DOT#441

[redacted]

ENSCO, INC.®

LABORATORY PROCEDURES TO DETERMINE THE BREAKAWAY BEHAVIOR OF LUMINAIRE SUPPORTS IN MINI-SIZED VEHICLE COLLISIONS

FHWA CONTRACT NO.
DTFH61-81-C-00036

LOW SPEED OFF CENTER FRONTAL IMPACT OF A MINICOMPACT SEDAN AND A VALIDATED SURROGATE BREAKAWAY LUMINAIRE SUPPORT

TEST RESULTS REPORT

TEST NUMBER 1469-3A82

Howerter, E. D.
Hinch, J. A.
Owings, R. P.

Prepared for:

FEDERAL HIGHWAY ADMINISTRATION
Office of Research
400 Seventh Street, S.W.
Washington, DC 20590

12 April 1982

Prepared by:

ENSCO, INC.
Transportation Technology Engineering Division
5400 Port Royal Road
Springfield, VA 22151

NOTICE

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no liability for its contents or use thereof. The contents of this report reflect the views of the contractor, who is responsible for the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policy of the Department of Transportation. This report does not constitute a standard, specification, or regulation.

The United States Government does not endorse products, or manufacturers. Trade or manufactuers' names appear herein only because they are considered essential to the object of this document.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (Cont)

LIST OF FIGURES (Cont)

LIST OF TABLES

1.0 SUMMARY

This test investigated the impact behavior and post-impact stability of a minicompact sedan (1,800S) during a low speed off center collision with a surrogate breakaway luminaire support.[1,2] The test vehicle was a 1976 Volkswagon Rabbit.[3] The surrogate breakaway luminaire support was chosen since it was known to induce a momentum change close to the upper limit of the acceptable standard of 1,100 lb-sec (4,893 N-s) when impacted by a 1971 Chevrolet Vega at an impact speed of 60 mph (26.8 m/s).[4,5]

The test vehicle momentum change at the impact speed of 19.0 mph (8.49 m/s) was 1276 lb-sec (5,676 N-s) based on the analysis techniques specified for processing acceleration data given in NCHRP 230, with the corresponding velocity change being 13.18 mph (5.89 m/s).[6] Vehicle acceleration data was processed to determine the impact velocity of a hypothetical front seat passenger against the vehicle interior in accordance with NCHRP 230. The impact velocity of the hypothetical occupant was 19.45 ft/sec (5.93 m/s) which exceeds the design limit of 15.0 ft/sec (4.57 m/s) given in NCHRP 230. Analysis of the data from the anthropomorphic dummies indicated that they experienced an accident well within design limits for all parameters specified in NCHRP 230. The integrity of the test vehicle was maintained throughout the test and the roof structure of the test vehicle protected the occupants from injury when the 1003 pound luminaire support fell onto the vehicle roof. A summary of the test conditions and results for this full scale crash test are given in Table 1.

TABLE 1

SUMMARY OF TEST CONDITIONS AND
RESULTS FOR TEST NUMBER 1469-3A82

1.	Contract Number	DTFH61-81-C-00036
2.	Date of Test	March 29, 1982
3.	Test Vehicle	Volkswagon Rabbit, 1976
4.	Vehicle Weight, Original Conf. Actual	1,782 lbs
5.	Vehicle Weight, Test Inertial Planned Actual	1,800 ±50 lbs 1,807 lbs
6.	Vehicle Weight, Gross Static Planned (One Occupant) Actual (One Occupant)	1,950 ±50 lbs 1,970 lbs
7.	Vehicle Weight, Gross Static Actual (Two Occupants)	2,126 lbs
8.	Number of Occupants	Two
9.	Occupant Type	Anthropomorphic Dummy 50th Percentile Male
10.	Occupant Locations	Front, Driver and Passenger Seats
11.	Occupant Restraint Driver Passenger	 Restrained, Lap and Shoulder Belts Unrestrained
12.	Test Article	Surrogate Breakaway Luminaire Support
13.	Support Length (w/o Base)	34 ft
14.	Support Material	Steel 8-in (Nom.) Pipe (Schedule 40)
15.	Support Weight (w/Base)	1,002.7 lbs
16.	Base Type	Triangular Slip Base, 3-Bolt (Type 31)
17.	Slip Plane Mounting Height Above Grade	4.25 in

TABLE 1 (Cont'd)
SUMMARY OF TEST CONDITIONS AND
RESULTS FOR TEST NUMBER 1469-3A82

18.	Bolt Circle	14 in
19.	Bolt Size	1 in - 8 NC x 5 in long
20.	Bolt Load (Strain Gaged)	14,000 lbs each
21.	Foundation	W, 3 ft; L, 4 ft; D, 4 ft
22.	Ground Conditions	Dry
23.	Impact Speed	
	Planned	18.7 to 21.2 mph[6]
	Observed	19.0 mph
24.	Exit Speed, Observed	
	Acceleration Data, NCHRP 230	5.82 mph[6]
	Acceleration Data, TRC 191	5.84 mph[7]
25.	Speed Reduction, Observed	
	Acceleration Data, NCHRP 230	13.18 mph[6]
	Acceleration Data, TRC 191	13.16 mph[7]
26.	Impact Point	
	Planned	Front, Left of Centerline, 14.25 in
	Observed	Front, Left of Centerline, 12.25 in
27.	Impact Angle of Vehicle with Respect to Theoretical Mast Arm	30 Degrees[9]
28.	Exit Angle of Vehicle with Respect of Theoretical Mast Arm	38.8 Degrees
29.	Vehicle Crush	
	Residual	15.1 in
	Dynamic	19.25 in
30.	Traffic Accident Data, TAD[10]	12FLEN2
31.	Vehicle Damage Index, VDI[11]	12-FC-2

TABLE 1 (Cont'd)
SUMMARY OF TEST CONDITIONS AND
RESULTS FOR TEST NUMBER 1469-3A82

32.	Hypothetical Occupant Impact Velocity	
	Design Limit	15 ft/sec[6]
	Observed	19.45 ft/sec[6]
33.	Hypothetical Occupant Ride-down Acceleration	
	Design Limit	15.00 g[6]
	Observed	1.91 g[6]
34.	Head Injury Criteria (HIC)	
	Design Limit	1000[8]
	Driver, Observed	57
	Passenger, Observed	45
35.	Peak Resultant Chest Acceleration	
	Design Limit ($t \geq 0.003$ sec)	60 g[8]
	Driver, Observed	15.44 g
	Passenger, Observed	11.04 g
36.	Chest Severity Index (CSI)	
	Design Limit	1000[12]
	Driver, Observed	33
	Passenger, Observed	15
37.	Femur Loads	
	Design Limit	2250 lbs[8]
	Driver, Observed	
	Left Leg	+116.7 lbs (Extension)
	Right Leg	+98.6 lbs. (Extension)
	Passenger, Observed	
	Left Leg	-542.1 lb (Compression)
	Right Leg	-652.6 lb (Compression)
38.	Momentum Change	
	Acceleration Data, NCHRP 230	1276 lb-sec[6]
	Accelerations Data, TRC 191	1274 lb-sec[7]

---

1 lb = .454 kg
1 ft = .3048 m
1 in = .0254 m
1 lb-sec = 4.448 N-s
1 ft-kip = 1,355 N-m

2.0 OBJECTIVE

The objective of this test was to investigate the impact behavior and post-impact stability of a minicompact sedan (1,800S) during a low speed offcenter collision with a surrogate breakaway luminaire support. This test is the third of a series of five full scale crash tests to be conducted under Task A of Contract Number DTFH61-81-C-00036.[1,2]

The vehicle chosen for this test was a Volkswagon Rabbit based upon the results of a limited engineering study conducted by ENSCO, Inc.[3] The vehicle contained two instrumented 50th percentile male anthropomorphic test dummies located in the front driver and passenger seats, respectively. A triaxial accelerometer package was mounted on the lateral centerline of the vehicle at the longitudinal location of the center of gravity. These were used to measure vehicle impact behavior and occupant injury potential based upon criteria set forth in TRC 191 and NCHRP 230.[6,7] The vehicle also was instrumented with a contact switch mounted on the front bumper to permit vehicle and occupant data to be measured relative to the time of impact.

Each of the instrumented dummies had two triaxial accelerometer packages located at the center of gravity of the head and at the upper thorax region, respectively. These were used to yield the acceleration levels experienced in the respective regions of the test dummies and to analyze the Head Injury Criteria (HIC) and Chest Severity Index (CSI) for each occupant as specified in FMVSS 208 and SAE Information Report J885a.[8,12] The legs of each occupant contained load cells implanted in the femur to measure the load applied to the legs of the occupants during the collision for comparison with the acceptable limits specified in FMVSS 208.

The surrogate breakaway luminaire support was chosen since it was known to induce a momentum change close to the upper limit of the acceptable standard of 1,100 lb-sec (4,893 N-s) when impacted by a 1971 Chevrolet Vega at an impact speed of 60 mph (26.8 m/s).[4,5] The momentum change induced by the surrogate breakaway luminaire support when impacted by a 1971 Chevrolet Vega at an impact speed of 60 mph (26.8 m/s) during full scale crash test 1469-1A81 was 1,131 lb-sec (5031 N-s).[5]

3.0 APPURTENANCE DESCRIPTION

The physical properties of the surrogate breakaway luminaire support are contained in Table 2. The surrogate breakaway luminaire support incorporated a triangular 3-bolt slip base which was designed using the California state plan for a Type 31 support.[13] The luminaire support was installed using the guidelines provided by the California DOT.[13] The slip base was positioned so impact would occur against the lead bolt, which is equivalent to a 30° impact angle with respect to the mast arm.[9] The luminaire support did not have a mast arm attached during this test. The slip base was clamped together with three strain gaged bolts which were tightened to 14,000 pounds (62,300 N) each just prior to the test. The surrogate breakaway luminaire support is shown in Figure 1.

Figure 1. Pre-Crash Photograph of Surrogate Breakaway Luminaire Support

TABLE 2

SUMMARY OF PHYSICAL PROPERTIES OF
THE SURROGATE BREAKAWAY LUMINAIRE SUPPORT

Length (Support)	34 feet
Material (Support)	Steel 8-inch (Nom.) Pipe (Schedule 40)
Outside Diameter (Support)	8.625 inches (Actual)
Weight (Support)	28.55 lb/ft; 970.7 pounds
Wall Thickness (Support)	0.322-inch
Base Type	Triangular Slip Base, 3-Bolt (Type 31)
Base Thickness	1 inch
Weight (Base)	32 pounds
Weight (Total, M_p)	1002.7 pounds (31.14 slugs)
Base Bolts	1 inch diam. (Strain Gaged)
Bolt Circle	14 inch diam.
Bolt Load (Slip Base)	14,000 pounds
Mounting Height (Base)	0.25 feet
Mass Moment of Inertia, I_p	3183.8 lb-ft-sec^2
Center of Gravity, X_{cg}	16.56 feet
Impact Impulse Level Arm, D_I	15.38 feet

---

1 lb = .454 kg
1 ft = .3048 m
1 in = .0254 m
1 lb-sec = 4.448 N-s
1 lb-ft-sec^2 = 1.356 N-m-s^2

4.0 VEHICLE DESCRIPTION

The test vehicle was a 1976 Volkswagon Rabbit. The weight of the vehicle prior to incorporating the instrumentation for the test was 1,782 pounds. The test inertia weight for the vehicle was 1,807 pounds and the gross static weight when both occupants were included in the vehicle was 2,126 pounds. The longitudinal center of gravity of the vehicle without the occupants was located 32.8 inches behind the centerline of the front axle. The weight distribution of the vehicle in its as delivered and instrumented configurations are given in Tables 3 through 5.

TABLE 3

WEIGHT DISTRIBUTION OF TEST VEHICLE
IN AS DELIVERED CONFIGURATION

	Left (lbs)	Right (lbs)	Subtotal (lbs)
Front	590	565	1,155
Rear	310	317	627
Subtotal	900	882	1,782

1 lb = .454 kg

TABLE 4

WEIGHT DISTRIBUTION OF TEST VEHICLE
IN PRE-TEST CONFIGURATION WITHOUT OCCUPANTS

	Left (lbs)	Right (lbs)	Subtotal (lbs)
Front	599	581	1,180
Rear	301	326	627
Subtotal	900	907	1,807

1 lb = .454 kg

Figure 2. Pretest Photograph of Test Vehicle, Left Side View

Figure 3. Pretest Photograph of Test Vehicle, Front View

TABLE 5

WEIGHT DISTRIBUTION OF TEST VEHICLE
IN PRE-TEST CONFIGURATION WITH BOTH OCCUPANTS

	Left (lbs)	Right (lbs)	Subtotal (lbs)
Front	686	664	1,350
Rear	376	400	776
Subtotal	1,062	1,064	2,126

1 lb = .454 kg

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. The vehicle was also equipped with a contact switch mounted on the front bumper to permit vehicle and occupant data to be measured relative to the time of impact. The test vehicle is shown in Figures 2 through 5.

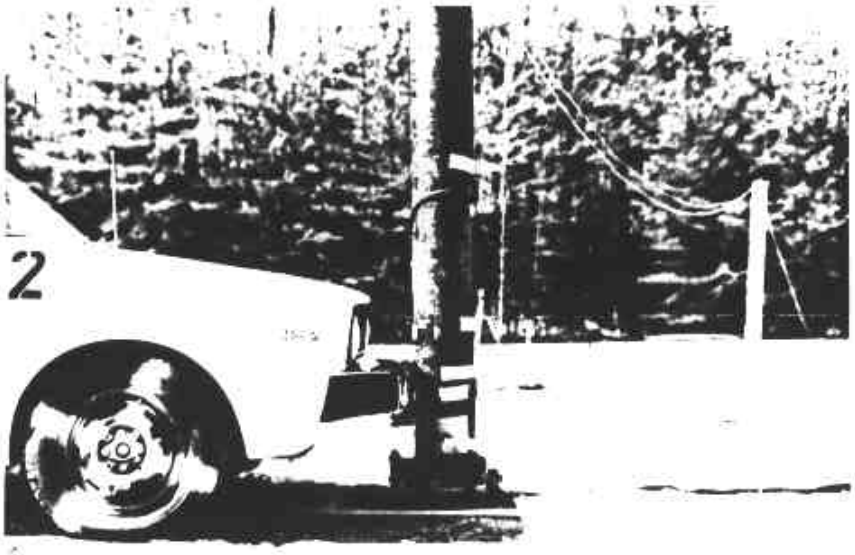


Figure 4. Pretest Photograph of Test Vehicle Shown in Contact with Surrogate Luminaire Support, Right Side View

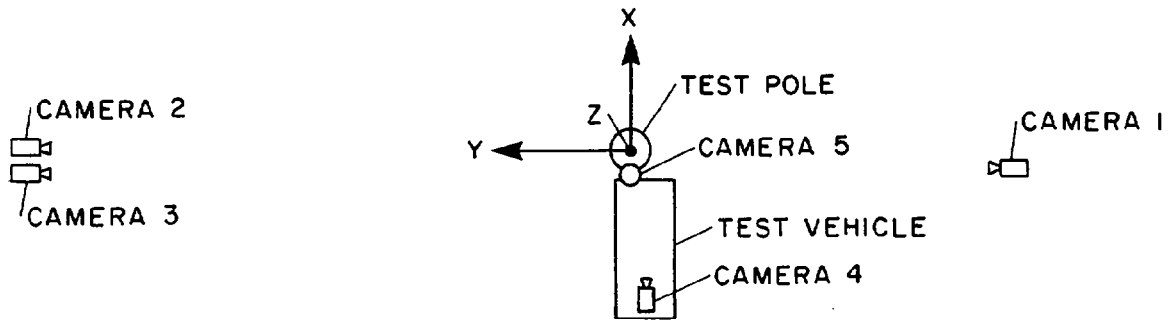
Figure 5. Pretest Photograph of Test Vehicle Shown in Contact with Surrogate Luminaire Support, Front View

5.0 TEST INSTRUMENTATION

Film data of the test was taken as described in Table 5. Transducer data was recorded as listed in Table 6. The transducer data was collected in analog form on a Honeywell 5600C recorder at 60 ips. The multiplexed data and the 32 kHz control signal were recorded in direct mode with a bandpass of 300 to 300 kHz. The speed trap data was recorded in frequency modulated mode with a bandpass of 0 to 20 kHz. The multiplexed data was played back through SAE Class 1000 filters and each channel was digitized at 8,000 Hz as required by the contract. A digital data tape was created in accordance with the specifications defined by NHTSA.[14] The test data was analyzed on a DEC 11/70 using the ENSCO general purpose highway research analysis programs. The 32 kHz control signal was initiated by the tape switch approximately two seconds prior to the vehicle impacting the luminaire support. This control signal was used to externally trigger the digitizing unit and automatically synchronized all data channels. The speed trap system used two sets of roadway contact switches which were positioned 46.25 inches apart. The first trap started measurement of time seven feet prior to the impact point and the remaining set was started five feet from the impact point. The signal conditioning unit onboard the vehicle was a Series 300 FM data multiplexer manufactured by Metraplex Corporation. The instrumentation used to collect the transducer data during the test conformed with SAE Recommended Practice J211b.[15]

TABLE 6

DESCRIPTION OF FILM DATA ACQUISITION
SYSTEM FOR FULL SCALE CRASH TEST 1469-3A82



Camera	Model	Position	Placement X(ft),Y(ft),Z(ft)	Speed	Lens
1	Redlake Locam	Rt. Side	3, -49, 3	500 pps	50 mm
2	Redlake Locam	Lt. Side	0, 96, 3	500 pps	25 mm
3	Redlake Hycam	Lt. Side	-3, 96, 3	500 pps	50 mm
4	Redlake Locam	On Board	-	500 pps	5.7 mm
5	Redlake Locam	Overhead	-1, -1, 48	500 pps	12.5 mm
6	Arrieflex	Documen-tation	-	24 pps	Zoom

1 ft = .3048 m

TABLE 7

TRANSDUCER DATA CHANNEL DESCRIPTION FOR
FULL SCALE CRASH TEST NUMBER 1469-2A82

Data Channel	Recorder Channel	Channel Description	Transducer Model	Transducer Serial Number	Multiplex Frequency	Deviation Frequency
1	1	D Head X	ENDEVCO 2264-2000	AN83	32 kHz	-14.80 Hz/g
2	1	D Head Y	ENDEVCO 2264-2000	AR36	48 kHz	+15.32 Hz/g
3	1	D Head Z	ENDEVCO 2264-2000	AT31	64 kHz	+19.69 Hz/g
4	1	D Chest X	ENDEVCO 7231C-750	CM19	80 kHz	+19.60 Hz/g
5	1	D Chest Y	ENDEVCO 7231C-750	CM20	96 kHz	-19.87 Hz/g
6	1	D Chest Z	ENDEVCO 7231C-750	CQ44	112 kHz	-22.23 Hz/g
7	1	D Femur L	GSF 2430	673	128 kHz	+1.475 Hz/lb
8	1	D Femur R	GSF 2430	682	144 kHz	+1.563 Hz/lb
9	2	P Head X	ENDEVCO 7231C-750	CS10	32 kHz	+22.63 Hz/g
10	2	P Head Y	ENDEVCO 7231C-750	CS74	48 kHz	-19.54 Hz/g
11	2	P Head Z	ENDEVCO 7231C-750	CV52	64 kHz	-19.52 Hz/g
12	2	P Chest X	ENDEVCO 7231C-750	CT78	80 kHz	+19.37 Hz/g
13	2	P Chest Y	ENDEVCO 7231C-750	CZ17	96 kHz	-19.28 Hz/g
14	2	P Chest Z	ENDEVCO 7231C-750	CZ39	112 kHz	-19.73 Hz/g
15	2	P Femur L	GSF 2430	683	128 kHz	+1.705 Hz/lb
16	2	P Femur R	GSF 2430	684	144 kHz	+1.655 Hz/lb
17	3	Vehicle X	Statham A69TC-25-350	18181	32 kHz	-114.05 Hz/g
18	3	Vehicle Y	Statham A69TC-15-350	16522	48 kHz	-135.41 Hz/g
19	3	Vehicle Z	Statham A69TC-15-350	16189	64 kHz	+138.94 Hz/g
20	3	Impact	Tape Switch No. 107-LS	N/A	80 kHz	+2kHz/Contact
21	6	Speed Trap	Tape Switch, Model RB-S	N/A	N/A	N/A
22	7	Sync. 32 kHz	N/A	N/A	N/A	N/A

6.0 TEST RESULTS

The impact conditions were 19.0 mph (8.49 m/s) at a point on the front bumper 12.25 inches (.31 m) to the left of the lateral center line of the vehicle. The residual crush of the vehicle at the impact point was 15.1 inches (.38 m). The dynamic crush as measured from the high speed film data with parallax correction was 19.25 inches (.49m). Photographs of the vehicle and luminaire support after the collision event are shown in Figures 6 through 9.

Initiation of the breakaway fracture mechanism of the luminaire support occurred at approximately .081 seconds after impact. The force levels at the time of initiation of the breakaway fracture mechanism of the luminaire support were 24,535 pounds and 26,372 pounds based on the vehicle acceleration data filtered at SAE Class 60 and 180, respectively.

After the initial separation from the vehicle the luminaire support translated forward at a speed of 5.83 f/s (1.78 m/s) with a rotation rate of 0.633 rad/sec. The base of the luminaire support hit the ground .400 seconds after impact and the vehicle struck the luminaire support again .660 seconds after impact. Forward vehicle motion ceased 1.300 seconds after impact and the luminaire support fell on the roof of the vehicle 2.820 seconds after impact. The luminaire support came to rest 4.960 seconds after impact while still in contact with the roof of the vehicle. Vehicle integrity was maintained throughout the test sequence and the roof structure of the vehicle protected the occupants from impact damage when the lumiaire support fell on the vehicle roof. The top of the luminaire support impacted the ground 24.1 feet behind and 4 feet to the right of the original center line position of the luminaire support.

Figure 6. Post-Test Photograph of Test Vehicle, Left Side View

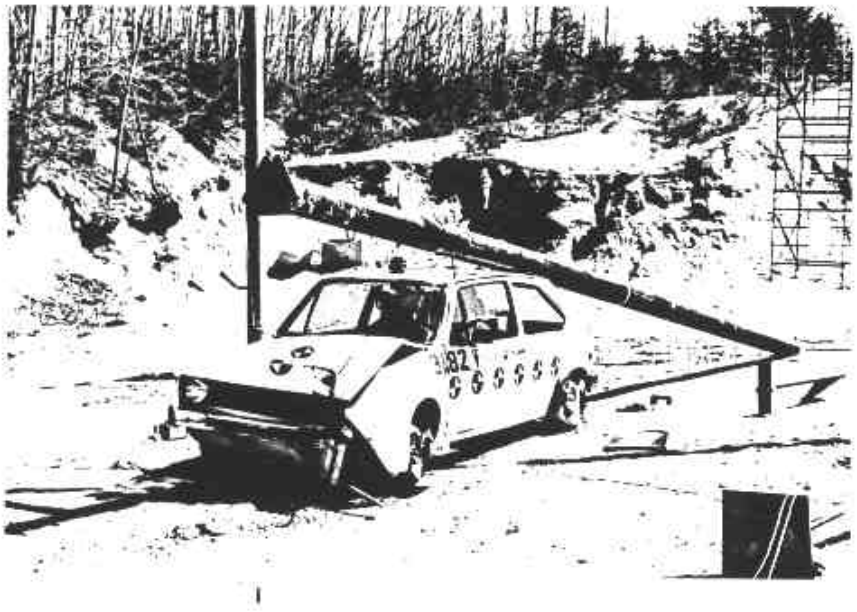


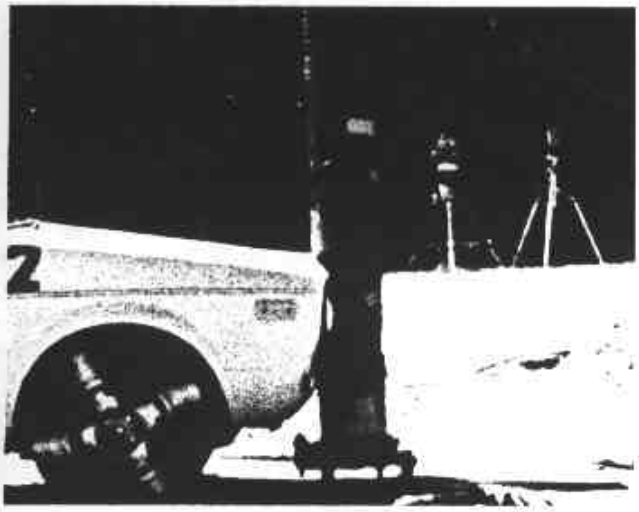
Figure 7. Post-Test Photograph of Test Vehicle, Right Angle View

Figure 8. Post-Test Photograph of Test Vehicle, Front View

Figure 9. Post-Test Photograph of Test Vehicle, Rear View

t = 0.00 sec

t = 0.090 sec



t = 0.030 sec

t = 0.120 sec

t = 0.060 sec

t = 0.150 sec

Figure 10. Test Sequence for the Initial Collision Event of Full Scale Crash Test Number 1469-3A82

t = 0.00 sec

t = 1.800 sec

t = 0.600 sec

t = 2.400 sec

t = 1.200 sec

t = 3.000 sec

Figure 11. Test Sequence of the Entire Collision Event for Full Scale Crash Test Number 1469-3A82

The front left tire locked up for approximately .055 sec at .072 sec after the vehicle impacted the luminaire support due to the crushing of the front end of the vehicle. The test sequence is depicted in Figures 10 and 11. The final resting position of the test vehicle is shown in Table 8.

TABLE 8

FINAL RESTING POSITION OF THE OUTSIDE EDGE OF THE TEST VEHICLE'S TIRES AT THE COMPLETION OF THE FULL SCALE CRASH TEST 1469-3A82 RELATIVE TO IMPACT POINT*

	Front		Rear	
	X(ft)	Y(ft)	X(ft)	Y(ft)
Left	3.33	2.17	-4.42	0.42
Right	4.25	-2.92	-3.33	-4.54

1 ft = .3048 m

*See coordinate reference given in Table 6.

7.0 TEST ANALYSIS

Data from this test were evaluated using several techniques. The pre-impact speed was determined from the speed trap and high speed film information. The signals from the accelerometers mounted on the vehicle were debiased and filtered at SAE Class 60 and integrated to yield the change in the speed of the vehicle during the test in accordance with TRC 191. This filtered data was then used to yield the impact velocity of a hypothetical front seat passenger against the vehicle using the techniques described in NCHRP 230 as specified in the approved test plan.[1,6] The signals from the accelerometers mounted on the vehicle were also filtered at SAE Class 180 and processed to yield vehicle change in speed and the associated occupant injury parameters in accordance with NCHRP 230.

The accelerometers mounted in the head of each of the test dummies were used to yield resultant accelerations and the Head Injury Criteria as specified in FMVSS 208. The accelerometers mounted in the upper thorax of the test dummies were filtered at SAE Class 180 and processed to yield resultant accelerations. The peak resultant acceleration whose duration exceeded 3 milliseconds were reported in accordance with FMVSS 208. Also, the chest severity indices were calculated by the method described in SAE Information Report J885a. Finally, the femur loads experienced by the test dummies were filtered at SAE CLass 600 and examined to yield peak loads and compared to the limits presented in FMVSS 208.

7.1 FILM AND SPEED TRAP VELOCITY ANALYSIS

The impact speed was determined by analysis from the high-speed films. The impact speed was determined from the speed trap by referencing the distance base of 46.25 in (1.17 m) located 3 feet

TABLE 9

TEST VEHICLE SPEED RESULTS BASED ON THE SPEED TRAP AND FILM ANALYSIS

Camera	Position	Impact Speed (mph)
2	Left Side	18.96
5	Overhead	19.08
N/A	Speed Trap	18.96
		19.00

1 mph = .44704 m/sec

(1.2 m) prior to the impact point to a crystal controlled oscillator. Results from the speed analysis are contained in Table 9. Based upon this analysis, the impact speed of the vehicle was 19.0 mph (8.49 m/s).

7.2 ANALYSIS OF VEHICLE MOUNTED ACCELEROMETERS

The data collected from the accelerometers mounted to the vehicle were filtered at SAE Class 60 and 180 per TRC 191 and NCHRP 230 requirements, respectively. The three individual accelerometer signals were in each case combined to yield the resultant accelerations occurring during the impact event. For comparison purposes, a resultant was evaluated with and without the data from the accelerometer whose sensitive axis was aligned vertically. The acceleration traces and resultants obtained with the use of the SAE Class 60 (f_c = 100 Hz) filtering technique are presented in Figures 12 through 16. The acceleration traces and resultants obtained with the use of the SAE Class 180 (f_c = 300 Hz) filtering technique are presented in Figures 17 through 21.

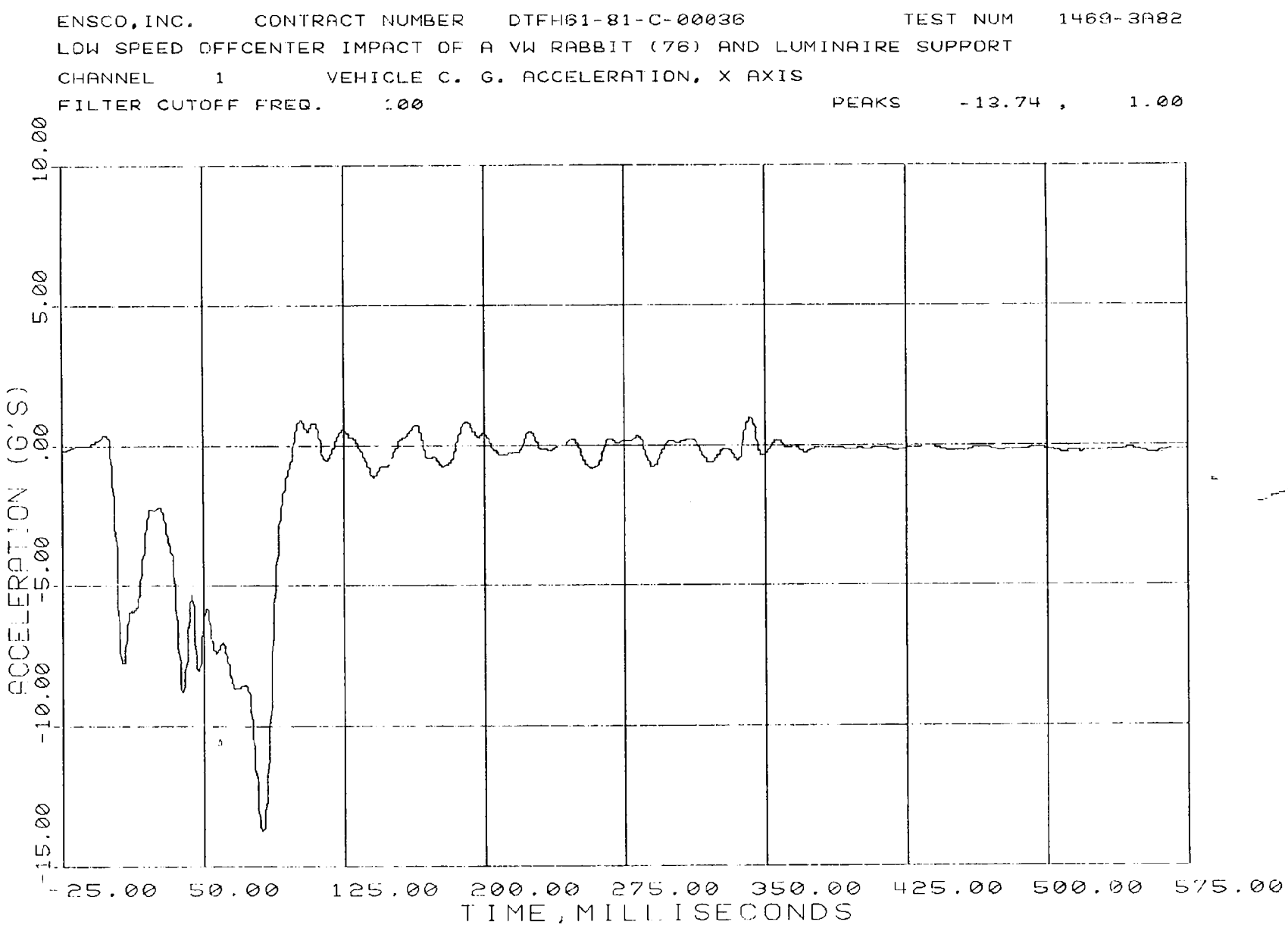


Figure 12. Vehicle C.G. Acceleration, X Axis (SAE Class 60)

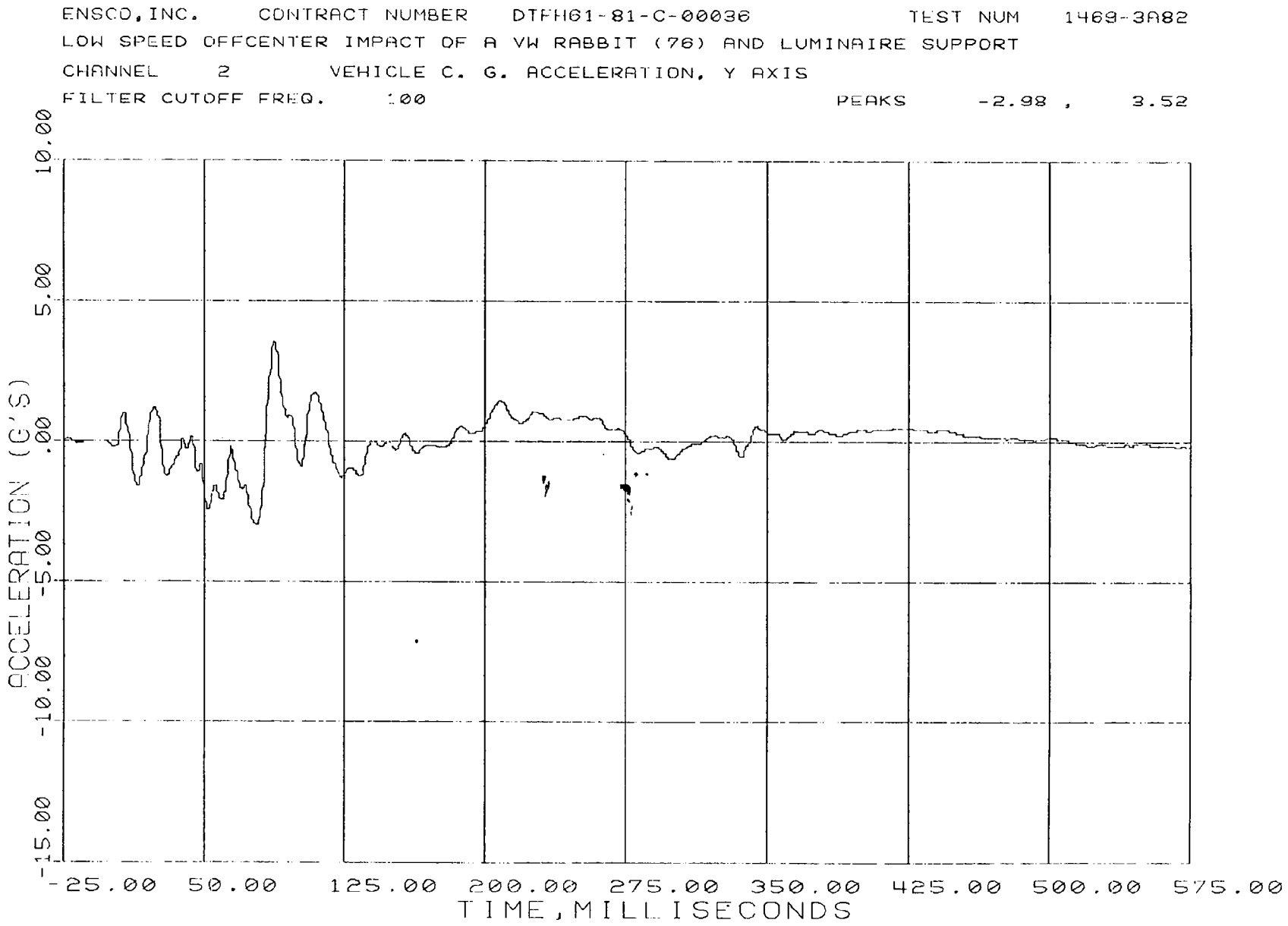


Figure 13. Vehicle C.G. Acceleration, Y Axis (SAE Class 60)

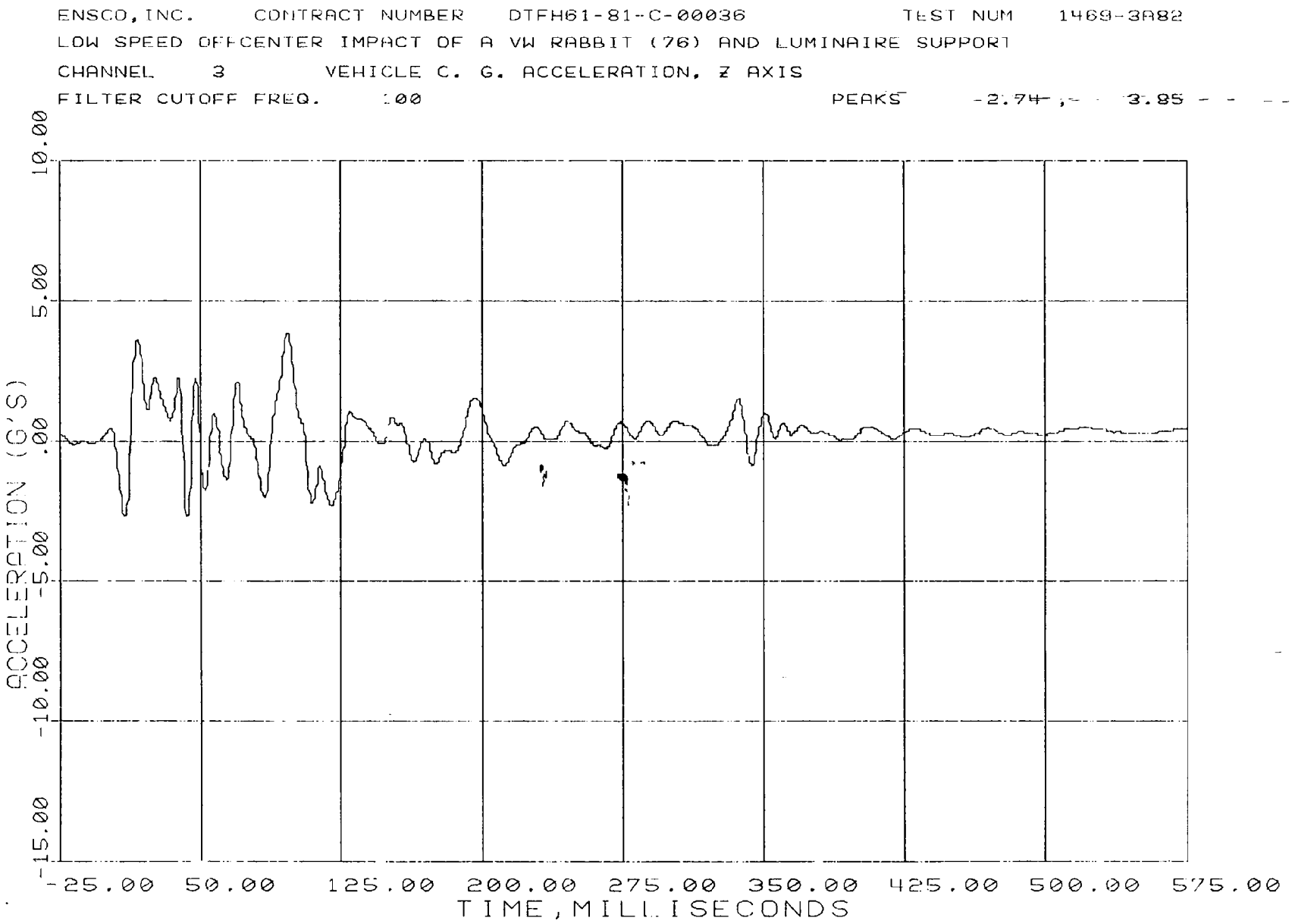


Figure 14. Vehicle C.G. Acceleration, Z Axis (SAE Class 60)

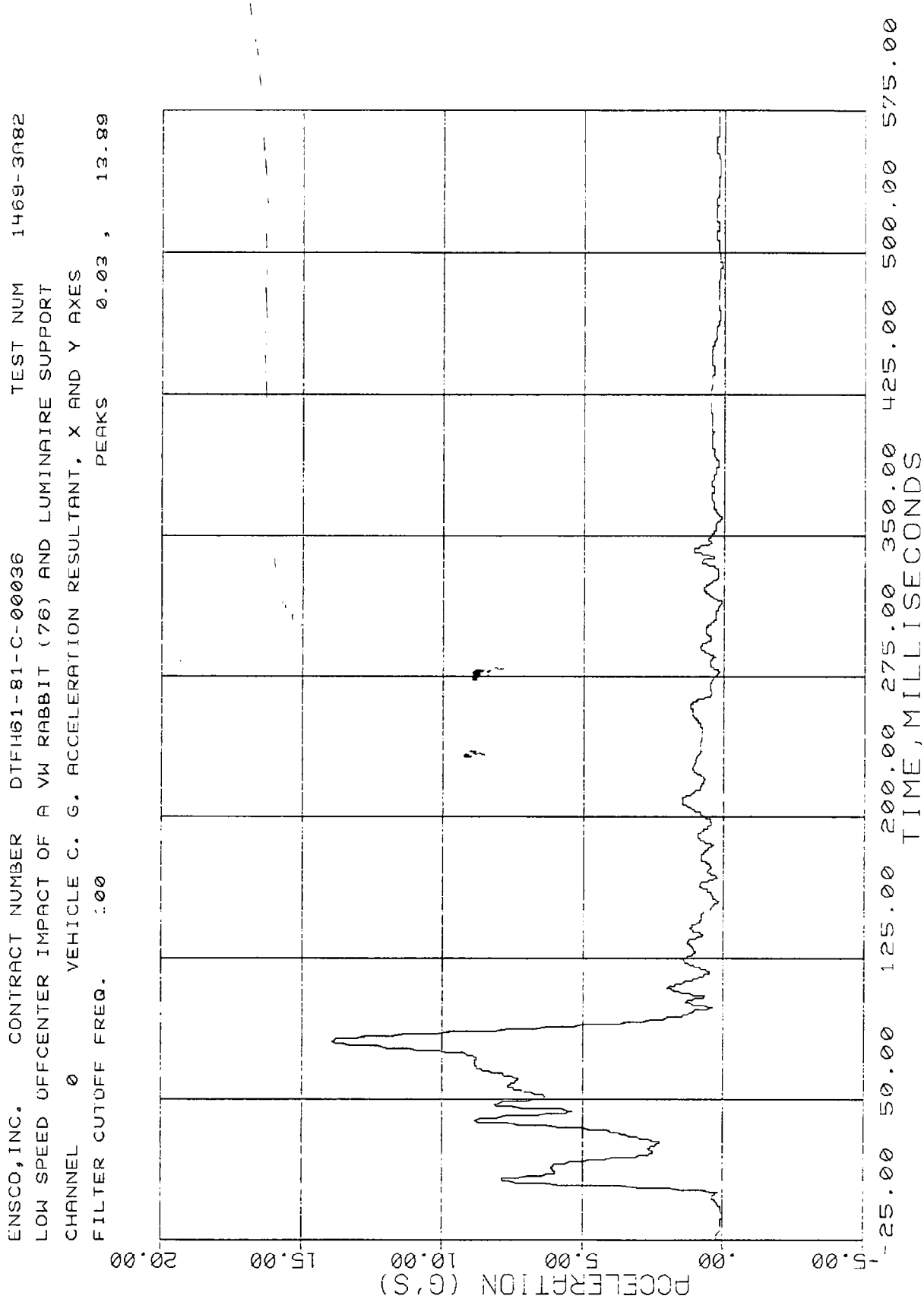


Figure 15. Vehicle C.G. Acceleration, X and Y Axes (SAE Class 60)

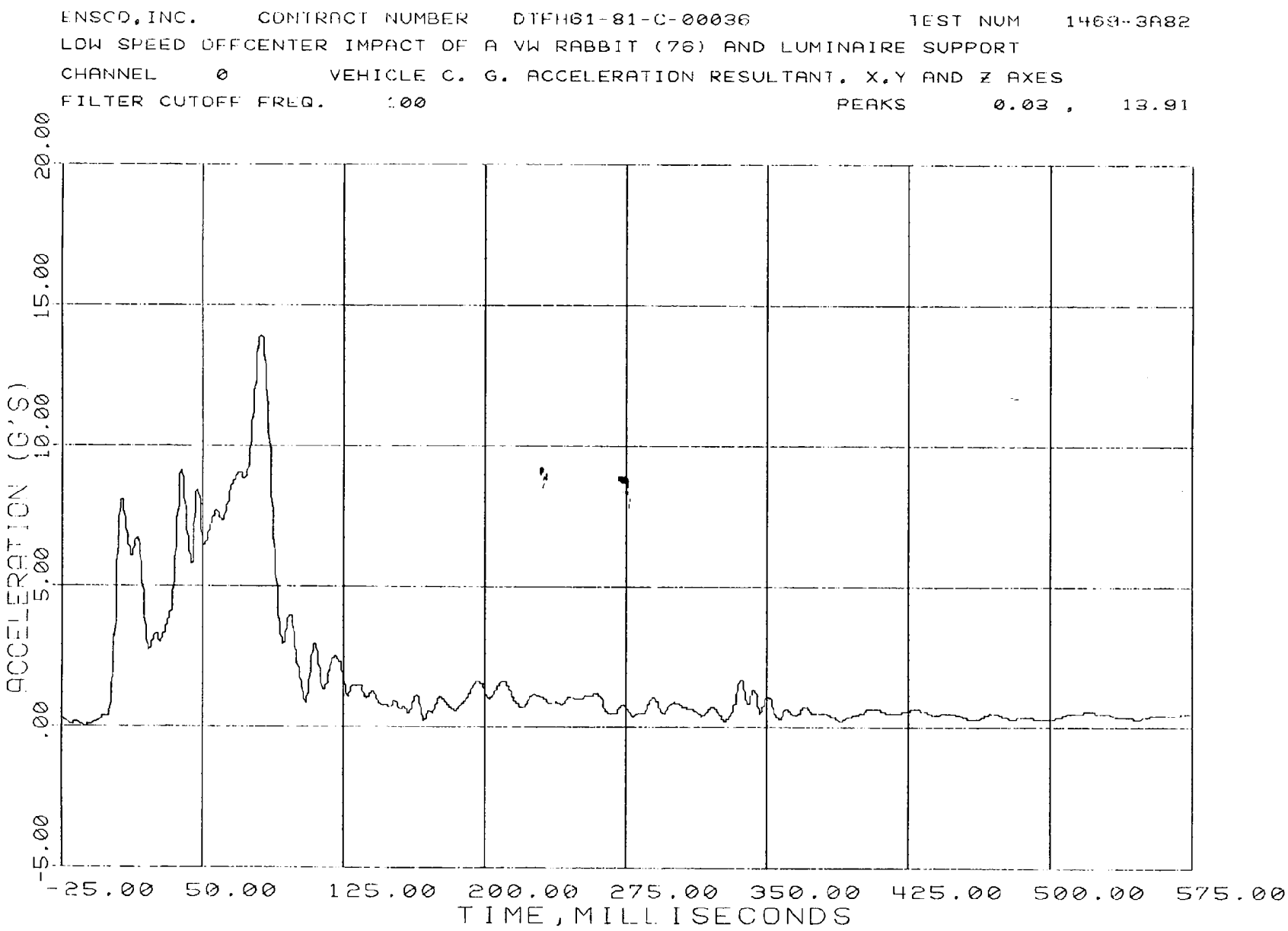


Figure 16. Vehicle C.G. Acceleration, X, Y and Z Axes (SAE Class 60)

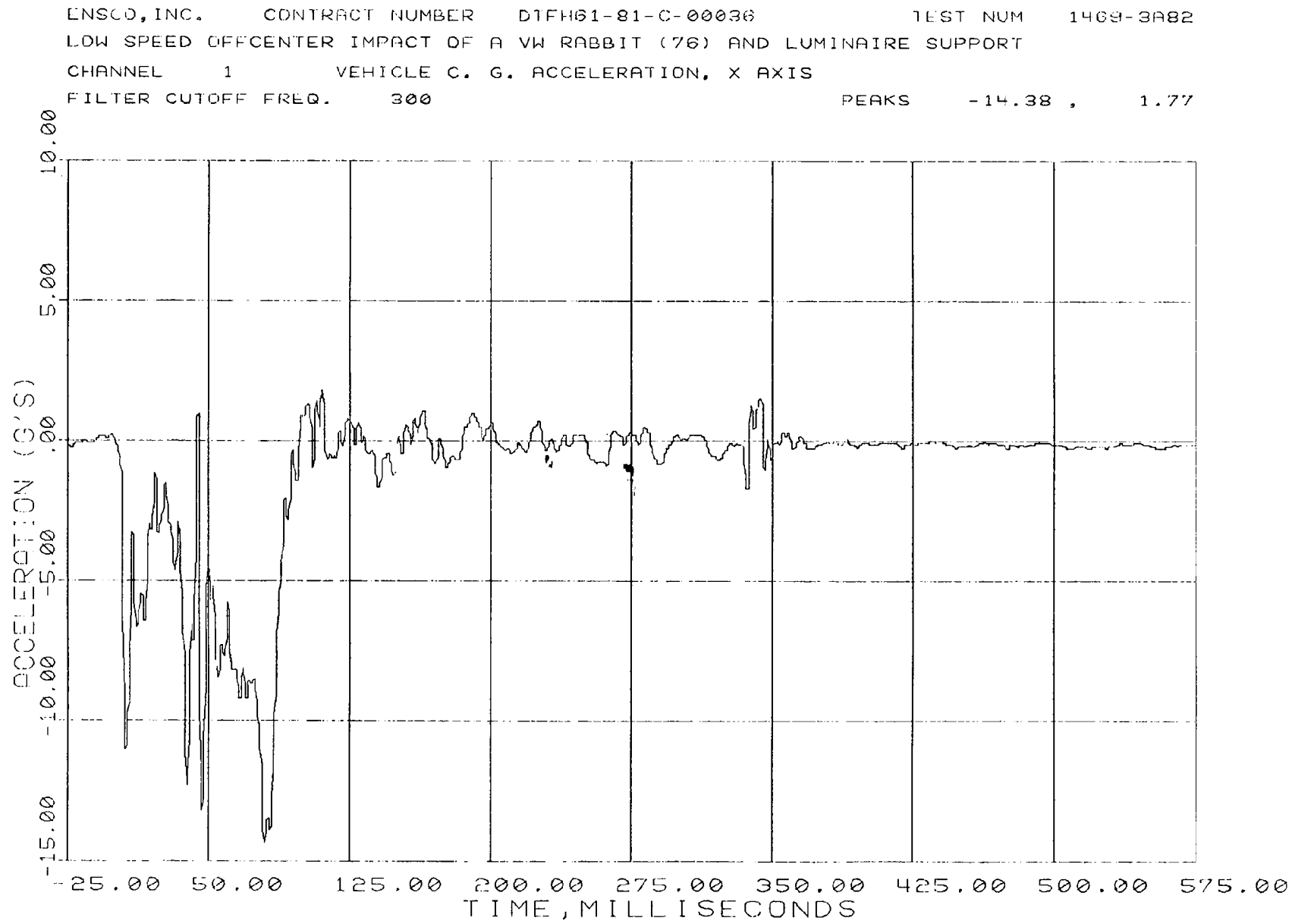


Figure 17. Vehicle C.G. Acceleration, X Axis (SAE Class 180)

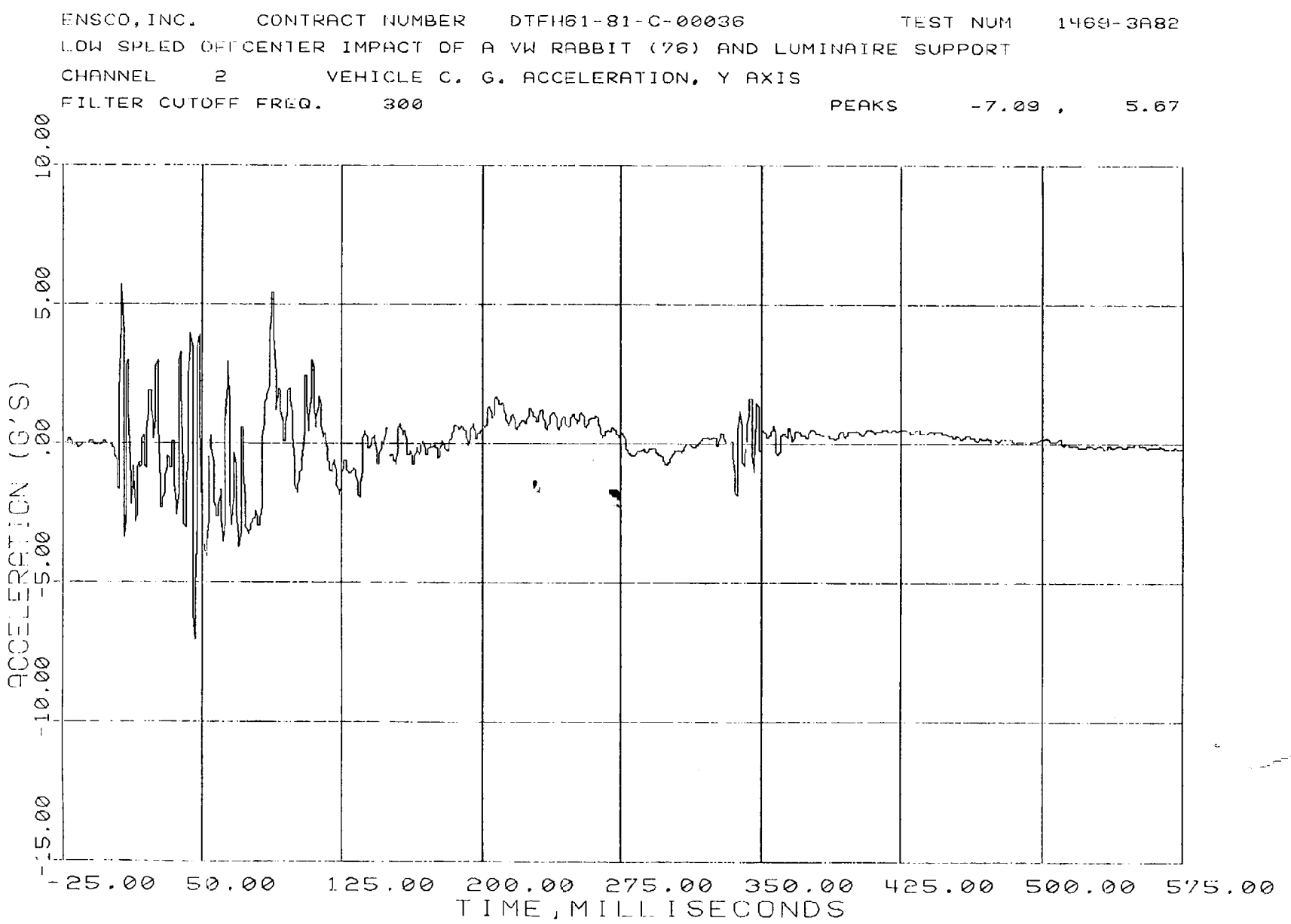


Figure 18. Vehicle C.G. Acceleration, Y Axis (SAE Class 180)

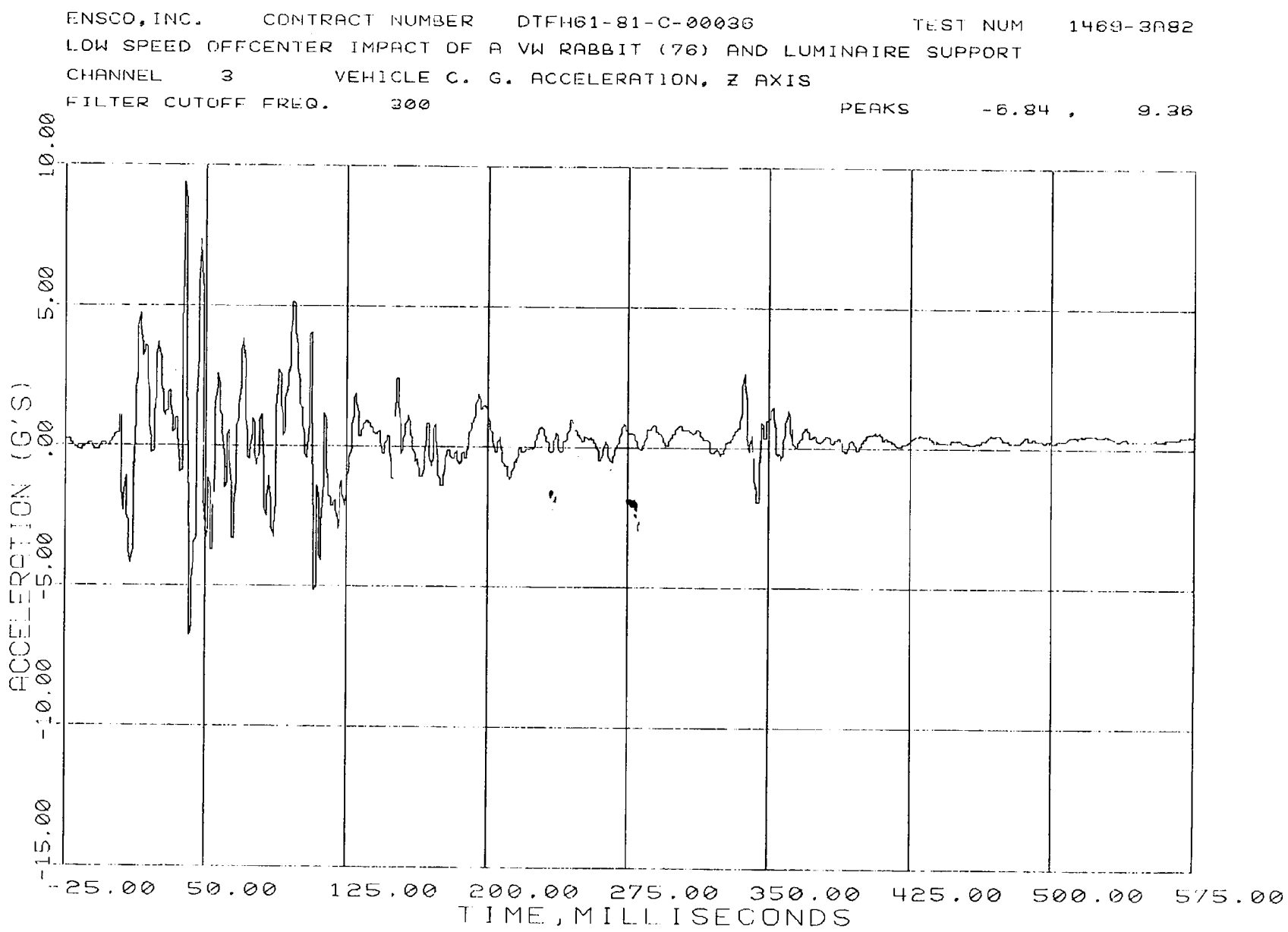


Figure 19. Vehicle C.G. Acceleration, Z Axis (SAE Class 180)

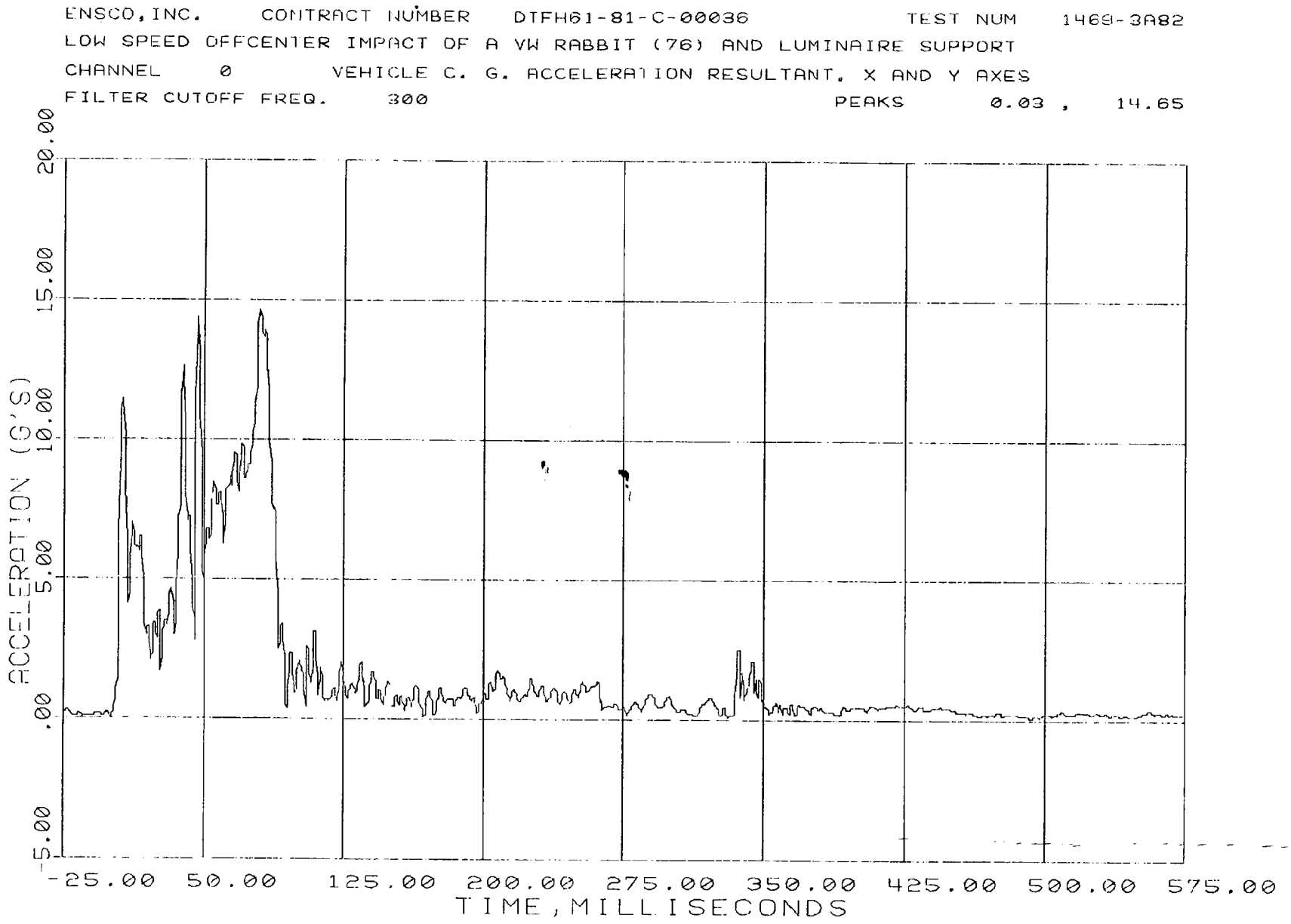


Figure 20. Vehicle C.G. Acceleration, X and Y Axes (SAE Class 180)

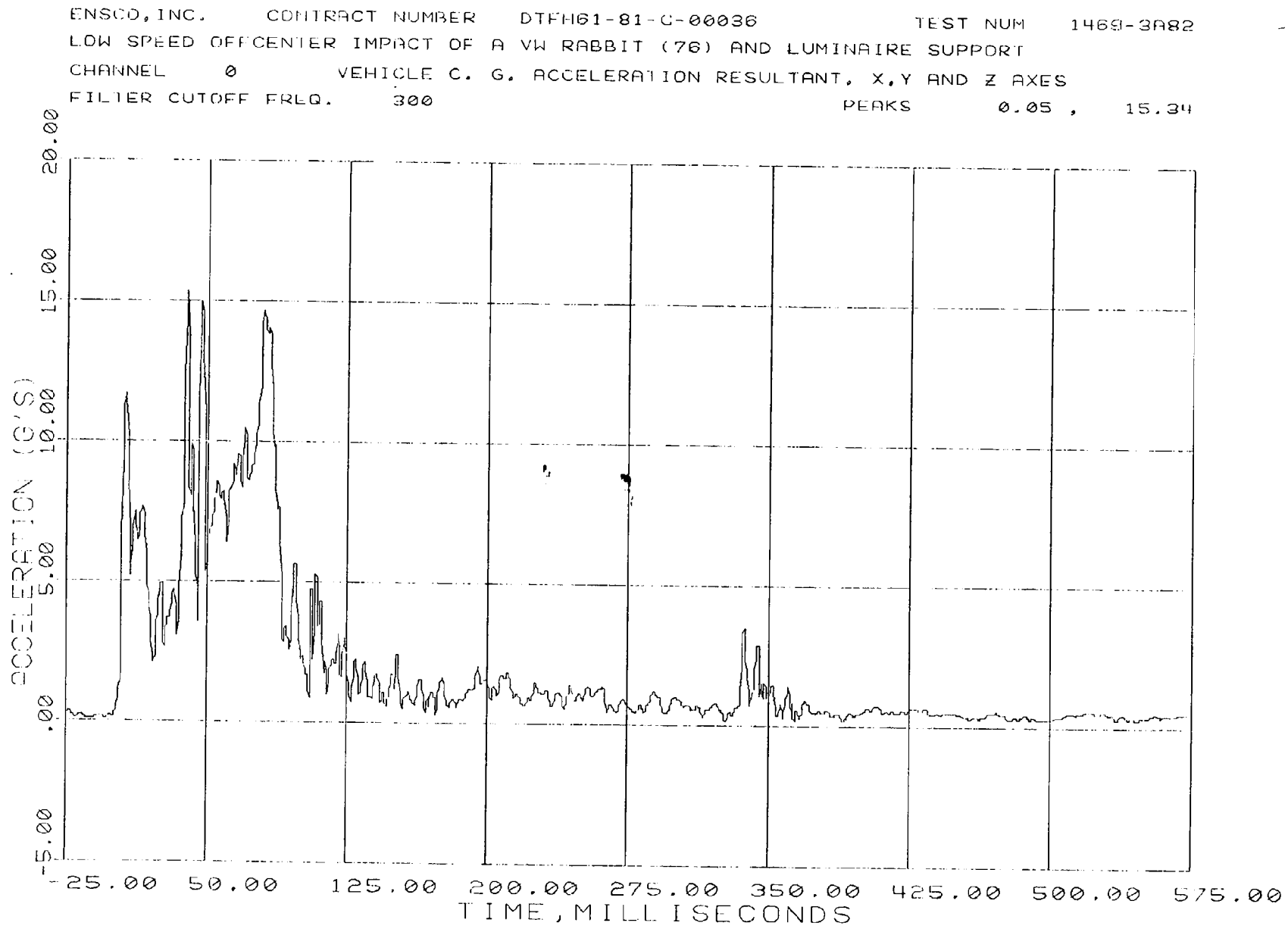


Figure 21. Vehicle C.G. Acceleration, X, Y and Z Axes (SAE Class 180)

Table 10 contains several pertinent details regarding the data obtained from the vehicle mounted accelerometers. The resulting change in velocity and momentum change of the vehicle based upon integrating the acceleration signals in the fixed vehicle coordinate system are shown in Table 11.

Analysis of the impact velocity of a hypothetical front seat passenger against the vehicle interior, calculated from the vehicle accelerations and a 24 in (0.61 m) forward displacement, yielded the results shown in Table 12. A hypothetical front seat occupant would have impacted the interior of the vehicle in the longitudinal direction at an approximate impact velocity of 19.45 ft/sec (5.93 m/s) and 19.41 ft/sec (5.92 m/s) based upon data filtered at SAE Class 60 and 180, respectively. The impact velocity design specified in NCHRP 230 is 15 ft/sec (4.57 m/s) for the data filtered at SAE Class 180.

The highest ride down acceleration after the hypothetical front seat passenger impacted the interior of the vehicle was -1.91 g's occurring at .683 sec using 10msec averages of the longitudinal acceleration data filtered at SAE Class 60 or 180. Both of these ride down decelerations were within the design limits of 15 g's specified in NCHRP 230.

TABLE 10

PEAK ACCELERATIONS OBTAINED FROM VEHICLE MOUNTED ACCELEROMETERS

	SAE Class 60 Data		SAE Class 180 Data	
Description	Peak (g's)	Time (m sec)	Peak (g's)	Time (m sec)
X Axis	-13.74	81.4	-14.38	80.3
Y Axis	3.52	77.8	-7.09	46.3
Z Axis	3.85	96.9	9.36	39.4
Resultant, X and Y	13.89	81.3	14.65	80.3
Resultant, X, Y and Z	13.91	81.3	15.34	39.1

TABLE 11

VEHICLE VELOCITY AND MOMENTUM
CHANGE OCCURRING DURING IMPACT EVENT

	SAE Class 60 Data[a]	SAE Class 180 Data[b]
X Axis	-13.26 mph	-13.24 mph
Y Axis	-0.97 mph	-0.97 mph
$M_s\Delta V$(19.0 mph)	1276 lb-sec	1274 lb-sec

1 mph = .44704 m/sec

NOTE: a. Time duration used for integrating acceleration data based on 24 in. flail space distance for hypothetical occupant using filters set for SAE Class 60.

b. Time duration used for integrating acceleration data based on 24 in. flail space distance for hypothetical occupant using filters set for SAE Class 180.

TABLE 12

LONGITUDINAL IMPACT VELOCITIES OF HYPOTHETICAL FRONT SEAT PASSENGER EVALUATED IN ACCORDANCE WITH NCHRP 230 USING TEST DATA FILTERED AT SAE CLASS 60 AND 180

SAE Class 60 Data	SAE Class 180 Data
Δv = 19.45 ft/sec	Δv = 19.41 ft/sec
t = .15738 sec	t = .15763 sec

1 ft/sec = .3048 m/s
1 ft = .3048 m

7.3 COMPARISON OF PREDICTED RESULTS TO TEST OBSERVABLES

Several comparisons between the observable and predicted data can be made from the results of this test.[16] Basically, the impact of the vehicle and luminaire support can be separated into three phases:

1. Crushing of the automobile with insignificant motion of structure being impacted.
2. Activation and completion of the breakaway failure mechanism.
3. Acceleration of structure by the impacting vehicle.

These three phases are shown graphically in Figure 22. The expression for the momentum change in the three phase description is given by:

$$M\Delta V = \int_{t_1}^{t_3} F_c dt$$

$$= \int_0^{t_1} F_c dt + \int_{t_1}^{t_3} F_b dt + \int_{t_1}^{t_3} (F_c - F_b) dt$$

$$= \int_0^{t_1} F_c dt + \int_{t_1}^{t_2} F_b dt + \int_{t_1}^{t_3} (F_c - F_b) dt$$

$$\triangleq I_1 + I_2 + I_3$$

where the terms in the above equation are given in Figure 22.

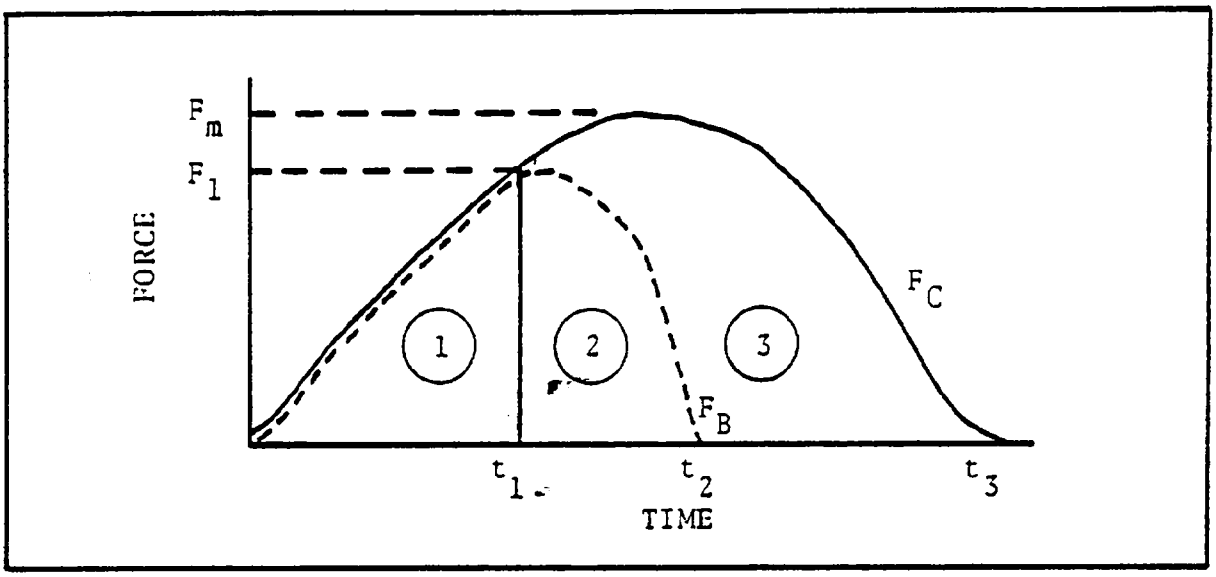


Figure 22. Graphic Representation of Three Phase Analysis of Momentum Change Occurring During the Impact of a Vehicle with a Breakaway Support

The downstream speed and rotational rate of the luminaire support can be related to the third phase of the vehicle momentum change by the following:

$$\dot{x}_{cg} = \frac{1}{M_p} I_3,$$

and

$$\dot{\theta} = \frac{D_I}{I_p} I_3$$

where $\dot{x}_{cg}$ = longitudinal velocity of the luminaire support c.g.,

$\dot{\theta}$ = rotational rate of luminaire support,

D_I = impulse level arm during Phase 3,

M_p = mass of luminaire support,

I_p = rotational inertial of the luminaire support,

and I_3 = momentum change occurring during Phase 3.[17]

From the film data $\dot{x}_{cg}$ = 5.83 f/s (1.78 m/s) and 0.633 rad/sec. Using these two numbers the momentum change occurring during Phase 3 is given by

$$I_3 = M_p \dot{x}_{cg}$$

$$= 182 \text{ lb-sec } (808 \text{ N-s})$$

or

$$I_3 = \dot{\theta} \frac{I_p}{D_I}$$

$$= 131 \text{ lb-sec } (583 \text{ N-s}).$$

The average momentum change associated with the third phase of the vehicle momentum change is 157 lb-sec (698 N-s). The variation of the relative comparison of these two measurements is due to the relatively short interval of time between the initial pole release from the vehicle and the time when the base hit the ground.

The change in vehicle momentum occurring during the first and second phases of the impact event can be found by subtracting the third phase momentum from the total momentum change, i.e., $I_{1\&2} = I_T - I_3$. The vehicle change in momentum occurring during the second phase depends upon the energy dissipation caused by the breakaway fracture mechanisn and the velocity of the vehicle at the moment of breakaway.[5] The change in momentum during the first phase is calculated by subtracting the change in momentum during the second phase from the total of the first and second phases, $I_1 = I_{1\&2} - I_2$. The results of this analysis for acceleration data filtered at SAE Class 60 and 180 are shown in Table 13.

TABLE 13

EXAMINATION OF THE MOMENTUM TRANSFER DURING THE COLLISION EVENT

		Class 60 (lb-sec)	Class 180 (lb-sec)
I_T	=	1276[a]	1274[b]
I_3	=	-157[c]	-157[c]
$I_{1\&2}$	=	1119	1117
I_2	=	-262	-261
I_1		857	856
I_1	=	883[d]	880[e]

1 lb-sec = 4.445 N-s

Notes:
a. Total change in vehicle momentum occurring during the impact event evaluated from acceleration data filtered at SAE Class 60.
b. Total change in vehicle momentum occurring during the impact event evaluated from acceleration data processed in accordance with NCHRP 230.
c. Phase 3 change in momentum of vehicle evaluated from luminaire support translational and rotational data.
d. Phase 1 change in momentum of vehicle evaluated from acceleration data processed in accordance with TRC 191.
e. Phase 1 change in momentum of vehicle evaluated from acceleration data processed in accordance with NCHRP 230.

Several important observations can be made from the information presented in Table 13. The momentum dissipated during the first phase of the collision event is nearly three times that anticipated for a 1971 Chevolet Vega used in full scale crash test 1469-1A81.[4] This difference is due to the drastically different crush characteristics of the Vega at its center line and the Rabbit near its quarter bumper point. The energy disapated during the second phase of the collision event is approximately 2.5 times that anticipated for the 1971 Chevrolet Vega used in full scale crash test 1469-1A81[4]. This increase is due to the reduced velocity of the vehicle caused by the increased energy dissipation which occurs in the first phase of the collision event. Further, the crush characteristics of the test vehicle used for the present crash test are more uniformly higher than those of the Vega causing increased variability in the energy dissipation occurring in the first phase of the collision event and therefore the relative severity of the impact.

7.4 HEAD INJURY CRITERIA EVALUATION

The data obtained from the three accelerometers located in the head 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 were evaluated in accordance with the procedures outlined in FMVSS 208.[8] 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 23 through 26 for the driver and Figures 27 through 30 for the passenger. The results of the HIC numbers calculated for the occupants during this test is shown in Table 14. Comparing the results to the acceptable limit of 1000 indicates that the collision event was relatively mild.

7.5 CHEST SEVERITY INDEX EVALUATION

The data obtained from the three accelerometers located in the chest of the occupants during the test were filtered at SAE Class

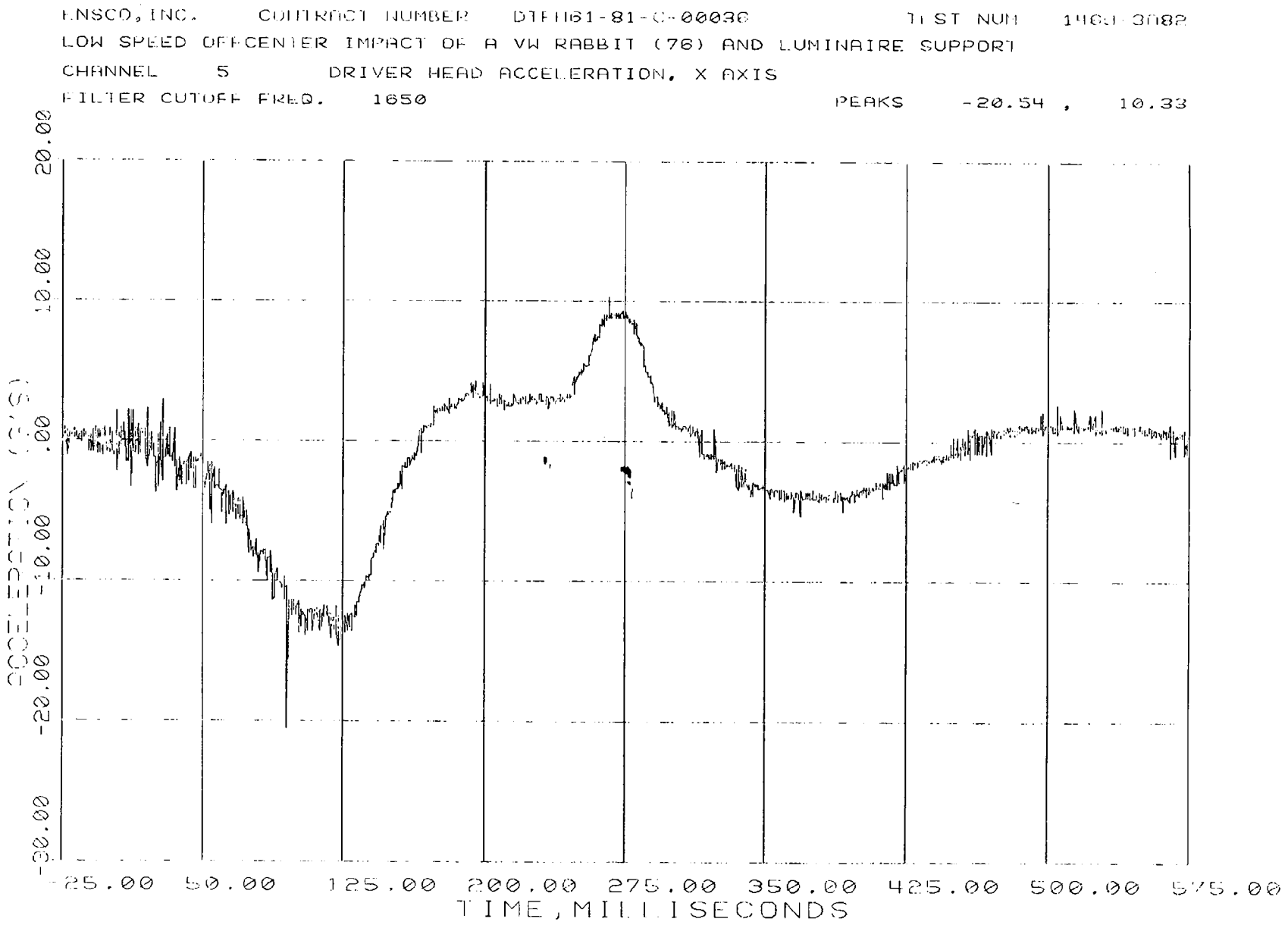


Figure 23. Driver Head Acceleration, X Axis (SAE Class 1000)

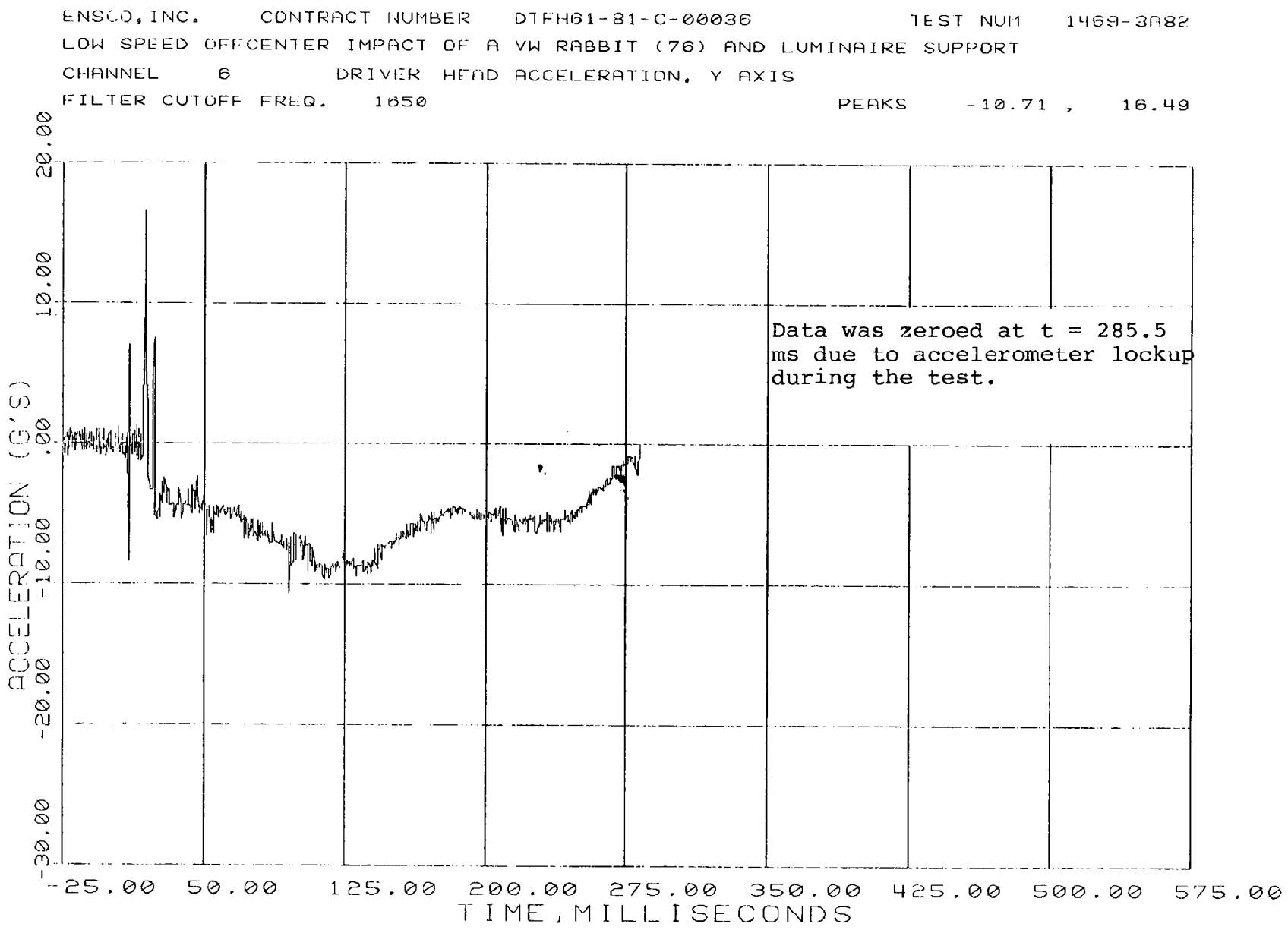


Figure 24. Driver Head Acceleration, Y Axis (SAE Class 1000)

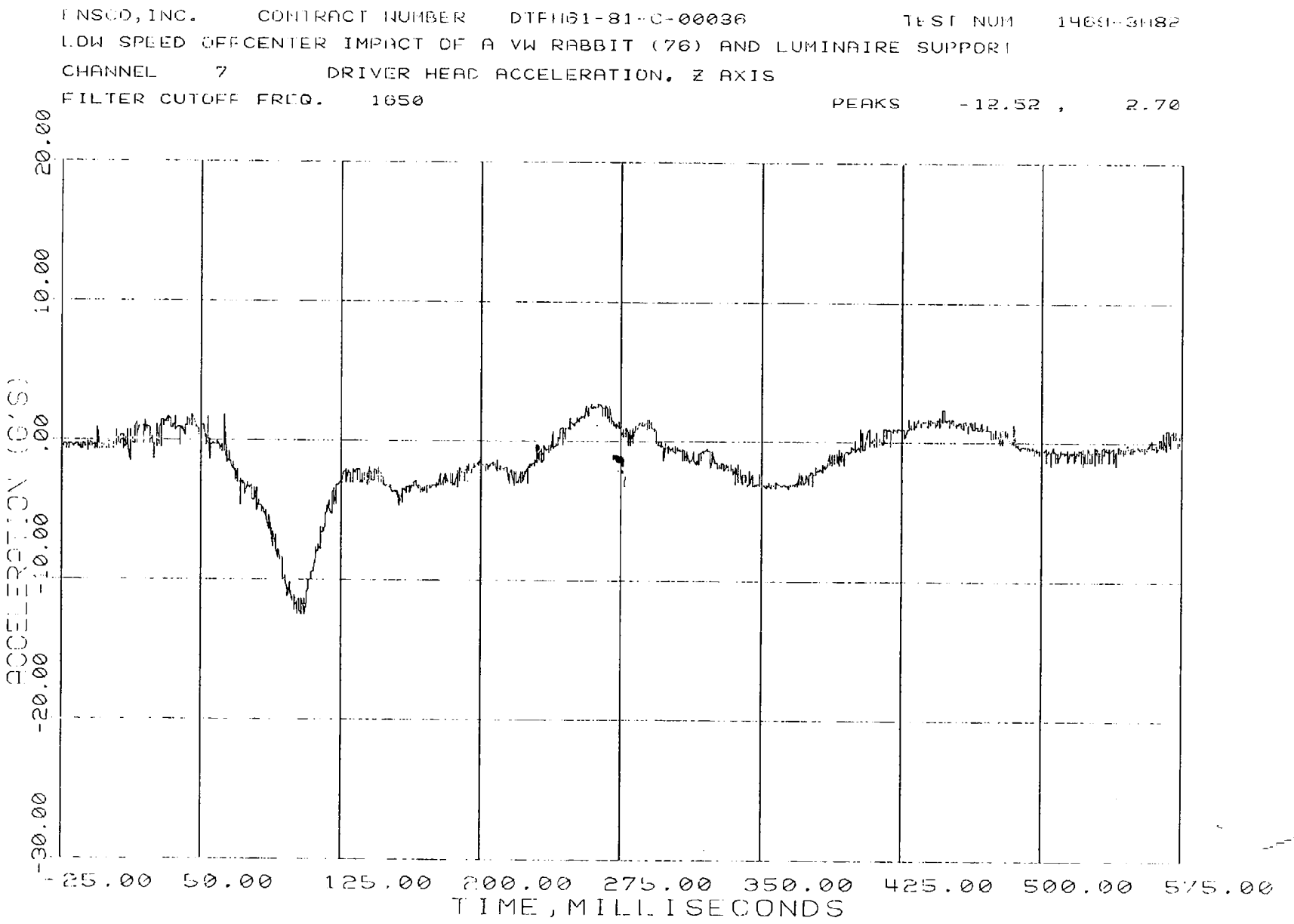


Figure 25. Driver Head Acceleration, Z Axis (SAE Class 1000)

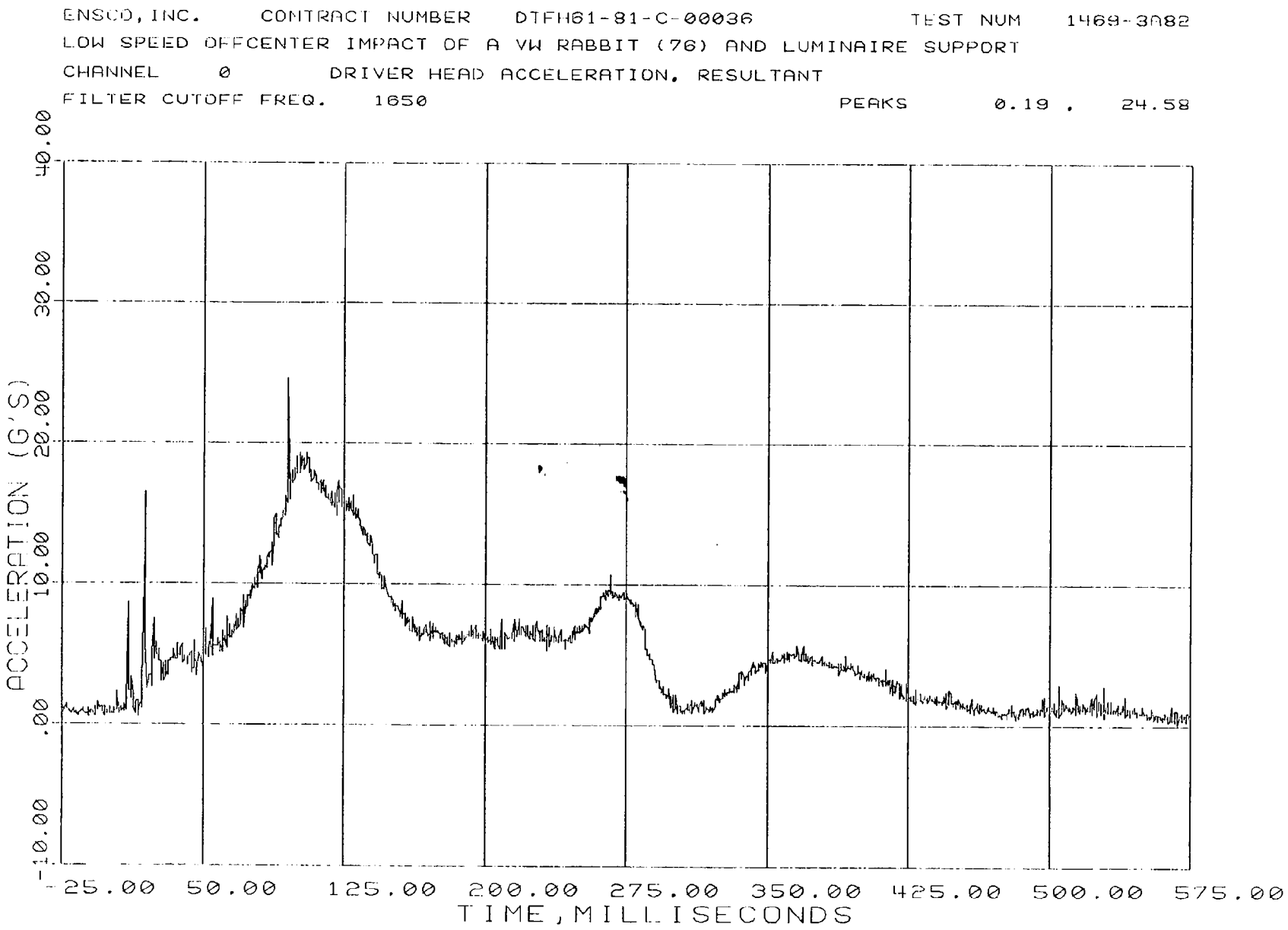


Figure 26. Driver Head Acceleration, Resultant (SAE Class 1000)

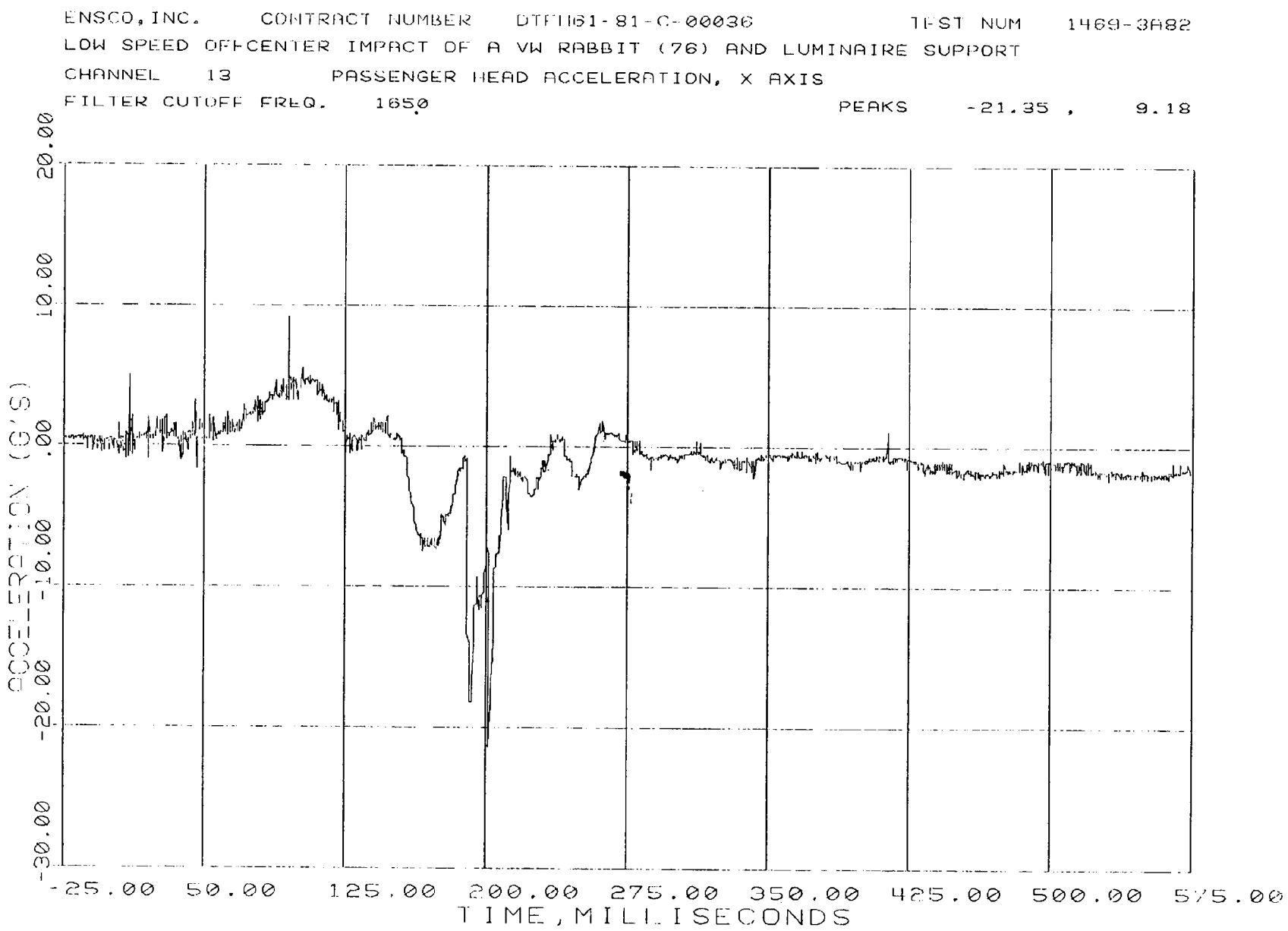


Figure 27. Passenger Head Acceleration, X Axis (SAE Class 1000)

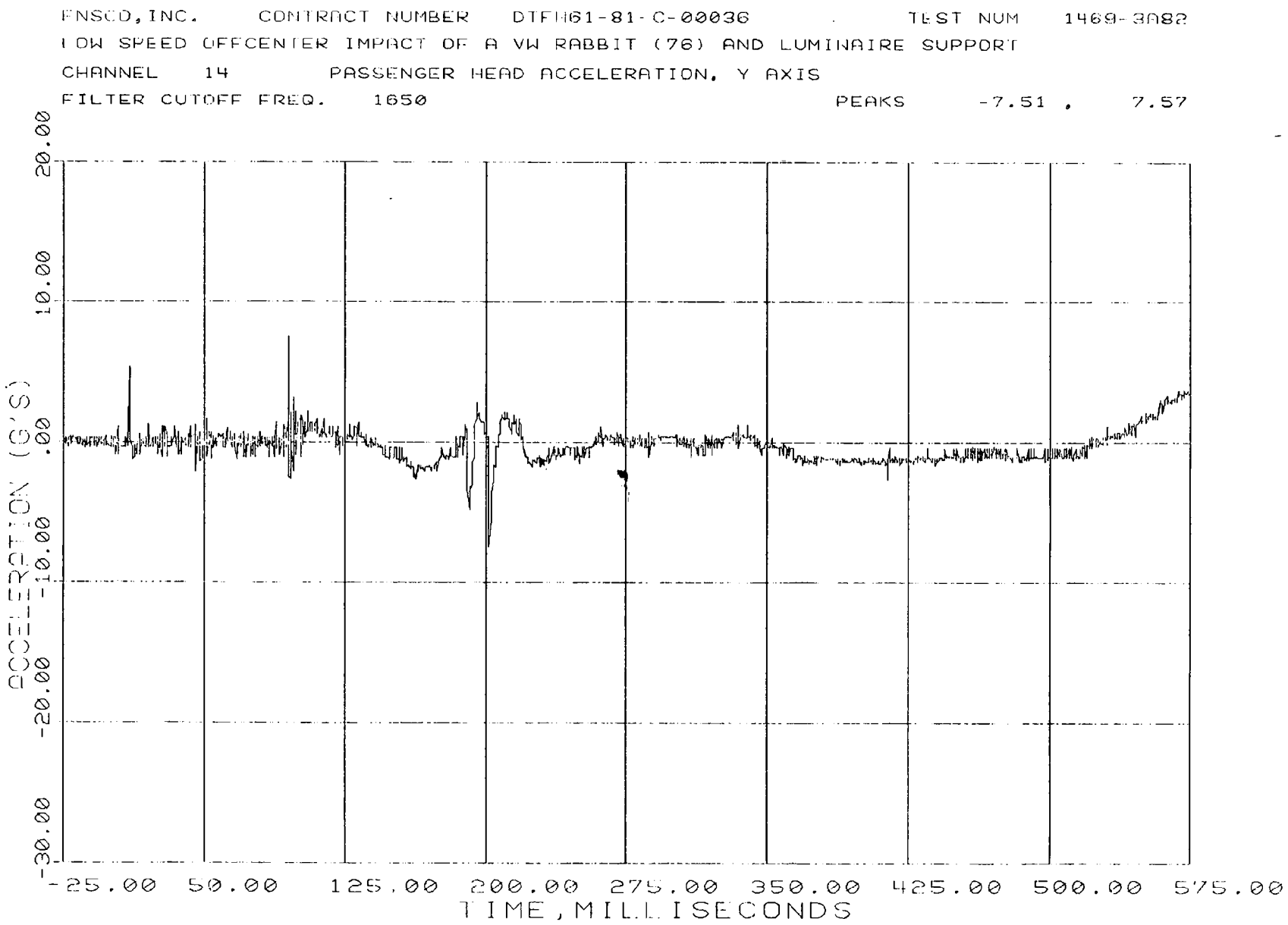


Figure 28. Passenger Head Acceleration, Y Axis (SAE Class 1000)

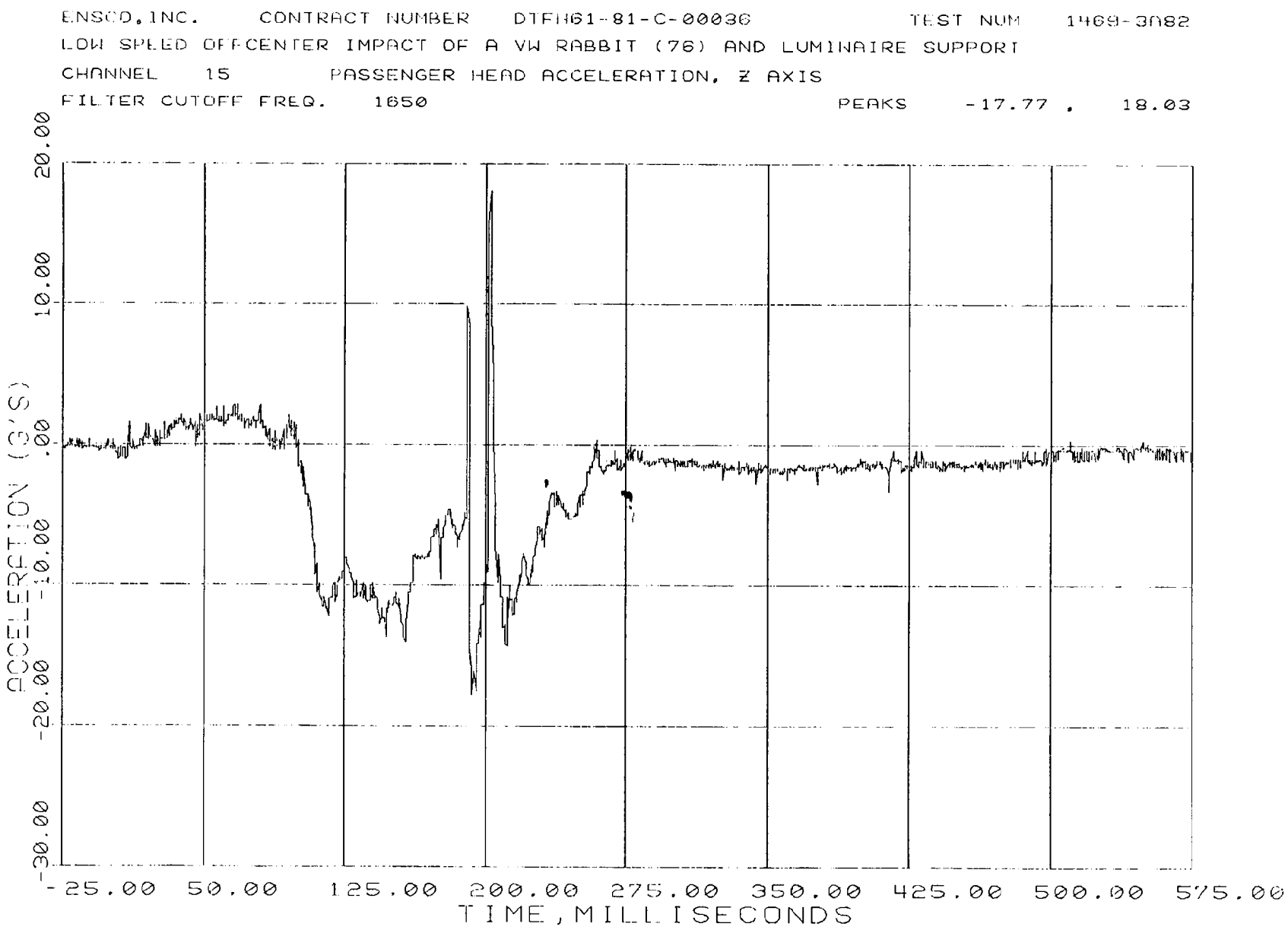


Figure 29. Passenger Head Acceleration, Z Axis (SAE Class 1000)

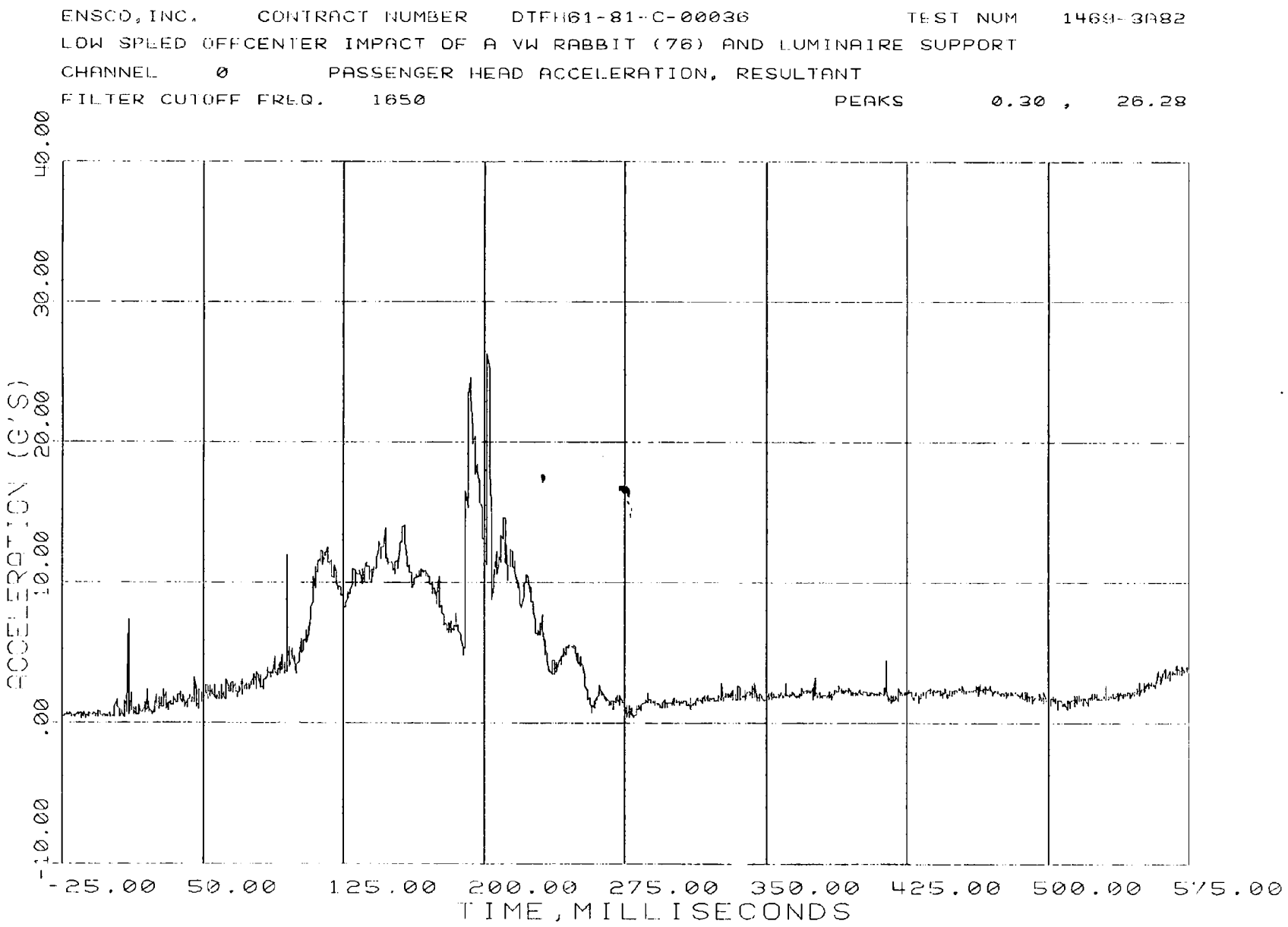


Figure 30. Passenger Head Acceleration, Resultant (SAE Class 1000)

TABLE 14

HEAD INJURY CRITERIA EVALUATED FOR FULL SCALE CRASH TEST 1469-3A82

	Driver	Passenger
HIC	57	45
t(Start)	62.5 ms	107.13 ms
t(Stop)	285.5 ms	231.88 ms
t(Duration)	223.0 ms	124.75 ms

180 and combined to yield a resultant acceleration occurring during the impact event. The CSI were evaluated in accordance with SAE Information Report J885.[12] In addition, the maximum resultant acceleration whose cumulative duration is not more than 3 milliseconds was evaluated in accordance with FMVSS 208.[8] The acceleration traces and resultants obtained with the use of the SAE Class 180 (f_c = 300 Hz) filtering techniques are presented in Figures 31 through 34 for the driver and Figures 35 through 38 for the passenger. The results of the CSI and maximum acceleration analysis are given in Table 15. The maximum acceleration resultants are considerable less then the acceptable limit of 60 g's.

TABLE 15

CHEST SEVERITY INDEX EVALUATED FOR FULL SCALE CRASH TEST 1469-3A82

	Driver	Passenger
CSI	33	15
a_{max} ($t \geq .003$ sec)	15.44 g's	11.04 g's
$t(a_{max})$	91.87 msec	201.63 msec

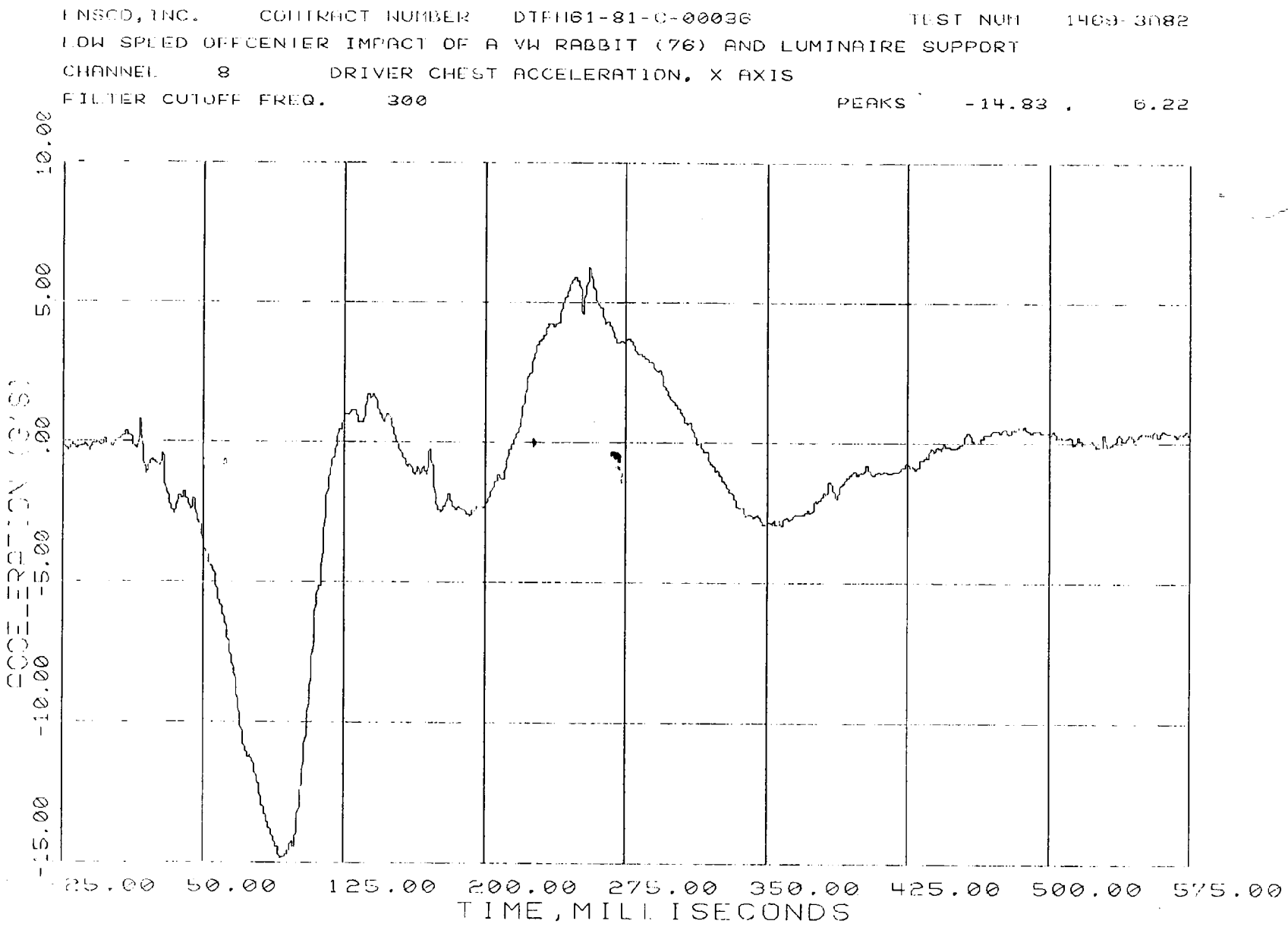


Figure 31. Driver Chest Acceleration, X Axis (SAE Class 180)

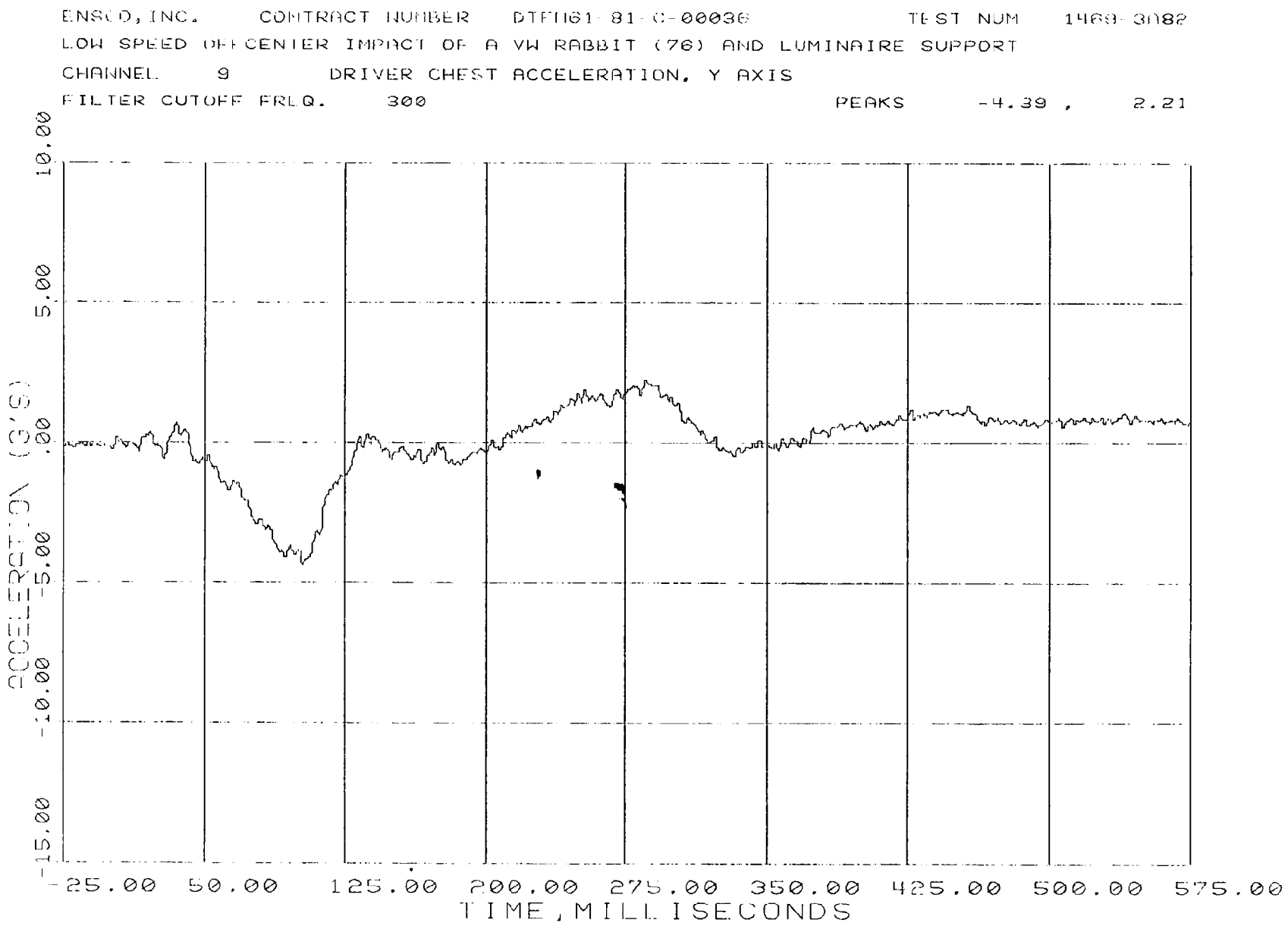


Figure 32. Driver Chest Acceleration, Y Axis (SAE Class 180)

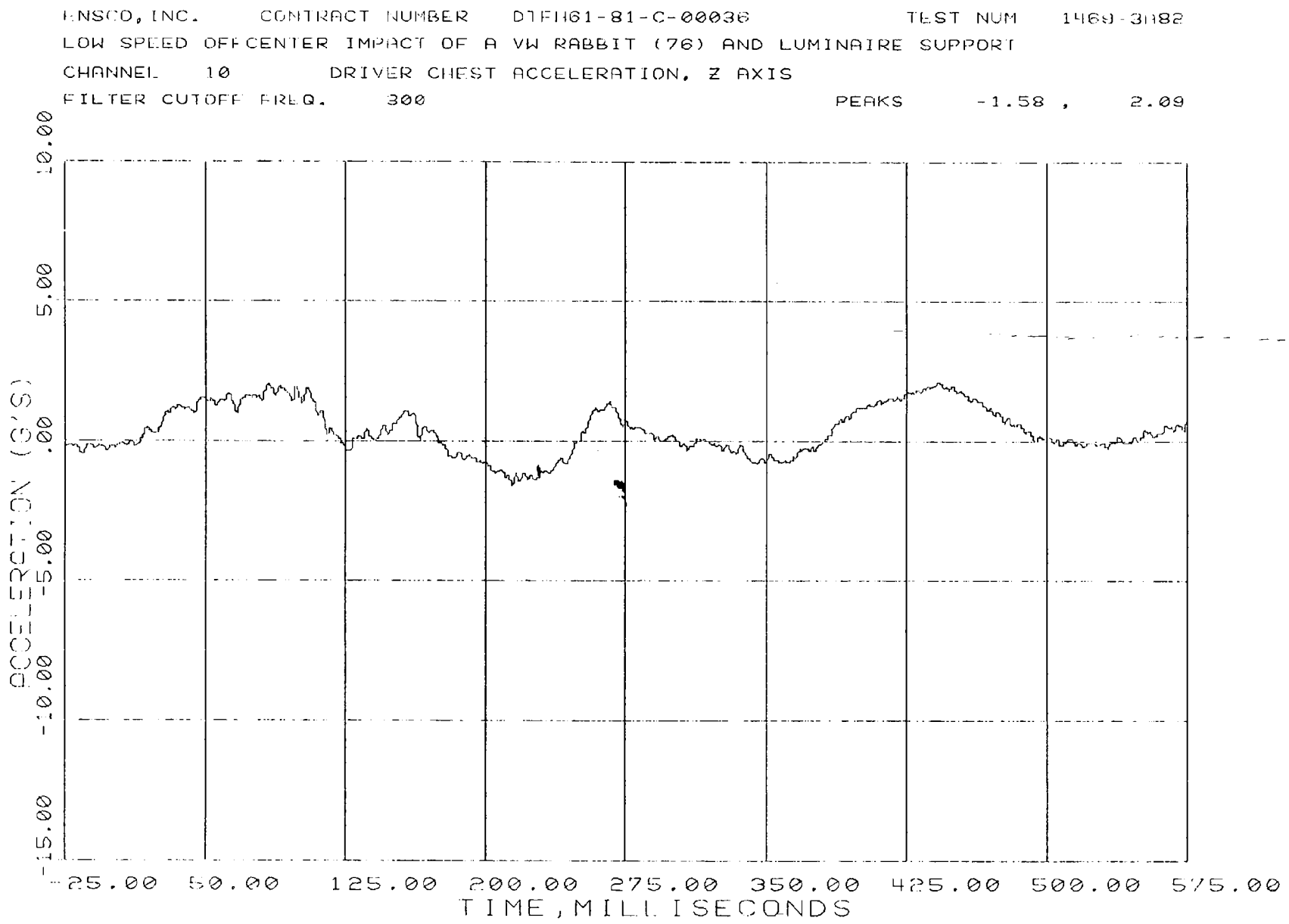


Figure 33. Driver Chest Acceleration, Z Axis (SAE Class 180)

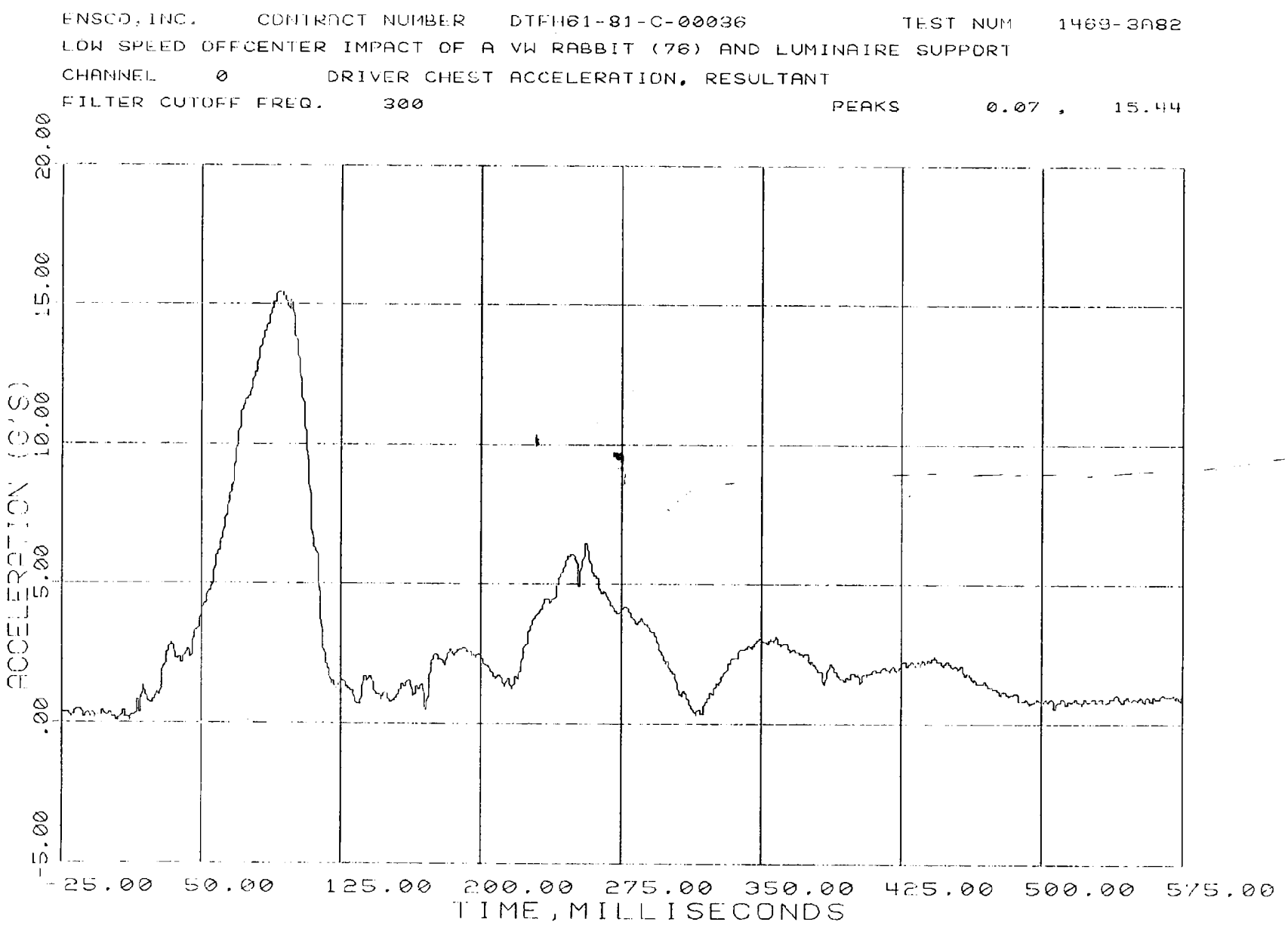


Figure 34. Driver Chest Acceleration, Resultant (SAE Class 180)

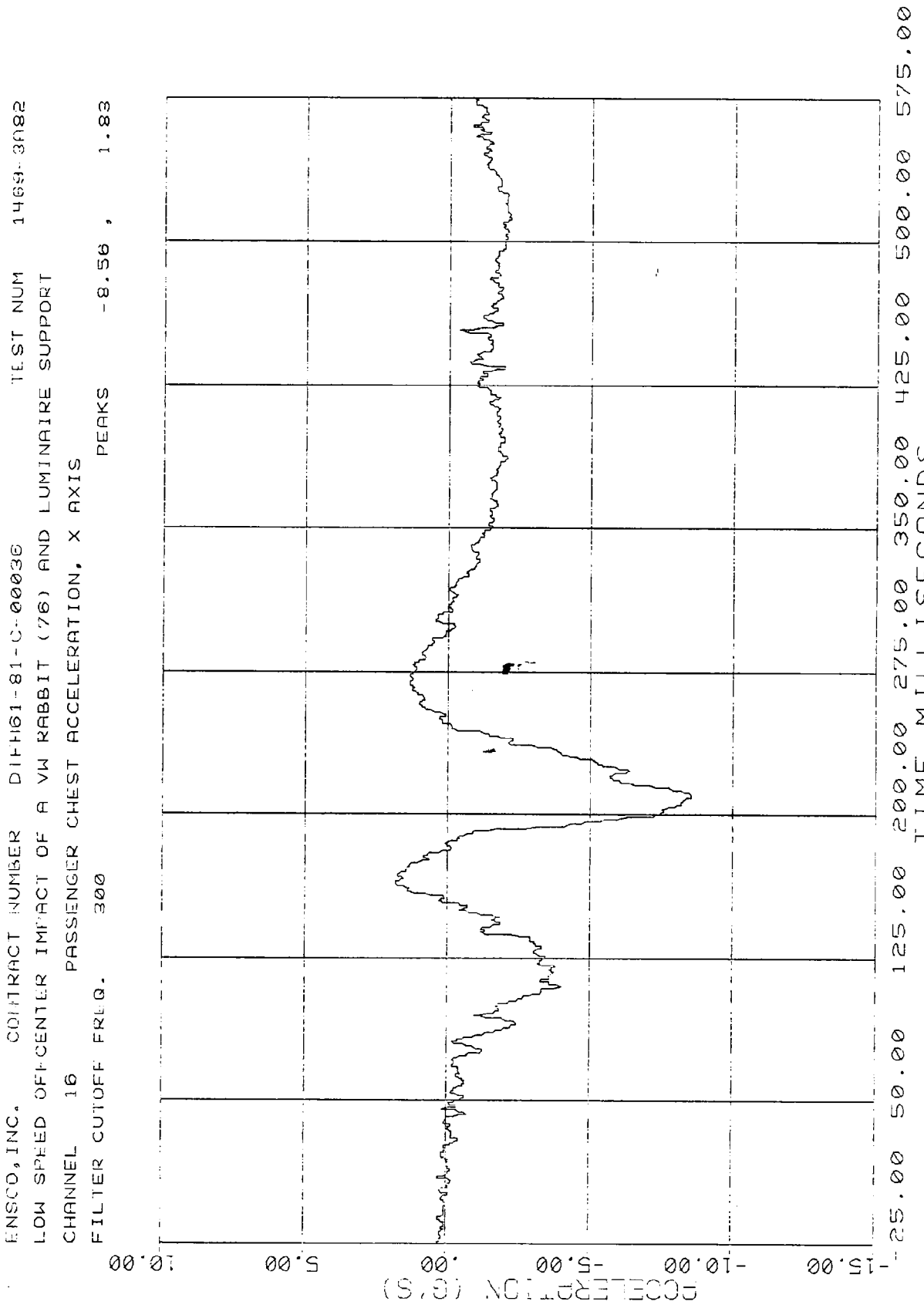


Figure 35. Driver Chest Acceleration, X Axis (SAE Class 180)

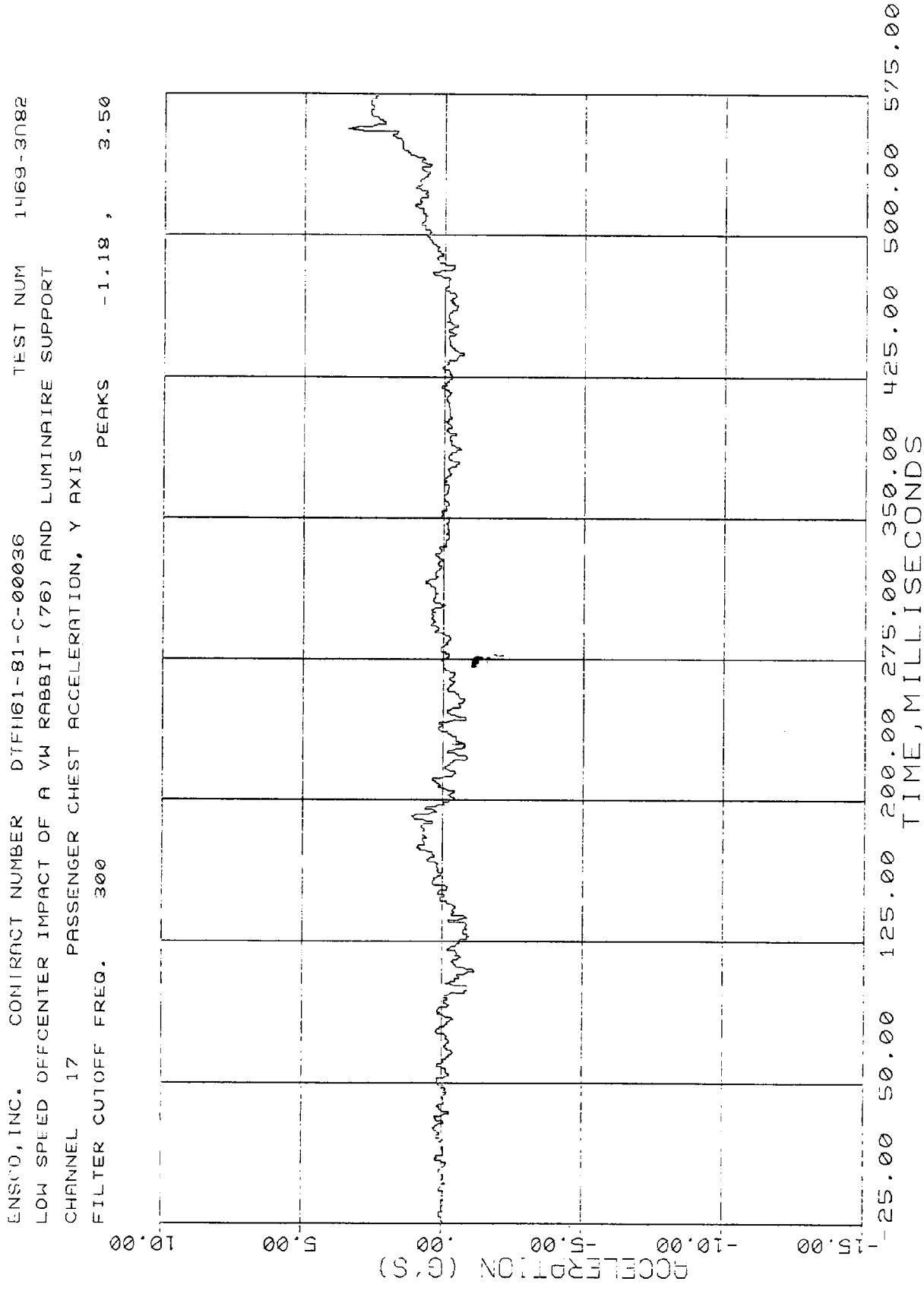


Figure 36. Driver Chest Acceleration, Y Axis (SAE Class 180)

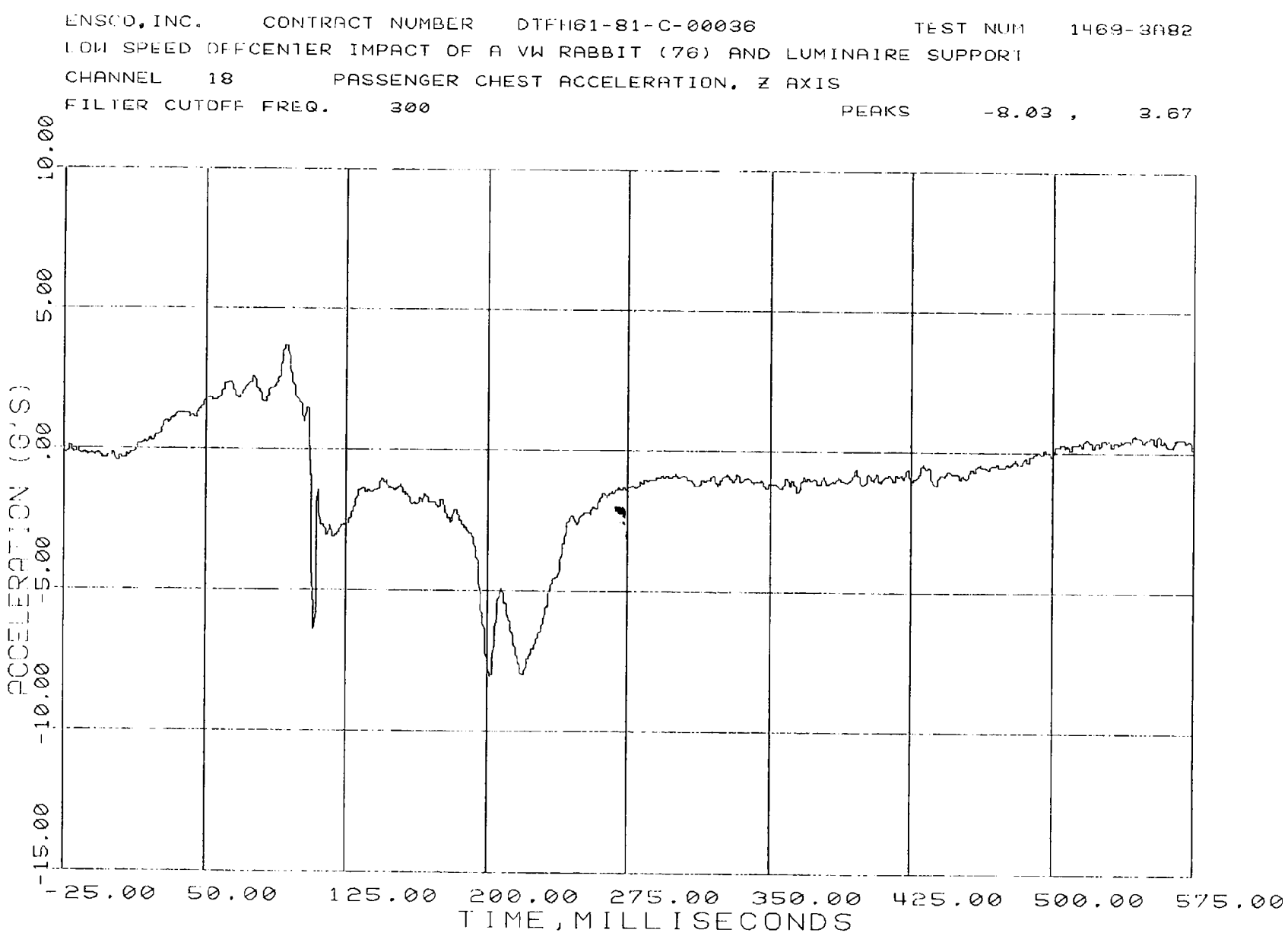


Figure 37. Driver Chest Acceleration, Z Axis (SAE Class 180)

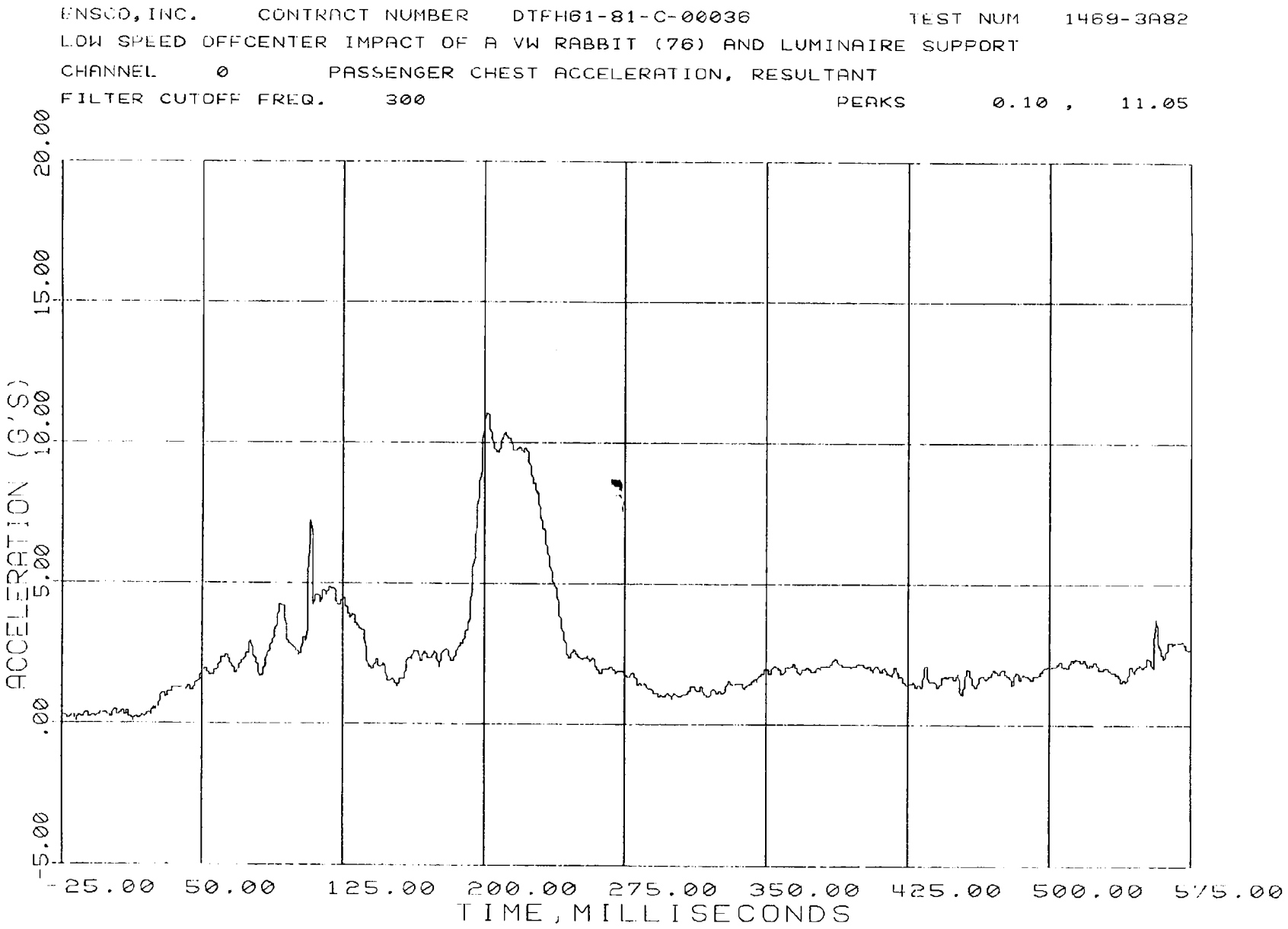


Figure 38. Passenger Chest Acceleration, Resultant (SAE Class 180)

7.6 FEMUR LOAD EVALUATION

The data obtained from the two load cells located in the femur of each leg of the occupants 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 39 through 42. The femur loads for each the of the driver's legs indicated that it went into extension since the driver was restrained by the seat belt. The maximum loads were 117 pounds and 99 pounds for the left and right legs, respectively. The femur loads for the left and right legs of the passenger were -542 and -643 pounds, respectively. These are well within the acceptable limit of 2,250 pounds.

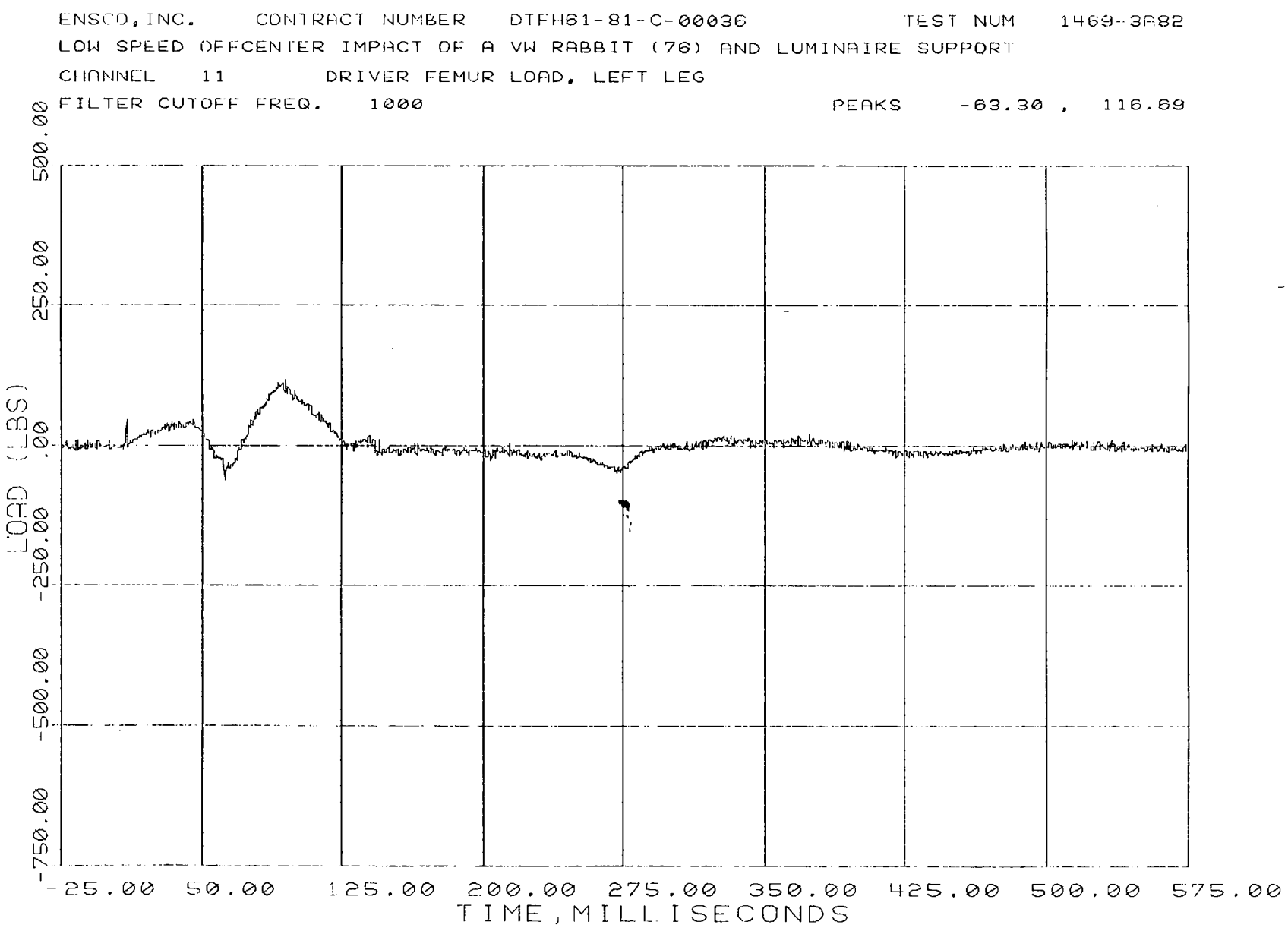


Figure 39. Driver Femur Load, Left Leg (SAE Class 600)

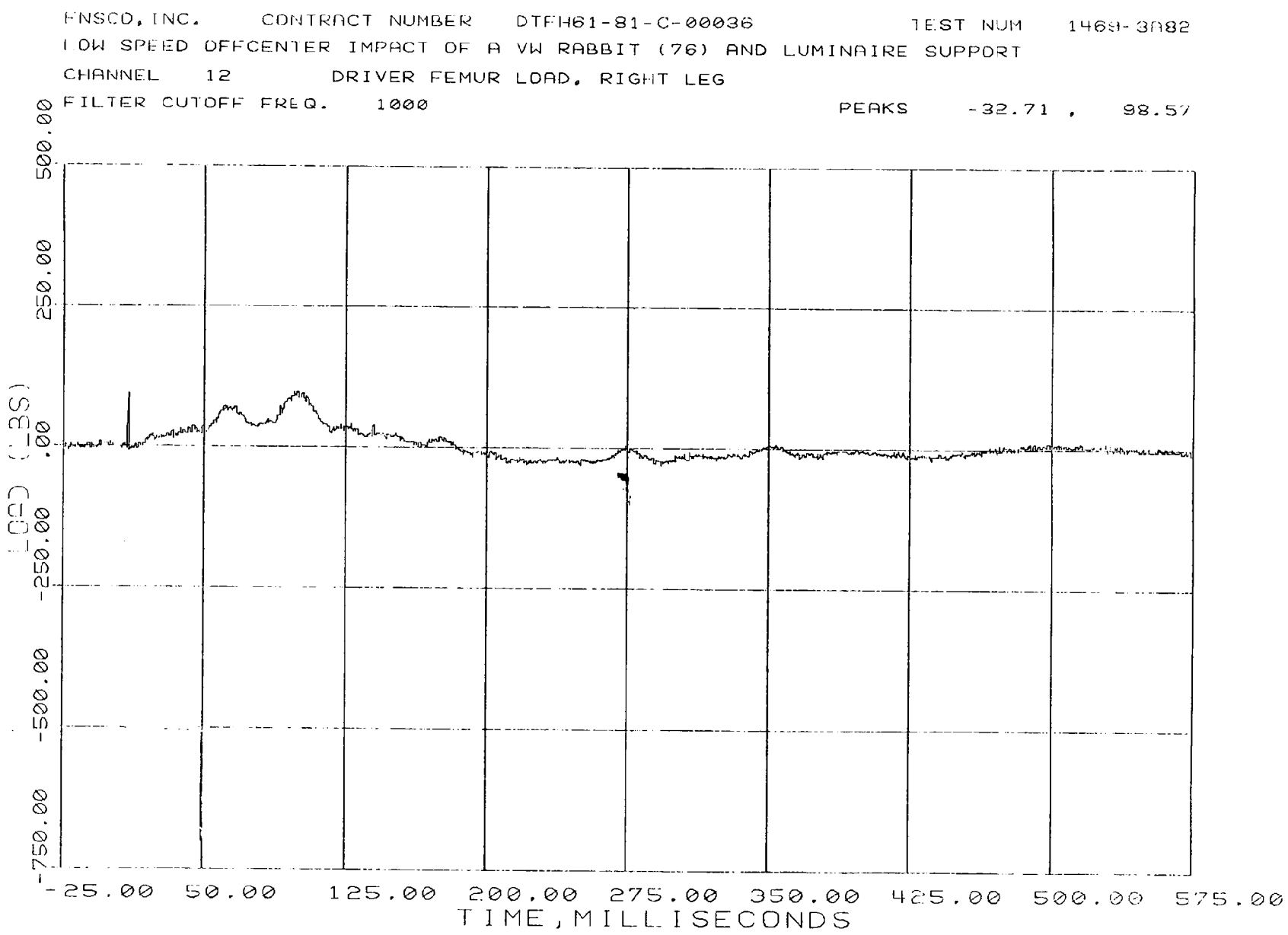


Figure 40. Passenger Femur Load, Right Leg (SAE Class 600)

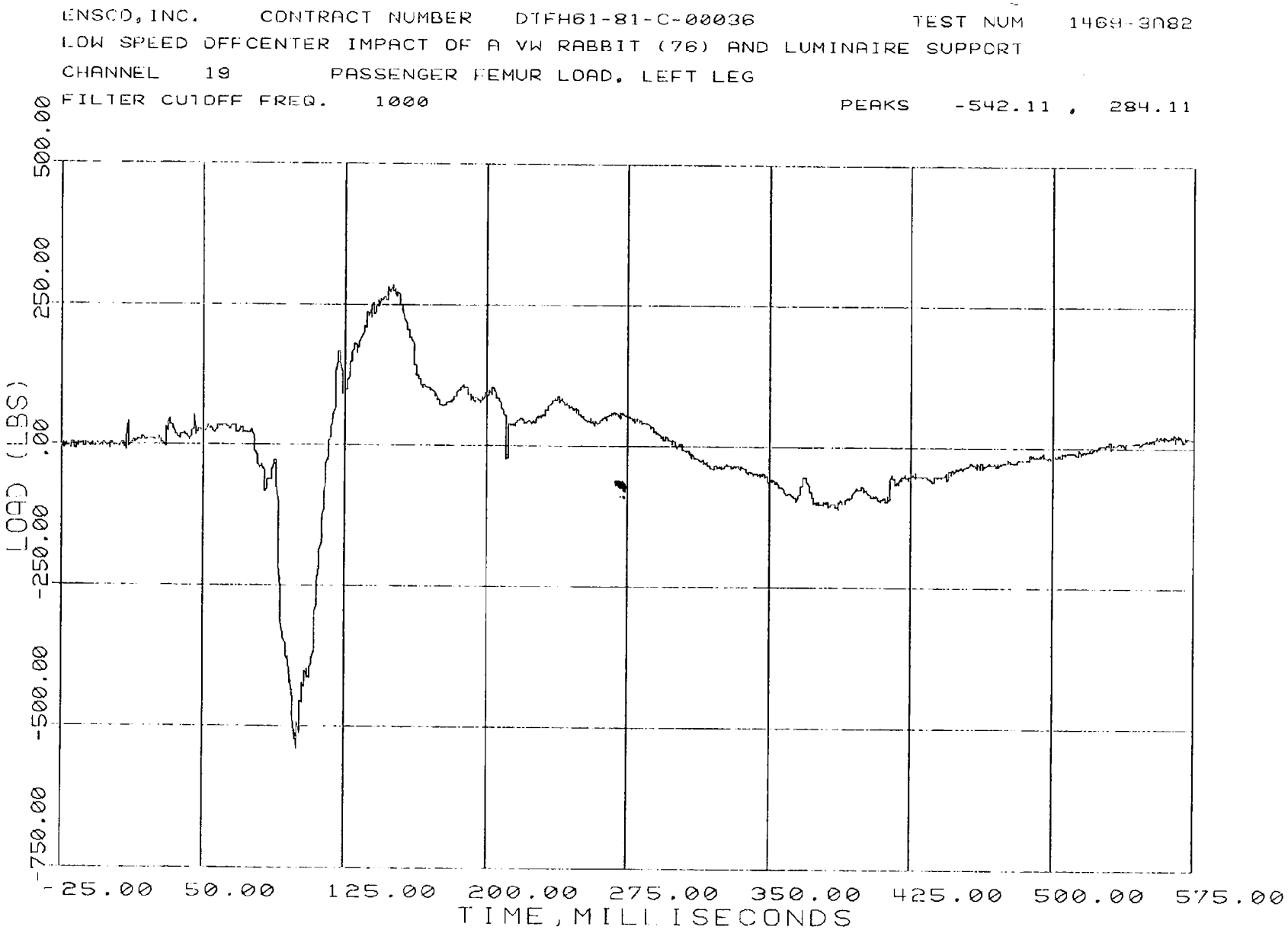


Figure 41. Passenger Femur Load, Left Leg (SAE Class 600)

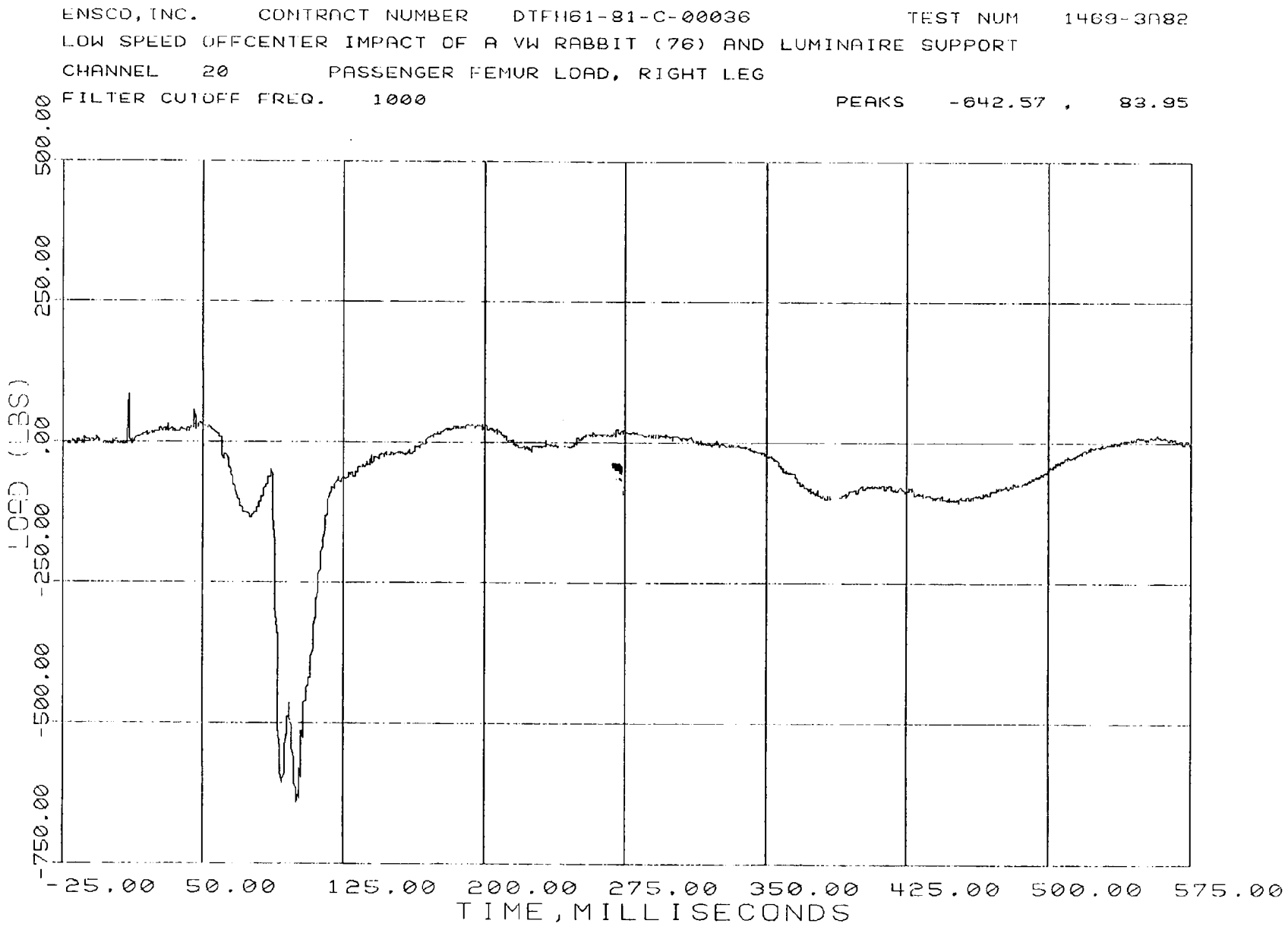


Figure 42. Passenger Femur Load, Right Leg (SAE Class 180)

8.0 CONCLUSIONS

The objective of this test was to investigate the impact behavior and post-impact stability of a minicompact sedan (1,800S) during a low speed offcenter collision with a breakaway luminaire support. The vehicle chosen for this test was a Volkswagon Rabbit based upon the results of a limited engineering study conducted by ENSCO, Inc. The surrogate luminaire support was chosen since it was known to induce a momentum change close to the upper limit of the acceptable standard of 1,100 lb-sec (4,893 N-s) when impacted by a 1971 Chevrolet Vega at an impact speed of 60 mph (26.8 m/s). The vehicle momentum change at the impact speed of 19.0 mph (27.5 m/s) was determined to be 1274 lb-sec (5,667 N-s) when evaluated from the acceleration data in accordance with NCHRP 230.

The corresponding change in the longitudinal velocity of the vehicle due to the initial collision with the surrogate luminaire support was 13.24 mph (5.92 m/s). A hypothetical front seat passenger impacted the interior of the test vehicle in the longitudinal direction at 19.4 ft/sec (5.91 m/s) which exceeds the design limit specified in NCHRP 230. Subsequent maximum 10 millisecond averaged ridedown accelerations were 1.91 g's which is well within the design limit of 15 g's.

The HIC evaluated for the driver and passenger were 57 and 45. The CSI evaluated for the driver and passenger were 33 and 15 when evaluated in accordance with SAE Information Report J885 indicating that the occupants chest injuries were mild. Further, the maximum chest acceleration whose duration exceeds .003 milliseconds were 15.4 g's and 11.0 g's for the driver and passenger, respectively. Both of the acceleration levels are within the design goal of 60 g's. Femur loads for the driver were 117 pounds and 99 pounds for the left and right legs, respectively. The femur loads for the passenger were -542 pounds and -643 pounds

for the left and right legs, respectively. These are all within the design limit of 2250 pounds specified in FMVSS 208.

The vehicle maintained its integrity during impact and protected the occupants from injury when the luminaire support fell on the roof. Crush characteristics of the test vehicle increased the momentum change which occurred during the initial impact event relative to design vehicle chosen to qualify the breakaway hardware (1971, Chevrolet Vega).

9.0 REFERENCES

1. "Revised Full Scale Crash Test Plan," Revision 2, ENSCO, Inc., FHWA Contract No. DTFH61-81-C-00036, May 1981.

2. Letter of approval for test plan and vehicle selection for crash testing to be conducted under the first task of Contract No. DTFH61-81-C-00036, L. D. McCollum, Chief, Office of Contracts and Procurement, FHWA, HCP-41, October 1981.

3. "Selection of a Vehicle for Frontal and Broadside Impact Testing Into a Luminaire Support," Revised Report, ENSCO, Inc., Contract No. DTFH61-81-C-00036, June 1981.

4. "Design and Analysis of a Surrogate Breakaway Support for Vehicle Testing," Revision 3, ENSCO, Inc., FHWA Contract No. DTFH61-81-C-00036, September 1981.

5. "Surrogate Luminaire Support Validation Test Results Report, Test Number 1469-2A82," Hinch, J. A., Howerter, E. D., Owings, R. P., ENSCO, Inc. FHWA Contract No. DTFH61-81-C-00036, 31 December 1982.

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, Transportation, Part 571, Motor Vehicle Safety Standard No. 208.

9. "Multi-Directional Slip Base for Breakaway Luminaire Supports," Edwards, T. C., Research Report 75-10 Texas Transportation Institute, August 1975.

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. "Standard Plans," California Department of Transportation, January 1981, pp. 209.

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. "Safer Sign and Luminaire Supports," Owings, R. P., et al, Final Report, ENSCO, Inc., Contract No. DOT-FH-11-8118, October 1975.

17. Laboratory Acceptance Testing of Breakaway Supports for Signs and Luminaires, Owings, R. P., Cantor, C. and Adair, J. W., ENSCO, Inc., Paper presented at TRB 55th Annual Meeting, 1976, pp. 39.