FHWA-84-04

FEDERAL HIGHWAY ADMINISTRATION CONTRACT
DTFH61-83-C-00140

IMPACT ATTENUATORS
A CURRENT ENGINEERING EVALUATION

Test Results Report for
Test #1625-B-01-84

Task B

Prepared for:

FEDERAL HIGHWAY ADMINISTRATION
Department of Transportation
400 Seventh Street, SW
Washington, D. C. 20590

28 December 1984

Prepared by:

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Applied Technology and Engineering Division
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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
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 Reserach 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 systems, a series of fourteen full scale crash tests (nine mini-compact sedan, five large sedan) are planned under FHWA contract DTFH61-83-C-00140. Three tests were conducted in the Summer of 1984 crashing a mini-compact sedan into a six-bay Guard Rail Energy Absorption Terminal (GREAT) system. Eleven tests are planned over the next six months using Energite III and Fitch barrel systems. This report provides the results on the first of the barrel tests. The test number as defined in the test plan approved by FHWA on 6 March 1984 is 1625-B-01-84. The objective of the test was to investigate the dynamics of a full-sized vehicle impacting a 15 barrel Energite III impact attenuator system. This test was the only planned test using gravel as the fill material. All other barrel tests will use sand as the fill material. A summary of the test conditions and results are provided in Table 1-1.

This report documents the Test Results for FHWA test 1625-B-01-84. 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 Energite III parameters. Safety implications are reviewed in Section 5.0.

TABLE 1-1

SUMMARY OF TEST CONDITIONS AND RESULTS - TEST 1625-B-01-84

Contract Number: DTFH61-83-C-00140 — Date: 21 September 1984
Test Vehicle: Ford LTD II (White) — Weather: Sunny, 80F

Energite III Configuration: 400#, 400#, 2-400#, 2-700#, 3-1400#, 3-1400#, 2-2100#

Back-up Structure: Imitation Gore with two CMB's anchored to concrete pad

1. Vehicle Weight:

	Test Inertial	Gross Static
Planned	4500 ± 200	4500 ± 300
Actual	4312	4621

2. Number of Occupants: Two

3. Occupants Model: Anthropomorphic Dummies, 50th% males, SN 189 and 186

4. Occupants Locations: Drivers Seat, Unrestrained; Passenger Seat, Unrestrained

5. Impact:

	Speed	Angle	Location
Planned	60 mph	0	Center of 1st barrel
Actual	58.8 mph	0	2" off Center

6. Rebound Data:

Speed:	Negligible
Angle:	Negligible
Distance:	2 feet

7. Total Speed Change: 89.6 ft/sec

8. Vehicle Damage Index, SAE J22Aa: 12FDEW2

9. NCHRP 230 Test Number: 50

10. Vehicle Analysis:

	Observed	Design Limit (Absolute)
ΔV, NCHRP 230:	-24.5 ft/sec	30.0 ft/sec
Ridedown Accel., NCHRP 230: (10 msec):	-15.4 g's	15.0 g's •
Avg Accel. over stopping distance, TRC 191:	-4.9	8.0 g's
Stopping distance:	23.5 ft	-

11. Occupant Analysis:

	Driver	Passenger	Design Limit
HIC	264.9	313.9	1000
CSI	329.0	218.1	1000
Max Chest Accel	81.9	47.7	60 g's
Right Femur Load	620.0	738.0	2250 lbs
Left Femur Load	625.0	525.0	2250 lbs

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. 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 sheves 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 APPURTENANCE

The test appurtenance was a 15-barrel configuration of Energite III impact attenuators positioned for a 0 degree impact angle. The selection of the configuration was based on the following requirements stated in the contract:

TEST SITE

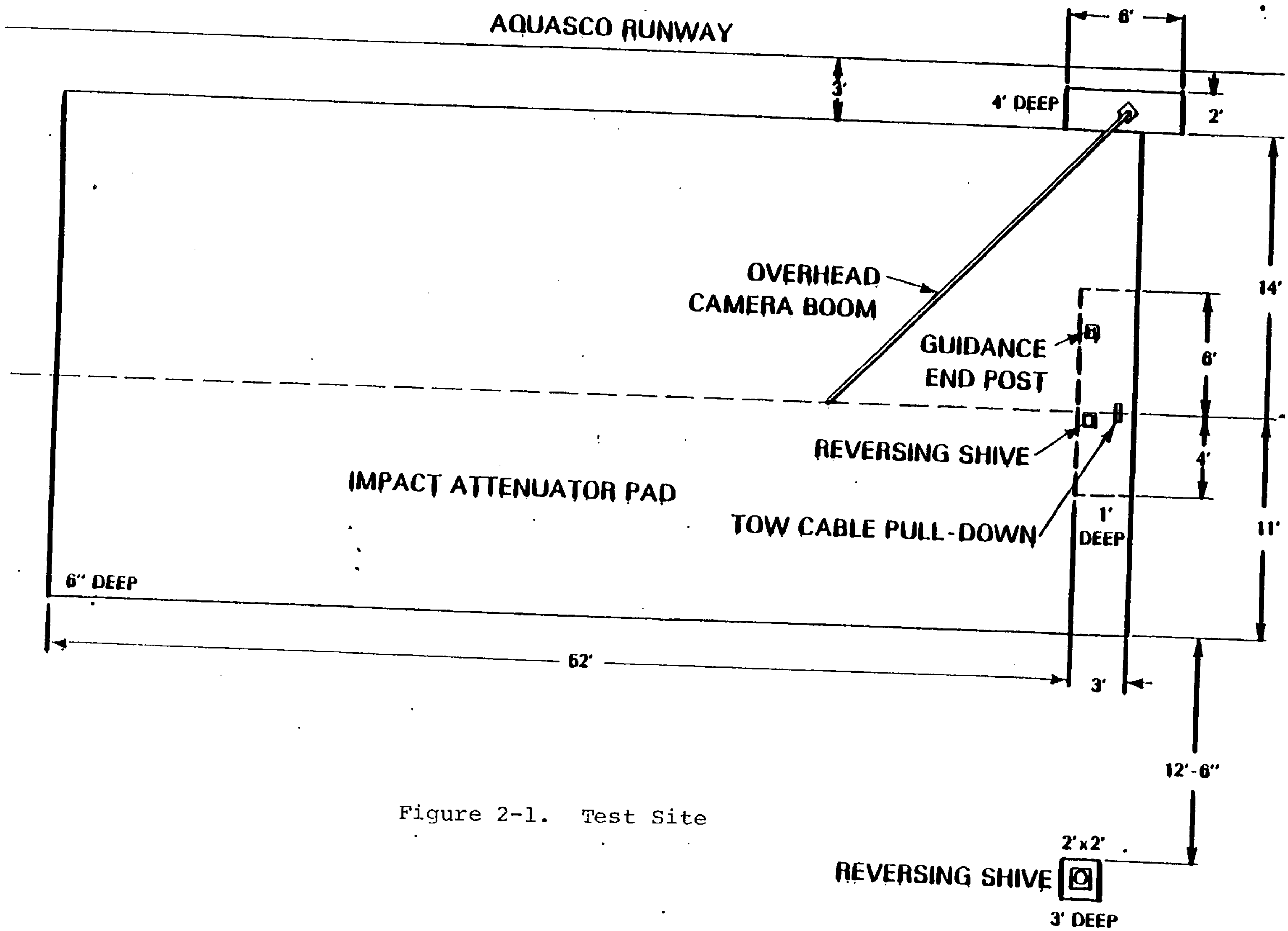


Figure 2-1. Test Site

- protect a five foot gore
- overlap of 30 inches of barrel on gore
- use of seven rows or less to minimize length of installation
- use of 2100 pound barrels in last row
- same configuration for all tests
- six inch longitudinal space between barrels

The methodology for arriving at the configuration consisted of discussions with Energy Absorption Systems (EAS), Inc. personnel and Roadside Safety Service, Inc. personnel, discussions with Jim Hatton and Marty Hargrave of FHWA, and the use of a computer program to predict expected behavior. Details of this information are well documented in the contract test plan.

Figure 2-2 provides the layout of the impact attenuators and the backup structure. Lateral spacing of the barrels was selected as 1.5 inches inches for rows 3,4, and 5; 3.0 inches for row 6; and 6 inches for row seven. This provides a flaring effect for the system. The seven row configuration provides for a 25.5 foot distance between the front of the first barrel and the gore.

A summary of the Energite III modules manufactured by Energy Absorption Systems is shown in Figure 2-3. As specified in the contract, pea gravel was used as the fill material for this test. Subsequent tests will use sand. It should be noted that the 2100 pound module (model 21) shown in the figures was not used. The tests incorporated the current model 21 barrel. This barrel is a current design by Energy Absorption Systems that is slightly conical in shape for ease in stacking. It is also 11 inches higher than the standard Energite III 2100 pound barrel.

The layout of the imitation gore and temporary CMB's backup structure is shown in Figure 2-4. To provide fixity each CMB was attached to the concrete pad using steel angle brackets. Three

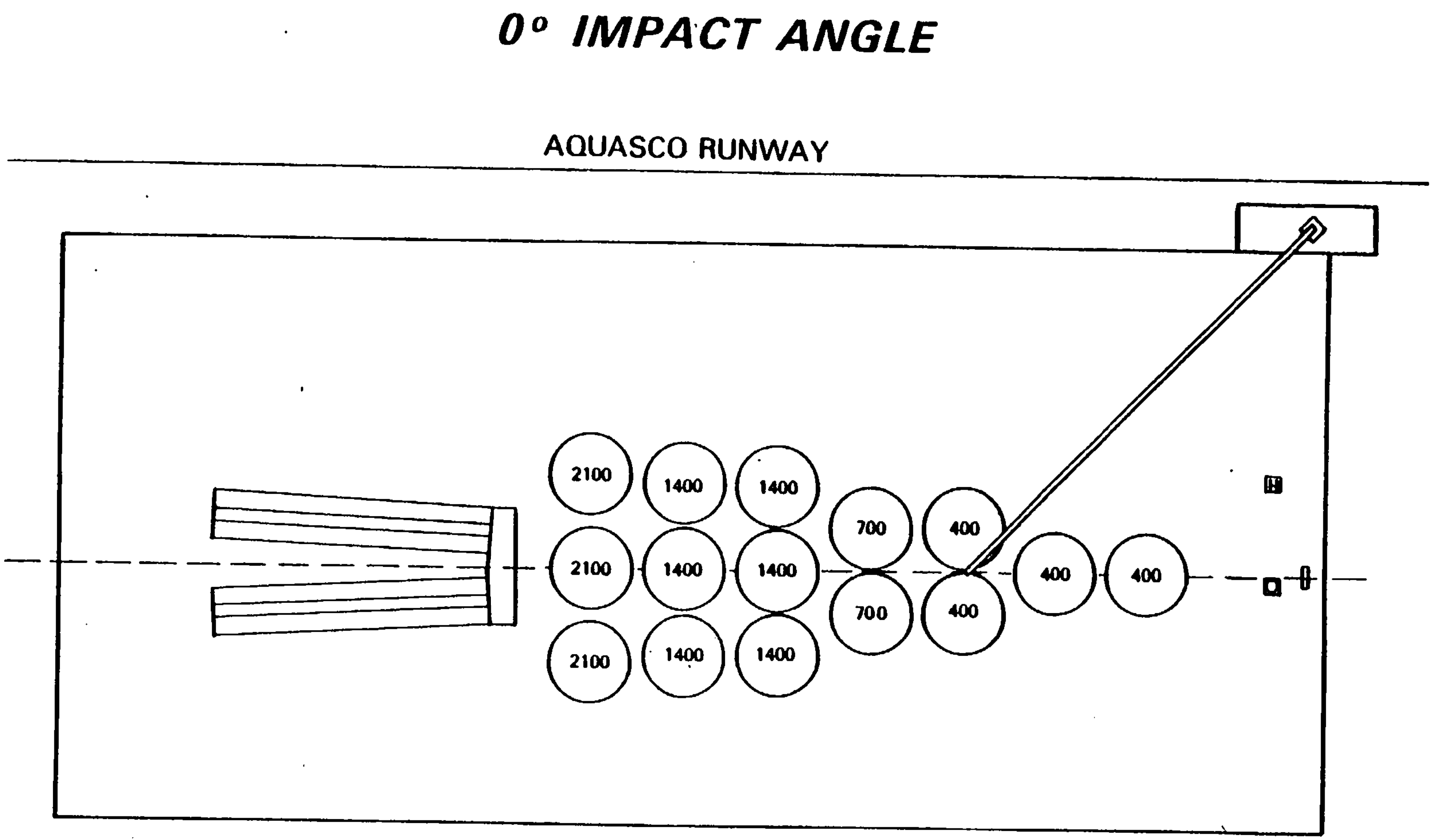
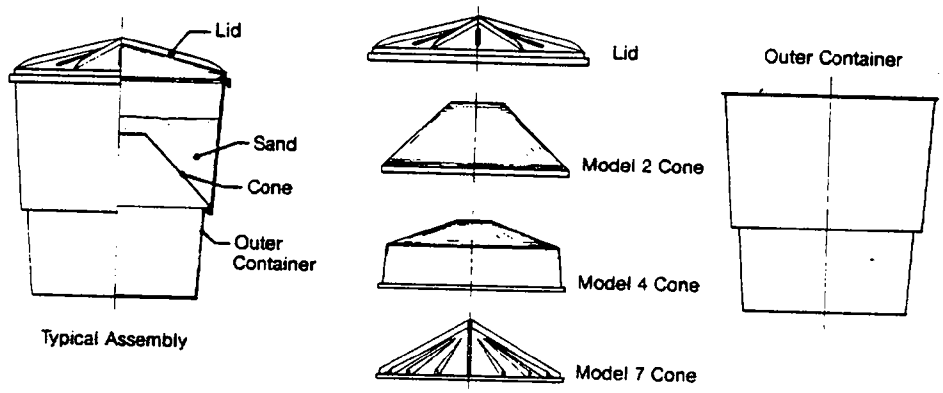


Figure 2-2. Inertial Attenuator, 0° Impact Angle

THE ENERGITE® III MODULE



APPLICATIONS:

- Wide hazards, such as "T" intersections.
- Fixed obstacles far off the highway.
- Overpass pillars in wide medians.
- Temporary hazard protection during construction or highway repair.

DESIGN ADVANTAGES:

- Installation is fast and economical.
- Only three complete parts per module—the outer container, the inner cone, and the lid.
- Exclusive inner cones come in three sizes, to contain from 200 to 1,400 pounds of sand, dependent upon the needs as determined by the engineer.
- Inner cones designed to insure that the center of gravity is at the proper elevation to discourage ramping.
- Ideal for temporary-site protection. Completely self-contained, enclosed modules are designed for durability even when mounted on skids and pallets. The solid-bottom design insures long-term stability.
- Simple module design assures constant effectiveness, even under severe vibration.
- Simple module design assures long-lasting resistance to the elements.
- Modules are nestable for easier storage of replacement parts.
- All parts come completely assembled.

ENERGY ABSORPTION SYSTEMS INC

Corporate Offices:
One East Wacker Drive, Chicago, IL 60601-2076
Telephone: 312/467-6750 • Telex: 253368
Engineering and Manufacturing Facility:
860 S. River Road, West Sacramento, CA 95691-2893
Telephone: 916/371-3900 • Telex 377332

SYSTEM CHARACTERISTICS:

Debris scatter	Sand and plastic parts scatter in direction of impact (50 feet or more)
Repair time for 3-man crew	4 hours
Equipment needed for repair	Pickup truck, sand truck, and front-end loader

SAND FILL VOLUMES

ENERGITE III MODULE DESIGNATION	ALLOWABLE VOLUME IN CU FT	REQUIRED FILL FOR FOLLOWING SAND UNIT WEIGHTS (in inches from top)		
		100 lbs	90 lbs	80 lbs
2	6.41	7.9	7.5	7.0
4	6.18	3.6	2.7	1.6
7	9.64	4.4	2.9	1.1
14	15.75	3.3	0	*
21	23.00	3.5	**	***

*80 pcf sand would require 17.5 cu ft, but only 15.75 cu ft available.
**90 pcf sand would require 23.3 cu ft, but only 23.0 cu ft available.
***80 pcf sand would require 26.3 cu ft, but only 23.0 cu ft available.

ENERGITE® III DIMENSIONS:

Outer container height	36"
Outer container width at top	36"
Outer container width at bottom	27½"
Model 21 width at top and bottom	36"

Form No. EN 310-882

Printed in U.S.A.

Figure 2-3. Summary of Energite III Modules

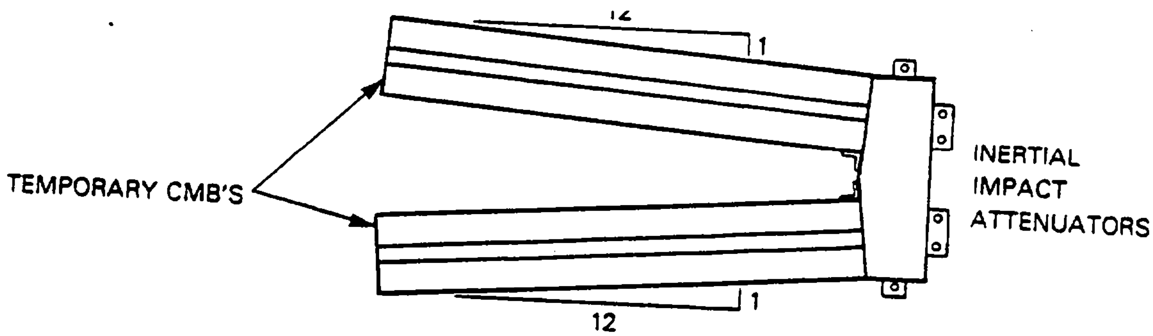


Figure 2-4 Imitation Gore Site

brackets were positioned uniformly on each side of each CMB on four foot centers from the longitudinal center. The brackets are based on the State of Maryland design shown in Figure 2-5. A bracket was used at the back end of the CMB's to provide additional fixity, as shown in Figure 2-6. The fasteners used to hold the CMB's to the concrete pad were 3/4" Hilti expansion Anchors.

Figures 2-7 and 2-8 show pre-test photographs of the Energite III barrel system. These barrels were provided free of charge to FHWA for research purposes. The barrels were new and installation was achieved without difficulty in an eight-hour period with a three man crew. Most of this time was spent in loading the pea gravel into the barrels. A crane was used to position the imitation gore and the two temporary CMB's.

2.3 TEST VEHICLE

The test vehicle was a white 1979 Ford LTD II, (see Figure 2-9 and 2-10) corresponding to the NCHRP 230 classification of 4500S. The initial weight of the vehicle was 3915 pounds. The vehicle was prepared for testing by removing the gas tank, battery and back seat. The weight of the vehicle after incorporating the instrumentation and 380 pounds of ballast was 4312 pounds. The weight distributions of the vehicle with and without occupants are given in Tables 2-1 and 2-2.

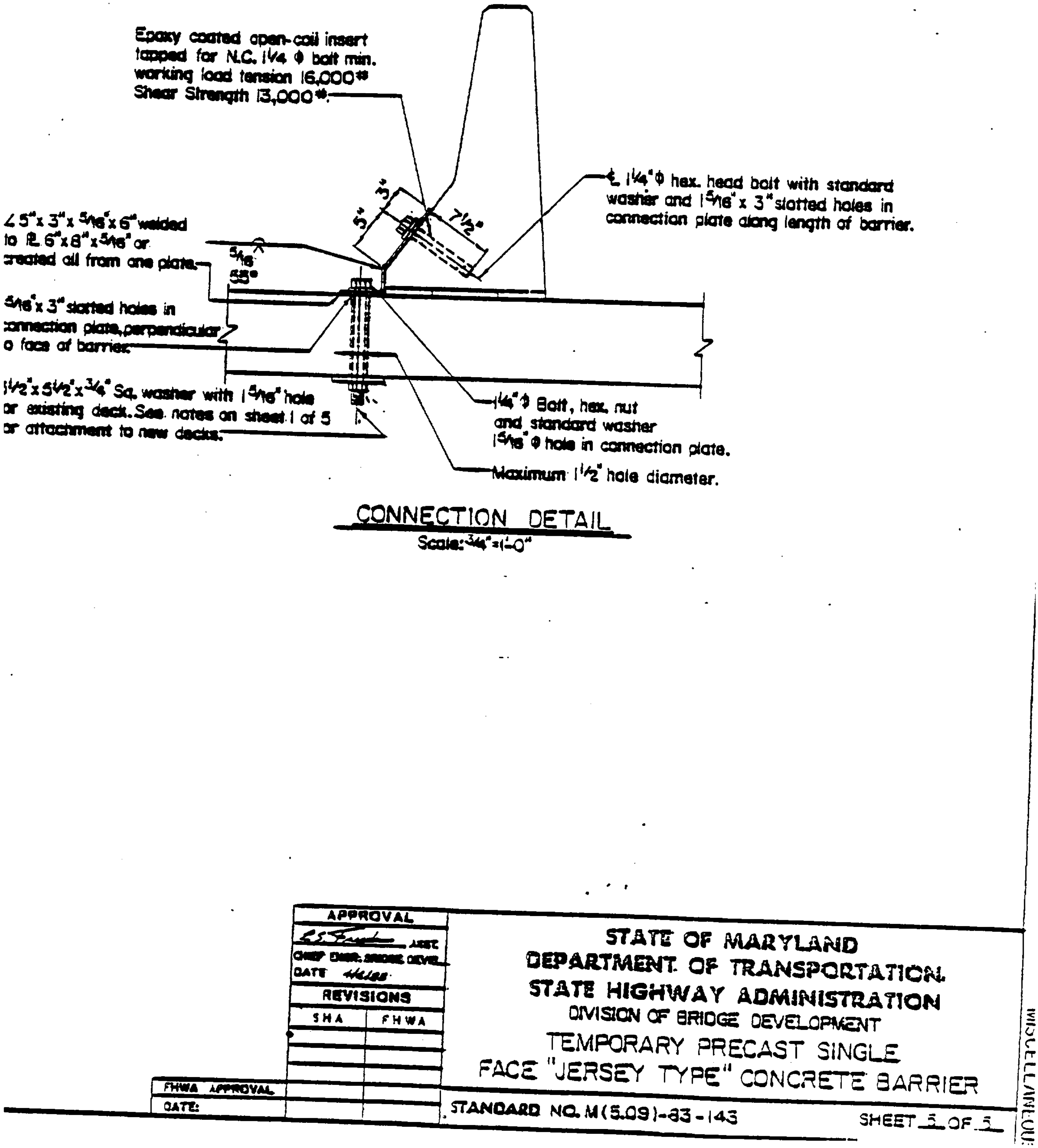


Figure 2-5. CMB Fasteners

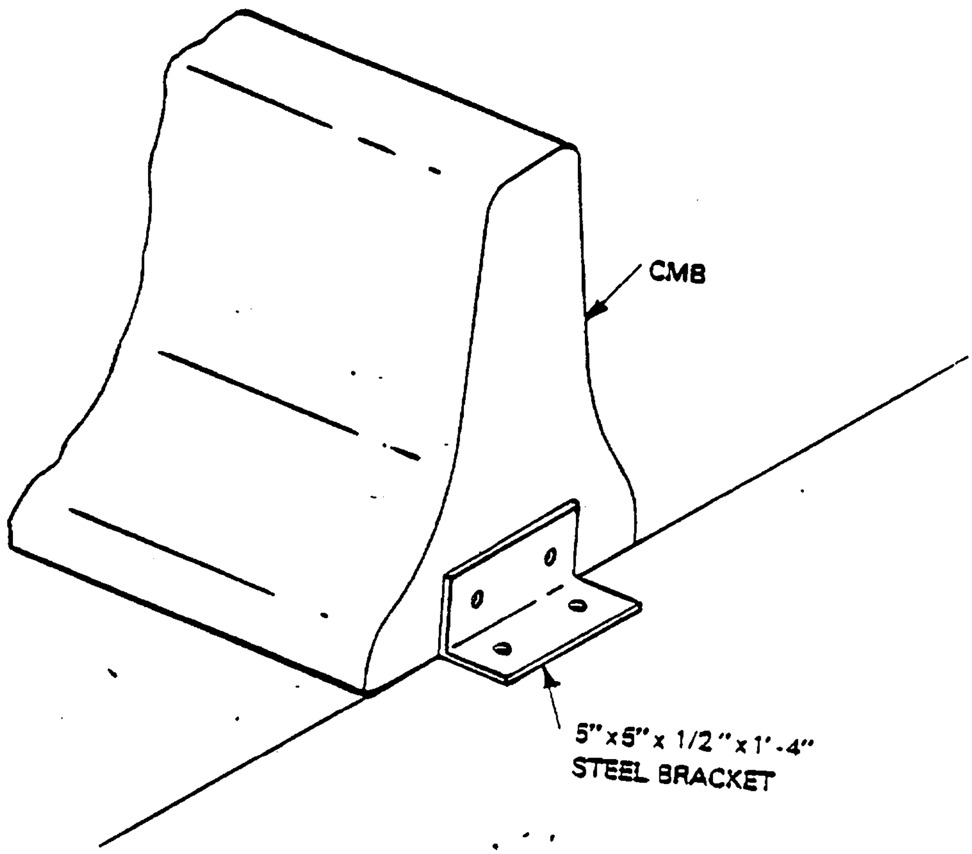


Figure 2-6. CMB End Bracket

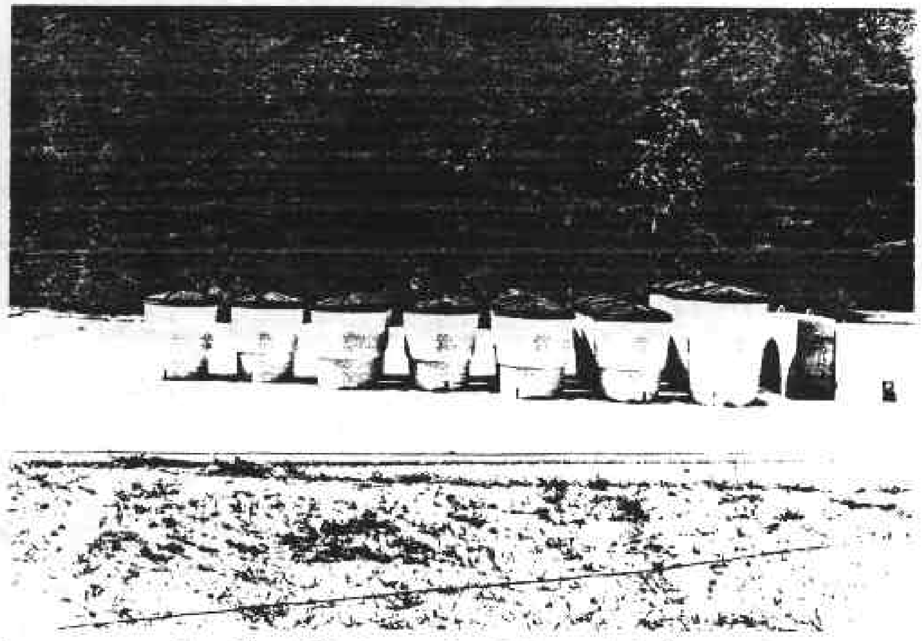


Figure 2-7 Pre-Test Photograph of Inertial Impact Attenuator, Side View

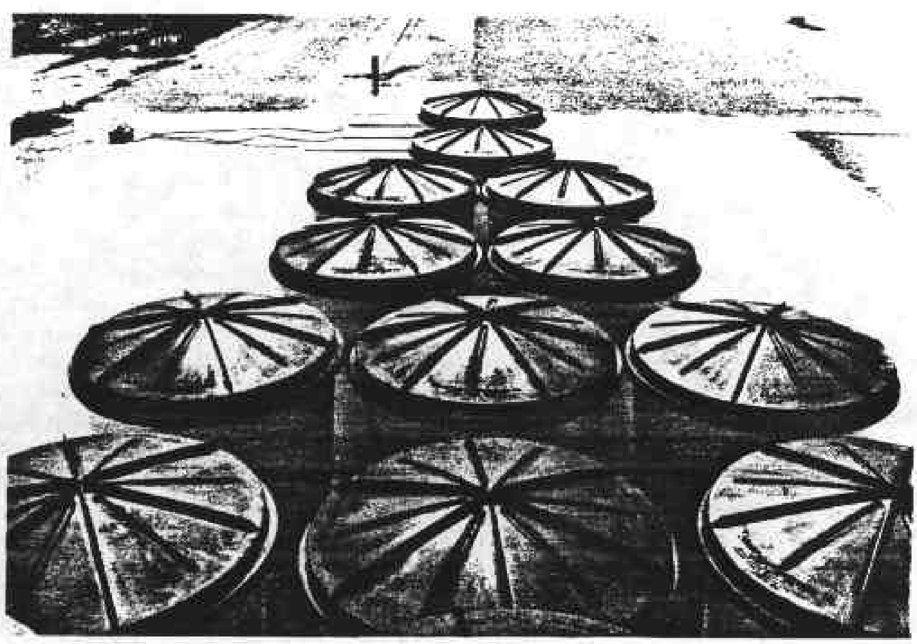


Figure 2-8 Pre-Test Photograph of Inertial Impact Attenuator, Top View

Figure 2-9 Pre-Test Photograph of Test Vehicle, Side View

Figure 2-10 Pre-Test Photograph of Test Vehicle, Rear View

TABLE 2-1

Weight Distribution of Test Vehicle Without Occupants

	Left (lbs)	Right (lbs)	Total (lbs)	% of Total
Front	1240	1159	2399	55.6
Rear	918	995	1913	44.4
Total	2158	2154	4312	100.0

TABLE 2-2

Weight Distribution of Test Vehicle With Occupants

	Left (lbs)	Right (lbs)	Total (lbs)	% of Total
Front	1248	1284	2532	54.8
Rear	1030	1059	2089	45.2
Total	2278	2343	4621	100.0

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. The vehicle was also equipped with contact switches mounted on the front bumper to mark the impact on the analog tape recorder and to trigger strobe flashes for movie film analysis.

2.4 INSTRUMENTED DUMMIES

Two part 572 instrumented dummies were used in the test for simulating and measuring occupant dynamics. Dummy 13 (serial #189) occupied the driver's position in the vehicle, unrestrained, and dummy 12 (Serial #186) occupied the passenger seat in the vehicle, unrestrained. The instrumentation located in each dummy consisted of three linear accelerometers in the head, three linear accelerometers in the chest,and two femur load cells. The dummies were calibrated prior to testing and the results are given in Appendix A.

2.5 DATA ACQUISITION SYSTEM

The major components of the data acquisition system (DAS) 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 2-11 shows a schematic of the Data Acquisition System.

The multiplexed data and the 32 KHz control signal were recorded in direct mode with a bandpass of 300HZ 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. It should be noted that the DAS was not installed in the stationary equipment trailer as is usually the case. Since the umbilical cable was too short for a high speed large sedan test, the DAS was installed on a van owned by ENSCO. The van was positioned approximately 30 feet east of the Aquasco runway and approximately 50 feet south of the impact attenuator pad.

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

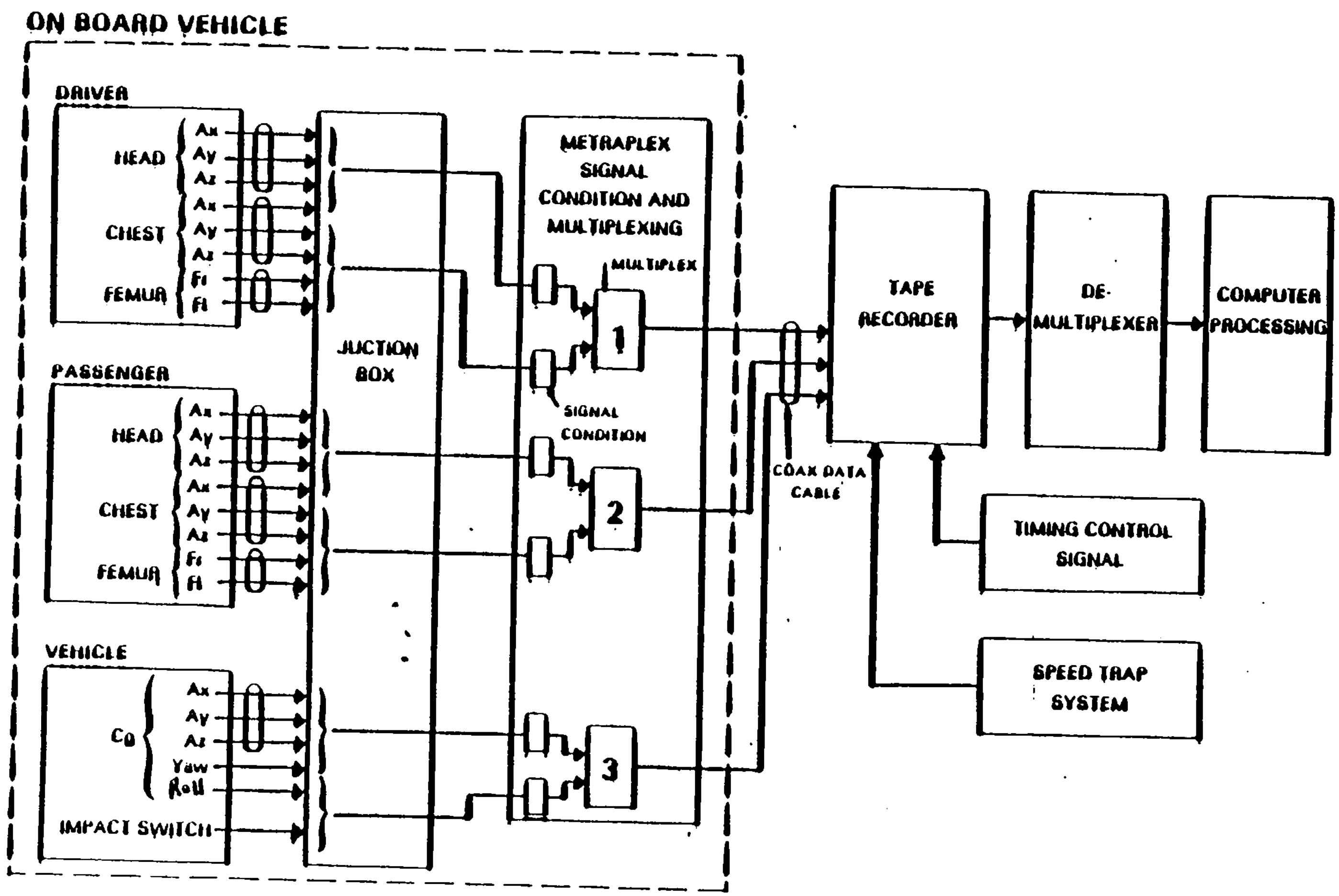


Figure 2-11. Schematic of Data Acquisition System

TABLE 2-3

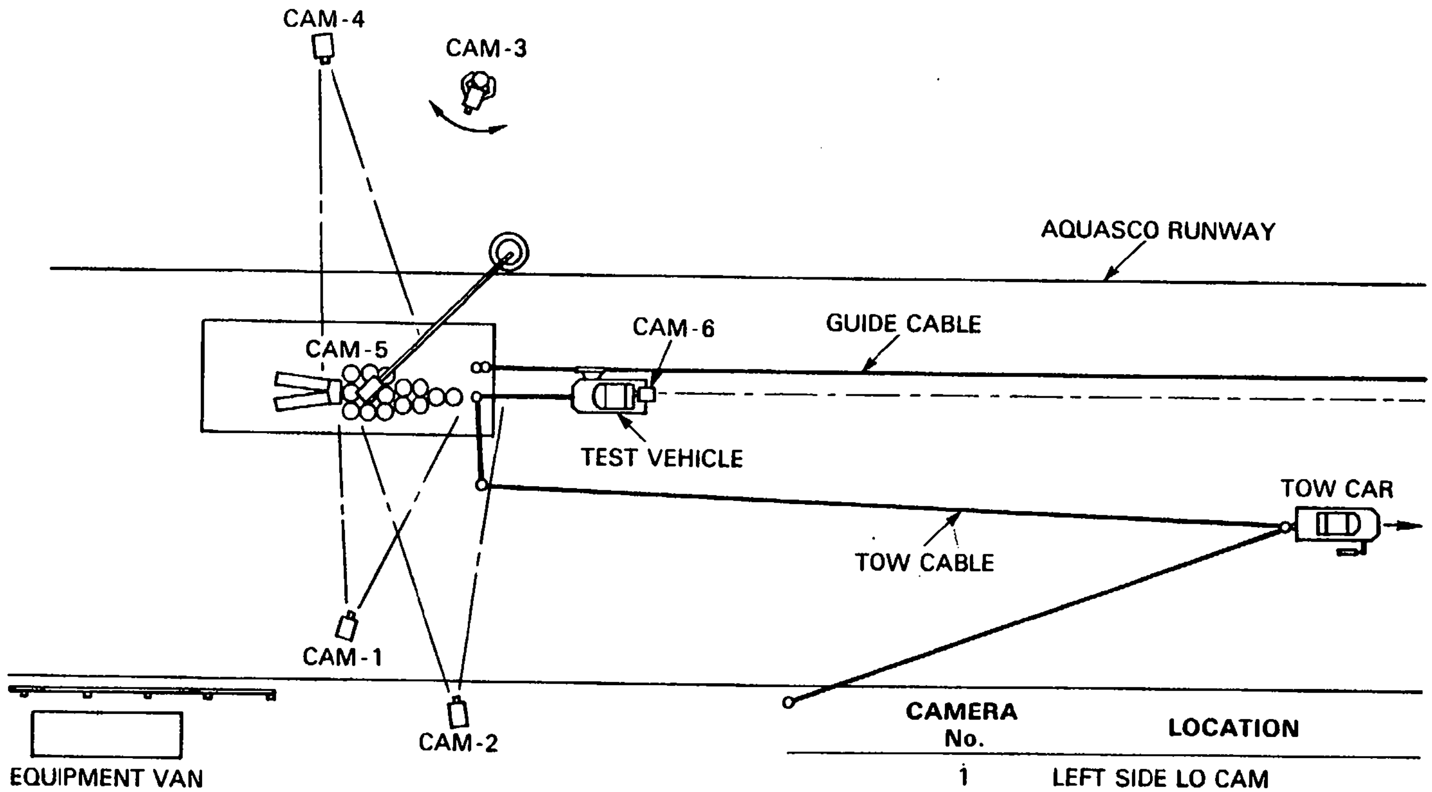
TRANSDUCER DATA CHANNEL DESCRIPTION

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	D Head X	ENDEVCO 2264-2000	32 kHz
10	2	D Head Y	ENDEVCO 2264-2000	48 kHz
11	2	D Head Z	ENDEVCO 2264-2000	64 kHz
12	2	D Chest X	ENDEVCO 7231C-750	80 kHz
13	2	D Chest Y	ENDEVCO 7231C-750	96 kHz
14	2	D Chest Z	ENDEVCO 7231C-750	112 kHz
15	2	D Femur R	GSF 2430	128 kHz
16	2	D 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 R51	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

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.

2.6 PHOTOGRAPHY

Photographic coverage was provided by five high speed (500 frames per second) and one real time (24 frames per second) 16mm cameras. The location of these cameras is shown in Figure 2-12. 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.



CAMERA No.	LOCATION
1	LEFT SIDE 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 2-12. 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 2 degree impact angle and at a speed of 58.8 mph. Close examination also indicated that the vehicle was approximately 1 to 2" off center (vehicle right) of the first barrel center. This is considered reasonable based on the expected accuracy of the vehicle guidance system.

The Energite III system is designed to provide controlled penetration of the vehicle into the impact attenuator system. From the movie films this mechanism was observed to consist of sequential disintegration of the first five barrel rows. The sixth row squeezed and ultimately ruptured while the seventh row was pushed back approximately three feet. The two outside barrels of the seventh row were reusable after the test. The stopping distance of the vehicle center of gravity was estimated to be 23.5 feet, including 0.5 feet of crush to the vehicle front. The total dynamic crush of the Energite III system was 22'-1". A vehicle rebound of 1' was observed.

During the impact the vehicle remained quite stable in the yaw, roll and pitch modes. The vehicle pitched forward approximately 4 degrees from the horizontal plane and the resting place of the vehicle was 4 degrees from the longitudinal vehicle direction. Barrel fragments and lids were thrown as high as 20 feet and as far as 100 feet. The pea gravel remained concentrated in a 36' x 47' teardrop shaped area starting from the first row of 1400# barrels. The fact that the pea gravel was thrown 13 feet to each side of the barrel system indicates that both lanes of traffic could have been affected in a highway system. The rolling/marble effect of pea gravel increases the potential for an additional accident since braking and vehicle handling are reduced. The vehicle trajectory path and time are shown in Figure 3-1. It should be noted that the hood disengaged by the second barrel, approximately 60 miliseconds after impact.

Since the onboard camera malfunctioned during the test, wayside cameras were used for dummy observation. It was observed that the two dummies impacted the dashboard/steering column twice during the crash. The final resting position of the driver was in an upright seated position while the passenger was leaned back with it's knees under the glove compartment. It appeared that neither dummy impacted the windshield.

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 and 3-3. Using the NHTSA vehicle damage measurements shown below in Figure 3-4, the following measurements were made:

1.	Penetration Distances (inches):	C1 - 1.0 C2 - 4.0 C3 - 6.0		C4 - 5.5 C5 - 4.0 C6 - 2.0
2.	Length of Damage (inches):			L = 79.0 L/2 = 39.5
3.	Distance Between Center of Damage Area and C. G. Axis (inches):			D = 0.0

Based on the Society of Automotive Engineers recommended practice J224a, "Collision Deformation Classification", the vehicle was rated 12FDEW2. It should be noted that the hood of the vehicle disengaged immediately upon impact with the second barrel and it raised to a vertical position by the fifth barrel row. Since it did not damage the vehicle windshield, this vehicle type is recommended for subsequent large sedan tests under this contract.

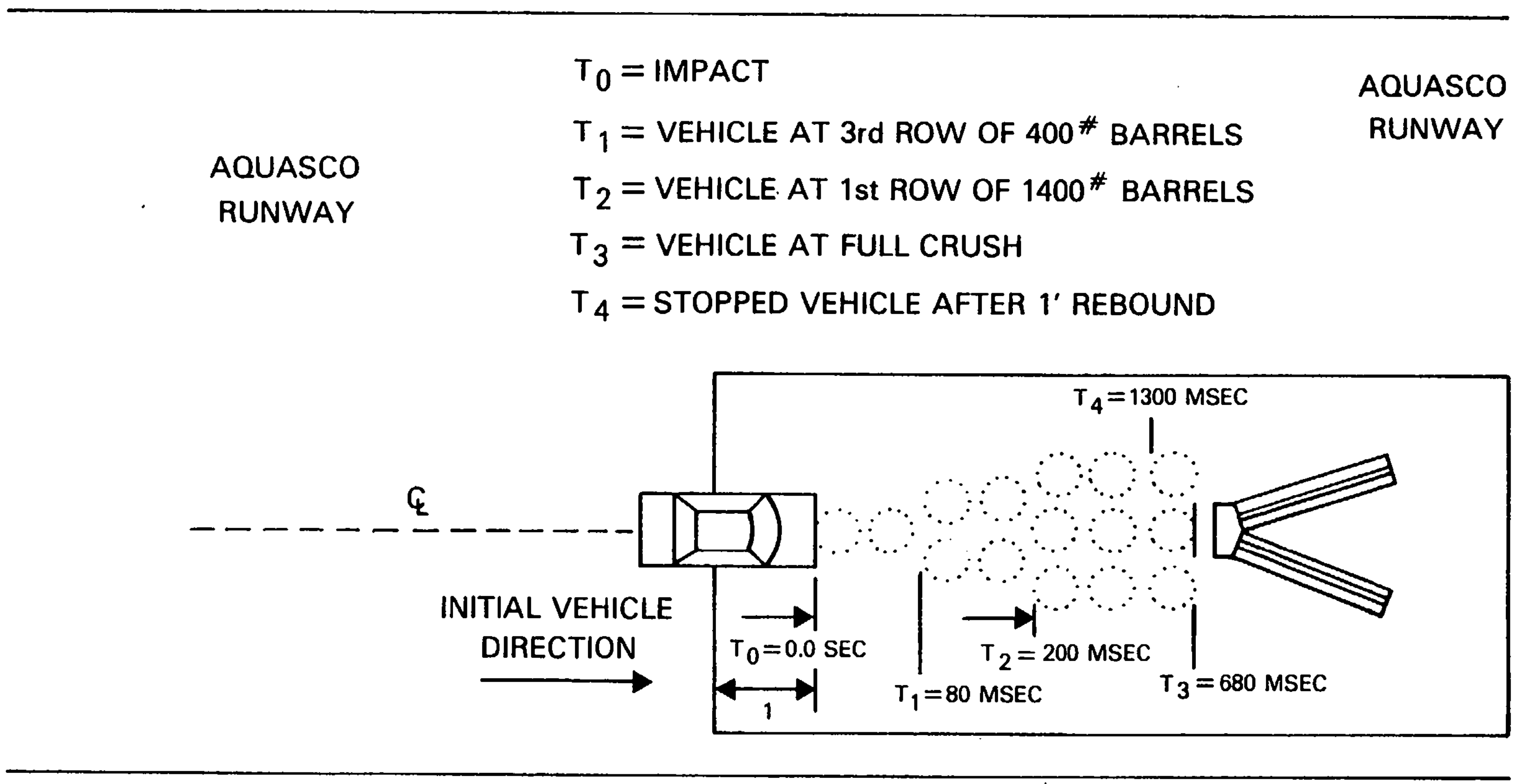


Figure 3.1. Vehicle Trajectory Path.

Figure 3-2 Post Test Photograph of Test Vehicle, Side View

Figure 3-3 Post Test Photograph of Test Vehicle, Inside View

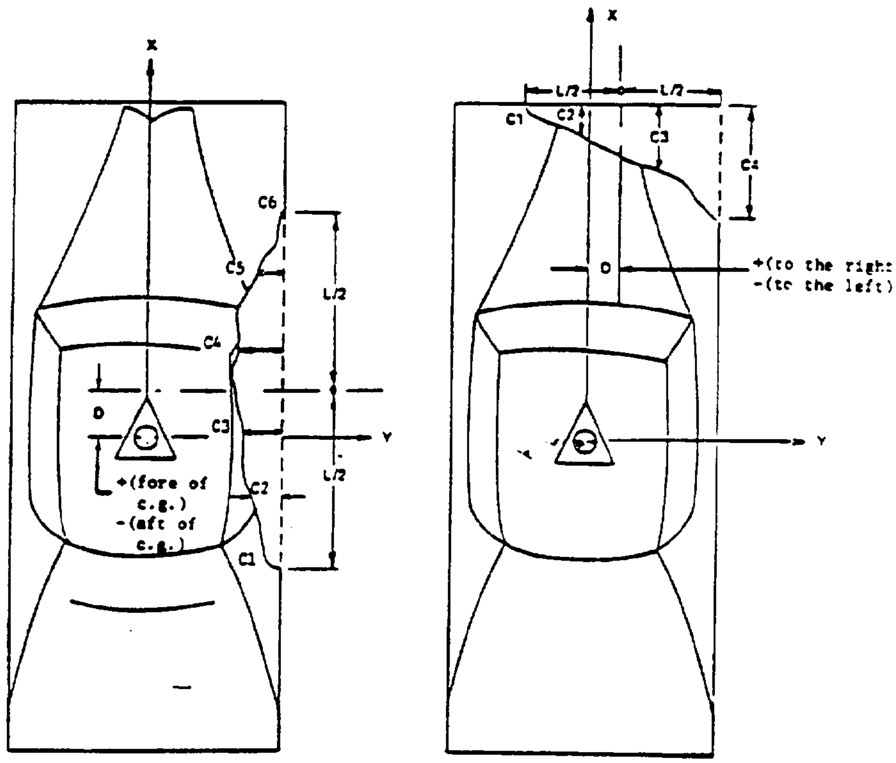


Figure 3-4. NHTSA Vehicle Damage Measurements

3.3 IMPACT ATTENUATOR DAMAGE/DEBRIS PATTERN

The Energite III system performed exactly as it was designed. Thirteen of the fifteen barrels were ruptured during the impact and pea gravel was thrown a considerable distance. As stated in Section 3.1, barrel fragments and lids were thrown as high as 20 feet and as far as 100 feet. Figures 3-5 and 3-6 are photographs

Figure 3-5 Post Test Photograph of Inertial Impact Attenuator, Side View

Figure 3-6 Post Test Photograph of Inertial Impact Attenuator, Rear View

of the Energite III system after the crash. The pea gravel remained concentrated in a 36' x 37' teardrop shaped area starting from the first row of 1400# barrels. Most of barrels fragments were logged between ~~the~~ vehicle front and the imitation gore face. Two 2100# barrels were left standing aproximately 3 feet away from their initial position.

3.4 PHOTOGRAPHY

The composite movie film of the test shows a panning view of the impact, an overhead view, and wayside coverage from both sides. The onboard camera malfunctioned during the test. The pre-test and post-test conditions of the vehicle and Energite III system are shown using the panning camera. Two copies of the composite film are provided with this test results report. The master will be retained by ENSCO until the completion of this contract.

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

4.0 DATA ANALYSIS

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

4.1 VEHICLE ANALYSIS

Vehicle analysis consisted of determining vehicle speed, 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, the fifth wheel mounted to the tow car, and the speed trap. The high-speed movie films were analyzed through the use of a Photo Optical Data Analyzer owned by ENSCO. The speed trap data was used by referencing the distance base of 24 inches located prior to the impact point to a crystal controlled 100 Hz time reference recorder during the test. Based upon this analysis, the impact speed of the vehicle was estimated to be 58.8 mph (86.3 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 89.6 ft/sec. This includes a rebound speed of approximately 2-3 ft/sec. Thus, the reported impact speed is considered an accurate estimate within 2%. 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 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

TABLE 4-1

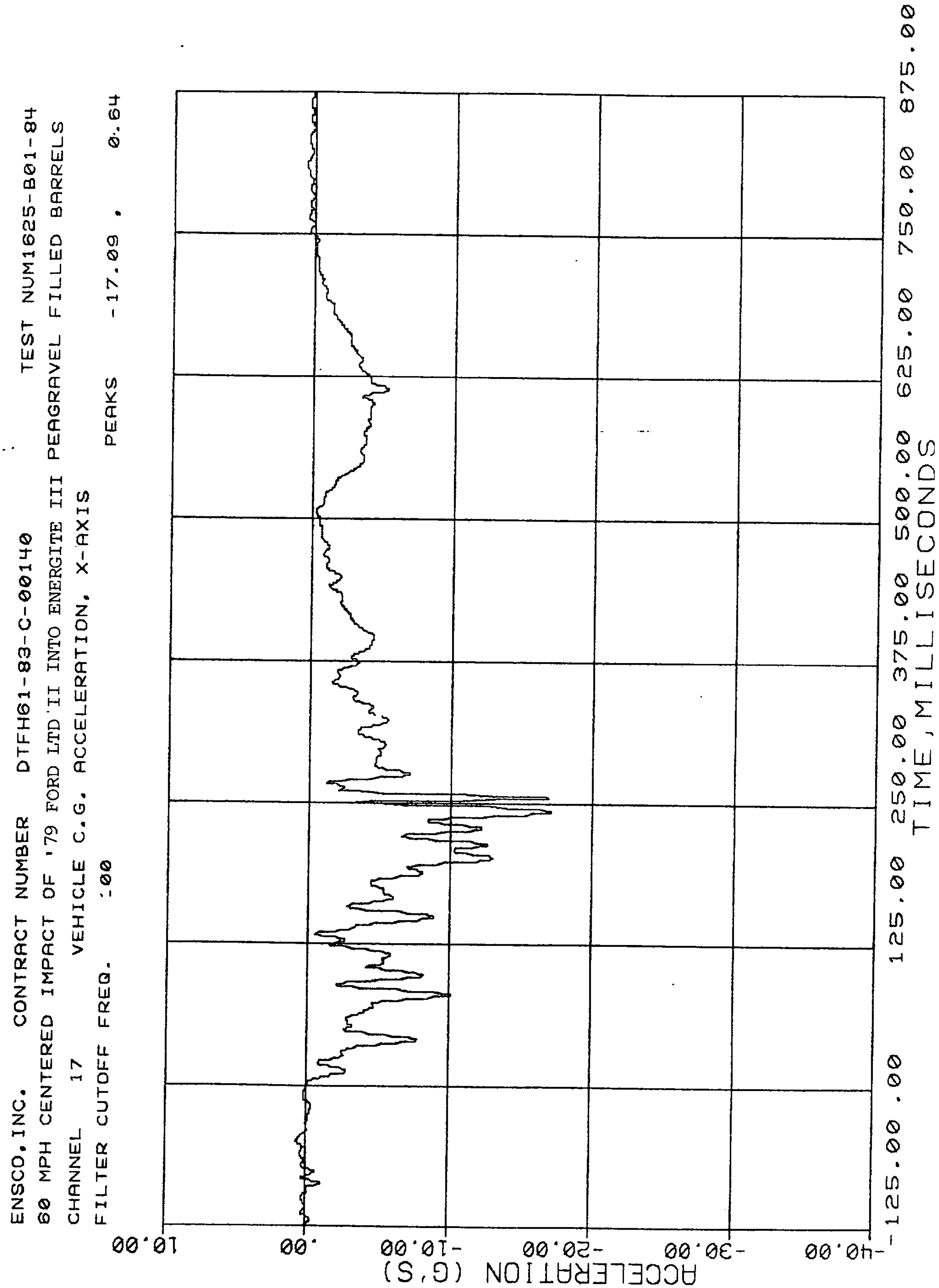
TEST VEHICLE SPEED RESULTS

	Impact Speed (mph)
Movie Film Average	58.8
Fifth Wheel	58.2
Speed Trap	59.5
Average	58.8

1 mph = 1.467 ft/sec

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 gyro's were filtered at SAE class 60. These angular rate measurements are shown in Figures 4-7 and 4-8. Figure 4-9 shows the impact marker. Please note that for all plots the vehicle/Energite III impact occurs at time 0.00.

Review of Figures 4-1 and 4-4 indicates a number of distinct areas of high deceleration: these are due to the sequential crushing of barrel rows. In order to summarize Figures 4-1 through 4-9, Table 4-2 presents the peak vehicle transducer measurements and times based on the SAE class 60 and 180 filters.



ENSCO, INC. CONTRACT NUMBER DTFH61-83-C-00140 TEST NUM1625-B01-84
60 MPH CENTERED IMPACT OF '79 FORD LTD II INTO ENERGITE III PEAGRAVEL FILLED BARRELS
CHANNEL 17 VEHICLE C.G. ACCELERATION, X-AXIS
FILTER CUTOFF FREQ. .00 PEAKS -17.09 , 0.64
ACCELERATION (G'S)
10.00
.00
-10.00
-20.00
-30.00
-40.00
TIME, MILLISECONDS
-125.00
.00
125.00
250.00
375.00
500.00
625.00
750.00
875.00

Figure 4-1.

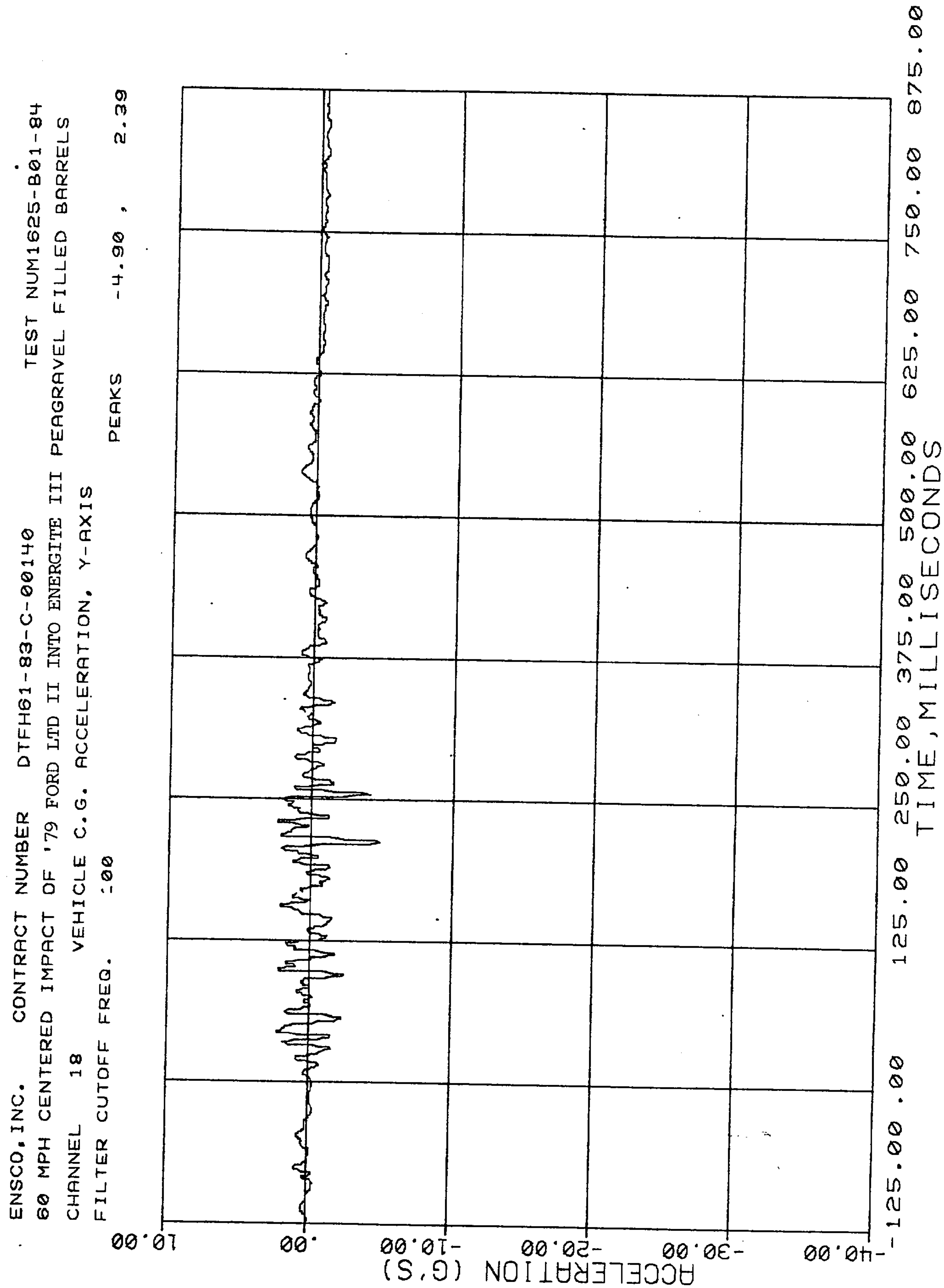
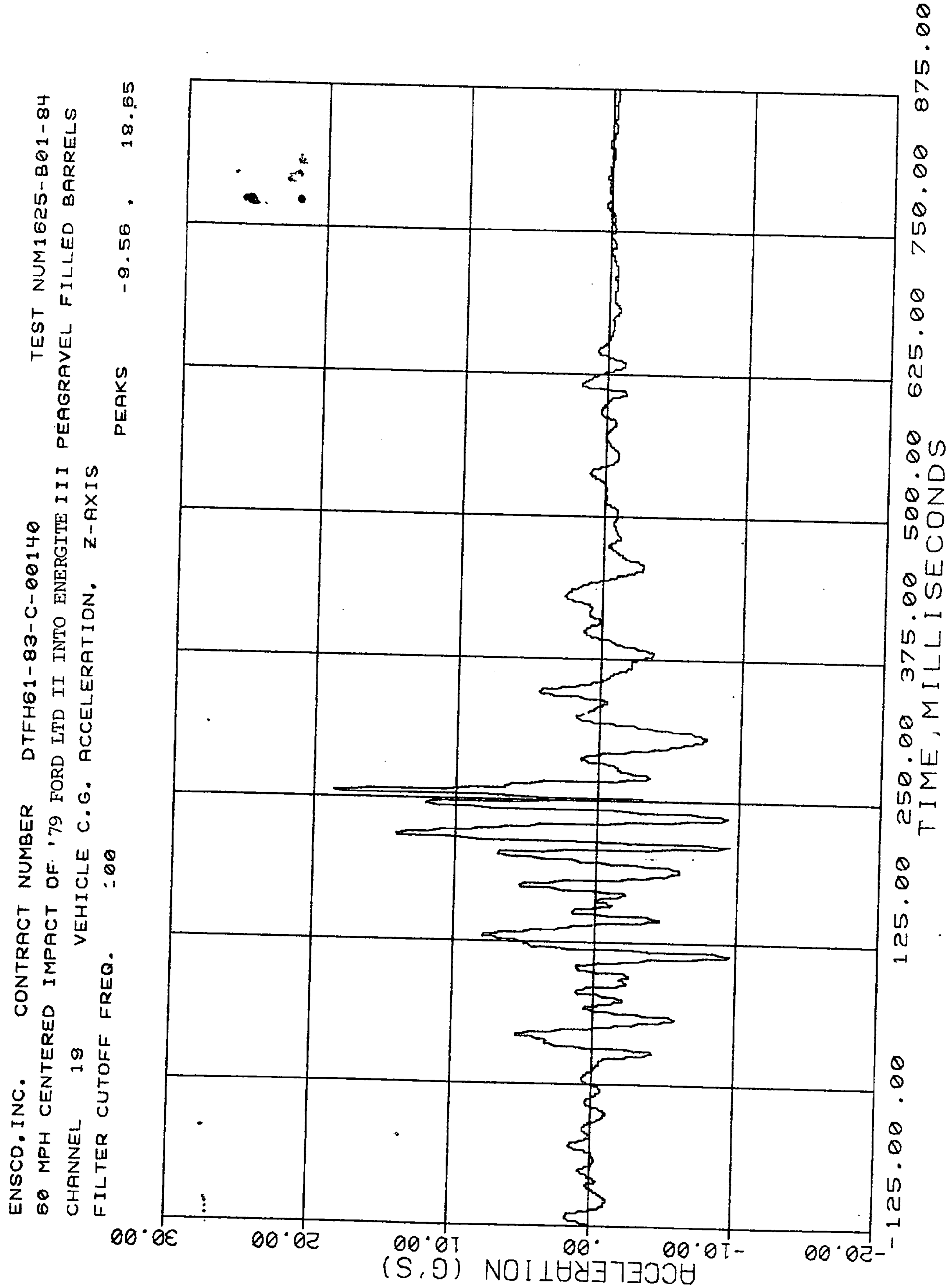
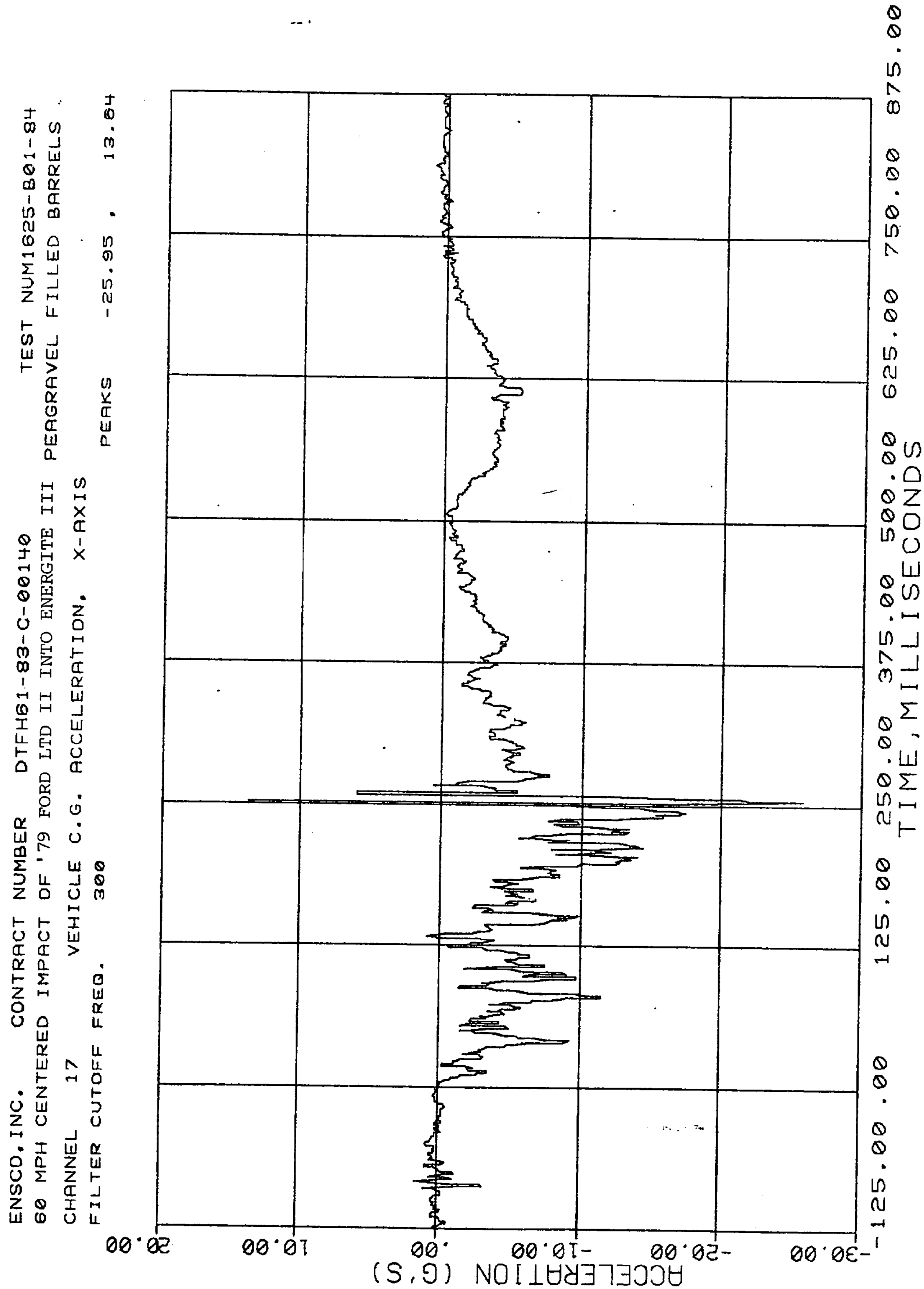

ENSCO, INC.
CONTRACT NUMBER DTFH61-83-C-00140
TEST NUM1625-B01-84
60 MPH CENTERED IMPACT OF '79 FORD LTD II INTO ENERGITE III PEAGRAVEL FILLED BARRELS
CHANNEL 18
VEHICLE C.G. ACCELERATION, Y-AXIS
FILTER CUTOFF FREQ. .00
PEAKS -4.90 , 2.39
-125.00
.00
125.00
250.00
375.00
500.00
625.00
750.00
875.00
TIME, MILLISECONDS
10.00
.00
-10.00
-20.00
-30.00
-40.00
ACCELERATION (G'S)

Figure 4-2.



ENSCO, INC.   CONTRACT NUMBER   DTFH61-83-C-00140   TEST NUM1625-B01-84
60 MPH CENTERED IMPACT OF '79 FORD LTD II INTO ENERGITE III PEAGRAVEL FILLED BARRELS
CHANNEL 19   VEHICLE C.G. ACCELERATION, Z-AXIS
FILTER CUTOFF FREQ. :00
PEAKS -9.56 , 18.65
-125.00 .00 125.00 250.00 375.00 500.00 625.00 750.00 875.00
TIME, MILLISECONDS
30.00 20.00 10.00 .00 -10.00 -20.00
ACCELERATION (G'S)

Figure 4-3.



ENSCO, INC. CONTRACT NUMBER DTFH61-83-C-00140 TEST NUM1625-B01-84
60 MPH CENTERED IMPACT OF '79 FORD LTD II INTO ENERGITE III PEAGRAVEL FILLED BARRELS
CHANNEL 17 VEHICLE C.G. ACCELERATION, X-AXIS
FILTER CUTOFF FREQ. 300
PEAKS -25.95 , 13.64
-125.00 .00 125.00 250.00 375.00 500.00 625.00 750.00 875.00
TIME, MILLISECONDS
20.00 10.00 .00 -10.00 -20.00 -30.00
ACCELERATION (G'S)

Figure 4-4.

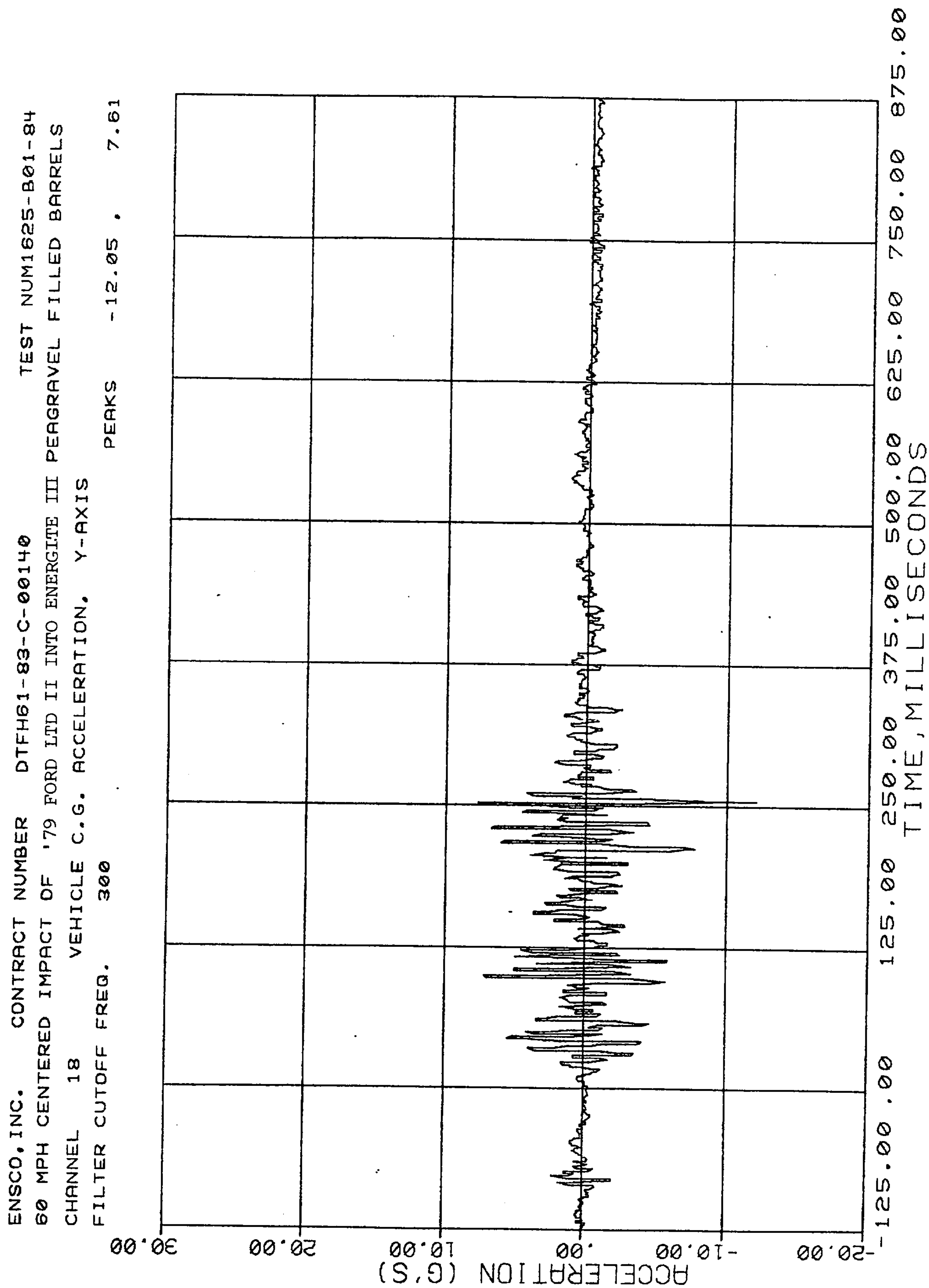

ENSCO, INC. CONTRACT NUMBER DTFH61-83-C-00140 TEST NUM1625-B01-84
60 MPH CENTERED IMPACT OF '79 FORD LTD II INTO ENERGITE III PEAGRAVEL FILLED BARRELS
CHANNEL 18 VEHICLE C.G. ACCELERATION, Y-AXIS
FILTER CUTOFF FREQ. 300
PEAKS -12.05 , 7.61
-125.00
.00
125.00
250.00
375.00
500.00
625.00
750.00
875.00
TIME, MILLISECONDS
30.00
20.00
10.00
.00
-10.00
-20.00
ACCELERATION (G'S)

Figure 4-5.

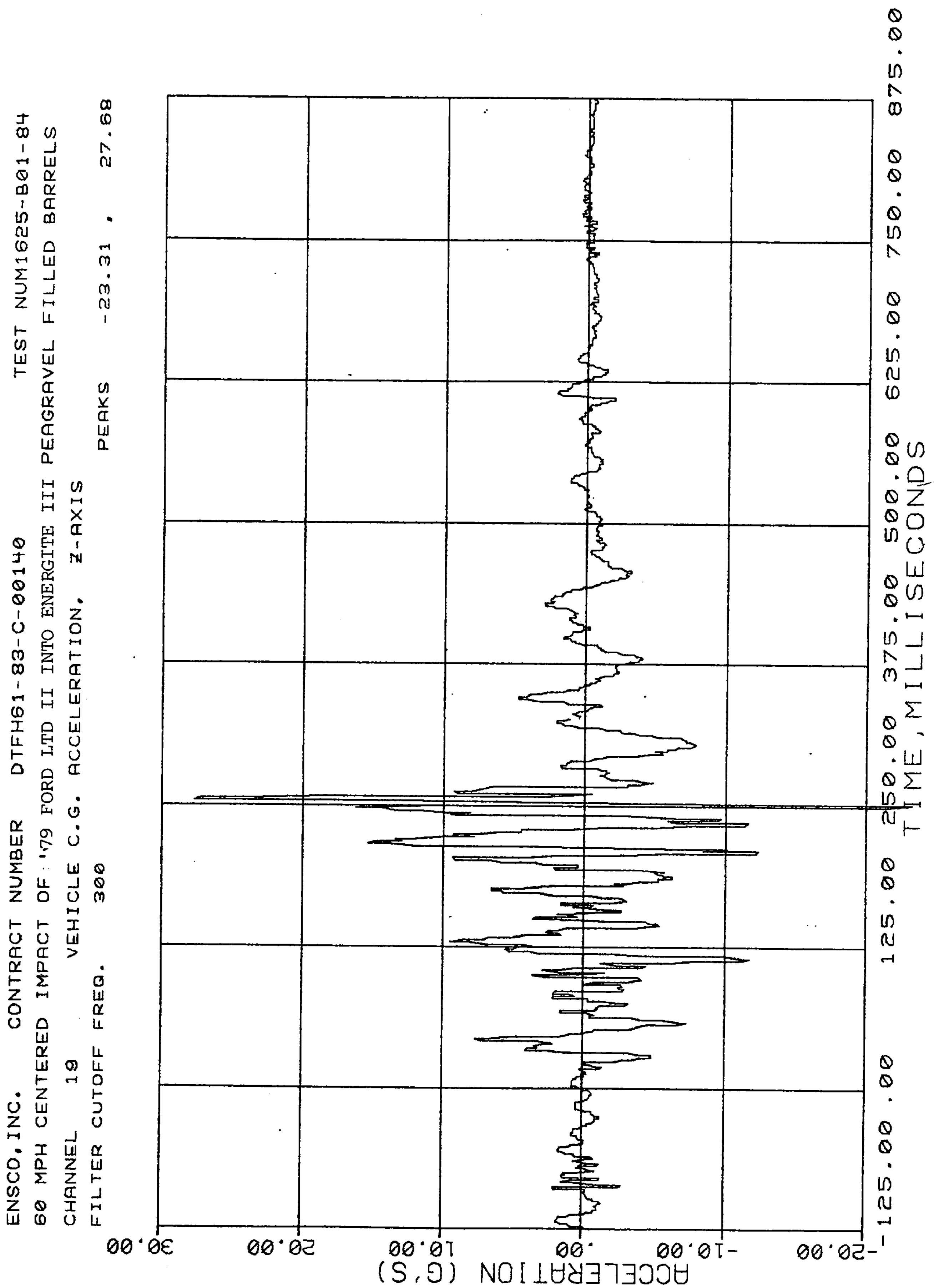
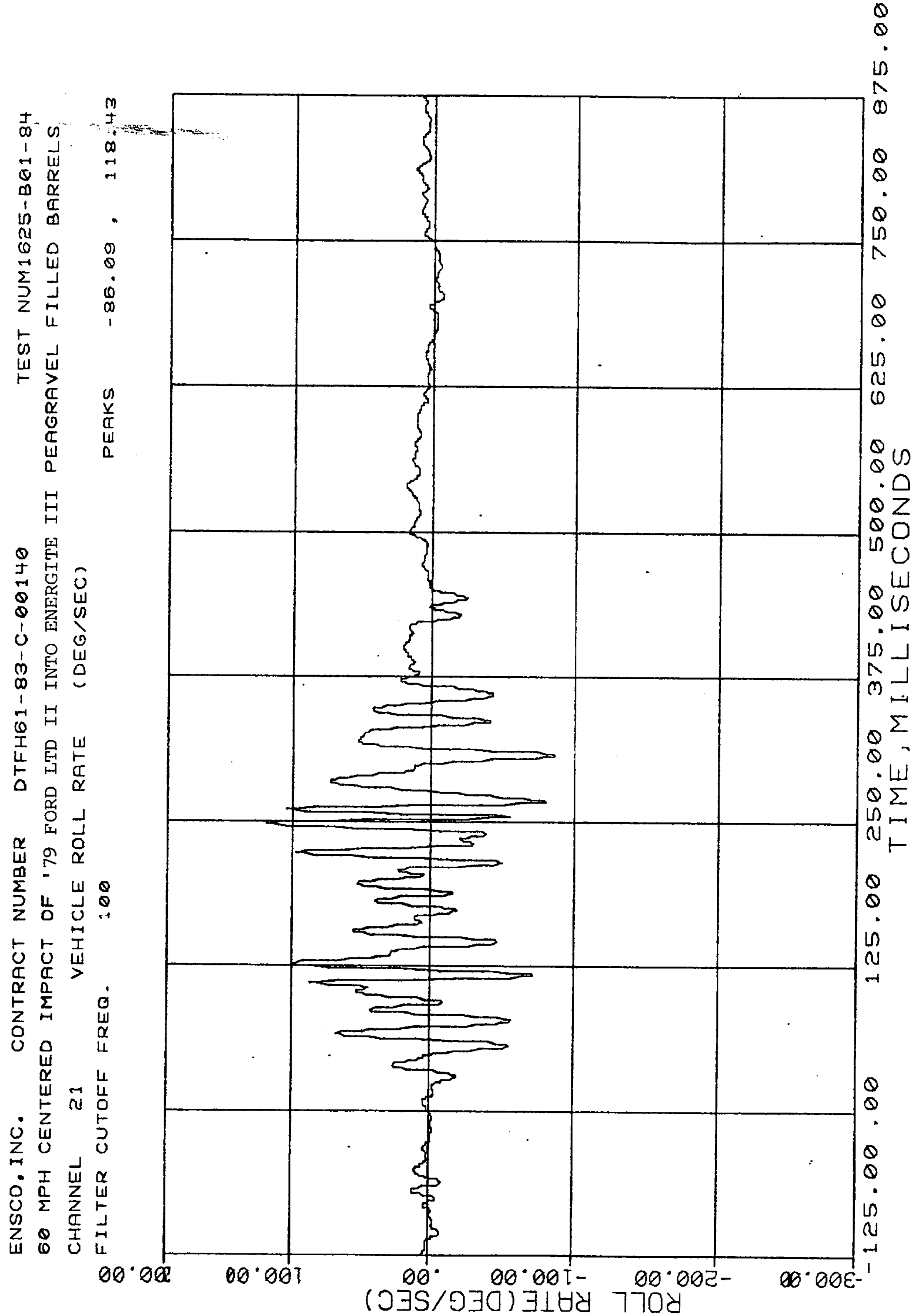
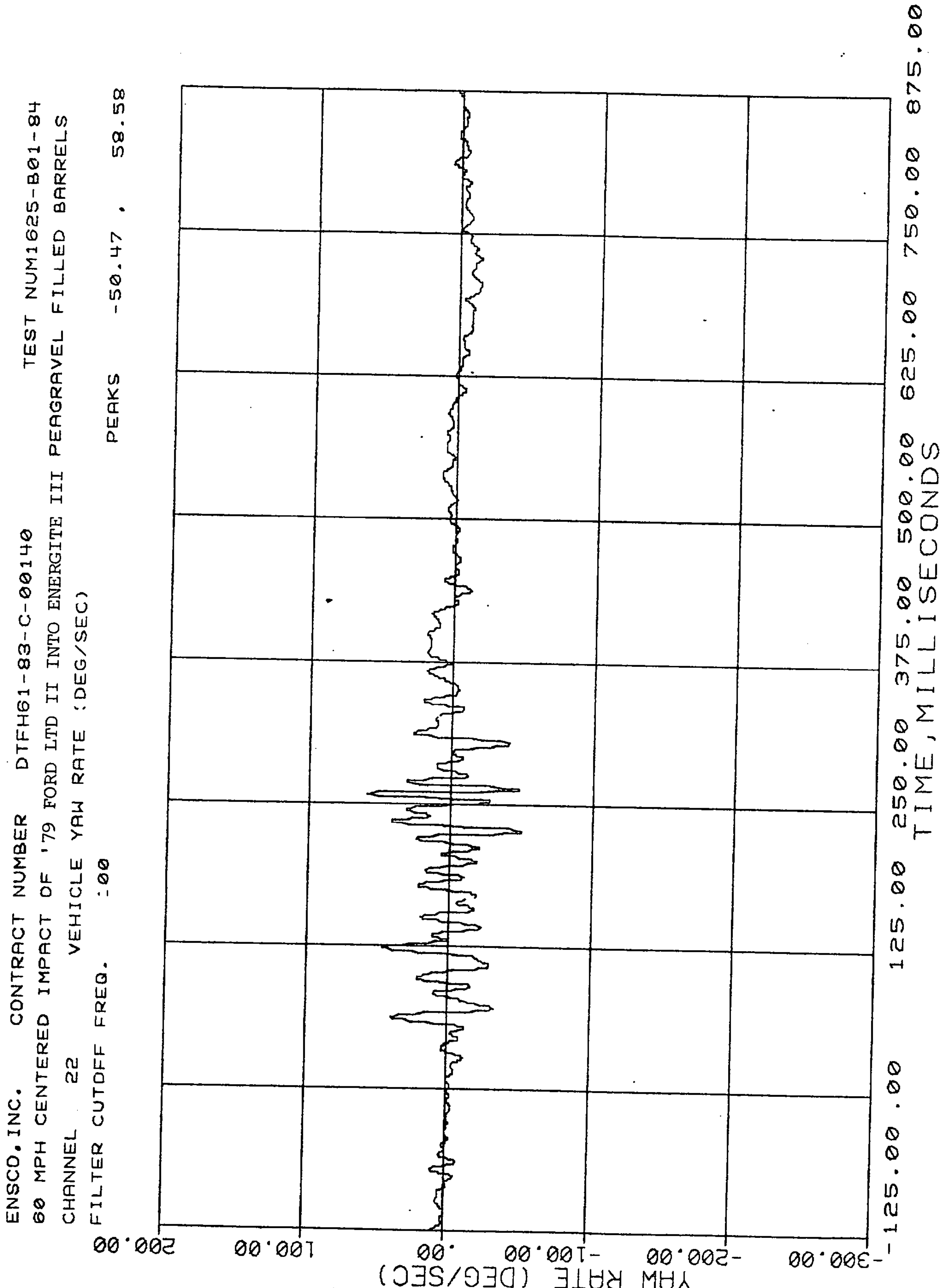

ENSCO, INC.
CONTRACT NUMBER DTFH61-83-C-00140
TEST NUM1625-B01-84
60 MPH CENTERED IMPACT OF '79 FORD LTD II INTO ENERGITE III PEAGRAVEL FILLED BARRELS
CHANNEL 19
VEHICLE C.G. ACCELERATION, Z-AXIS
FILTER CUTOFF FREQ. 300
PEAKS -23.31 , 27.68
-125.00
.00
125.00
250.00
375.00
500.00
625.00
750.00
875.00
TIME, MILLISECONDS
30.00
20.00
10.00
.00
-10.00
-20.00
ACCELERATION (G'S)

Figure 4-6.



ENSCO, INC.
CONTRACT NUMBER DTFH61-83-C-00140
TEST NUM1625-B01-84
60 MPH CENTERED IMPACT OF '79 FORD LTD II INTO ENERGITE III PEAGRAVEL FILLED BARRELS
CHANNEL 21
VEHICLE ROLL RATE (DEG/SEC)
FILTER CUTOFF FREQ. 100
PEAKS -86.09 , 118.43
-125.00
.00
125.00
250.00
375.00
500.00
625.00
750.00
875.00
TIME, MILLISECONDS
200.00
100.00
.00
-100.00
-200.00
-300.00
ROLL RATE(DEG/SEC)

Figure 4-7.



ENSCO, INC.   CONTRACT NUMBER   DTFH61-83-C-00140   TEST NUM1625-B01-84
60 MPH CENTERED IMPACT OF '79 FORD LTD II INTO ENERGITE III PEAGRAVEL FILLED BARRELS
CHANNEL 22   VEHICLE YAW RATE (DEG/SEC)
FILTER CUTOFF FREQ.   .00   PEAKS   -50.47 ,   58.58
-125.00 .00 125.00 250.00 375.00 500.00 625.00 750.00 875.00
TIME, MILLISECONDS
200.00 100.00 .00 -100.00 -200.00 -300.00
YAW RATE (DEG/SEC)

Figure 4-8.

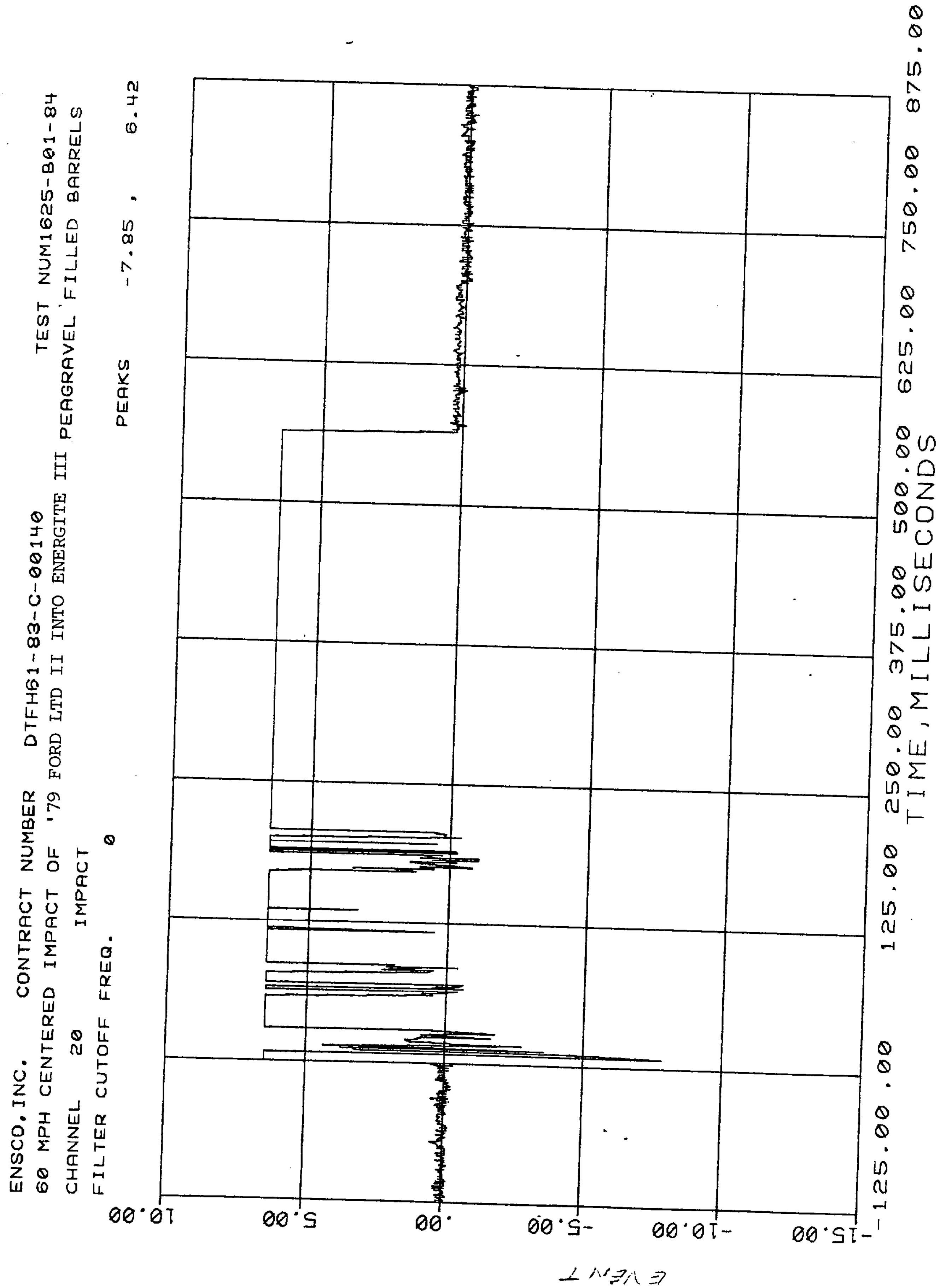

ENSCO, INC. CONTRACT NUMBER DTFH61-83-C-00140 TEST NUM1625-B01-84
60 MPH CENTERED IMPACT OF '79 FORD LTD II INTO ENERGITE III PEAGRAVEL FILLED BARRELS
CHANNEL 20 IMPACT
FILTER CUTOFF FREQ. 0
PEAKS -7.85 , 6.42
TIME, MILLISECONDS
-125.00 .00 125.00 250.00 375.00 500.00 625.00 750.00 875.00
10.00 5.00 .00 -5.00 -10.00 -15.00
EVENT

Figure 4-9.

TABLE 4-2

VEHICLE TRANSDUCER MEASUREMENTS

Description	SAE Class 60 Data Peak	SAE Class 60 Data Time (m sec)	SAE Class 180 Data Peak	SAE Class 180 Data Time (m sec)
Accel, Longitudinal (g's)	-17.1	243	-26.0	255
Accel., Lateral (g's)	-4.9	212	-12.1	254
Accel., Vertical (g's)	18.7	256	27.7	255
Roll Rate (deg/sec)	118.4	252		
Yaw Rate (deg/sec)	58.6	259		

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 each occupant within the vehicle. ΔV was computed for the two foot displacement given in NCHRP 230. From this point, the ridedown acceleration was computed as the peak 10 msec average acceleration from the ΔV location.

In TRC 191 the average acceleration over the stopping distance is specified for direct-on impacts. This parameter was computed in the longitudinal direction using the formula $a = V^2/2S$ where S is the stopping distance of 23.5 feet and V is the initial vehicle velocity of 58.8 mph (86.3 ft/sec).

Table 4-3 presents the results of occupant risk parameter calculations. According to the flail space recommendations in Table 8 of NCHRP 230, the calculated ΔV at 2 feet of -24.5 ft/sec is below the absolute design value of 30 ft/sec. The absolute value ridedown acceleration of 15.4 g's is greater than the absolute

TABLE 4-3

OCCUPANT RISK PARAMETERS (Longitudinal)

NCHRP 230:

ΔV at 2 feet:	- 24.5 ft/sec @ 0.183 sec
Ridedown Acceleration:	- 15.4 g's @ 0.243 sec

TRC 191:

Average Accel. over Stopping Distance	- 4.9 g's

design value 15.0 but less than the absolute limit value of 20.0 g's. According to the safety evaluation guidelines in Table 8 of TRC 191 the computed average acceleration over the stopping distance of -4.9 g's is less than the absolute preferred limit of 8 g's. The peak 50 msec average acceleration was also computed, for comparison purposes, from the longitudinal acceleration measurements filtered at 100 Hz. It was found to equal -11.2 g's from 0.323 to 0.373 sec.

Based on the NCHRP 230 and TRC 191 parameters, occupant risk during test 1625-B-01-84 should be mild. ΔV and average acceleration over the stopping distance were below the preferred criteria while ridedown was slightly above the preferred criteria.

4.2 OCCUPANT ANALYSIS

The data obtained from the instrumented dummy 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 pages.

4.2.1 HEAD INJURY CRITERIA (HIC) EVALUATION

The data obtained from the three accelerometers located in the head of the driver and the passenger 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 4-10 through 4-13 for the driver and Figures 4-14 through 4-17 for the passenger.

The resultant acceleration calculated for the driver's and passenger's heads was for all practical purposes self-contained within the collision event. The HIC evaluated for the driver was 265 within the time interval of 0.153 to 0.160 seconds for a time duration of 0.007 seconds. The HIC evaluated for the passenger was 313 within the time interval of 0.14 to 0.301 seconds for a time duration of 0.161 seconds. Given an acceptable limit of 1000, these HIC numbers indicate that the occupants experienced moderate collisions.

4.2.2 CHEST SEVERITY INDEX (CSI) EVALUATION

The data obtained from the three accelerometers located in the chest of the driver and the passenger 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 4-18 through 4-21 for the driver and Figures 4-22 through 4-25 for the passenger.

The peak resultant acceleration whose duration is greater than .003 seconds was 81.9 g's occurring at 0.148 seconds for the driver and 47.7 g's occuring approximately at 0.220 seconds for the passenger after initial impact. The CSI was calculated to be 329 for the driver and 218 for the passenger. Given the acceptable limits of 60 g's for peak acceleration and 1000 for CSI, the driver's chest experienced an unacceptable accident and the passenger's chest experienced a severe accident.

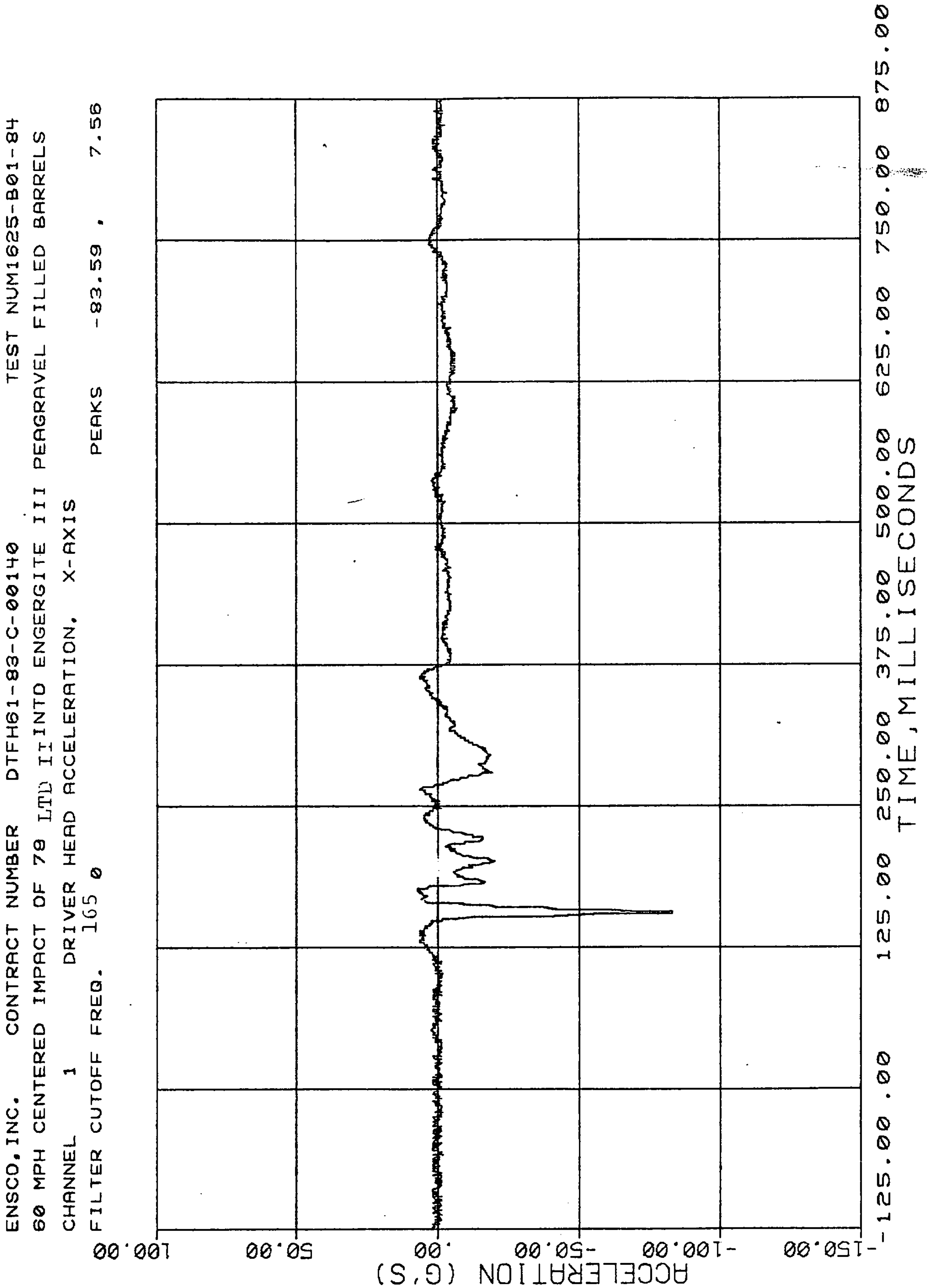

ENSCO, INC.   CONTRACT NUMBER   DTFH61-83-C-00140   TEST NUM1625-B01-84
60 MPH CENTERED IMPACT OF 79 LTD II INTO ENGERGITE III PEAGRAVEL FILLED BARRELS
CHANNEL 1   DRIVER HEAD ACCELERATION, X-AXIS
FILTER CUTOFF FREQ. 165 0   PEAKS   -83.59 ,   7.56
-125.00 .00 125.00 250.00 375.00 500.00 625.00 750.00 875.00
TIME, MILLISECONDS
100.00 50.00 .00 -50.00 -100.00 -150.00
ACCELERATION (G'S)

Figure 4-10

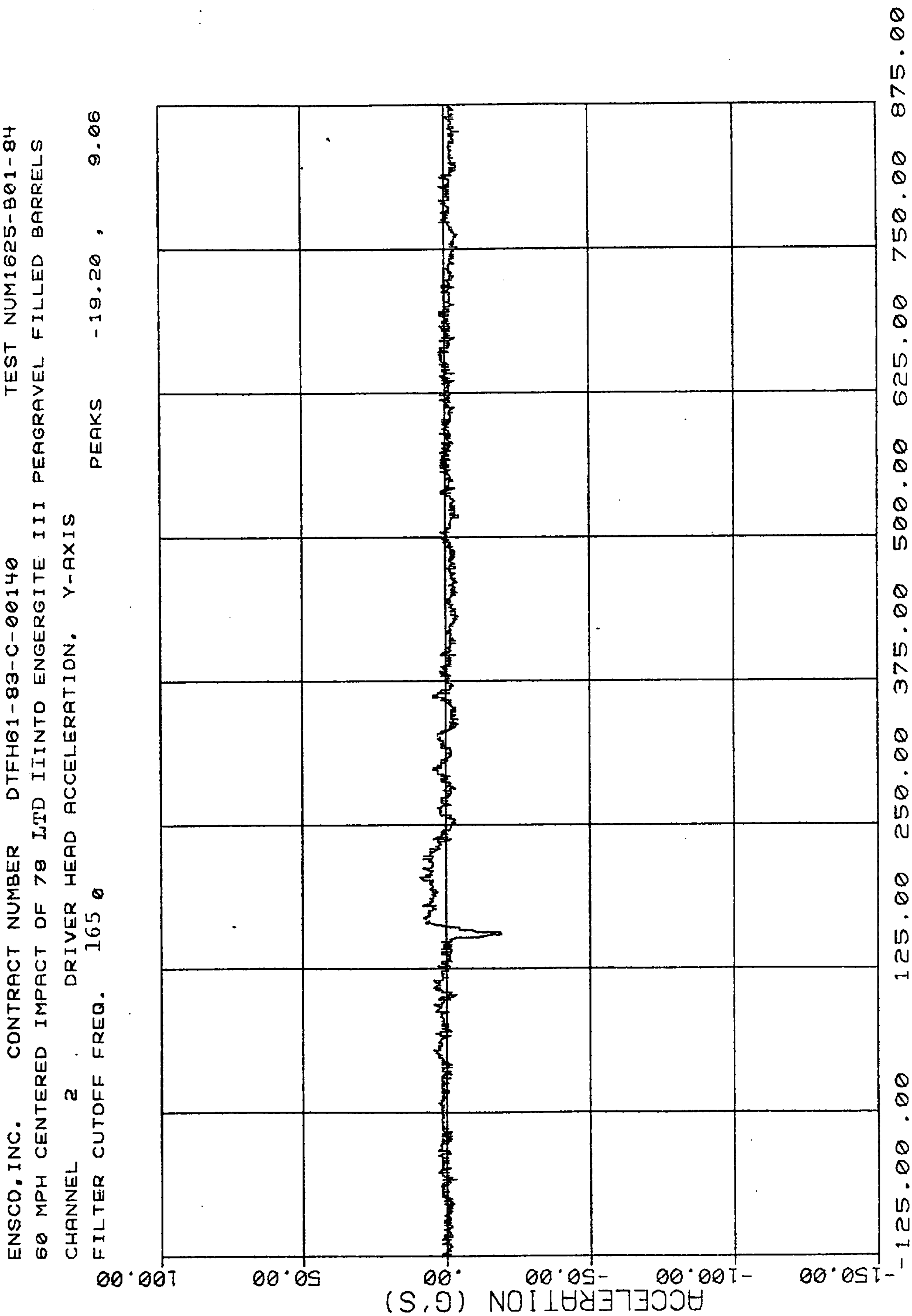

ENSCO, INC. CONTRACT NUMBER DTFH61-83-C-00140 TEST NUM1625-B01-84
60 MPH CENTERED IMPACT OF 79 LTD IIINTO ENGERGITE III PEAGRAVEL FILLED BARRELS
CHANNEL 2 DRIVER HEAD ACCELERATION, Y-AXIS
FILTER CUTOFF FREQ. 165 0
PEAKS -19.20 , 9.06
-125.00
.00
125.00
250.00
375.00
500.00
625.00
750.00
875.00
100.00
50.00
.00
-50.00
-100.00
-150.00
ACCELERATION (G'S)

Figure 4-11.

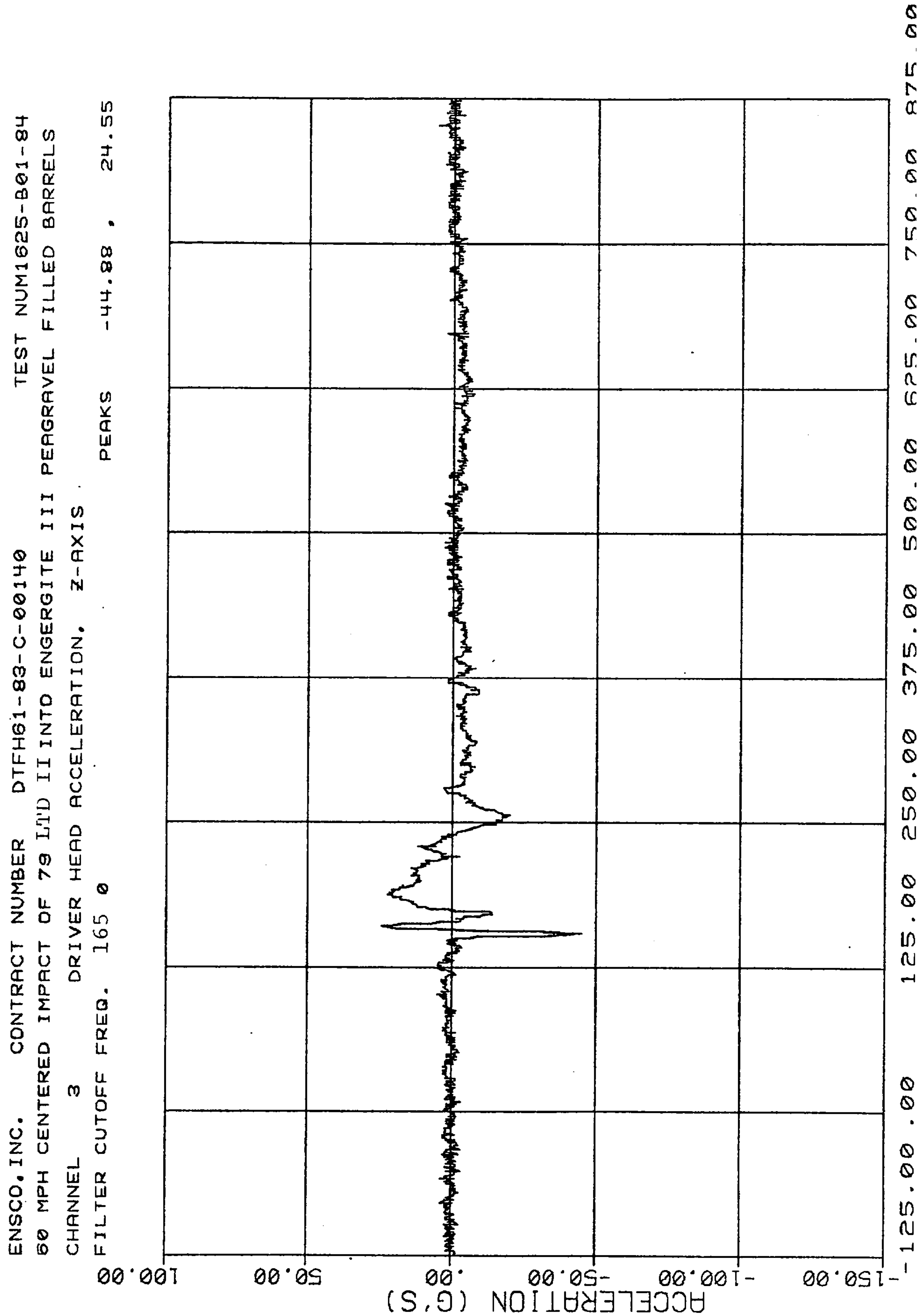

ENSCO, INC.   CONTRACT NUMBER   DTFH61-83-C-00140   TEST NUM1625-B01-84
60 MPH CENTERED IMPACT OF 79 LTD II INTO ENGERGITE III PEAGRAVEL FILLED BARRELS
CHANNEL 3   DRIVER HEAD ACCELERATION, Z-AXIS
FILTER CUTOFF FREQ. 165 0   PEAKS -44.88 , 24.55
100.00
50.00
.00
-50.00
-100.00
-150.00
ACCELERATION (G'S)
-125.00
.00
125.00
250.00
375.00
500.00
625.00
750.00
875.00

Figure 4-12.

ENSCO, INC.   CONTRACT NUMBER   DTFH61-83-C-00140   TEST NUM1625-B01-84
60 MPH CENTERED IMPACT OF 79 LTD IIINTO ENGERGITE III PEAGRAVEL FILLED BARRELS
CHANNEL   0   DRIVER HEAD ACCELERATION, RESULTANT
FILTER CUTOFF FREQ.   :00   PEAKS   0.53 ,   91.97

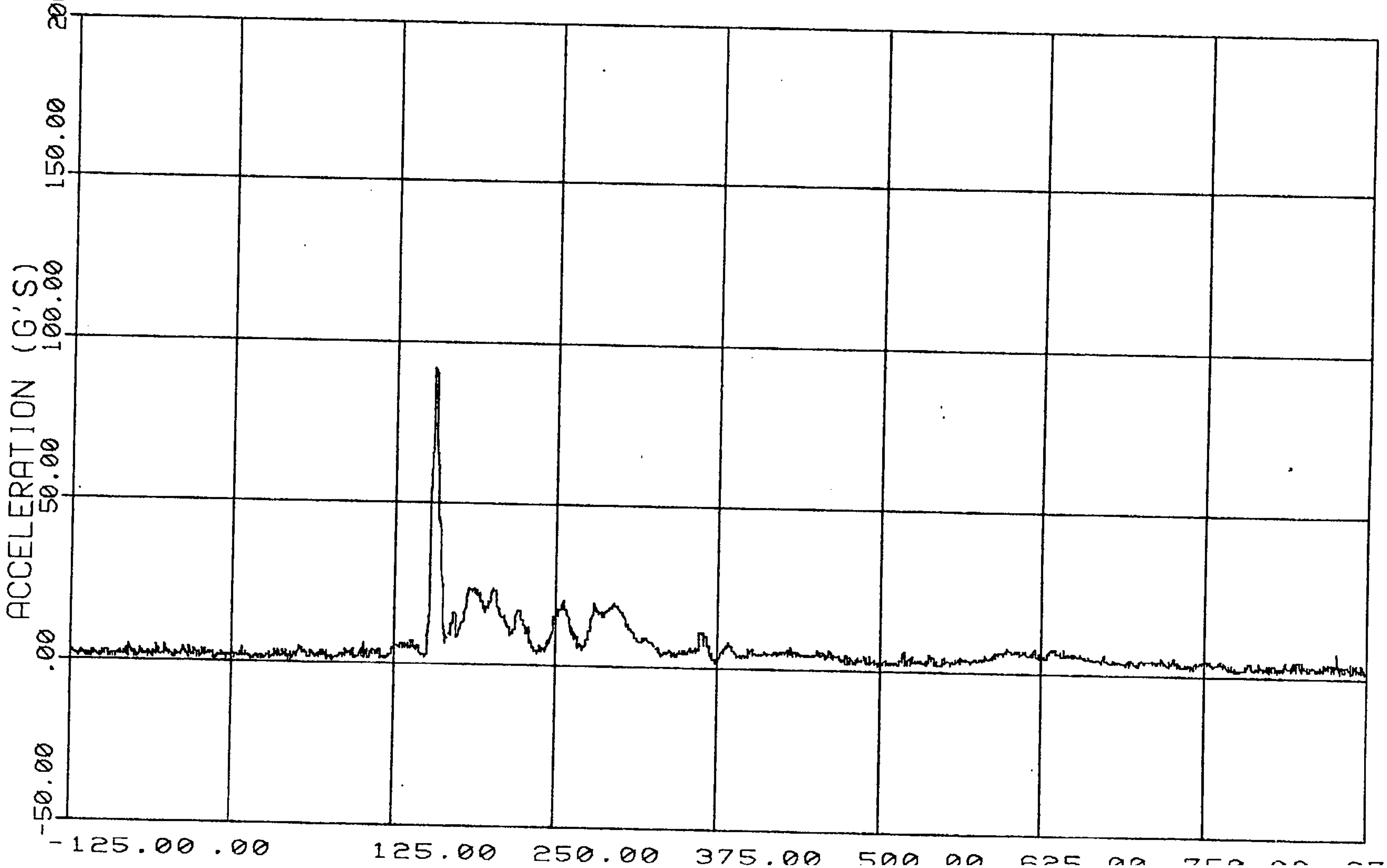
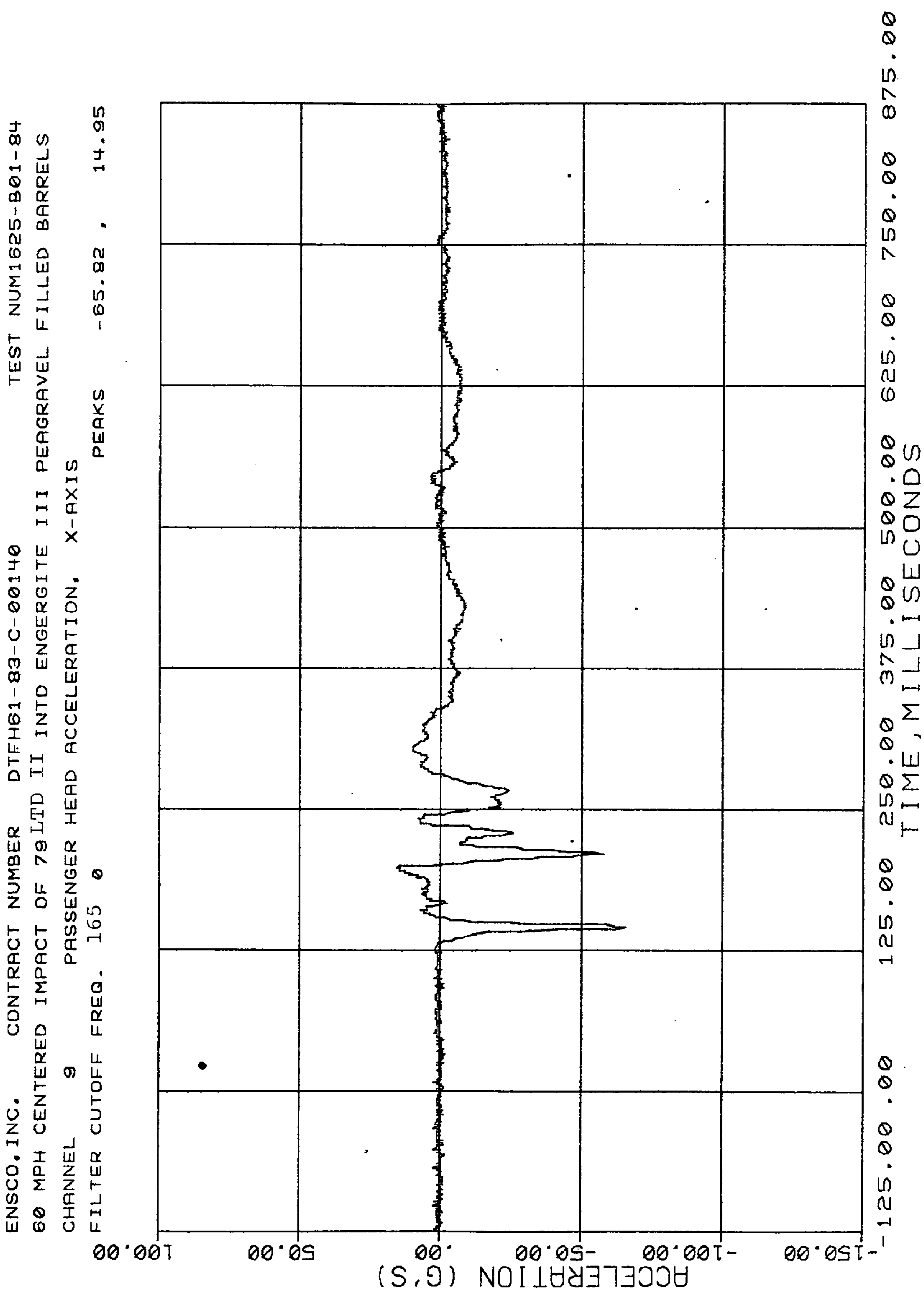


Figure 4-13.


ENSCO, INC. CONTRACT NUMBER DTFH61-83-C-00140 TEST NUM1625-B01-84
60 MPH CENTERED IMPACT OF 79 LTD II INTO ENGERGITE III PEAGRAVEL FILLED BARRELS
CHANNEL 9 PASSENGER HEAD ACCELERATION, X-AXIS
FILTER CUTOFF FREQ. 165 0 PEAKS -65.82 , 14.95
-125.00 .00 125.00 250.00 375.00 500.00 625.00 750.00 875.00
TIME, MILLISECONDS
100.00 50.00 .00 -50.00 -100.00 -150.00
ACCELERATION (G'S)
Figure 4-14.

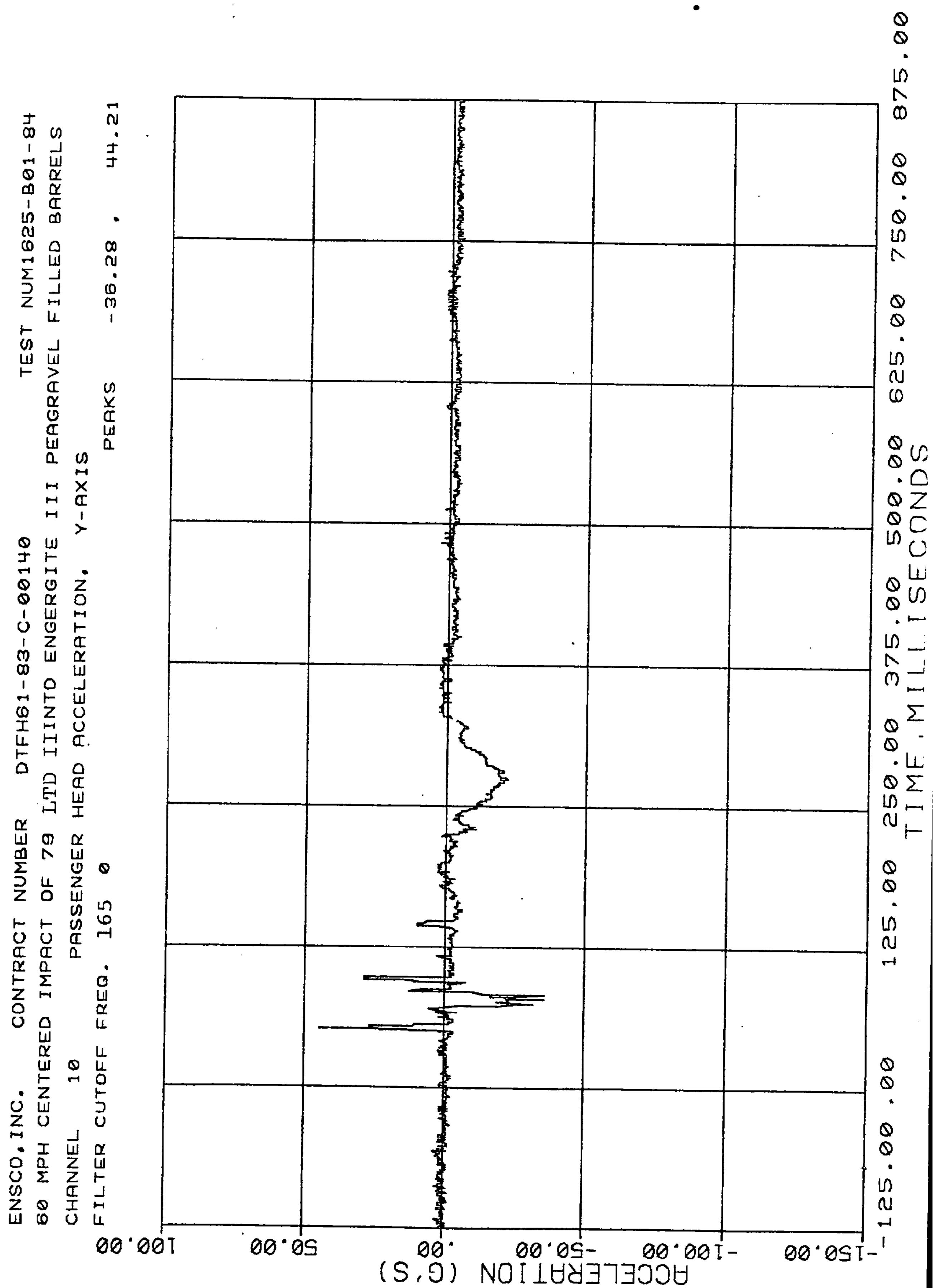

ENSCO, INC. CONTRACT NUMBER DTFH61-83-C-00140 TEST NUM1625-B01-84
60 MPH CENTERED IMPACT OF 79 LTD IIINTO ENGERGITE III PEAGRAVEL FILLED BARRELS
CHANNEL 10 PASSENGER HEAD ACCELERATION, Y-AXIS
FILTER CUTOFF FREQ. 165 0 PEAKS -38.28 , 44.21
-125.00
.00
125.00
250.00
375.00
500.00
625.00
750.00
875.00
TIME,MILLISECONDS
100.00
50.00
.00
-50.00
-100.00
-150.00
ACCELERATION (G'S)

Figure 4-15.

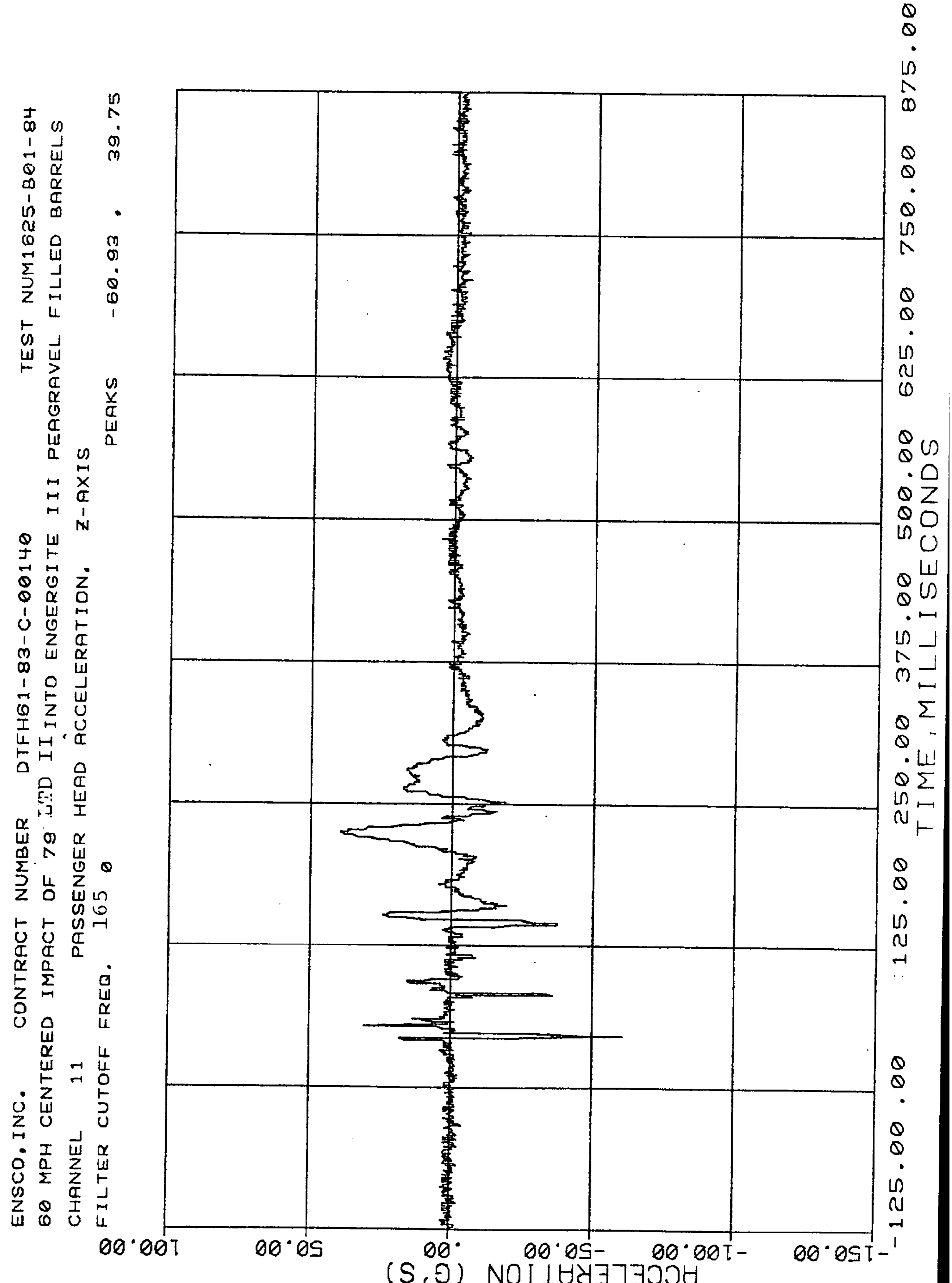
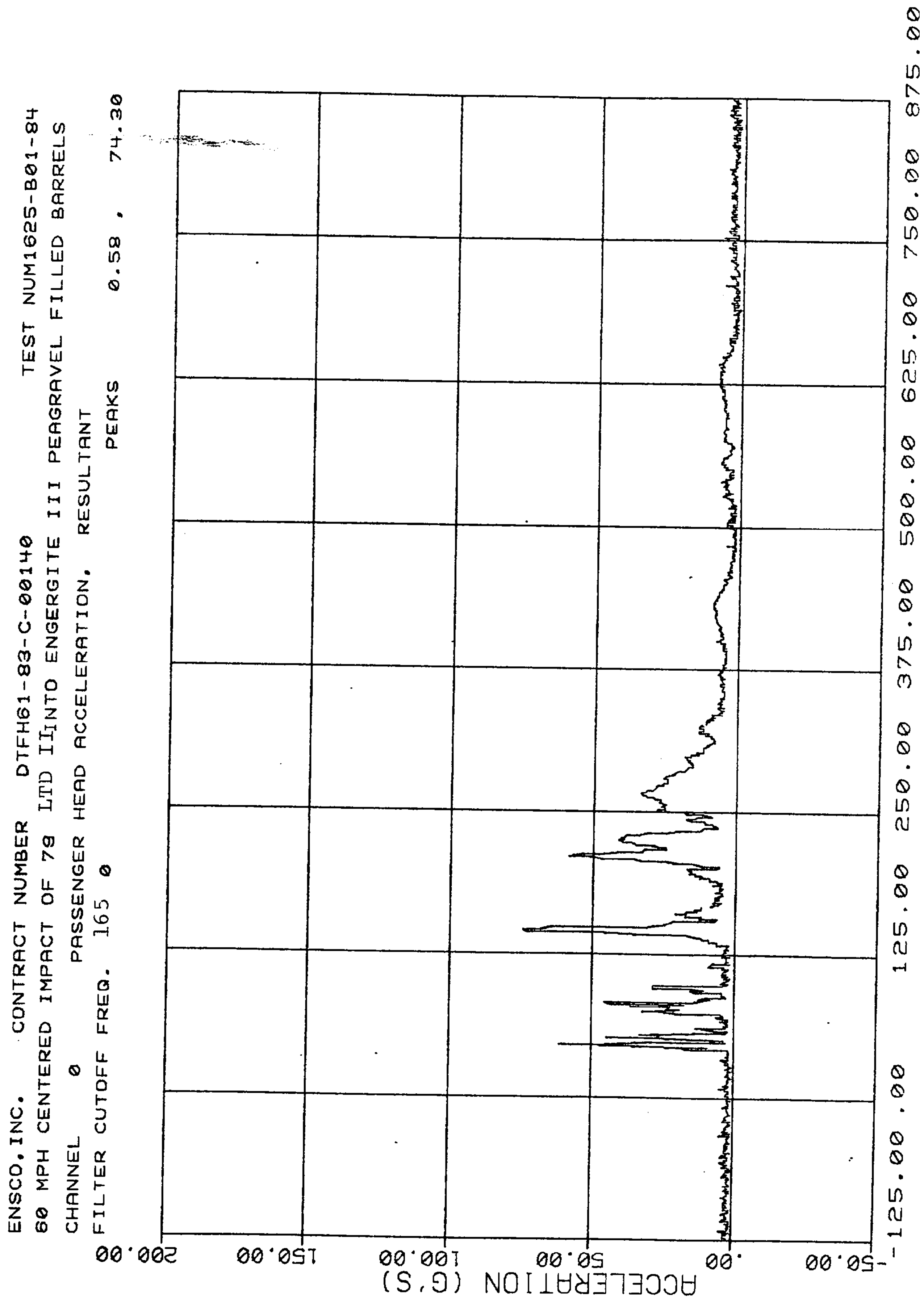

ENSCO, INC.
CONTRACT NUMBER DTFH61-83-C-00140
TEST NUM1625-B01-84
60 MPH CENTERED IMPACT OF 79
II INTO ENGERGITE III PEAGRAVEL FILLED BARRELS
CHANNEL 11
PASSENGER HEAD ACCELERATION, Z-AXIS
FILTER CUTOFF FREQ. 165 0
PEAKS -60.93 , 39.75
-125.00
.00
125.00
250.00
375.00
500.00
625.00
750.00
875.00
TIME, MILLISECONDS
100.00
50.00
.00
-50.00
-100.00
-150.00
ACCELERATION (G'S)

Figure 4-16.



ENSCO, INC. CONTRACT NUMBER DTFH61-83-C-00140 TEST NUM1625-B01-84
60 MPH CENTERED IMPACT OF 79 LTD II INTO ENGERGITE III PEAGRAVEL FILLED BARRELS
CHANNEL 0 PASSENGER HEAD ACCELERATION, RESULTANT
FILTER CUTOFF FREQ. 165 0 PEAKS 0.58 , 74.30
-125.00
.00
125.00
250.00
375.00
500.00
625.00
750.00
875.00
200.00
150.00
100.00
50.00
.00
-50.00
ACCELERATION (G'S)

Figure 4-17.

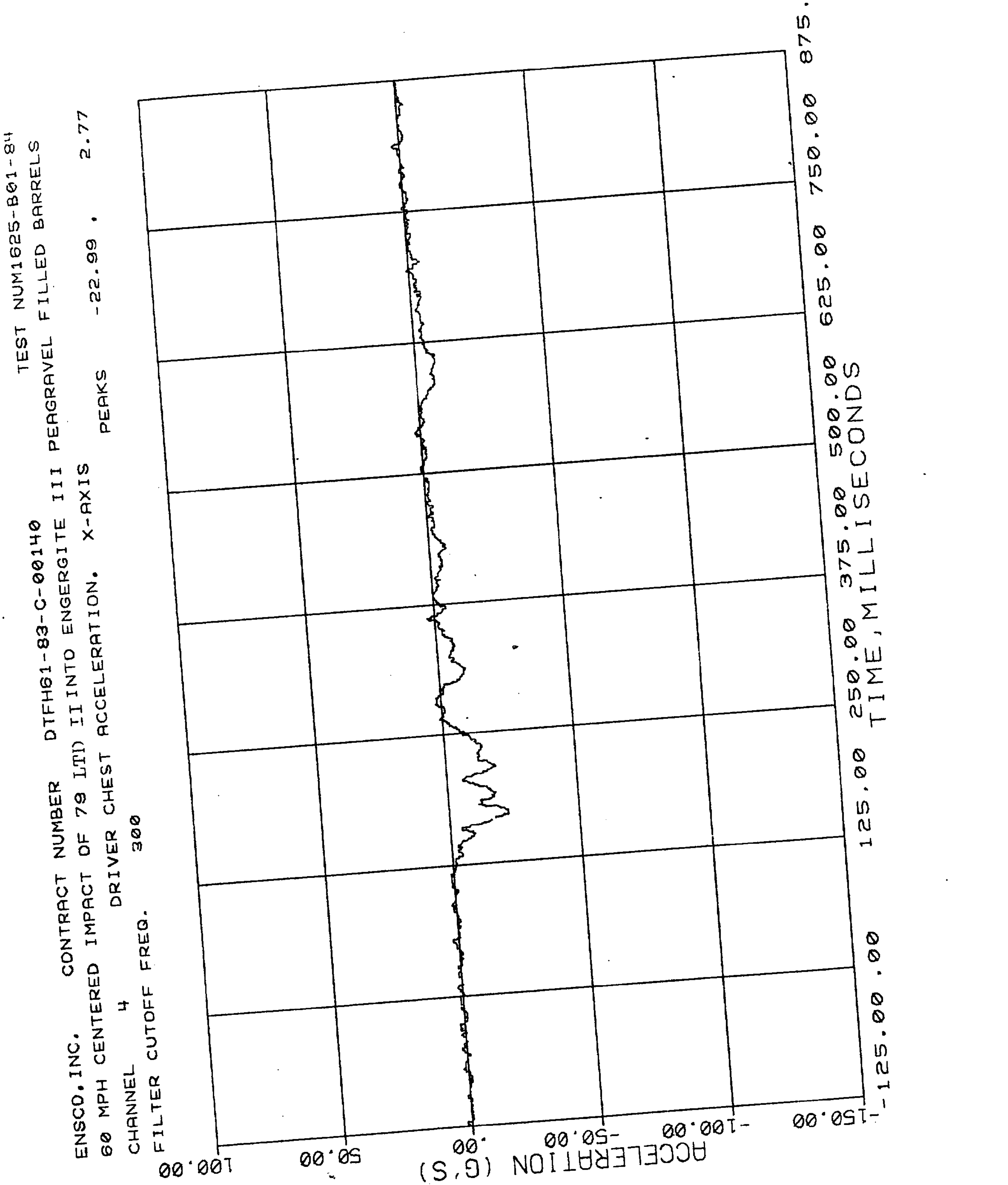

ENSCO, INC. CONTRACT NUMBER DTFH61-83-C-00140 TEST NUM1625-B01-84
60 MPH CENTERED IMPACT OF 79 LTD II INTO ENGERGITE III PEAGRAVEL FILLED BARRELS
CHANNEL 4 DRIVER CHEST ACCELERATION. X-AXIS
FILTER CUTOFF FREQ. 300 PEAKS -22.99 , 2.77
TIME, MILLISECONDS
-125.00 .00 125.00 250.00 375.00 500.00 625.00 750.00 875.
ACCELERATION (G'S)
100.00 50.00 .00 -50.00 -100.00 -150.00

Figure 4-18.

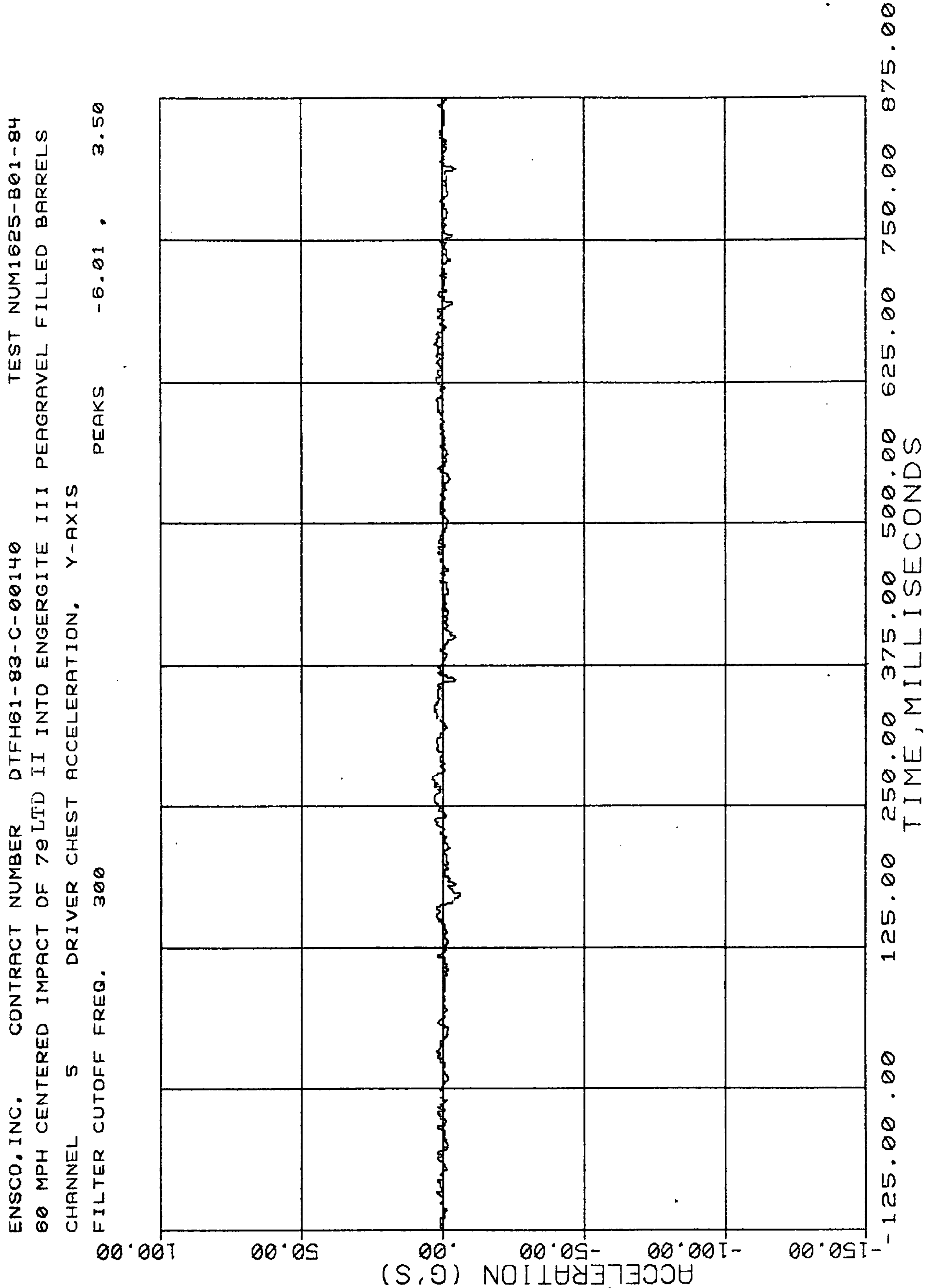

ENSCO, INC. CONTRACT NUMBER DTFH61-83-C-00140 TEST NUM1625-B01-84
60 MPH CENTERED IMPACT OF 79 LTD II INTO ENGERGITE III PEAGRAVEL FILLED BARRELS
CHANNEL 5 DRIVER CHEST ACCELERATION, Y-AXIS
FILTER CUTOFF FREQ. 300 PEAKS -6.01 , 3.50
-125.00
.00
125.00
250.00
375.00
500.00
625.00
750.00
875.00
TIME, MILLISECONDS
100.00
50.00
.00
-50.00
-100.00
-150.00
ACCELERATION (G'S)

Figure 4-19.

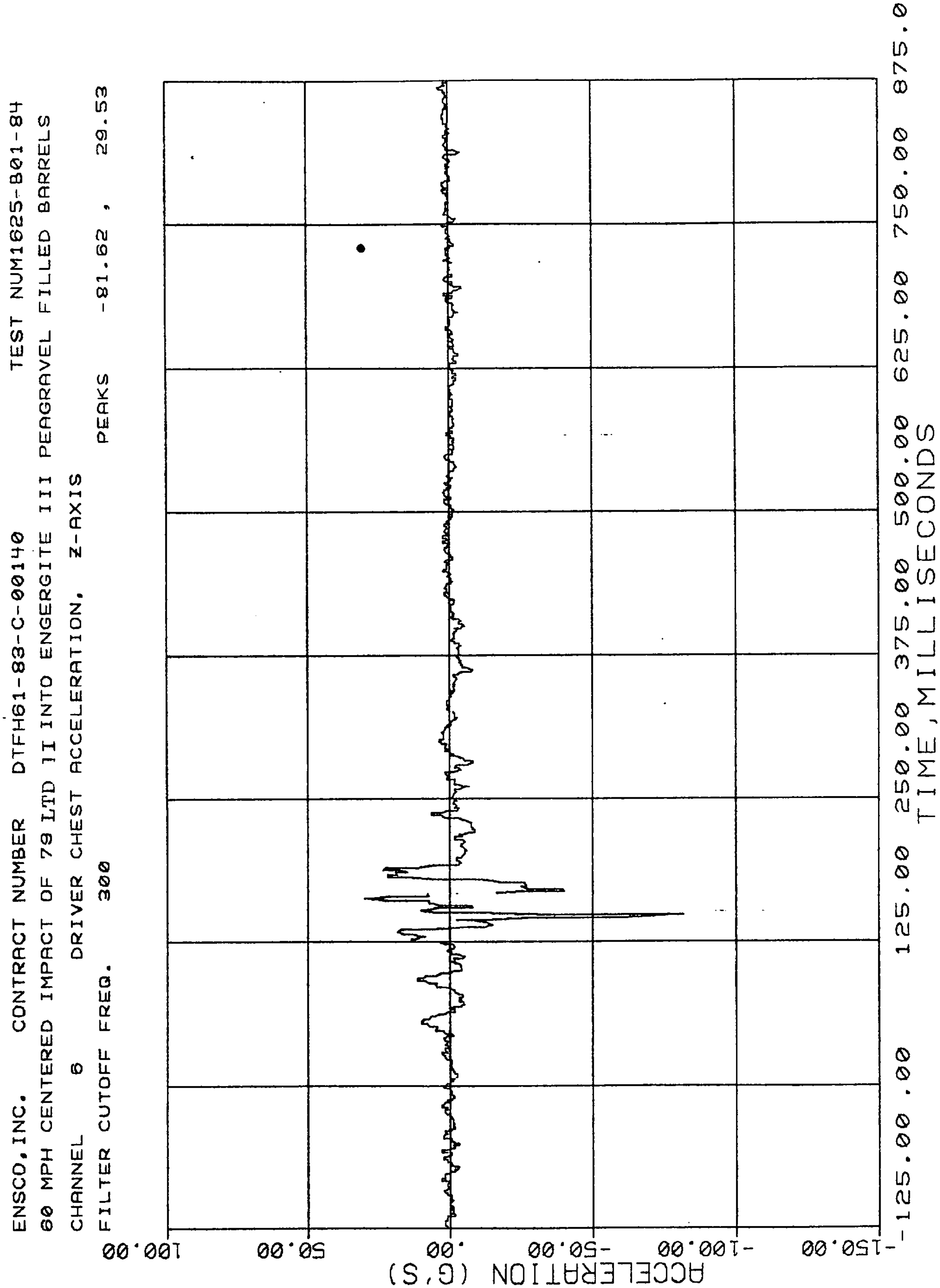

ENSCO, INC.
CONTRACT NUMBER DTFH61-83-C-00140
TEST NUM1625-B01-84
60 MPH CENTERED IMPACT OF 79 LTD II INTO ENGERGITE III PEAGRAVEL FILLED BARRELS
CHANNEL 6
DRIVER CHEST ACCELERATION, Z-AXIS
FILTER CUTOFF FREQ. 300
PEAKS -81.62 , 29.53
-125.00
.00
125.00
250.00
375.00
500.00
625.00
750.00
875.00
TIME, MILLISECONDS
100.00
50.00
.00
-50.00
-100.00
-150.00
ACCELERATION (G'S)

Figure 4-20.

ENSCO, INC.   CONTRACT NUMBER   DTFH61-83-C-00140   TEST NUM1625-B01-84
60 MPH CENTERED IMPACT OF 79 LTD IIINTO ENGERGITE III PEAGRAVEL FILLED BARRELS
CHANNEL   0   DRIVER CHEST ACCELERATION, RESULTANT
FILTER CUTOFF FREQ.   300   PEAKS   1.20 ,   81.88

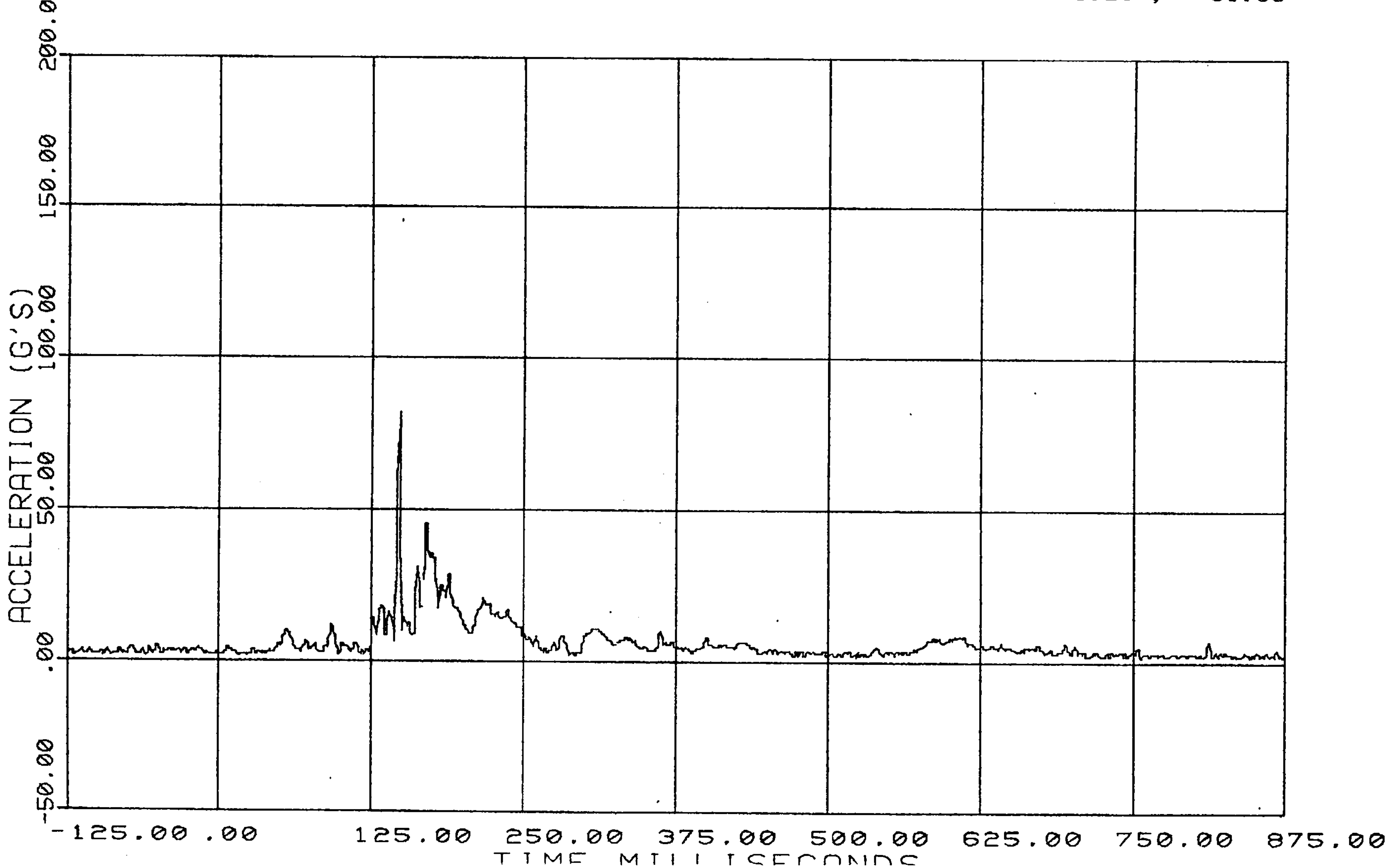


Figure 4-21

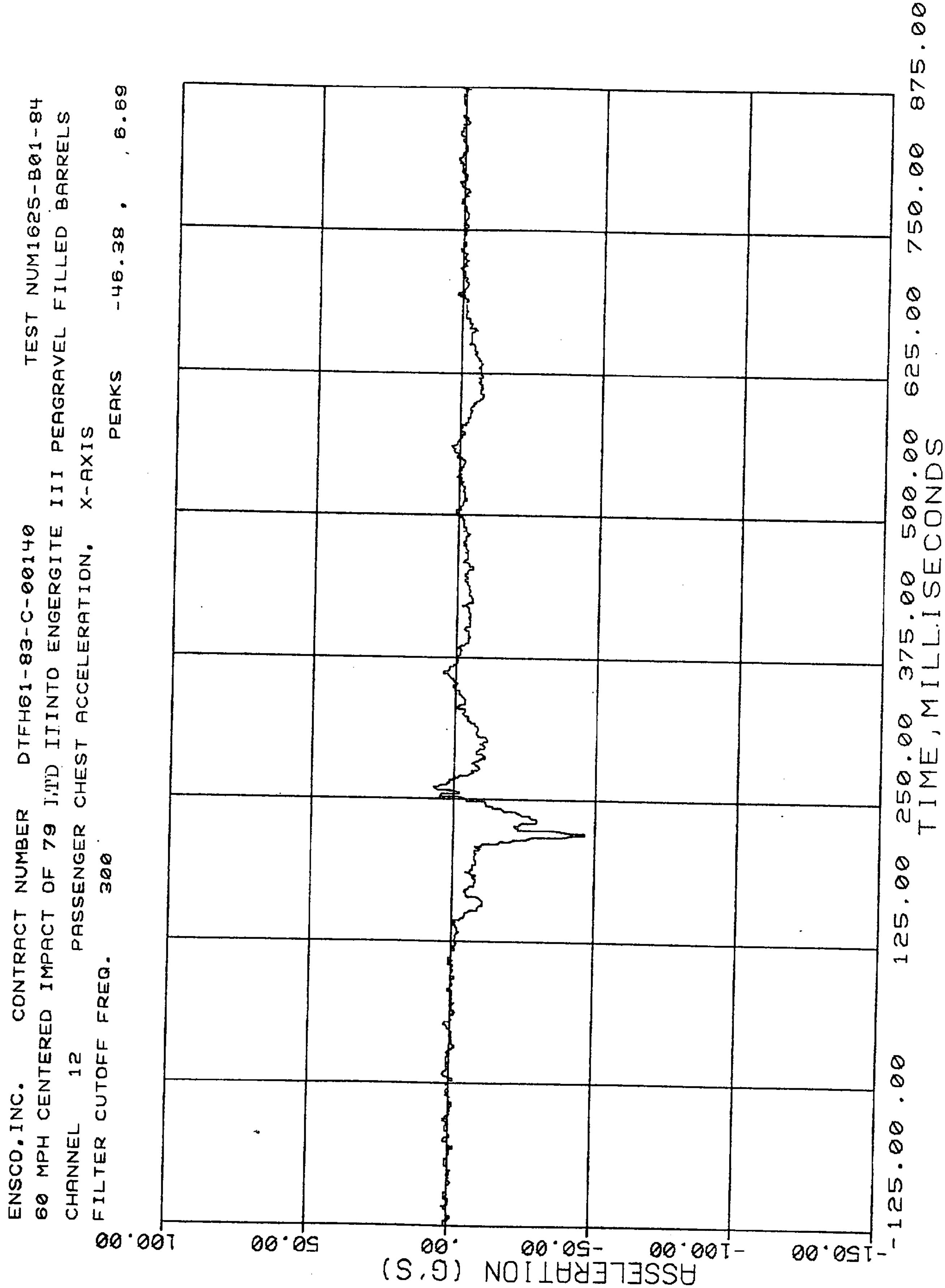

ENSCO, INC. CONTRACT NUMBER DTFH61-83-C-00140 TEST NUM1625-B01-84
60 MPH CENTERED IMPACT OF 79 LTD INTO ENGERGITE III PEAGRAVEL FILLED BARRELS
CHANNEL 12 PASSENGER CHEST ACCELERATION, X-AXIS
FILTER CUTOFF FREQ. 300 PEAKS -46.38 , 6.69
-125.00 .00 125.00 250.00 375.00 500.00 625.00 750.00 875.00
TIME, MILLISECONDS
100.00 50.00 .00 -50.00 -100.00 -150.00
ASSELERATION (G'S)

Figure 4-22

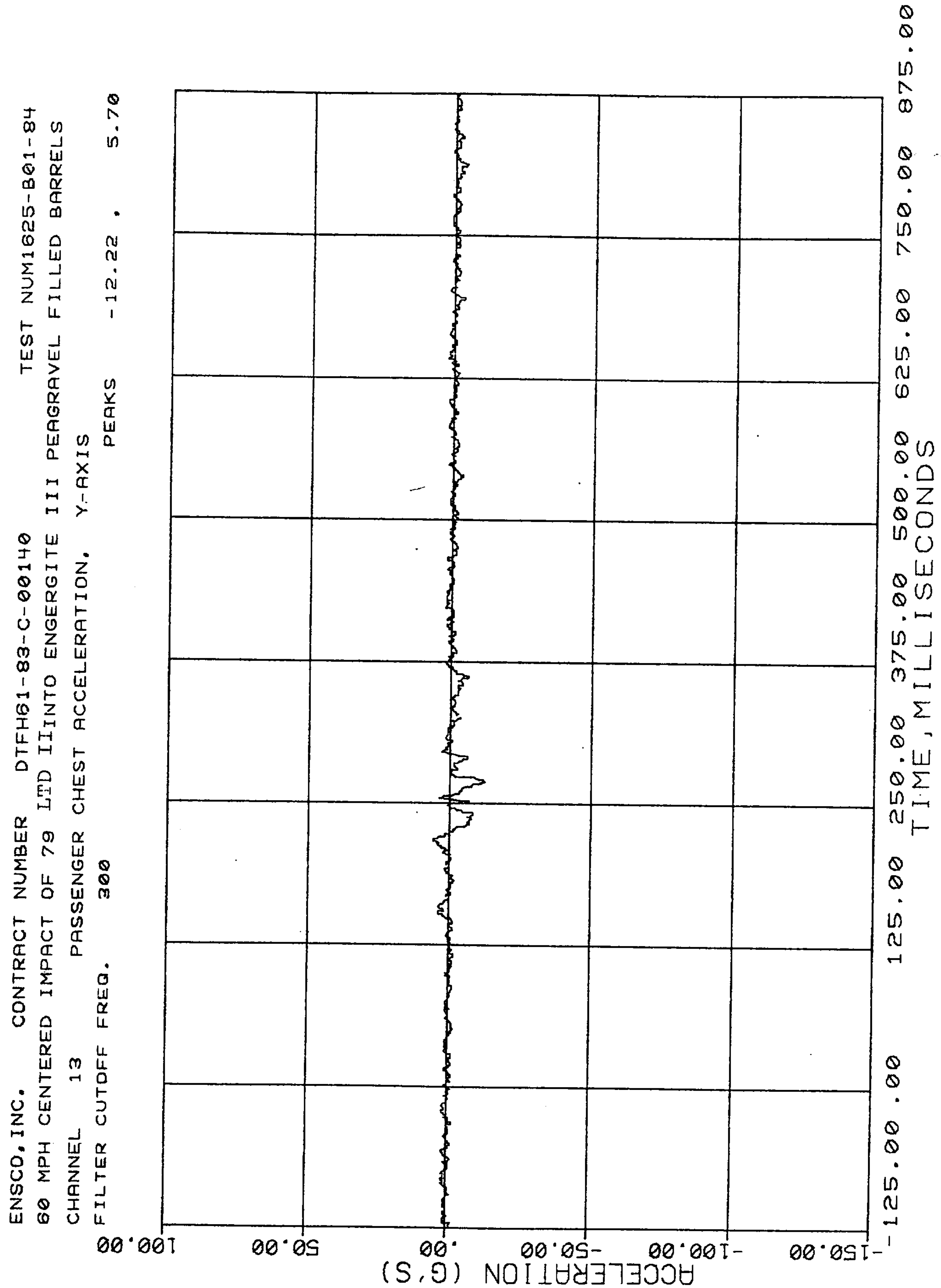

ENSCO, INC.   CONTRACT NUMBER   DTFH61-83-C-00140   TEST NUM1625-B01-84
60 MPH CENTERED IMPACT OF 79 LTD II INTO ENGERGITE III PEAGRAVEL FILLED BARRELS
CHANNEL 13   PASSENGER CHEST ACCELERATION, Y-AXIS
FILTER CUTOFF FREQ. 300   PEAKS -12.22 , 5.70
-125.00
.00
125.00
250.00
375.00
500.00
625.00
750.00
875.00
TIME, MILLISECONDS
100.00
50.00
.00
-50.00
-100.00
-150.00
ACCELERATION (G'S)

Figure 4-23.

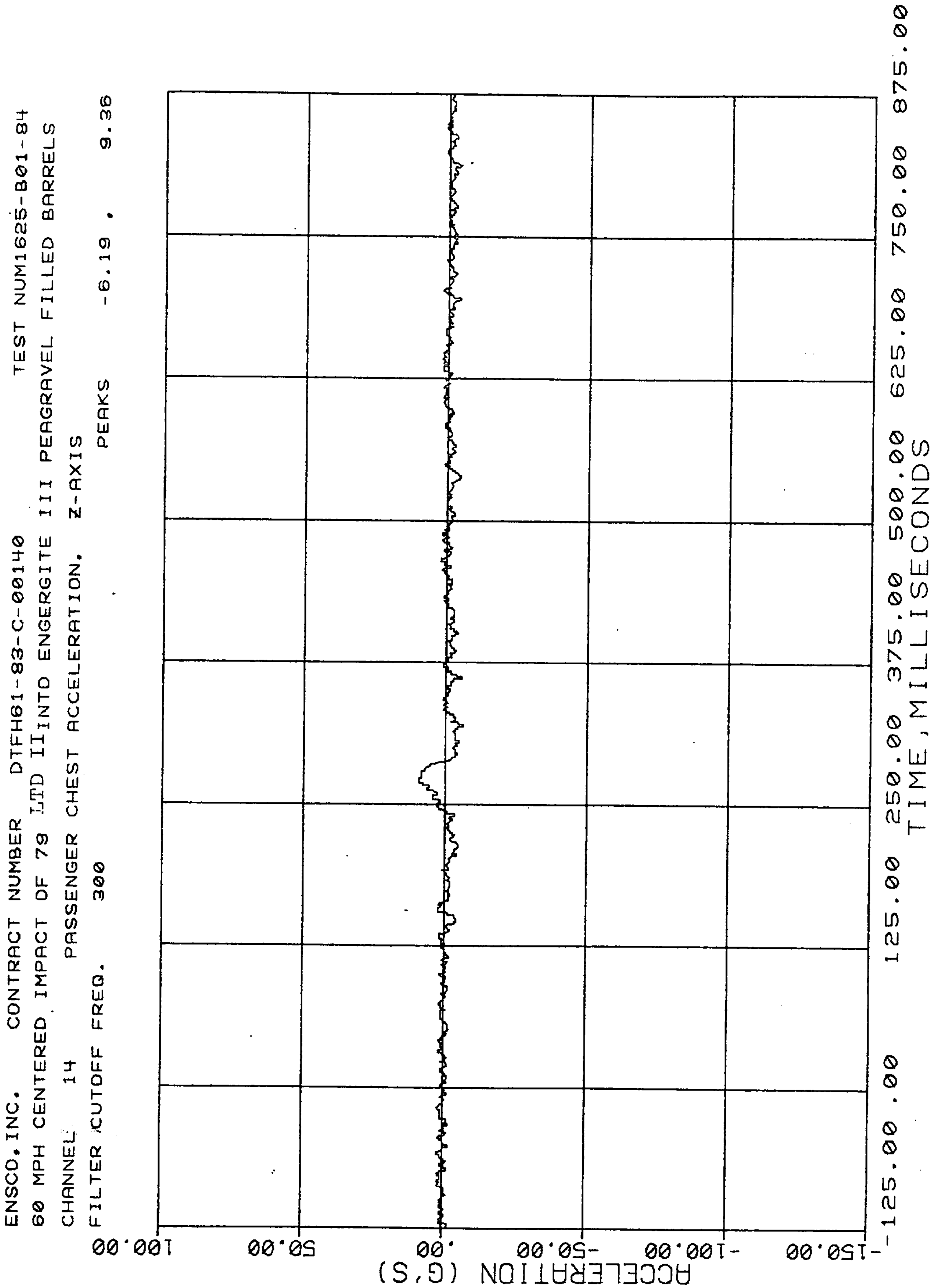
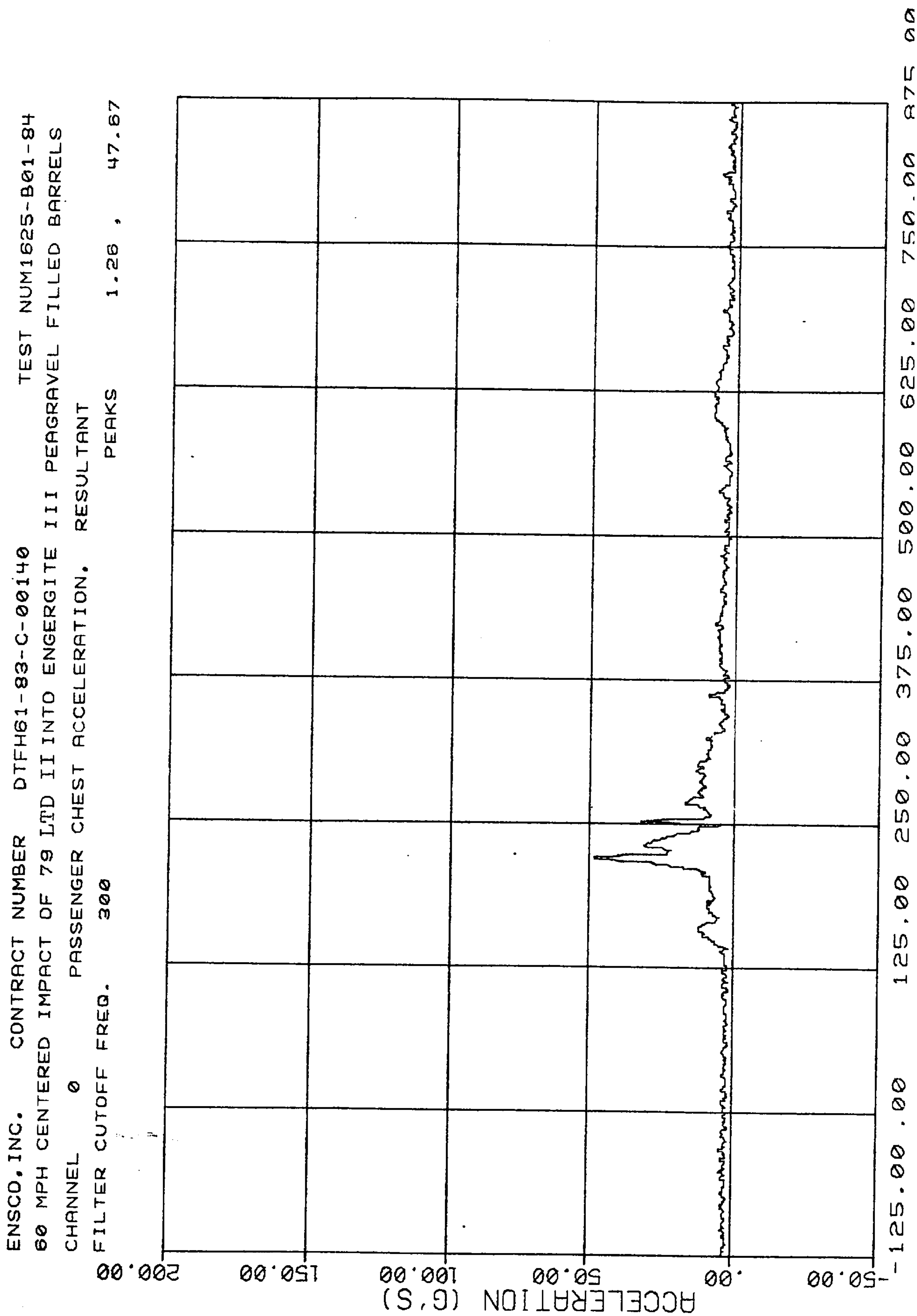

ENSCO, INC.   CONTRACT NUMBER   DTFH61-83-C-00140   TEST NUM1625-B01-84
60 MPH CENTERED IMPACT OF 79 LTD II INTO ENGERGITE III PEAGRAVEL FILLED BARRELS
CHANNEL 14   PASSENGER CHEST ACCELERATION. Z-AXIS
FILTER CUTOFF FREQ. 300   PEAKS -6.19 , 9.36
-125.00
.00
125.00
250.00
375.00
500.00
625.00
750.00
875.00
TIME, MILLISECONDS
100.00
50.00
.00
-50.00
-100.00
-150.00
ACCELERATION (G'S)

Figure 4-24.



ENSCO, INC.
CONTRACT NUMBER DTFH61-83-C-00140
TEST NUM1625-B01-84
60 MPH CENTERED IMPACT OF 79 LTD II INTO ENGERGITE III PEAGRAVEL FILLED BARRELS
CHANNEL 0
PASSENGER CHEST ACCELERATION. RESULTANT
FILTER CUTOFF FREQ. 300
PEAKS 1.26 , 47.67
ACCELERATION (G'S)
200.00
150.00
100.00
50.00
.00
-50.00
-125.00
.00
125.00
250.00
375.00
500.00
625.00
750.00
875.00

Figure 4-25.

4.2.3 FEMUR LOAD EVALUATION

The data obtained from the two load cells located in the femur of each leg of the driver and passenger were filtered at SAE 600. The maximum load which occurred in each femur was then determined and compared to the acceptable limit of 2,250 lbs as specified in FMVSS 208.[8] The load traces obtained with the use of the SAE Class 600 (f_c = 1000 Hz) filtering technique are presented in Figures 4-26 and 4-27 for the driver and in Figures 4-28 and 4-29 for the passenger. The maximum femur loads of the driver were 620 pounds for the right leg and 625 pounds for the left leg. The maximum femur loads of the passenger were 786 pounds for the right leg and 525 pounds for the left leg. The measured femur loads are well below the acceptable limit of 2,250 pounds. Figures 4-26 and 4-29 contain electrical spiking of the data probably due to intermittent electrical connections during the impact event.

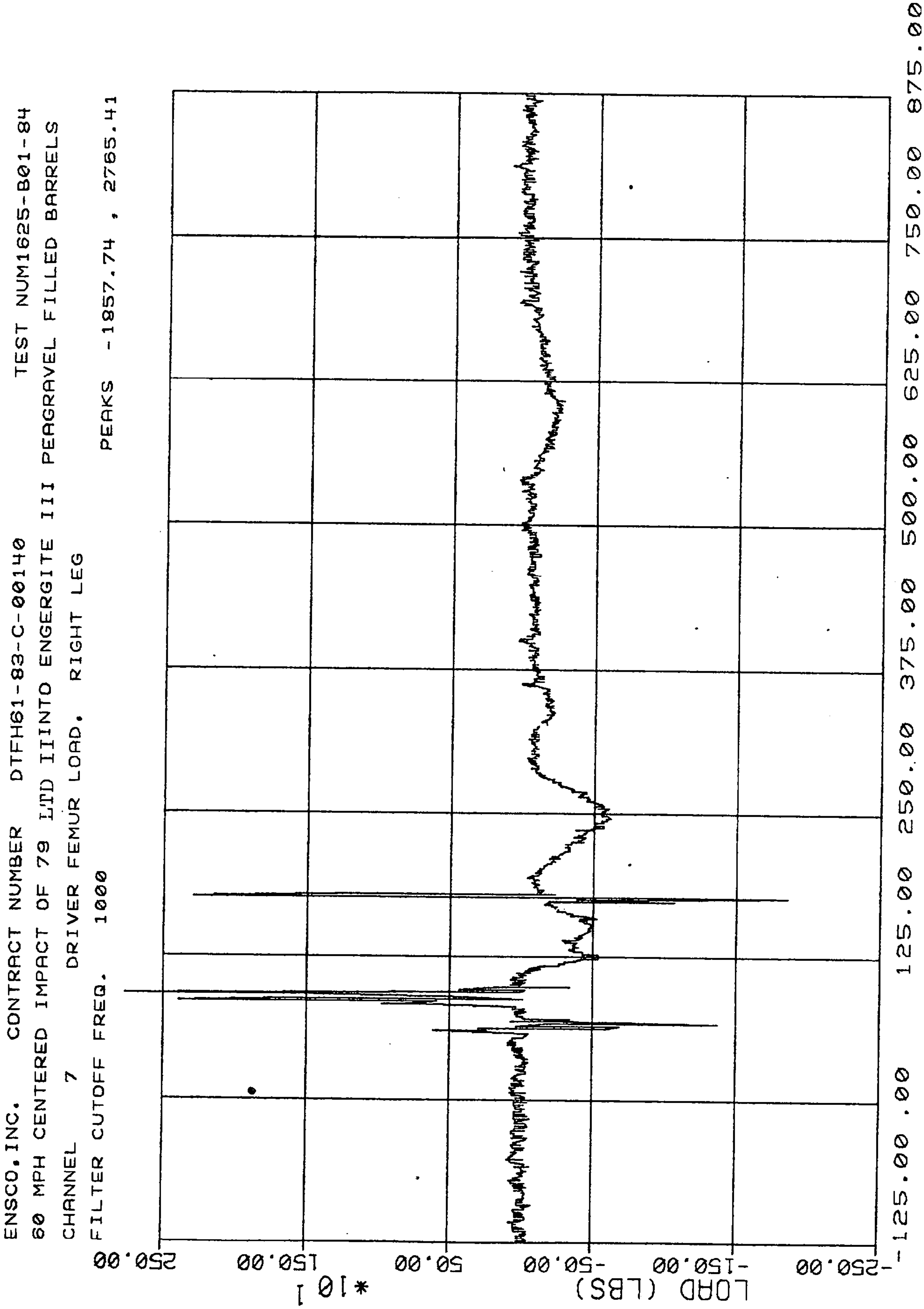

ENSCO.INC. CONTRACT NUMBER DTFH61-83-C-00140 TEST NUM1625-B01-84
60 MPH CENTERED IMPACT OF 79 LTD IIINTO ENGERGITE III PEAGRAVEL FILLED BARRELS
CHANNEL 7 DRIVER FEMUR LOAD. RIGHT LEG
FILTER CUTOFF FREQ. 1000
PEAKS -1857.74 , 2765.41
250.00
150.00
50.00
-50.00
-150.00
-250.00
*10 1
LOAD (LBS)
-125.00
.00
125.00
250.00
375.00
500.00
625.00
750.00
875.00

Figure 4-26.

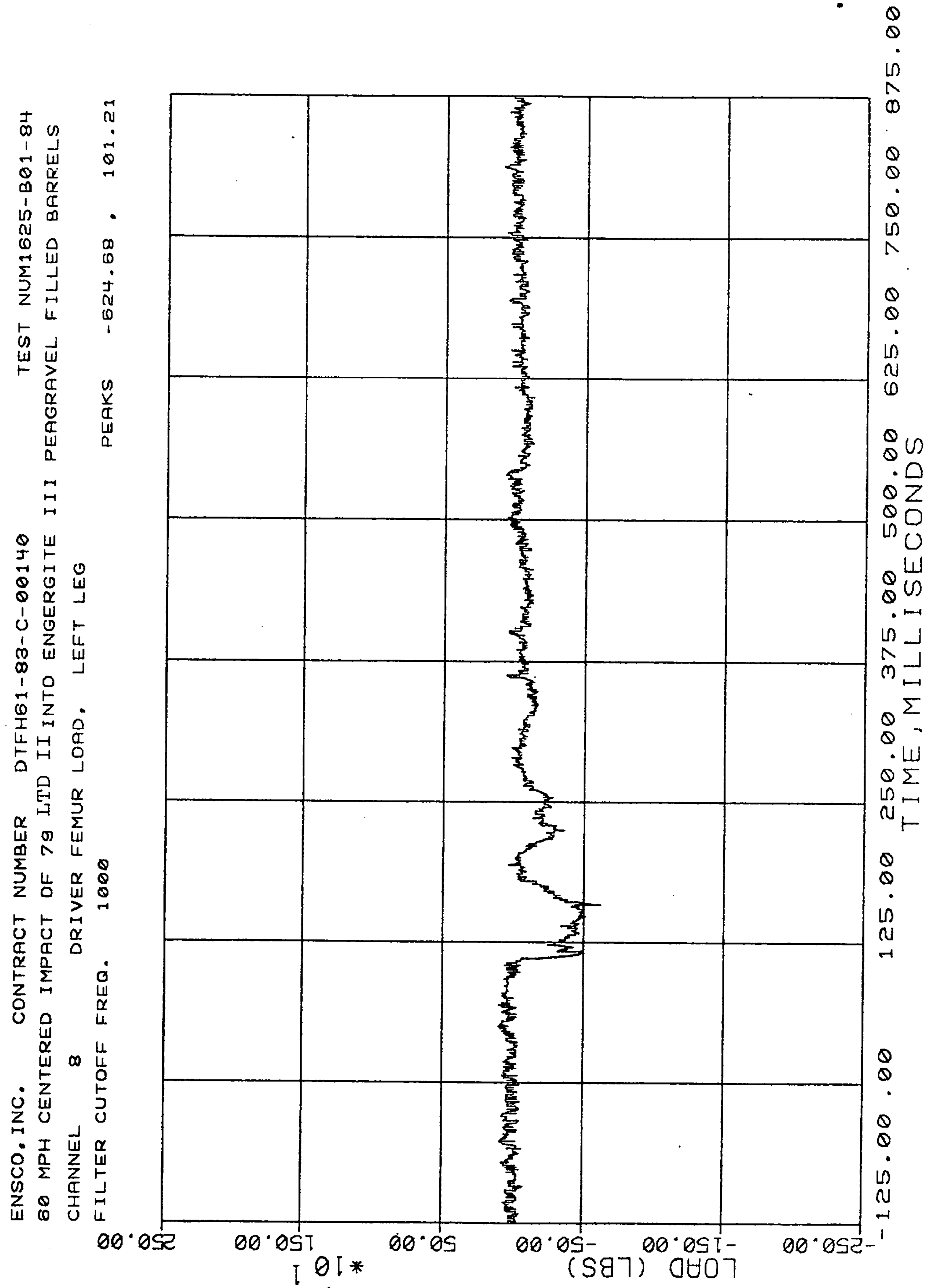

ENSCO, INC.   CONTRACT NUMBER   DTFH61-83-C-00140   TEST NUM1625-B01-84
60 MPH CENTERED IMPACT OF 79 LTD II INTO ENGERGITE III PEAGRAVEL FILLED BARRELS
CHANNEL 8   DRIVER FEMUR LOAD, LEFT LEG
FILTER CUTOFF FREQ. 1000   PEAKS -624.68 , 101.21
-125.00
.00
125.00
250.00
375.00
500.00
625.00
750.00
875.00
TIME, MILLISECONDS
250.00
150.00
50.00
-50.00
-150.00
-250.00
*10 1
LOAD (LBS)

Figure 4-27.

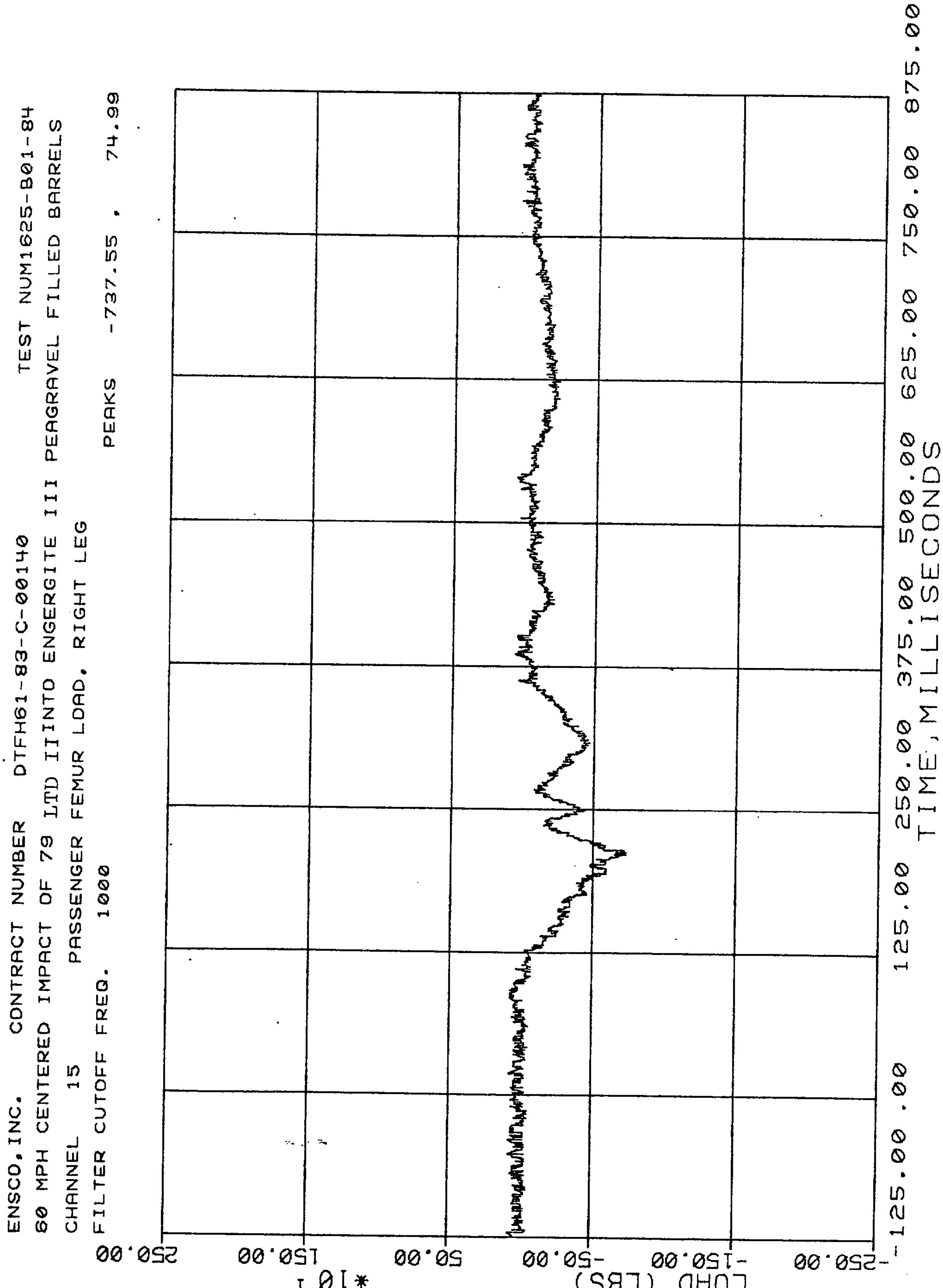

ENSCO, INC.
CONTRACT NUMBER DTFH61-83-C-00140
TEST NUM1625-B01-84
60 MPH CENTERED IMPACT OF 79 LTD II INTO ENGERGITE III PEAGRAVEL FILLED BARRELS
CHANNEL 15
PASSENGER FEMUR LOAD, RIGHT LEG
FILTER CUTOFF FREQ. 1000
PEAKS -737.55 , 74.99
-125.00 .00 125.00 250.00 375.00 500.00 625.00 750.00 875.00
TIME, MILLISECONDS
250.00 150.00 50.00 -50.00 -150.00 -250.00
*10 1
LOAD (LBS)

Figure 4-28.

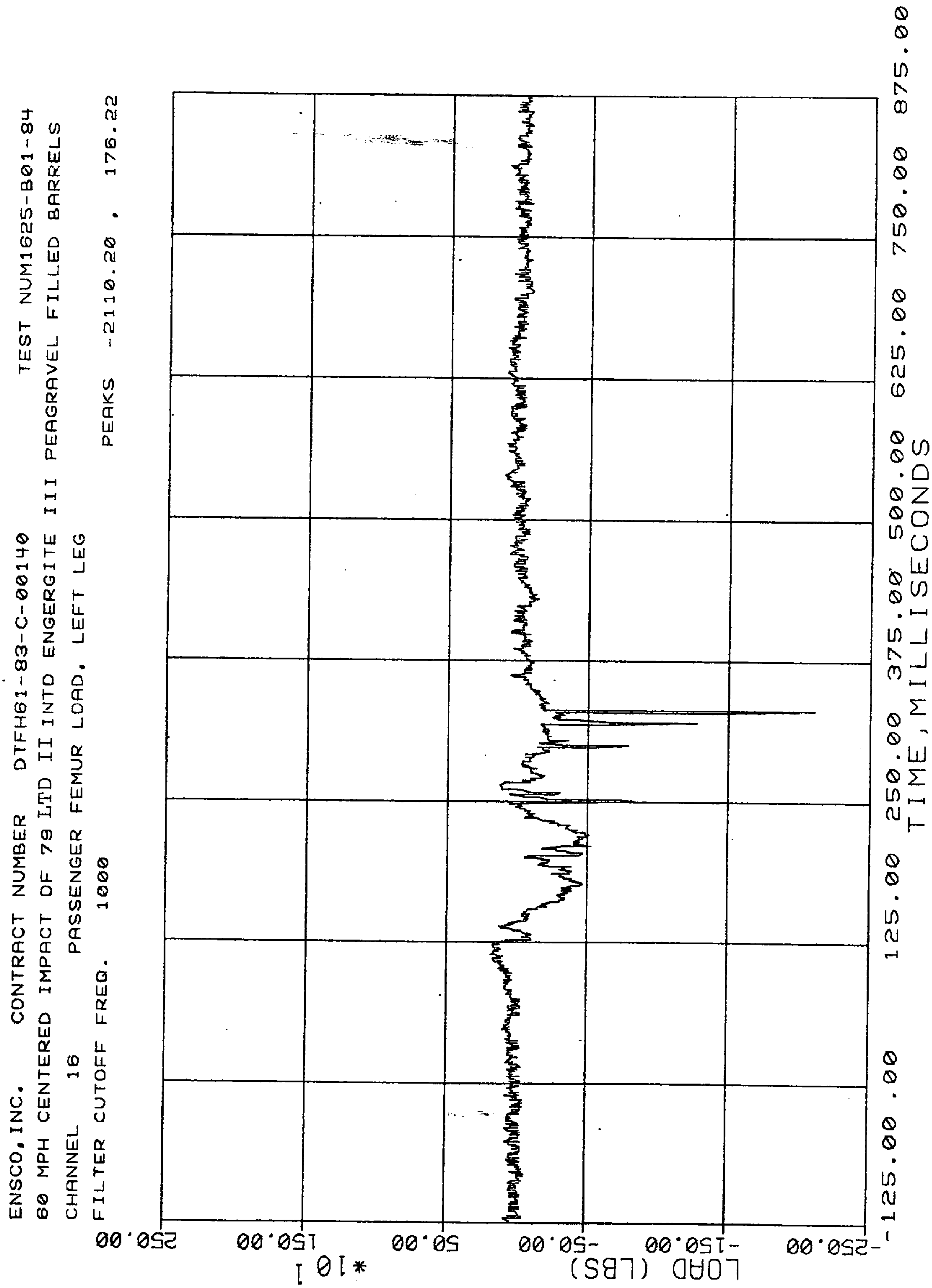

ENSCO, INC.   CONTRACT NUMBER   DTFH61-83-C-00140   TEST NUM1625-B01-84
60 MPH CENTERED IMPACT OF 79 LTD II INTO ENGERGITE III PEAGRAVEL FILLED BARRELS
CHANNEL   16   PASSENGER FEMUR LOAD, LEFT LEG
FILTER CUTOFF FREQ.   1000   PEAKS   -2110.20 ,   176.22
-125.00
.00
125.00
250.00
375.00
500.00
625.00
750.00
875.00
TIME, MILLISECONDS
250.00
150.00
50.00
-50.00
-150.00
-250.00
*10 1
LOAD (LBS)

Figure 4-29.

4.3 IMPACT ATTENUATOR ANALYSIS

The force-deflection characteristic and the total energy absorbed by the Energite III impact attenuator system, as well as the vehicle speed reduction, are estimated in this section. The law of physics can be applied for this test by modeling the vehicle/Energite III impact attenuator as shown in Figure 4-30. The vehicle is a moving mass (M_C) with a crush stiffness of K_C, the dummies are a moving mass (M_D) with the vehicle interior crush stiffness of K_I, and the stationary Energite III system has a crush stiffness of K_B.

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:

$$\frac{1}{2} \times \frac{4312 \text{ lbs}}{32.2 \text{ ft/sec}^2} \times \frac{(86.3 \text{ ft/sec})^2}{1000 \text{ lbs/kip}} = 498.7 \text{ kip-ft}$$

The kinetic energy delivered by the 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 dummies (KE_D) equals

$$\frac{1}{2} \times \frac{309 \text{ lbs}}{32.2 \text{ ft/sec}^2} \times \frac{(86.3 \text{ ft/sec})^2}{1000 \text{ lbs/kip}} = 35.7 \text{ kip-ft}$$

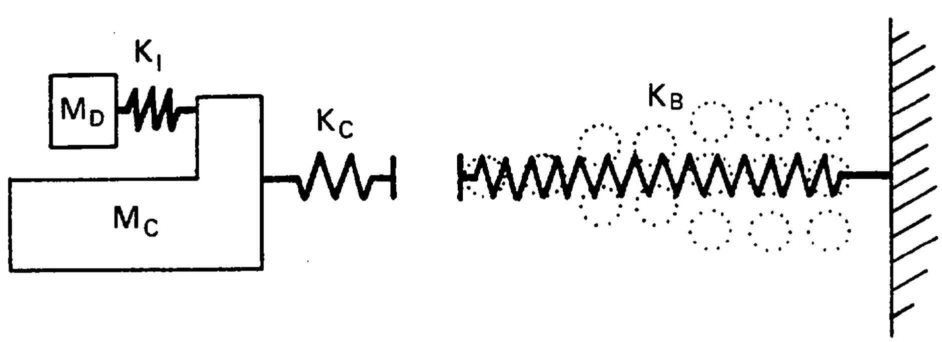


Figure 4-30. Schematic of Vehicle/Energite III Interaction.

The total kinetic energy delivered by the vehicle and the dummy is 534.4 kip-ft (498.7 + 35.7). It is felt that approximately 50% of KE_D is absorbed in the vehicle when the dummies crush the steering column, and bounce in the occupant compartment.

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

1. The first approximation uses the ratio of the vehicle crush to the Energite III crush. The energy aborbed by the Energite III 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 4-31 a force vs displacement curve was generated over the 23.5 feet stopping distance of the vehicle c.g., representing vehicle and barrel crush together. Integration of Figure 4-31 produced the total energy of the system equal to 520 kip-ft as shown in Figure 4-32. This explains over 97% of the kinetic energy delivered by the vehicle and the dummy.

Visual observation of the overhead movie film indicated that the frontal crush of the vehicle was 0.5 feet. Thus, the crush of the barrel system equals 23.5 - 0.5 = 23.0 feet. A first order estimate of the energy of the Energite III system is the total energy of the system times the ratio of barrel crush/vehicle c.g. stopping distance, as shown below.

$$\text{ENERGITE III ENERGY ABSORBED} = 520 \text{ kip-ft} \times \frac{23.0}{23.5} = 508.9 \text{ kip-ft}$$

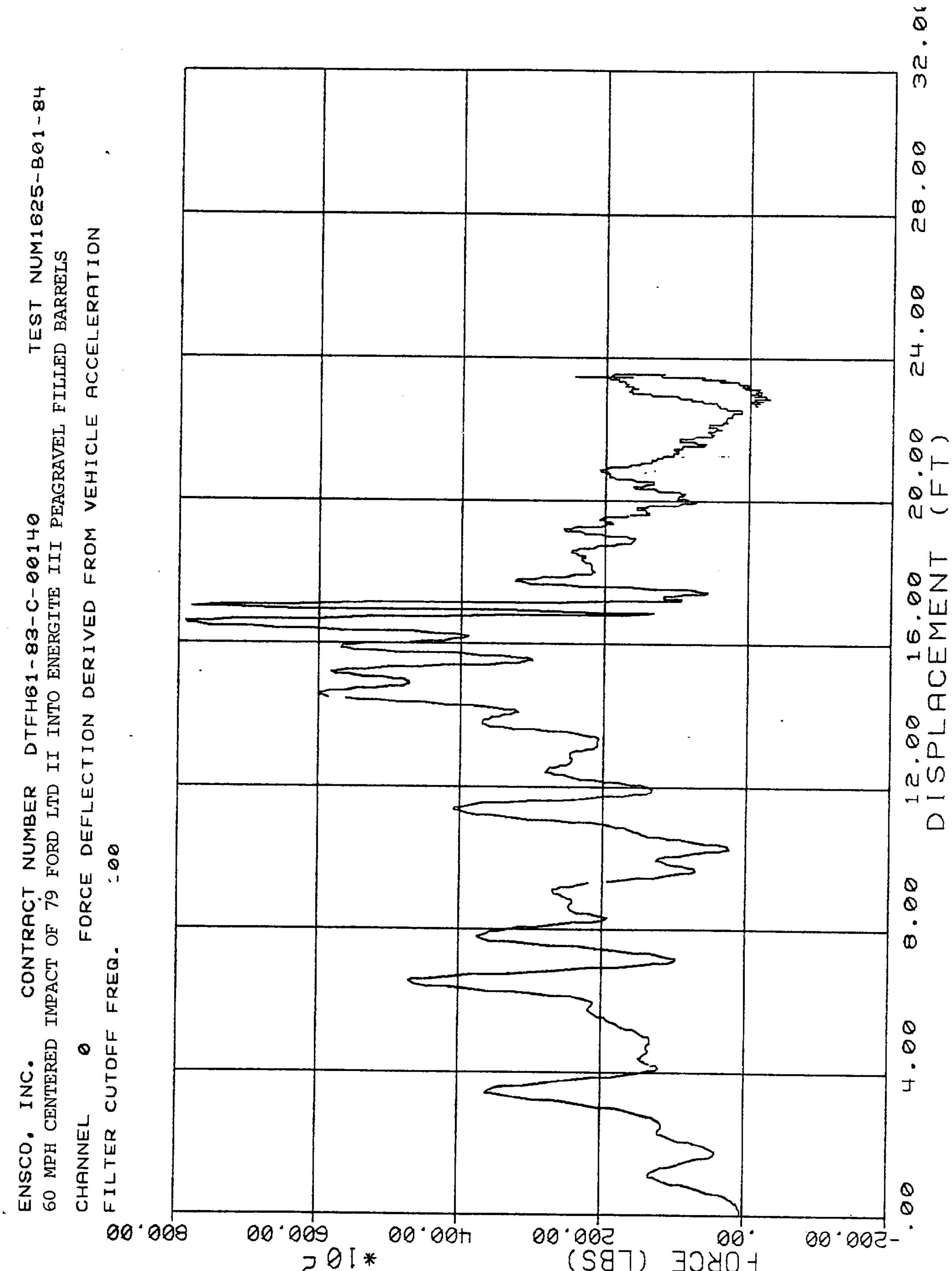

ENSCO, INC. CONTRACT NUMBER DTFH61-83-C-00140 TEST NUM1625-B01-84
60 MPH CENTERED IMPACT OF 79 FORD LTD II INTO ENERGITE III PEAGRAVEL FILLED BARRELS
CHANNEL 0 FORCE DEFLECTION DERIVED FROM VEHICLE ACCELERATION
FILTER CUTOFF FREQ. .00
FORCE (LBS) *10²
800.00
600.00
400.00
200.00
.00
-200.00
DISPLACEMENT (FT)
.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00

Figure 4-31.

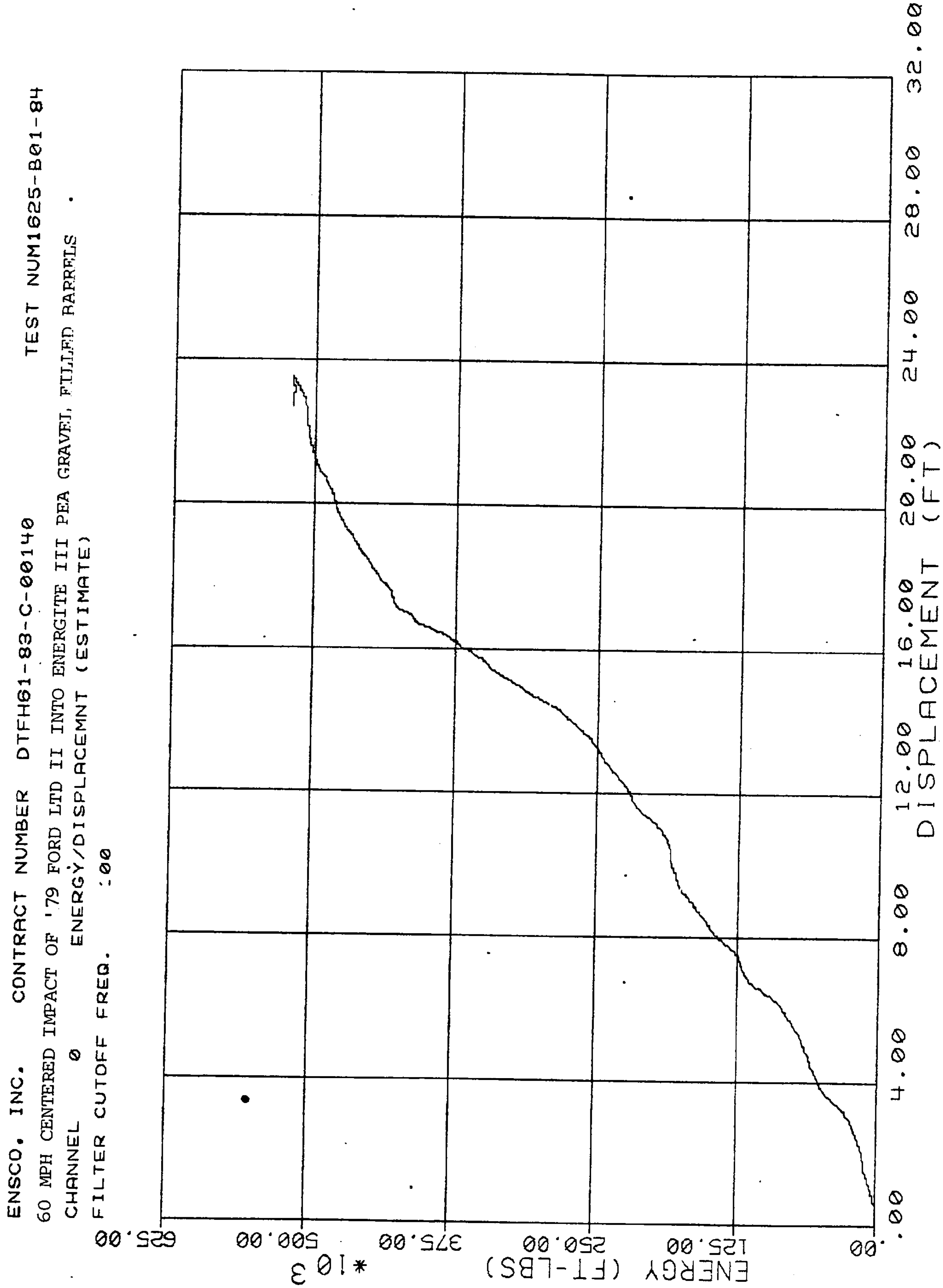

ENSCO, INC.   CONTRACT NUMBER DTFH61-83-C-00140   TEST NUM1625-B01-84
60 MPH CENTERED IMPACT OF '79 FORD LTD II INTO ENERGITE III PEA GRAVEL FILLED BARRELS
CHANNEL 0   ENERGY/DISPLACEMNT (ESTIMATE)
FILTER CUTOFF FREQ. :00
.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
DISPLACEMENT (FT)
.00
125.00
250.00
375.00
500.00
625.00
ENERGY (FT-LBS) *10 3

Figure 4-32.

The absorbed energy of the vehicle is 520 - 508.9 = 11.1 kip-ft.

To estimate the force vs. displacement curve of the ENERGITE III system the displacement axis of Figure 4-31 was scaled down in a linear fashion by the ratio of 23.0/23.5 or 97.9%. Figure 4-33 shows the force vs displacement curve of the Energite III system using this simple approximation. It is felt that Figure 4-33 is only an approximation because it assumes that vehicle crush occurs in a linear fashion over the entire crush region of the barrel system. Review of the movie film data indicates that the vehicle crushes during the first half of the Energite III system crush.

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

2. The second approximation method assumes that vehicle crush is completed at the maximum force level experienced by the vehicle c.g. Using Figure 4-31, the maximum force level of 78.5 kips occurs at 16.5 feet of c.g. displacement. Knowing that the vehicle front crushed 0.5 feet from movie films and static measurements, the energy of the impact attenuator and vehicle can be estimated at the 16.5 displacement. The total energy absorbed at this point is determined from Figure 4-32 as 380 kip-ft.

The energy absorbed by the vehicle is 380 kip-ft x 0.5 ft/16.5 ft = 11.5 kips. Therefore, the energy absorbed by the Energite III system over the entire event is the total energy absorbed (520 kip-ft) minus the energy absorbed by the vehicle. This value equals 520 - 11.5 = 508.5 kip ft.

Based on this approximation method the crush of the vehicle was 0.5 feet and the deflection of the Energite III barrels were 16.0 feet at the maximum force of 78.5 kips. From the maximum force location it is assumed that the vehicle no longer is crushing.

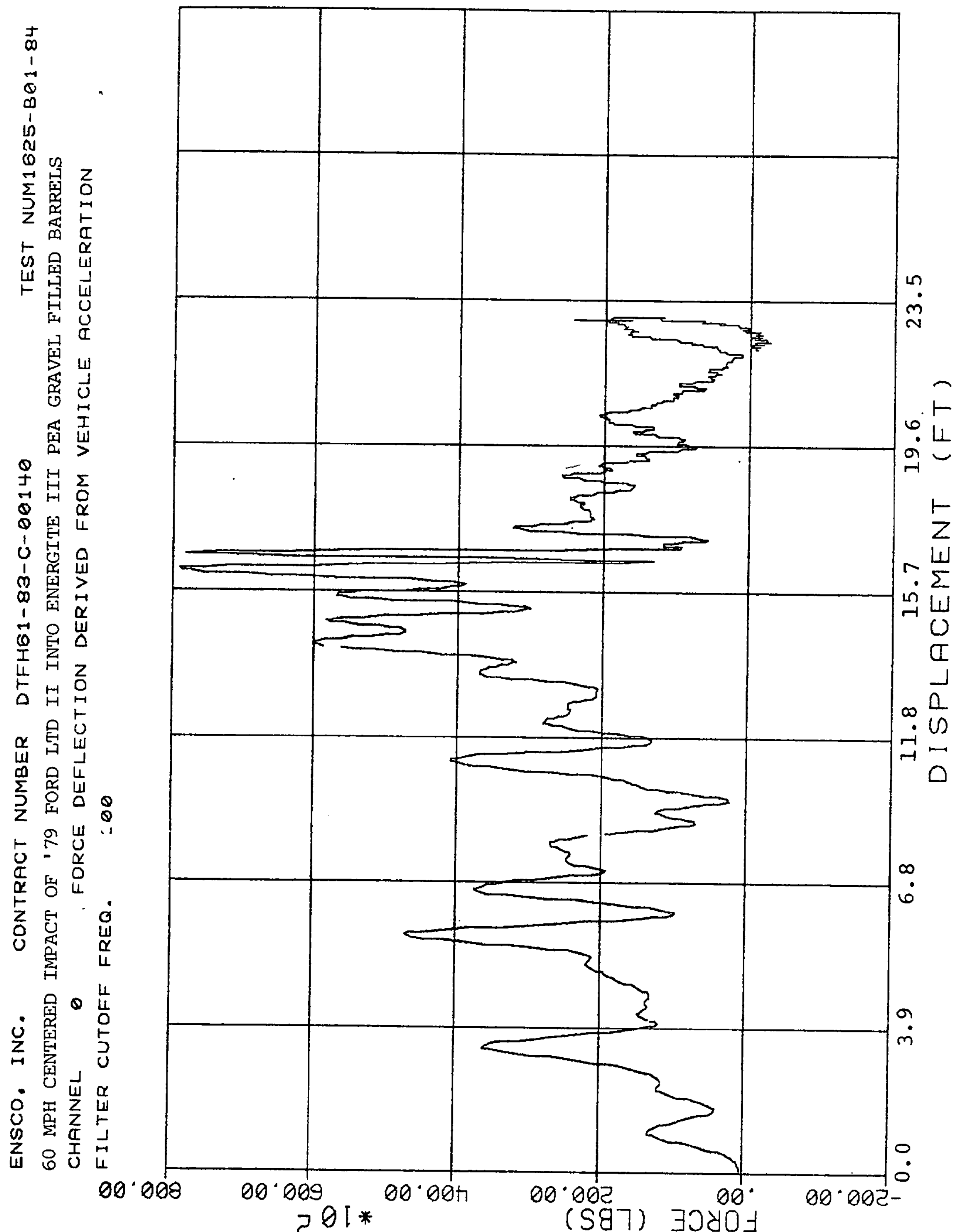

ENSCO. INC.
CONTRACT NUMBER DTFH61-83-C-00140
TEST NUM1625-B01-84
60 MPH CENTERED IMPACT OF '79 FORD LTD II INTO ENERGITE III PEA GRAVEL FILLED BARRELS
CHANNEL 0
FORCE DEFLECTION DERIVED FROM VEHICLE ACCELERATION
FILTER CUTOFF FREQ. 100
0.0
3.9
6.8
11.8
15.7
19.6
23.5
DISPLACEMENT (FT)
-200.00
.00
200.00
400.00
600.00
800.00
FORCE (LBS)
*10 2

Figure 33

Figure 4-34 presents the force vs deflection curve of the Energite III system over the entire impact using this approach. This curve was produced by scaling Figure 4-32, as required, about the maximum force location.

In summary, methods 1 and 2 have similar results for approximating the energy absorbed during the impact. Assuming that 50% of dummy kinetic energy is absorbed in the vehicle, then a total of 516.6 kip-ft (498.7 + 17.9) or 99% of the total vehicle/dummy kinetic energy is explained. Furthermore, the energy absorbed by the Energite III system of 508.9 kip-ft by method 1 and 508.5 kip-ft by method 2, are nearly identical results. The energy absorbed by the vehicle frontal crush is quite similar. Method 1 predicted 11.1 kip-ft and method 2 predicted 11.5 kip-ft.

The force vs deflection characteristics described in methods 1 and 2 are approached somewhat different. Method 2 is more realistic and accurate in describing test 1625-B-01-84.

As the vehicle proceeds through the impact attenuator, its velocity can be estimated by integrating the longitudinal acceleration measurements over the stopping distance of the vehicle c.g. Figure 4-35 presents this estimate over the crush distance (23.0 feet) of the Energite III system as the solid line. In addition, a dashed line is plotted based on the results of the computer model included in the full scale crash test plan, report number FHWA 84-03. This model applies the laws of physics and momentum transfer to estimate vehicle speed change. As can be seen in Figure 4-35 the model did a very good job of predicting vehicle speed versus attenuator displacement.

4.4 NHTSA DATA TAPE

A digital magnetic tape containing the data from test 1625-B-01-84 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:

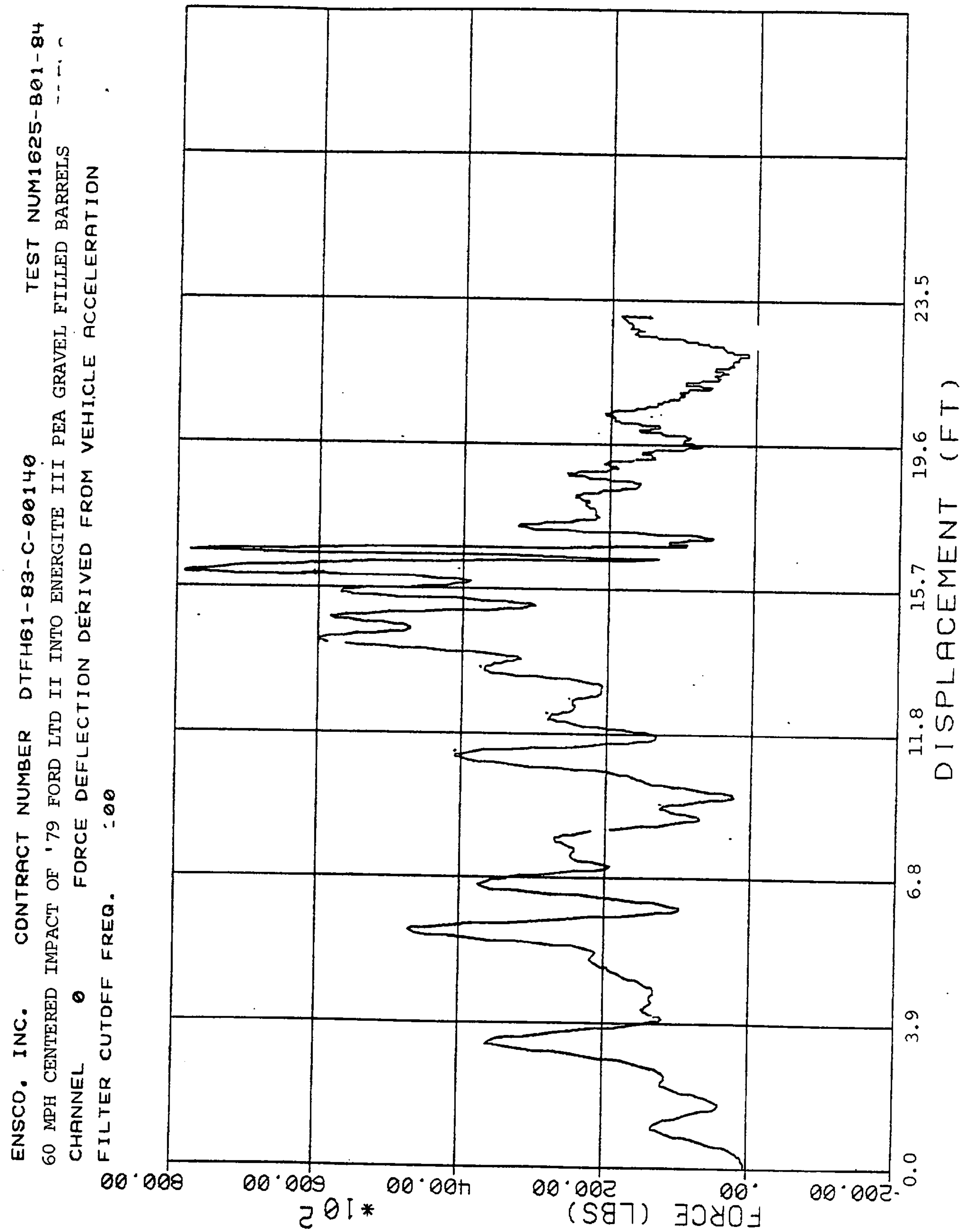

ENSCO, INC.
CONTRACT NUMBER DTFH61-83-C-00140
TEST NUM1625-B01-84
60 MPH CENTERED IMPACT OF '79 FORD LTD II INTO ENERGITE III PEA GRAVEL FILLED BARRELS
CHANNEL 0
FORCE DEFLECTION DERIVED FROM VEHICLE ACCELERATION
FILTER CUTOFF FREQ.
0.0
3.9
6.8
11.8
15.7
19.6
23.5
DISPLACEMENT (FT)
-200.00
.00
200.00
400.00
600.00
800.00
FORCE (LBS)
*10 2

Figure 4-34

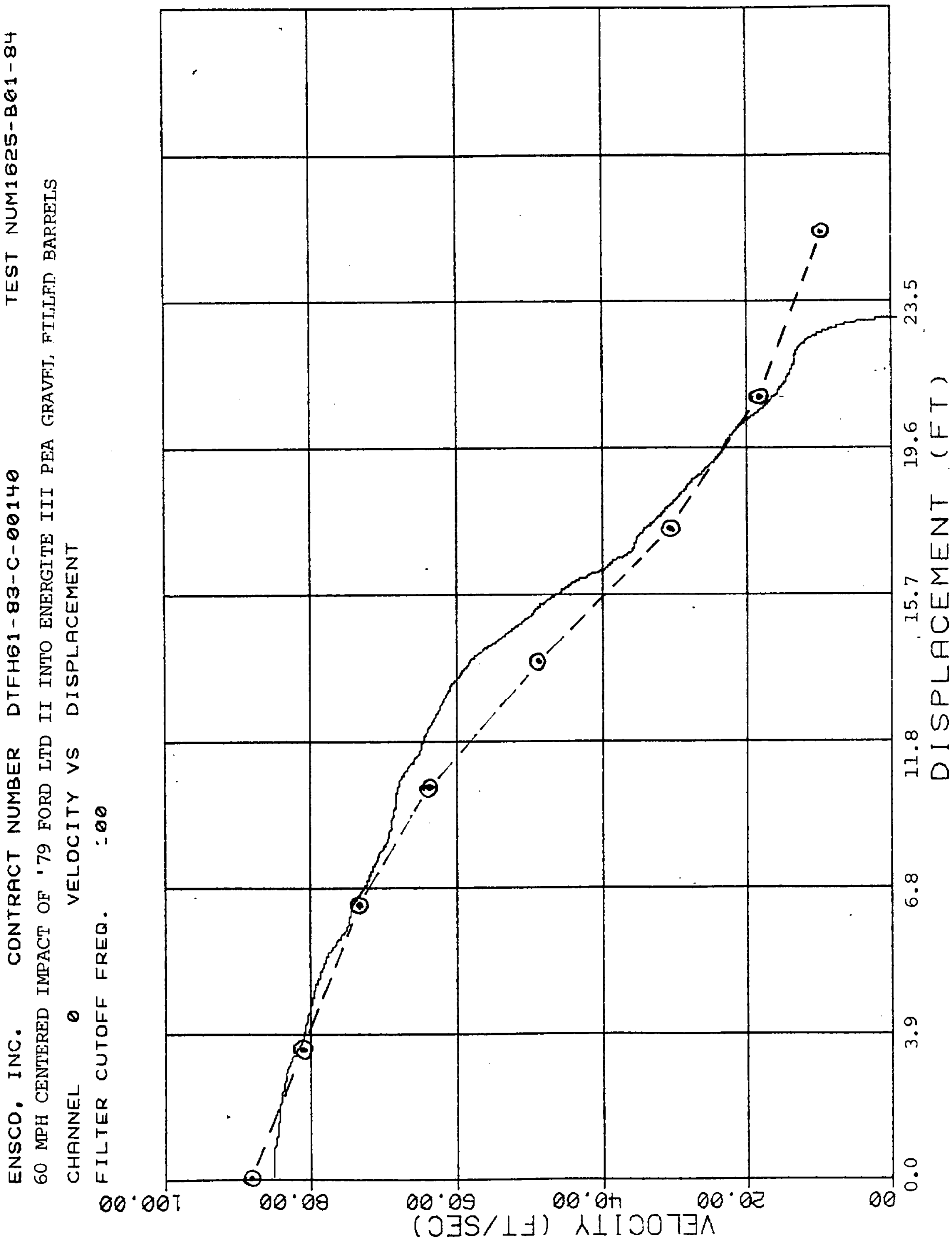

ENSCO, INC. CONTRACT NUMBER DTFH61-83-C-00140 TEST NUM1625-B01-84
60 MPH CENTERED IMPACT OF '79 FORD LTD II INTO ENERGITE III PEA GRAVEL FILLED BARRELS
CHANNEL 0 VELOCITY VS DISPLACEMENT
FILTER CUTOFF FREQ. 100
0.0
3.9
6.8
11.8
15.7
19.6
23.5
DISPLACEMENT (FT)
100.00
80.00
60.00
40.00
20.00
00
VELOCITY (FT/SEC)

Figure 4-35

- 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 15-barrel Energite III impact attenuator. The test results indicate a controlled arresting of the vehicle in 23.5 feet with minimal rebounding of the vehicle. In addition, little yawing, rolling, or pitching of the vehicle were observed. However, the 36' x 47' area of pea gravel could provide danger to oncoming traffic. The impact should be considered severe due to the very nature of stopping the vehicle from an initial speed of 60 mph in 23.5 feet.

Safety performance of the impact attenuator 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-B-01-84. From a structural adequacy standpoint the Energite III system performed adequately. The system remained essentially intact;however, barrel lids, fragments, and pea gravel were scattered. The system did provide predictable controlled penetration.

Occupant risk was appraised with fairly good results. Using the instrumented dummy parameters the test was acceptable except for the drivers peak chest acceleration. Using the vehicle data to simulate occupant risk the test was good. Based on the TRC 191 and FMVSS 208 data, it appears that NCHRP 230 criteria are slightly conservative in nature (too low). The ridedown acceleration was slightly above the design value. Combining the dummy and vehicle parameters, occupant risk should be considered moderate.

Vehicle trajectory hazard was rated good. The vehicle was controlled during and after the crash. Rebound of the vehicle was less than 2 feet. Considering the fact that the vehicle transmission was in neutral during the test, thus allowing free travel of the vehicle, the results should be considered good.

TABLE 5-1
SAFETY EVALUATION PARAMETERS

	Structural Adequacy	Occupant Risk		Vehicle Trajectory
		Dummy	Vehicle	
TRC 191	Adequate Predictable Controlled Penetration Scattered Debris Fill Material Scattered	Not Applicable	Acceptable Below Absolute Design Value	Moderate Potential Risk Remained in Vehicle Directional Path
FMVSS 208	Not Applicable	Acceptable Most Parameters Below Acceptable Limits	Not Applicable	Not Applicable
NCHRP 230	Adequate It Remained Fairly Intact Much Debris Pea Gravel Causes Problem	Not Applicable	Below Limit Values ΔV Below Design Value Ridedown Above Design Value	Low Trajectory Hazard Remained in own Traffic Lane Controllable Post Crash

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. The Energite System, The Better Inertial Barrier For Law Frequency Impact.

4. The Energite III System, The Better Inertial Barrier for Law-Frequency Impact Sites, Form No. EN 310-882.

5. The Energite III Inertial Barrier System, Energy Absorption Systems, Inc., January 1983.

6. Energite Array fopr ENSCO Testing Agency, Drawing Numbers 58-01-31, 58-01-32.

7. Crash Test Evaluation of the Energite Module Inertial Barrier, Energy Absorption Systems, Inc., 18 October 1974.

8. Crash Cushions, Selection Criteria and Design, U.S. Department of Transportation, Federal Highway Administration, September 1975.

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

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

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

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

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

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

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

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

APPENDIX A

DUMMY CALIBRATION DATA

P.572 DUMMY CALIBRATION TEST DATA

HHTSA I.D. NO.:

LABORATORY TECHNICIAN: John Hinch, D. Sawyer

	Pre-Test Calibration	Post-Test Calibration
Date of Dummy Calibration		
Calibration Sequential Number For Dummy	12 (#186)	13 (#189)
Temperature in Lab. (Spec. = 66 to 78° F)		
Relative Humidity in Lab. (Spec. = 10 to 70%)		

TEST PARAMETER			SPECIFICATION	Pre-Test Calibration	Post-Test Calibration
1. HEAD DROP TEST:					
a. Peak Resultant Accel.			210 to 260G	241.00	236.00
b. Peak Lateral Accel.			≤ 10G	7.00	2.50
c. Time above 100G			0.9 to 1.5 ms	1.25	1.30
2. NECK BENDING TEST:					
a. Pendulum Speed			21.5 to 25.5 fps	25.50	25.10
b. Pendulum Avg. Decel. (over $t_3 - t_2$)			20 to 24G	22.90	23.00
c. Peak Resultant Head Acceleration			26G maximum	23.50	26.00
d. Pendulum Decel. (t_2-t_1)			≤ 3 ms	2.20	2.50
e. Pendulum Decel. (t_3-t_2)			25 to 30 ms	27.50	27.50
f. Pendulum Decel. (t_4-t_3)			≤ 10 ms	4.70	4.70
g. Pendulum Direction Reversal Time				112.00	109.00
h. Max. Head Rotation			63 to 73°	65°	64°
i. Chordal Displacement: Head Rotation Angle					
	0°	Time	-2 to 2 ms	0.00	0.00
		Displ.	-.5 to .5 in.	0.00	0.00
	30°	Time	25.6 to 34.4 ms	28.00	30.00
		Displ.	2.1 to 3.1 in.	2.80	3.00
	60°	Time	40.3 to 51.7 ms	48.00	48.00
		Displ.	4.3 to 5.3 in.	5.10	5.10
	Maximum (65 °)	Time	53.2 to 66.8 ms	60.00	56.00
		Displ.	5.0 to 6.0 in.	5.70	5.30

Dummy I.D. No.:

TEST PARAMETER			SPECIFICATION	Pre-Test Calibration	Post-Test Calibration
2. NECK BENDING TEST.... Continued:					
i. Chordal Displacement: Head Rotation Angle--				12	13
	60°	Time	67.0 to 83.0 ms	67.00	67.00
		Displ.	4.3 to 5.3 in.	4.90	4.80
	30°	Time	85.4 to 104.6 ms	86.00	86.00
		Displ.	2.1 to 3.1 in.	2.30	2.30
	0°	Time	101.0 to 123.0 ms	102.00	101.00
		Displ.	-.5 to 0.5 in.	0.00	0.00
3. ABDOMINAL COMPRESSION TEST:					
(Preload = 10 pounds)					
a. Force @ .5"------			23.5 to 36.5 lbs.	28.50	32.50
b. Force @ .75"-----			36.8 to 49.8 lbs.	37.00	44.60
c. Force @ 1.0"-----			50 to 63 lbs.	51.00	60.40
d. Force @ 1.3"-----			73 to 88 lbs.	79.00	88.00
4. LUMBAR FLEXION TEST:					
a. Force @ 20°------			22 to 34 lbs.	Initial 20° 27.00	Initial 12° 24.00
b. Force @ 30°------			34 to 46 lbs.	36.50	35.00
c. Force @ 40°------			46 to 58 lbs.	54.00	47.00
d. Return Angle -----			12° maximum	10° (30°)	7° (19°)
5. CHEST IMPACT TESTS:					
a. High Speed					
(1) Probe Speed---			21.78-22.22 fps	21.81	22.05
(2) Peak Deflection-			1.7" maximum	1.64	1.36
(3) Peak Resistive Force------			2250 lbs. maximum	1676.00	1678.00
(4) Internal Hysteresis ---			50 to 70%	61%	65%
b. Low Speed					
(1) Probe Speed---			13.86-14.14 fps	14.04	14.01
(2) Peak Deflection-			1.1" maximum	1.10	0.86
(3) Peak Resistive Force------			1450 lbs. maximum	1224.00	1276.00
(4) Internal Hyster.			50 to 70%	68.00	51.00

P.572 DUMMY CALIBRATION TEST DATA....Continued:

Dummy I.D. No.:

TEST PARAMETER	SPECIFICATION	Pre-Test Calibration	Post-Test Calibration
6. KNEE IMPACT TESTS:		12	13
a. Right Side--			
(1) Probe Speed - - -	6.76 to 7.04 fps	6.82	6.84
(2) Maximum Force - -	1850 to 2500 lbs.	1936.00	1965.00
(3) Time Above 1000#-	1.7 ms minimum	2.20	1.80
b. Left Side--			
(1) Probe Speed - - -	6.76 to 7.04 fps	6.81	6.83
(2) Maximum Force - -	1850 to 2500 lbs.	2298.00	2382.00
(3) Time Above 1000#-	1.7 ms minimum	2.10	2.00