FHWA-85-12

FEDERAL HIGHWAY ADMINISTRATION CONTRACT
DTFH61-83-C-00140

IMPACT ATTENUATORS
A CURRENT ENGINEERING EVALUATION

Test Results Report for
Test #1625-C-04-85

Task C

Prepared for:

FEDERAL HIGHWAY ADMINISTRATION
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CONVERSION FACTORS

1 inch = 0.0254 meter	1 lb = 0.454 kilogram
1 foot = 0.3048 meter	1 kip = 4,448 Newton
1 ft/sec = 0.3048 meter/sec	1 kip-ft = 1,355 Newton-meter
1 mph = 0.447 meter/sec	1 g = 32.2 ft/sec^2

LIST OF KEY ABBREVIATIONS

c.g. - Center of Gravity
CMB - Concrete Median Barrier
CSI - Chest Severity Index
EAS - Energy Absorption Systems, Inc.
f_c - Filter Corner Frequency
FHWA - Federal Highway Administration
ft - Foot or Feet
GREAT - Guard Rail Energy Absorption Terminal
HIC - Head Injury Criteria
Hz - Hertz
lb - Pound
m - Meter
msec - Millisecond
mph - Miles Per Hour
NCHRP - National Cooperative Highway Research Program
NHTSA - National Highway Traffic Safety Administration
SAE - Society of Automotive Engineers
sec - Second
TRC - Transportation Research Circular

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1.0 INTRODUCTION

Previous testing and analysis of impact attenuators has been based mainly on vehicles weighing 2,250 lbs or greater. Due to the recent upsurge in sales of mini-compact sedans (1,800 lb range) this class is becoming a significant portion of the vehicle population. This poses new problems that were not previously of concern. The small size and weight of the mini-sized cars with reduced dimensions of the wheel base, track width, and crush space lowers the mass moments of inertia in comparison to larger cars. These differences effect the behavior of the car in a collision, especially since most impact attenuators are designed for larger vehicles.

In order to better understand the behavior of impact attenuator collisions a series of 17 full scale crash tests with impact attenuators were planned under FHWA contract DTFH61-83-C-00140. Four tests were conducted with a Guard Rail Energy Absorption Terminal (GREAT) system and 13 tests were conducted with Fitch or Energite barrel systems. This report provides the results on the fourth GREAT test, the only GREAT test using a large sedan as the test vehicle. A similar test was previously performed using a mini-compact sedan. The test number, following the convention in the test plan as approved by FHWA is 1625-C-04-85. The objective of this test was to investigate the dynamics of a large sedan vehicle impacting a Guard Rail Energy Absorption Terminal (GREAT). A summary of the test conditions and results are provided in Table 1-1.

This report documents the Test Results for FHWA test 1625-C-04-85. Section 2.0 summarizes the test conditions, including discussions of the appurtenance, vehicle, and instrumentation. Test results are reviewed in Section 3.0 according to impact description, vehicle damage, impact attenuator damage/debris pattern and photography. In Section 4.0 the data analysis is divided into vehicle, dummy, and GREAT parameters. Safety implications are reviewed in Section 5.0.

TABLE 1-1

SUMMARY OF TEST CONDITIONS AND RESULTS - TEST 1625-C-04-85

Contract Number: DTFH61-83-C-00140 Date: 23 July 1985

Test Vehicle: 1979 Ford LTD II Weather: Sunny, 80F

GREAT Configuration: Two-foot wide,six-bay,hexfoam cartridges

Back-up Structure: Two 12-foot CMB's, anchored to concrete pad

1. Vehicle Weight:

	Test Inertial	Gross Static
Planned	4500 ± 200	4500 ± 300
Actual	4346	4720

2. Number of Occupants: Two

3. Occupant Model: Anthropomorphic Dummy, 50th% male, SN 186 and SN 189

4. Occupant Location: Driver's Seat, Unrestrained; Passenger's Seat, Restrained

5. Impact:

	Speed	Angle	Location
Planned	60 mph	0	Center of Nose
Actual	58.4 mph	0	Center of Nose

6. Rebound Data:
   - Speed: 7.9 mph
   - Angle: 6 degrees
   - Distance: 11.7 feet

7. Total Speed Change: (accelerometer data) 105.2 ft/sec

8. Vehicle Damage Index, SAE J224a: 12FCEN2

9. NCHRP 230 Test Number: 50

TABLE 1-1 (Cont'd)

SUMMARY OF TEST CONDITIONS AND RESULTS - TEST 1625-C-04-85

10. Vehicle Analysis:

	Observed	Design Limit (Absolute)	Limit Value (Absolute)
ΔV, NCHRP 230:	-27.0 ft/sec	30.0 ft/sec	40.0 ft/sec
Ridedown Accel., NCHRP 230: (10 msec)	-42.3 g's	15.0 g's	20.0 g's
Avg Accel. over stopping distance, TRC 191	-6.1 g's[1]	8.0 g's	12.0 g's
Stopping distance	18.4 ft[2]		
50 msec Average Acceleration	-24.1 g's	8.0 g's	

11. Occupant Analysis:

	Driver	Passenger	Design Limit
HIC	293	260	1000
CSI	286	174	1000
Max Chest Accel	35.7	30.0	60 g's
Right Femur Load	795	280	2250 lbs
Left Femur Load	957	100	2250 lbs

[1] Cannot be used because actual decelerations are not reasonably constant. Must use 50 msec average acceleration instead.

[2] Composed of 16.6 feet of GREAT system crush and 2.2 feet of vehicle crush.

2.0 TEST CONDITIONS

The test was conducted at the ENSCO Aquasco Test Facility under good weather conditions (sunny, dry, 80° F). The test corresponds to Test 50 of NCHRP 230 which specifies a 4500S vehicle impacting the crash cushion at a speed of 60 mph and at a 0 degree impact angle. Details of the test conditions are given in the following pages.

2.1 TEST FACILITY

The test facility incorporates a reverse tow vehicle propulsion system. Vehicle guidance is accomplished through a self-correcting cable system. Both the towing and the guidance systems are designed to detach from the test vehicle just prior to impact, thus eliminating any effect of these systems on the impact.

A concrete pad (see Figure 2-1) was constructed and installed for the impact attenuator testing under this contract. The pad provides the following required fixtures:

- End post for guidance system
- Reversing sheaves for propulsion system.
- Tow Cable Pull-Down for release of propulsion cable
- Overhead camera boom
- 25' by 55' pad for installing crash cushions of various configurations.

2.2 TEST ARTICLE

The GREAT system consists of crushable Hex-Foam cartridges surrounded by a framework of triple-corrugated-steel guardrail. (See Figure 2-2) When hit head-on, the energy-absorbing cartridges crush to absorb the energy of the impact, while the steel guardrail side panels maintain directional control. Generally,

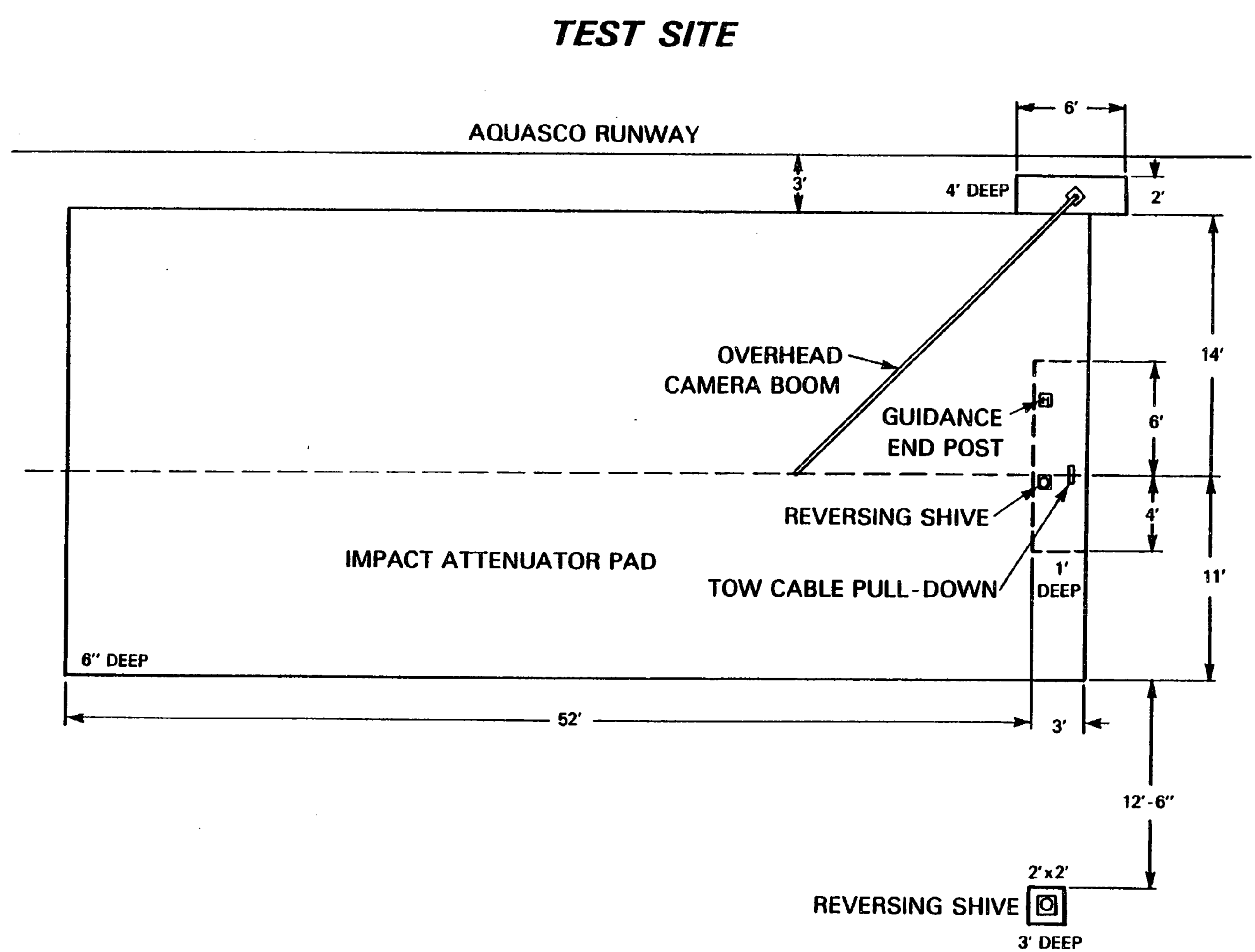
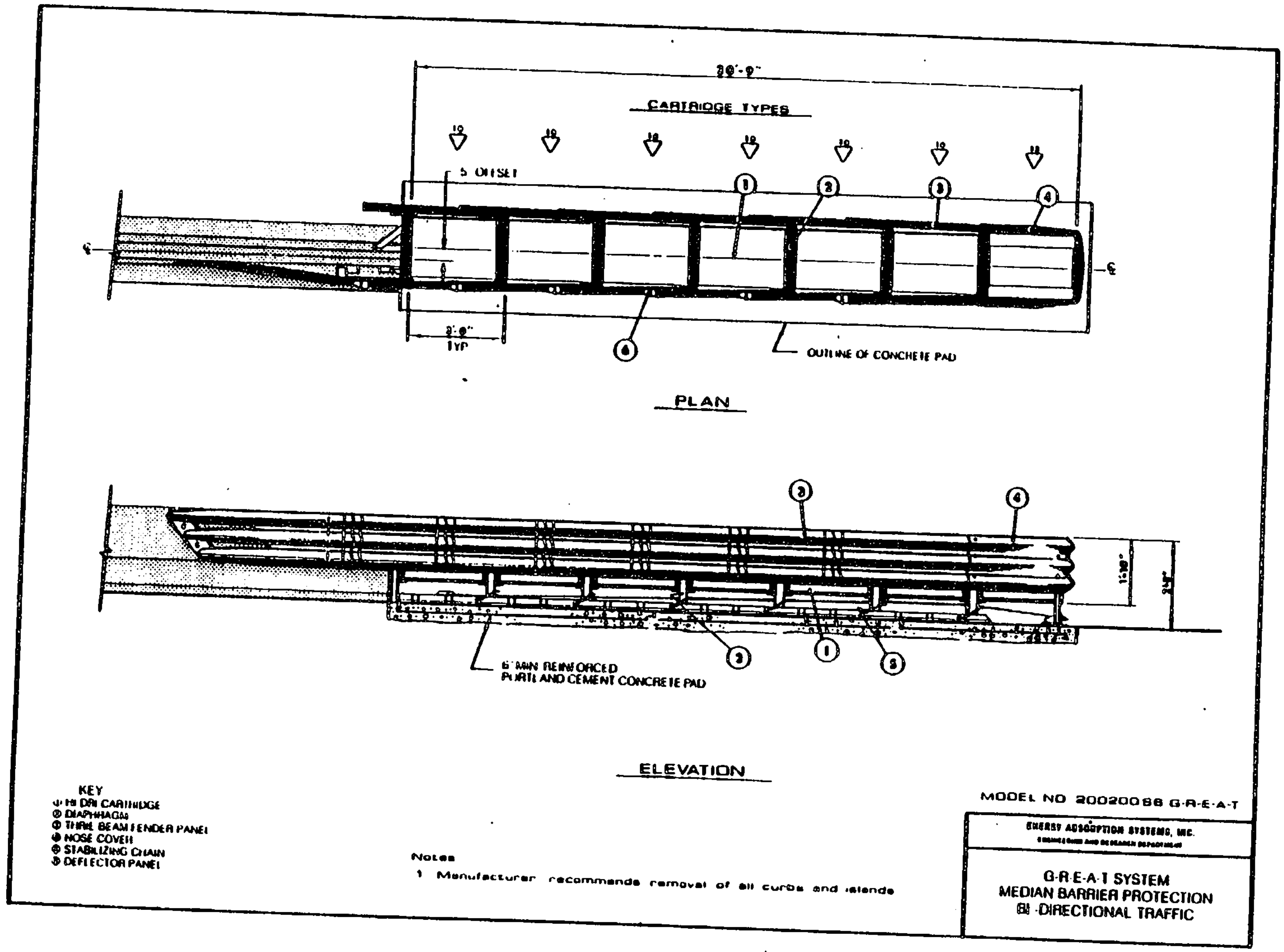


Figure 2-1. Test Site



NOTE: HI-DRI CARTRIDGE SYSTEM ILLUSTRATED
HEX-FOAM CARTRIDGE SYSTEM ACTUALLY USED

Figure 2-2. GREAT System

only the cartridges and nose cone are expended during a typical impact. When hit from the side, these panels are restrained by leg pins and guidance cables to redirect the errant vehicle. A two foot wide six bay Bi-Directional configuration of the GREAT was selected to represent a typical highway installation. This allows vehicle redirection from opposite traffic directions.

The GREAT system was installed, as specified in the Installation Instructions, with a five inch lateral offset to the right of the two 12 foot temporary Concrete Median Barriers (CMB). (Figure 2-3). Each CMB was attached to the pad using steel angle brackets. The brackets are based on the State of Maryland design shown in Figure 2-4. The fasteners are 3/4" Hilti Expansion Anchors. A bracket was used at the end of the back CMB to provide additional fixity, as shown in Figure 2-5.

A plan view of the back-up structure is shown in Figure 2-6. Figure 2-7 shows the GREAT system prior to the test.

The GREAT system was installed from the Installation Instructions. However, the anchor bolts provided with the system for the chain rail were replaced by the Hilti Expansion Anchors. The expansion bolts provided with the GREAT system provide a threaded stud above ground level. The use of these bolts would have required that the studs be cut off each time the test configuration was moved on the pad. The Hilti anchors are installed with the female end of the fastener in the pad flush with the top of the pad. The substitute anchor was approved by Energy Absorption Systems, Inc.

The GREAT system for the test was used in three previous 60 mph tests of mini-compact sedans. It is considered in excellent condition. Installation of the system was achieved without difficulty in an eight hour period with a three man crew. A crane was used to position the two temporary CMB's.

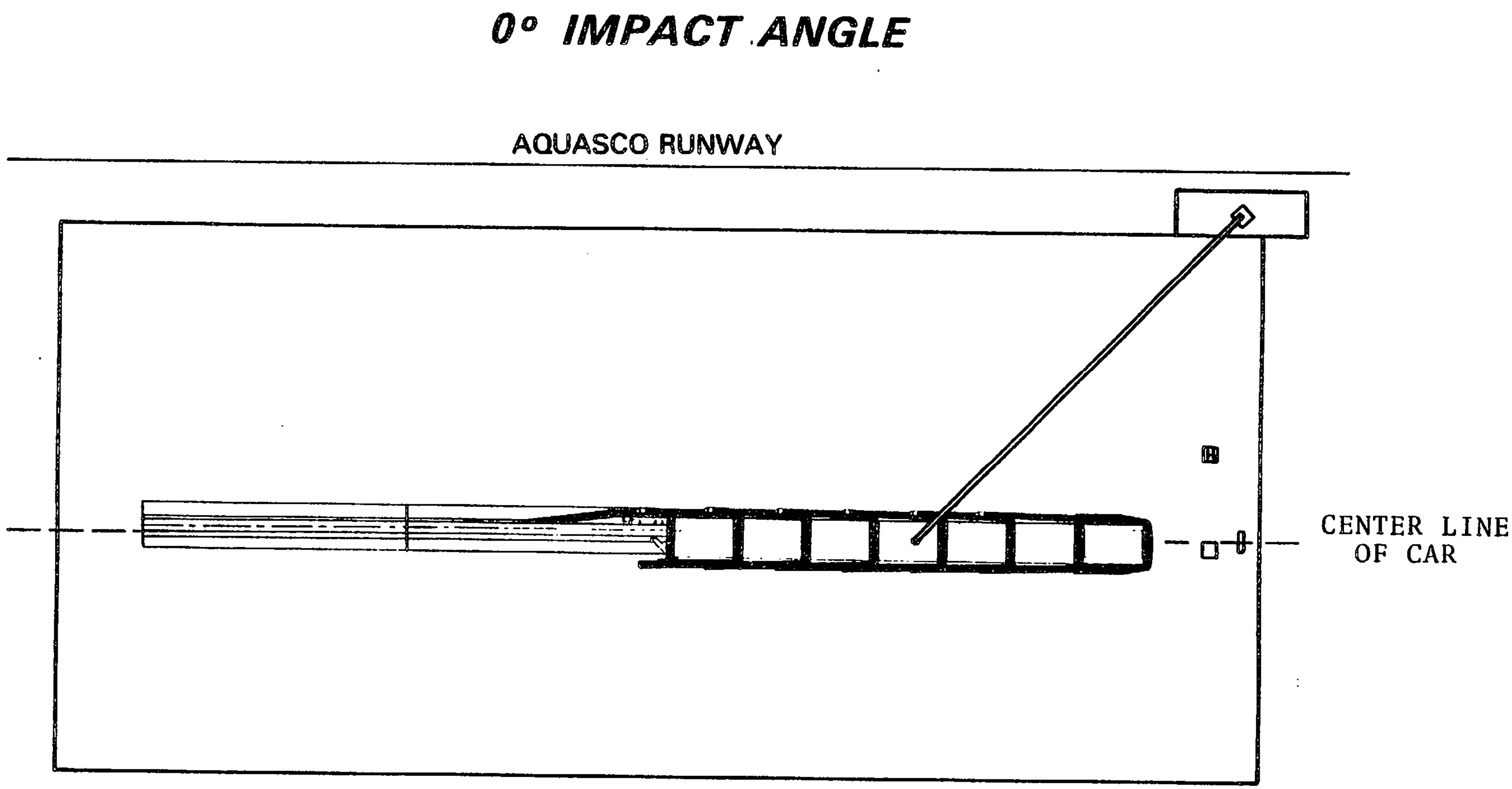
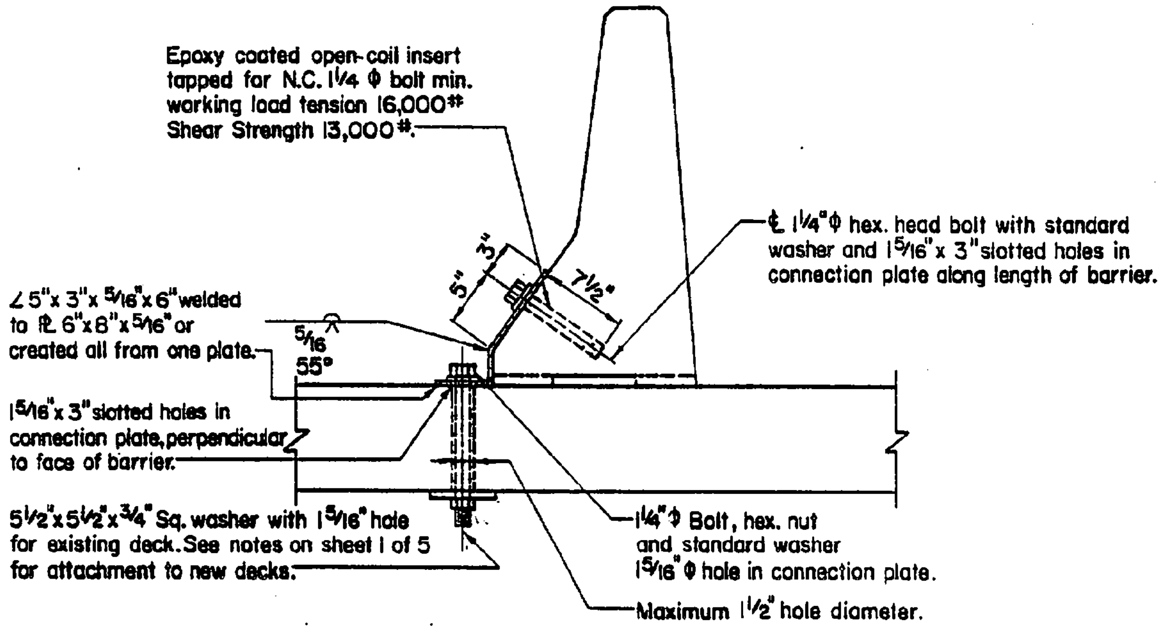


Figure 2-3. GREAT 0° Impact Test



CONNECTION DETAIL
Scale: ¾" = 1'-0"

APPROVAL		STATE OF MARYLAND DEPARTMENT OF TRANSPORTATION STATE HIGHWAY ADMINISTRATION DIVISION OF BRIDGE DEVELOPMENT TEMPORARY PRECAST SINGLE FACE "JERSEY TYPE" CONCRETE BARRIER
E.S. Fr[illegible] ASST. CHIEF ENGR. BRIDGE DEVEL. DATE 4/6/83		
REVISIONS		
SHA	FHWA	
FHWA APPROVAL DATE:		STANDARD NO. M(5.09)-83-143 SHEET 5 OF 5

Figure 2-4. CMB Fasteners

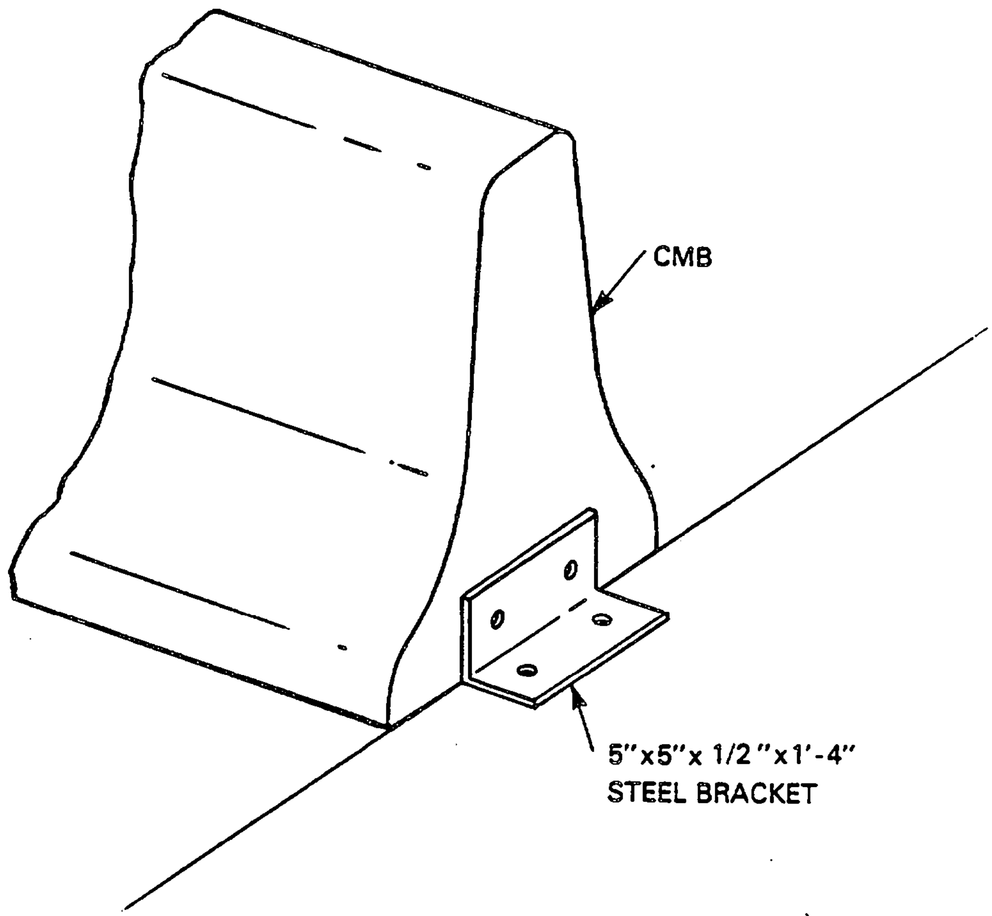


Figure 2-5. CMB End Bracket

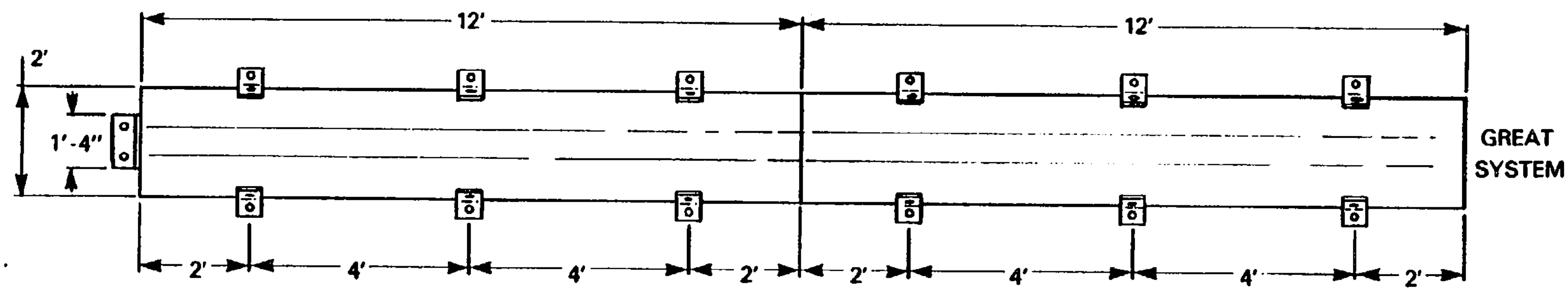
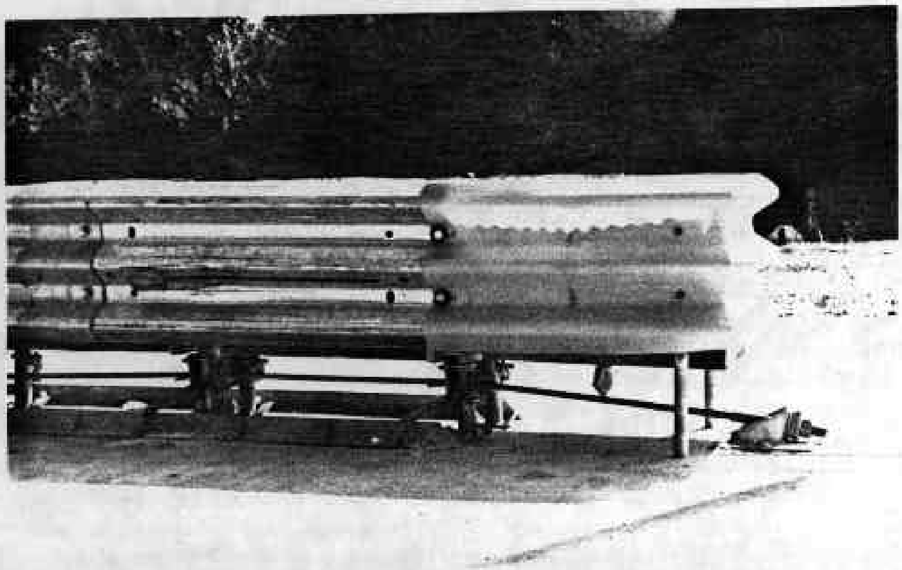


Figure 2-6. Location of CMB Brackets



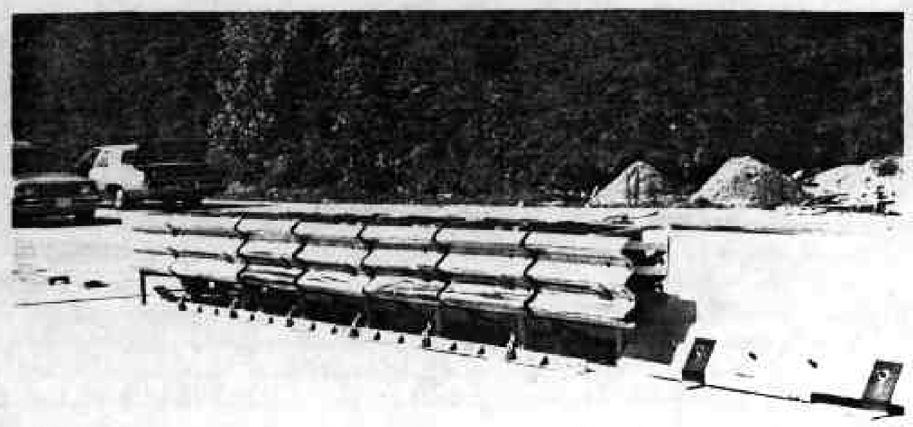


Figure 2-7. Pre-Test Photographs of GREAT System

2.3 TEST VEHICLE

The test vehicle was a dark blue 1979 Ford LTD II, (see Figure 2-8) corresponding to the NCHRP 230 classification of 4500S. The initial weight of the vehicle was 3945 pounds. The vehicle was prepared for testing by removing the gas tank and battery. The weight of the vehicle after incorporating the instrumentation and 370 pounds of ballast was 4346 pounds. The weight distributions of the vehicle with and without occupant are given in Tables 2-1 and 2-2.

TABLE 2-1

Weight Distribution of Test Vehicle Without Occupants

	Left (lbs)	Right (lbs)	Total (lbs)	% of Total
Front	1231	1182	2413	55.5
Rear	983	950	1933	44.5
Total	2214	2132	4346	100.0

TABLE 2-2

Weight Distribution of Test Vehicle With Occupants

	Left (lbs)	Right (lbs)	Total (lbs)	% of Total
Front	1310	1280	2590	54.9
Rear	1089	1041	2130	45.1
Total	2399	2321	4720	100.0

Figure 2-8. Pre-Test Photographs of Test Vehicle

The vehicle was equipped with a triaxial accelerometer package mounted on the lateral centerline of the vehicle at the longitudinal location of the center of gravity. Roll and yaw rate gyros were located on the same mounting block as the accelerometers. A high speed movie camera (500 frames per second) was mounted onboard to observe the movements of the dummies. The vehicle was also equipped with contact switches mounted on the front bumper to mark the impact and to trigger strobe flashes for movie film alignment and analysis. Distance decals were also installed for post-test film analysis of vehicle speed.

2.4 INSTRUMENTED DUMMIES

Two part 572 instrumented dummies were used in the test for simulating and measuring occupants dynamics. Dummy (serial #189) was unrestrained in the driver seat of the vehicle and dummy #186 was restrained in the passenger seat. The dummy instrumentation consisted of three linear accelerometers in the head, three linear accelerometers in the chest,and two femur load cells.

2.5 DATA ACQUISITION SYSTEM

The major components of the data acquisition system were a Metraplex Series 300 FM data multiplexer and a Honeywell 5600C tape recorder. The Metraplex system was used to condition and multiplex dummy and vehicle transducer data into three output channels. These three channels were transferred to the Honeywell recorder via an umbilical cable made up of several coaxial cables. Two other data channels are also recorded on the tape recorder. A 32 KHz control signal was recorded to externally trigger the post-test digitizing unit and to automatically synchronize all data channels. A speed trap signal was also recorded to measure vehicle impact speed. Figure 2-9 shows a schematic of the Data Acquisition System.

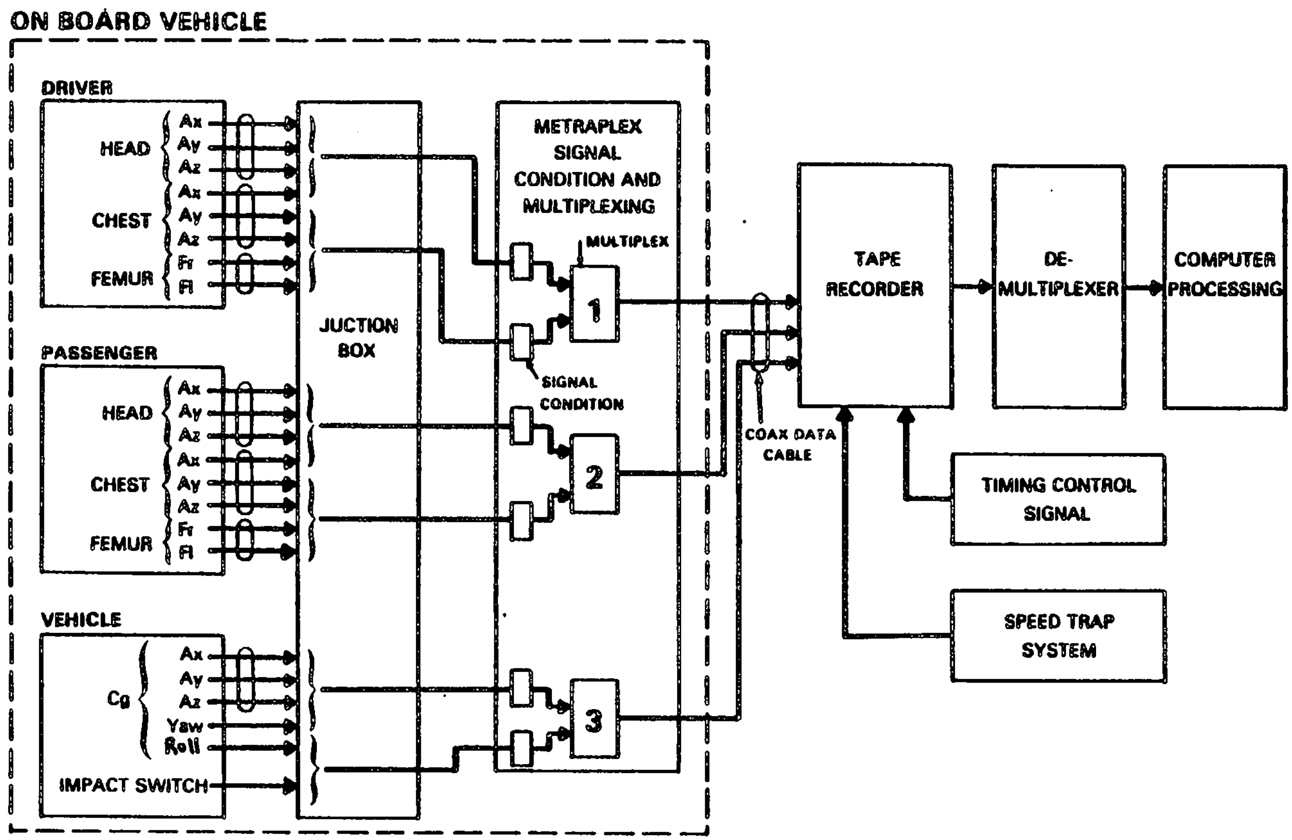


Figure 2-9. Schematic of Data Acquisition System

The multiplexed data and the 32 KHz control signal were recorded in direct mode with a bandpass of 300 Hz to 300 KHz. The speed trap data was recorded in a frequency modulated (FM) mode with a bandpass of 0 to 20 KHz. Table 2-3 provides a channel table of all data recorded by the data acquisition system.

In order to process the analog data tape offline a number of steps occurred. The tape was first demultiplexed. Next, the demultiplexed data was played back through SAE Class 1000 filters and each channel was digitized at 8000 Hz. At this point a digital data tape was created in accordance with the specifications defined by NHTSA. The test data was then analyzed by ENSCO using a DEC 11/70 mini-computer system and several general purpose highway research analysis programs. The results of this data processing and analysis are documented in Section 4.0.

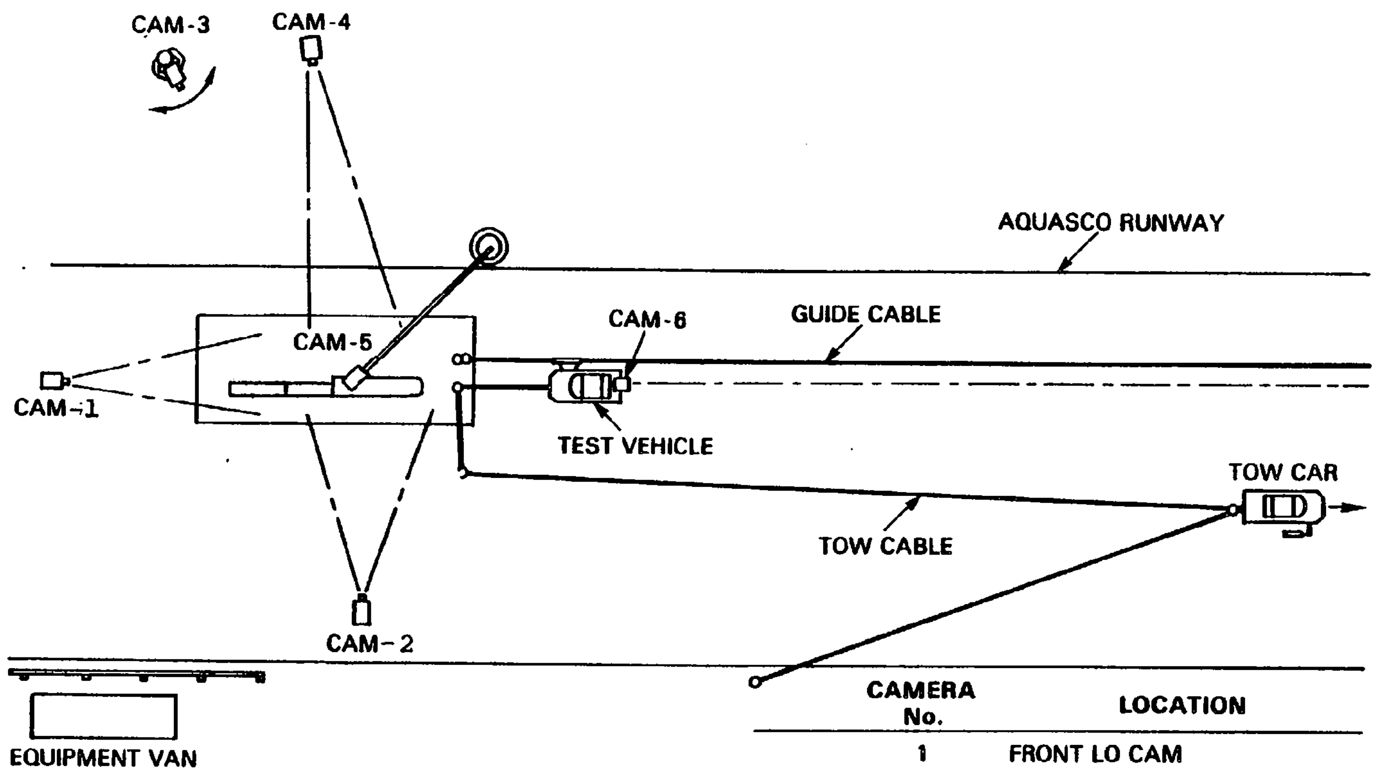
2.6 PHOTOGRAPHY

Photographic coverage was provided by five high speed (500 frames per second) cameras and one real time (24 frames per second) 16mm camera. The location of these cameras is shown in Figure 2-10. In addition, 35mm black and white prints and 35 mm color slides of the test appurtenance and the test vehicle in the pre-crash, crash and post-crash condition were taken.

TABLE 2-3

TRANSDUCER DATA CHANNEL DESCRIPTION

Data Channel	Recorder Channel	Channel Description	Multiplex Transducer Model	Center Frequency
1	1	D Head X	ENDEVCO 2264-2000	32 kHz
2	1	D Head Y	ENDEVCO 2264-2000	48 kHz
3	1	D Head Z	ENDEVCO 2264-2000	64 kHz
4	1	D Chest X	ENDEVCO 7231C-750	80 kHz
5	1	D Chest Y	ENDEVCO 7231C-750	96 kHz
6	1	D Chest Z	ENDEVCO 7231C-750	112 kHz
7	1	D Femur R	GSF 2430	128 KHz
8	1	D Femur L	GSF 2430	144 kHz
9	2	P Head X	ENDEVCO 2264-2000	32 kHz
10	2	P Head Y	ENDEVCO 2264-2000	48 kHz
11	2	P Head Z	ENDEVCO 2264-2000	64 kHz
12	2	P Chest X	ENDEVCO 7231C-750	80 kHz
13	2	P Chest Y	ENDEVCO 7231C-750	96 kHz
14	2	P Chest Z	ENDEVCO 7231C-750	112 kHz
15	2	P Femur R	GSF 2430	128 kHz
16	2	P Femur L	GSF 2430	144 kHz
17	3	Vehicle X	Statum A69TC-25-350	32 kHz
18	3	Vehicle Y	Statum A69TC-25-350	48 kHz
19	3	Vehicle Z	Statum A69TC-25-350	64 kHz
20	3	Impact	Tape Switch #107-LS	80 kHz
21	3	Vehicle Roll Rate	Humphrey RG51	96 kHz
22	3	Vehicle Yaw Rate	Humphrey RG51	112 kHz
23	6	Speed trap	Tape Switch Model RB-S	N/A
24	7	Sync. 32 kHz	N/A	N/A



CAMERA No.	LOCATION
1	FRONT LO CAM
2	LEFT SIDE (IMPACT) HY CAM
3	PAN CAMERA
4	RIGHT SIDE WIDE, LO CAM
5	OVERHEAD CAMERA, LO CAM
6	ONBOARD CAMERA, LO CAM

Figure 2-10, Camera Layout of Test Site.

3.0 TEST RESULTS

This section provides test results based on visual observations during the test, measurements taken during and after the test, and examination of the movie films of the test.

3.1 IMPACT DESCRIPTION

Review of the high speed movie films and the fifth wheel indicated that the test vehicle impacted at a 0 degree impact angle and at a speed of 58.4 mph. Close examination also indicated that the vehicle impacted at the center of the nose piece. This is expected based on the accuracy of the vehicle guidance system.

The GREAT system is designed to provide controlled penetration of the vehicle into the GREAT. From the movie film it was observed to consist of the nose piece cartridge crushing first, followed by sequential crushing of the six remaining cartridges. The stopping distance of the vehicle was estimated to be 18.8 feet including 2.2 feet of vehicle crush. The total dynamic deflection of the GREAT system was 16.6 feet; however, a dynamic rebound of 2.5 feet occurred resulting in a total static crush of 14.1 feet. Table 3-1 provides the static crush pattern of the six bays of GREAT. As stated previously, it was observed that the GREAT dynamically crushed another 30 inches. Subtracting this from the measurements of Table 3-1, the average dynamic spacing of the six remaining bays can be calculated to be approximately 5.2 inches. Subtracting this from the initial spacing of 32.25 inches yields an average dynamic crush of 27.05 inches. The nose cartridge, the space between the nose cartridge and the nose wrap, and the nose wrap dynamically crushed from an original length of 38 inches to approximately 2 inches. This nose crush of approximately 36 inches along with the 27.05 inches of average dynamic crush per bay accounts for the total dynamic crush of 16.6 feet. Mr. F. Taminini of Energy Absorption approximately 25.5 inches. This corresponds to 80% of the original length. Therefore the system crushed beyond the 80% level.

During the impact the vehicle remained quite stable in the yaw and roll modes, however it pitched forward enough for the rear wheels to leave the ground by 6 inches. After crushing the GREAT system the vehicle rebounded 11.7 feet and at an angle of 6 degrees clockwise. (See Vehicle Trajectory Path and Time in Figure 3-1.) This should be considered a minimal hazard to oncoming traffic. It should be noted that the nose cartridge remained with the vehicle after the impact.

Inside the vehicle it was observed that upon impact both the dummies lunged forward and the driver's head shattered the windshield. The final resting place of both dummies was in a normal sitting position in their respective seats.

TABLE 3-1

STATIC CRUSH PATTERN OF GREAT

Bay* Number	Spacing Of Bay** (Inches)	
	Drivers Side	Passenger Side
1	12.75	9.75
2	13.75	12.25
3	7.75	10.25
4	9.75	5.25
5	4.75	11.75
6 (Next to backup)	13.75	10.75
AVERAGE	10.4	10.0

* Bays are numbered from nose to backup structure. The first bay behind the nose bay (second bay overall) is bay number one.

**Initial Spacing was 32.25", nose cartridge remained with vehicle and thus no static crush measurement was made.

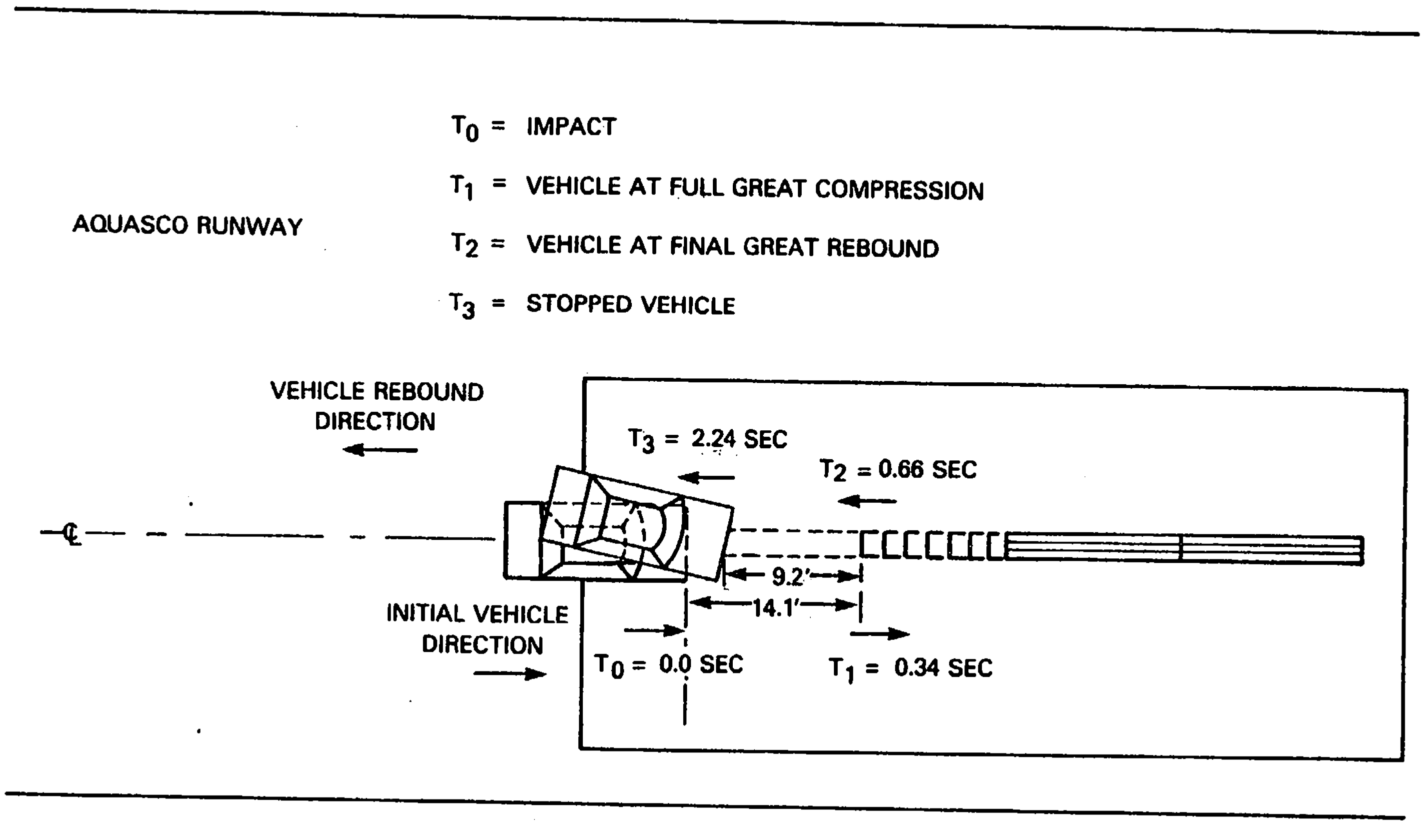


Figure 3-1. Vehicle Trajectory Path and Time

Figure 3-2. Post-Test Photographs of Test Vehicle and Attenuator

3.2 VEHICLE DAMAGE

Damage to the vehicle ocurred in a fairly uniform half-oval shape to the front end, as shown in Figure 3-2. Using the NHTSA vehicle damage measurements shown in Figure 3-3, the following measurements were made:

1.	Penetration: Distances:	C1 - 1.5" C2 - 12.0" C3 - 26.0"	C4 - 28.0" C5 - 24.0" C6 - 0.0"
2.	Length of Damage:		L= 50.0" L/2= 25.0"
3.	Distance Between Center of Damage Area and C. G. Axis:		D = 0.0"

Based on the Society of Automotive Engineers recommended practice J224a, "Collision Deformation Classification", the vehicle was rated 12FCEN2.

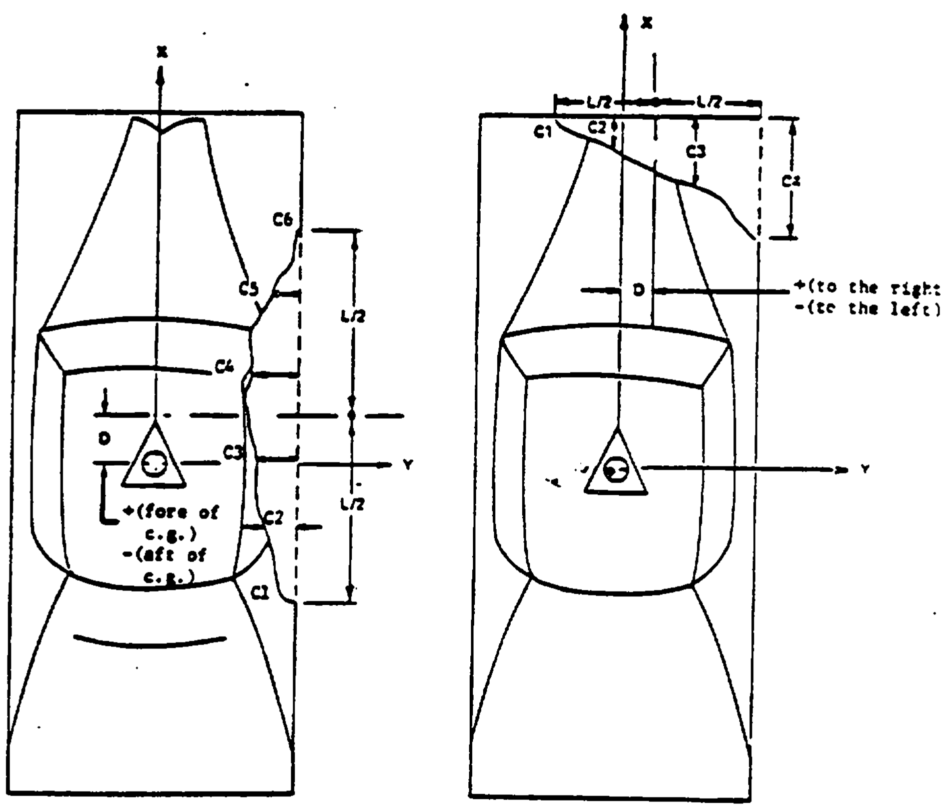


Figure 3-3. NHTSA Vehicle Damage Measurements

3.3 IMPACT ATTENUATOR DAMAGE/DEBRIS PATTERN

The GREAT system performed exactly as designed. The nose piece and cartridges were crushed and the guard rail side panels collapsed properly. No structural damage to the system was observed and the fixity of the CMB's was good. The CMB's shifted longitudinally 1/8 inch. It is believed that this was mainly due to slack in the system taken up by the impact. Figure 3-4 shows the GREAT system and the vehicle, attenuator and pad after the crash.

The only GREAT debris were fragments of the nose piece in the area of the GREAT system.

3.4 PHOTOGRAPHY

The composite movie film of the test shows a panning view of the impact, an overhead view, an onboard view, and wayside coverage from two sides. The end view (northside) camera malfunctioned during the test. Furthermore, the pre-test and post-test conditions of the vehicle and GREAT system are shown using the panning camera. Two copies and the master of this composite film are provided with this test results report.

In addition, still 35mm color slides of the vehicle and GREAT system in the pre-crash and post-crash conditions are provided to FHWA with this report.

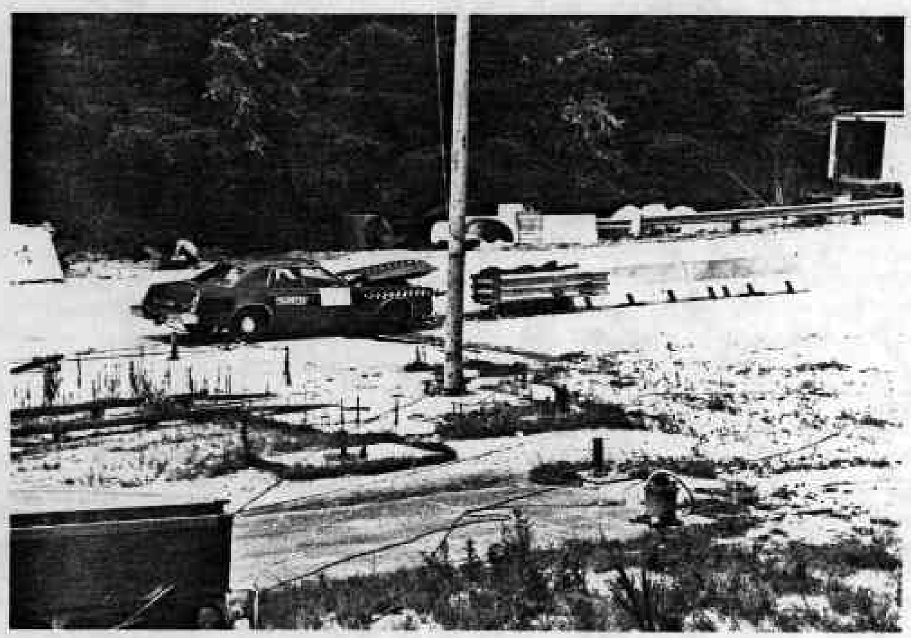


Figure 3-4. Post-Test Photographs of GREAT System and Vehicle, Attenuator and Pad

4.0 DATA ANALYSIS

Data analysis for this test is divided and reported in the following areas: vehicle analysis, occupant analysis, and GREAT analysis.

4.1 VEHICLE ANALYSIS

Vehicle analysis consisted of estimating vehicle speed, determining the peak measurements from vehicle-mounted transducers, and calculating occupant risk parameters.

4.1.1 VEHICLE SPEED

The impact speed was determined from the average of the movie films and the fifth wheel. The high-speed movie films were analyzed through the use of a Photo Optical Data Analyzer owned by ENSCO. The speed trap data was lost due to a tape recorder problem. Based upon this analysis, the impact speed of the vehicle was 58.4 mph (85.7 ft/sec). The rebound speed of 7.9 mph was determined using the movie films also. Thus, the total change in the speed of the vehicle during the collision was 66.3 mph (97.2 ft/sec). This was checked by integrating the 100 Hz longitudinal acceleration measurements over the impact event. Results of this processing indicated that the total speed change was 71.7 mph (105.2 ft/sec). This 8.2% deviation from the 66.3 mph estimate is higher than normally would be expected. However, this deviation was probably caused by the severe impact suffered by the car when the attenuator bottomed out forcing the engine rearward as the vehicle pitched up in the rear. Nevertheless, the data is felt to be accurate. Vehicle speed estimates are summarized in Table 4-1.

4.1.2 PEAK TRANSDUCER MEASUREMENTS

The data collected from the longitudinal, lateral, and vertical accelerometers mounted to the vehicle were filtered at SAE class

TABLE 4-1

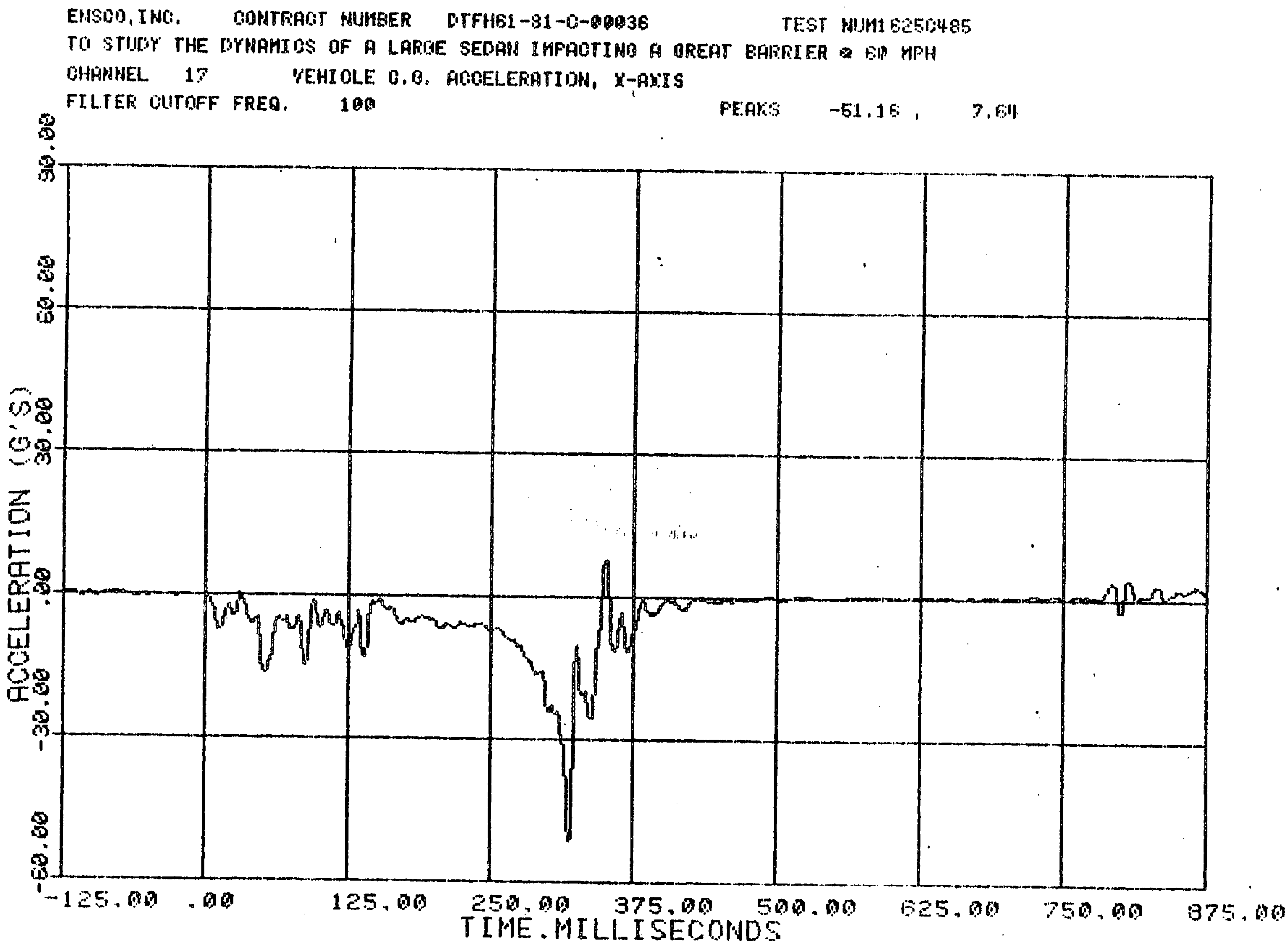
TEST VEHICLE SPEED RESULTS

	Impact Speed (mph)	Rebound Speed (mph)
Movie Film Average	58.0	7.9
Fifth Wheel	58.8	N/A
Speed Trap	N/A	N/A
Average	58.4	7.9

1 mph = 1.467 ft/sec

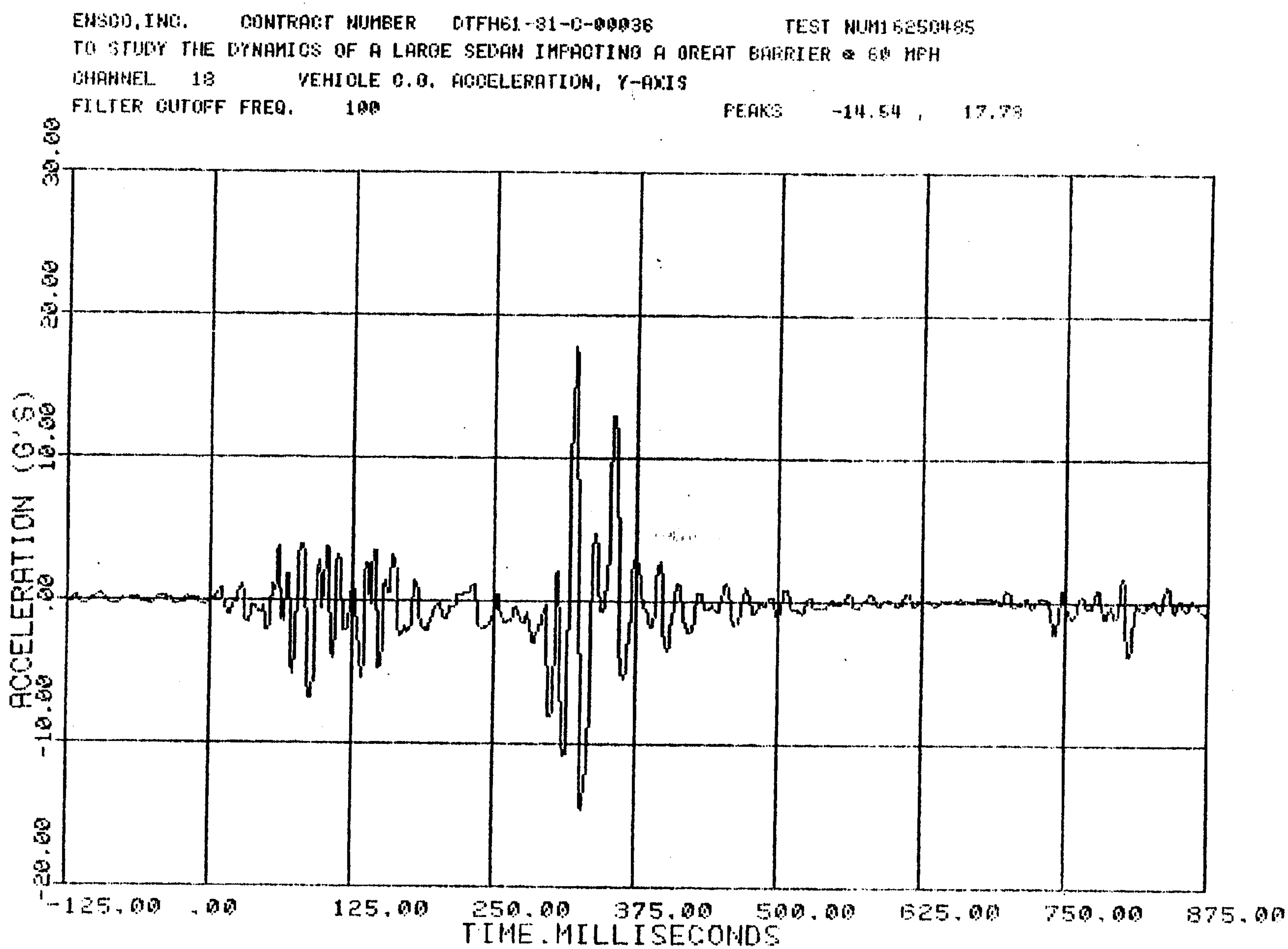
60 and 180 per TRC 191 and NCHRP 230 requirements, respectively. The acceleration traces obtained with the use of the SAE Class 60 (f_c = 100 Hz) filtering technique are presented in Figures 4-1 through 4-3. The acceleration traces obtained with the use of the SAE Class 180 (f_c = 300 Hz) filtering technique are presented in Figures 4-4 through 4-6. The data collected from the roll and yaw rate gyros were filtered at SAE Class 60 and SAE Class 6 (f_c = 10 Hz). The Class 60 traces are shown in Figures 4-7 and 4-8 and the Class 6 traces are shown in Figures 4-9 and 4-10. Figure 4-11 shows the impact marker. Please note that for all plots the vehicle/GREAT impact occurs at time 0.00.

Review of Figures 4-1 and 4-4 indicates two distinct areas of deceleration. The first area (0-150 msec) indicates sequential crushing of the bays of the GREAT while the second area (300 msec) occurred at the final dynamic crush of the system. In order to summarize Figures 4-1 through 4-6, Table 4-2 presents the peak vehicle accelerations and times based on the SAE Class 60 and 180 filters.



ENSCO,INC.   CONTRACT NUMBER   DTFH61-81-C-00036   TEST NUM16250485
TO STUDY THE DYNAMICS OF A LARGE SEDAN IMPACTING A GREAT BARRIER @ 60 MPH
CHANNEL 17   VEHICLE C.G. ACCELERATION, X-AXIS
FILTER CUTOFF FREQ. 100   PEAKS -51.16 , 7.60
90.00
60.00
30.00
.00
-30.00
-60.00
ACCELERATION (G'S)
-125.00
.00
125.00
250.00
375.00
500.00
625.00
750.00
875.00
TIME.MILLISECONDS

Figure 4-1.



ENSCO,INC. CONTRACT NUMBER DTFH61-81-C-00036 TEST NUM16250485
TO STUDY THE DYNAMICS OF A LARGE SEDAN IMPACTING A GREAT BARRIER @ 60 MPH
CHANNEL 18 VEHICLE C.G. ACCELERATION, Y-AXIS
FILTER CUTOFF FREQ. 100
PEAKS -14.54 , 17.79
30.00
20.00
10.00
.00
-10.00
-20.00
ACCELERATION (G'S)
-125.00
.00
125.00
250.00
375.00
500.00
625.00
750.00
875.00
TIME.MILLISECONDS

Figure 4-2.

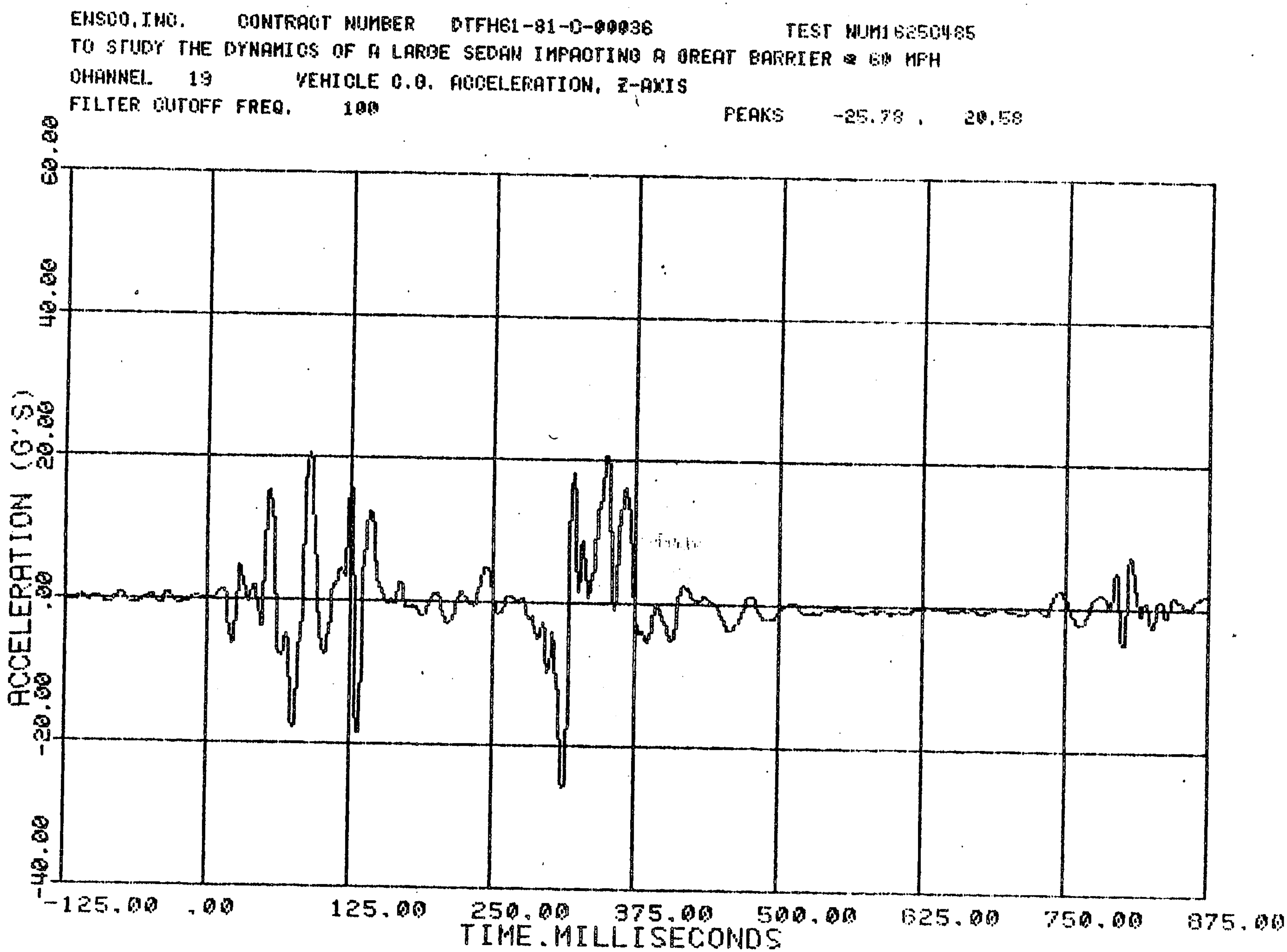

ENSCO,INC. CONTRACT NUMBER DTFH61-81-C-00036 TEST NUM16250485
TO STUDY THE DYNAMICS OF A LARGE SEDAN IMPACTING A GREAT BARRIER @ 60 MPH
CHANNEL 19 VEHICLE C.G. ACCELERATION, Z-AXIS
FILTER CUTOFF FREQ. 100
PEAKS -25.78 , 20.58
ACCELERATION (G'S)
60.00
40.00
20.00
.00
-20.00
-40.00
-125.00
.00
125.00
250.00
375.00
500.00
625.00
750.00
875.00
TIME.MILLISECONDS

Figure 4-3.

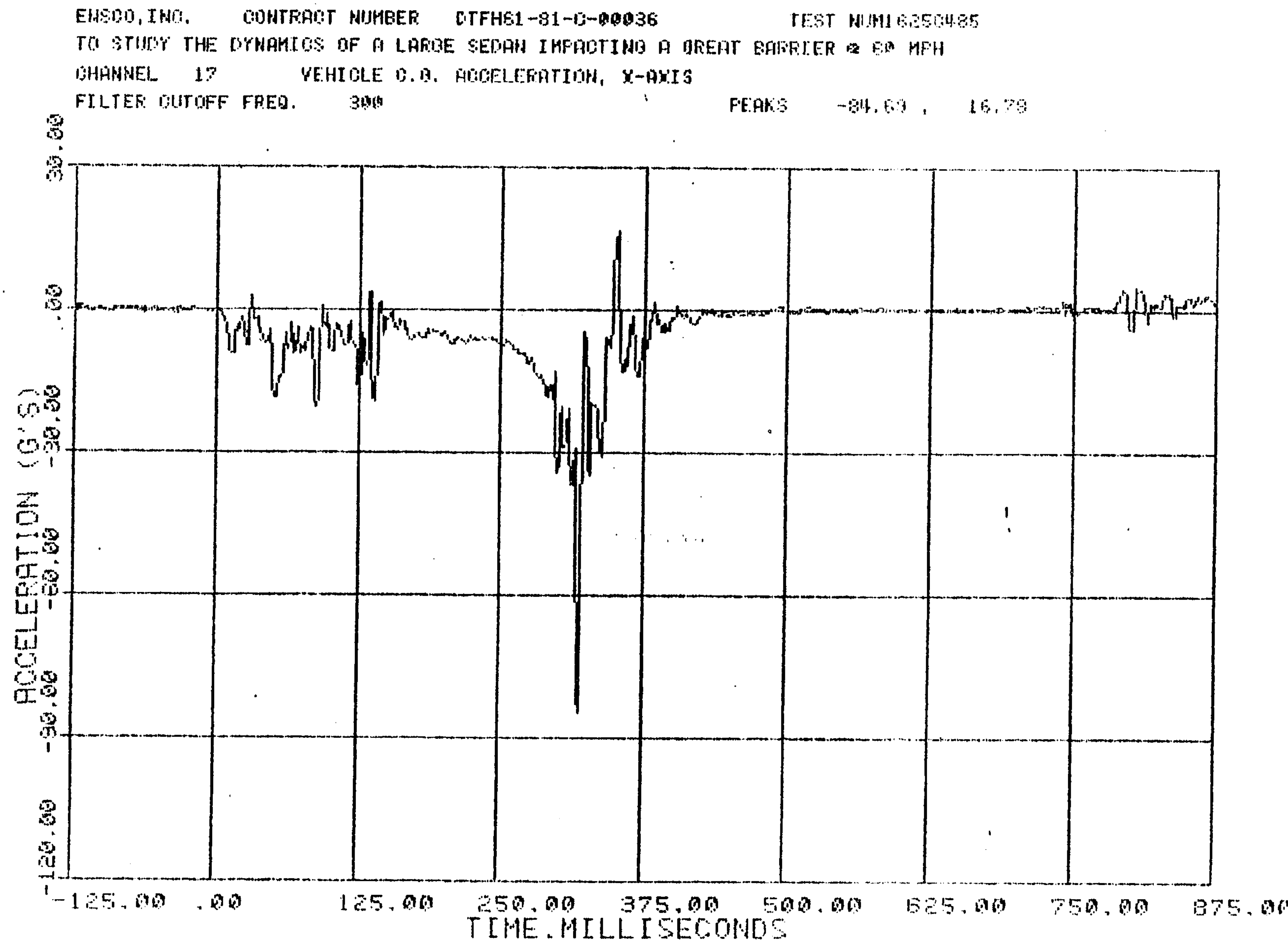

ENSCO,INC.   CONTRACT NUMBER   DTFH61-81-C-00036   TEST NUM16250485
TO STUDY THE DYNAMICS OF A LARGE SEDAN IMPACTING A GREAT BARRIER @ 60 MPH
CHANNEL 17   VEHICLE C.G. ACCELERATION, X-AXIS
FILTER CUTOFF FREQ.   300   PEAKS   -84.69 , 16.79
30.00
.00
-30.00
-60.00
-90.00
-120.00
ACCELERATION (G'S)
-125.00 .00 125.00 250.00 375.00 500.00 625.00 750.00 875.00
TIME.MILLISECONDS

Figure 4-4.

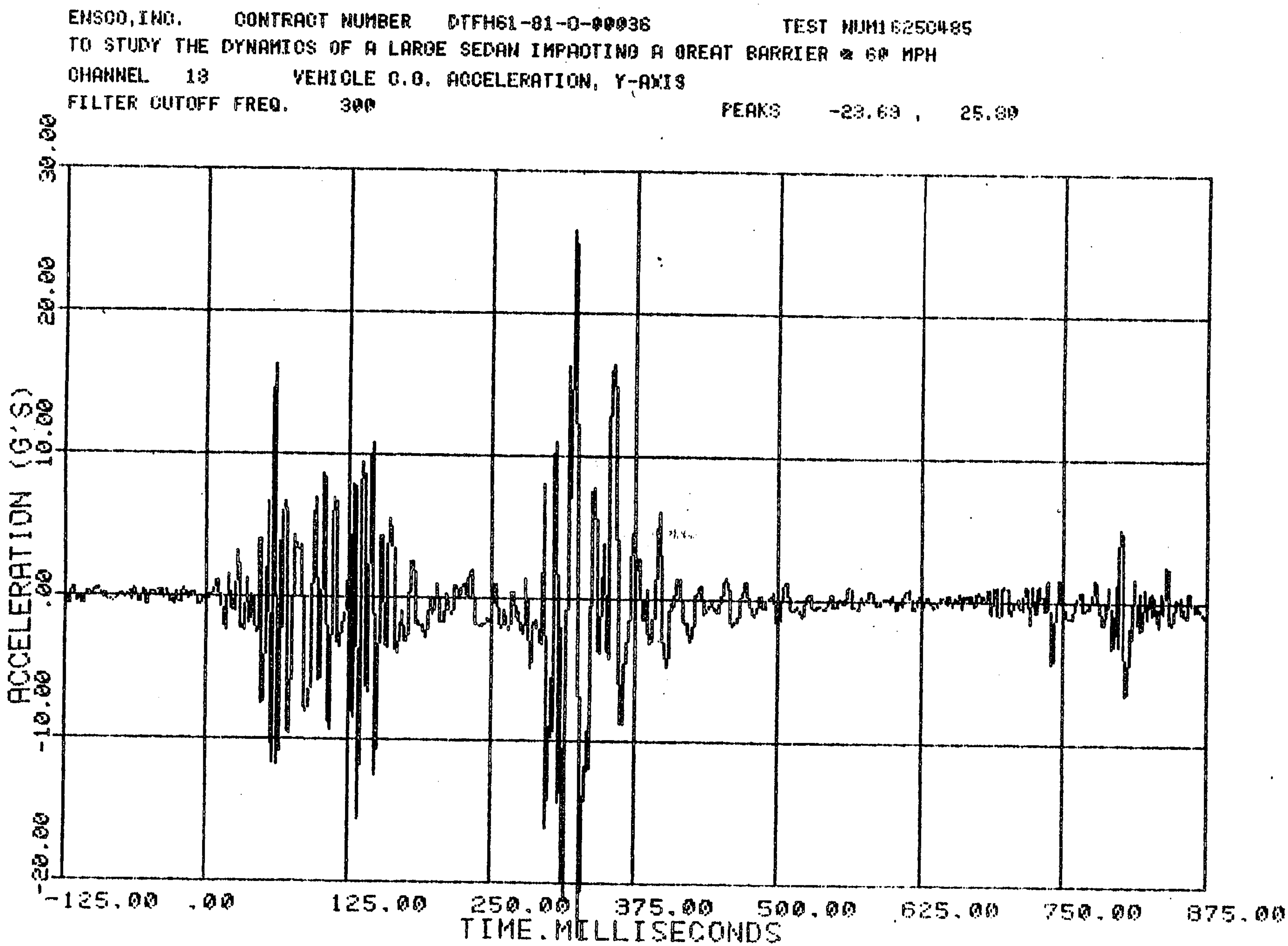

ENSCO,INC.
CONTRACT NUMBER DTFH61-81-C-00036
TEST NUM16250485
TO STUDY THE DYNAMICS OF A LARGE SEDAN IMPACTING A GREAT BARRIER @ 60 MPH
CHANNEL 13
VEHICLE C.G. ACCELERATION, Y-AXIS
FILTER CUTOFF FREQ. 300
PEAKS -23.69 , 25.00
30.00
20.00
10.00
.00
-10.00
-20.00
ACCELERATION (G'S)
-125.00
.00
125.00
250.00
375.00
500.00
625.00
750.00
875.00
TIME.MILLISECONDS

Figure 4-5.

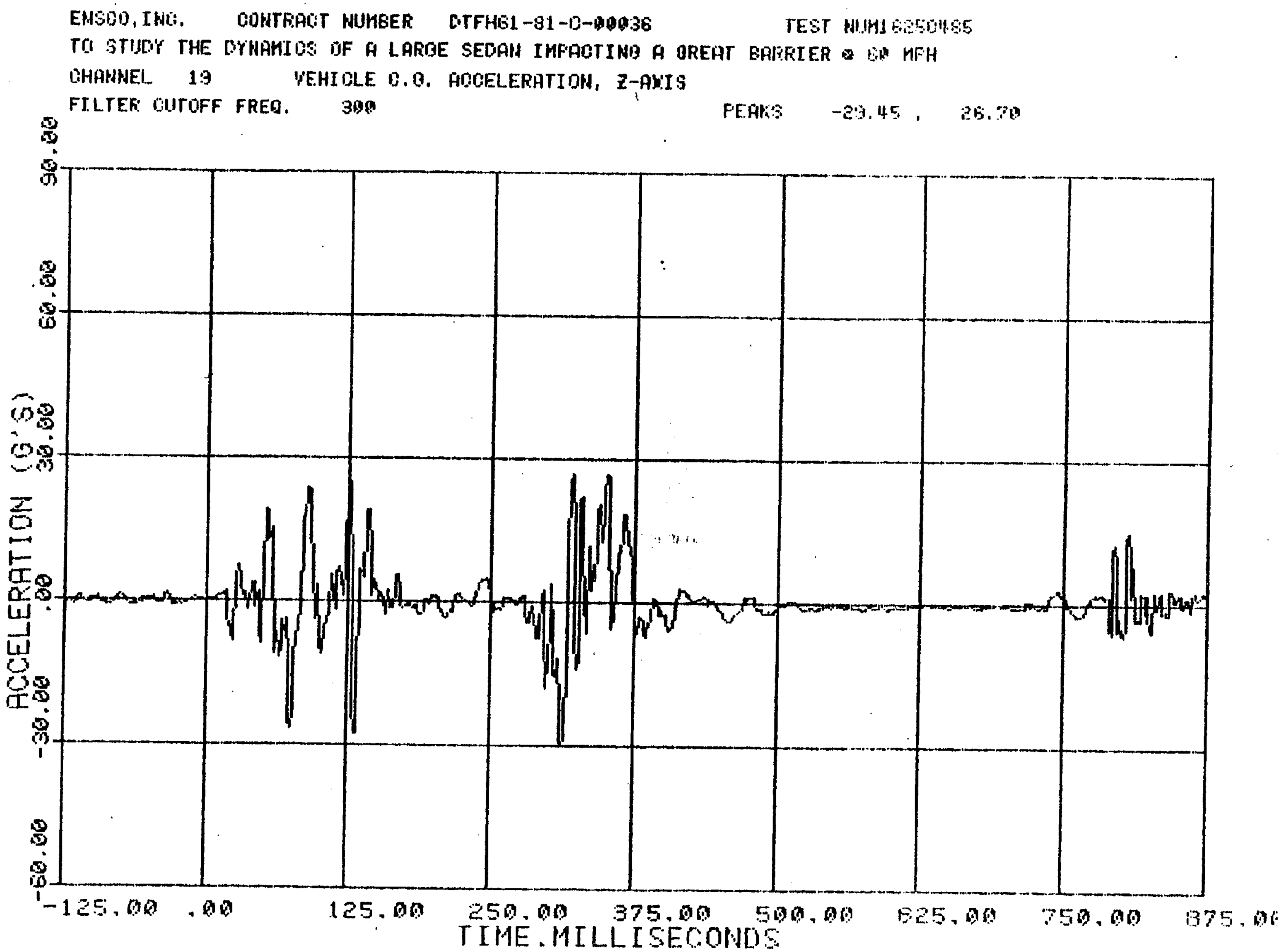

ENSCO, INC.   CONTRACT NUMBER   DTFH61-81-C-00036   TEST NUM16250485
TO STUDY THE DYNAMICS OF A LARGE SEDAN IMPACTING A GREAT BARRIER @ 60 MPH
CHANNEL   19   VEHICLE C.G. ACCELERATION, Z-AXIS
FILTER CUTOFF FREQ.   300   PEAKS   -29.45 ,   26.70
ACCELERATION (G'S)
90.00
60.00
30.00
.00
-30.00
-60.00
-125.00
.00
125.00
250.00
375.00
500.00
625.00
750.00
875.00
TIME.MILLISECONDS

Figure 4-6.

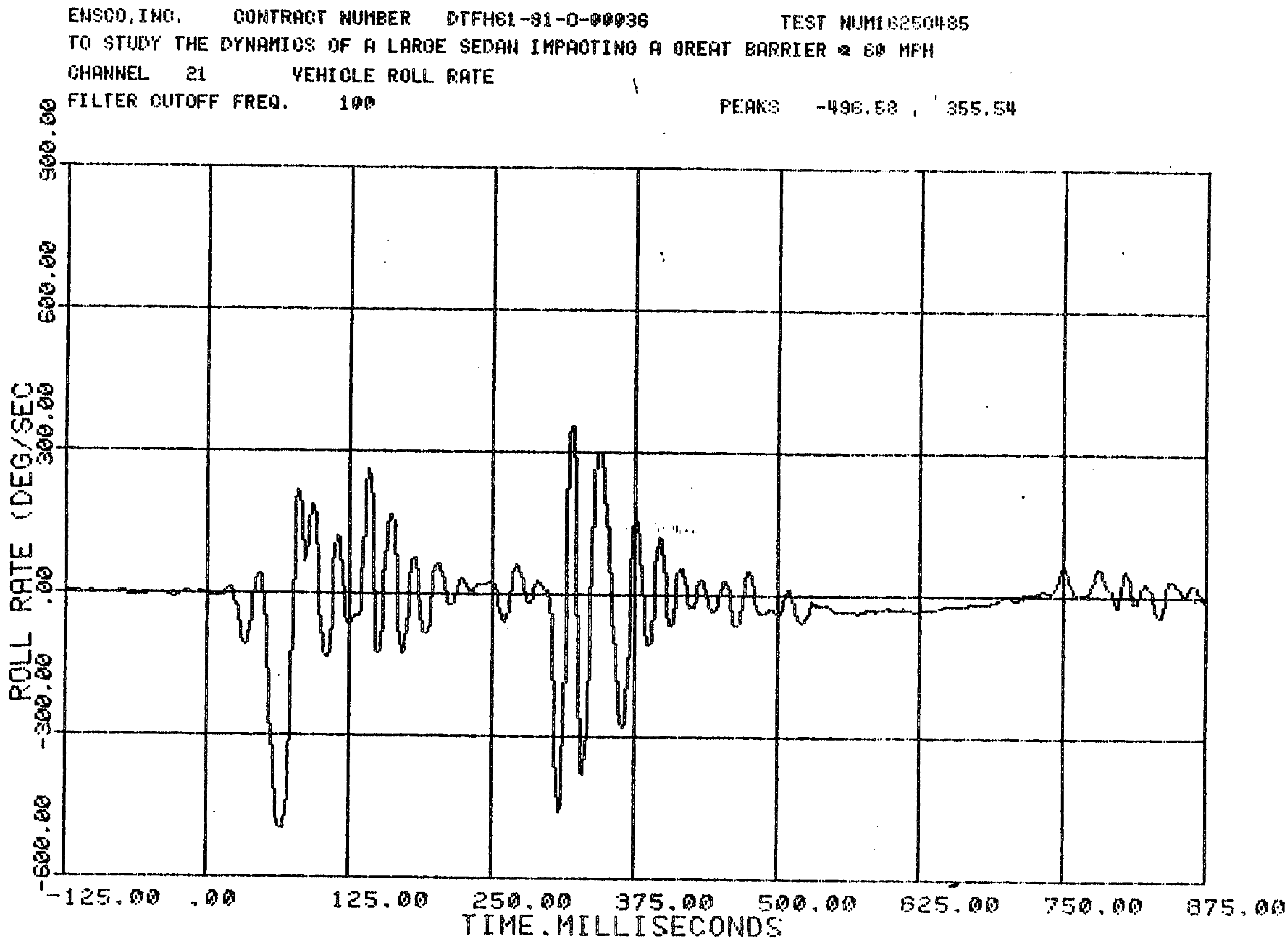

ENSCO,INC. CONTRACT NUMBER DTFH61-81-C-00036 TEST NUM1625O485
TO STUDY THE DYNAMICS OF A LARGE SEDAN IMPACTING A GREAT BARRIER @ 60 MPH
CHANNEL 21 VEHICLE ROLL RATE
FILTER CUTOFF FREQ. 100
PEAKS -496.58 , 355.54
ROLL RATE (DEG/SEC
900.00
600.00
300.00
.00
-300.00
-600.00
-125.00
.00
125.00
250.00
375.00
500.00
625.00
750.00
875.00
TIME.MILLISECONDS

Figure 4-7.

ENSCO,INC.   CONTRACT NUMBER   DTFH61-81-C-00036   TEST NUM16250485

TO STUDY THE DYNAMICS OF A LARGE SEDAN IMPACTING A GREAT BARRIER @ 60 MPH

CHANNEL   22   VEHICLE YAW RATE

FILTER CUTOFF FREQ.   100   PEAKS   -254.92 , 229.00

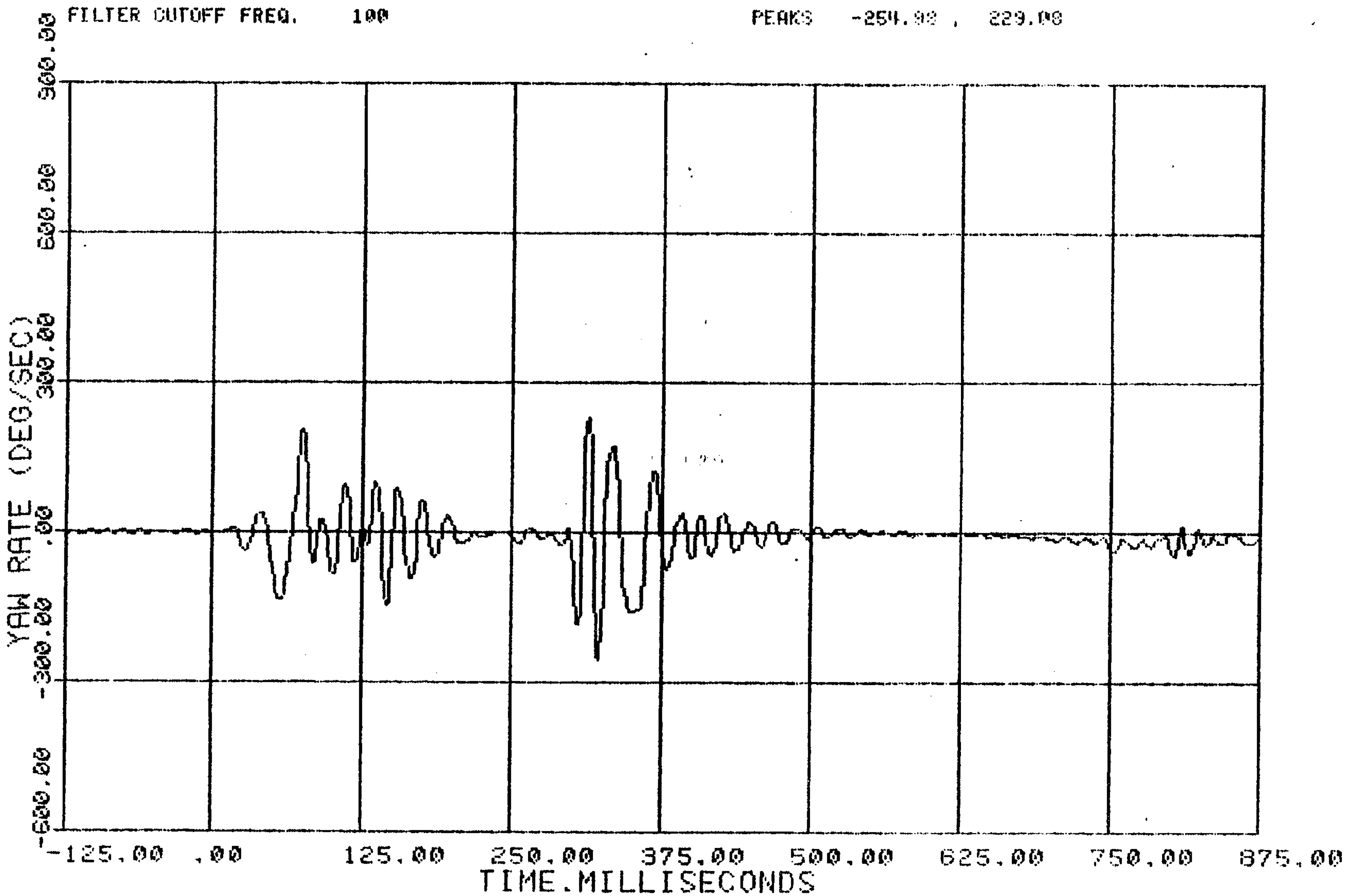


Figure 4-8.

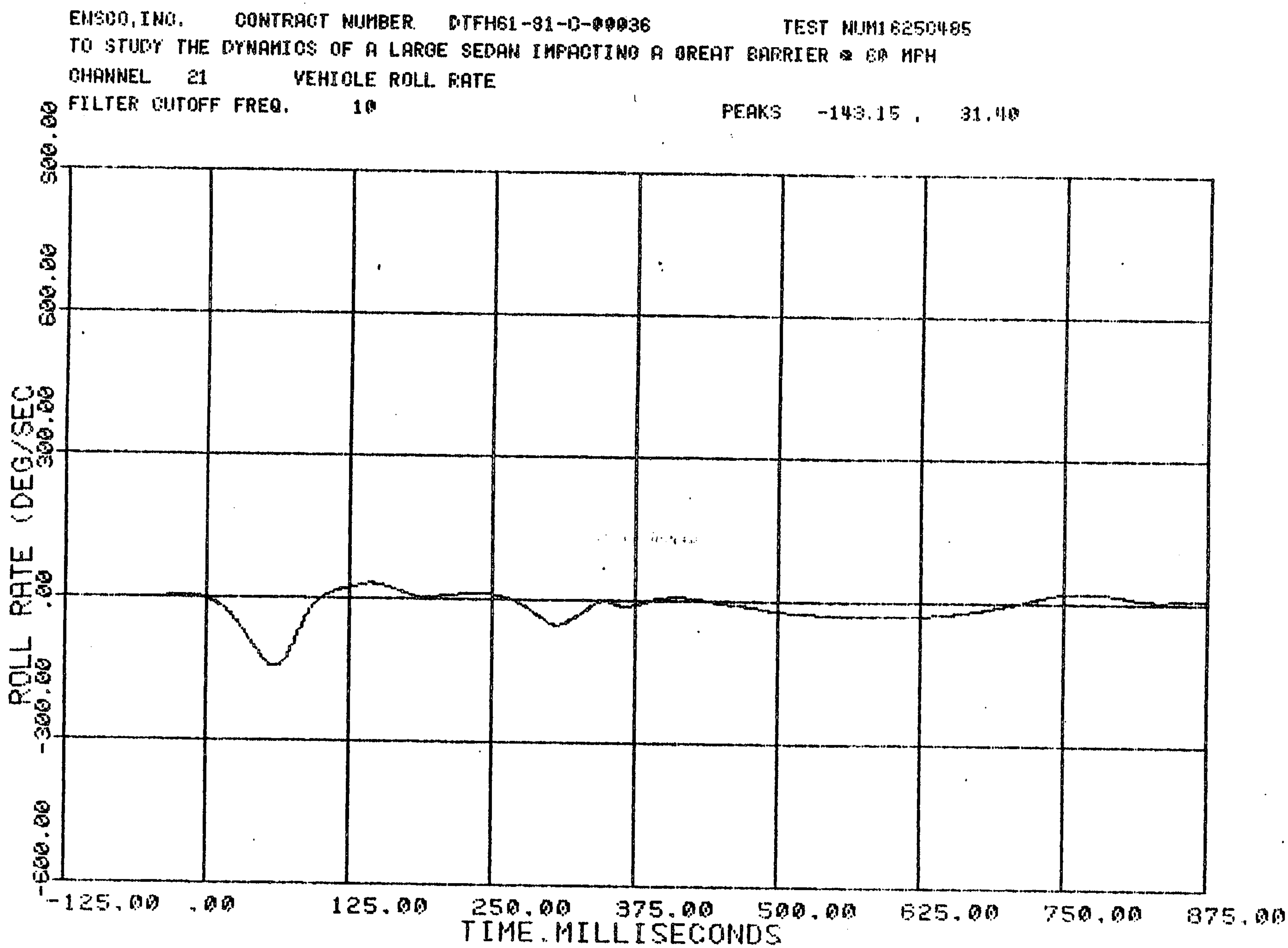
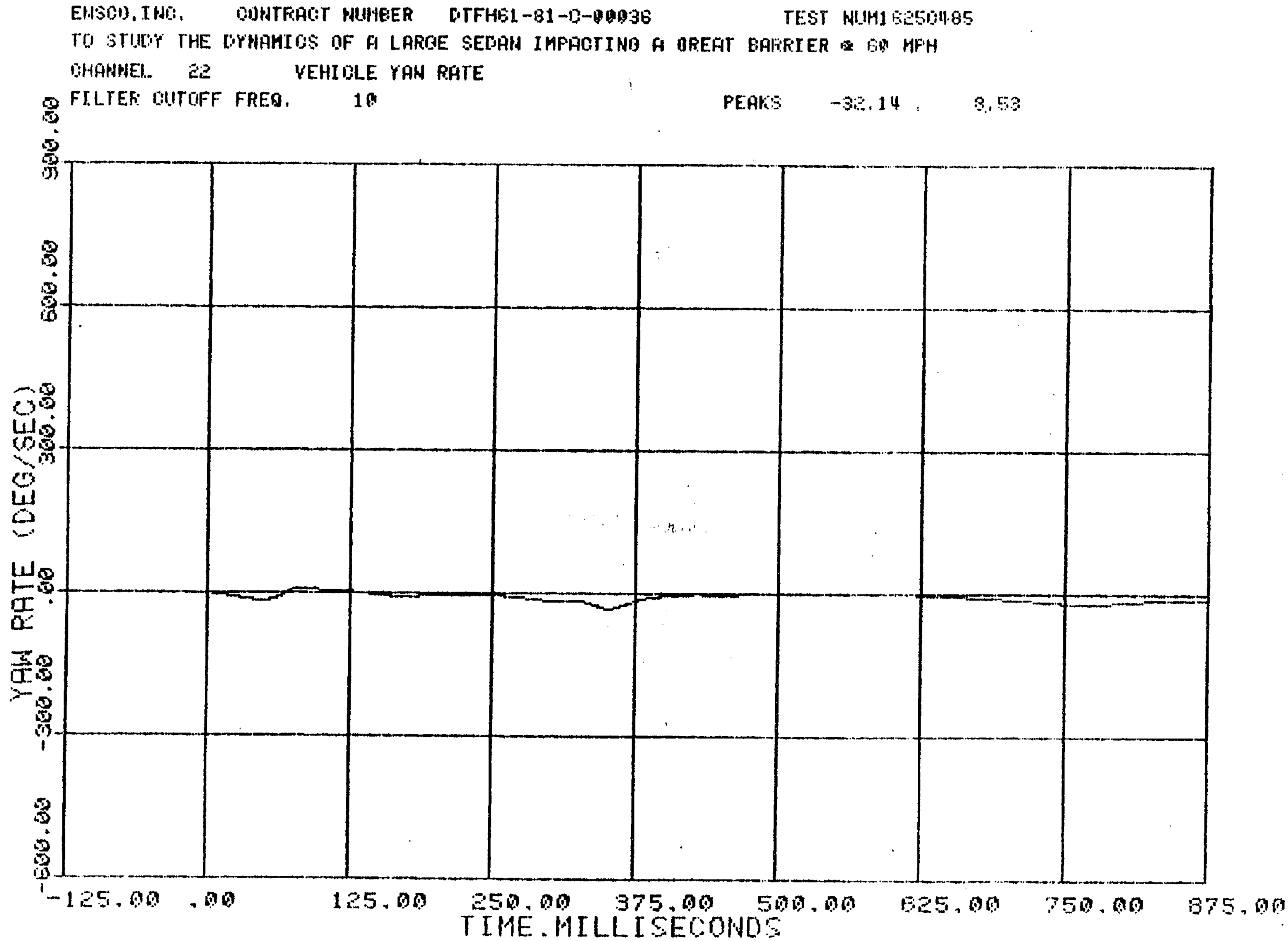

ENSCO,INC. CONTRACT NUMBER DTFH61-81-C-00036 TEST NUM16250485
TO STUDY THE DYNAMICS OF A LARGE SEDAN IMPACTING A GREAT BARRIER @ 60 MPH
CHANNEL 21 VEHICLE ROLL RATE
FILTER CUTOFF FREQ. 10 PEAKS -143.15 , 31.40
900.00
600.00
300.00
.00
-300.00
-600.00
ROLL RATE (DEG/SEC
-125.00
.00
125.00
250.00
375.00
500.00
625.00
750.00
875.00
TIME.MILLISECONDS

Figure 4-9



ENSCO, INC. CONTRACT NUMBER DTFH61-81-C-00036 TEST NUM16250485
TO STUDY THE DYNAMICS OF A LARGE SEDAN IMPACTING A GREAT BARRIER @ 60 MPH
CHANNEL 22 VEHICLE YAW RATE
FILTER CUTOFF FREQ. 10
PEAKS -32.14 , 8.53
900.00
600.00
300.00
.00
-300.00
-600.00
YAW RATE (DEG/SEC)
-125.00
.00
125.00
250.00
375.00
500.00
625.00
750.00
875.00
TIME.MILLISECONDS

Figure 4-10

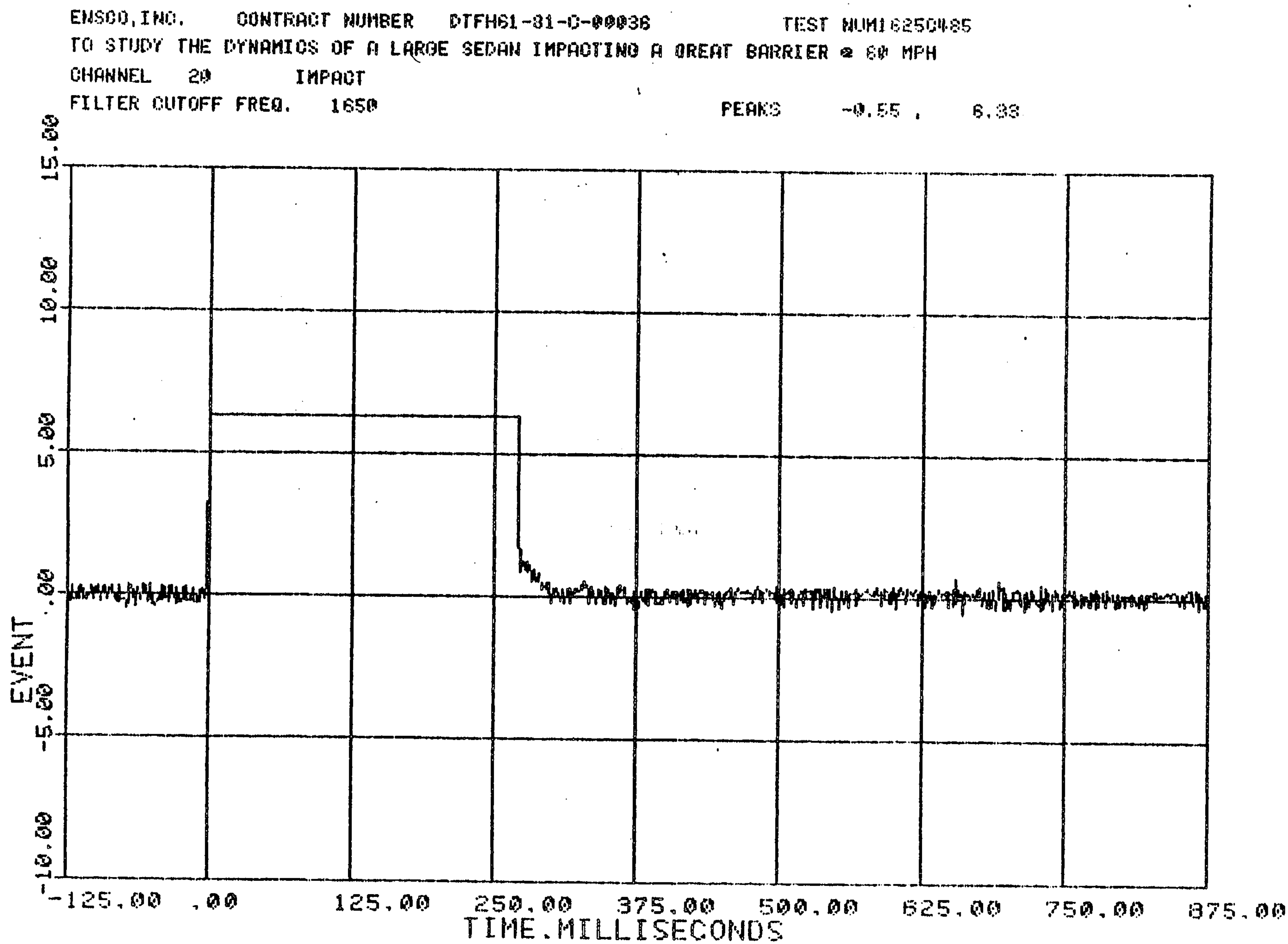

ENSCO,INC. CONTRACT NUMBER DTFH61-81-C-00036 TEST NUM16250485
TO STUDY THE DYNAMICS OF A LARGE SEDAN IMPACTING A GREAT BARRIER @ 60 MPH
CHANNEL 20 IMPACT
FILTER CUTOFF FREQ. 1650 PEAKS -0.55 , 6.33
15.00
10.00
5.00
.00
-5.00
-10.00
EVENT
-125.00
.00
125.00
250.00
375.00
500.00
625.00
750.00
875.00
TIME.MILLISECONDS

Figure 4-11.

TABLE 4-2

VEHICLE TRANSDUCER MEASUREMENTS

Description	SAE Class 60 Data Peak (g's)	SAE Class 60 Data Time (m sec)	SAE Class 180 Data Peak (g's)	SAE Class 180 Data Time (m sec)
Accel, Longitudinal (g's)	-51.2	319	-84.7	321
Accel, Lateral (g's)	17.7	321	25.8	321
Accel, Vertical (g's)	-25.8	311	-29.5	313
Roll Rate (deg/sec)	-496.6	65		
Yaw Rate (deg/sec)	-255.0	323		

4.1.3 OCCUPANT RISK PARAMETERS

Occupant risk is estimated using two parameters specified in NCHRP 230 and one parameter specified by TRC 191. In NCHRP 230, the Occupant/Compartment Impact Velocity (ΔV) and Occupant Ride-down Acceleration are used. The longitudinal acceleration measurements filtered at 300 Hz were double integrated to determine a forward displacement for the impact of the occupant within the vehicle. ΔV was computed for the two foot displacement given in NCHRP 230 and the actual head to windshield measurement of 2.08 feet for the driver and 1.88 feet for the passenger. The ride-down acceleration was computed as the peak 10 msec average acceleration subsequent to the ΔV location.

In TRC 191 the average acceleration over the stopping distance is specified for direct-on impacts for smooth decelerating devices. This parameter was computed in the longitudinal direction using the formula $a = V^2/2S$ where S is the stopping distance of 18.8 feet and V is the initial vehicle velocity of 58.4 mph (85.7 ft/sec). The average acceleration over the stopping distance was calculated to be -6.1 g's. For devices where the deceleration is not smooth, the maximum 50 msec data processing technique must be used (see TRC 191, p.21). Since the deceleration trace clearly shows much higher deceleration levels toward the end of the

TABLE 4-3

OCCUPANT RISK PARAMETERS (Longitudinal)

<u>NCHRP 230:</u>	
ΔV at 2'	-27.0 ft/sec @ .155 sec
Ridedown Acceleration	-42.3 g's @ .317 sec
ΔV for Driver at 2.08'	-27.3 ft/sec @ .159 sec
Ridedown Acceleration	-42.3 g's @ .317 sec
ΔV for Passenger at 1.88'	-26.9 ft/sec @ .151 sec
Ridedown Acceleration	-42.3 g's @ .317 sec
<u>TRC 191:</u>	
Average Accel. over Stopping Distance	-6.1 g's (Calculation not valid. See TRC 191, p.21)
Maximum 50 msec Acceleration	-24.1 g's

event, the maximum 50 msec level was computed. This value is -24.1 g's.

Table 4-3 presents the results of occupant risk parameter calculations. According to the longitudinal flail space recommendations in Table 8 of NCHRP 230, the calculated ΔV at 2 feet of -27.0 ft/sec, the ΔV for the driver at 2.08 feet of -27.3 ft/sec and the ΔV for the passenger at 1.88 feet of -26.9 ft/sec are below both the design value of 30 ft/sec and limit value of 40 ft/sec. The three ridedown accelerations of -42.3 g's greatly exceed the design and limit values of 15.0 and 20.0 g's, respectively. According to the safety evaluation guidelines in Table 8 of TRC 191 the computed average acceleration over the stopping distance of -6.1 g's is below both the absolute preferred limit of 8.0 g's and the absolute acceptable limit of 12.0 g's. The peak 50 msec average acceleration of -24.1 g's is well above the limit of 12 g's. The 50 msec measurement should be used for TRC 191 evaluation (in lieu of the average acceleration over the stopping distance) since the device produced such a non-constant deceleration.

Based on the NCHRP 230 and TRC 191 parameters, occupant risk during test 1625-C-04-85 should be considered high. ΔV was below the preferred and acceptable criteria, while the ridedown and the peak 50 msec average accelerations were much higher than both the preferred and acceptable criteria, double the highest criteria.

4.2 OCCUPANT ANALYSIS

The data obtained from the instrumented dummies was processed to compute a number of key parameters. Head Injury Criteria (HIC), Chest Severity Index (CSI), and Femur Load Evaluation are discussed in the following paragraphs.

4.2.1 HEAD INJURY CRITERIA (HIC) EVALUATION

The data obtained from the three accelerometers located in the heads of the occupants during the test were filtered at SAE Class 1000 and combined to yield a resultant acceleration occurring during the impact event. The HIC was evaluated in accordance with the procedures outlined in FMVSS 208. The acceleration traces and resultants obtained with the use of the SAE Class 1000 (f_c = 1,650 Hz) filtering techniques are presented in Figures 4-12 through 4-15 for the driver and Figures 4-16 through 4-19 for the passenger. Figure 4-12 indicates three distinct areas of high deceleration. The first spike (140-150 msec) occurred when the head impacted the windshield header. The second (175-185 msec) occurred when the head impacted and broke the windshield. The third (180-200 msec) roughly corresponds to the deceleration seen by the vehicle longitudinal accelerometer (see Figure 4-1). This occurred when the vehicle stopped after the complete crush of the GREAT barrier. The resultant acceleration calculated for the driver's head and the passenger's head was for all practical purposes self-contained within the collision event. The HIC evaluated for the driver was 293 within the time interval of .144 to .148 seconds for a time duration of .004 seconds. The HIC evaluated for the passenger was 260 within the time interval of

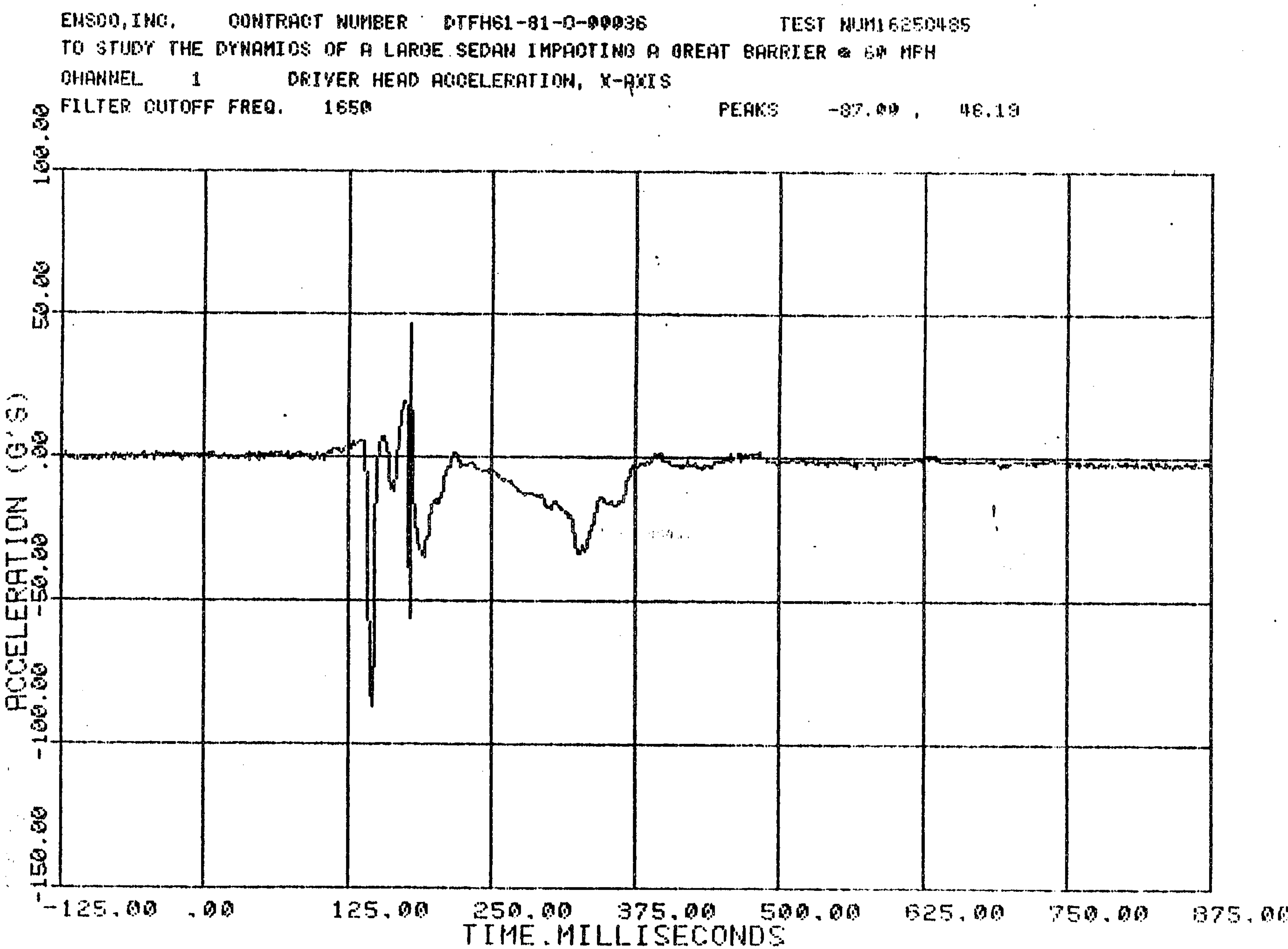

ENSCO,INC. CONTRACT NUMBER DTFH61-81-C-00036 TEST NUM16250485
TO STUDY THE DYNAMICS OF A LARGE SEDAN IMPACTING A GREAT BARRIER @ 60 MPH
CHANNEL 1 DRIVER HEAD ACCELERATION, X-AXIS
FILTER CUTOFF FREQ. 1650 PEAKS -87.00 , 46.19
100.00
50.00
.00
-50.00
-100.00
-150.00
ACCELERATION (G'S)
-125.00
.00
125.00
250.00
375.00
500.00
625.00
750.00
875.00
TIME.MILLISECONDS

Figure 4-12.

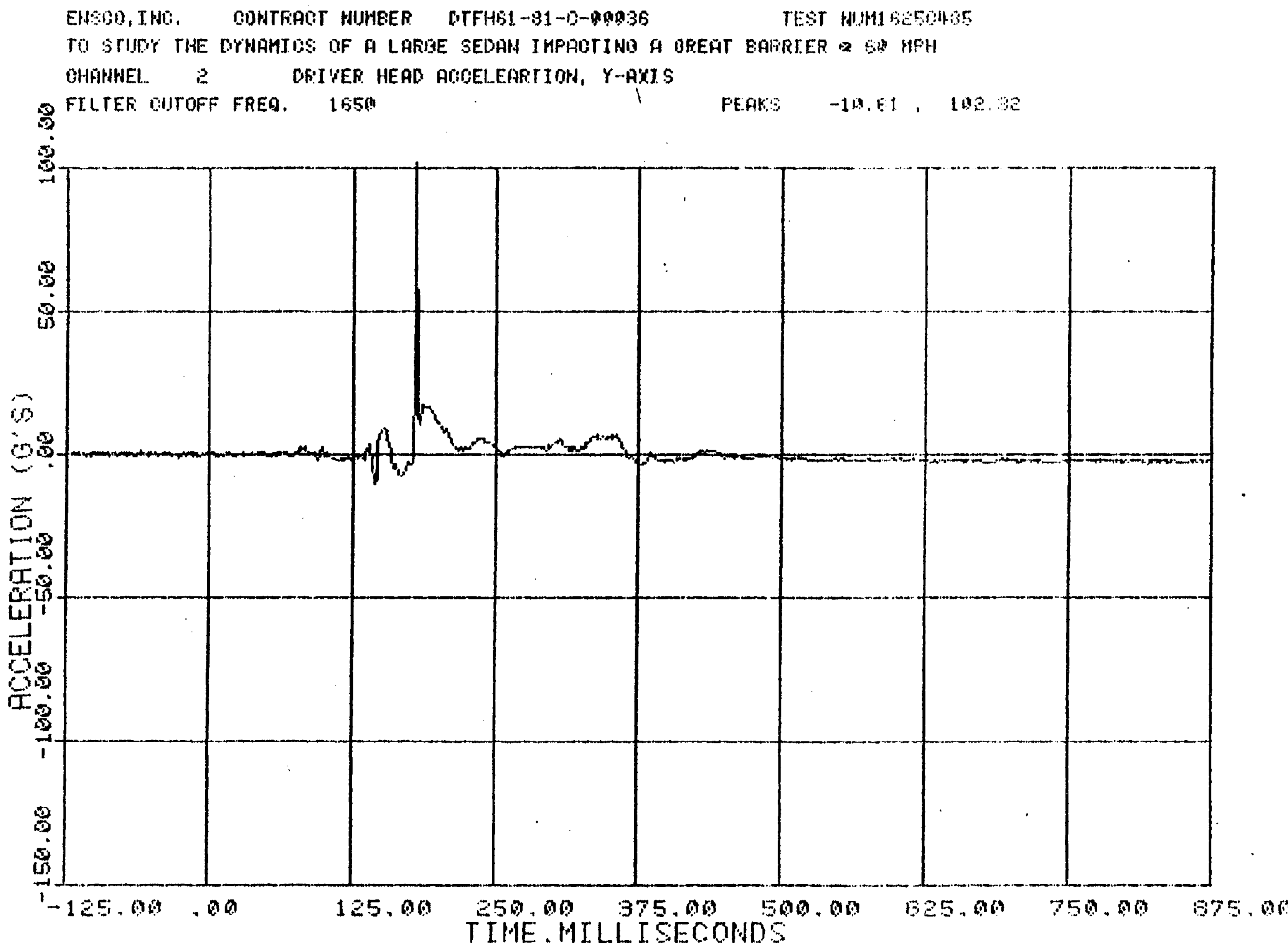

ENSCO,INC. CONTRACT NUMBER DTFH61-81-C-00036 TEST NUM16250435
TO STUDY THE DYNAMICS OF A LARGE SEDAN IMPACTING A GREAT BARRIER @ 60 MPH
CHANNEL 2 DRIVER HEAD ACCELEARTION, Y-AXIS
FILTER CUTOFF FREQ. 1650 PEAKS -10.61 , 102.32
100.00
50.00
.00
-50.00
-100.00
-150.00
ACCELERATION (G'S)
-125.00
.00
125.00
250.00
375.00
500.00
625.00
750.00
875.00
TIME.MILLISECONDS

Figure 4-13.

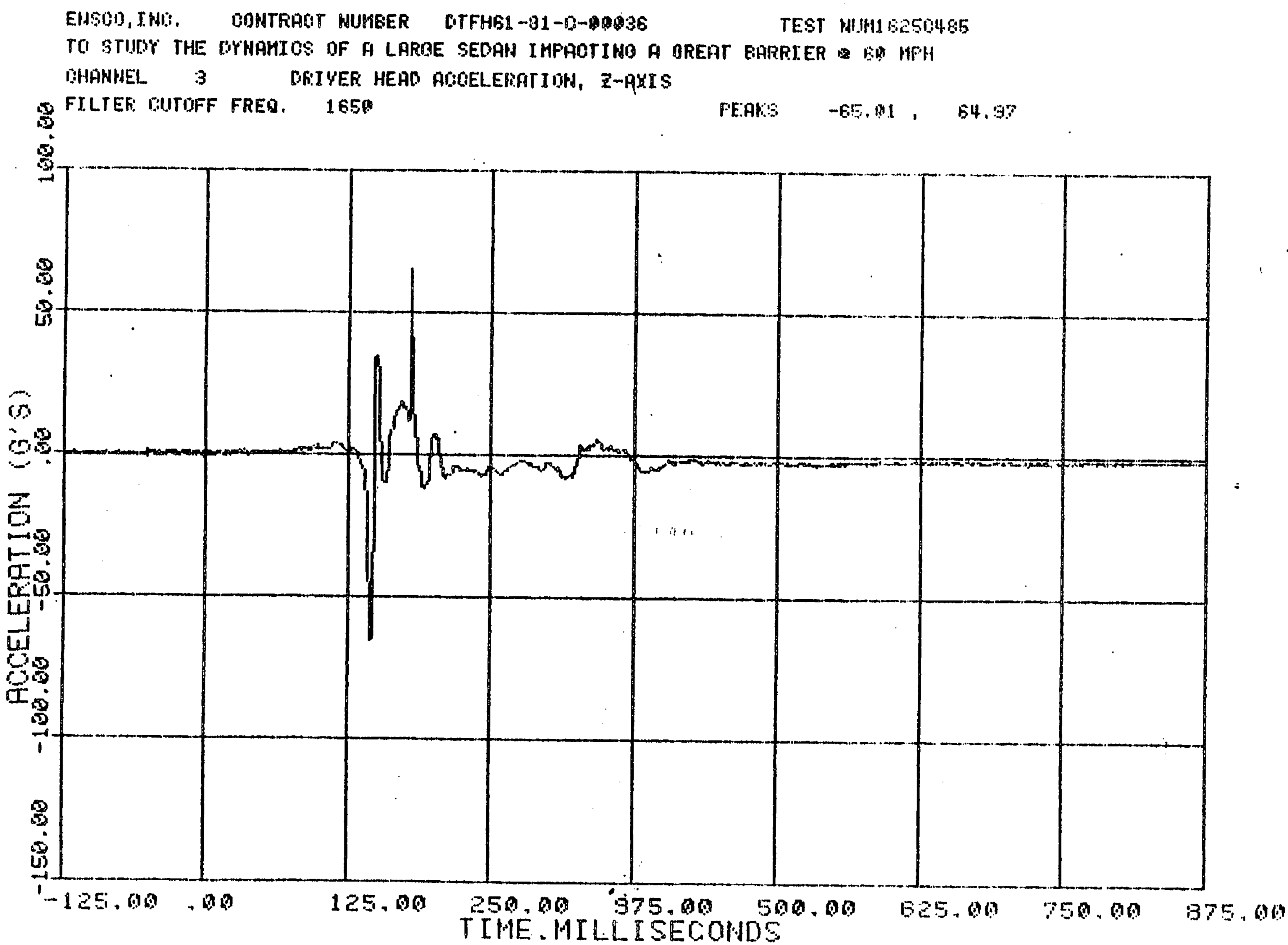

ENSCO,INC.   CONTRACT NUMBER   DTFH61-81-C-00036   TEST NUM16250485
TO STUDY THE DYNAMICS OF A LARGE SEDAN IMPACTING A GREAT BARRIER @ 60 MPH
CHANNEL 3   DRIVER HEAD ACCELERATION, Z-AXIS
FILTER CUTOFF FREQ. 1650   PEAKS -65.01 , 64.97
100.00
50.00
.00
-50.00
-100.00
-150.00
ACCELERATION (G'S)
-125.00 .00 125.00 250.00 375.00 500.00 625.00 750.00 875.00
TIME.MILLISECONDS

Figure 4-14.

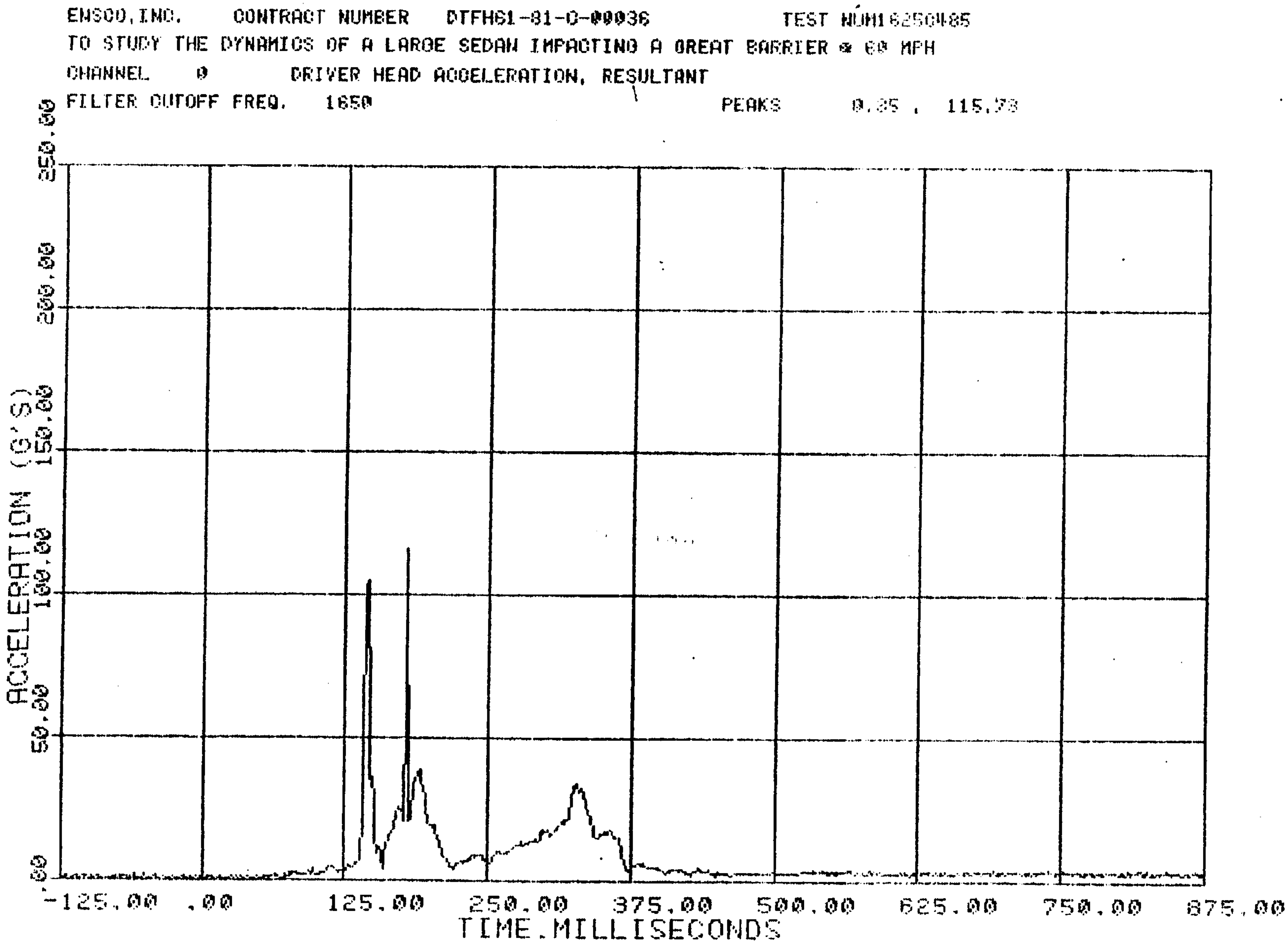

ENSCO, INC.   CONTRACT NUMBER   DTFH61-81-C-00036   TEST NUM16250485
TO STUDY THE DYNAMICS OF A LARGE SEDAN IMPACTING A GREAT BARRIER @ 60 MPH
CHANNEL 0   DRIVER HEAD ACCELERATION, RESULTANT
FILTER CUTOFF FREQ. 1650   PEAKS 0.35 , 115.73
ACCELERATION (G'S)
250.00
200.00
150.00
100.00
50.00
.00
-125.00 .00 125.00 250.00 375.00 500.00 625.00 750.00 875.00
TIME, MILLISECONDS

Figure 4-15.

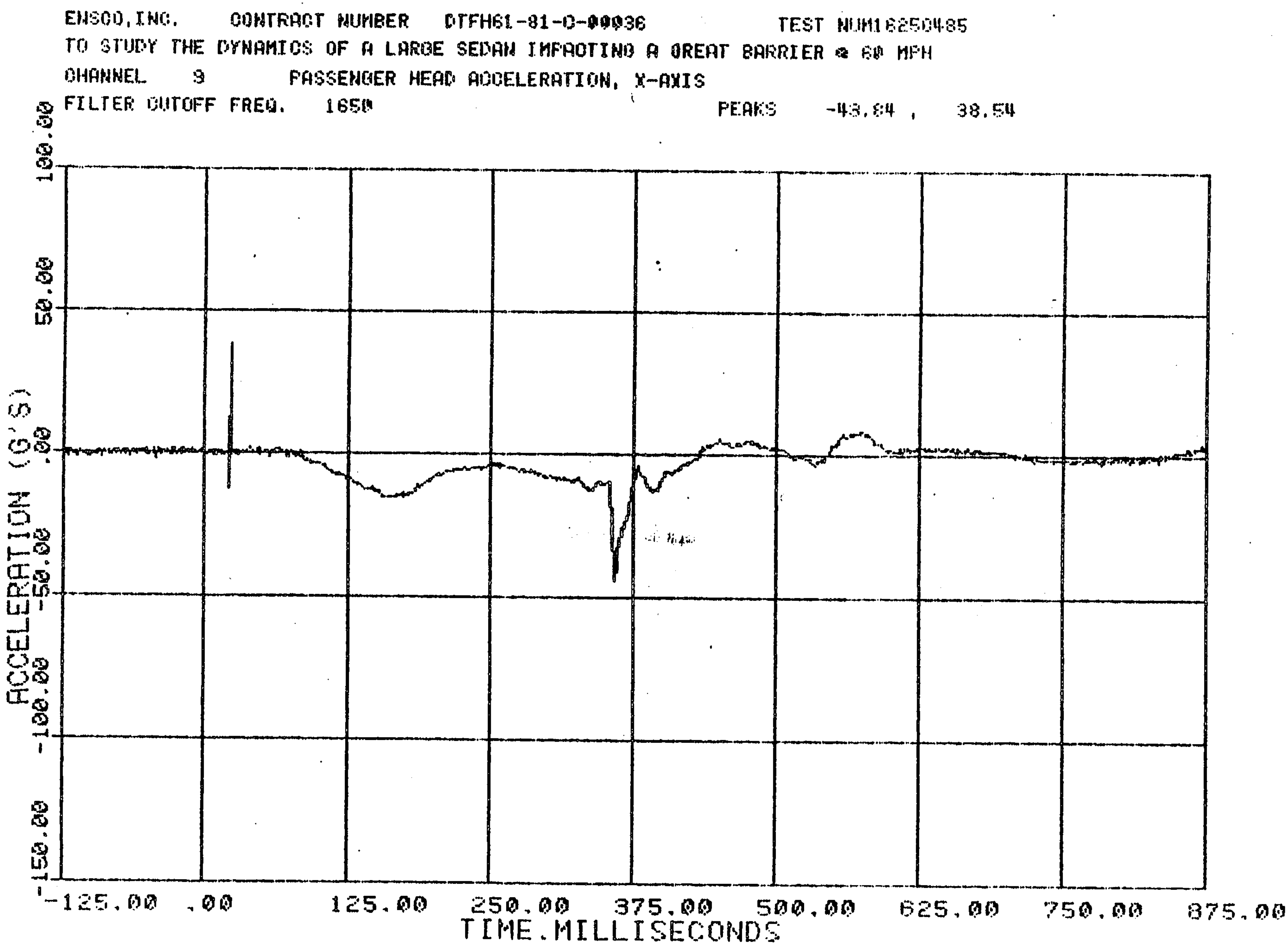

ENSCO,INC. CONTRACT NUMBER DTFH61-81-C-00036 TEST NUM16250485
TO STUDY THE DYNAMICS OF A LARGE SEDAN IMPACTING A GREAT BARRIER @ 60 MPH
CHANNEL 9 PASSENGER HEAD ACCELERATION, X-AXIS
FILTER CUTOFF FREQ. 1650 PEAKS -43.84 , 38.54
100.00
50.00
.00
-50.00
-100.00
-150.00
ACCELERATION (G'S)
-125.00
.00
125.00
250.00
375.00
500.00
625.00
750.00
875.00
TIME.MILLISECONDS

Figure 4-16

ENSCO,INC.   CONTRACT NUMBER   DTFH61-81-C-00036   TEST NUM16250485
TO STUDY THE DYNAMICS OF A LARGE SEDAN IMPACTING A GREAT BARRIER @ 60 MPH
CHANNEL 10   PASSENGER HEAD ACCELERATION, Y-AXIS
FILTER CUTOFF FREQ.   1650   PEAKS   -153.49 ,   7.05

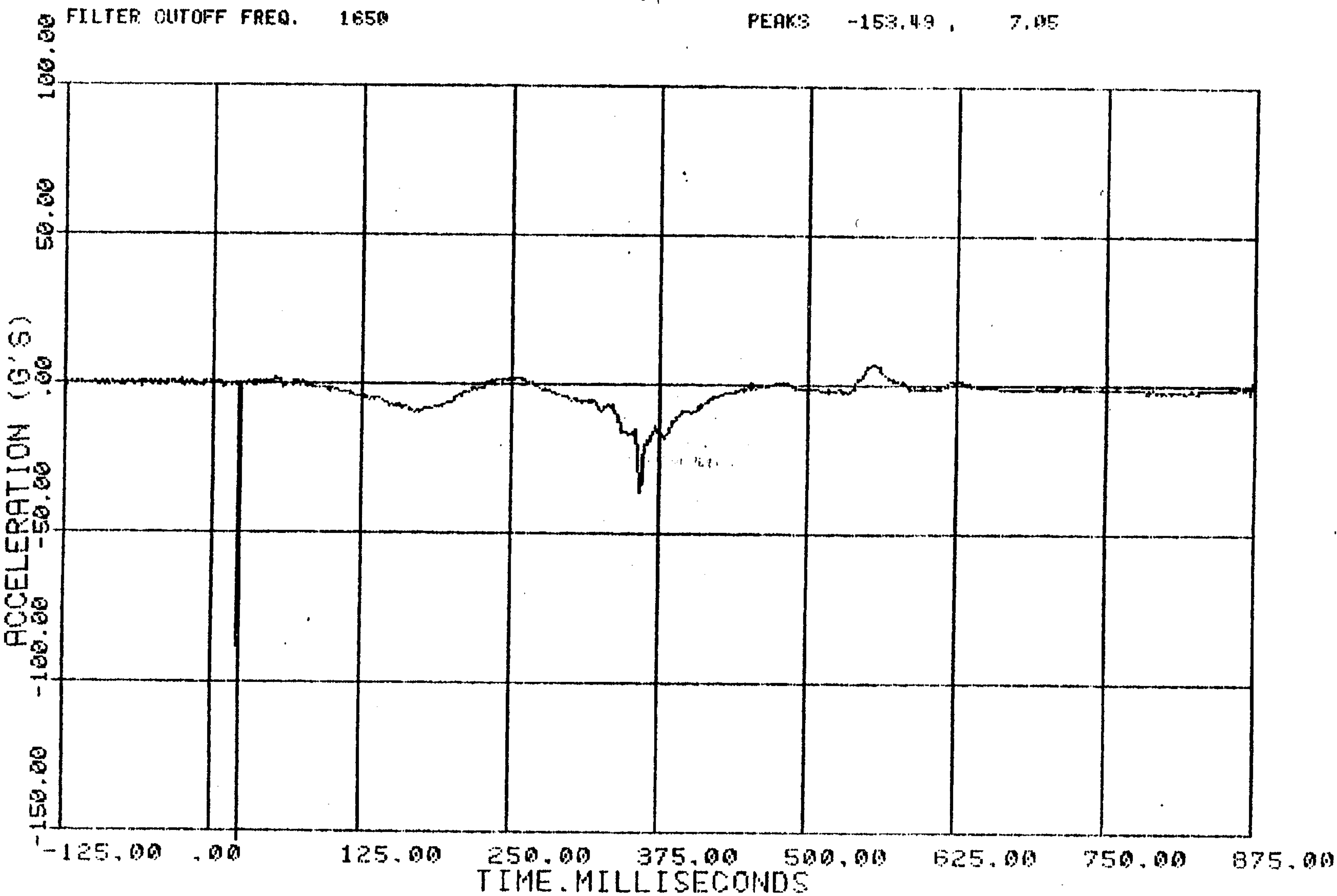


Figure 4-17.

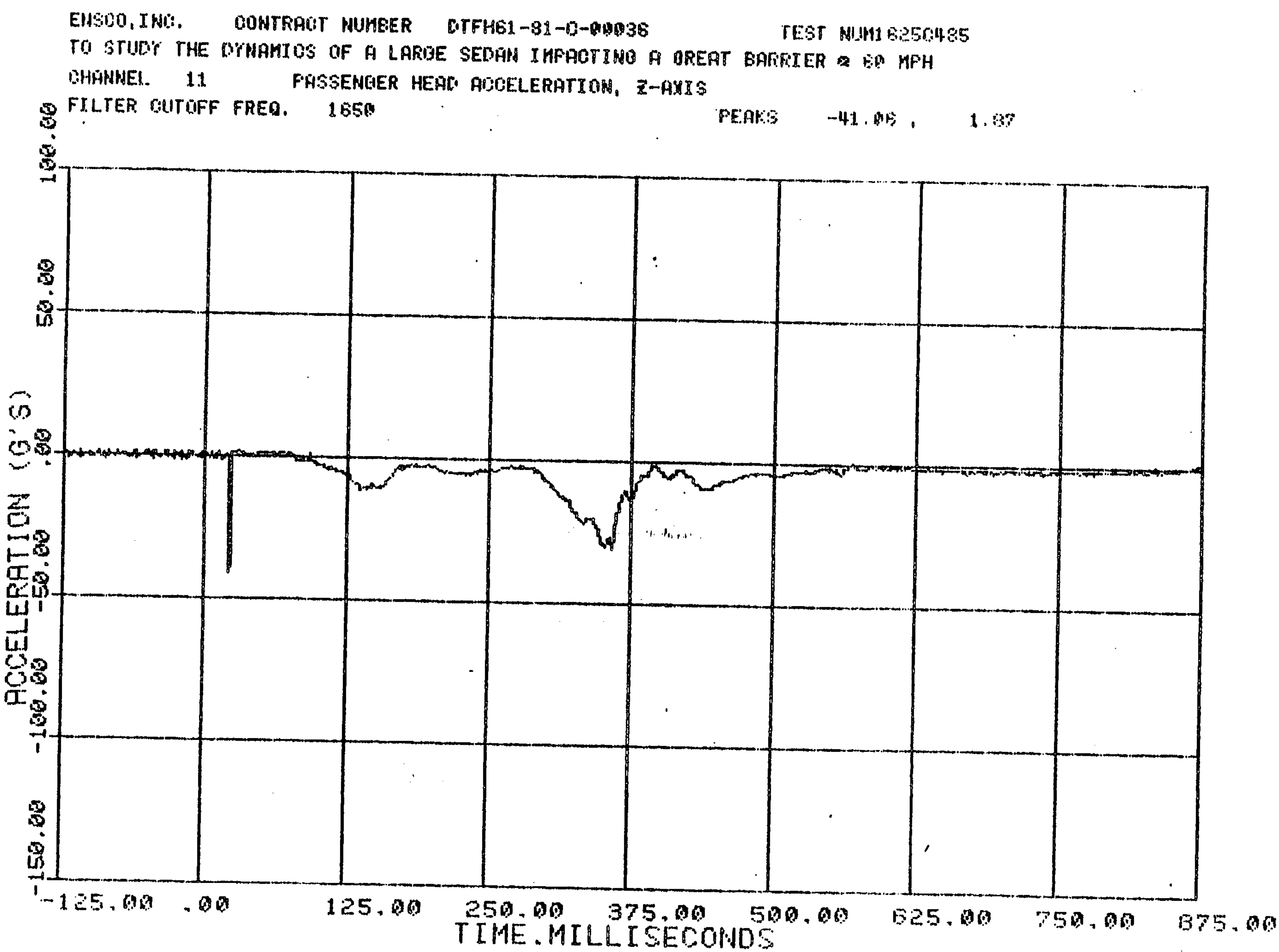

ENSCO,INC. CONTRACT NUMBER DTFH61-81-C-00036 TEST NUM16250485
TO STUDY THE DYNAMICS OF A LARGE SEDAN IMPACTING A GREAT BARRIER @ 60 MPH
CHANNEL 11 PASSENGER HEAD ACCELERATION, Z-AXIS
FILTER CUTOFF FREQ. 1650
PEAKS -41.06 , 1.87
100.00
50.00
.00
-50.00
-100.00
-150.00
ACCELERATION (G'S)
-125.00
.00
125.00
250.00
375.00
500.00
625.00
750.00
875.00
TIME.MILLISECONDS

Figure 4-18

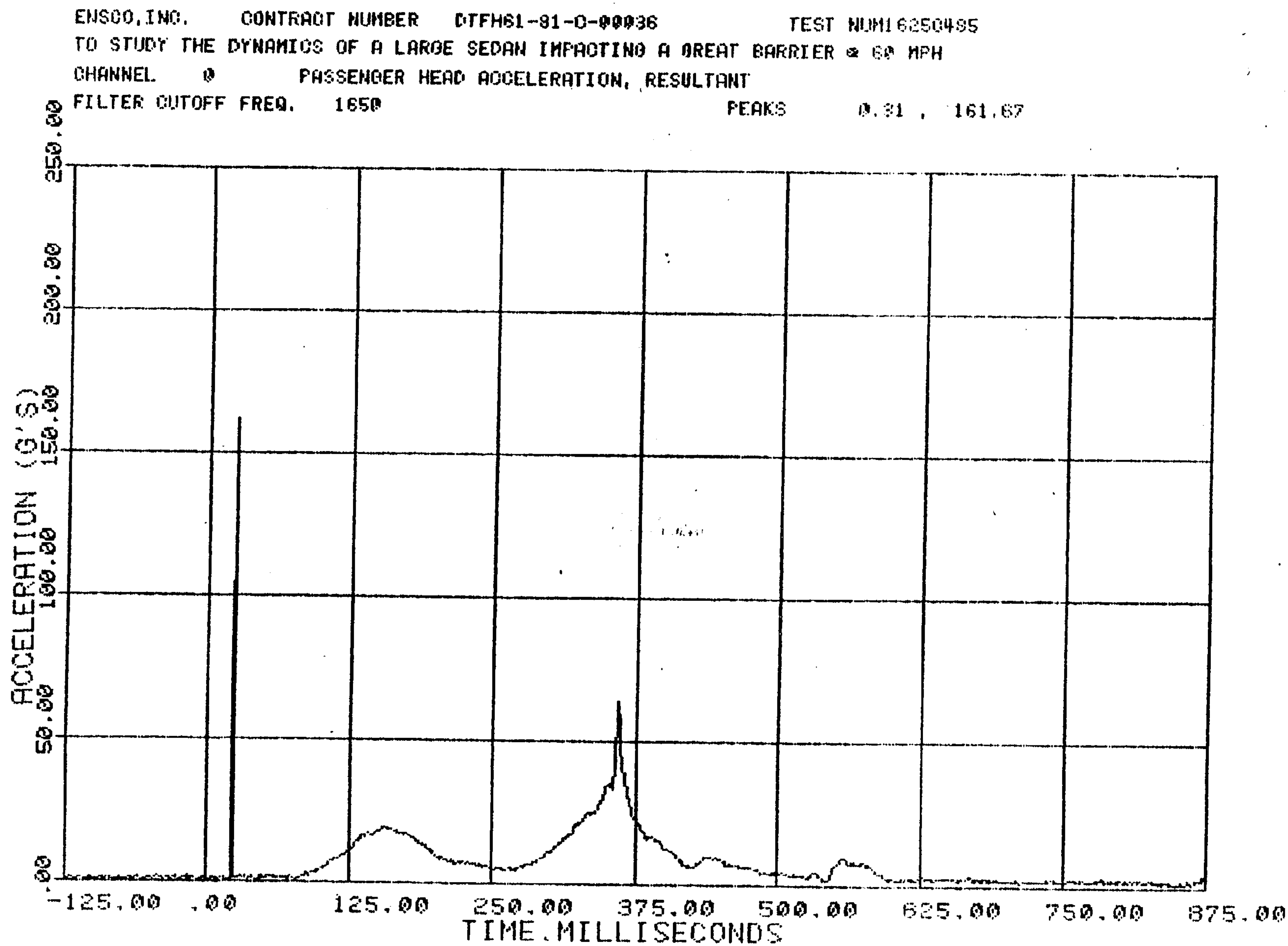

ENSCO,INC.   CONTRACT NUMBER   DTFH61-81-C-00036   TEST NUM16250485
TO STUDY THE DYNAMICS OF A LARGE SEDAN IMPACTING A GREAT BARRIER @ 60 MPH
CHANNEL   0   PASSENGER HEAD ACCELERATION, RESULTANT
FILTER CUTOFF FREQ.   1650   PEAKS   0.31 , 161.67
ACCELERATION (G'S)
250.00
200.00
150.00
100.00
50.00
.00
-125.00
.00
125.00
250.00
375.00
500.00
625.00
750.00
875.00
TIME.MILLISECONDS

Figure 4-19.

.315 to .392 seconds for a time duration of .077 seconds. Given an acceptable limit of 1000, this HIC number indicates that the occupants experienced a moderate collision. It should be noted that the spike in the passenger data traces which occurs at about 25 msec was caused by electrical noise, and thus should not be considered data.

4.2.2 CHEST SEVERITY INDEX (CSI) EVALUATION

The data obtained from the three accelerometers located in the chests of the occupants during the test were filtered at SAE Class 180 and combined to yield a resultant acceleration occurring during the impact event. The CSI was evaluated in accordance with SAE Information Report J885. In addition, the maximum resultant acceleration whose cumulative duration is not less than 3 milliseconds was evaluated in accordance with FMVSS 208. The acceleration traces and resultants obtained with the use of the SAE Class 180 (f_c = 300 Hz) filtering techniques are presented in Figures 4-20 through 4-22 for the driver and Figures 4-23 through 4-26 for the passenger. The driver's chest vertical acceleration data was lost due to a problem with the data acquisition system. The driver's chest resultant acceleration, the CSI and the maximum chest acceleration were calculated using the longitudinal and lateral accelerations only.

The peak resultant acceleration whose duration greater than .003 seconds was 35.7 g's occurring at .159 seconds for the driver and 30.0 g's occurring at .346 seconds for the passenger after initial impact. The CSI was calculated to be 286 for the driver and 174 for the passenger. Given the acceptable limits of 60 g's for peak acceleration and 1000 for CSI, the driver's chest and the passenger's chest experienced a moderate accident.

4.2.3 FEMUR LOAD EVALUATION

The data obtained from the load cell located in the femur of each leg of the occupants was filtered at SAE Class 600. The maximum

ENSCO, INC.   CONTRACT NUMBER   DTFH61-81-C-00036   TEST NUM16250485
TO STUDY THE DYNAMICS OF A LARGE SEDAN IMPACTING A GREAT BARRIER @ 60 MPH
CHANNEL 4   DRIVER CHEST ACCELERATION, X-AXIS
FILTER CUTOFF FREQ. 300   PEAKS -34.52 , 0.27

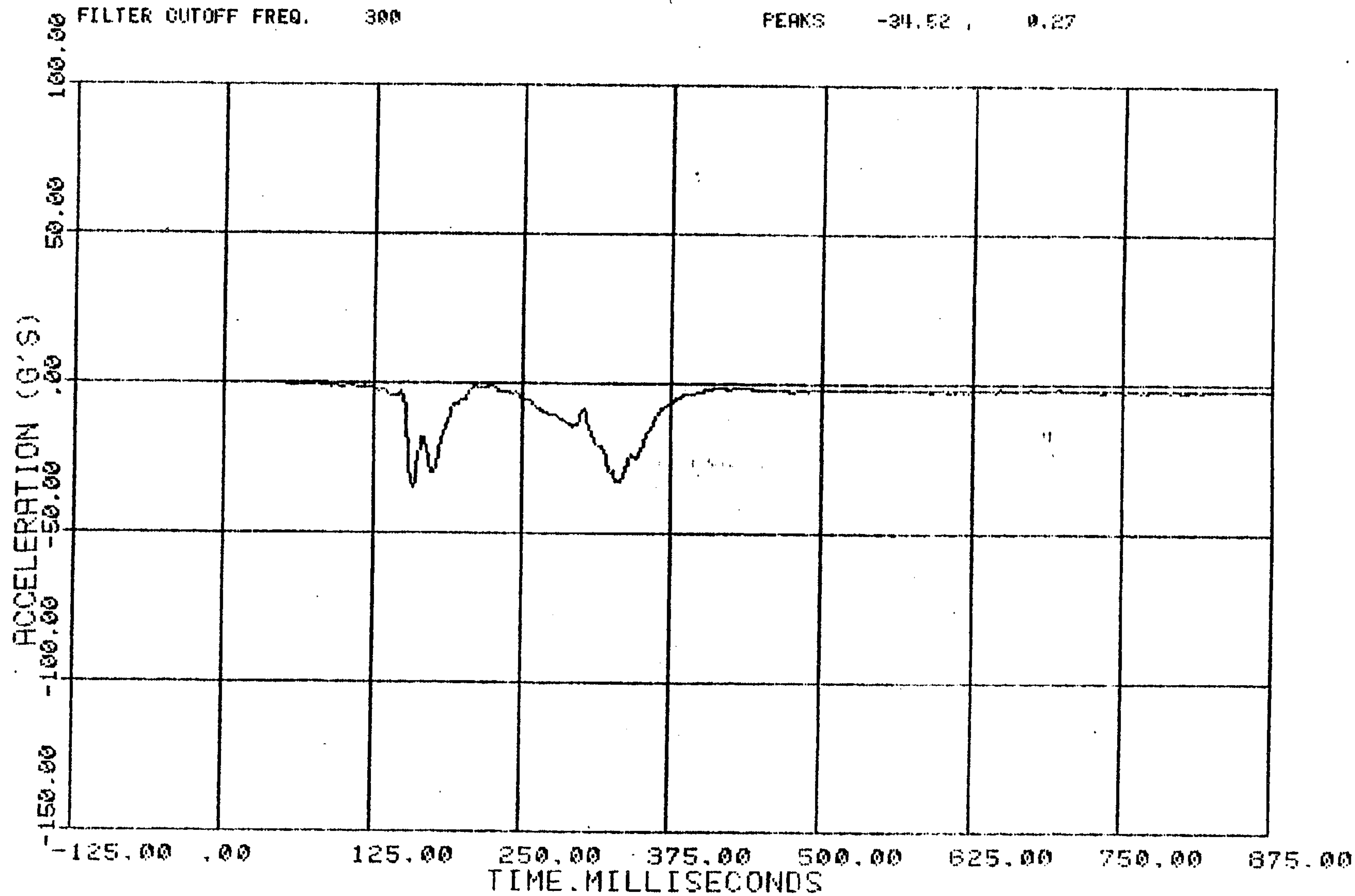


Figure 4-20.

EMSCO, INC.   CONTRACT NUMBER   DTFH61-81-C-00036   TEST NUM1625C405
TO STUDY THE DYNAMICS OF A LARGE SEDAN IMPACTING A GREAT BARRIER @ 60 MPH
CHANNEL   5   DRIVER CHEST ACCELERATION, Y-AXIS
FILTER CUTOFF FREQ.   300   PEAKS   -3.37 ,   6.10

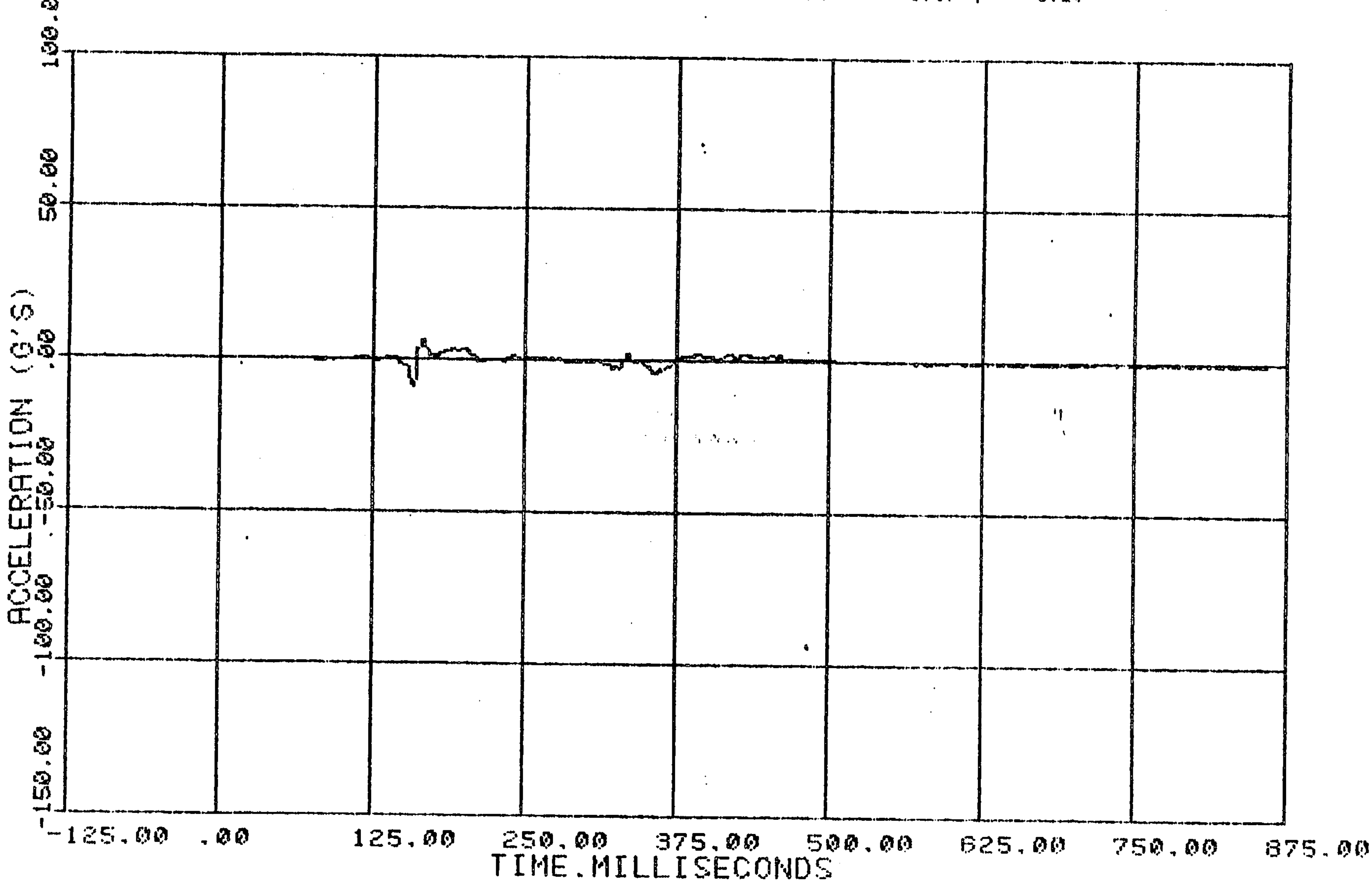


Figure 4-21.

ENSCO, INC.   CONTRACT NUMBER   DTFH61-81-C-00036   TEST NUM16250485
TO STUDY THE DYNAMICS OF A LARGE SEDAN IMPACTING A GREAT BARRIER @ 60 MPH
CHANNEL   0   DRIVER CHEST ACCELERATION, RESULTANT
FILTER CUTOFF FREQ.   300   PEAKS   0.03 ,   35.09

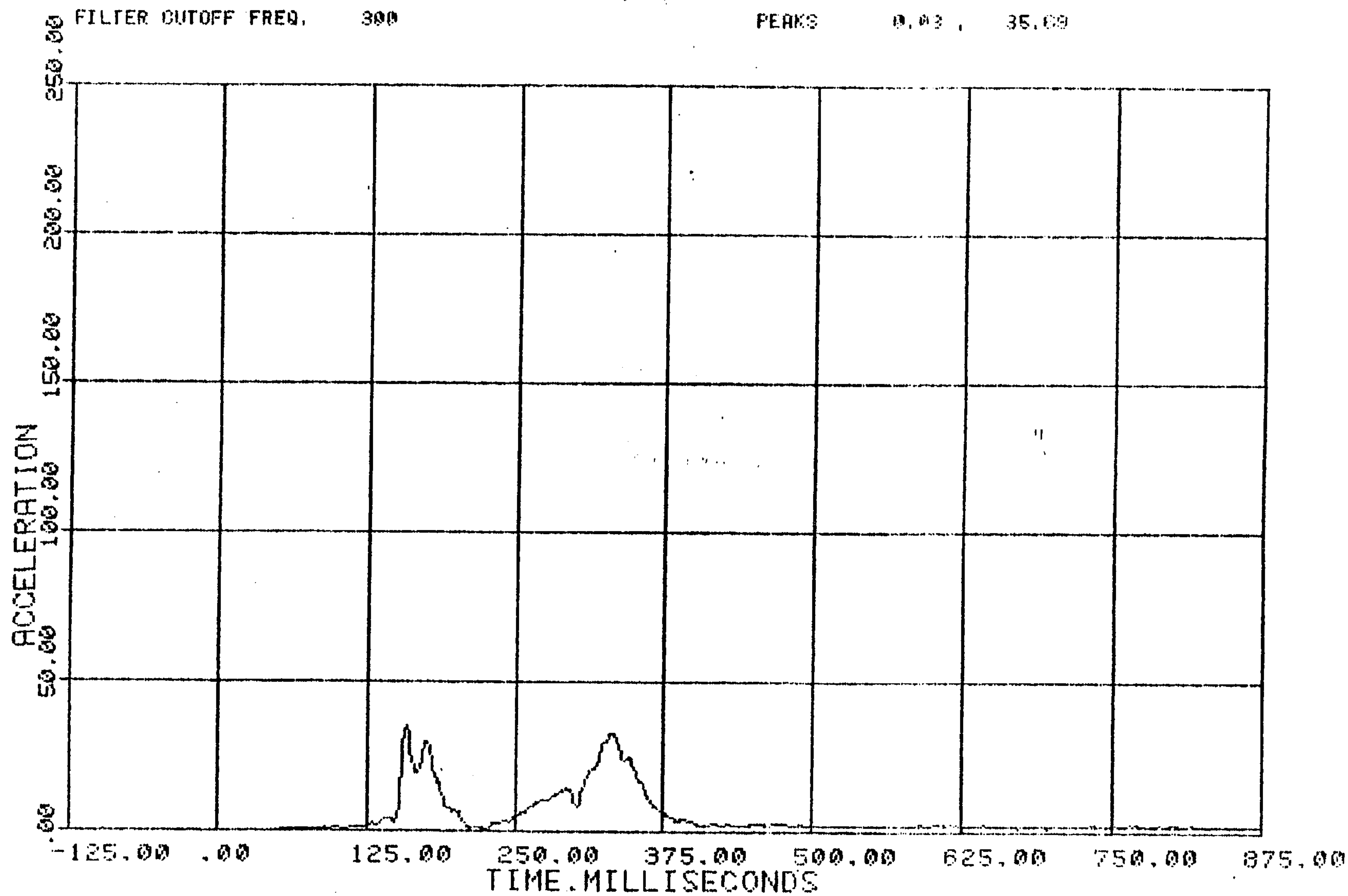


Figure 4-22.

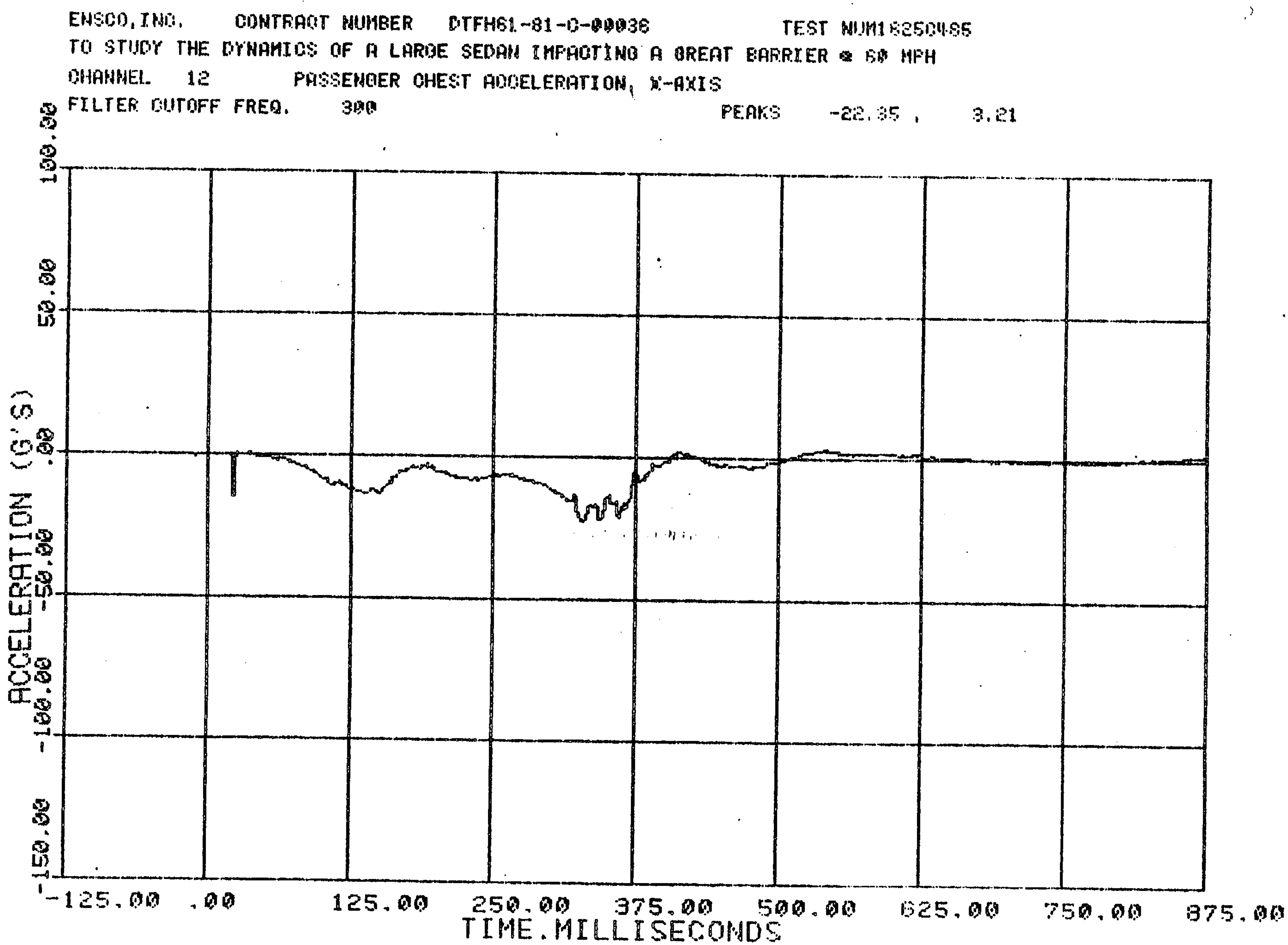

ENSCO,INC. CONTRACT NUMBER DTFH61-81-C-00036 TEST NUM18250485
TO STUDY THE DYNAMICS OF A LARGE SEDAN IMPACTING A GREAT BARRIER @ 60 MPH
CHANNEL 12 PASSENGER CHEST ACCELERATION, X-AXIS
FILTER CUTOFF FREQ. 300 PEAKS -22.35 , 3.21
100.00
50.00
.00
-50.00
-100.00
-150.00
ACCELERATION (G'S)
-125.00
.00
125.00
250.00
375.00
500.00
625.00
750.00
875.00
TIME.MILLISECONDS

Figure 4-23

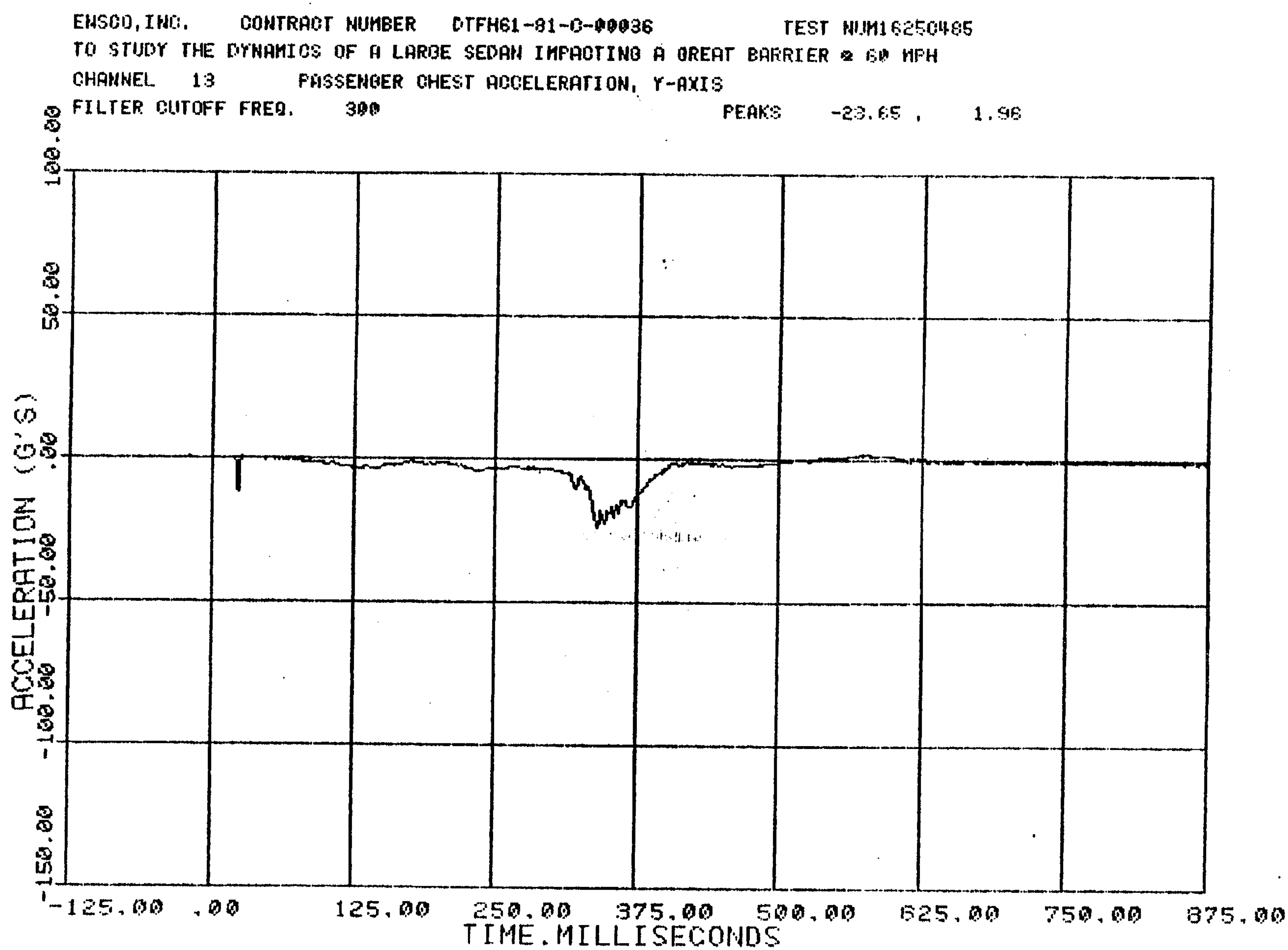

ENSCO,INC. CONTRACT NUMBER DTFH61-81-C-00036 TEST NUM16250485
TO STUDY THE DYNAMICS OF A LARGE SEDAN IMPACTING A GREAT BARRIER @ 60 MPH
CHANNEL 13 PASSENGER CHEST ACCELERATION, Y-AXIS
FILTER CUTOFF FREQ. 300 PEAKS -23.65 , 1.96
100.00
50.00
.00
-50.00
-100.00
-150.00
ACCELERATION (G'S)
-125.00
.00
125.00
250.00
375.00
500.00
625.00
750.00
875.00
TIME.MILLISECONDS

Figure 4-24

ENSCO, INC.   CONTRACT NUMBER   DTFH61-81-C-00036   TEST NUM16250485
TO STUDY THE DYNAMICS OF A LARGE SEDAN IMPACTING A GREAT BARRIER @ 60 MPH
CHANNEL   14   PASSENGER CHEST ACCELERATION, Z-AXIS
FILTER CUTOFF FREQ.   300   PEAKS   -3.58 ,   15.73

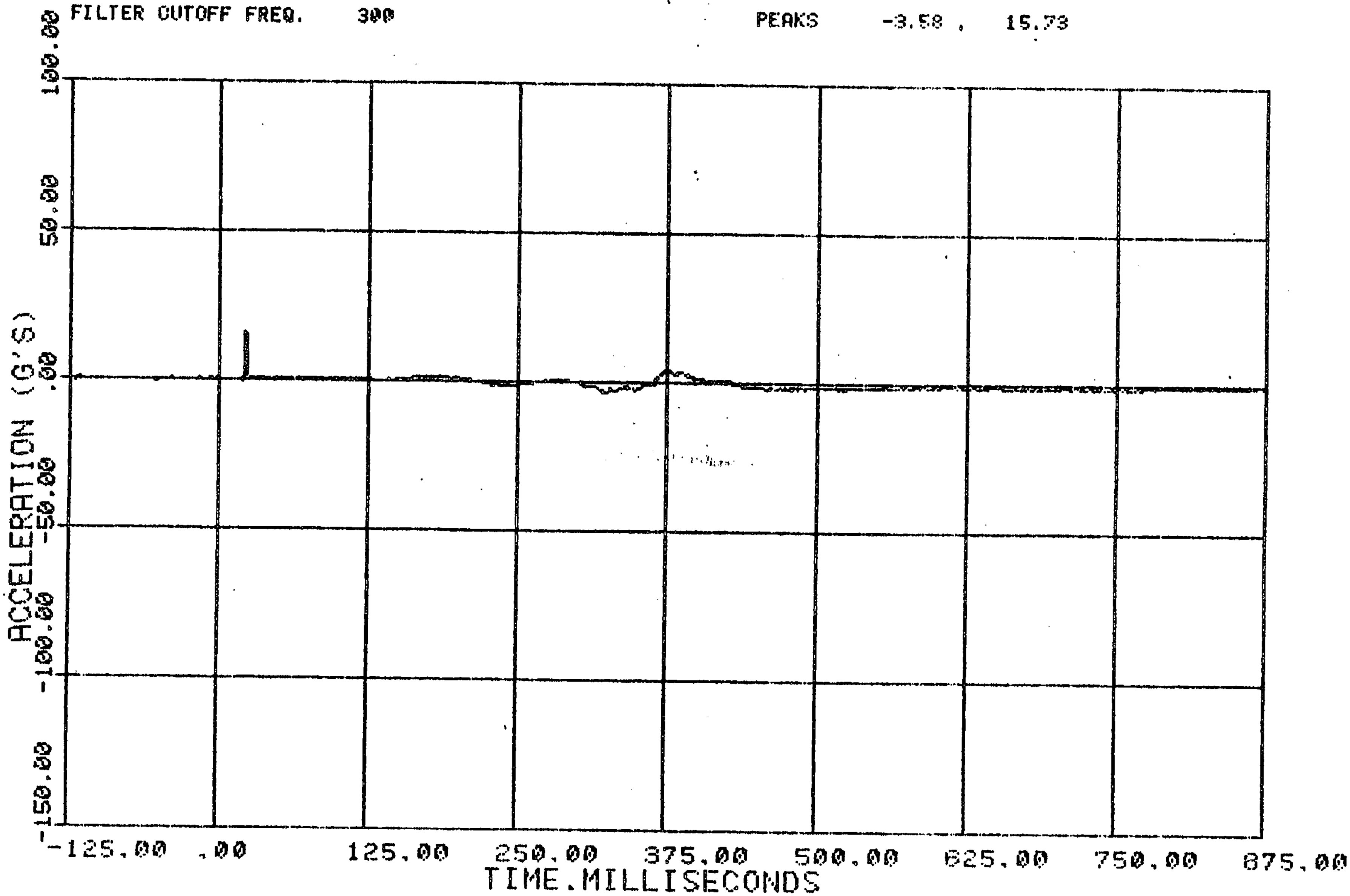


Figure 4-25.

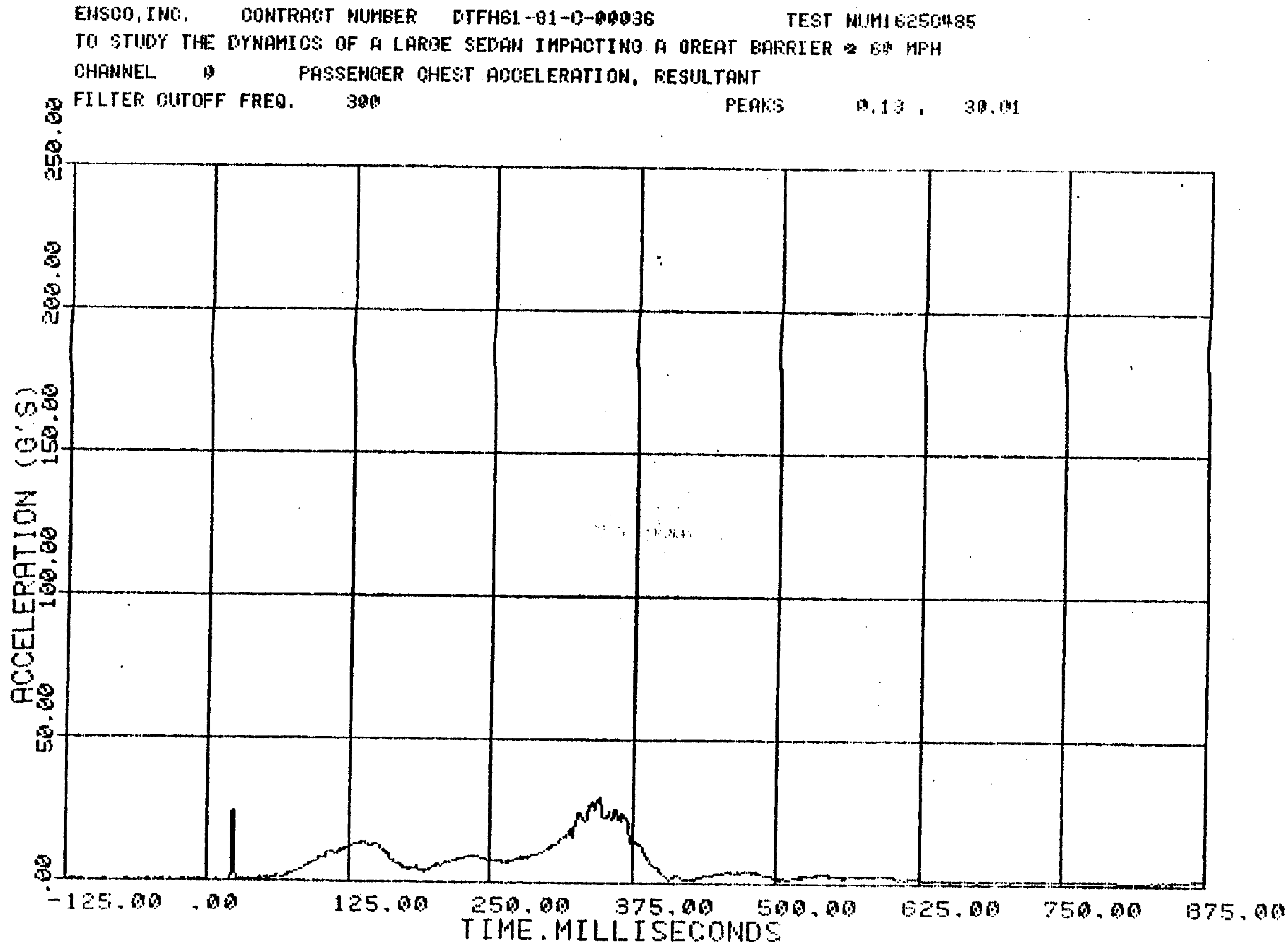

ENSCO, INC.
CONTRACT NUMBER DTFH61-81-C-00036
TEST NUM1625O485
TO STUDY THE DYNAMICS OF A LARGE SEDAN IMPACTING A GREAT BARRIER @ 60 MPH
CHANNEL 0
PASSENGER CHEST ACCELERATION, RESULTANT
FILTER CUTOFF FREQ. 300
PEAKS 0.13 , 30.01
ACCELERATION (G'S)
250.00
200.00
150.00
100.00
50.00
.00
-125.00
.00
125.00
250.00
375.00
500.00
625.00
750.00
875.00
TIME.MILLISECONDS

Figure 4-26.

load which occurred in each femur was then determined and compared to the acceptable limit of 2,250 lbs as specified in FMVSS 208. The load traces obtained with the use of the SAE Class 600 (f_c = 1000 Hz) filtering technique are presented in Figures 4-27 and 4-28 for the driver and Figures 4-29 and 4-30 for the passenger. The maximum femur loads of the driver were 795 pounds for the right leg and 957 pounds for the left leg. The maximum femur loads of the passenger were 280 pounds for the right leg and 100 pounds for the left leg. The measured femur loads are below the acceptable limit of 2,250 pounds.

4.3 GREAT ANALYSIS

The force-deflection characteristic and the total energy absorbed by the GREAT impact attenuator are estimated in this section. The law of physics can be applied for this test by modeling the vehicle/GREAT impact attenuator as shown in Figure 4-31. The vehicle is a moving mass (m_C) with a crush stiffness of K_C, the dummy is a moving mass (m_D) with the vehicle interior crush stiffness of K_I, and the stationary GREAT system has a crush stiffness of K_G.

The kinetic energy delivered by the vehicle equals 1/2 $m_C V^2$ where m_C is the vehicle mass (w/g) and V is the impact velocity. Therefore, the kinetic energy of the vehicle (KE_V) equals:

$$\frac{1}{2} \times \frac{4346 \text{ lbs}}{32.2 \text{ ft/sec}^2} \times (85.7 \text{ ft/sec})^2 = 495.6 \text{ kip-ft}$$

The kinetic energy delivered by the two dummies inside the vehicle equals 1/2 $m_D V^2$ where m_D is the total dummy mass and V is the impact velocity. The kinetic energy of the dummy (KE_D) equals

$$\frac{1}{2} \times \frac{374 \text{ lbs}}{32.2 \text{ ft/sec}^2} \times (85.7 \text{ ft/sec})^2 = 42.7 \text{ kip-ft}$$

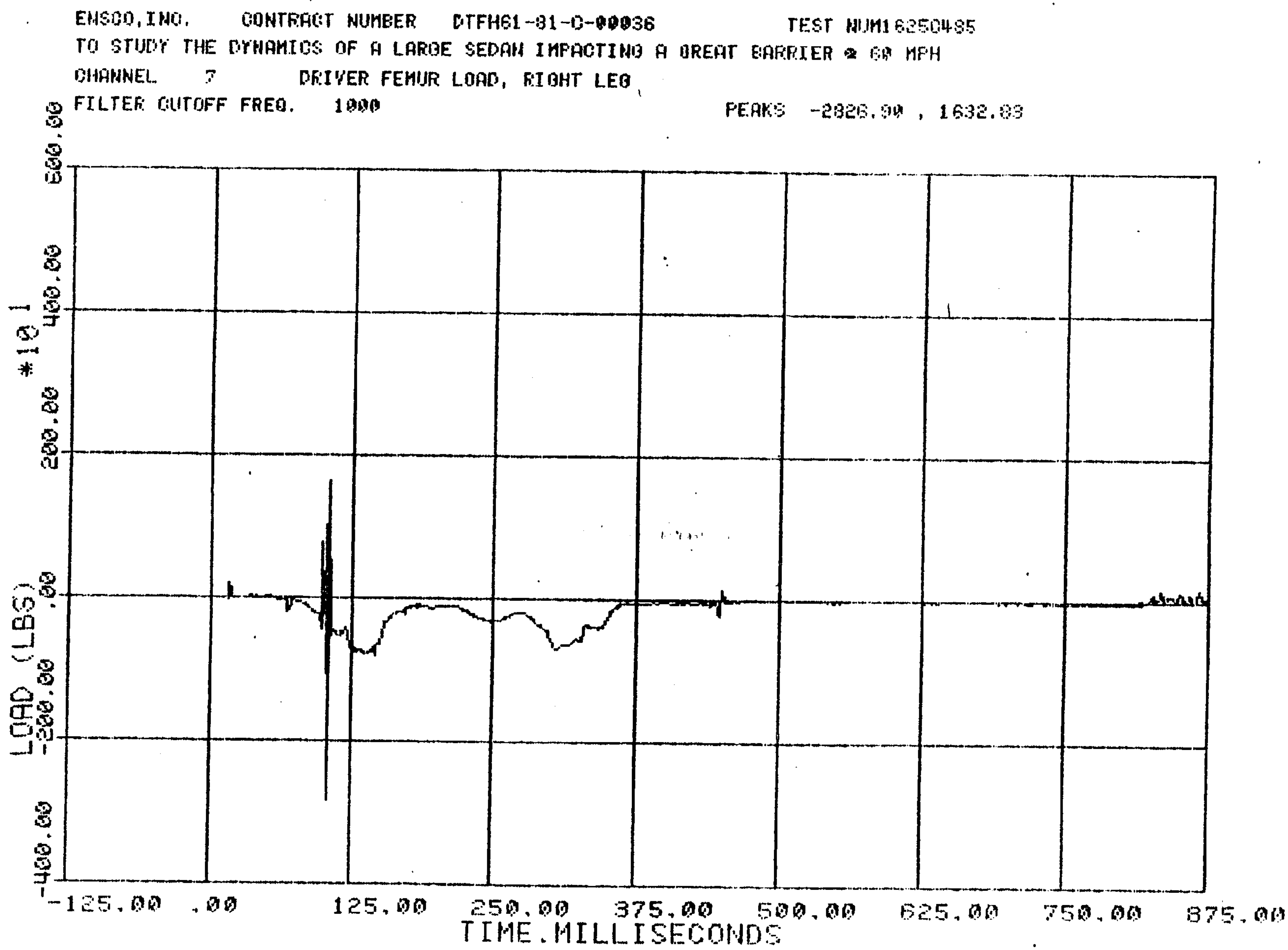

ENSCO,INC.   CONTRACT NUMBER   DTFH61-81-C-00036   TEST NUM16250485
TO STUDY THE DYNAMICS OF A LARGE SEDAN IMPACTING A GREAT BARRIER @ 60 MPH
CHANNEL   7   DRIVER FEMUR LOAD, RIGHT LEG
FILTER CUTOFF FREQ.   1000
PEAKS -2826.90 , 1632.03
LOAD (LBS) *10 1
600.00
400.00
200.00
.00
-200.00
-400.00
-125.00
.00
125.00
250.00
375.00
500.00
625.00
750.00
875.00
TIME.MILLISECONDS

Figure 4-27.

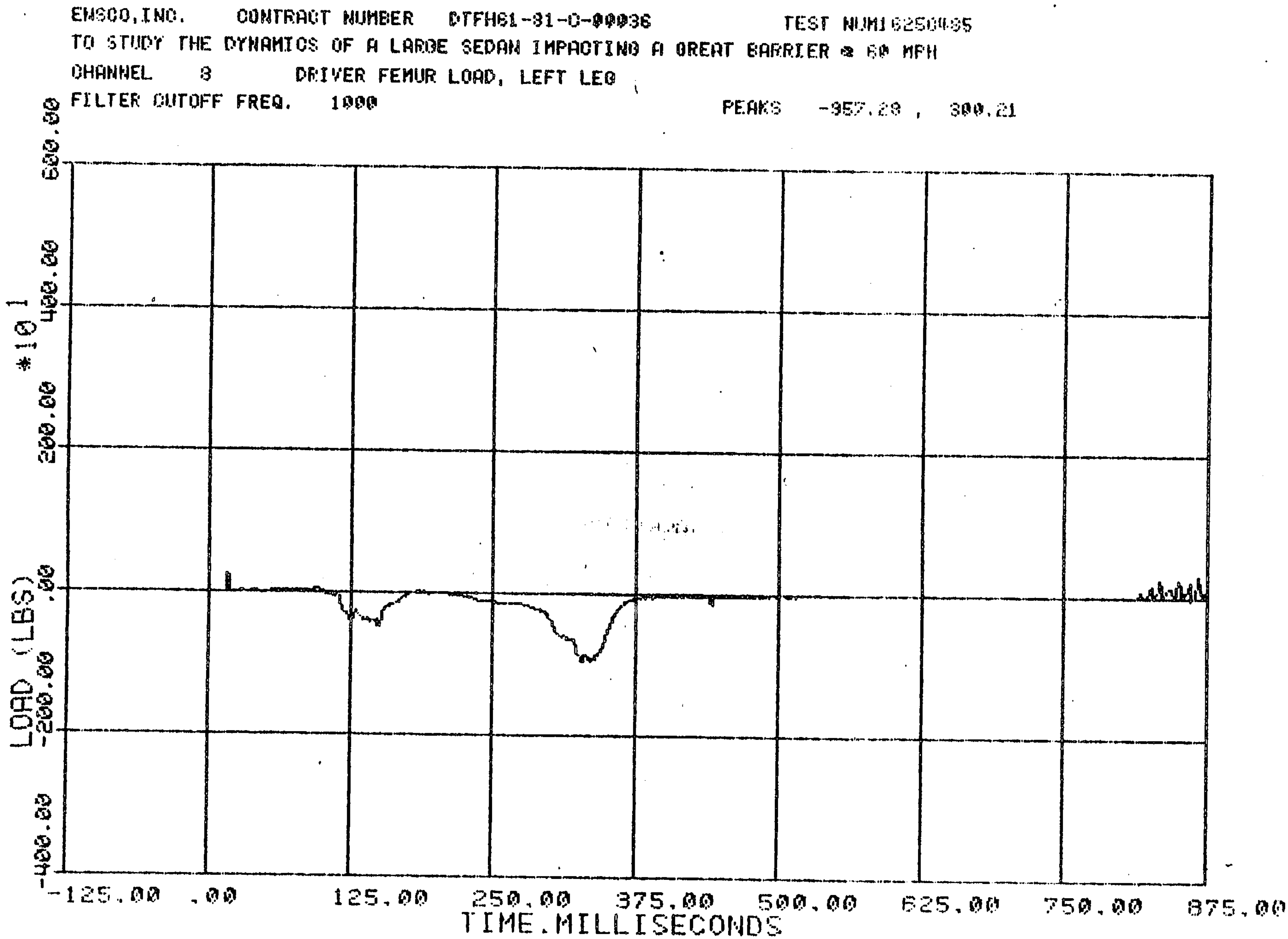

ENSCO,INC.   CONTRACT NUMBER   DTFH61-81-C-00036   TEST NUM16250035
TO STUDY THE DYNAMICS OF A LARGE SEDAN IMPACTING A GREAT BARRIER @ 60 MPH
CHANNEL   8   DRIVER FEMUR LOAD, LEFT LEG
FILTER CUTOFF FREQ.   1000   PEAKS   -957.28 , 300.21
600.00
400.00
200.00
.00
-200.00
-400.00
*10 1
LOAD (LBS)
-125.00
.00
125.00
250.00
375.00
500.00
625.00
750.00
875.00
TIME.MILLISECONDS

Figure 4-28.

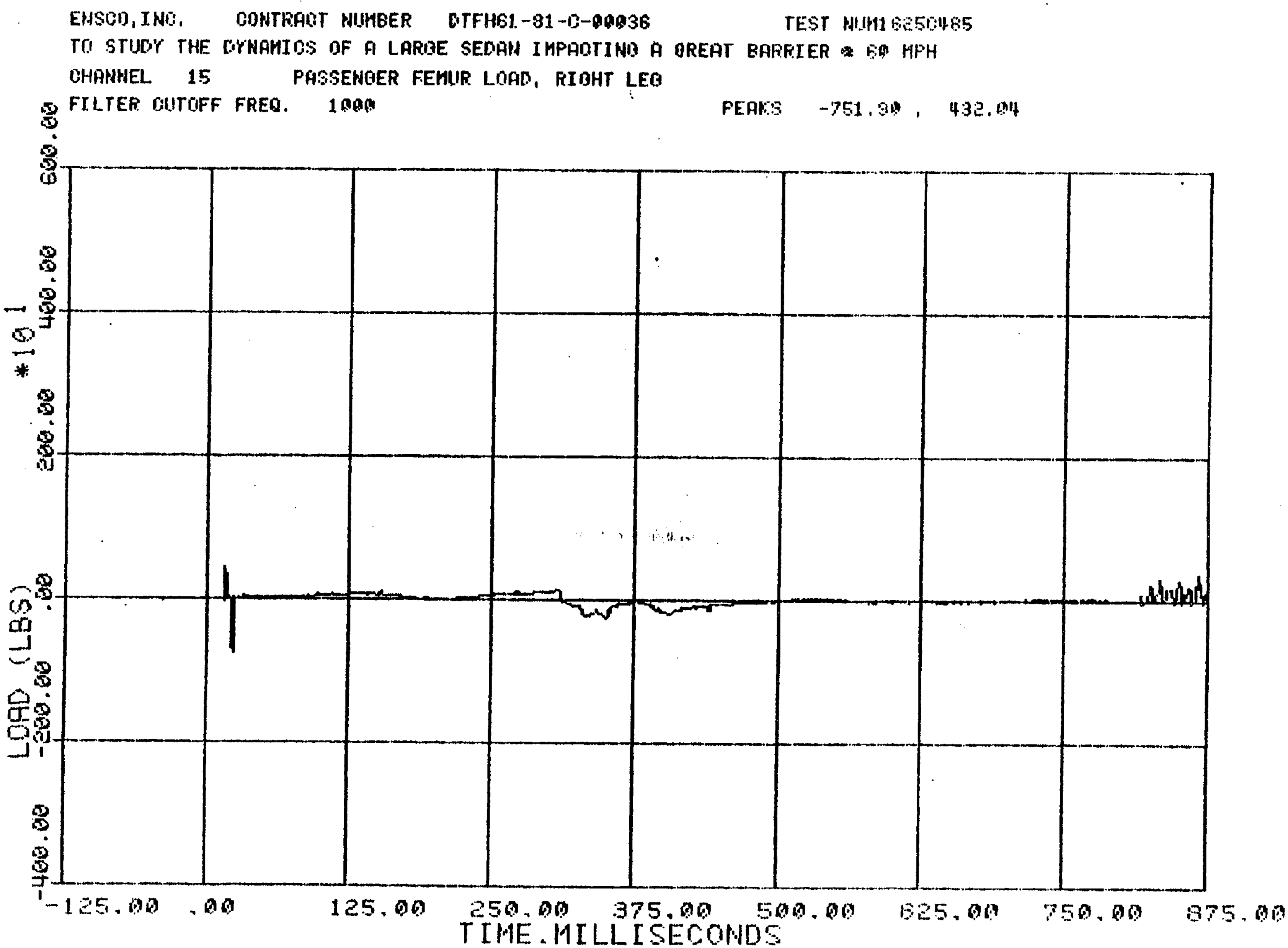
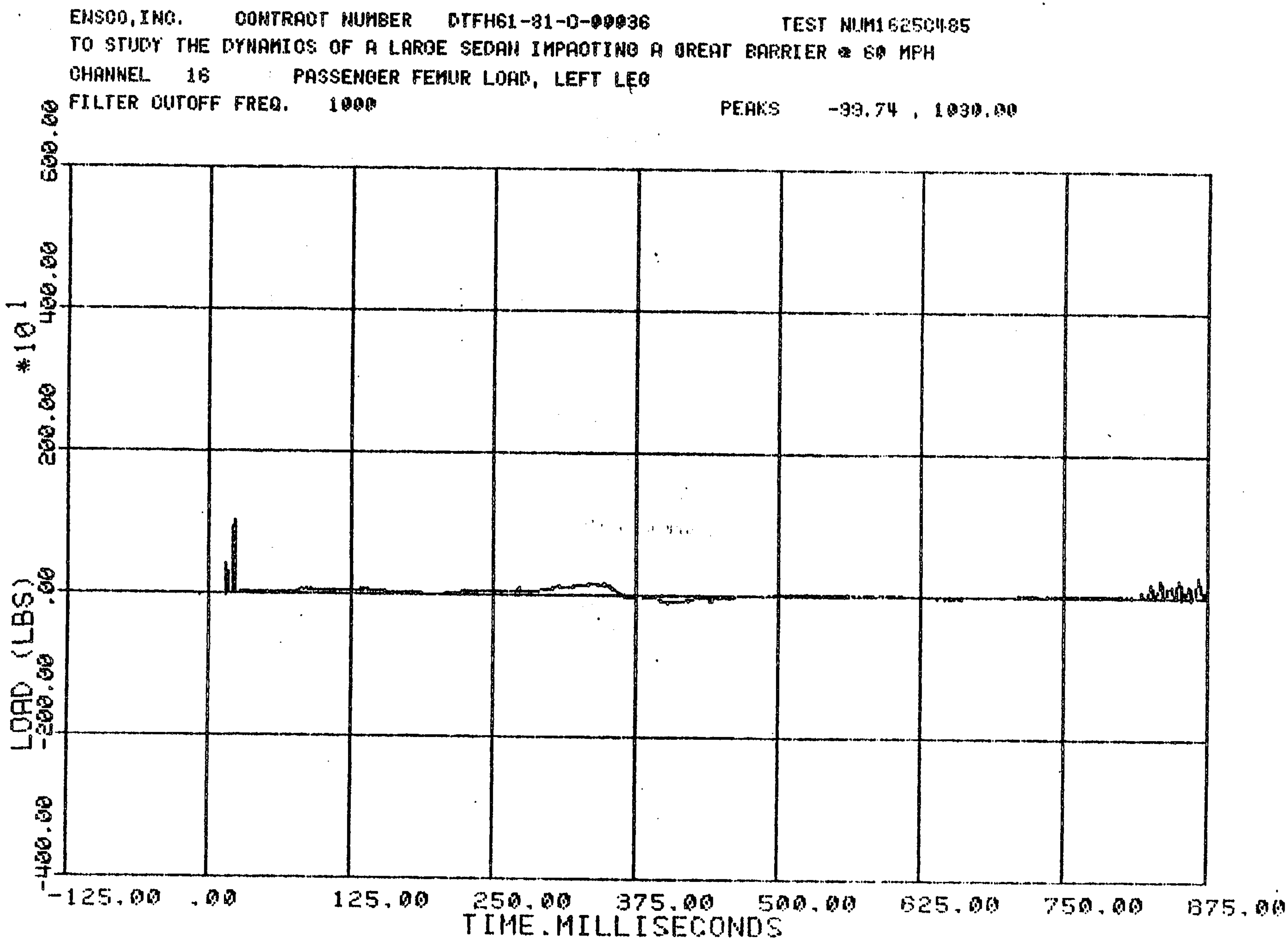

ENSCO,INC. CONTRACT NUMBER DTFH61-81-C-00036 TEST NUM16250485
TO STUDY THE DYNAMICS OF A LARGE SEDAN IMPACTING A GREAT BARRIER @ 60 MPH
CHANNEL 15 PASSENGER FEMUR LOAD, RIGHT LEG
FILTER CUTOFF FREQ. 1000 PEAKS -751.90 , 432.04
600.00
400.00
200.00
.00
-200.00
-400.00
*10 1
LOAD (LBS)
-125.00
.00
125.00
250.00
375.00
500.00
625.00
750.00
875.00
TIME.MILLISECONDS

Figure 4-29



ENSCO, INC. CONTRACT NUMBER DTFH61-81-C-00036 TEST NUM1625C485
TO STUDY THE DYNAMICS OF A LARGE SEDAN IMPACTING A GREAT BARRIER @ 60 MPH
CHANNEL 16 PASSENGER FEMUR LOAD, LEFT LEG
FILTER CUTOFF FREQ. 1000
PEAKS -93.74 , 1030.00
600.00
400.00
200.00
.00
-200.00
-400.00
*10 1
LOAD (LBS)
-125.00
.00
125.00
250.00
375.00
500.00
625.00
750.00
875.00
TIME.MILLISECONDS

Figure 4-30.

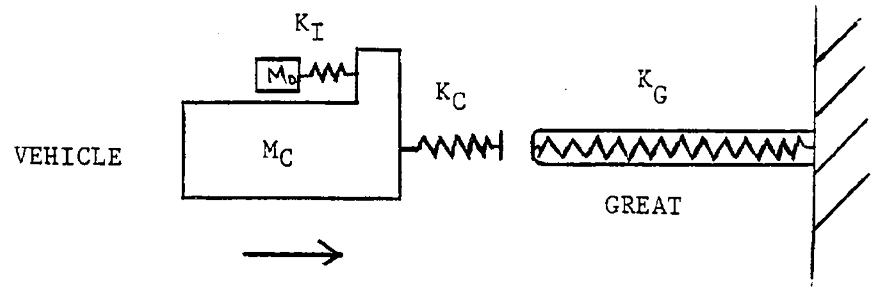


Figure 4-31. Schematic of Vehicle/GREAT Interaction

The total kinetic energy delivered by the vehicle and the dummy is 538.3 kip-ft (495.6 + 42.7). It is felt that at least 50% of driver energy is absorbed in the vehicle when the dummy shatters the windshield, crushes the steering column, and bounces in the occupant compartment. The total KE of the vehicle and the portion of the driver and passenger is: 495.6 + (42.7)(.75) = 527.6 kip-ft.

This kinetic energy of the vehicle and dummy will be absorbed by the crush of GREAT system and partially by the crush of the vehicle. To estimate the force vs deflection and total energy absorbed by the GREAT, two approximations are used. These are discussed below.

1. The first approximation uses the ratio of the vehicle crush to the GREAT crush. The energy aborbed by the GREAT system and the vehicle can be estimated using the longitudinal accelerometer mounted at the vehicle center of gravity (c.g.). The force (F) of the vehicle was calculated by the formula of F=ma where m is the vehicle plus dummy mass and a is the longitudinal acceleration. Double integration of the longitudinal acceleration

measurements produced displacements corresponding to specific acceleration levels. As shown in Figure 4-32 a force vs displacement curve was generated over the stopping distance of the vehicle c.g., representing vehicle and GREAT crush together. Integration of Figure 4-32 produced the total energy of the system equal to 531 kip-ft as shown in Figure 4-33.

Visual observation of the overhead movie film indicated that the frontal crush of the vehicle was 2.2 feet. Thus, the crush of the GREAT equals 18.8 - 2.2 = 16.6 feet. A first order estimate of the energy of the GREAT is the total energy of the system times the ratio of GREAT Crush/Vehicle c.g. Stopping Distance, as shown below.

$$\text{GREAT ENERGY ABSORBED} = 527.6 \text{ kip-ft} \times \frac{16.6}{18.8} = 465.9 \text{ kip-ft}$$

The energy absorbed by the vehicle is 527.6 - 465.9 = 61.7 kip-ft.

To estimate the force vs displacement of the GREAT the displacement axis of Figure 4-32 was scaled down in a linear fashion by the ratio of 16.6/18.8 or 88.3%. Figure 4-34 shows the force vs displacement curve of the GREAT using this simple approximation. It is felt that Figure 4-34 is only an approximation because it assumes that vehicle crush occurs in a linear fashion over the entire crush region of the GREAT.

A second approximation method is discussed in the following pages which produces a different technique for GREAT analysis.

2. The second approximation method assumes that vehicle crush is completed at the maximum force level experienced by the vehicle c.g. accelerometer. Using Figure 4-32, the maximum force level of 243 kips occurs at 18.8 feet of c.g. displacement (full crush). Knowing that the vehicle front crushed 2.2 feet from movie films, the energy of the GREAT and vehicle can be

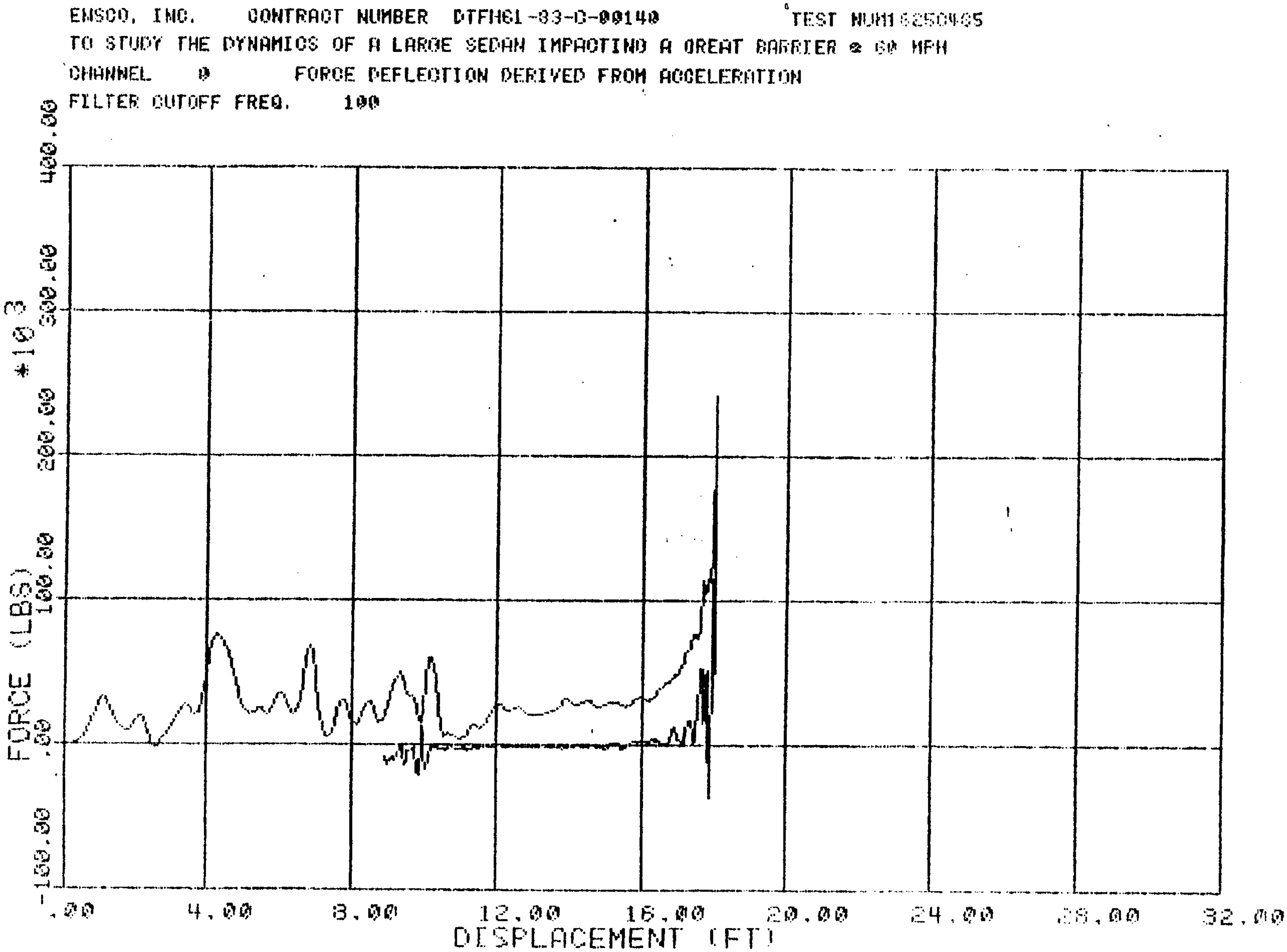

ENSCO, INC. CONTRACT NUMBER DTFH61-83-C-00140 TEST NUM
TO STUDY THE DYNAMICS OF A LARGE SEDAN IMPACTING A GREAT BARRIER @ 60 MPH
CHANNEL 0 FORCE DEFLECTION DERIVED FROM ACCELERATION
FILTER CUTOFF FREQ. 100
400.00
300.00
200.00
100.00
.00
-100.00
*10 3
FORCE (LBS)
.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
DISPLACEMENT (FT)

Figure 4-32

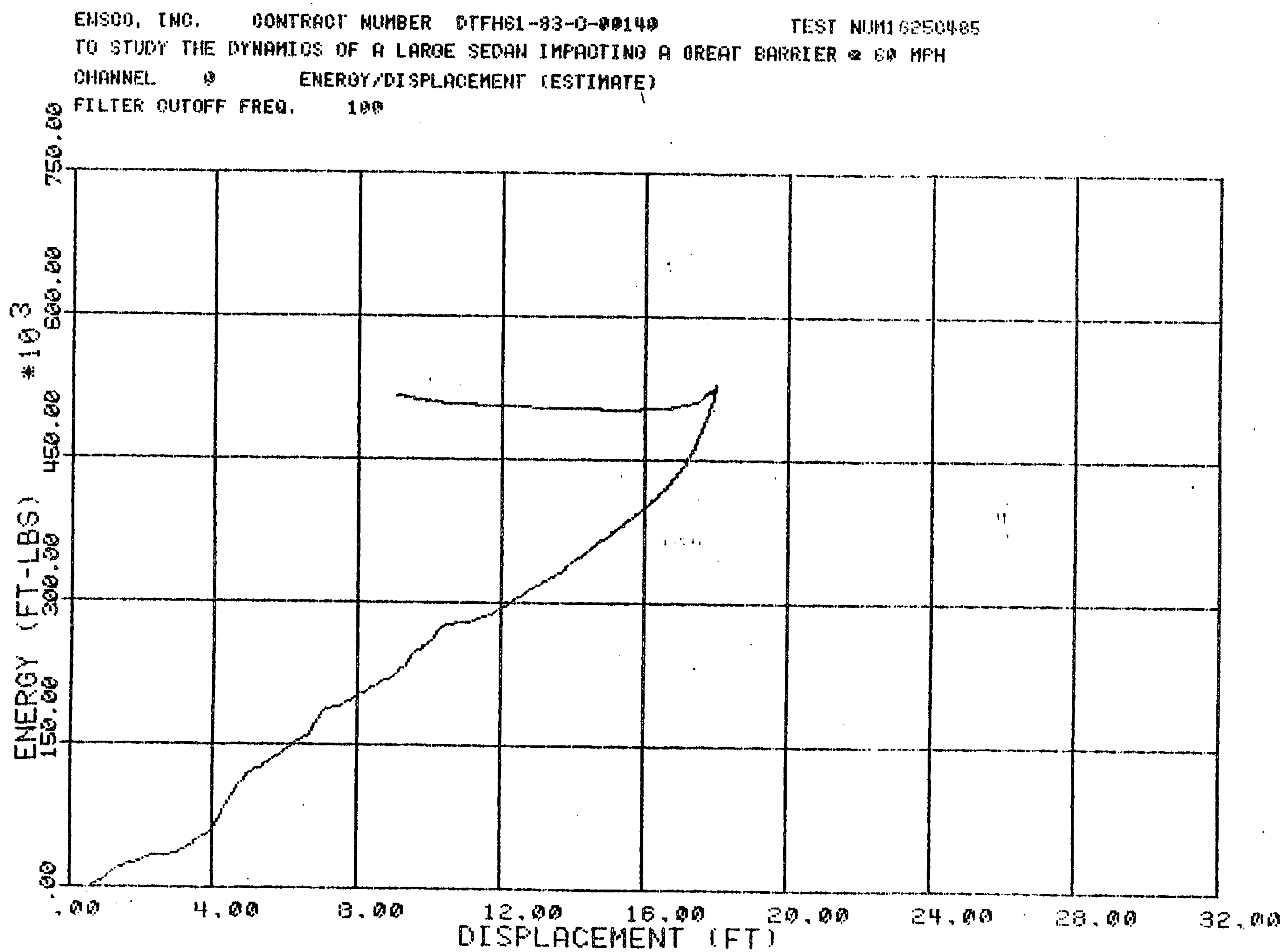

ENSCO, INC.   CONTRACT NUMBER DTFH61-83-C-00140   TEST NUM16250485
TO STUDY THE DYNAMICS OF A LARGE SEDAN IMPACTING A GREAT BARRIER @ 60 MPH
CHANNEL 0   ENERGY/DISPLACEMENT (ESTIMATE)
FILTER CUTOFF FREQ. 100
ENERGY (FT-LBS) *10 3
750.00
600.00
450.00
300.00
150.00
.00
.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
DISPLACEMENT (FT)

Figure 4-33.

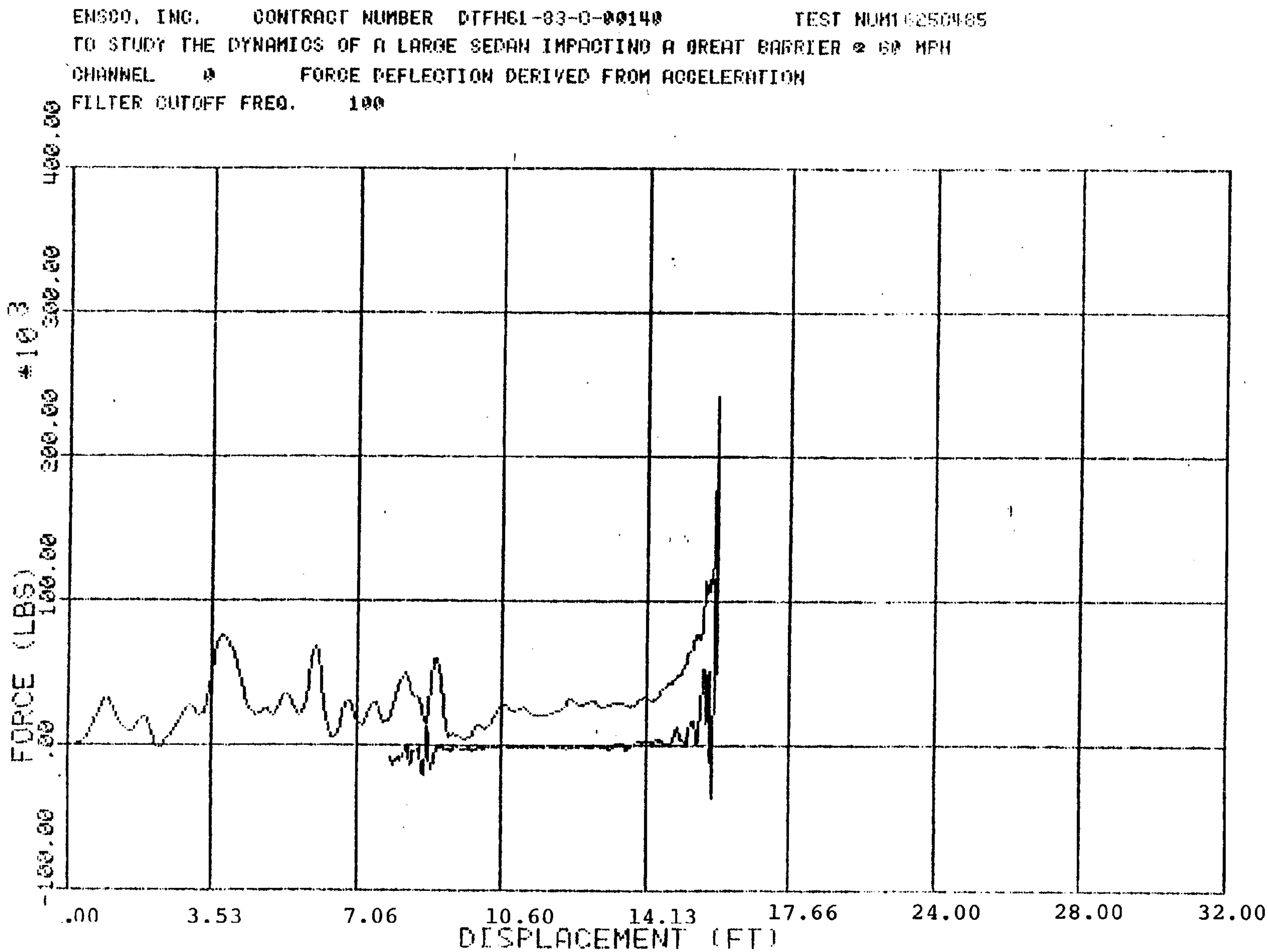

ENSCO, INC. CONTRACT NUMBER DTFH61-83-C-00140 TEST NUM1 6250485
TO STUDY THE DYNAMICS OF A LARGE SEDAN IMPACTING A GREAT BARRIER @ 60 MPH
CHANNEL 0 FORCE DEFLECTION DERIVED FROM ACCELERATION
FILTER CUTOFF FREQ. 100
400.00
300.00
200.00
100.00
.00
-100.00
FORCE (LBS)
*10 3
.00
3.53
7.06
10.60
14.13
17.66
24.00
28.00
32.00
DISPLACEMENT (FT)

Figure 4-34

estimated at the 18.8 foot displacement. The total energy absorbed at this point is 527.6 kip-ft.

The energy absorbed by the vehicle is 527.6 kip-ft x 2.2 ft/18.8 ft = 61.7 kips. Therefore, the energy absorbed by the GREAT system over the entire event is the total energy absorbed (527.6 kip-ft) minus the energy absorbed by the vehicle. This value equals 527.6 - 61.7 = 465.9 kip-ft.

Under this approximation method the deflection of the vehicle was 2.2 feet and the deflection of the GREAT was 16.6 feet at the maximum force of 243 kips. From Figure 4-32 it can be seen that the maximum force location is equivalent to the end of the displacement and therefore the end of the crush. Usually, a force vs. deflection plot is produced identical to Figure 4-32, with the displacement axis scaled about the maximum crush location. This is done using two different linear scales for the displacement.

However, when the maximum force occurs at the end of the displacement curve, only one linear scale can be used. In summary, methods 1 and 2 yield identical results for approximating the energies absorbed during the impact. This is due to the fact that the maximum force location is also the end of displacement.

4.4 NHTSA DATA TAPE

A digital magnetic tape containing the data from test 1625-C-04-85 is included with this report. The tape is formatted as specified in NHTSA document entitled "Dynamic Crash Test Information Reference Guide, Version II." Test specification and measurement data are provided on the tape in the following areas:

- General Test Information
- Vehicle Information
- Barrier Information
- Occupant Information
- Instrumentation Information

5.0 SAFETY IMPLICATIONS

The objective of this test was to investigate the impact behavior and post-impact stability of a large sedan (4500S) during a high speed (60 MPH) frontal impact with a 6 bay GREAT impact attenuator. The test results indicate a controlled arresting of the vehicle in 18.8 feet and rebounding of the vehicle at a speed of 7.9 mph. Little yawing and rolling but significant pitching of the vehicle were observed. The final resting position of the front of the vehicle was 16.3 feet in front of the CMB back up structure. The impact should be considered severe due to the very nature of stopping the vehicle from an initial speed of 60 mph in 18.8 feet.

Safety performance of the GREAT is evaluated according to the following three appraisal factors: structural adequacy, occupant risk, and vehicle trajectory. Occupant risk is divided into dummy assessment and vehicle simulated assessment. Criteria outlined in TRC 191, FMVSS 208, and NCHRP 230 will be used for the three appraisal factors, as appropriate. In TRC 191, a preferred limit and a permissable limit are specified while in NCHRP 230 a design value and a limit value are specified. For consistency of terms in this section, a design value and a limit value will be discussed for the lower and upper limits, respectively.

Table 5-1 outlines the safety evaluation parameters for test 1625-C-04-85. From a structural adequacy standpoint the GREAT performed very well. The GREAT remained intact; it provided predictable controlled penetration; and it provided minimal debris.

Occupant risk was appraised with mixed results. Using the instrumented dummy parameters the test was completely acceptable with all parameters below limits. Thus, the test article passed the criteria of FMVSS 208, however, using the vehicle data to

TABLE 5-1
SAFETY EVALUATION PARAMETERS

	Structural Adequacy	Occupant Risk		Vehicle Trajectory
		Dummy	Vehicle	
TRC 191	Very Good Predictable Con-trolled Penetration Remained Intact	Not Applicable	Failed Average Acceleration 50 mse Peak Accel-eration. Twice Limit Value	Acceptable Minimal Rebounding into Traffic Stream
FMVSS 208	Not Applicable	Acceptable All Parameters Below Acceptable Limits	Not Applicable	Not Applicable
NCHRP 230	Very Good It Remained Intact Minimal Debris	Not Applicable	Failed ΔV Below Design Values Ridedown Twice the the Limit Value	Acceptable Hazard Minimal rebounding into Traffic Lane Controllable Post Crash

simulate occupant risk the test article failed the criteria of NCHRP 230 because the ridedown accelerations were twice the limit value. (It should be noted that the ΔV's were below the limit values specified in that document.) Again using the vehicle data to simulate occupant risk, the article also fails TRC 191 due to the 50 msec average acceleration calculation. This was found to equal -24.1 g's which is more than double the limit value of 12 g's. The 50 msec average acceleration calculation was used in lieu of the average acceleration over the stopping distance due to the resulting nonuniform deceleration trace. Taking all appraisals into account, occupant risk is unacceptable.

Vehicle trajectory was rated acceptable, given the test conditions. The vehicle was controllable in the post crash state, and intrusion into the traffic lane was minimal. This statement should be qualified with the fact that the vehicle transmission was in neutral during the test thus allowing free travel of the vehicle. If the transmission was in gear the vehicle rebound may have been less.

6.0 REFERENCES

1. "Full Scale Crash Test Plan," Revision 1, ENSCO, Inc., FHWA Contract No. DTFH61-83-C-00190, 6 March 1984.

2. Letter of approval for test plan and vehicle selection for crash testing to be conducted under the first task of Contract No. DTFH61-C-00036, L. D. McCollum, Chief, Office of Contracts and Procurement, FHWA, HCP-41, October 1981.

3. G-R-E-A-T System Design Manual, Guardrail Energy Absorbing Terminal, Form No. EN 242-680.

4. The G-R-E-A-T System, The Idea Crash Cushion for Narrowsite Hazards, Form No. EN 363-383.

5. G-R-E-A-T System Maintenance Manual (including Hex-Foam and Hi-Dri units), Form No. EN 348-0583.

6. "Recommended Procedures for the Safety Performance Evaluation of Highway Appurtenances," National Cooperative Highway Research Program Report 230, March 1981.

7. "Recommended Procedures for Vehicle Crash Testing of Highway Appurtenances," Transportation Research Circular 191, February 1978.

8. "Occupant Crash Protection in Passenger Cars, Multipurpose Passenger Vehicles, Trucks and Buses," Code of Federal Regulations, Title 49, Transporation, Part 571, Motor Vehicle Safety Standard No. 208.

9. G-R-E-A-T System Design Manual Addendum, Hex-Foam, Form No. EN 303-781.

10. "Vehicle Damage Scale for Traffic Accident Investigators," Traffic Accident Data Project Technical Bulletin No. 1, National Safety Council, 1971.

11. "Collision Deformation Classification," Recommended Practice J224a, Society of Automotive Engineers, New York, February 1971.

12. "Human Tolerance To Impact Conditions As Related to Motor Vehicle Design," Information Report J885a, Society of Automotive Engineers, New York, December 1966.

13. G-R-E-A-T System Concrete Pad and Bolt Layout Detail for Tension Strut Backup, Drawing #27-46-09.

14. "Dynamic Crash Test Information Reference Guide," Version II, Automated Sciences Group, Inc., Silver Spring, Maryland, January 1, 1982.

15. "Instrumentation for Impact Tests," Recommended Practice J211b, Society of Automotive Engineers, New York, December 1974.

16. Crash Test Results of Hex-Foam Cartridges in G-R-E-A-T Attenuators, March 16, 1981.

17. Certification Tests of Hex-Foam Cartridges for G-R-E-A-T Attenuators, November 25, 1980.

18. Hex-Foam G-R-E-A-T System, Installation Manual, Form No. EN 332-782.