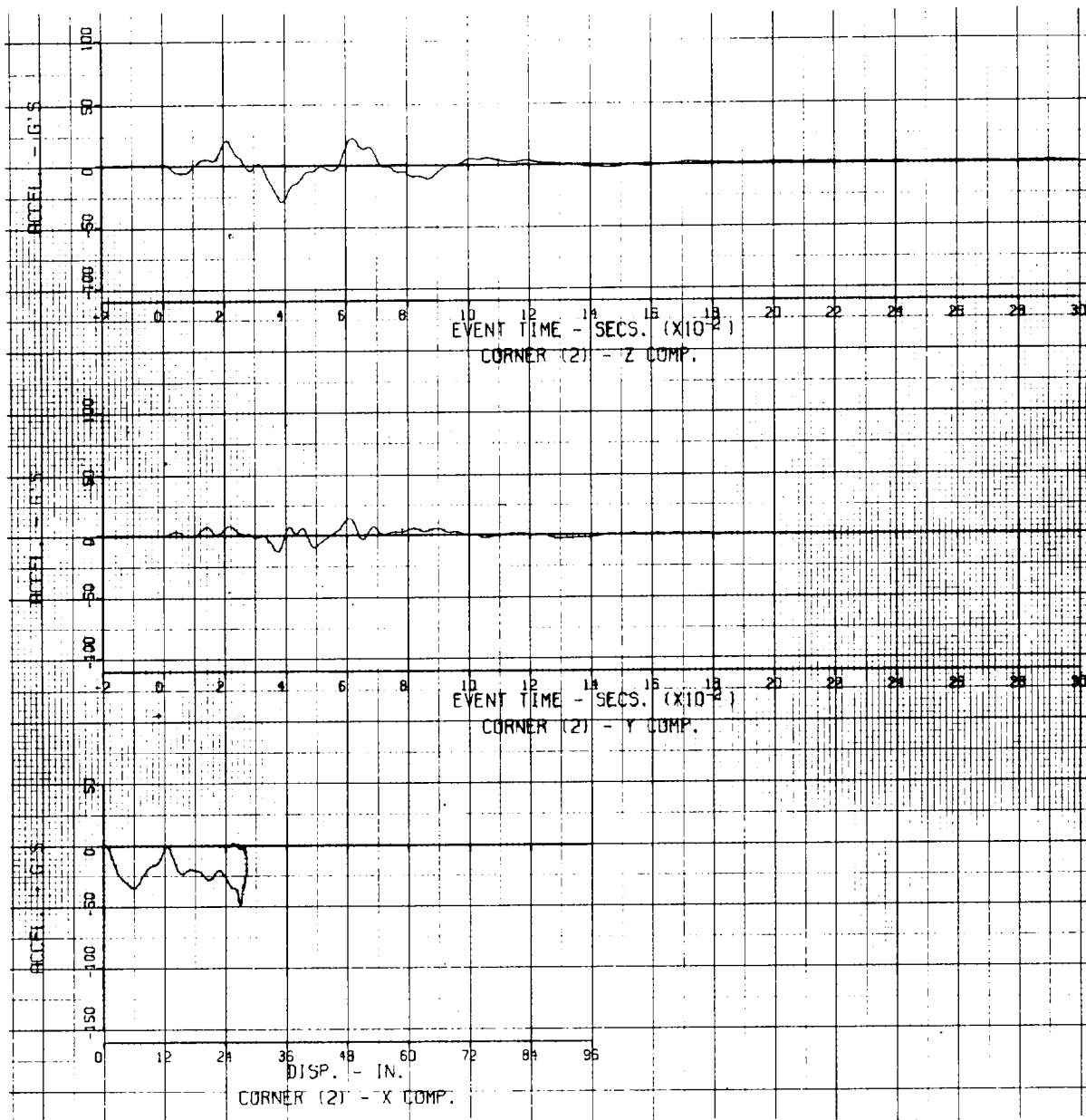


Figure B-35 (Cont.) PASSENGER COMPARTMENT ACCELERATION AND LONGITUDINAL KINEMATIC DATA, RIGHT FRONT CORNER LOCATION (TEST 84)

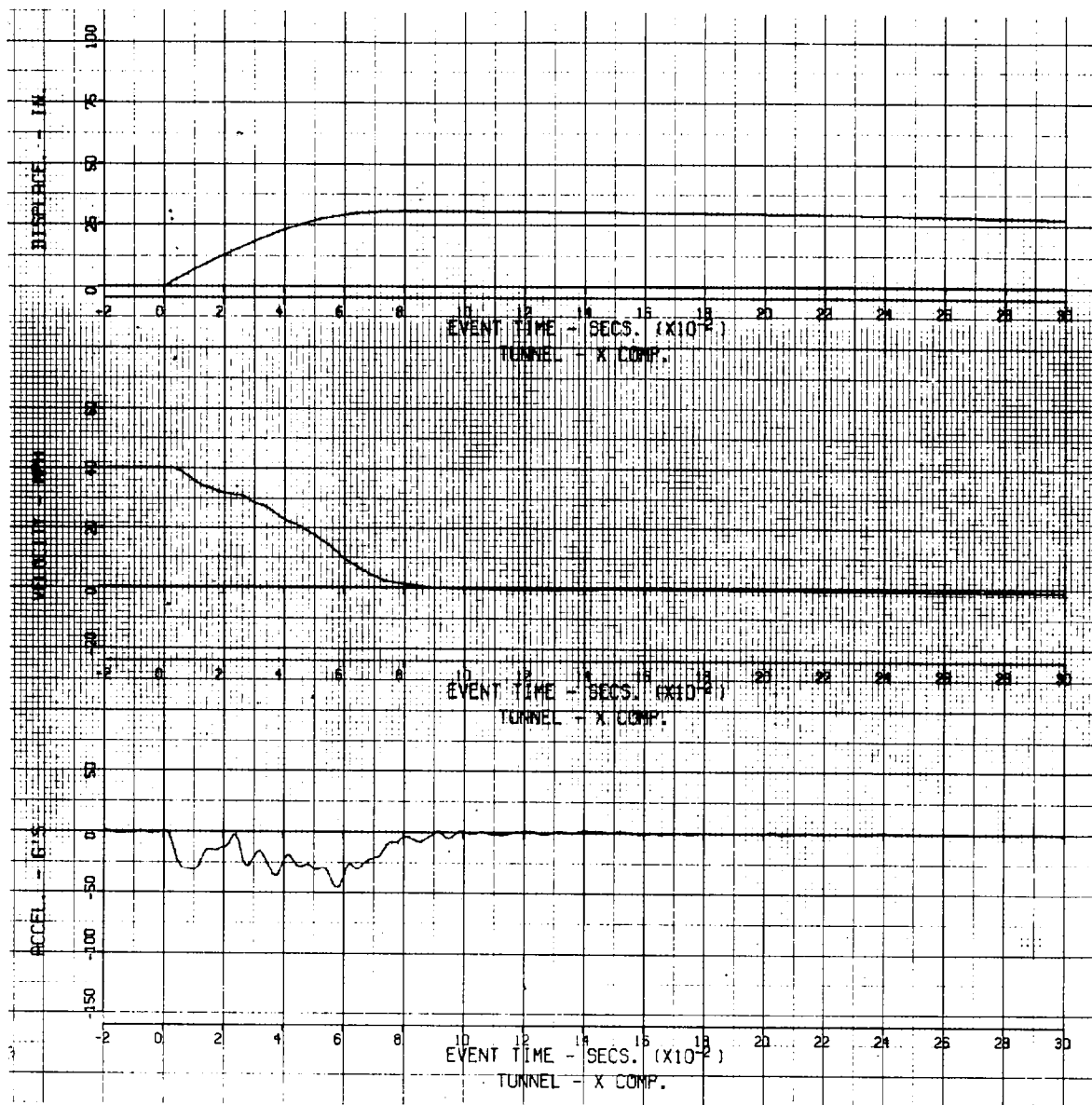


Figure B-36 PASSENGER COMPARTMENT ACCELERATION AND LONGITUDINAL KINEMATIC DATA, TUNNEL LOCATION (TEST 84)

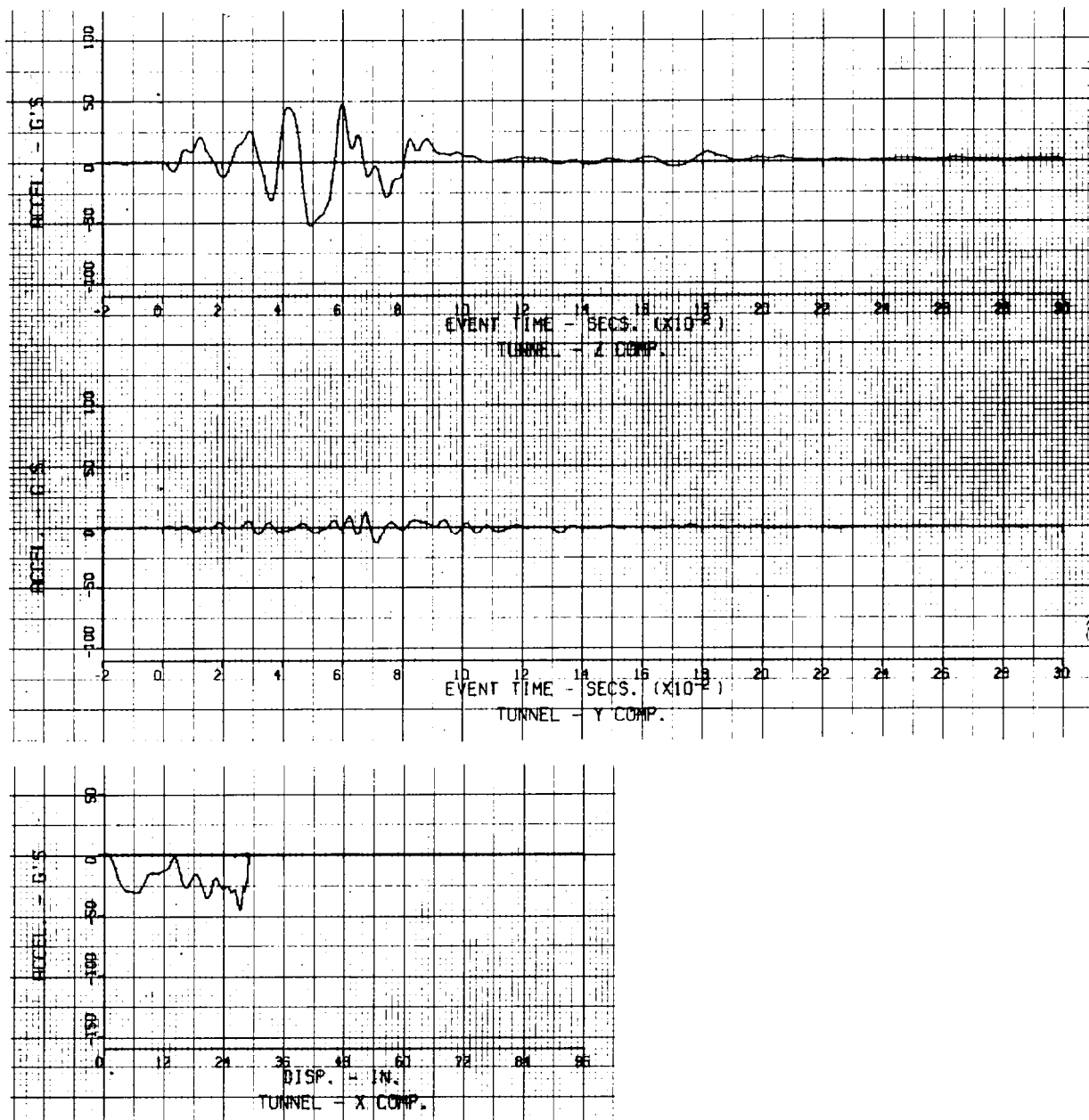


Figure B-36 (cont.) PASSENGER COMPARTMENT ACCELERATION AND LONGITUDINAL KINEMATIC DATA, TUNNEL LOCATION (TEST 84)

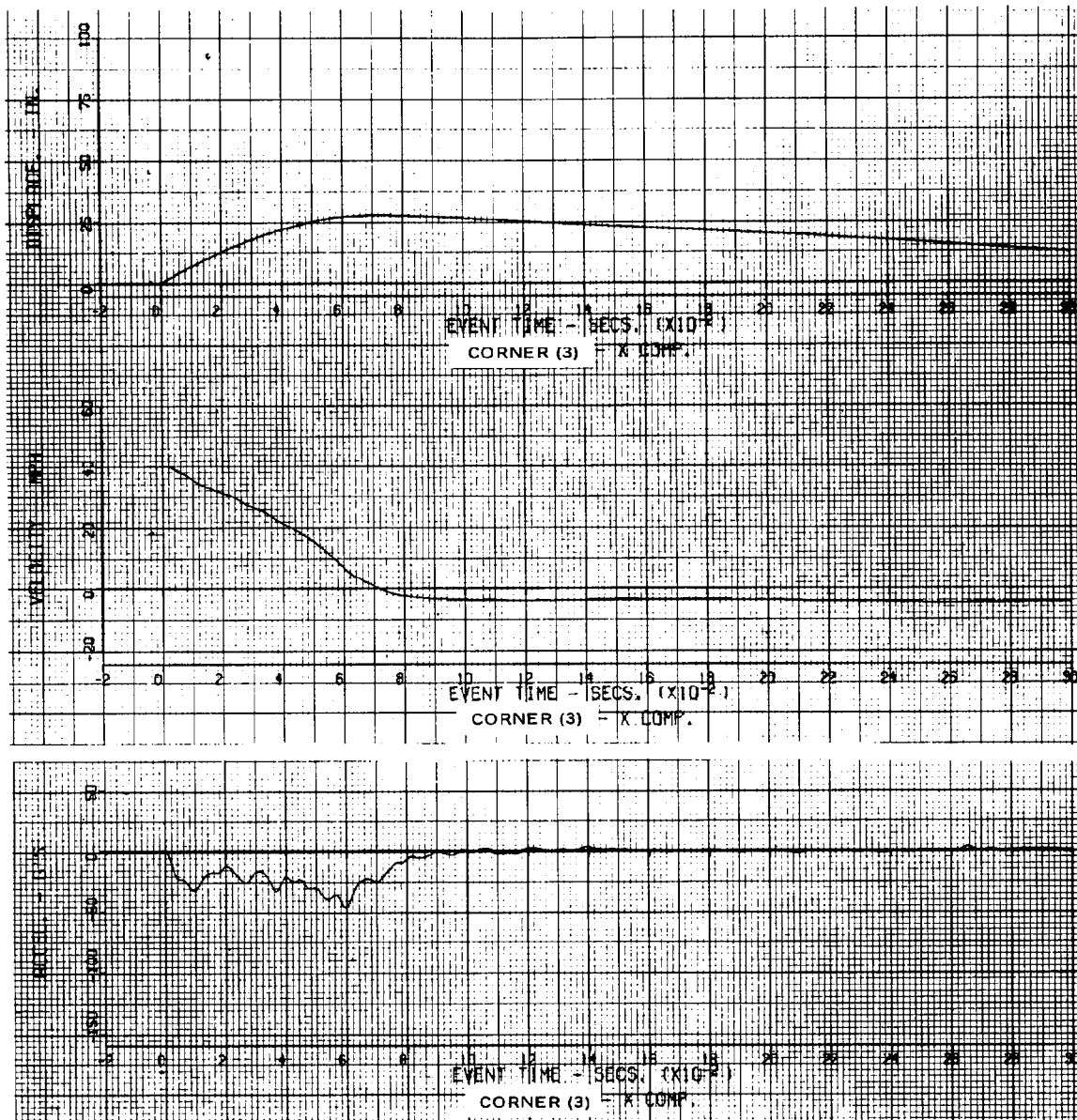


Figure B-37 PASSENGER COMPARTMENT ACCELERATION AND LONGITUDINAL KINEMATIC DATA, RIGHT REAR CORNER LOCATION (TEST 84)

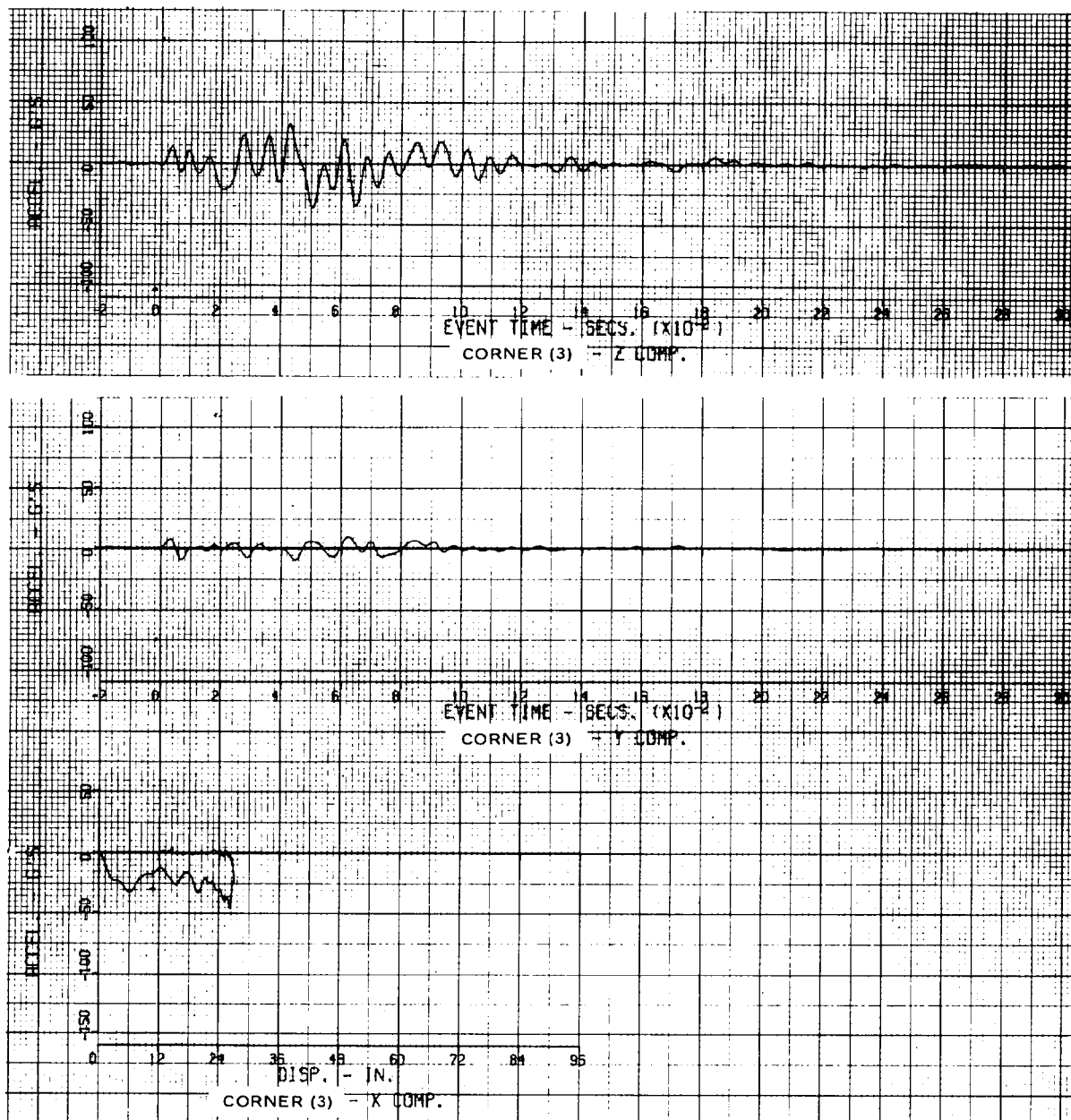


Figure B-37 (Cont.) PASSENGER COMPARTMENT ACCELERATION AND LONGITUDINAL KINEMATIC DATA, RIGHT REAR CORNER LOCATION (TEST 84)

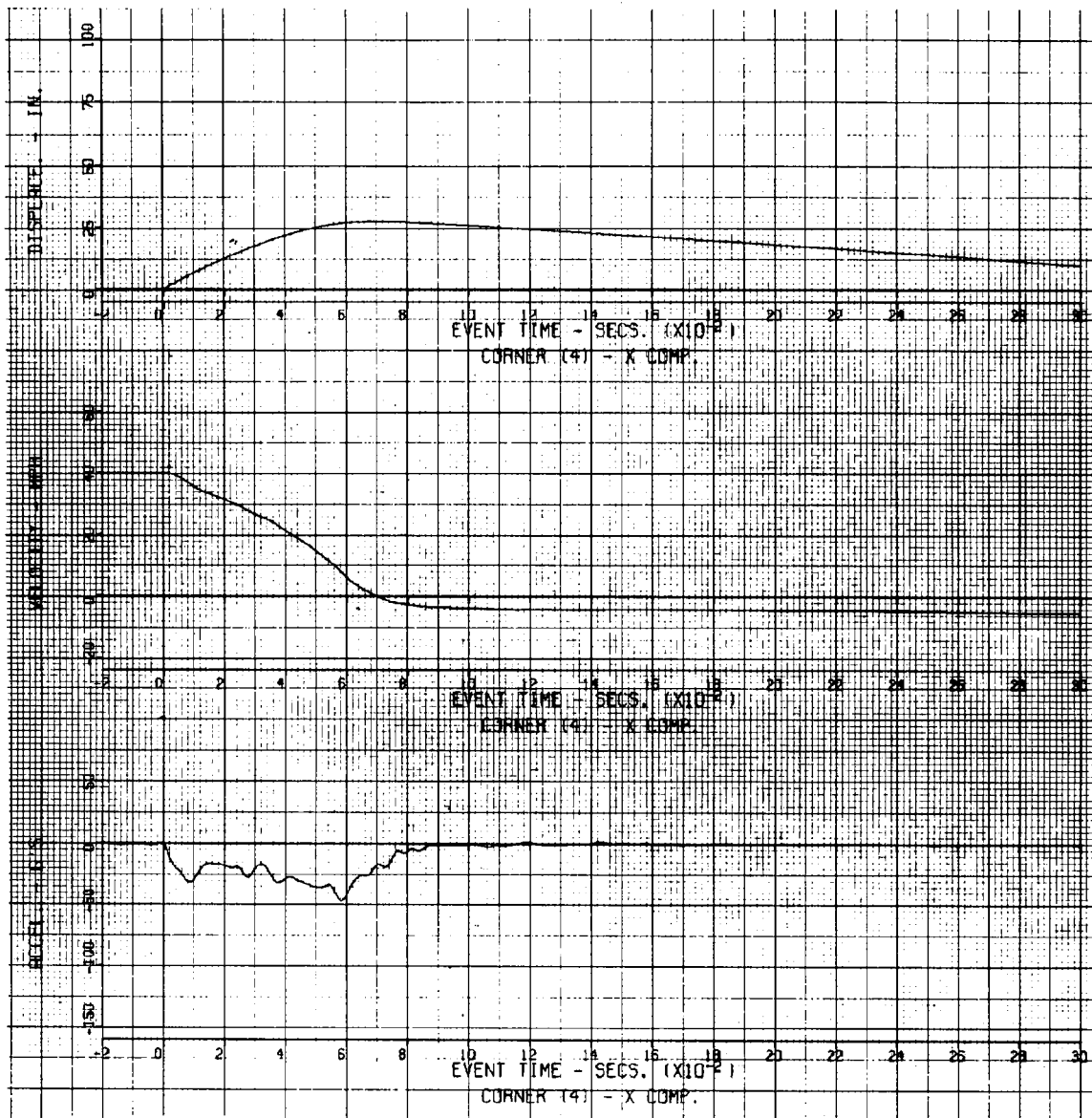


Figure B-38 PASSENGER COMPARTMENT ACCELERATION AND LONGITUDINAL KINEMATIC DATA, LEFT REAR CORNER LOCATION (TEST 84)

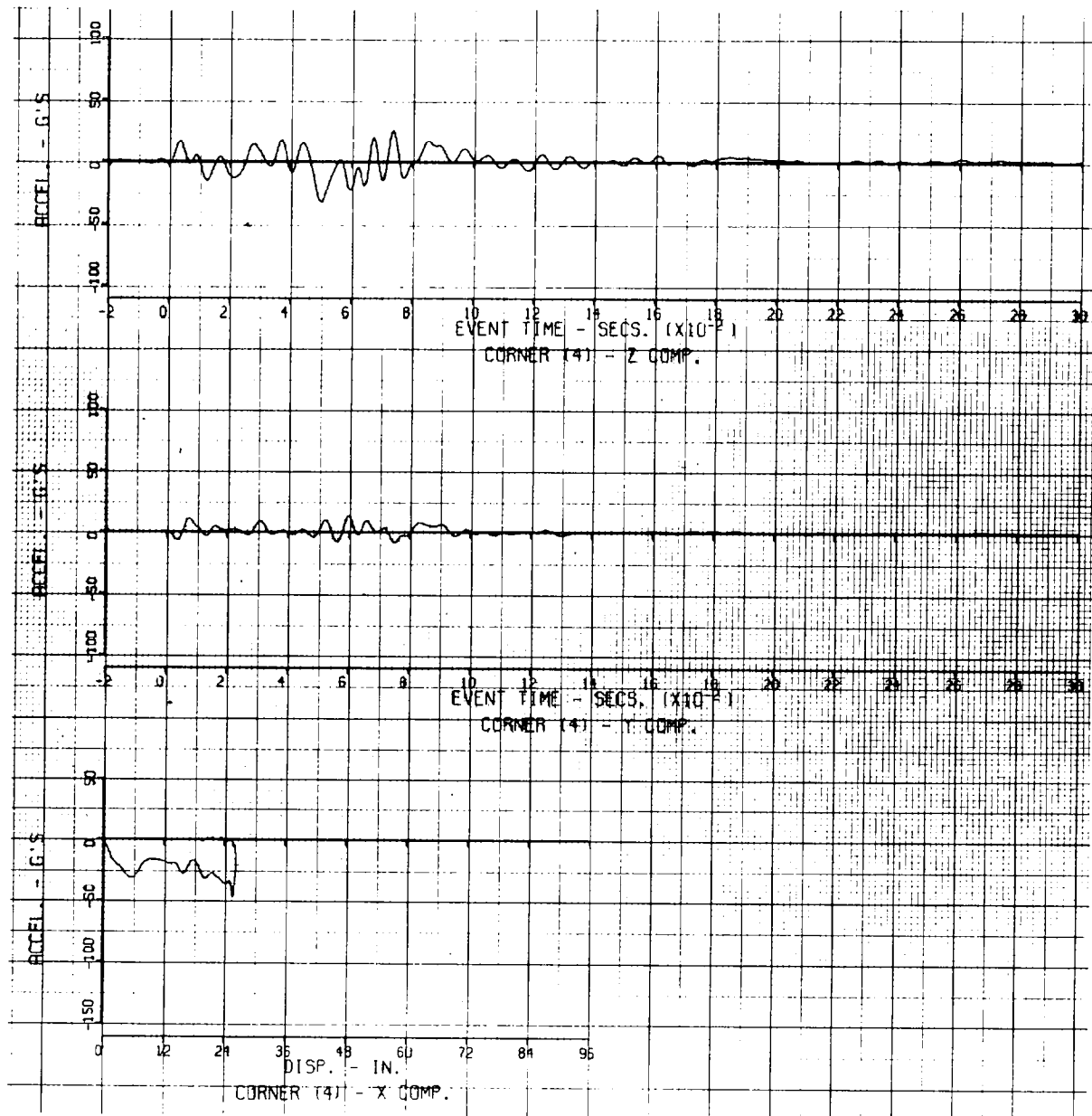


Figure B-38 (Cont.) PASSENGER COMPARTMENT ACCELERATION AND LONGITUDINAL KINEMATIC DATA, LEFT REAR CORNER LOCATION (TEST 84)

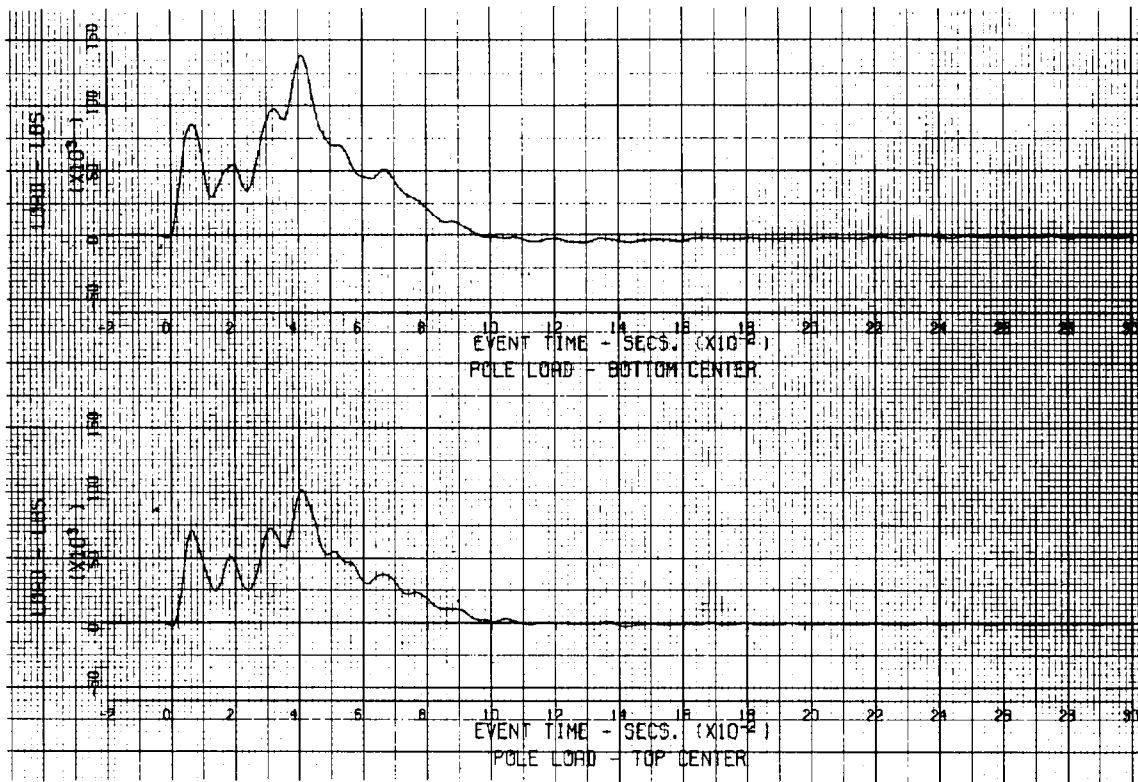


Figure B-39 LONGITUDINAL FORCES MEASURED ON POLE BARRIER (TEST 84)

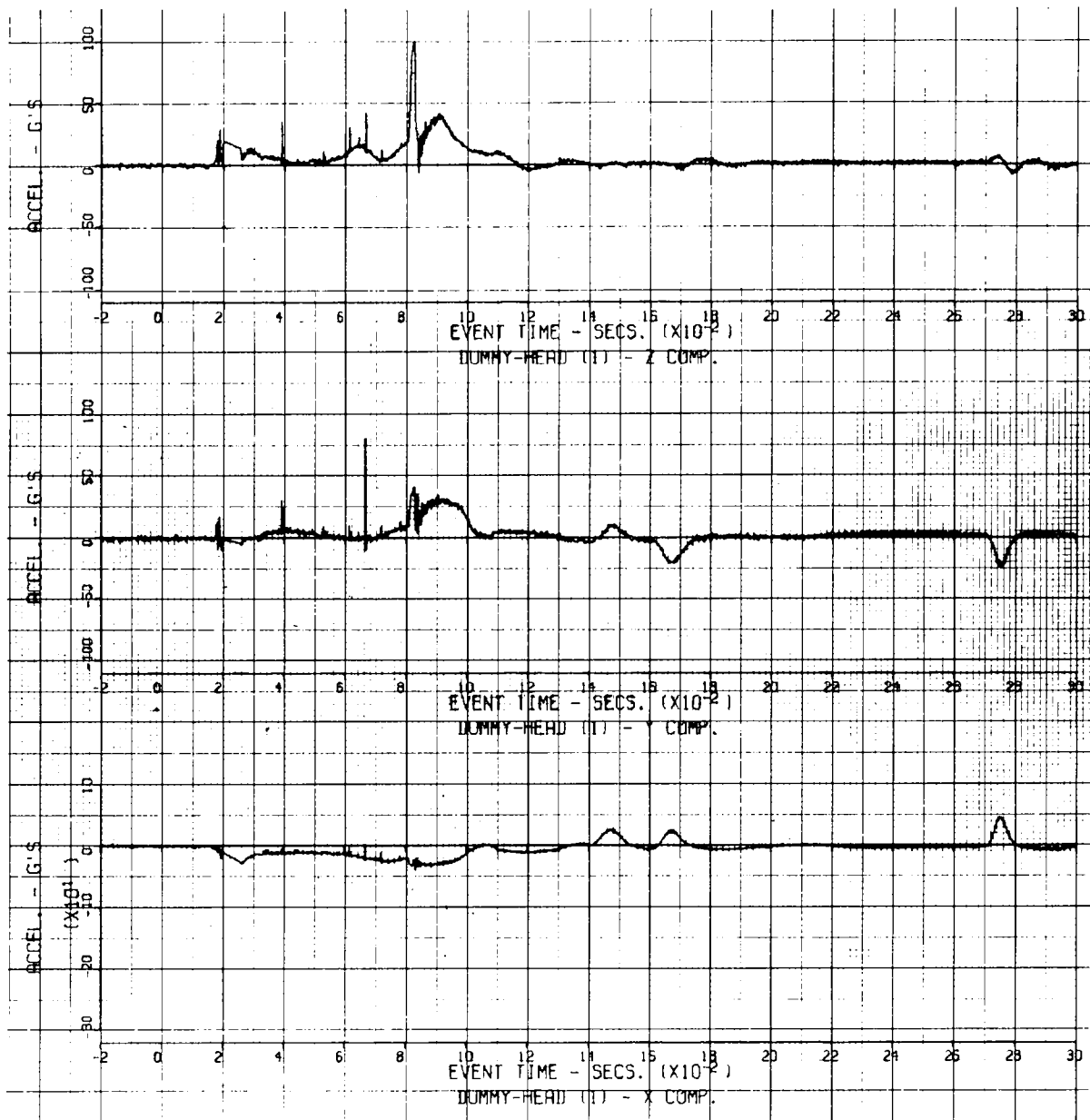


Figure B-40 DRIVER HEAD ACCELERATION (TEST 84)

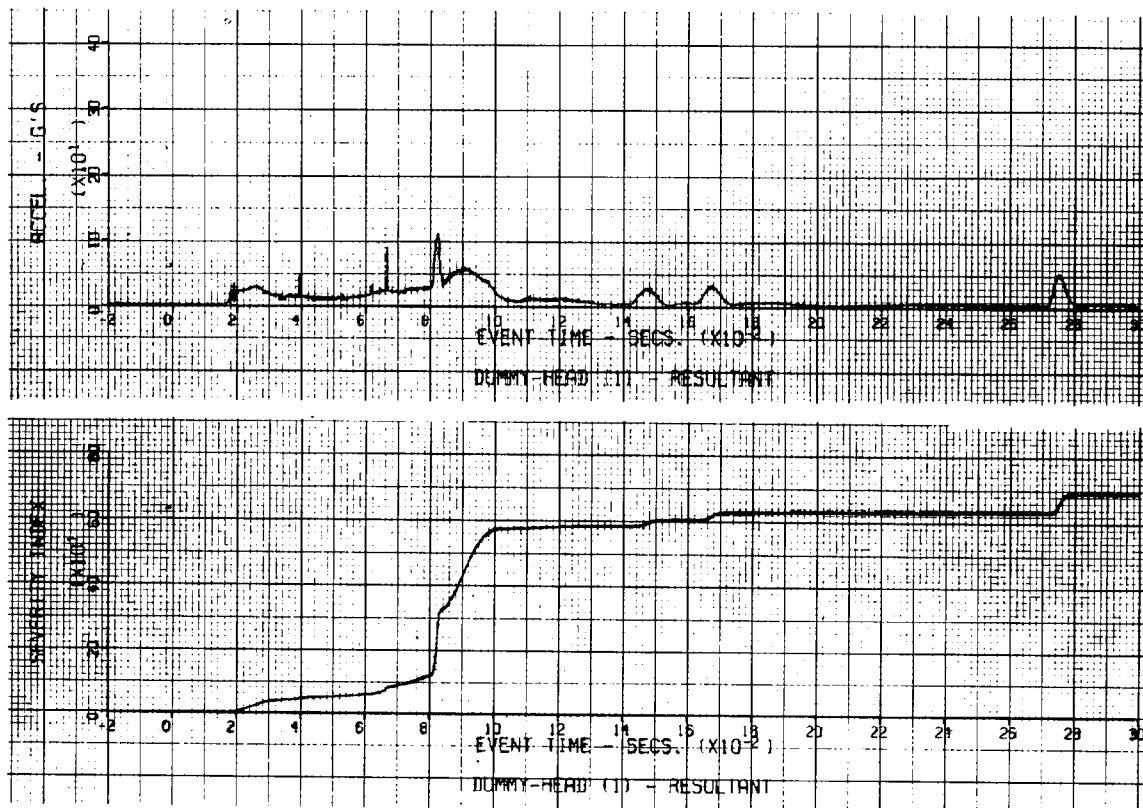


Figure B-40 (Cont.) DRIVER HEAD ACCELERATION (TEST 84)

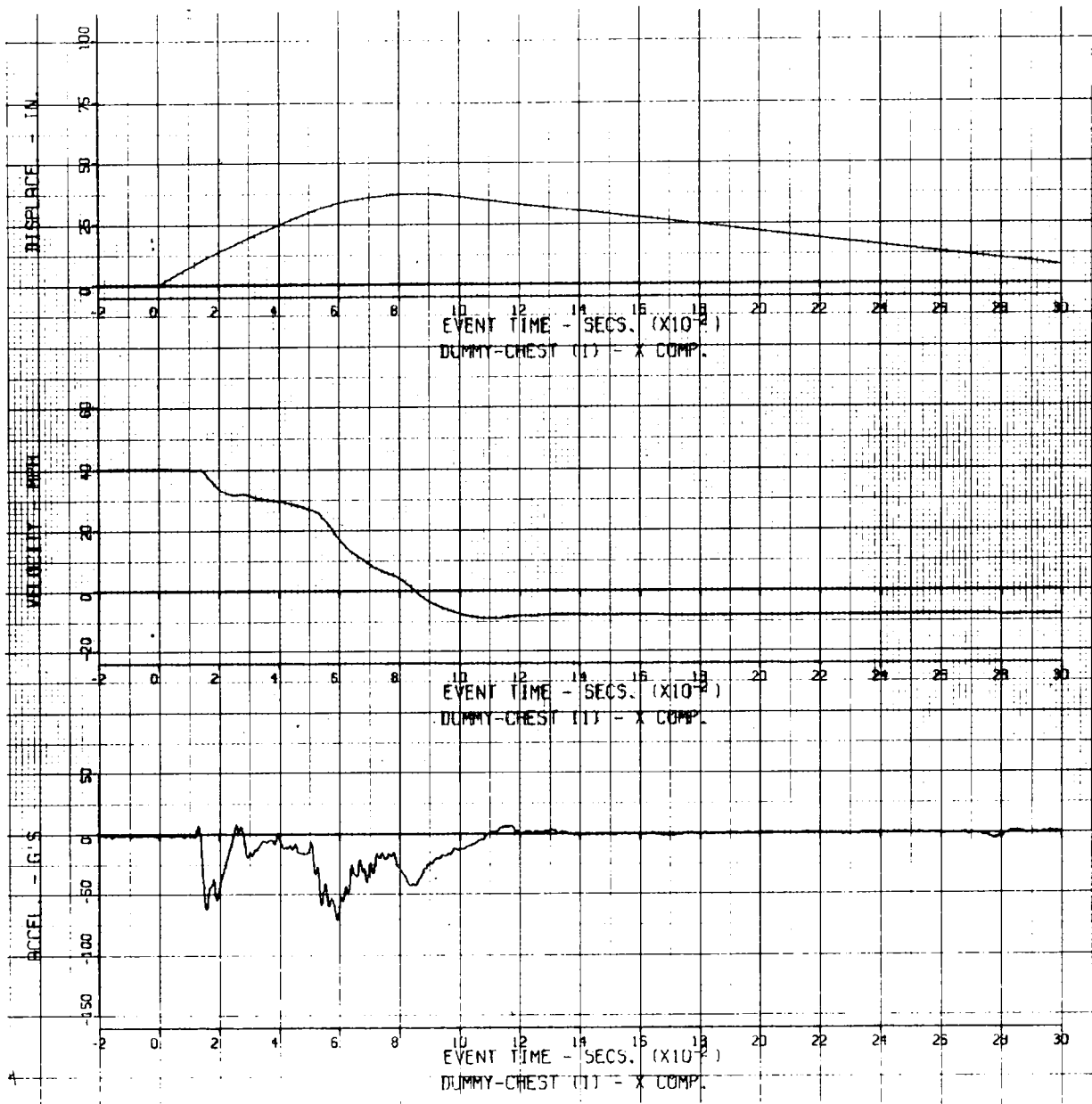


Figure B-41 DRIVER CHEST ACCELERATION AND LONGITUDINAL KINEMATIC DATA (TEST 84)

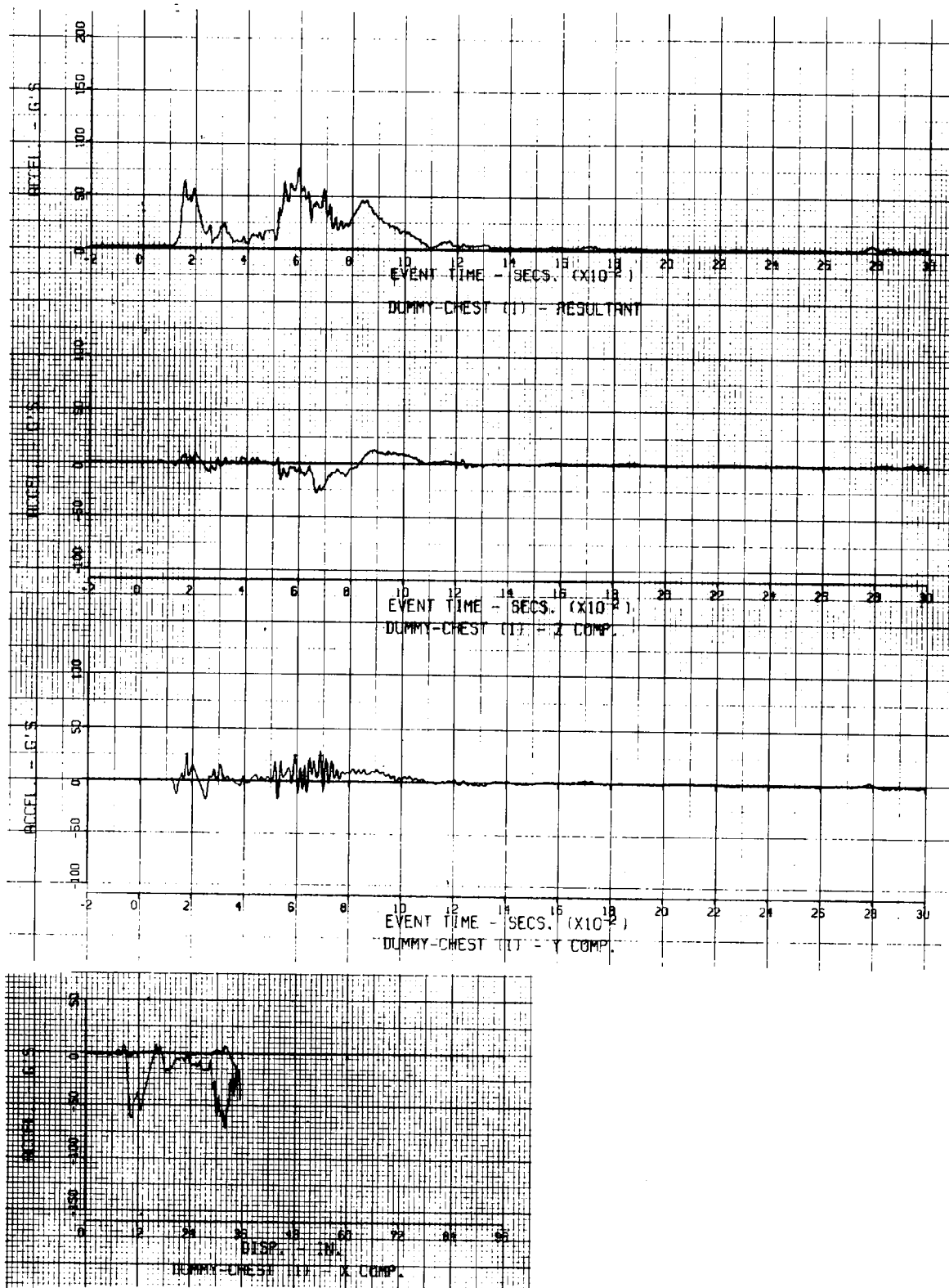


Figure B-41 (cont.) DRIVER CHEST ACCELERATION AND LONGITUDINAL KINEMATIC DATA (TEST 84)

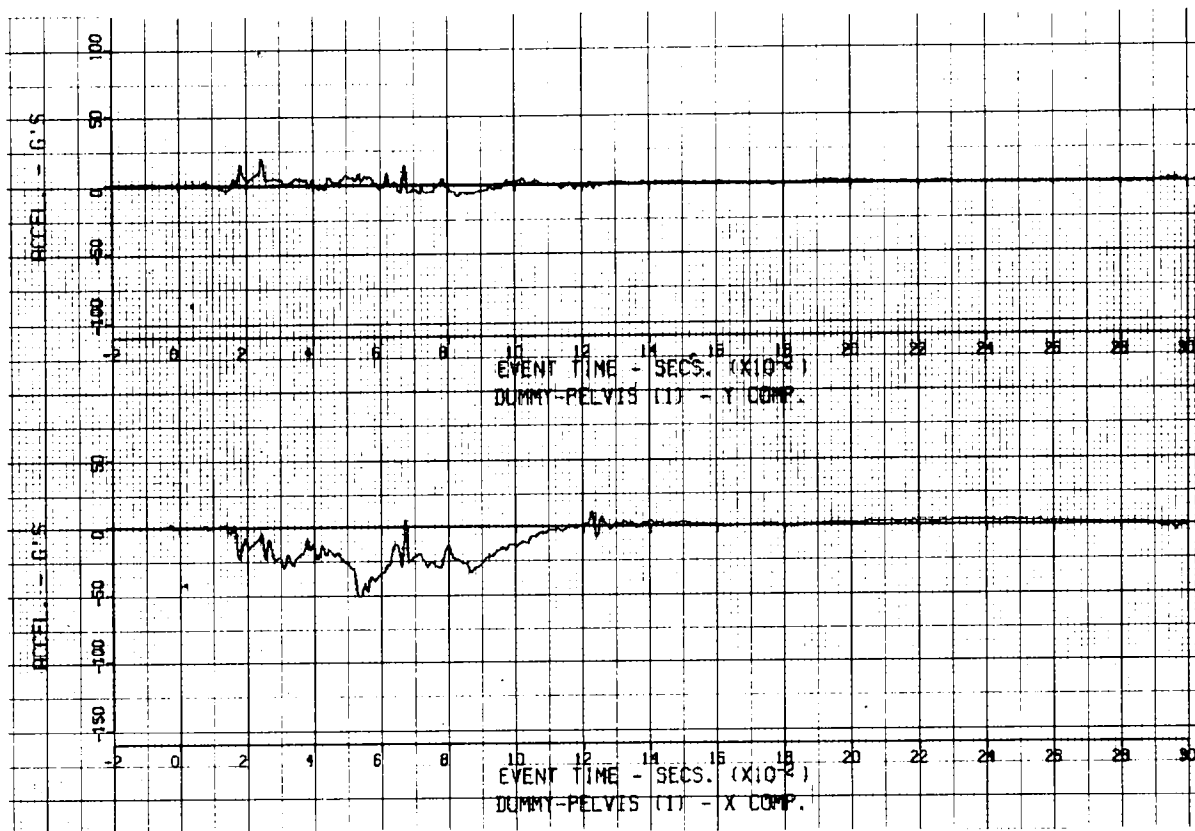


Figure B-42 DRIVER PELVIS ACCELERATION (TEST 84)

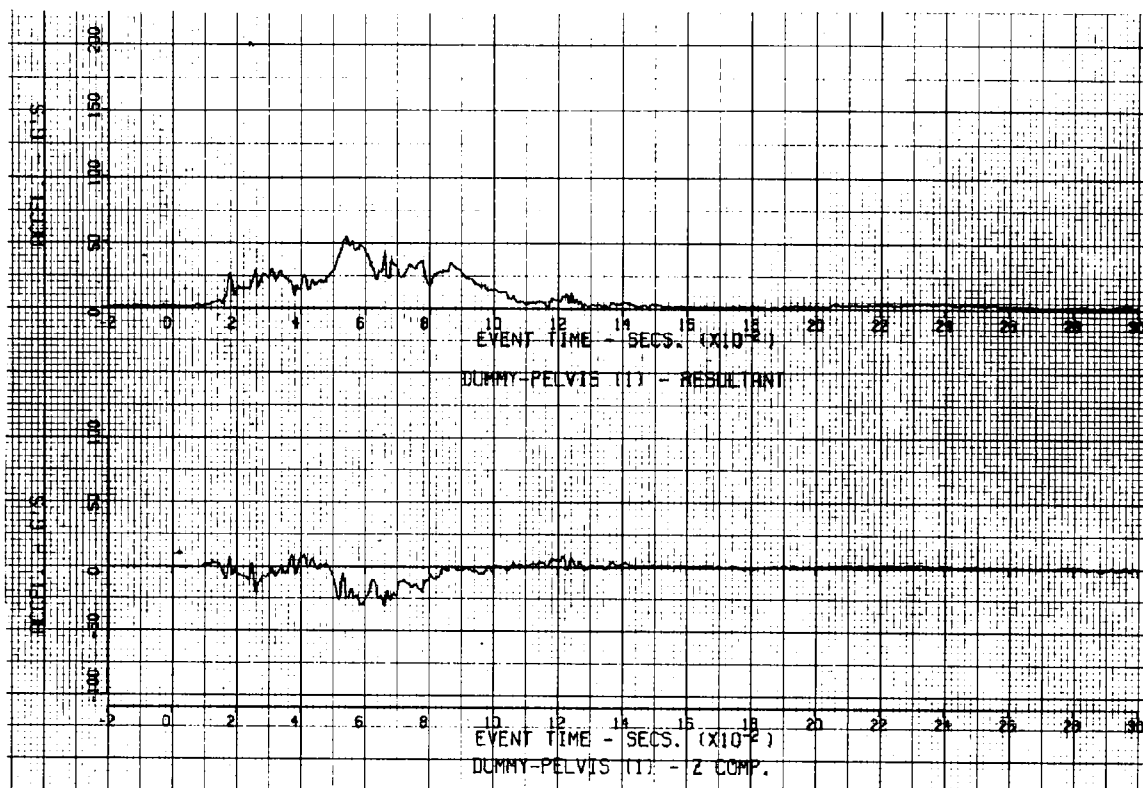


Figure B-42 (Cont.) DRIVER PELVIS ACCELERATION (TEST 84)

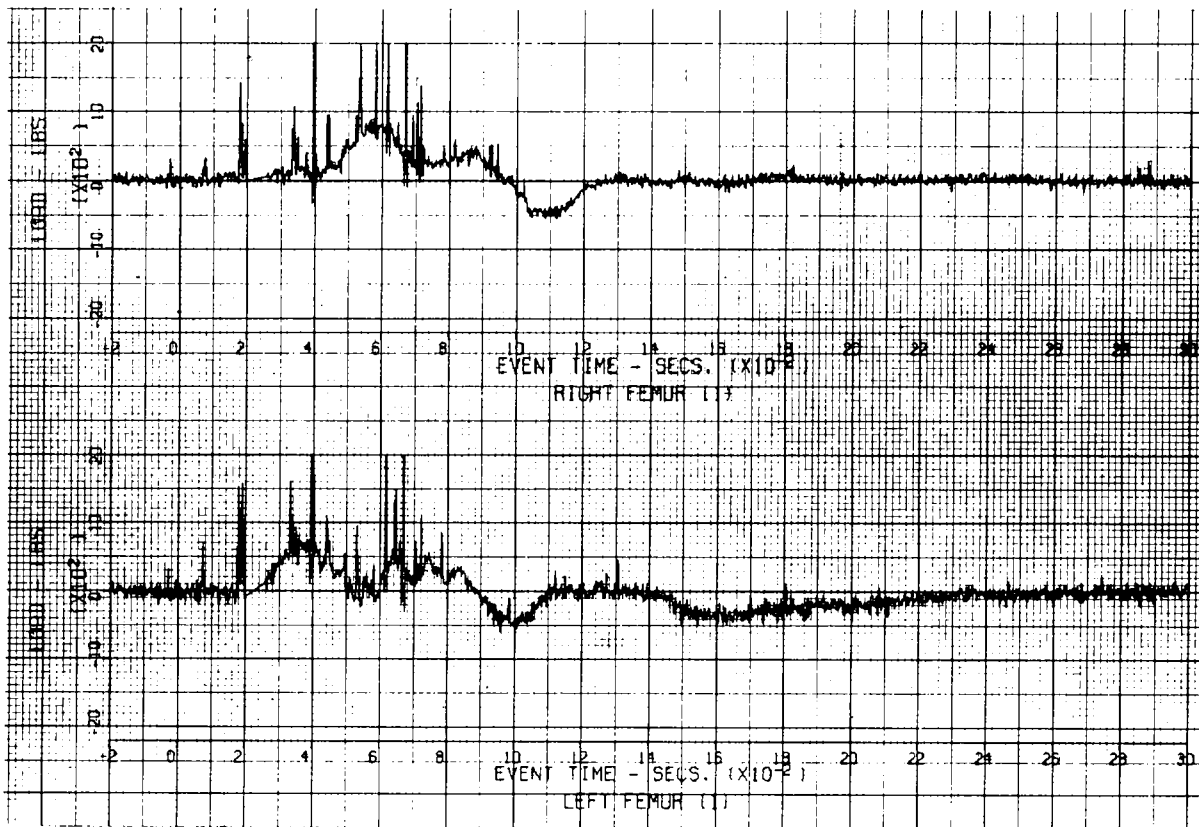


Figure B-43 DRIVER FEMUR LOAD DATA (TEST 84)

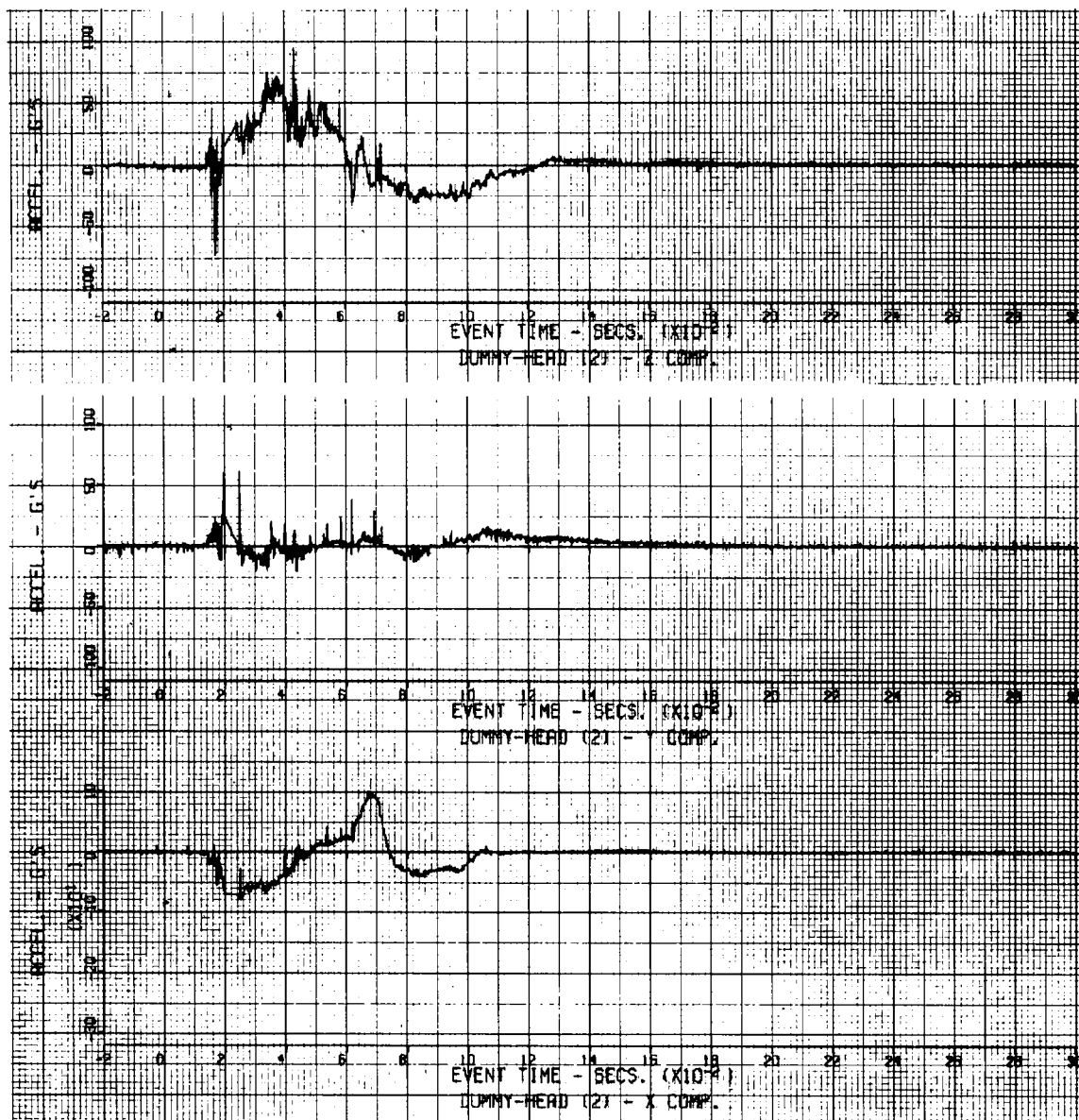


Figure B-44 RIGHT FRONT PASSENGER HEAD ACCELERATION (TEST 84)

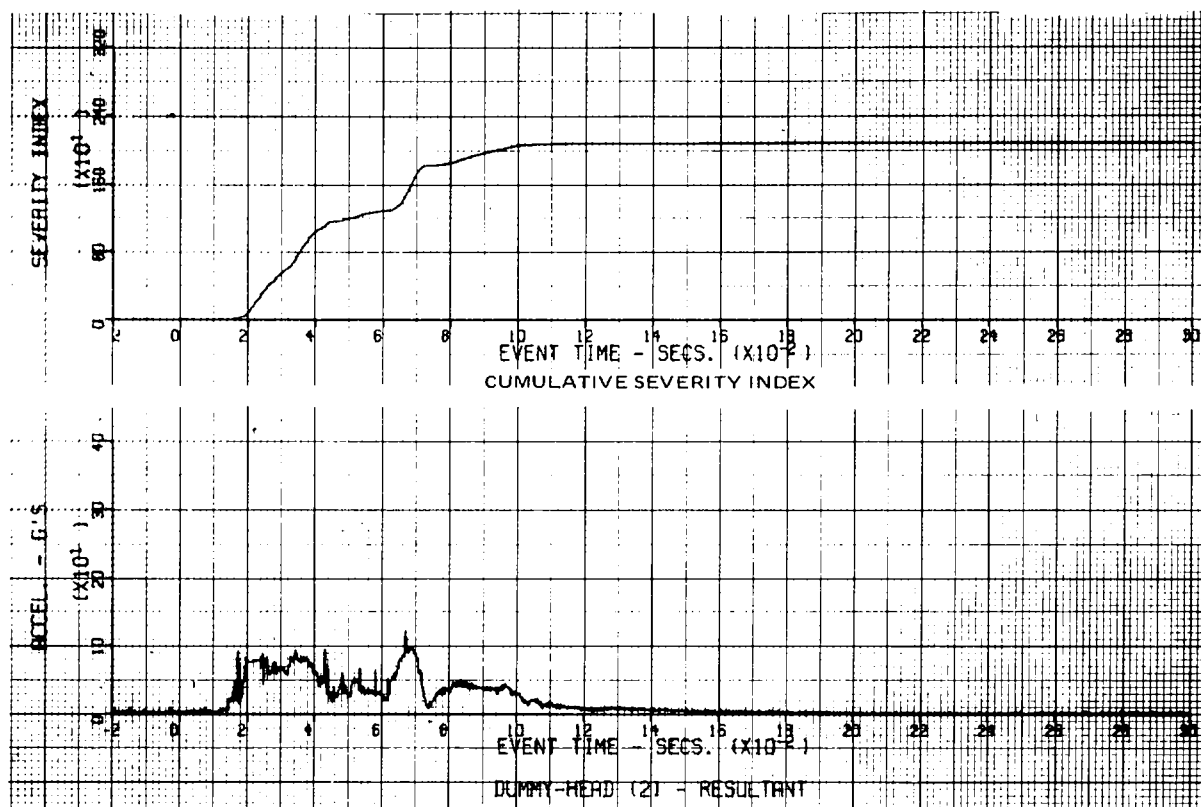


Figure B-44 (cont.) RIGHT FRONT PASSENGER HEAD ACCELERATION (TEST 84)

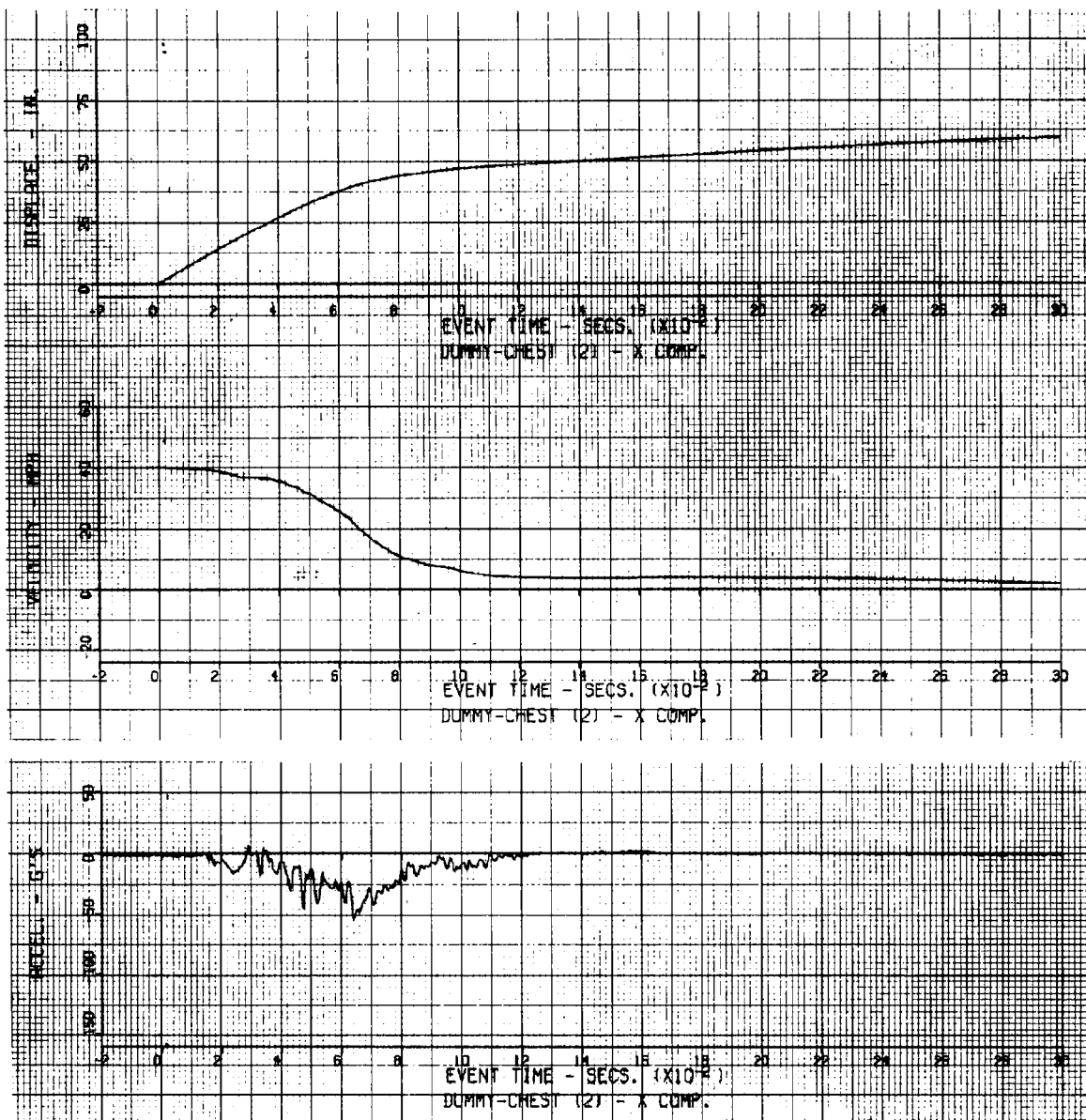


Figure B-45 RIGHT FRONT PASSENGER CHEST ACCELERATION AND LONGITUDINAL KINEMATIC DATA (TEST 84)

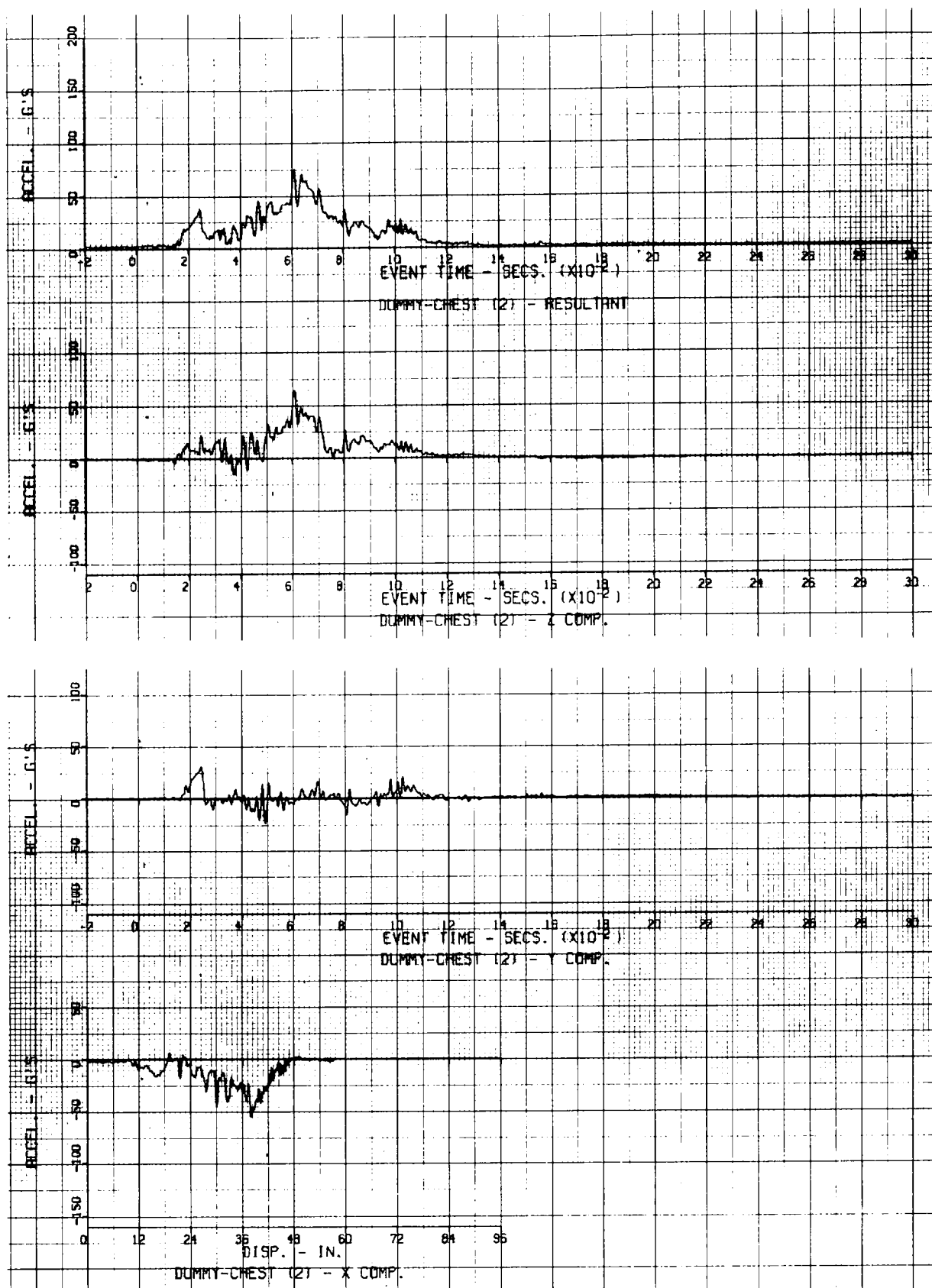


Figure B-45 (cont.) RIGHT FRONT PASSENGER CHEST ACCELERATION AND LONGITUDINAL KINEMATIC DATA (TEST 84)

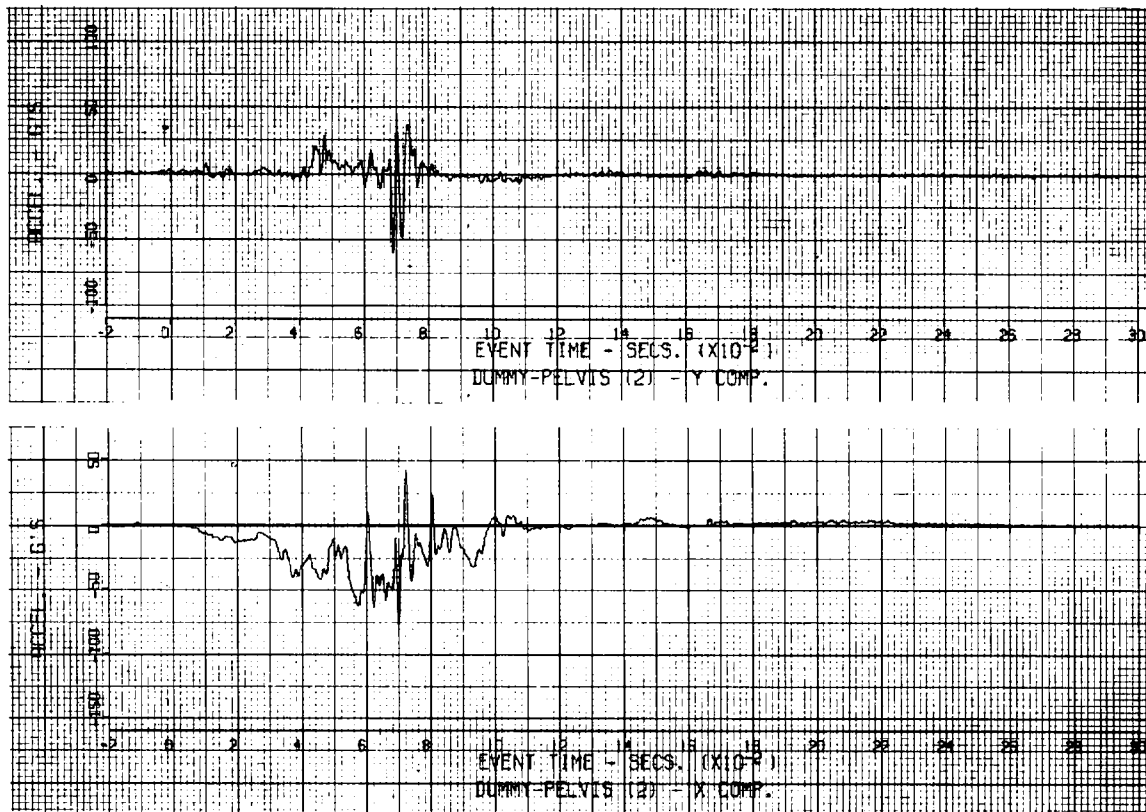


Figure B-46 RIGHT FRONT PASSENGER PELVIS ACCELERATION (TEST 84)

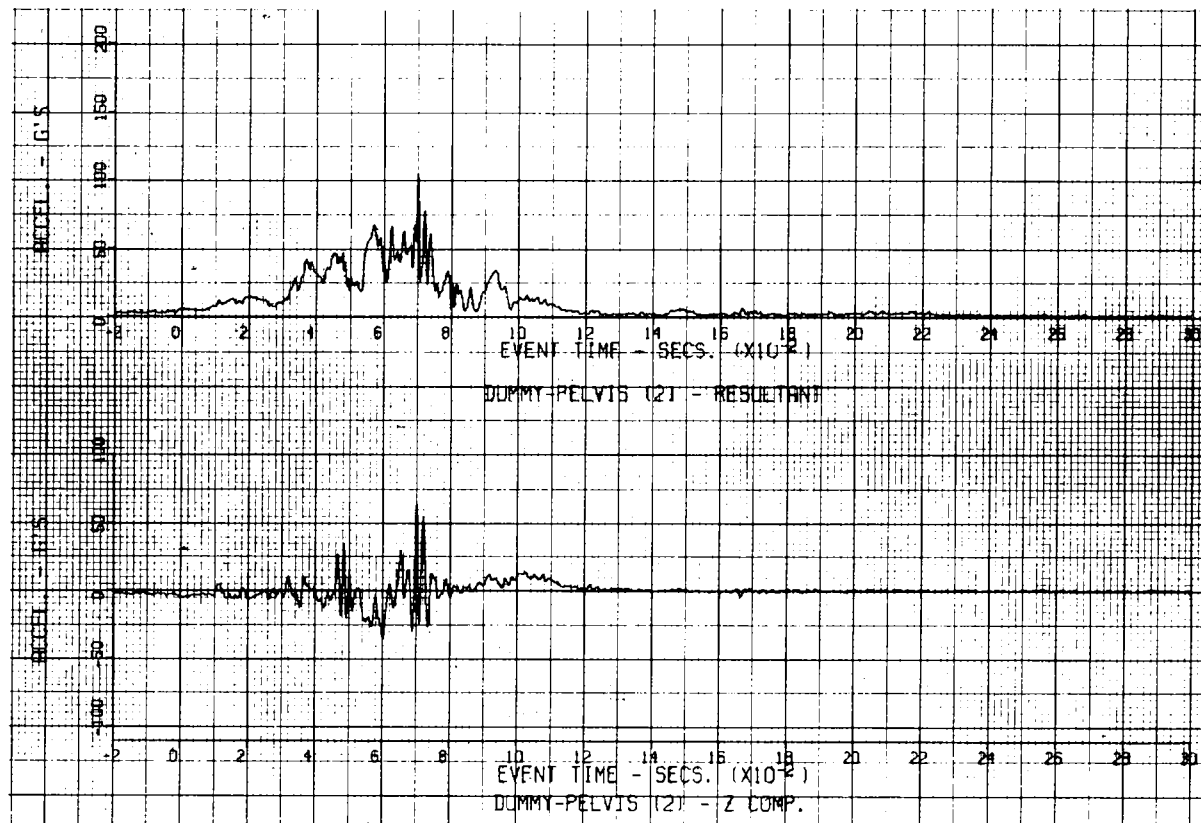


Figure B-46 (Cont.) RIGHT FRONT PASSENGER PELVIS ACCELERATION (TEST 84)

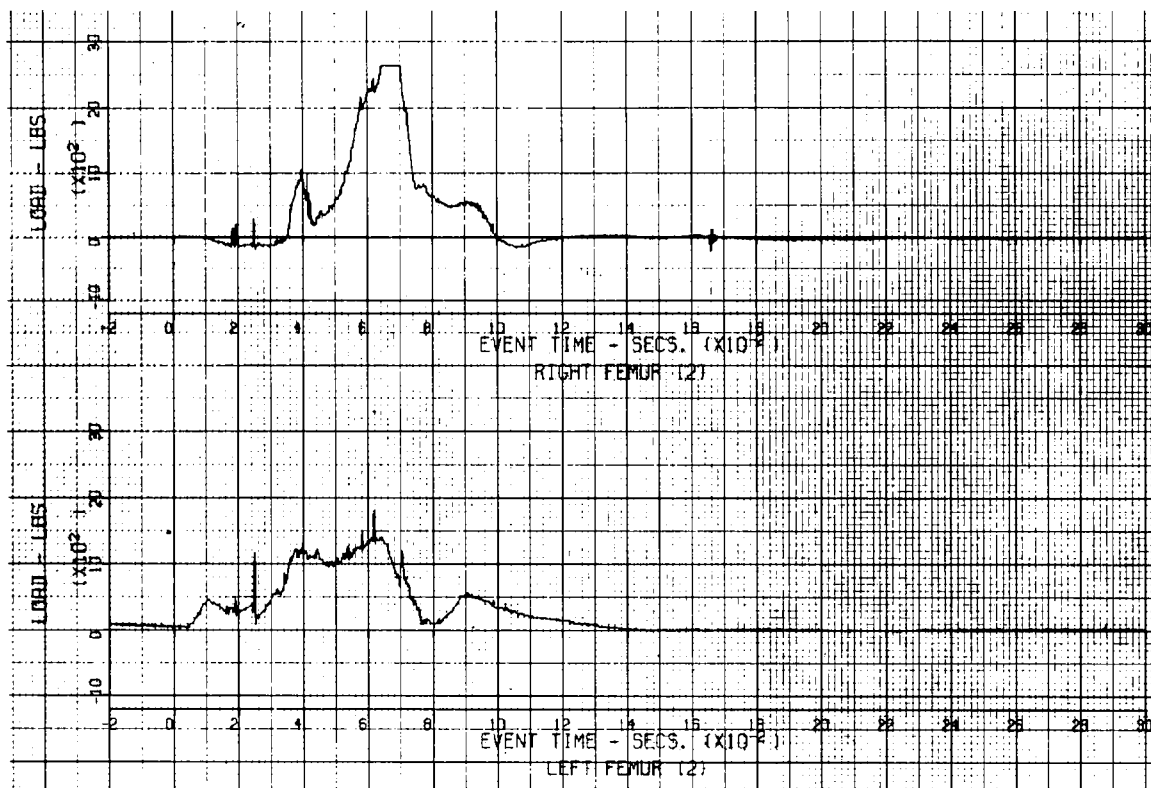


Figure B-47 RIGHT FRONT PASSENGER FEMUR LOAD DATA (TEST 84)

Test No. 90 Data

The following items are included:

1. Instrumentation requirements
2. Test site location of sensors and cameras
3. Before and after test photographs
4. Engine acceleration data
5. Passenger compartment acceleration data
6. Driver data
7. Passenger data

Note: The zero time is in error by -0.010 sec.
in the following channels - time is correct
in all other data channels:

- Corner (1)
- Corner (2)
- Driver dummy head and chest

INSTRUMENTATION REQUIREMENTS

FACILITY TEST NO. 153 PROGRAM TEST NO. 90
 PROGRAM: Crashworthiness II
 TEST DESCRIPTION: Flat barrier obstacle
 VEHICLE TYPE: OV-III

VEHICLE DESIGNATION	COMPONENT	COMPARTMENT			ENGINE	DUMMIES (1, 2)			RESTRAINT			RECORDER	OTHER
		TUNNEL	(1) (2) CORNERS (4) (3)	REAR DECK		HEAD	CHEST	PELVIS	LAP	SHOULDER	OTHER		
OV-III	X	A	1A, 2A, 3A, 4A		A	A	A	A					
	Y	A	1A, 2A, 3A, 4A			A	A	A					
	Z	A	1A, 2A, 3A, 4A			A	A	A					
	X												
	Y												
	Z												

LEGEND:

A - ACCELEROMETER
 V - VELOCITY METER
 D - DISPLACEMENT METER
 L - LOAD CELL

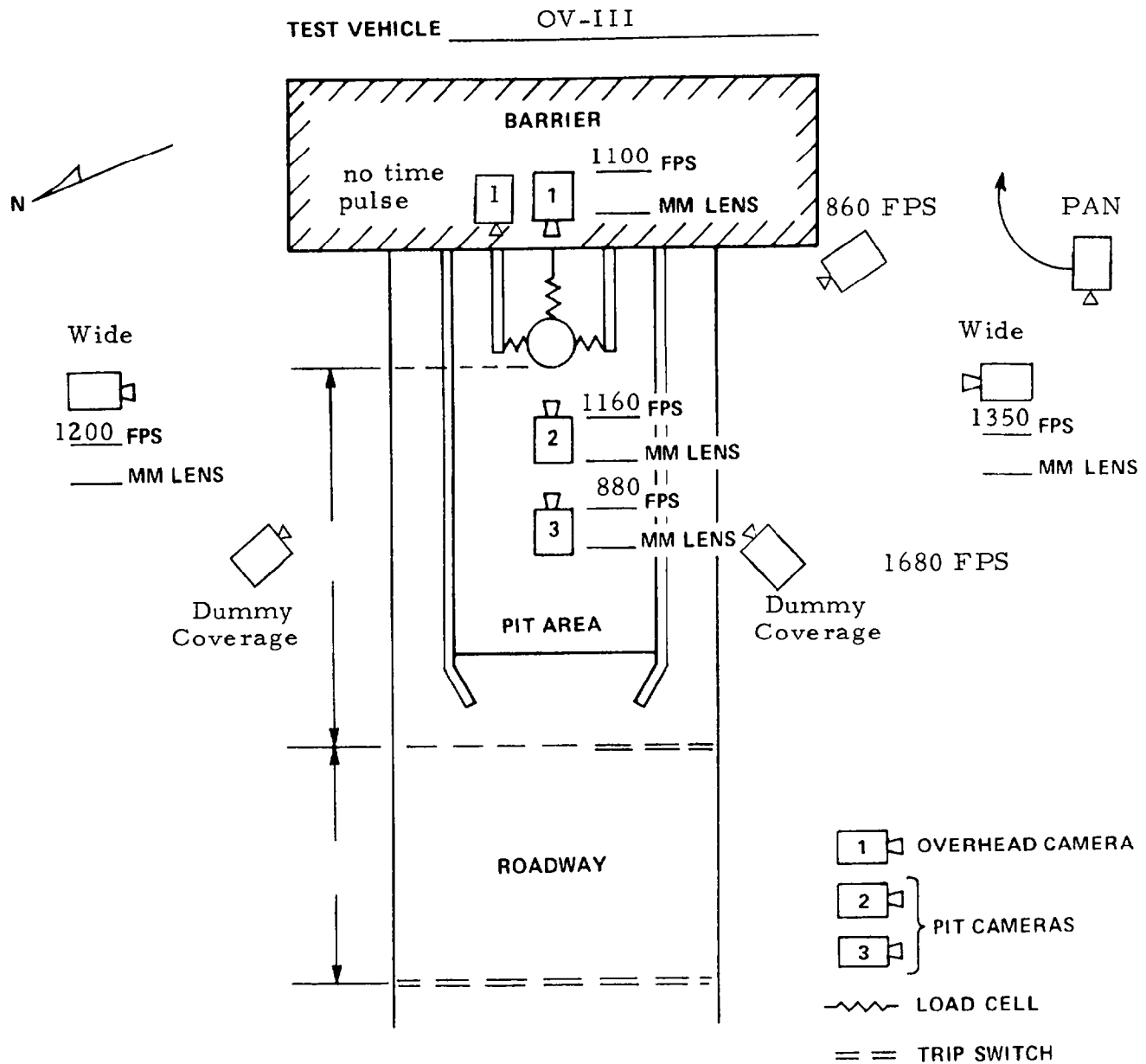
**DESCRIBE "OTHER"

**IF MORE THAN 1 DUMMY, NUMBER SEQUENTIALLY IN CLOCKWISE (FROM TOP VIEW) DIRECTION (i.e. DRIVER 1, PASS FRONT 2, etc)

MISCELLANEOUS

- CONTACT SWITCH/BAR:
- AIR BAG SENSORS:
- POSITION OF CARS:
- SPEED WINDOW: 50 + 2MPH

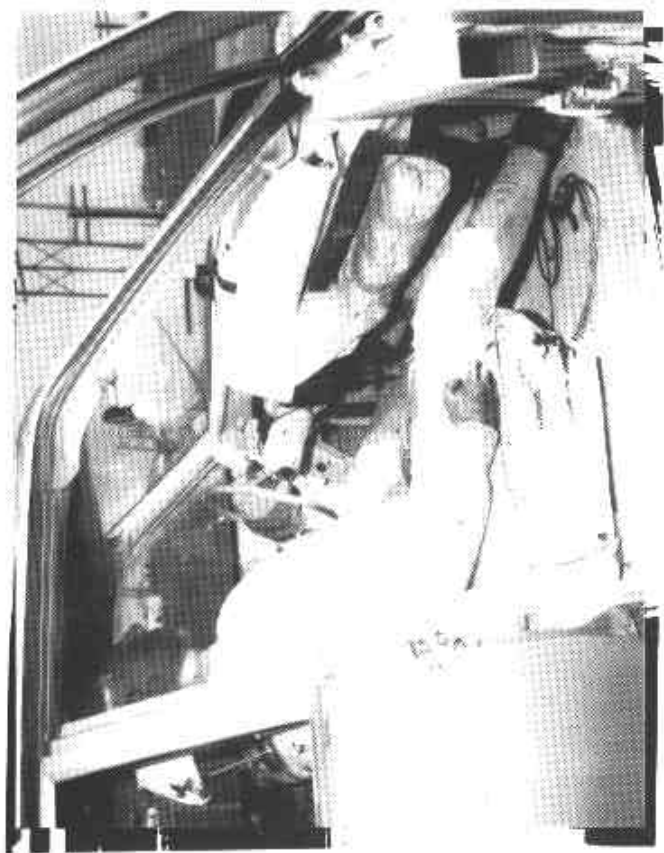
TEST SITE LOCATION OF SENSORS AND CAMERAS



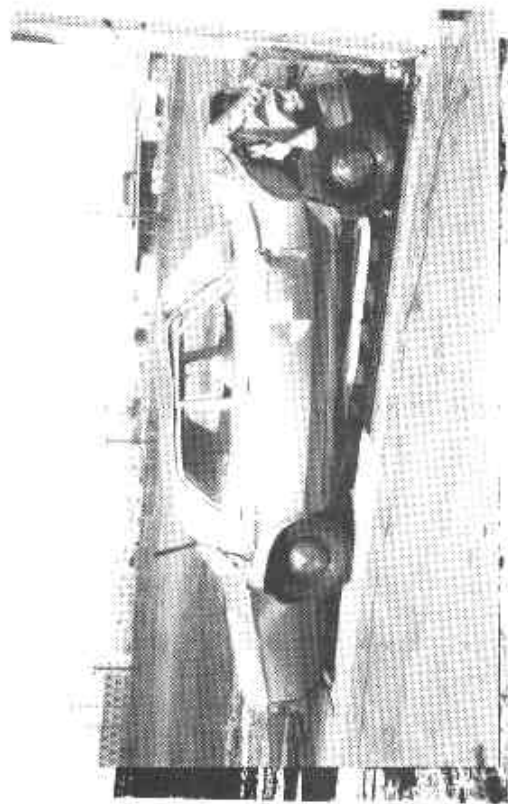
REMARKS:

Wide - indicates complete vehicle coverage

Note: two overhead and two pit cameras are required to have redundancy, documentary film coverage before and after test
R. Scott, set up sequence camera and action color



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YB-2987-V-19

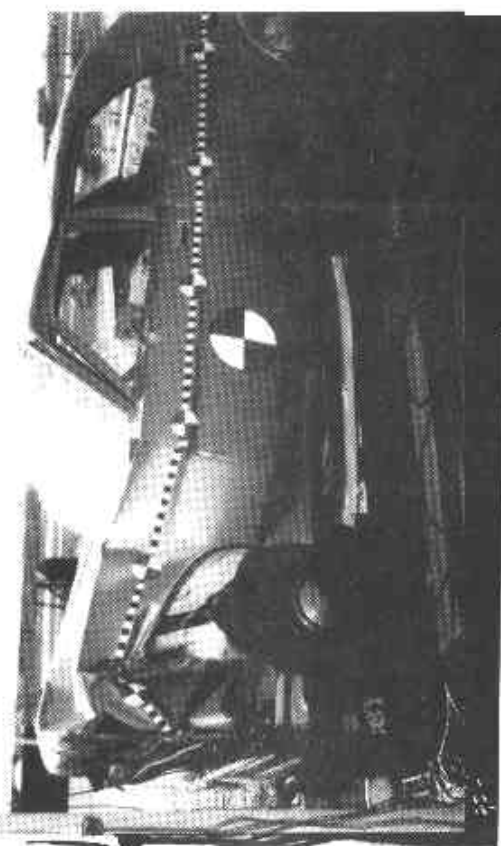
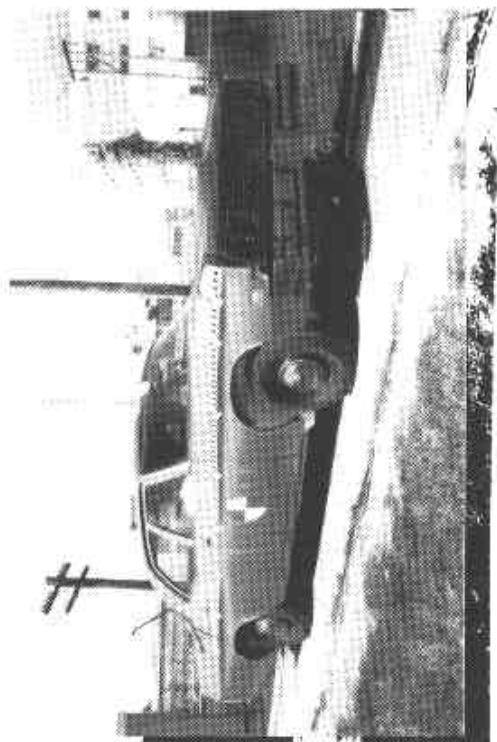


Figure B-48 BEFORE AND AFTER IMPACT VIEWS OF OV-III VEHICLE
(TEST 90)

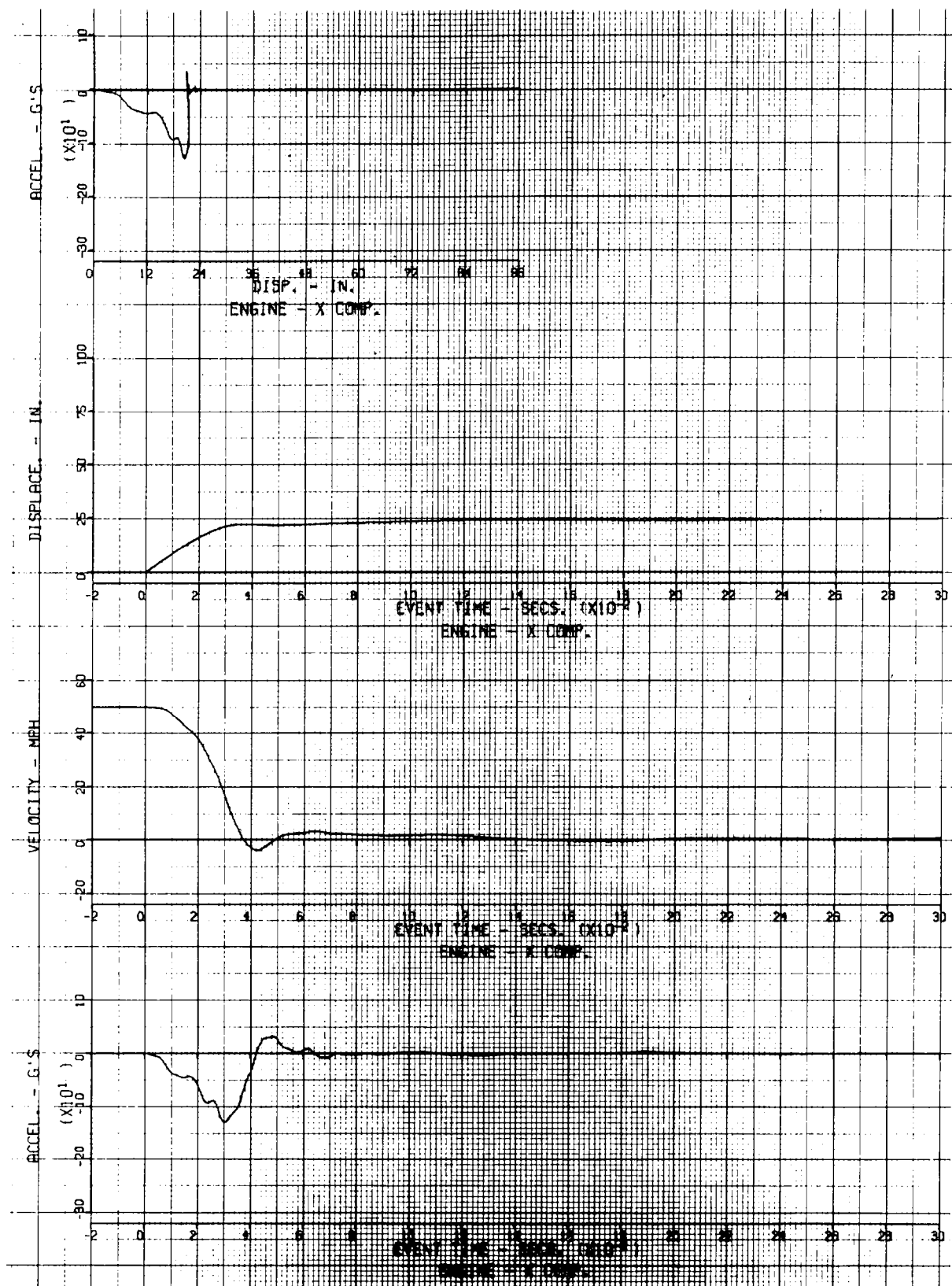


Figure B-49 ENGINE LONGITUDINAL KINEMATIC DATA (TEST 90)

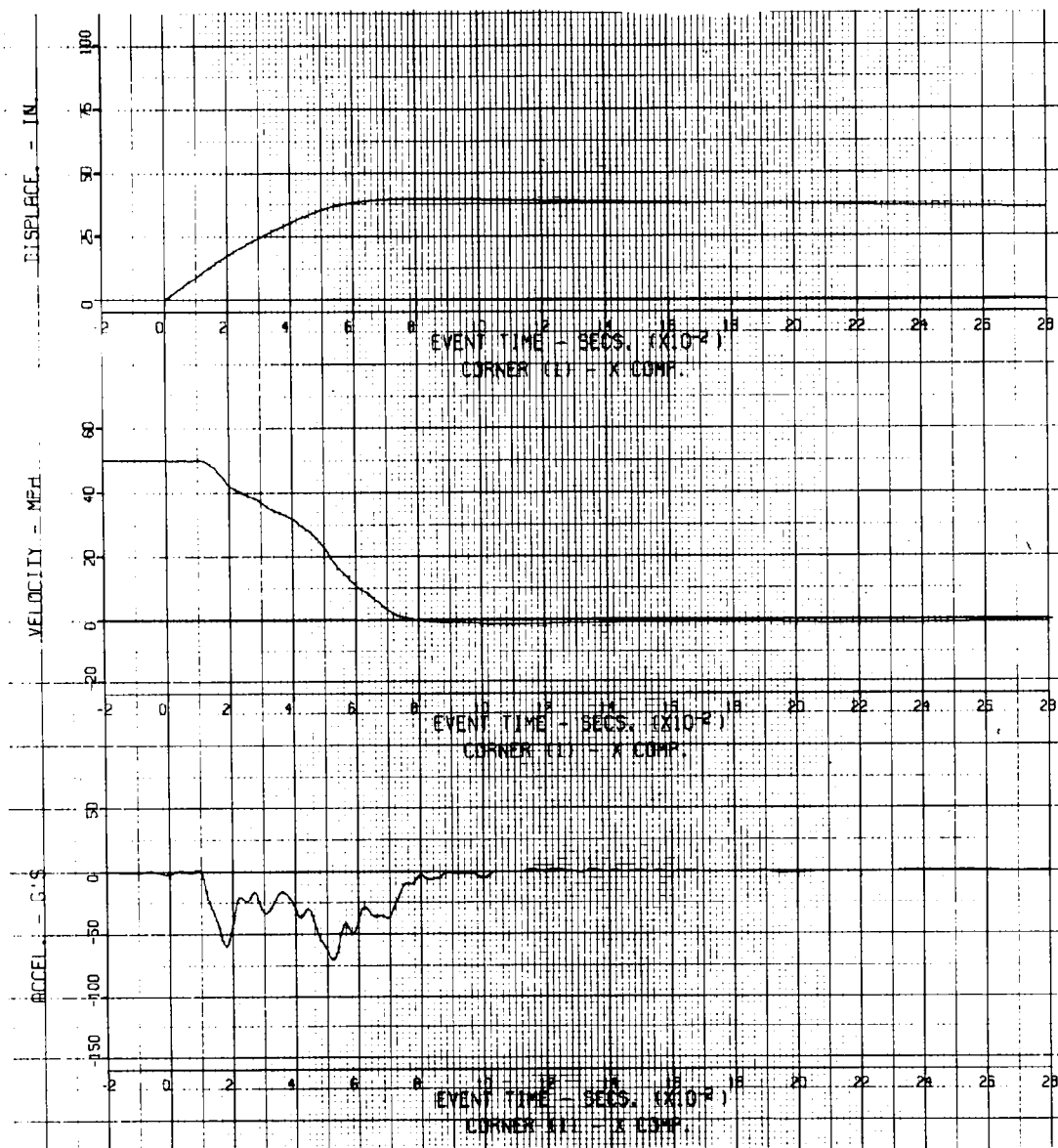


Figure B-50 PASSENGER COMPARTMENT ACCELERATION AND LONGITUDINAL KINEMATIC DATA, LEFT FRONT CORNER LOCATION (TEST 90)

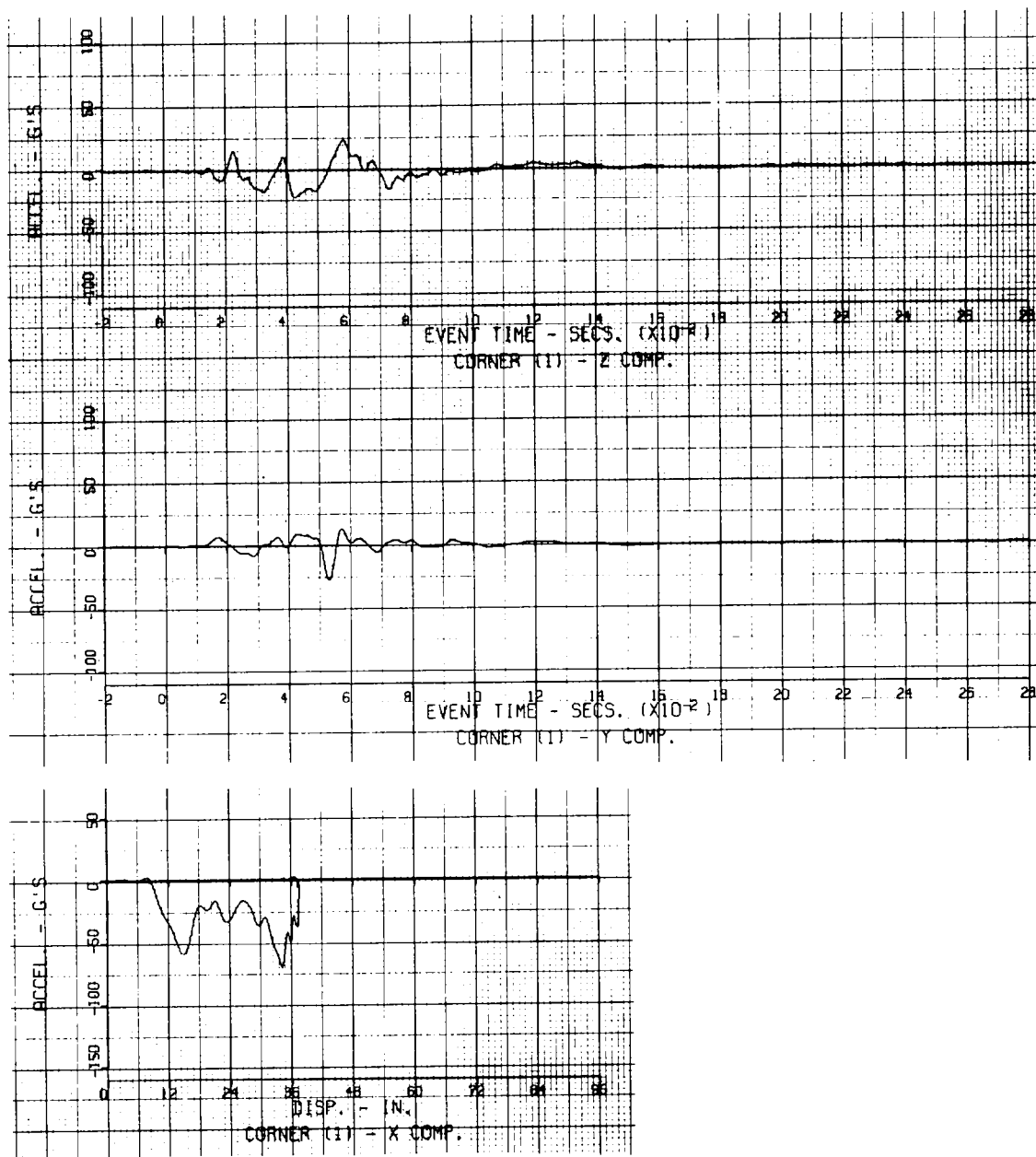


Figure B-50 (Cont.) PASSENGER COMPARTMENT ACCELERATION AND LONGITUDINAL KINEMATIC DATA, LEFT FRONT CORNER LOCATION (TEST 90)

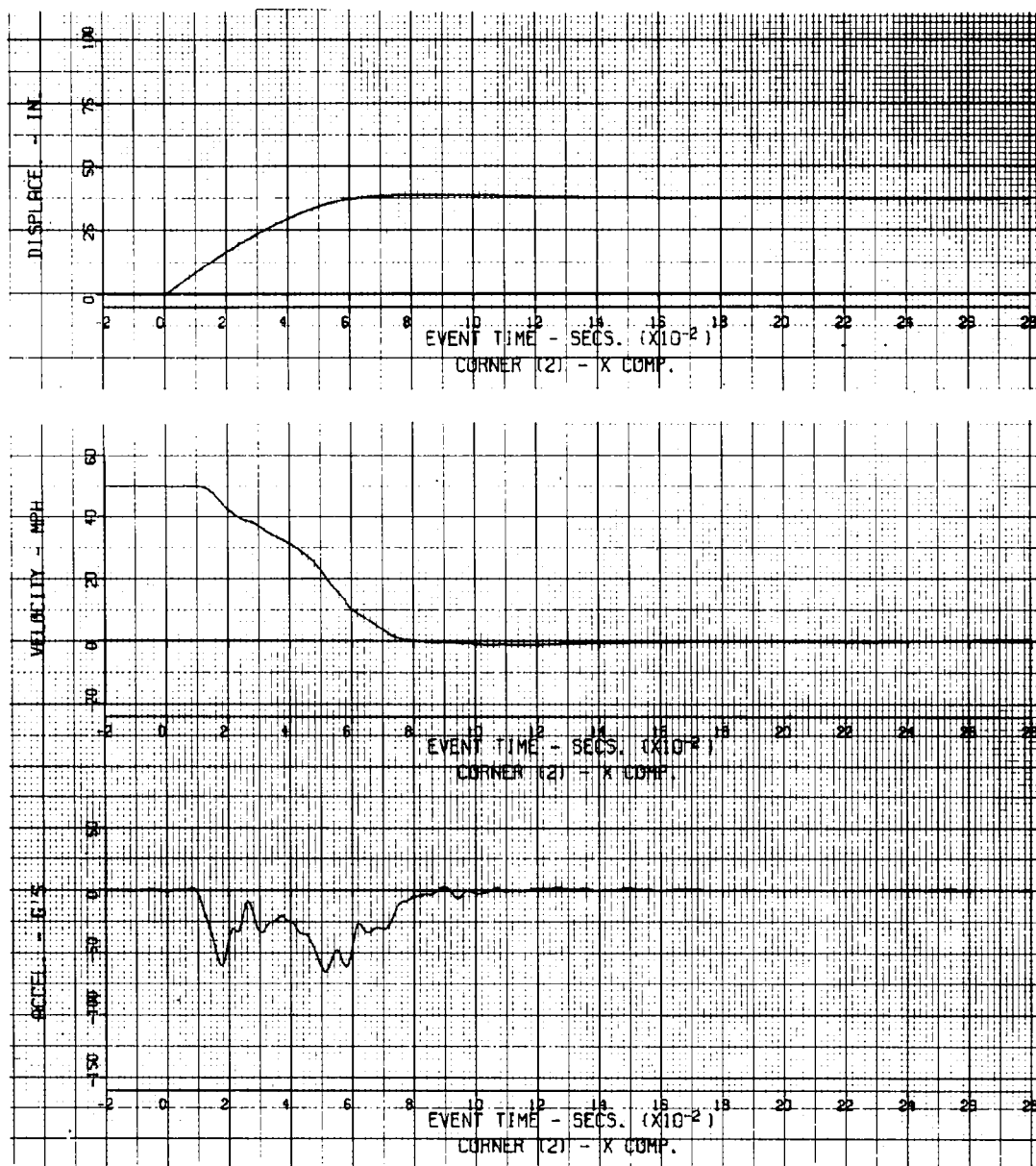


Figure B-51 PASSENGER COMPARTMENT ACCELERATION AND LONGITUDINAL KINEMATIC DATA, RIGHT FRONT CORNER LOCATION (TEST 90)

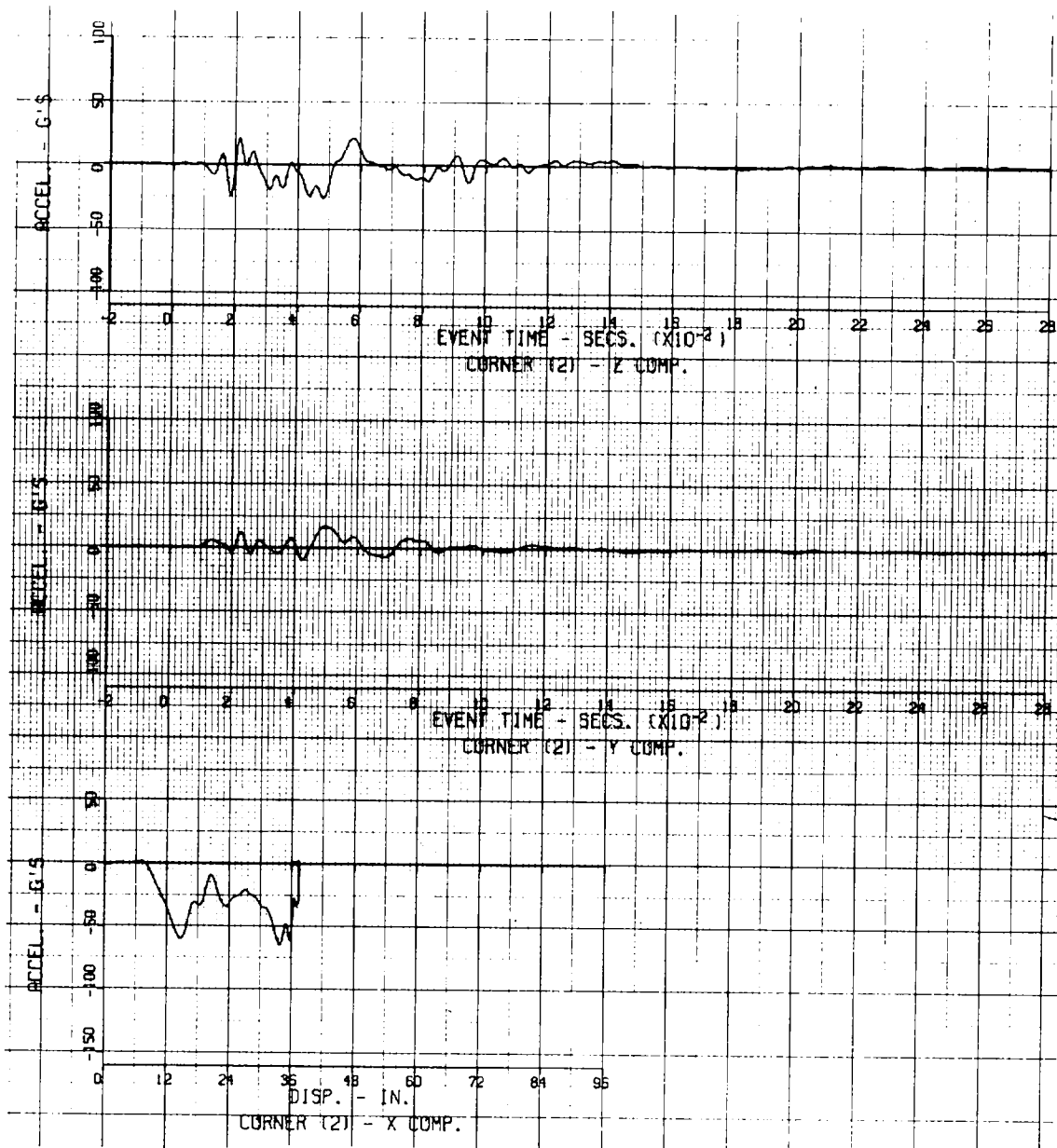


Figure B-51 (Cont.) PASSENGER COMPARTMENT ACCELERATION AND LONGITUDINAL KINEMATIC DATA, RIGHT FRONT CORNER LOCATION (TEST 90)

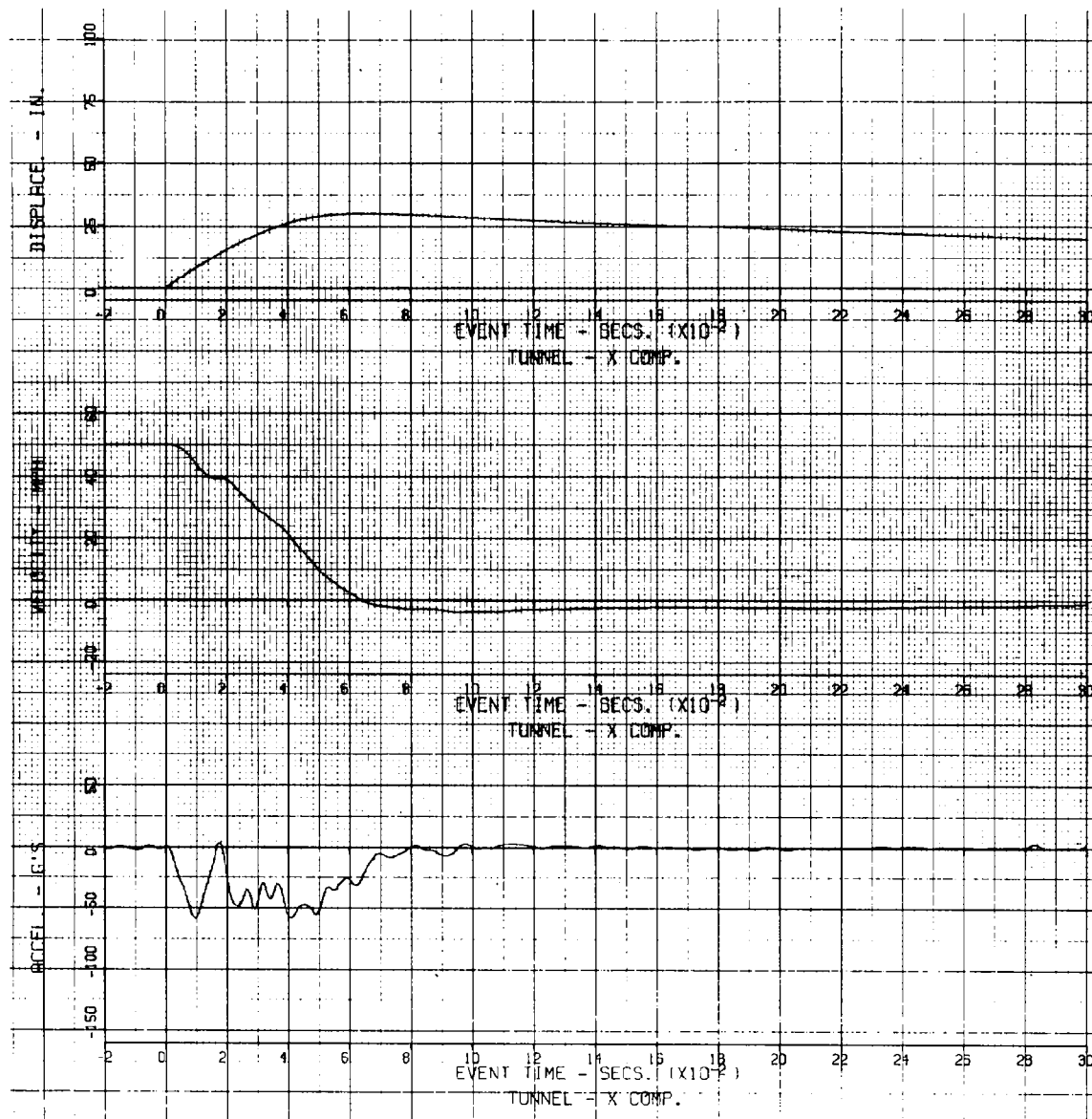


Figure B-52 PASSENGER COMPARTMENT ACCELERATION AND LONGITUDINAL KINEMATIC DATA, TUNNEL LOCATION (TEST 90)

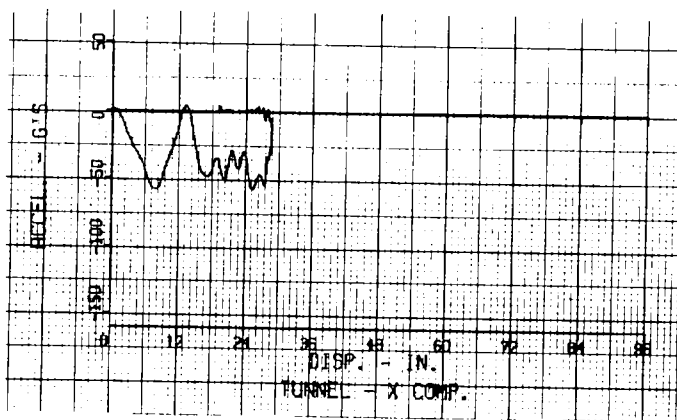
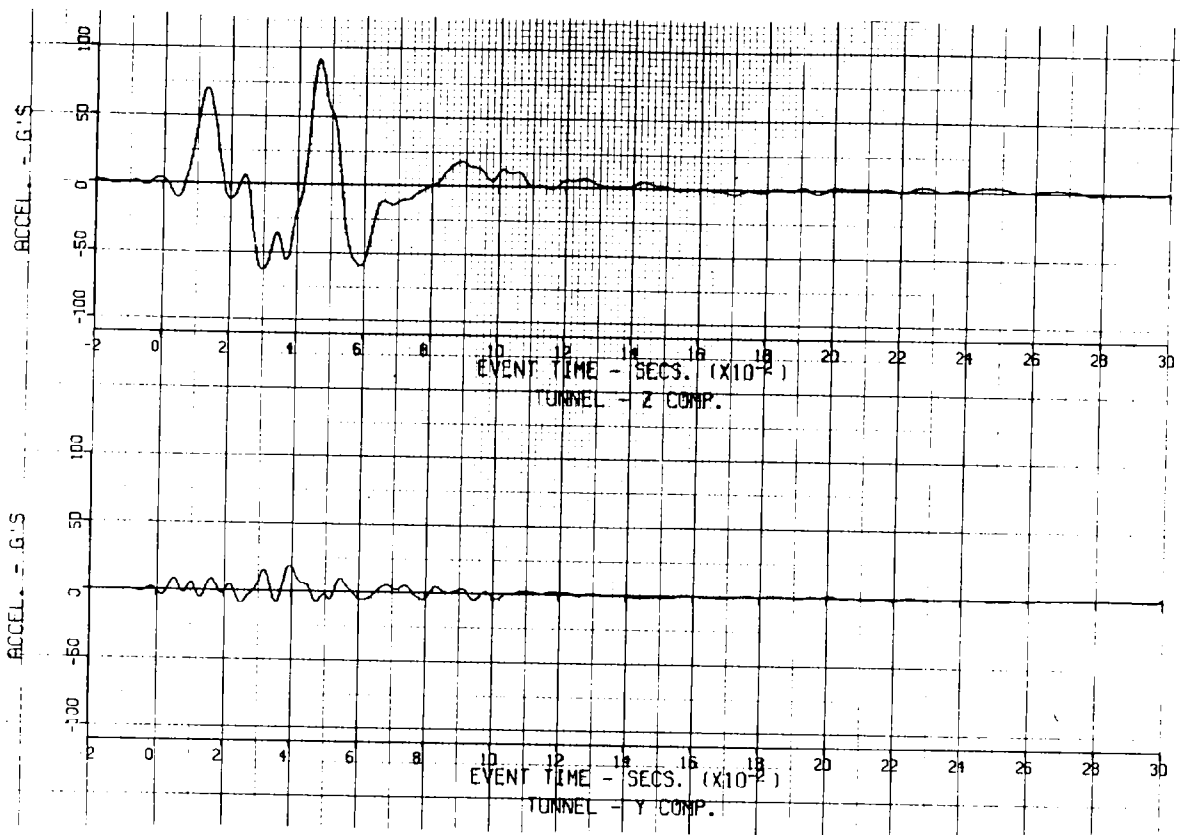


Figure B-52 (Cont.) PASSENGER COMPARTMENT ACCELERATION AND LONGITUDINAL KINEMATIC DATA, TUNNEL LOCATION (TEST 90)

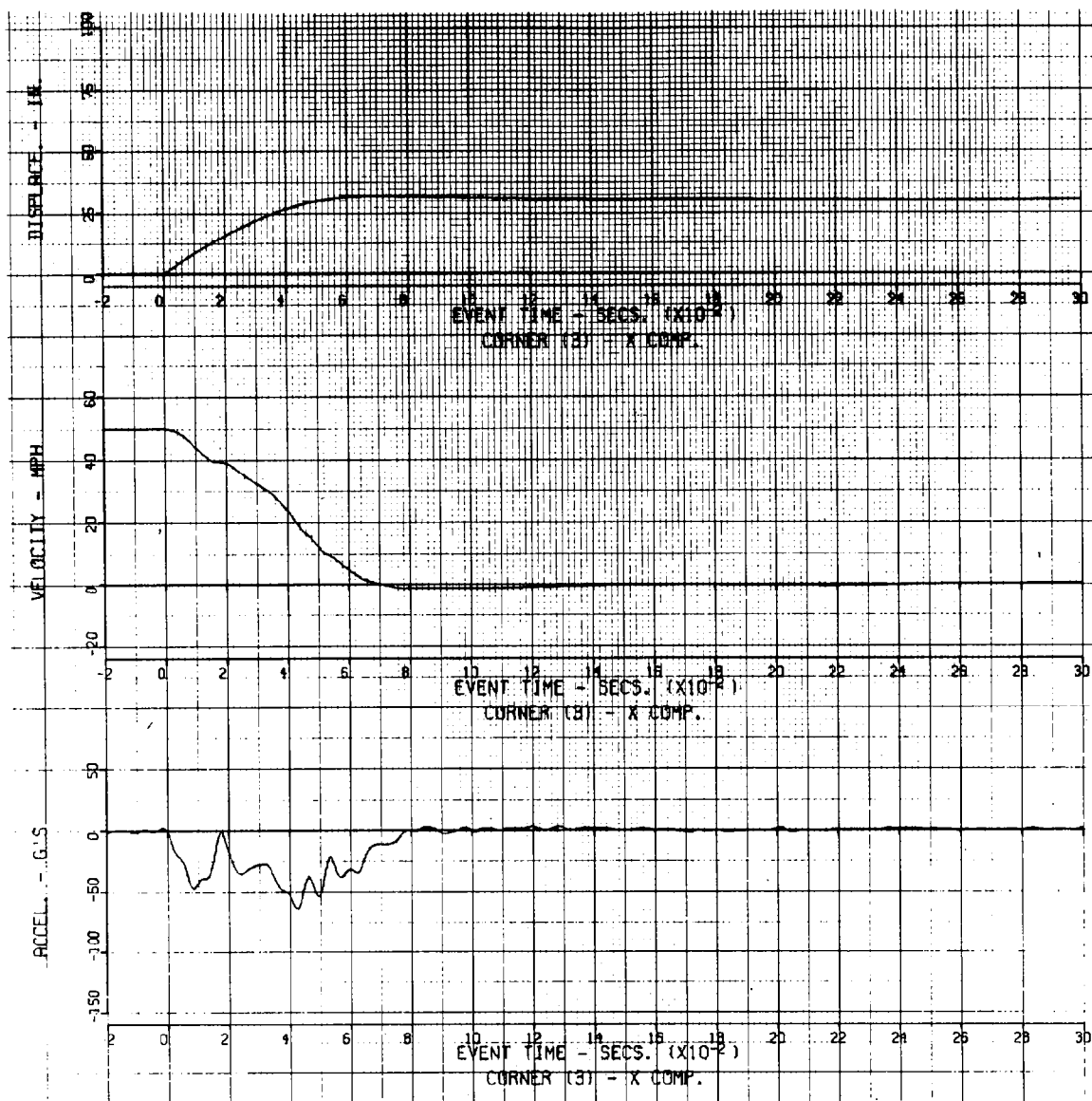


Figure B-53 PASSENGER COMPARTMENT ACCELERATION AND LONGITUDINAL KINEMATIC DATA, RIGHT REAR CORNER LOCATION (TEST 90)

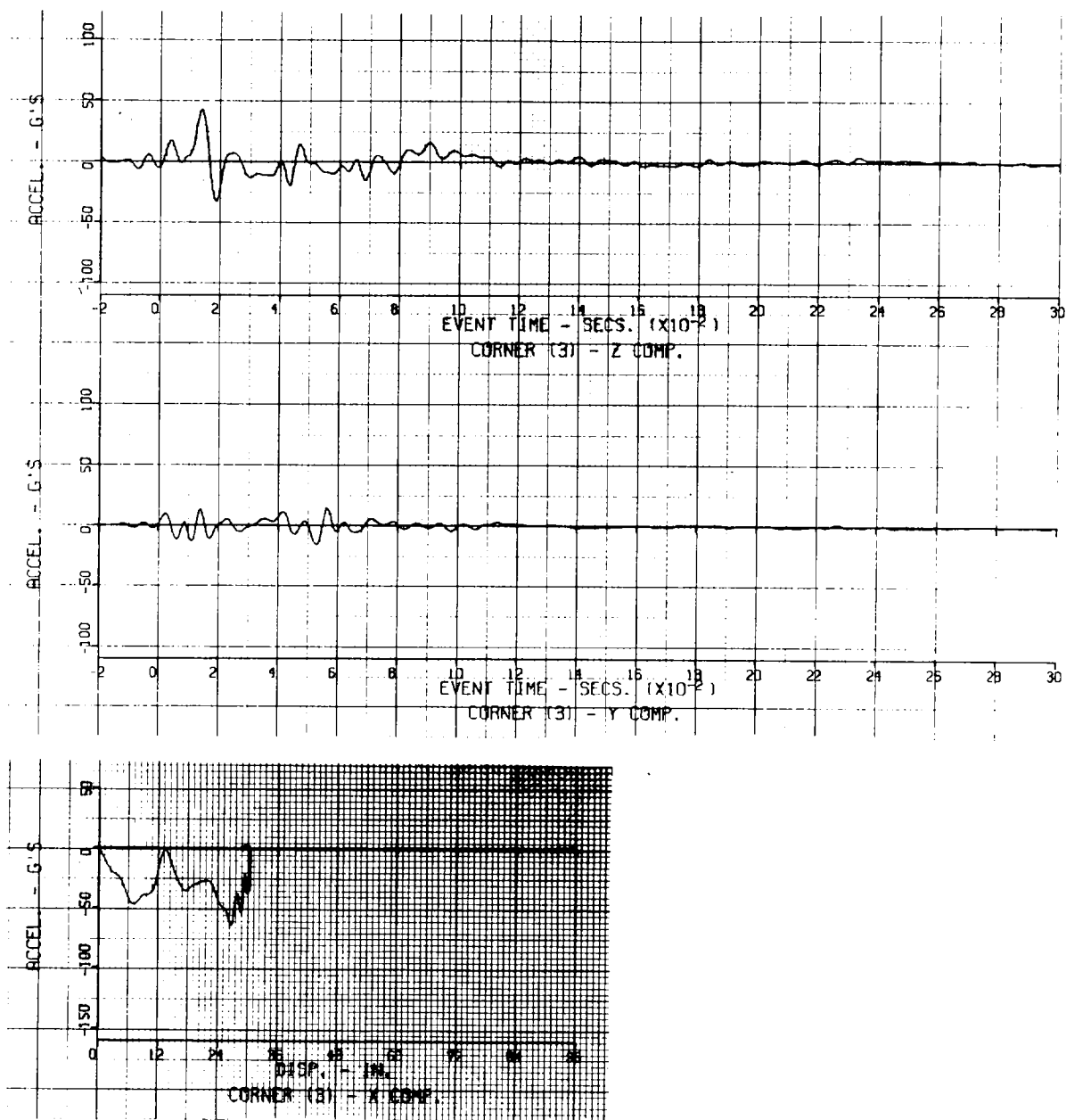


Figure B-53 (Cont.) PASSENGER COMPARTMENT ACCELERATION AND LONGITUDINAL KINEMATIC DATA, RIGHT REAR CORNER LOCATION (TEST 90)

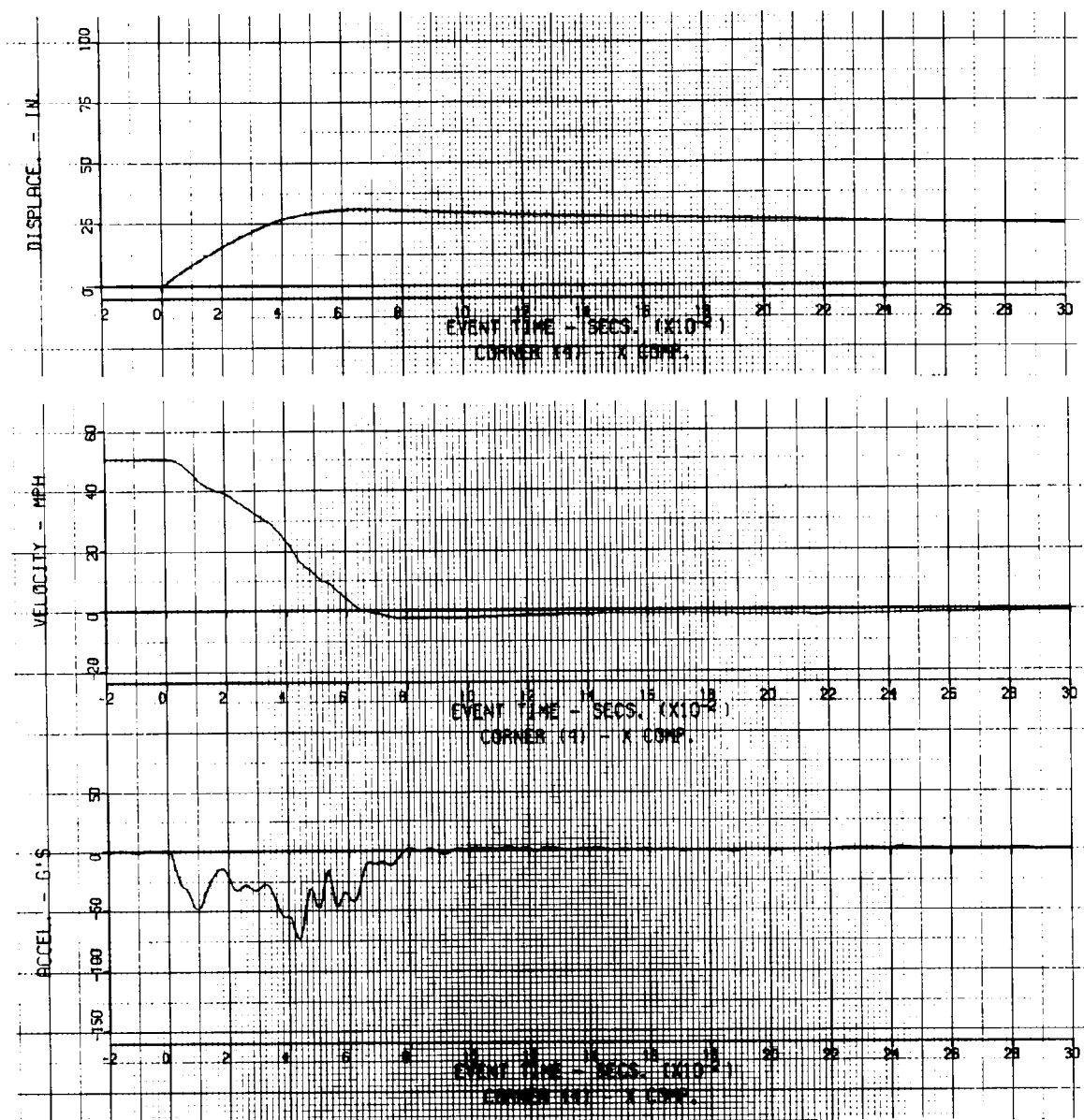


Figure B-54 PASSENGER COMPARTMENT ACCELERATION AND LONGITUDINAL KINEMATIC DATA, LEFT REAR CORNER LOCATION (TEST 90)

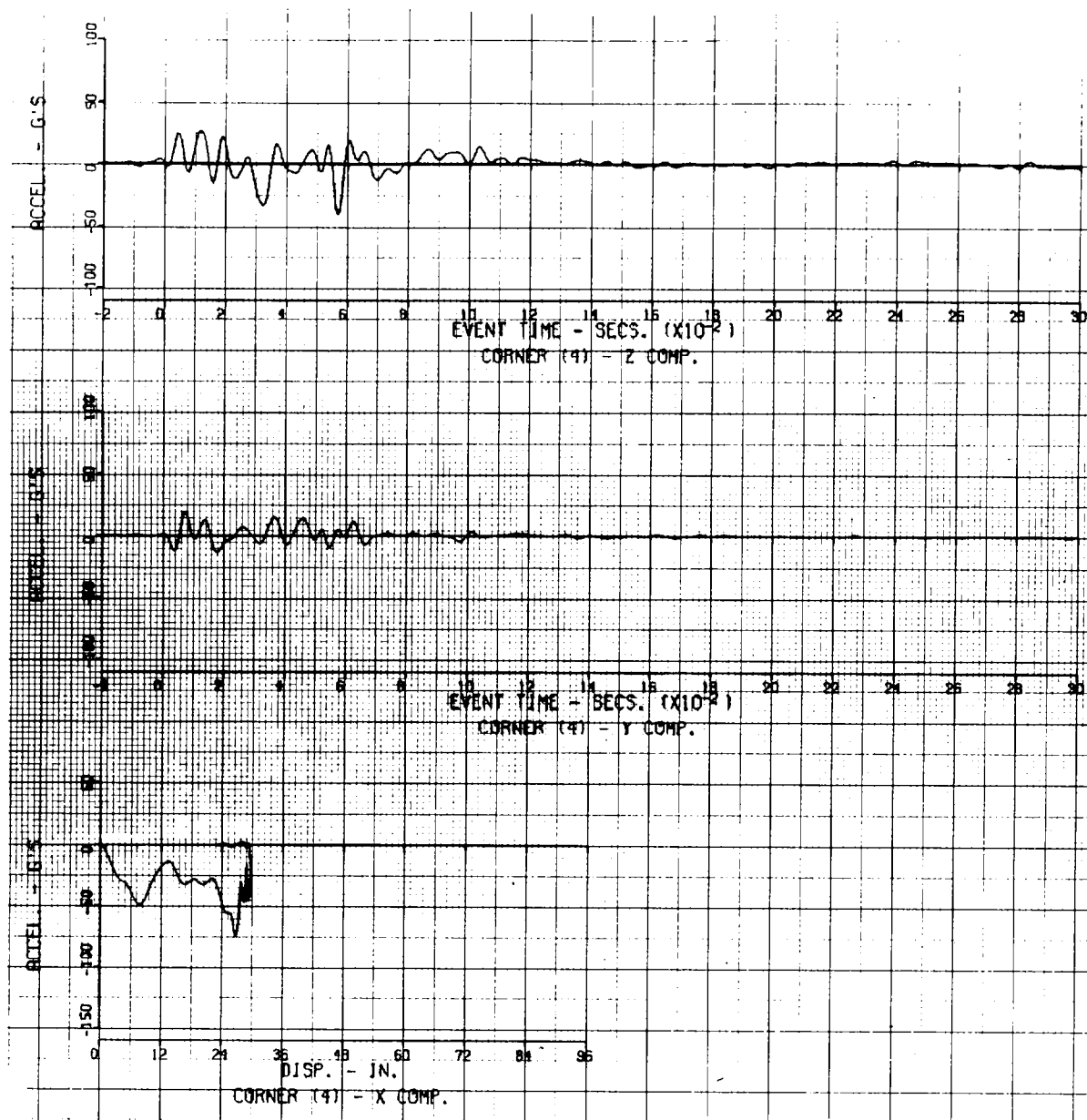


Figure B-54 (Cont.) PASSENGER COMPARTMENT ACCELERATION AND LONGITUDINAL KINEMATIC DATA, LEFT REAR CORNER LOCATION (TEST 90)

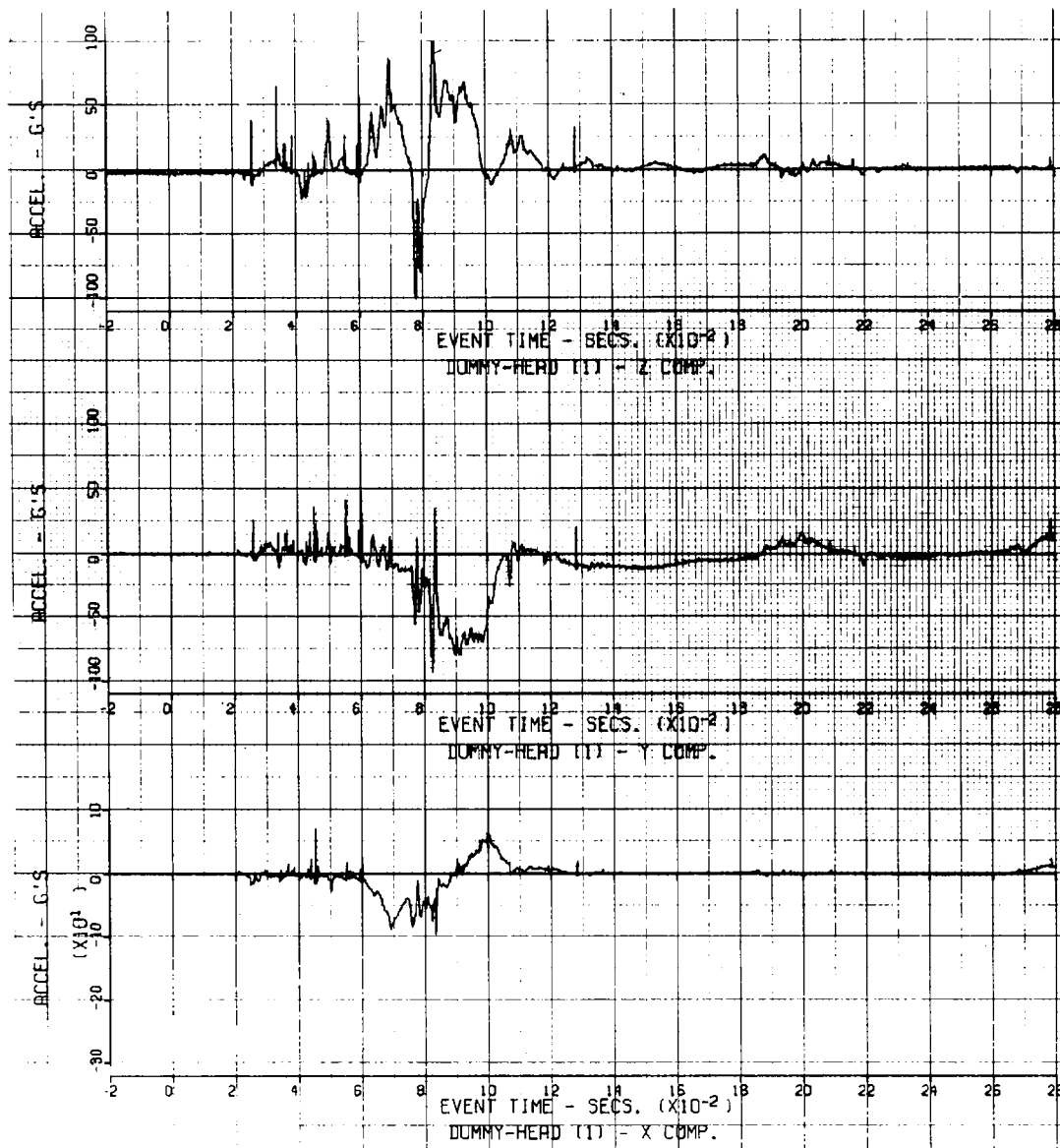
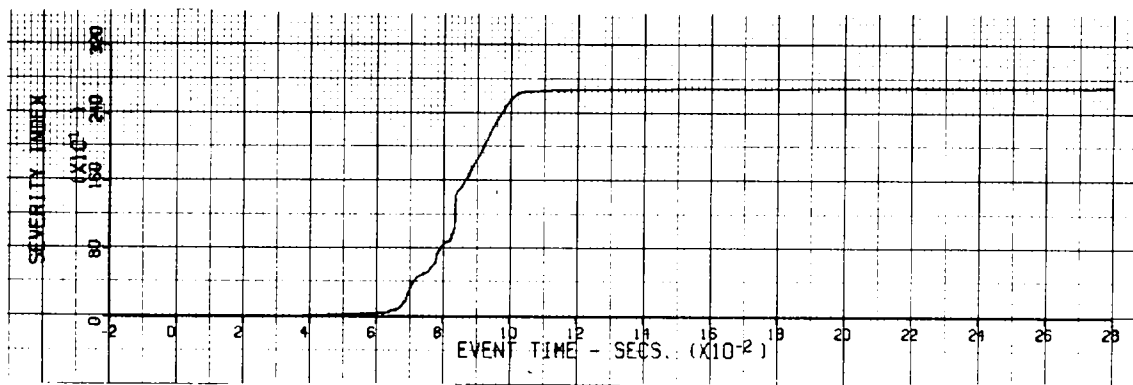


Figure B-55 DRIVER HEAD ACCELERATION (TEST 90)



CUMULATIVE SEVERITY INDEX

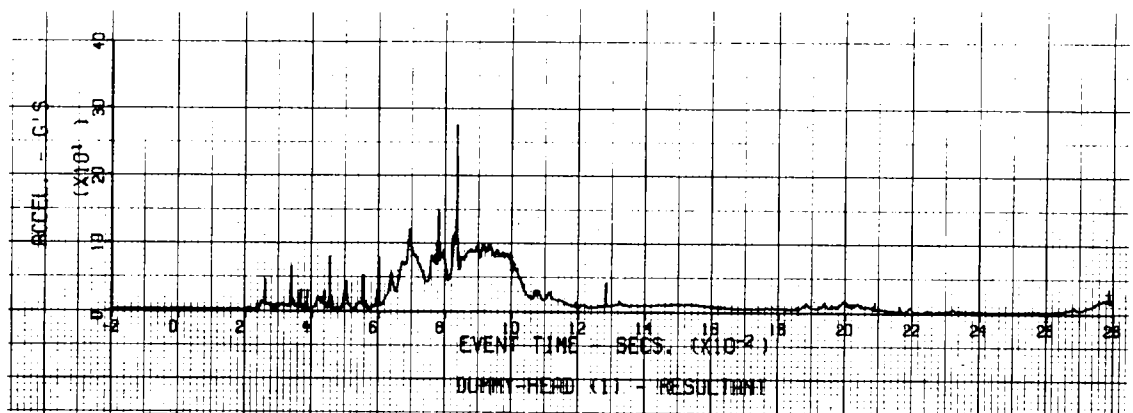


Figure B-55 (Cont.) DRIVER HEAD ACCELERATION (TEST 90)

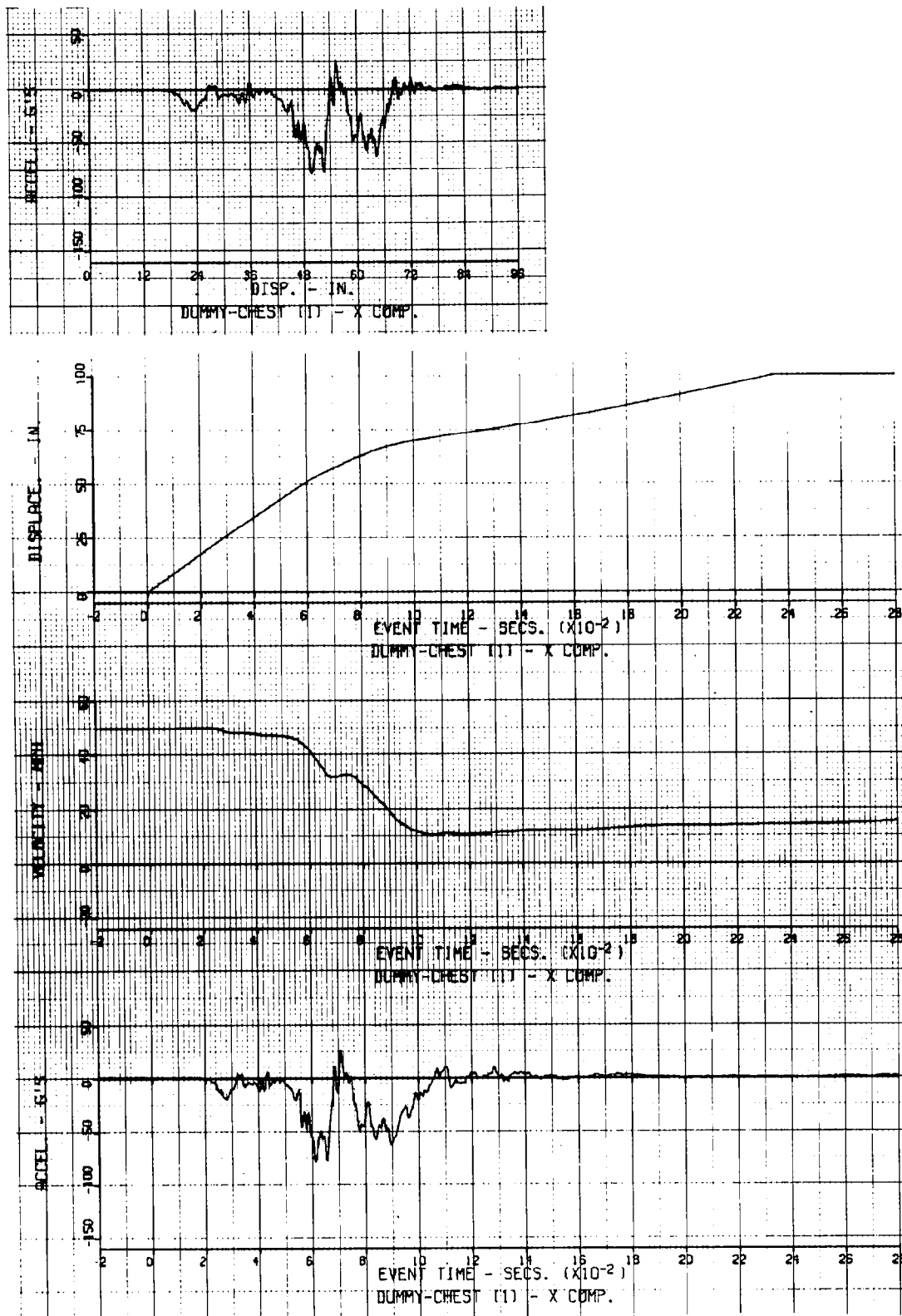


Figure B-56 DRIVER CHEST ACCELERATION AND LONGITUDINAL KINEMATIC DATA (TEST 90)

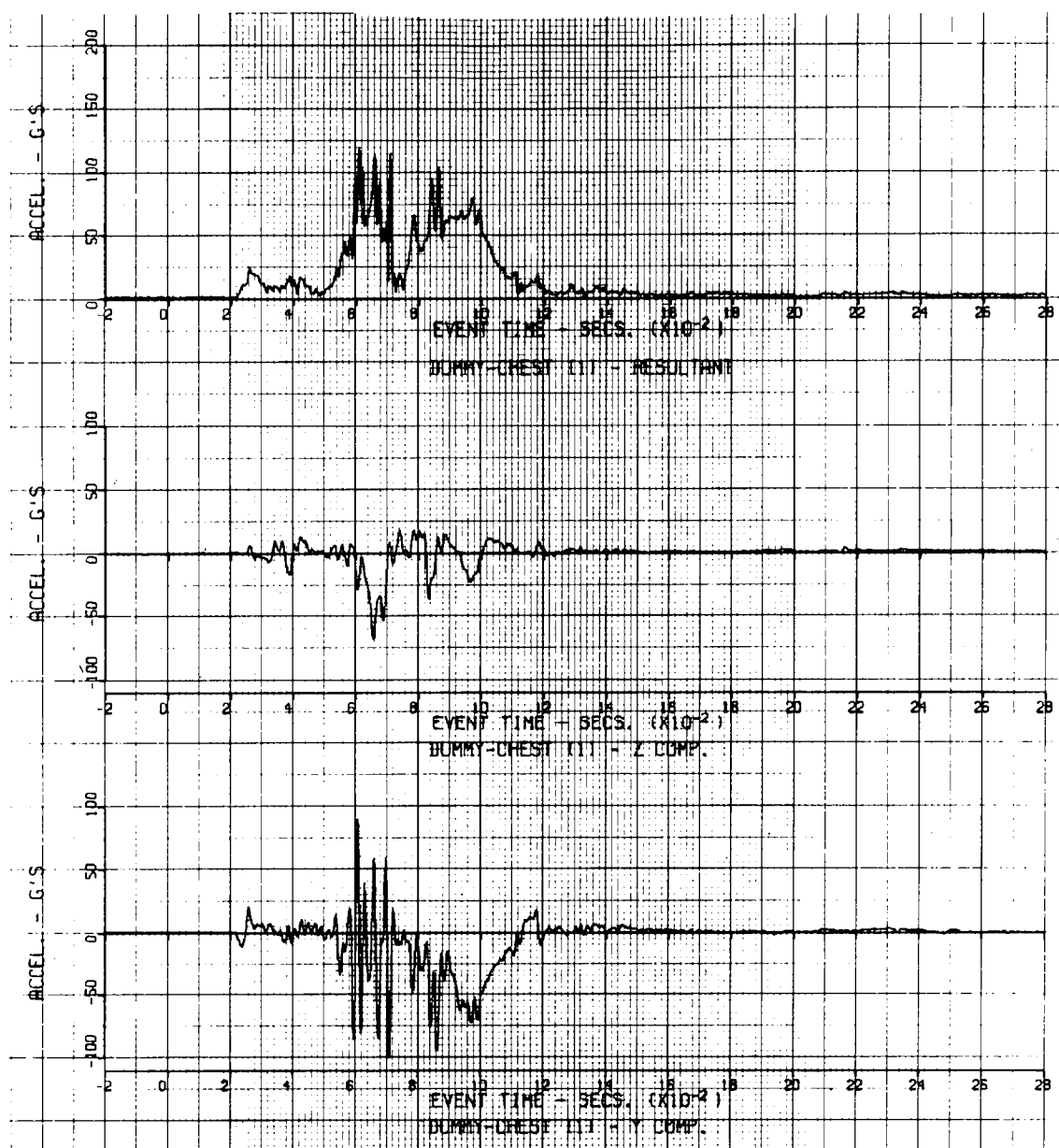


Figure B-56 (Cont.) DRIVER CHEST ACCELERATION AND LONGITUDINAL KINEMATIC DATA (TEST 90)

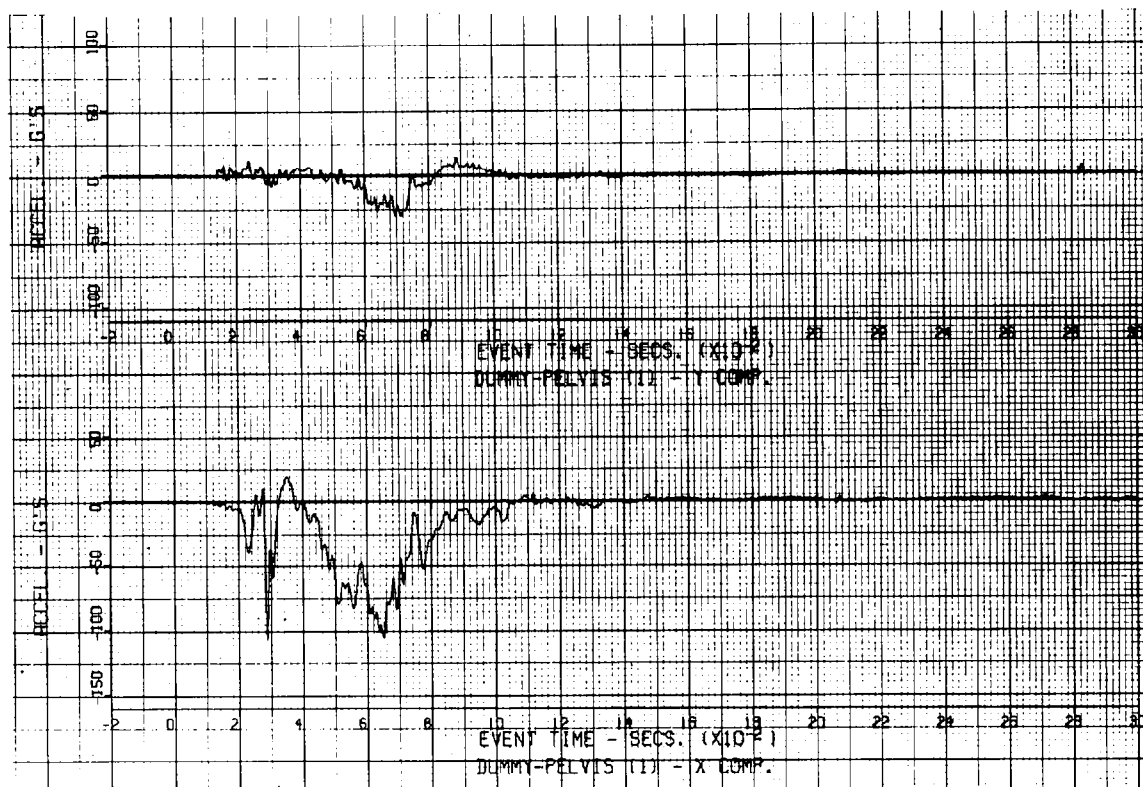


Figure B-57 DRIVER PELVIS ACCELERATION (TEST 90)

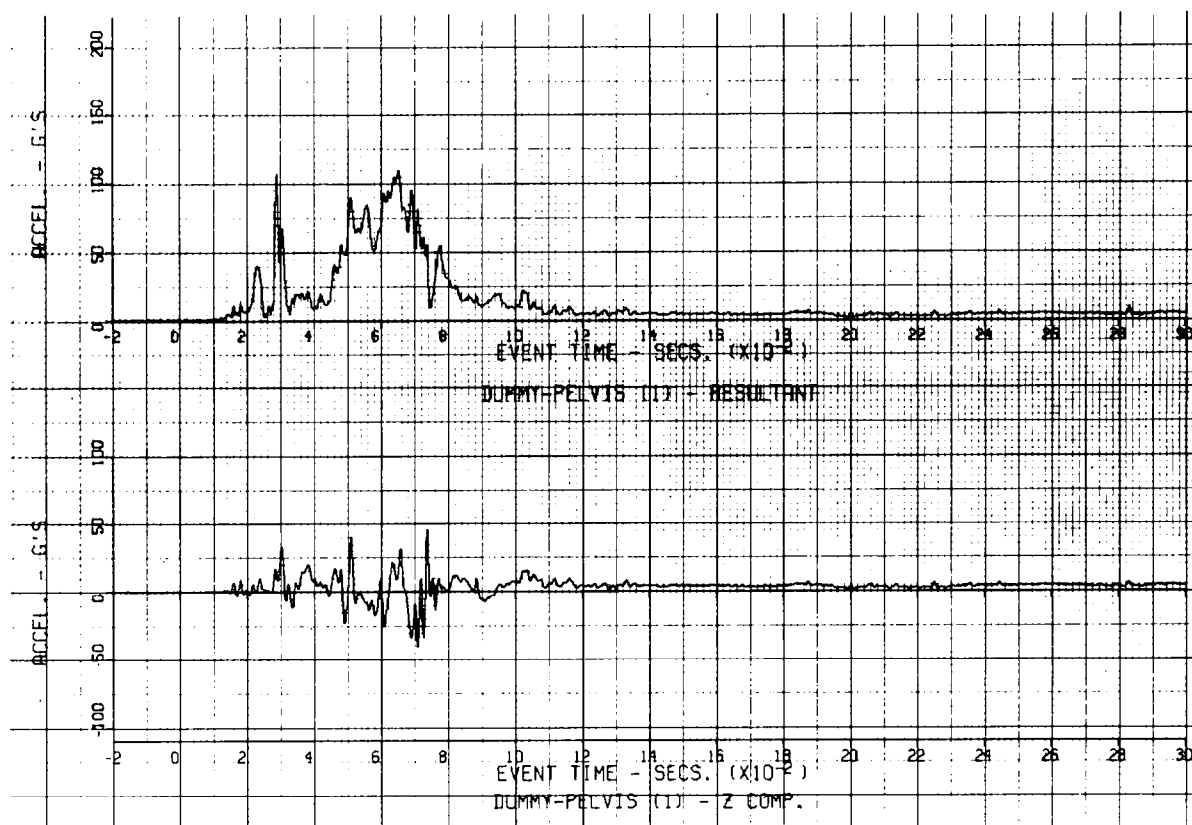


Figure B-57 (Cont.) DRIVER PELVIS ACCELERATION (TEST 90)

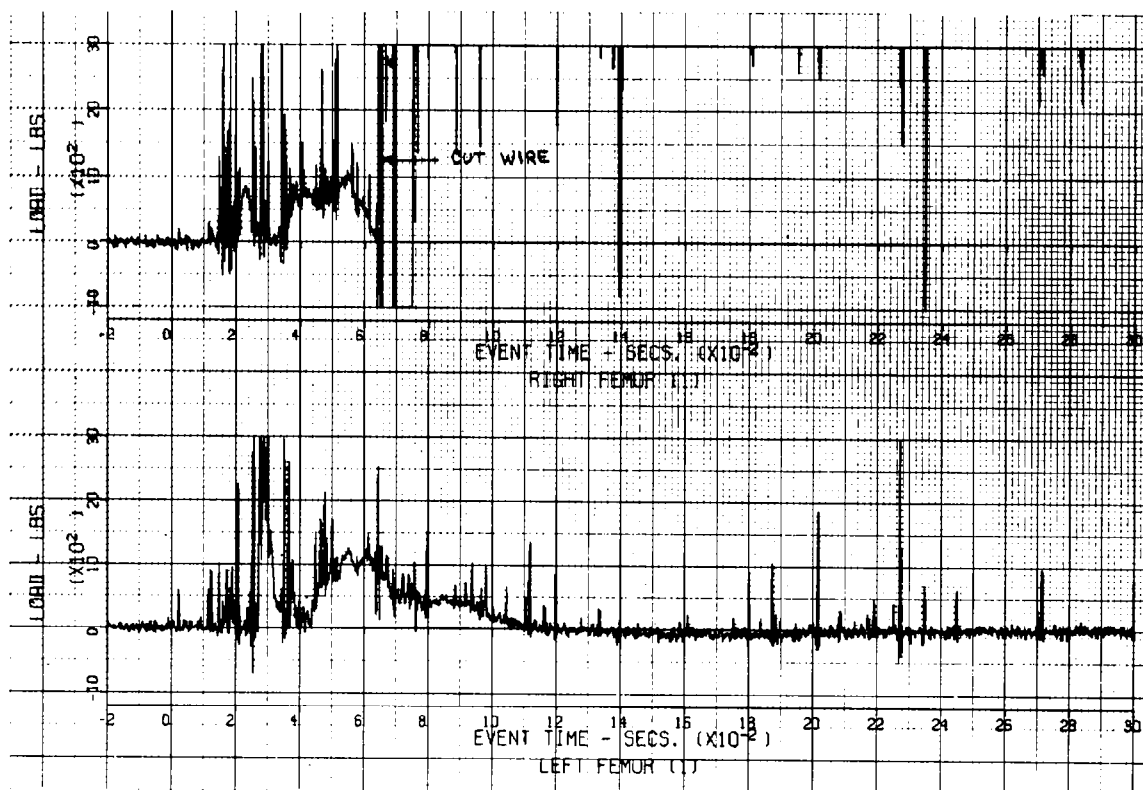


Figure B-58 DRIVER FEMUR LOAD DATA (TEST 90)

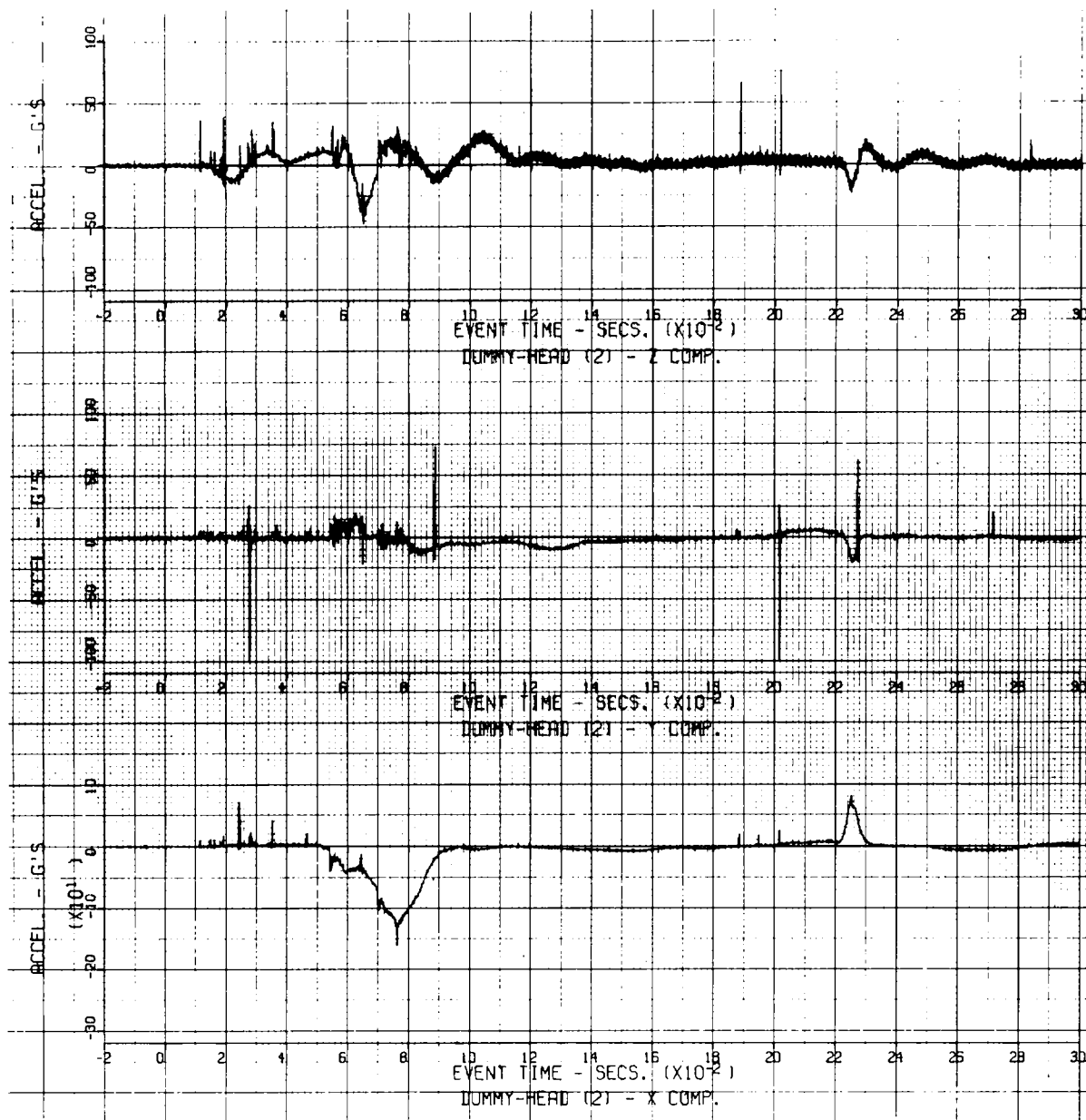


Figure B-59 RIGHT FRONT PASSENGER HEAD ACCELERATION (TEST 90)

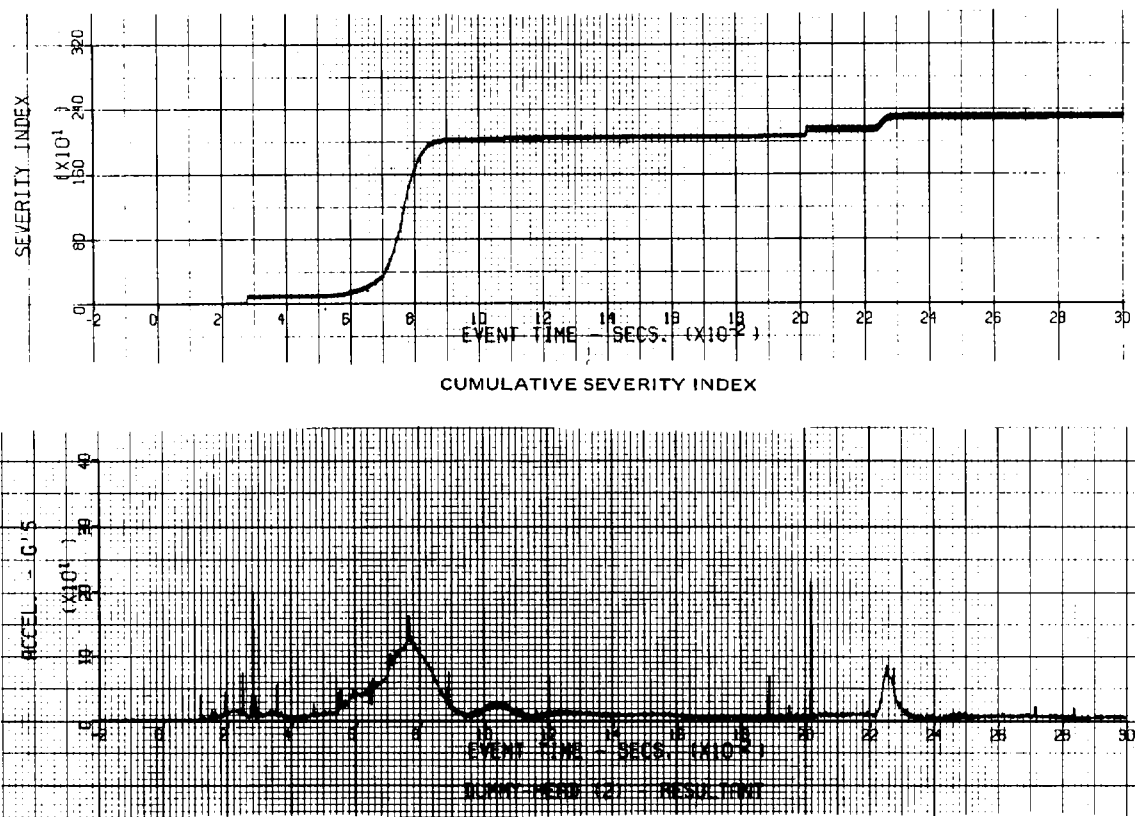


Figure B-59 (Cont.) RIGHT FRONT PASSENGER HEAD ACCELERATION (TEST 90)

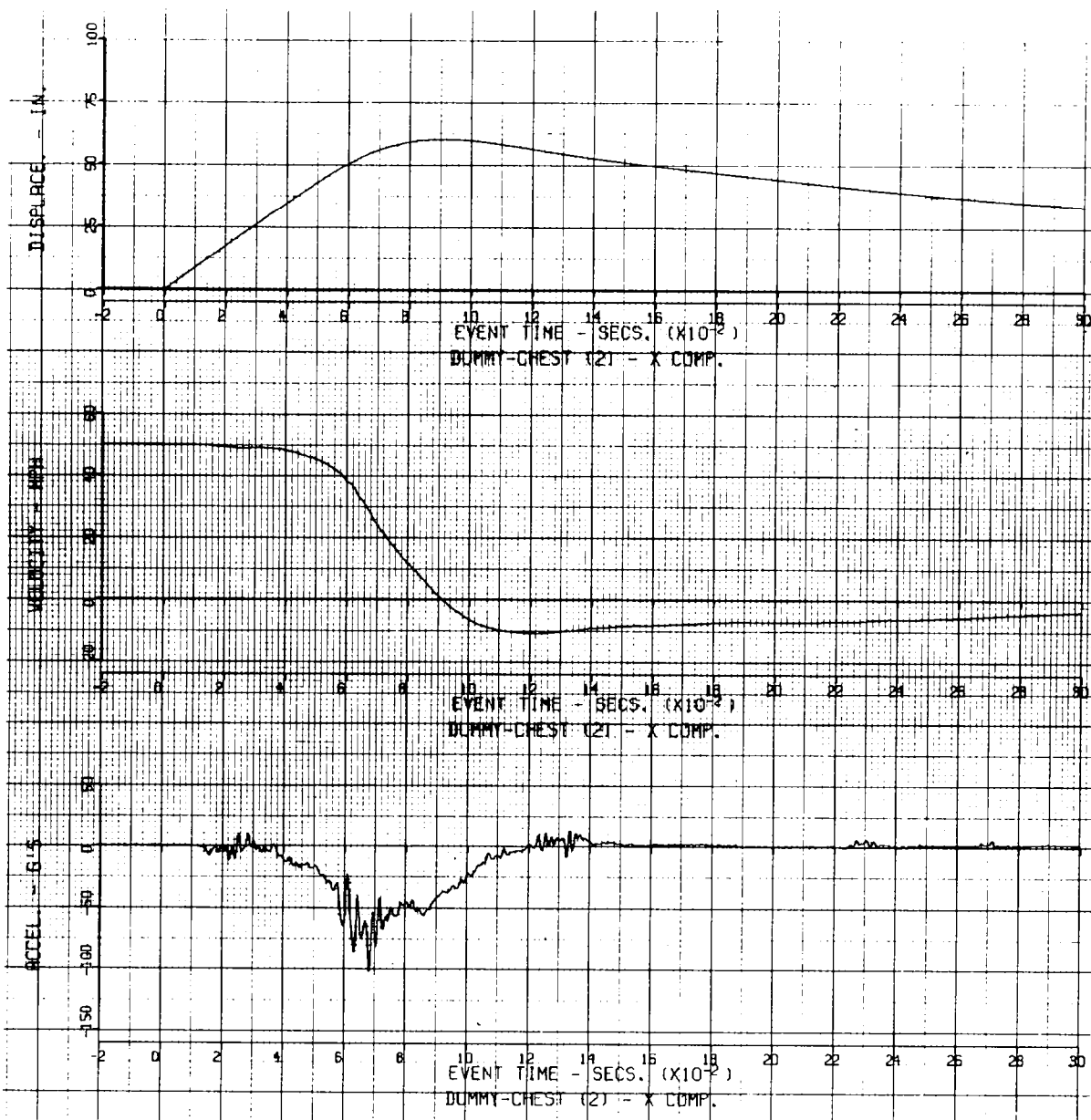
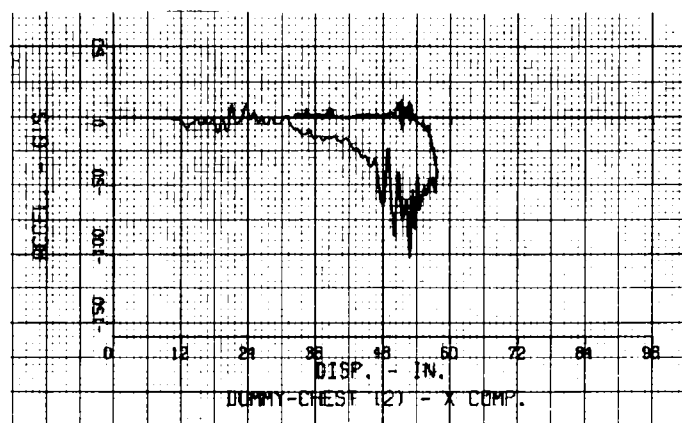


Figure B-60 RIGHT FRONT PASSENGER CHEST ACCELERATION AND HORIZONTAL KINEMATIC DATA (TEST 90)

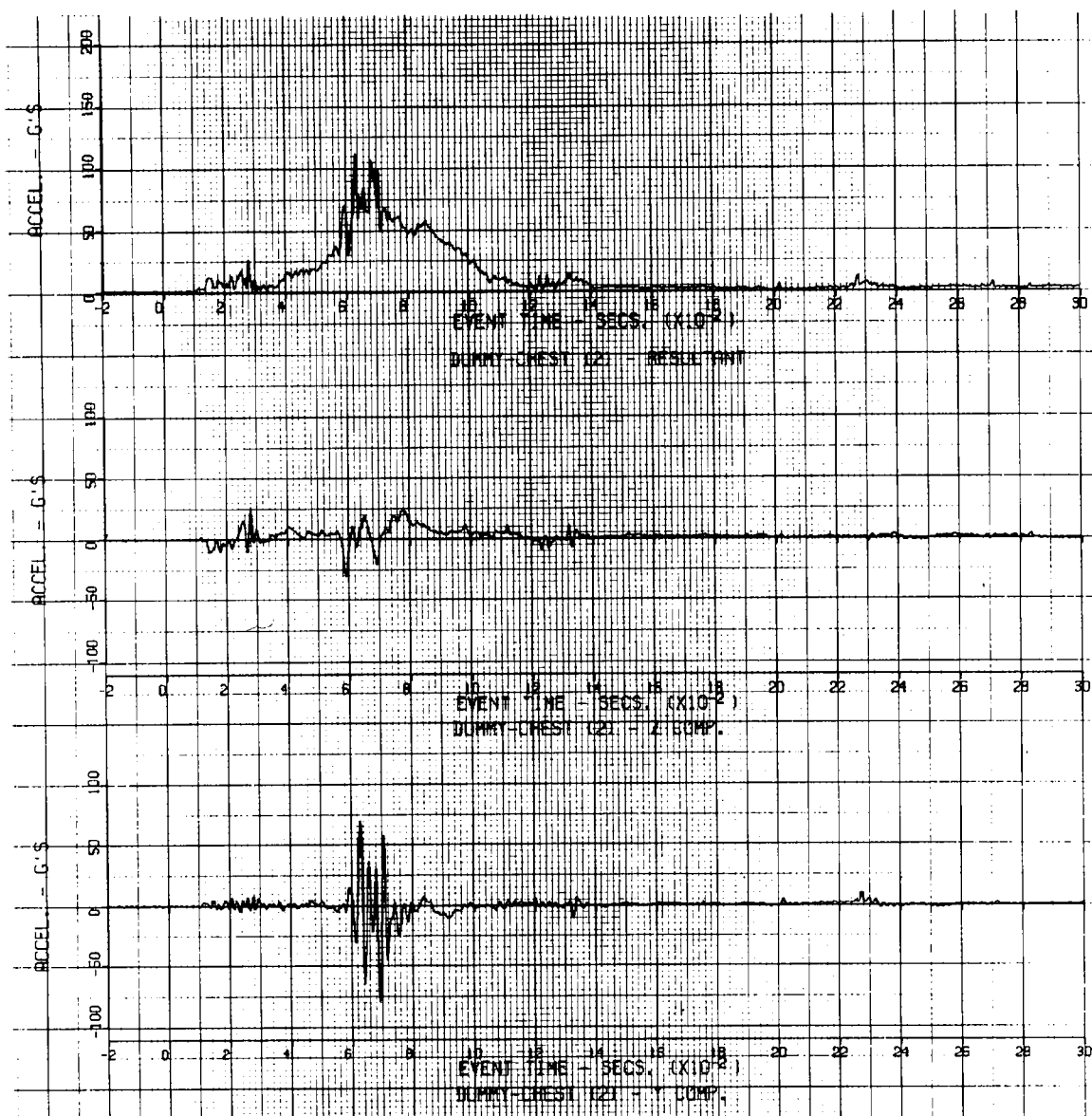


Figure B-60 (Cont.) RIGHT FRONT PASSENGER CHEST ACCELERATION AND LONGITUDINAL KINEMATIC DATA (TEST 90)

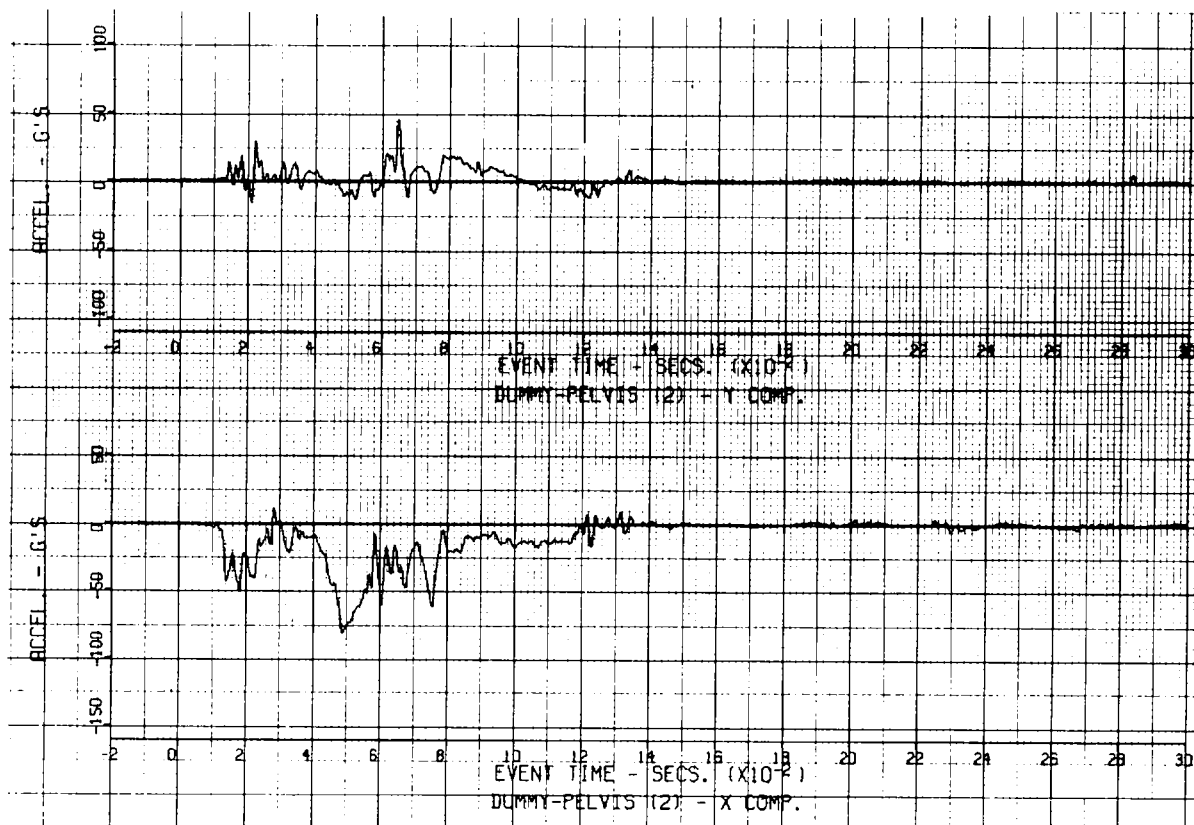


Figure B-61 RIGHT FRONT PASSENGER PELVIS ACCELERATION (TEST 90)

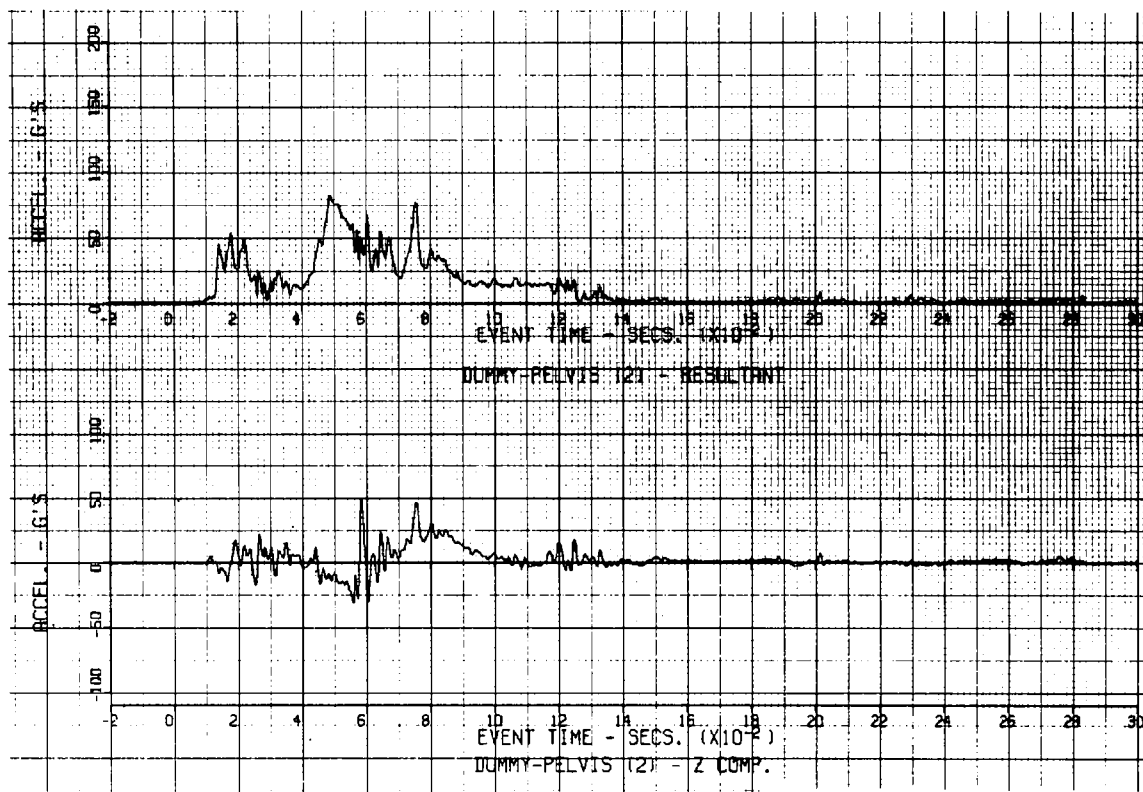


Figure B-61 (Cont.) RIGHT FRONT PASSENGER PELVIS ACCELERATION (TEST 90)

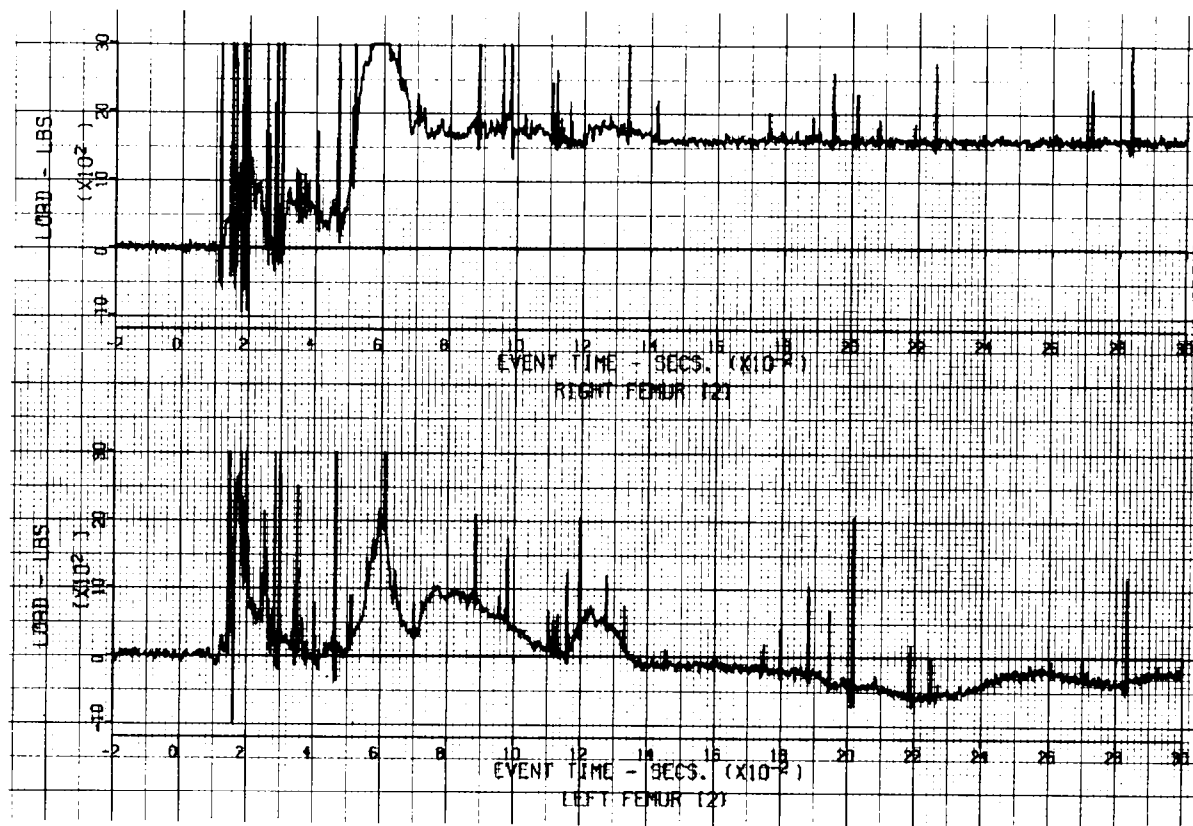


Figure B-62 RIGHT FRONT PASSENGER FEMUR LOAD DATA (TEST 90)

Test No. 91 Data

The following items are included:

1. Instrumentation requirements
2. Test site location of sensors and cameras
3. Before and after test photographs
4. Engine acceleration data
5. Passenger compartment acceleration data
6. Pole barrier loads

INSTRUMENTATION REQUIREMENTS

FACILITY TEST NO. 154 PROGRAM TEST NO. 91
 PROGRAM: Crashworthiness II
 TEST DESCRIPTION: Pole obstacle impact
 VEHICLE TYPE: OV-II (R) (Repaired Vehicle)

VEHICLE DESIGNATION	COM- PONENT	COMPARTMENT				ENGINE	DUMMIES (1, 2)				RESTRAINT			RECORDER	OTHER
		TUNNEL	(1) (2) CORNERS (4) (3)	REAR DECK	OTHER		HEAD	CHEST	PELVIS	LAP	SHOULDER	OTHER			
OV-II	X	A	1A, 2A, 3A, 4A			A									POLE X-comp. only
	Y	A	1A, 2A, 3A, 4A												
	Z	A	1A, 2A, 3A, 4A												
	X														
	Y														
	Z														

LEGEND:

A - ACCELEROMETER
 V - VELOCITY METER
 D - DISPLACEMENT METER
 L - LOAD CELL

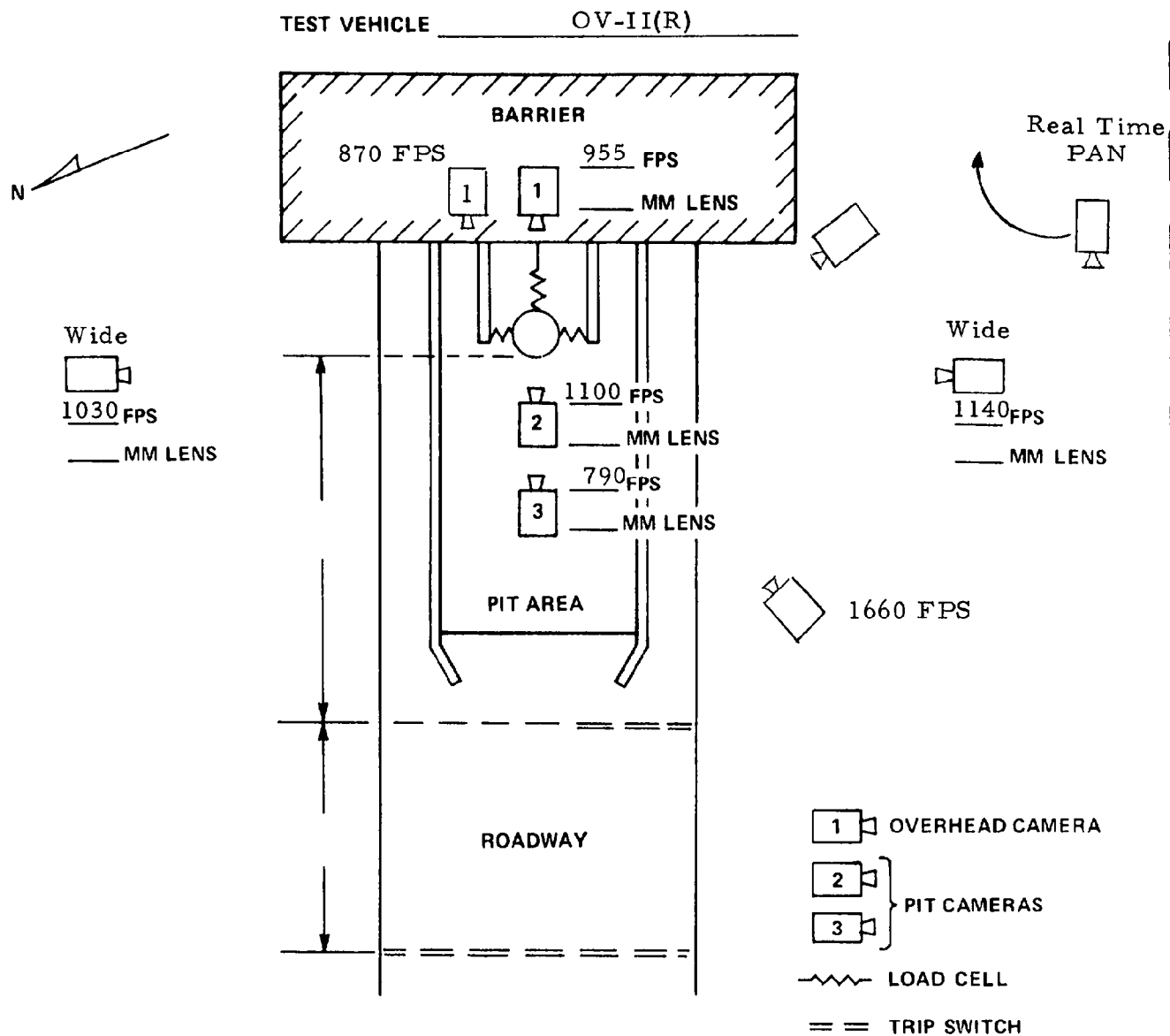
MISCELLANEOUS

- 1) CONTACT SWITCH/BAR:
- 2) AIR BAG SENSORS:
- 3) POSITION OF CARS:
- 4) SPEED WINDOW: 57.5 ± 2.5 MPH

PROJECT: Crashworthiness II TEST NO: 91

FACILITY TEST NO: 154

TEST SITE LOCATION OF SENSORS AND CAMERAS



REMARKS:

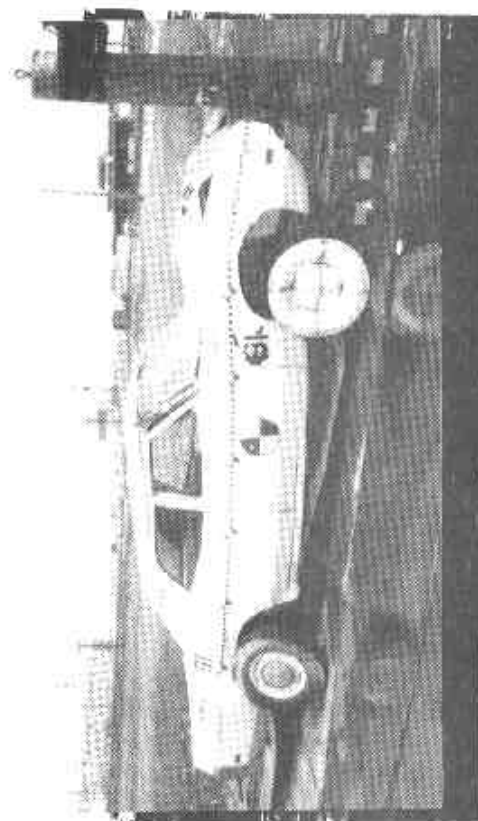
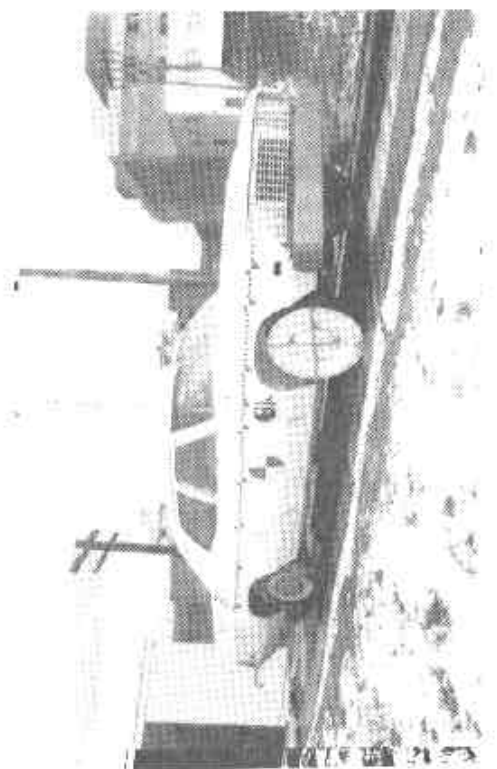
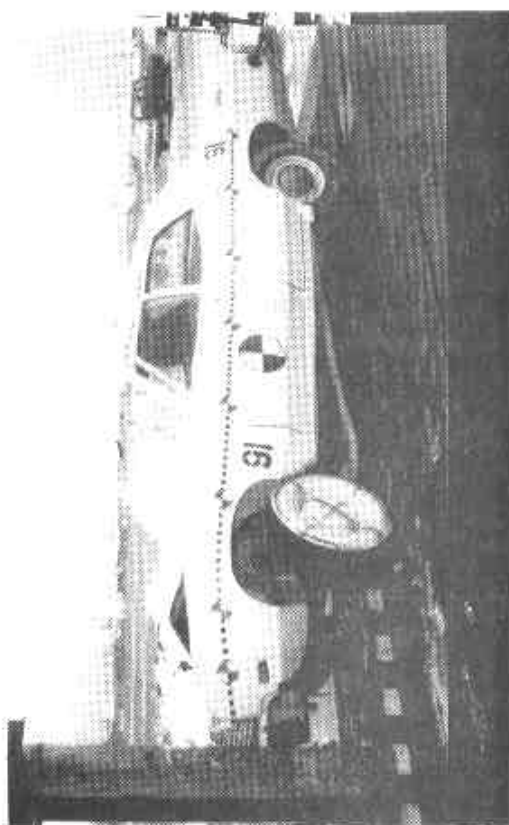
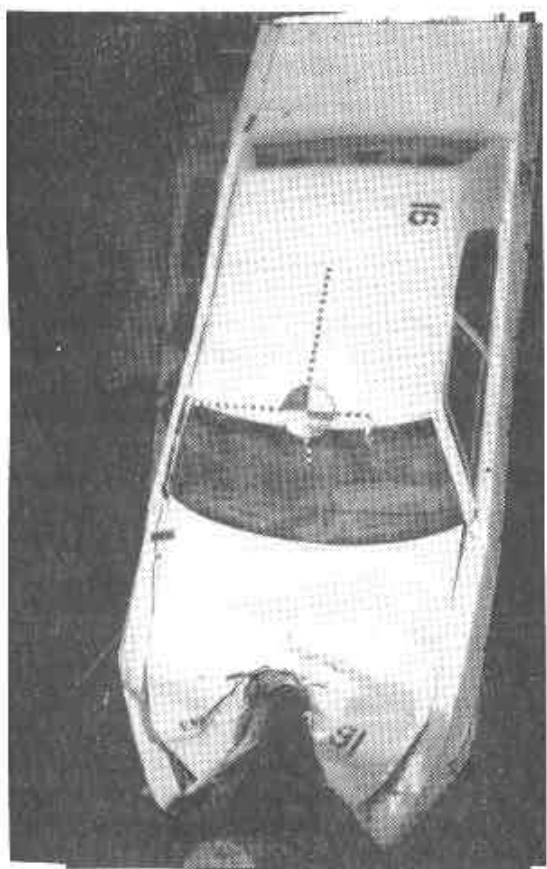


Figure B-63 EXTERIOR BEFORE AND AFTER IMPACT VIEWS OF OV-II (R) VEHICLE (TEST 91)

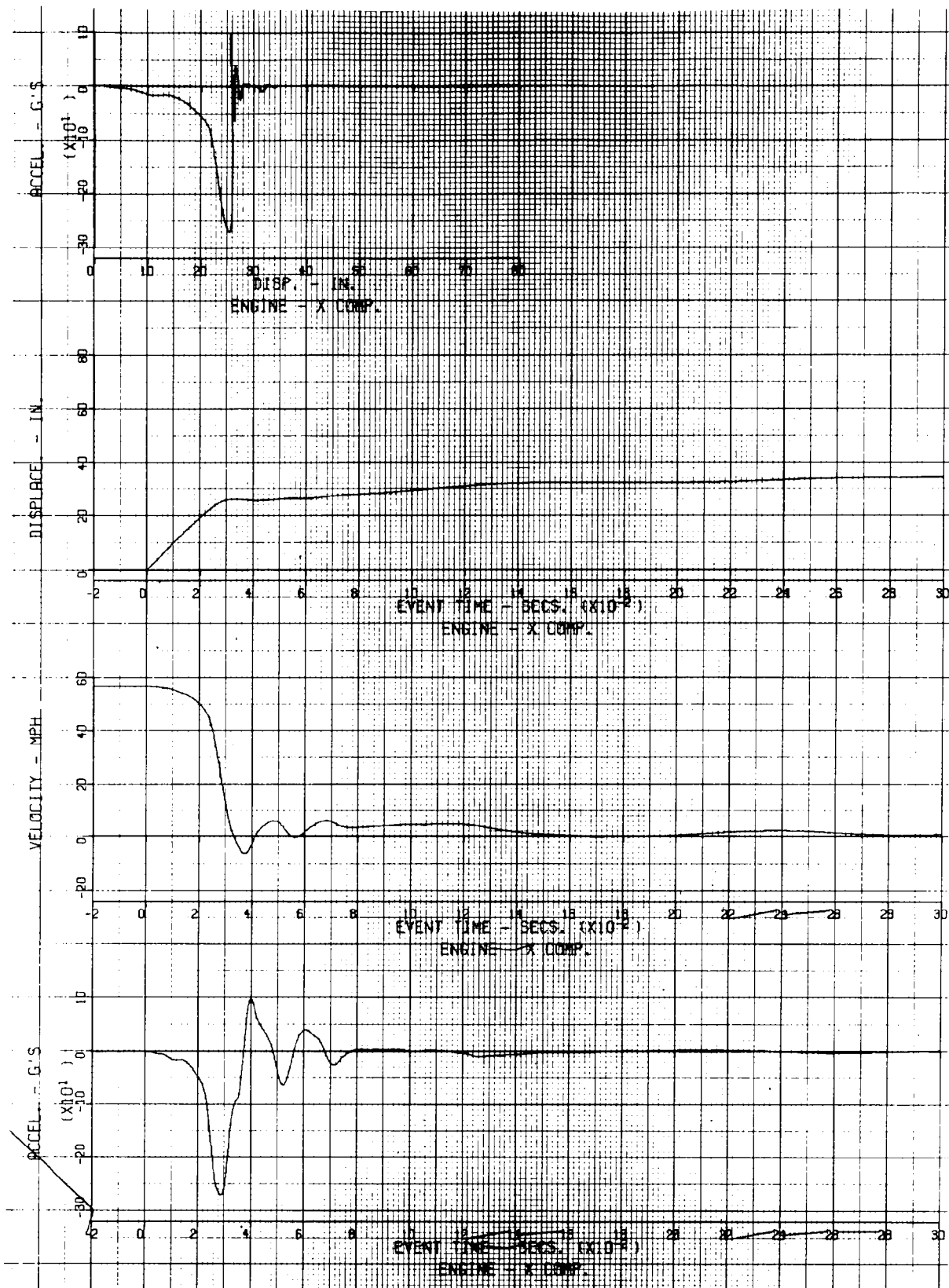


Figure B-64 ENGINE LONGITUDINAL KINEMATIC DATA (TEST 91)

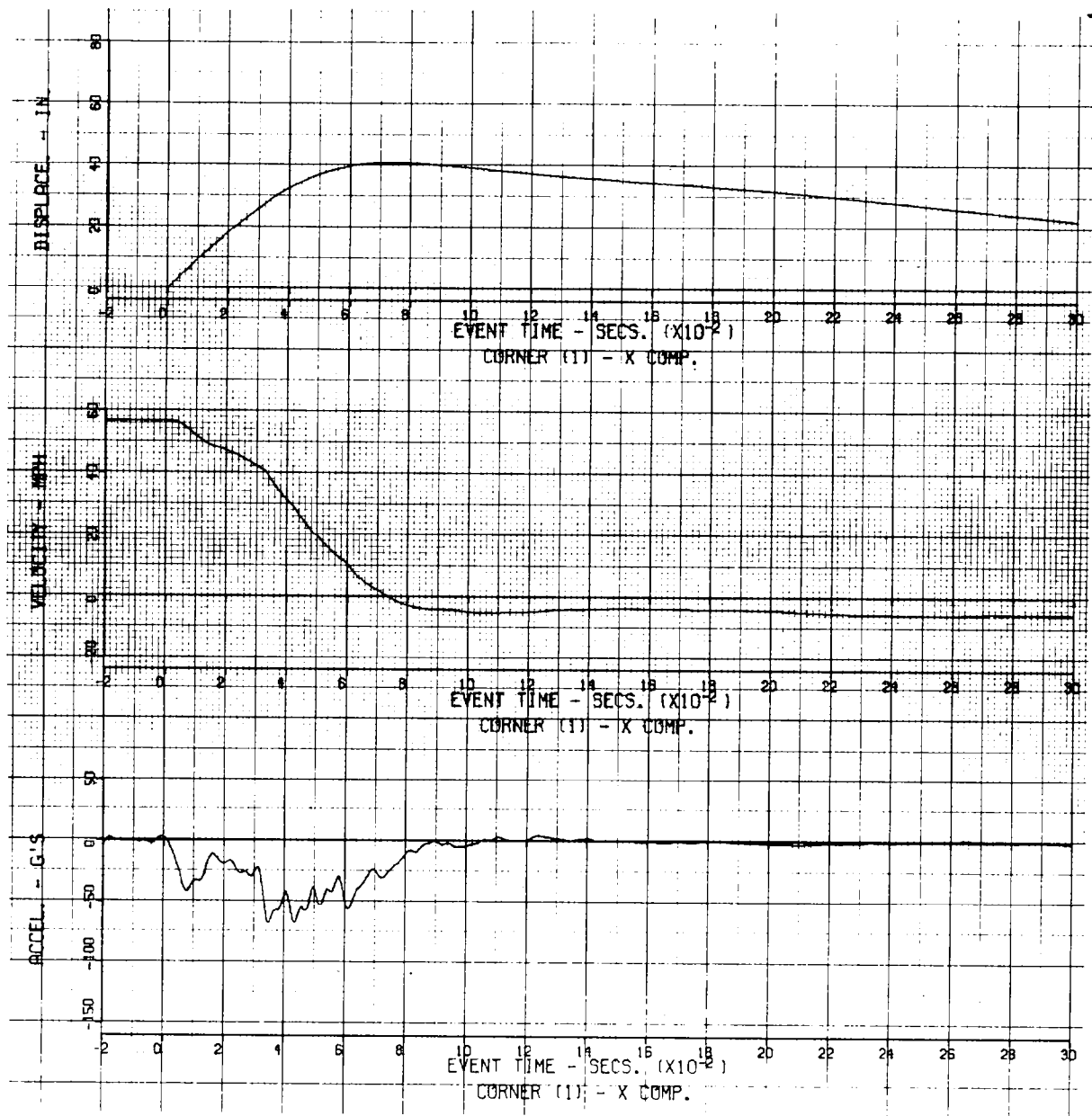


Figure B-65 PASSENGER COMPARTMENT ACCELERATION AND LONGITUDINAL KINEMATIC DATA, LEFT FRONT CORNER LOCATION (TEST 91)

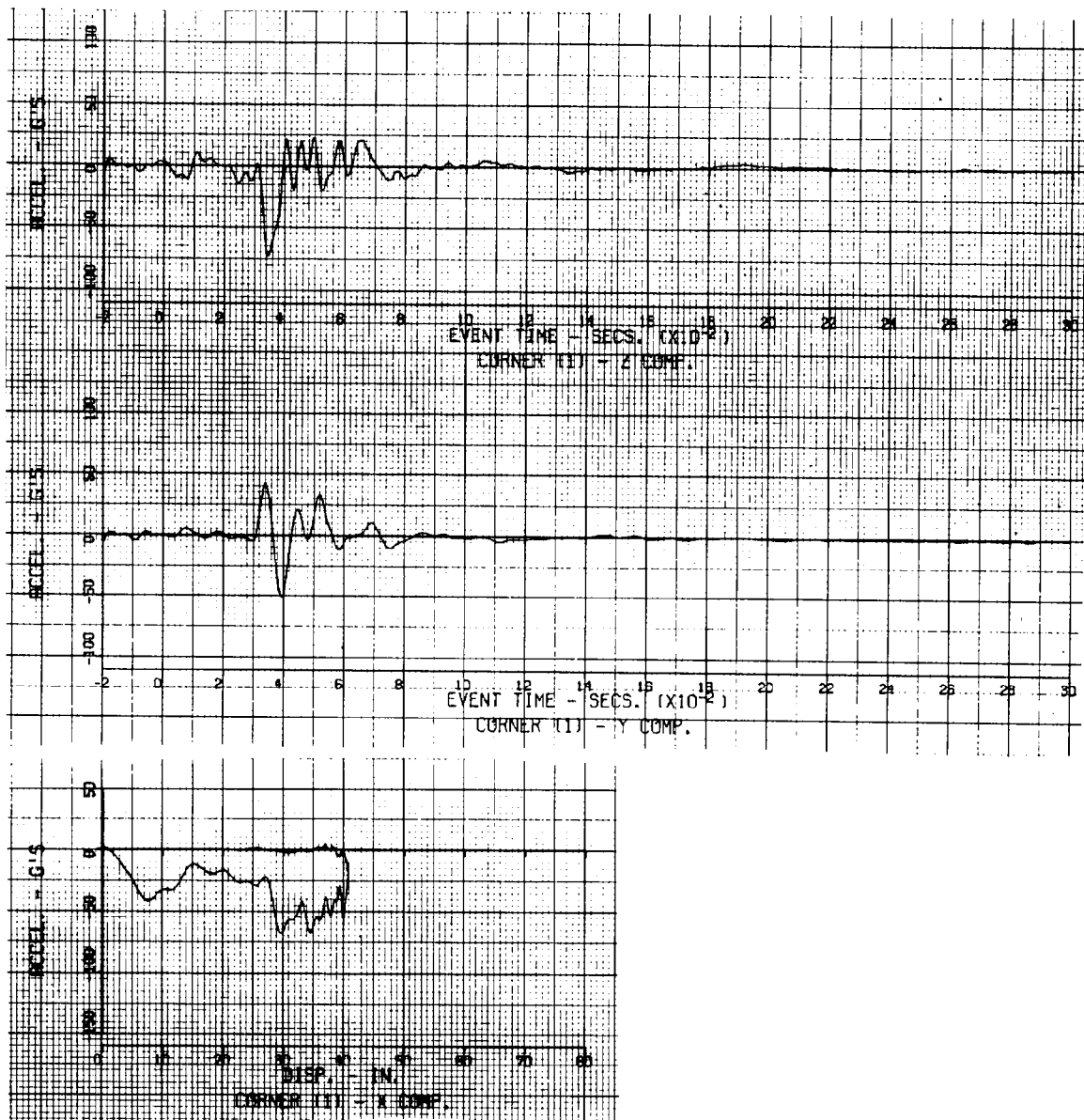


Figure B-65 (Cont.) PASSENGER COMPARTMENT ACCELERATION AND LONGITUDINAL KINEMATIC DATA, LEFT FRONT CORNER LOCATION (TEST 91)

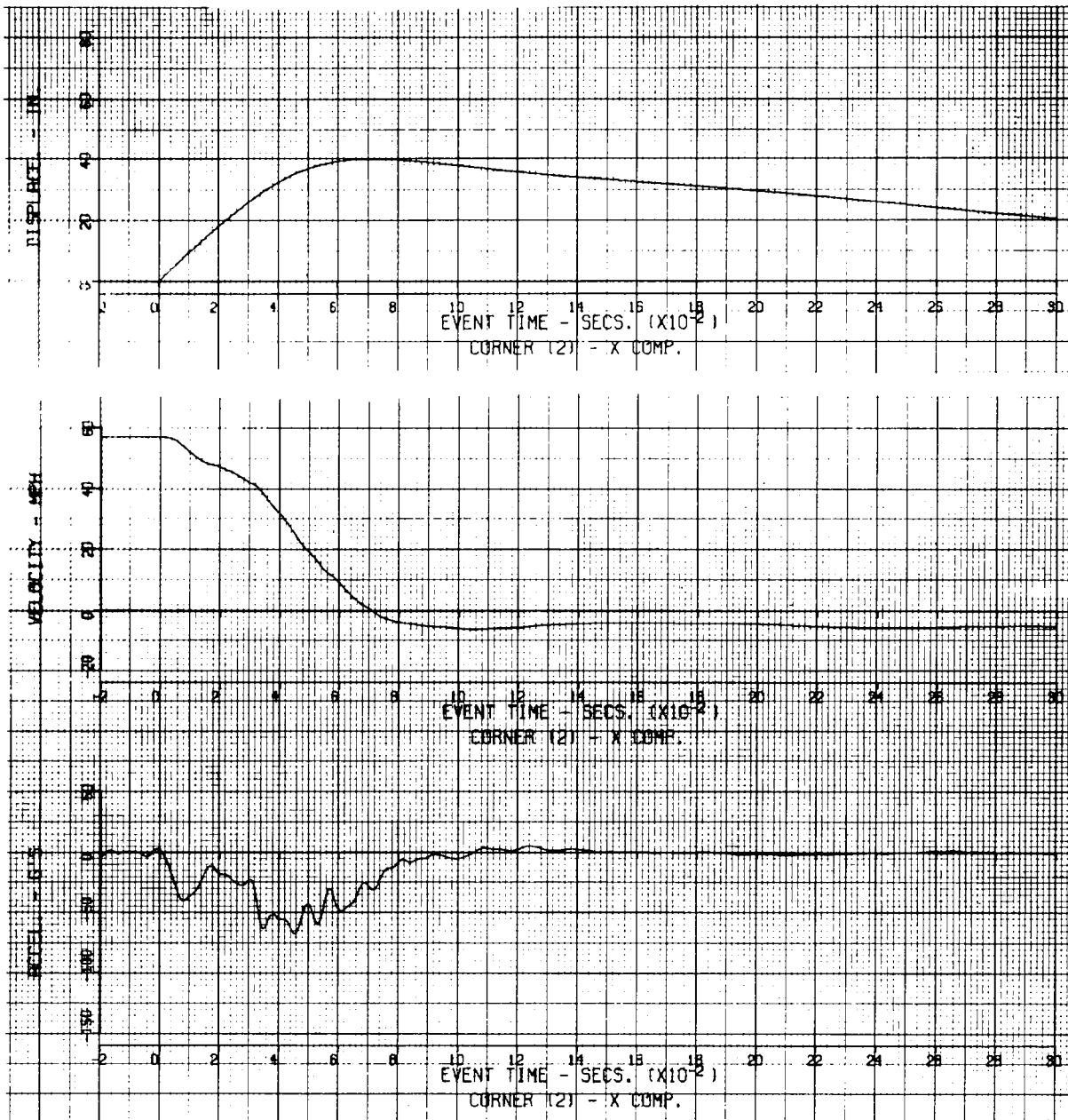


Figure B-66 PASSENGER COMPARTMENT ACCELERATION AND LONGITUDINAL KINEMATIC DATA, RIGHT FRONT CORNER LOCATION (TEST 91)

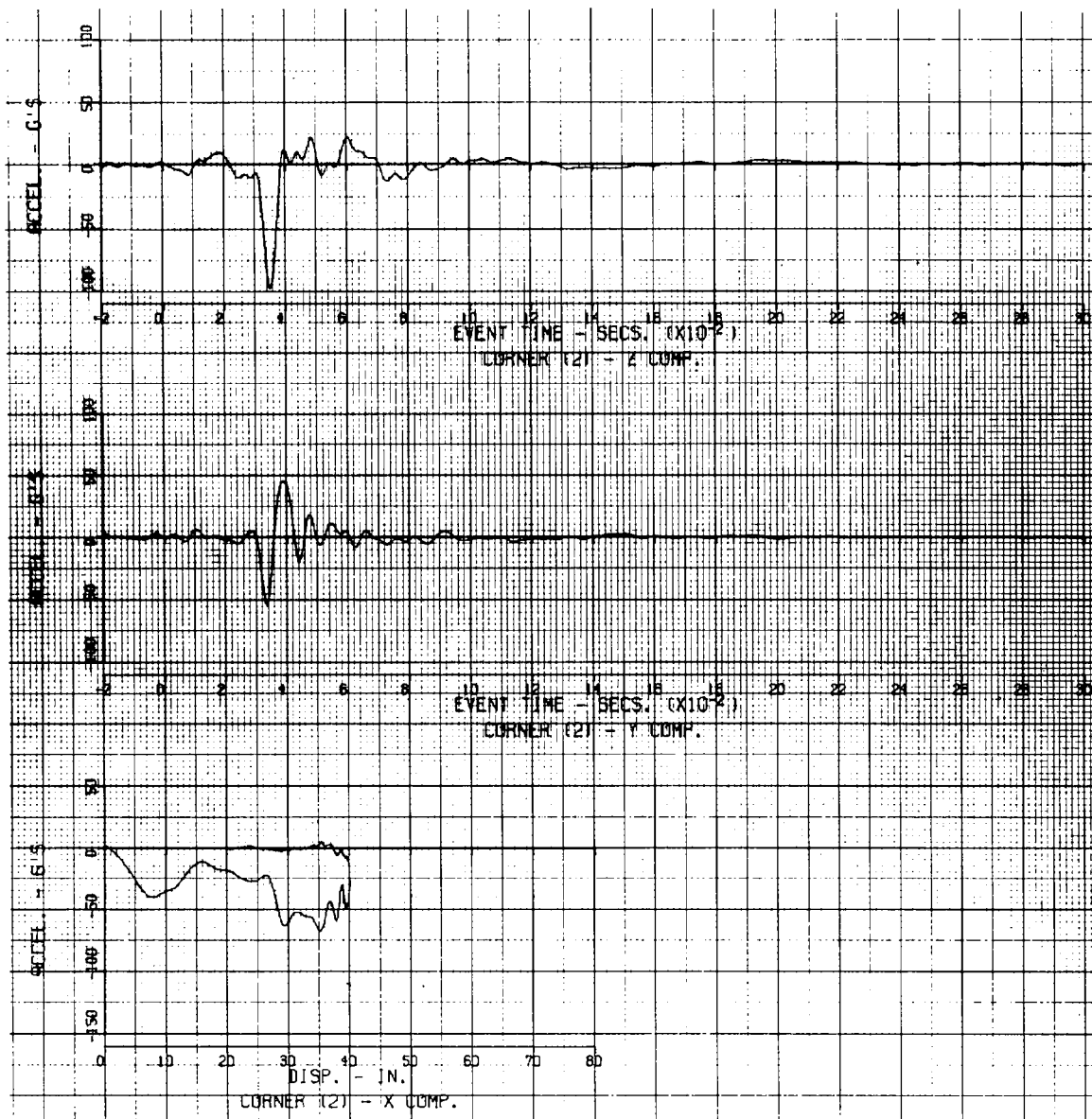


Figure B-66 (Cont.) PASSENGER COMPARTMENT ACCELERATION AND LONGITUDINAL KINEMATIC DATA, RIGHT FRONT CORNER LOCATION (TEST 91)

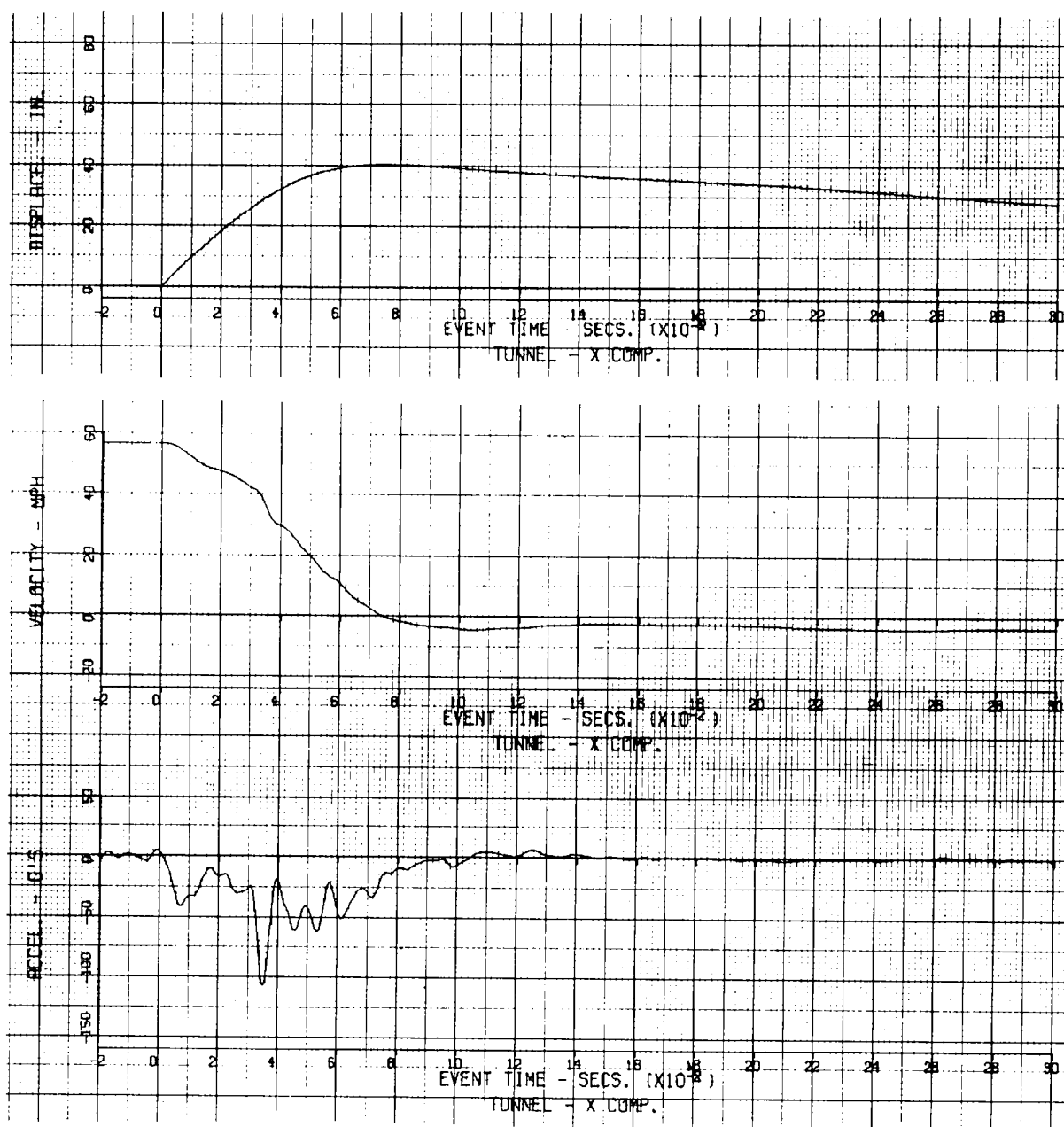


Figure B-67 PASSENGER COMPARTMENT ACCELERATION AND LONGITUDINAL KINEMATIC DATA, TUNNEL LOCATION (TEST 91)

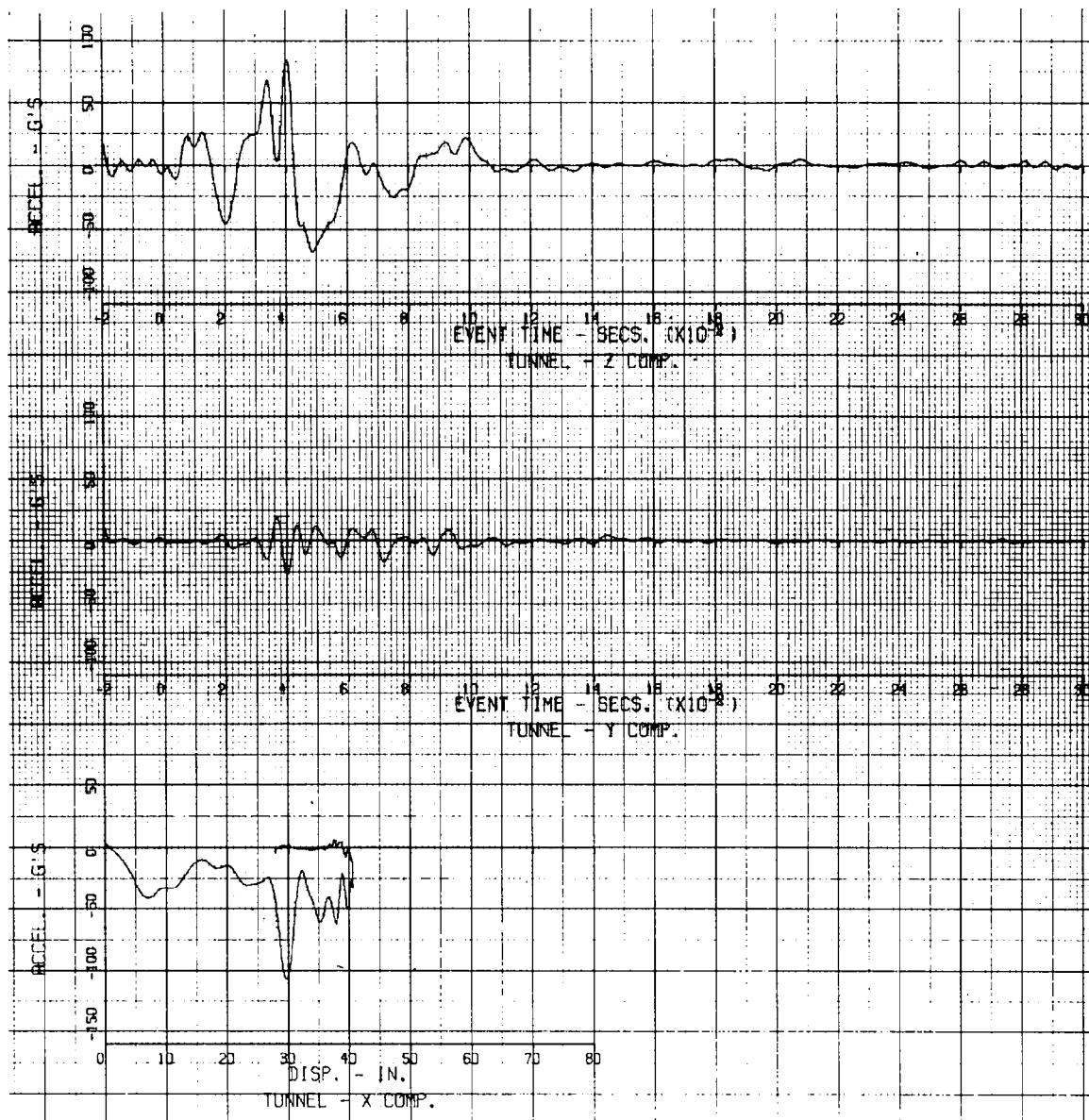


Figure B-67 (Cont.) PASSENGER COMPARTMENT ACCELERATION AND LONGITUDINAL KINEMATIC DATA, TUNNEL LOCATION (TEST 91)

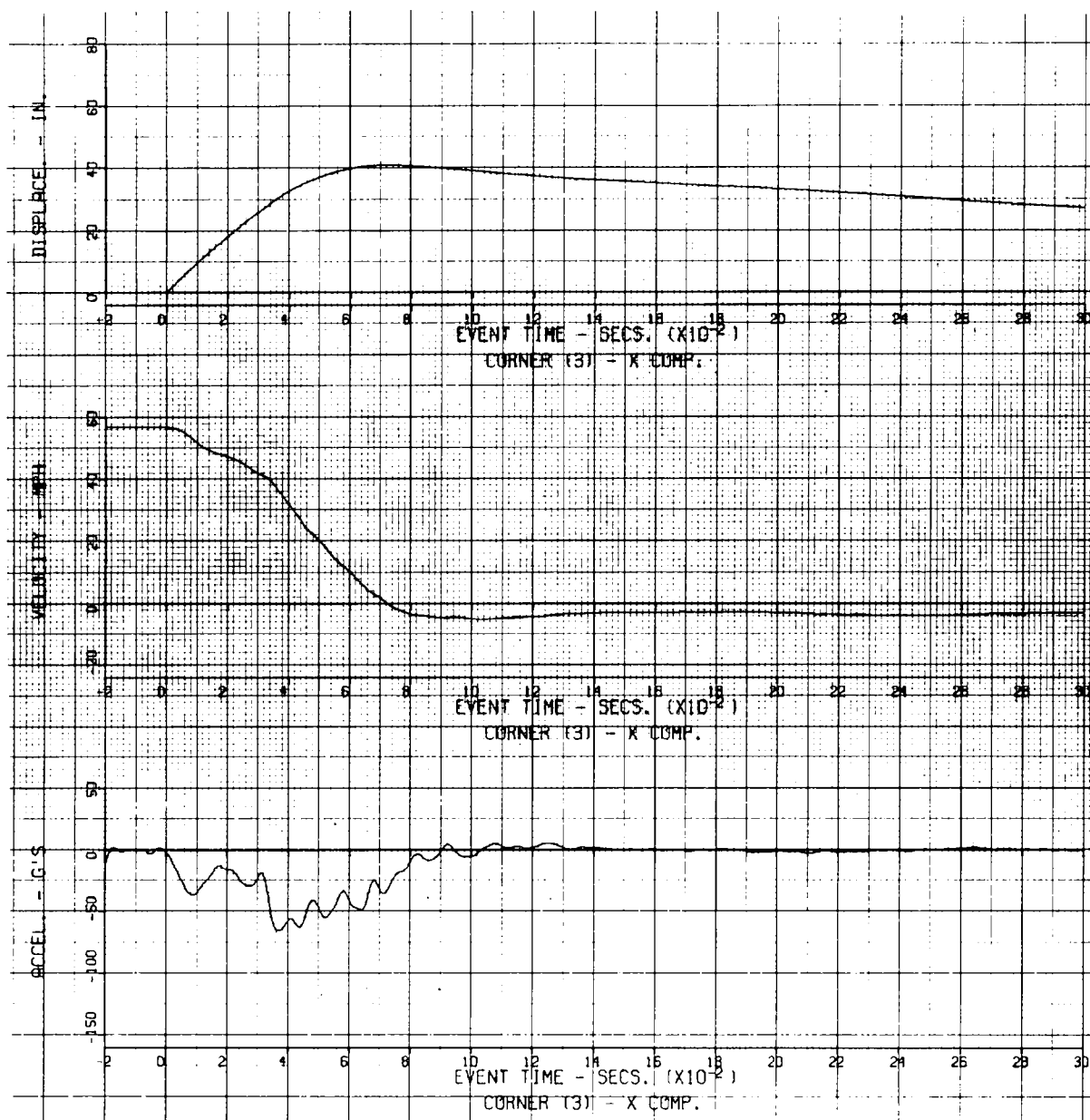


Figure B-68 PASSENGER COMPARTMENT ACCELERATION AND LONGITUDINAL KINEMATIC DATA, RIGHT REAR CORNER LOCATION (TEST 91)

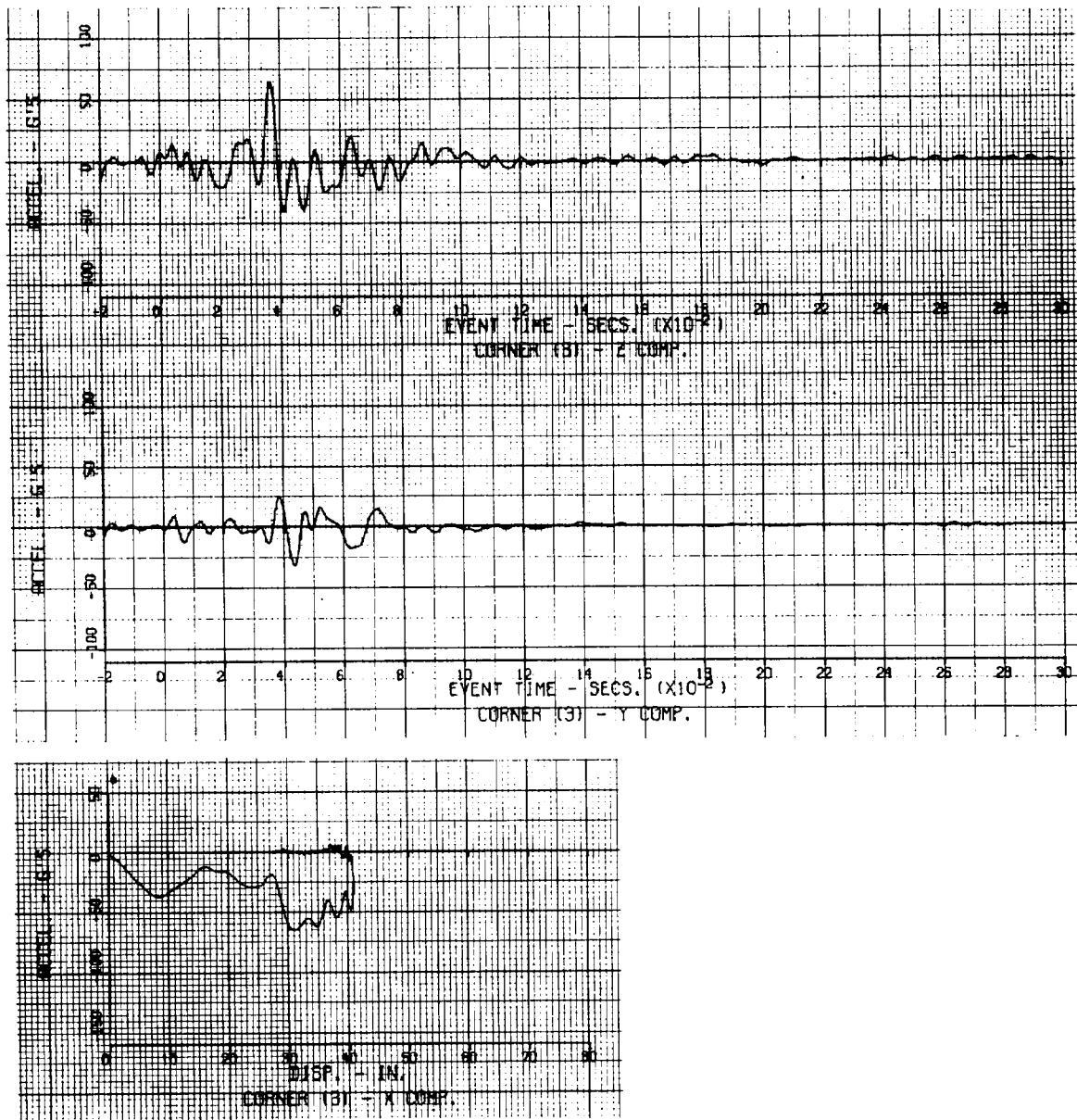


Figure B-68 (Cont.) PASSENGER COMPARTMENT ACCELERATION AND LONGITUDINAL KINEMATIC DATA, RIGHT REAR CORNER LOCATION (TEST 91)

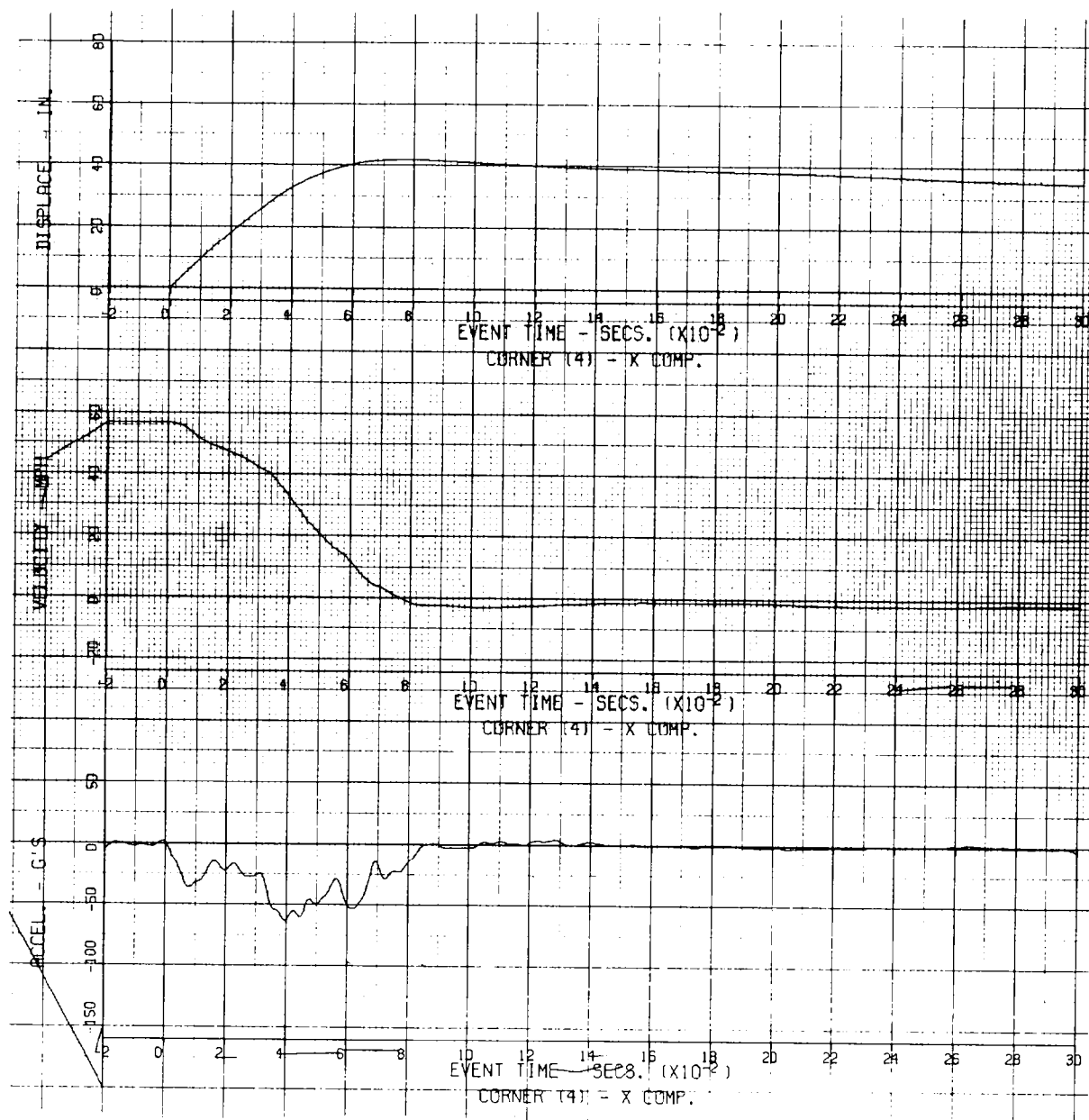


Figure B-69 PASSENGER COMPARTMENT ACCELERATION AND LONGITUDINAL KINEMATIC DATA, LEFT REAR CORNER LOCATION (TEST 91)

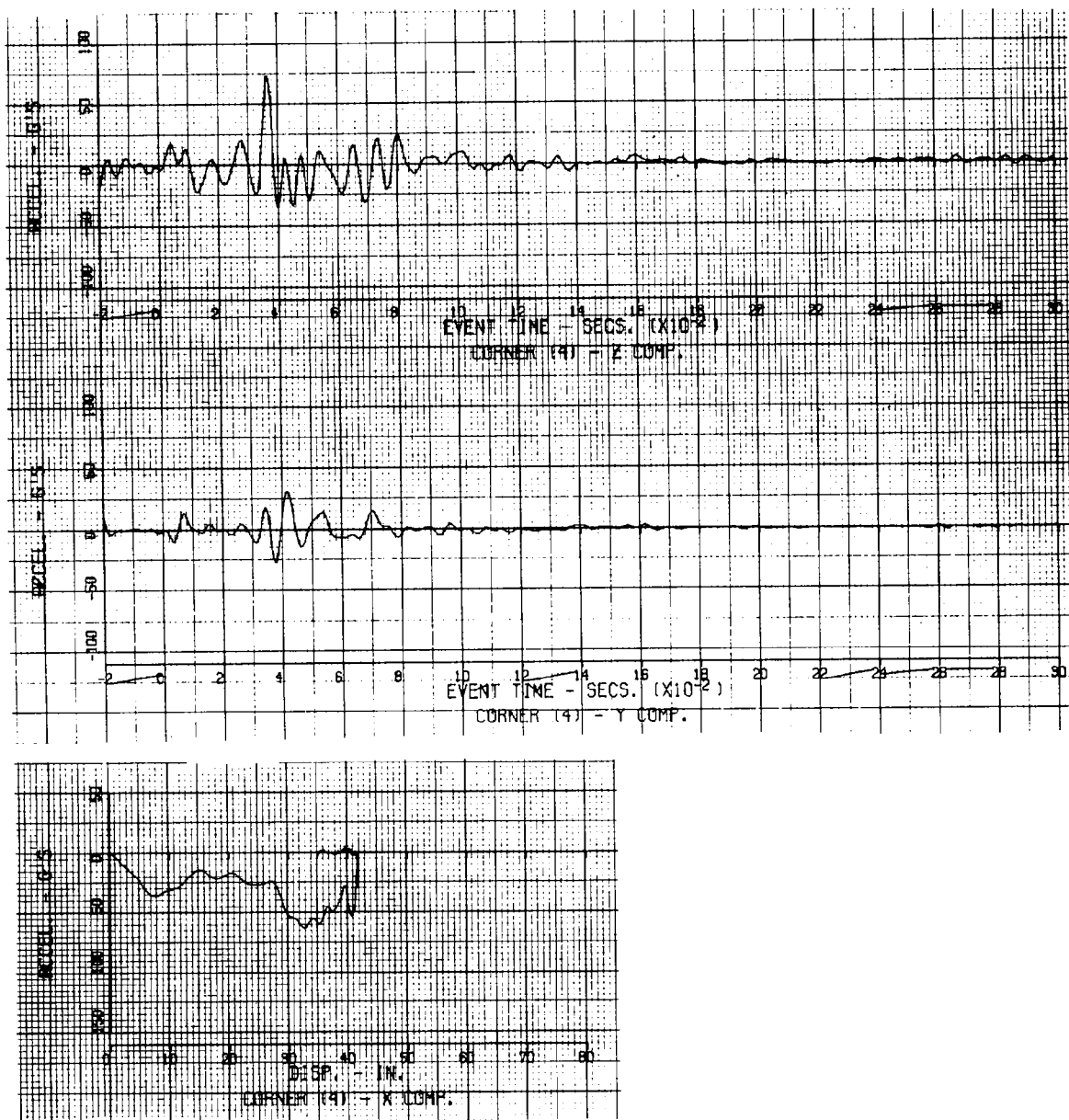


Figure B-69 (Cont.) PASSENGER COMPARTMENT ACCELERATION AND LONGITUDINAL KINEMATIC DATA, LEFT REAR CORNER LOCATION (TEST 91)

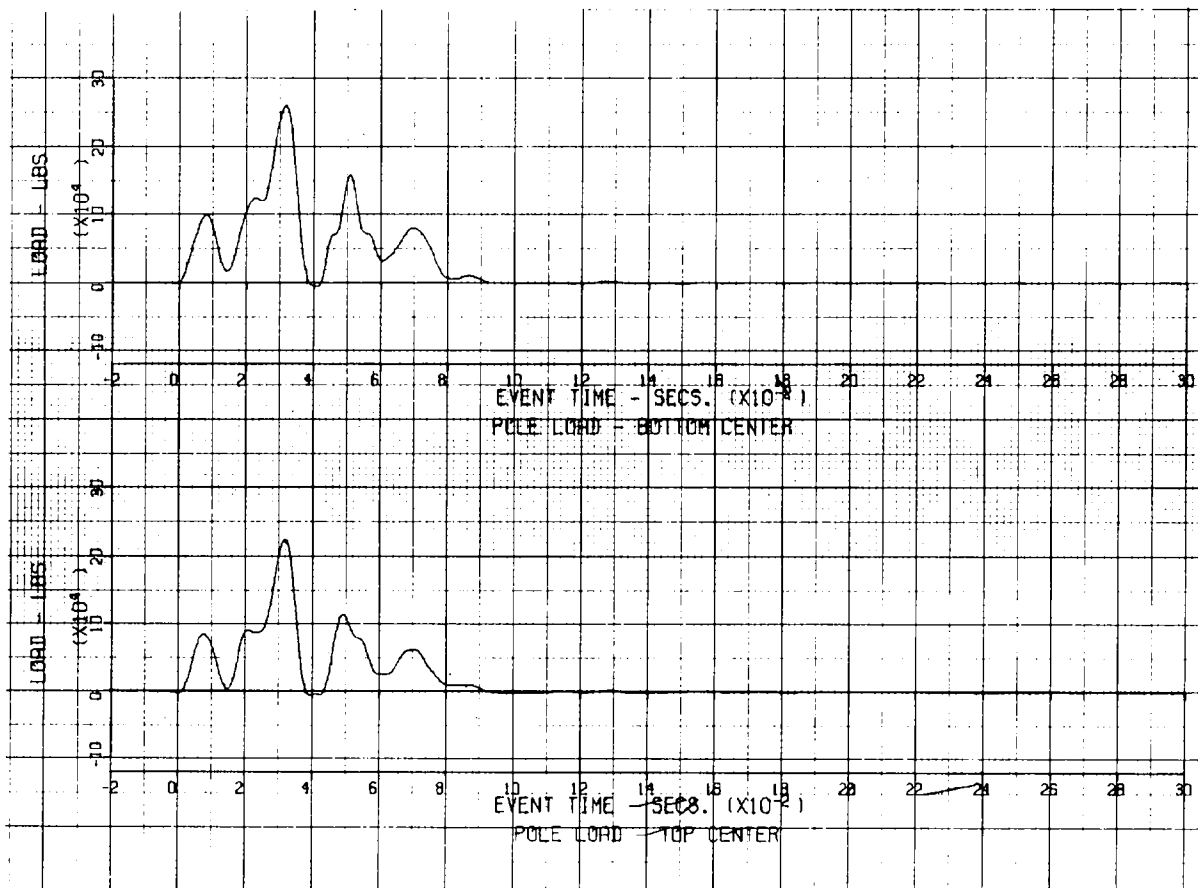


Figure B-70 LONGITUDINAL FORCES MEASURED ON POLE BARRIER (TEST 91)