DOT0469

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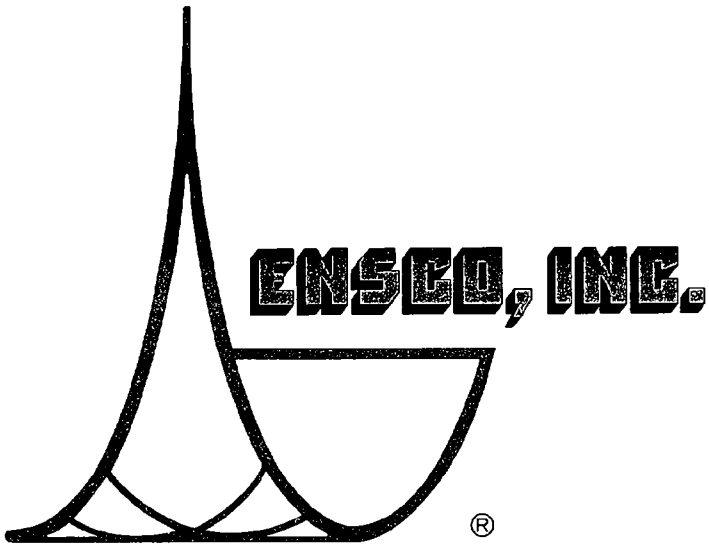

LABORATORY PROCEDURES TO DETERMINE THE BREAKAWAY BEHAVIOR OF LUMINAIRE SUPPORTS IN MINI-SIZED VEHICLE COLLISIONS

FHWA CONTRACT NO.
DTFH61-81-C-00036

LOW SPEED FORTY-FIVE DEGREE IMPACT OF A MINICOMPACT SEDAN AND A VALIDATED SURROGATE BREAKAWAY LUMINAIRE SUPPORT

TEST RESULTS REPORT

TEST NUMBER 1469-5A82

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1.0 SUMMARY AND CONCLUSIONS

This test investigated the impact severity of a minicompact sedan (1,800S) during a low speed forty-five degree 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 30.0 mph (13.39 m/s) was 552 lb-sec (2,455 N-s) based on the analysis techniques specified for processing acceleration data given in TRC 191 or NCHRP 230.[6,7] The velocity change corresponding to the observed vehicle momentum change was 9.1 mph (4.07 m/s). The integrity of the vehicle was maintained throughout the test. Maximum residual intrusion into the vehicle passenger compartment was 7.5 inches (0.19 m). Maximum residual crush of the side of the vehicle was 7.4 inches (0.19 m). The side structure of the test vehicle exhibited crush properties considerable stiffer than those for the same type of vehicle for a frontal impact. This caused the force levels on the luminaire support to increase rapidly upon impact thereby promptly activating the breakaway mechanism of the slip base which reduced the overall momentum change for the test in comparison to a frontal impact with the same type of vehicle under similar test conditions.

Vehicle acceleration data was processed to determine the impact velocity of a hypothetical front seat passenger against the vehicle interior in accordance with the flail space model recommended in NCHRP 230. The lateral impact velocity of the hypothetical occupant using the flail space model approach was 7.6 ft/sec (2.31 m/s) which occurred .16 sec after the initial impact of the vehicle with the luminaire support. This lateral

impact velocity is within the design limit of 20 ft/sec (6.10 m/s) specified for other forms of highway safety appurtances in NCHRP 230. Further, this lateral impact velocity is within the limit of 30 ft/sec (9.14 m/s) specified for occupants in FMVSS 204 and by reference in NCHRP 230.

The acceleration data from the anthropomorphic dummy was also analyzed using the processing techniques specified by Robbins.[18] Results of this analysis indicate that from the standpoint of thoracic injuries the occupant suffered an injury as measured on the American Association of Automotive Medicine's Abbreviated Injury Scale (AIS) of 0.75. This is well within the basic design goal for occupant responses of an AIS less than or equal to 3.0. Analysis of the acceleration data from the head of the anthropomorphic dummy yielded a Head Injury Criteria (HIC) of 29. This result is within the limit of 1000 specified in FMVSS 208 and by reference in NCHRP 230. 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 1469-5A82

1.	Contract Number	DTFH61-81-C-00036
2.	Date of Test	June 1, 1982
3.	Test Vehicle	Volkswagon Rabbit, 1976
4.	Vehicle Weight, Original Conf.	1,711 lbs
5.	Vehicle Weight, Test Inertial Planned Actual	 1,800 ±50 lbs 1,788 lbs
6.	Vehicle Weight, Gross Static Actual (One Occupant)	 1,954 lbs
7.	Number of Occupants	One
8.	Occupant Type	Anthropomorphic Dummy, 50th Percentile Male, Side Impact Thorax
9.	Occupant Location	Driver Seat
10.	Occupant Restraint	Unrestrained
11.	Test Article	Surrogate Breakaway Luminaire Support
12.	Support Length (w/o Base)	34 ft
13.	Support Material	Steel 8-in (Nom.) Pipe (Schedule 40)
14.	Support Weight (w/Base)	1,002.7 lbs
15.	Base Type	Triangular Slip Base, 3-Bolt (Type 31)
16.	Slip Plane Mounting Height Above Grade	4.25 in

TABLE 1 (Cont'd)
SUMMARY OF TEST CONDITIONS AND
RESULTS FOR TEST NUMBER 1469-5A82

17.	Bolt Circle	14 in
18.	Bolt Size	1 in - 8 NC x 5 in long
19.	Bolt Load (Strain Gaged)	14,000 lbs each
20.	Foundation	W, 3 ft; L, 4 ft; D, 4 ft
21.	Ground Conditions	Dry
22.	Impact Speed	
	Planned	30.00 mph
	Observed	29.96 mph
23.	Exit Speed, Observed	
	Acceleration Data, NCHRP 230	23.75 mph[6]
	Acceleration Data, TRC 191	23.76 mph[7]
24.	Speed Reduction, Observed	
	Acceleration Data, NCHRP 230	6.21 mph[6]
	Acceleration Data, TRC 191	6.20 mph[7]
25.	Impact Point	
	Planned	Left Side, A Pillar
	Observed	Left Side, A Pillar
26.	Impact Angle of Vehicle Motion with Respect to Theoretical Mast Arm	30 Degrees (Nominal)[9]
27.	Exit Angle of Vehicle with Respect of Theoretical Mast Arm	30 Degrees (Nominal)
28.	Max. Vehicle Residual Crush	7.4 in.
29.	Max. Interior Compartment Intrusion	7.5 in.
30.	Traffic Accident Data, TAD[10]	11-LP-3
31.	Vehicle Damage Index, VDI[11]	11LYAN2

TABLE 1 (Cont'd)
SUMMARY OF TEST CONDITIONS AND
RESULTS FOR TEST NUMBER 1469-5A82

32.	Hypothetical Occupant Impact Velocity	
	Design Limit (Redirectional Barriers)	20 ft/sec[6]
	Observed, NCHRP 230	7.65 ft/sec[6]
	Observed, TRC 191	7.64 ft/sec[7]
33.	Hypothetical Occupant Ride-down Acceleration	
	Design Limit (Redirectional Barriers)	15.00 g[6]
	Observed, NCHRP 230	1.19 g[6]
	Observed, TRC 191	1.14 g[7]
34.	Head Injury Criteria (HIC)	
	Design Limit	1000[8]
	Driver, Observed	29
35.	Peak Resultant Thorax/Pelvis Acceleration with Duration >.003 sec	
	Spine, Upper	15.57g
	Spine, Lower	19.86g
	Pelvis	11.15g
36.	Severity Index (SI)[12]	
	Spine, Upper	28
	Spine, Lower	76
	Pelvis	16
37.	Thoracic Injury Results[18]	
	Fatal Injury	6.00
	AIS	0.75
	MAIS	Below Injury Threshold
38.	Momentum Change	
	Acceleration Data, NCHRP 230	552 lb-sec[6]
	Accelerations Data, TRC 191	552 lb-sec[7]

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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 severity of a minicompact sedan (1,800S) during a low speed forty-five degree collision with a surrogate breakaway luminaire support. This test is the fifth 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] A triaxial accelerometer package was mounted on the lateral centerline of the vehicle at the longitudinal location of the center of gravity of the vehicle in its inertial test configuration. The data from these accelerometers 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 left door of the vehicle was instrumented with four accelerometers to characterize the acceleration environment of the door. The vehicle also was instrumented with a contact switch mounted at the location of the A pillar to permit vehicle and occupant data to be measured relative to the time of impact.

The vehicle contained one instrumented 50th percentile male anthropomorphic test dummy equipped with a thorax specifically designed for side impacts. The test dummy was positioned in the driver seat and was unrestrained. The data from the triaxial accelerometer sensor assembly in the head of the test dummy was used to evaluate the Head Injury Criteria (HIC) specified in FMVSS 208 and by reference in NCHRP 230. The data obtained from the triaxial accelerometer sensor assemblies located in the upper and lower parts of the spine and in the pelvis of the occupant were used to evaluate severity indices and maximum sustained accelerations experienced by the occupant in the respective locations in accordance with SAE Information Report J885a, FMVSS 208

and by reference NCHRP 230. The data obtained from the accelerometers located on the ribs and sternum of the occupant were used to evaluate the maximum sustained accelerations experienced by the occupant in the respective locations using the technique described in FMVSS 208. In addition, thoracic injury parameters associated with side impact conditions were analyzed using processing techniques specified by Eppinger[19] and Robbins.[18] Finally, occupant injury as measured on the American Association of Automotive Medicine's Abbreviated Injury Scale (AIS) and Modified AIS (MAIS) were evaluated using the approach outlined by Robbins.[18]

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. Pretest 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	14.83 feet

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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 1,711 pounds. The test inertial weight for the vehicle was 1,788 pounds and the gross static weight when the occupant was included in the vehicle was 1,954 pounds. The longitudinal center of gravity of the vehicle without the occupant was located 31.8 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	552	560	1,112
Rear	292	307	599
Subtotals	844	867	1,711

1 lb. = .454 kg

TABLE 4

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

	Left (lbs)	Right (lbs)	Subtotal (lbs)
Front	572	614	1,186
Rear	285	317	602
Subtotals	857	931	1,788

1 lb = .454 kg

TABLE 5

WEIGHT DISTRIBUTION OF TEST VEHICLE
IN PRE-TEST CONFIGURATION WITH OCCUPANT

	Left (lbs)	Right (lbs)	Subtotal (lbs)
Front	633	635	1,268
Rear	345	341	686
Subtotals	978	976	1,954

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 left side at the location of the A pillar 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 2. Pretest Photograph of Test Vehicle
Left Side View

Figure 3. Pretest Photograph of Test Vehicle
Front View

Figure 4. Pretest Photograph of Test Vehicle Shown Next to Surrogate Luminaire Support, Left Angle View

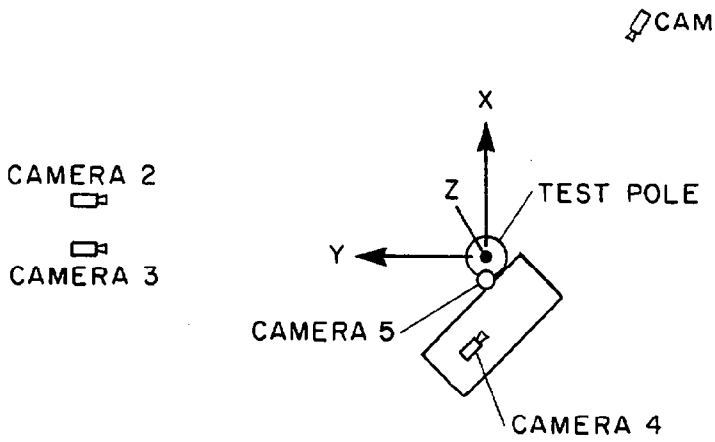
Figure 5. Pretest Photograph of Test Vehicle Shown Next to Surrogate Luminaire Support, Front View

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 Hz to 300 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 1.1 seconds prior to the vehicle impacting the luminaire support. This control signal was used to externally trigger the digitizing unit and automatically synchronize all data channels. 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 1469-5A82



Camera	Model	Position	Placement X(ft),Y(ft),Z(ft)	Speed Setting	Lens
1	Redlake Hycam	Rt. Side	180,-74, 2	500 pps	50 mm
2	Redlake Locam	Lt. Side	2, 75, 4	500 pps	50 mm
3	Redlake Locam	Lt. Side	0, 76, 5	500 pps	25 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 1469-5A82

Data Channel	Recorder Channel	Channel Description	Transducer Model	Transducer Serial #	Multiplex Frequency	Deviation Frequency
1	6	Vehicle, X	Statham A69TC-15-350	16522	32 kHz	-133.26 Hz/g
2	6	Vehicle, Y	Statham A69TC-25-350	18181	48 kHz	- 89.51 Hz/g
3	6	Vehicle, Z	Statham A69TC-15-350	16189	64 kHz	139.49 Hz/g
4	6	Impact, Y	Tape Switch No. 107-LS	N/A	80 kHz	+2 kHz/Contac
5	6	Door, Upper Center, Y	ENDEVCO 7231C-750	CY78	96 kHz	5.56 Hz/g
6	6	Door, Middle Forward, Y	ENDEVCO 7231C-750	CZ17	112 kHz	5.55 Hz/g
7	6	Door, Middle Rear, Y	ENDEVCO 7231C-750	CZ39	128 kHz	5.50 Hz/g
8	6	Door, Lower Center, Y	ENDEVCO 7231C-750	DD85	144 kHz	5.21 Hz/g
9	1	Sternum, Upper, X	ENDEVCO 2264-2000	AH21	32 kHz	-14.83 Hz/g
10	1	Sternum, Lower, X	ENDEVCO 2264-2000	AS69	48 kHz	-14.61 Hz/g
11	1	Rib, Left Upper, Y	ENDEVCO 2264-2000	AD55	64 kHz	-14.22 Hz/g
12	1	Rib, Left Lower, Y	ENDEVCO 2264-2000	AL31	80 kHz	-18.83 Hz/g
13	1	Rib, Right Upper, Y	ENDEVCO 2264-2000	AD59	96 kHz	13.60 Hz/g
14	1	Rib, Right Lower, Y	ENDEVCO 2264-2000	AD54	112 kHz	19.94 Hz/g
15	1	Spine, Upper, X	ENDEVCO 2264-2000	AD32	128 kHz	-17.82 Hz/g
16	1	Spine, Upper, Y	ENDEVCO 2264-2000	AA17	144 kHz	15.96 Hz/g
17	2	Spine, Upper, Z	ENDEVCO 2264-2000	AD80	32 kHz	19.27 Hz/g
18	2	Spine, Lower, X	ENDEVCO 2264-2000	AJ07	48 kHz	15.92 Hz/g
19	2	Spine, Lower, Y	ENDEVCO 2264-2000	AN74	64 kHz	18.44 Hz/g
20	2	Spine, Lower, Z	ENDEVCO 2264-2000	AS25	80 kHz	16.47 Hz/g
21	3	Pelvis, X	ENDEVCO 2264-2000	AR99	96 kHz	-18.26 Hz/g
22	3	Pelvis, Y	ENDEVCO 2264-2000	AR83	112 kHz	16.75 Hz/g
23	3	Pelvis, Z	ENDEVCO 2264-2000	AH02	128 kHz	-19.11 Hz/g
24	3	Head, X	ENDEVCO 7231C-750	CS10	144 kHz	24.96 Hz/g
25	3	Head, Y	ENDEVCO 7231C-750	CS74	32 kHz	-21.85 Hz/g
26	3	Head, Z	ENDEVCO 7231C-750	CV52	48kHz	-23.07 Hz/g
27	7	Sync. 32 kHz	N/A	N/A	N/A	N/A

6.0 TEST RESULTS

The impact conditions were 30.0 mph (13.39 m/s) at the A pillar on the left side of the vheicle 12.9 in (.33 m) ahead of the longitudinal location of the center of gravity of the vehicle in its inertial test configuration. The maximum residual crush of the vehicle at the impact point was 7.38 inches (.19 m). The maximum residual intrusion into vehicle compartment was 7.50 in (0.19 m). Photographs of the vehicle after the collision event are shown in Figures 6 through 9.

Initiation of the breakaway fracture mechanism of the luminaire support occurred at approximately .010 seconds after impact. The force levels at the time of initiation of the breakaway fracture mechanism of the luminaire support were 26,192 pounds and 26,980 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 13.11 f/s (3.996 m/s) with a rotation rate of 1.88 rad/sec. The luminaire support rotated up and over the test vehicle without any secondary impacts. The top of the luminaire support impacted the ground 4.5 feet behind and .9 feet to the right of the original center line position of the luminaire support. The test sequence is depicted in Figures 10 and 11. The dimensional relationships for full scale crash test number 1469-5A82 are shown in Figure 12. The residual test vehicle crush and interior intrusion resulting from the collision event were measured at the locations shown in Figure 13 and are given in Table 8.

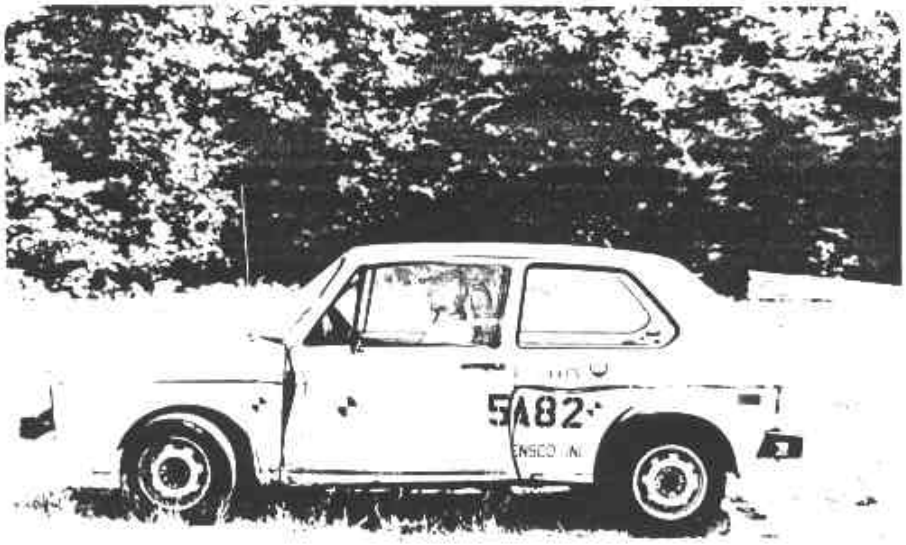


Figure 6. Post-Test Photograph of Test Vehicle, Left Side View

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

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

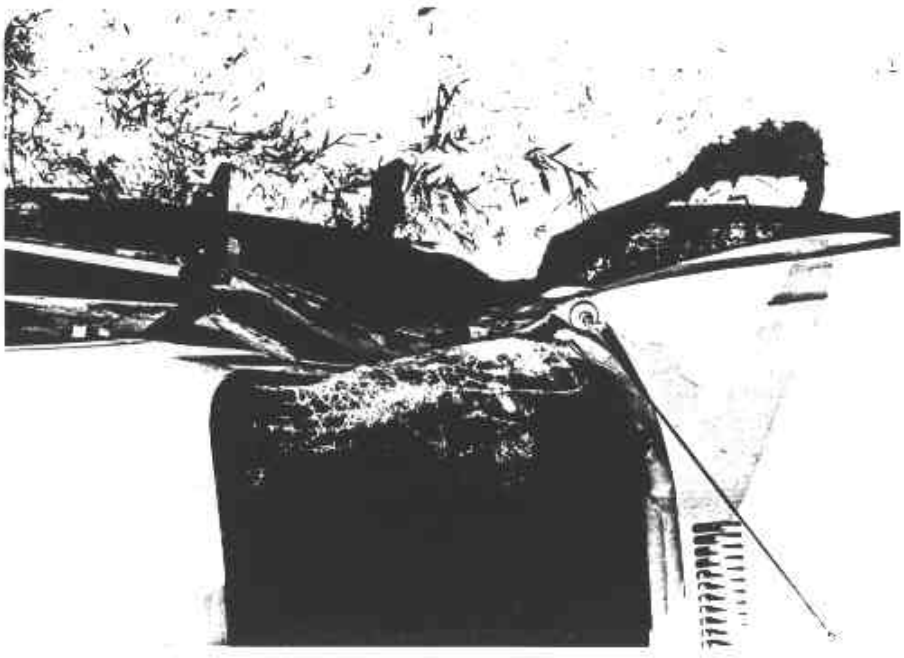


Figure 9. Post-Test Photograph of Test Vehicle, Overhead View

t = 0.00 sec

t = 0.090 sec

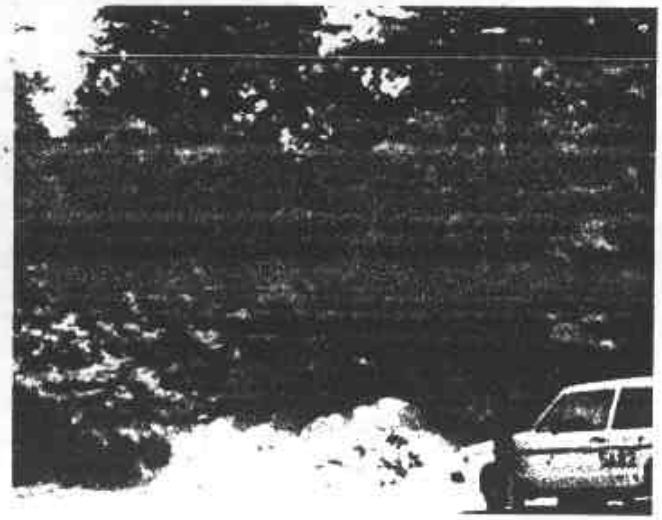
t = 0.030 sec

t = 0.120 sec

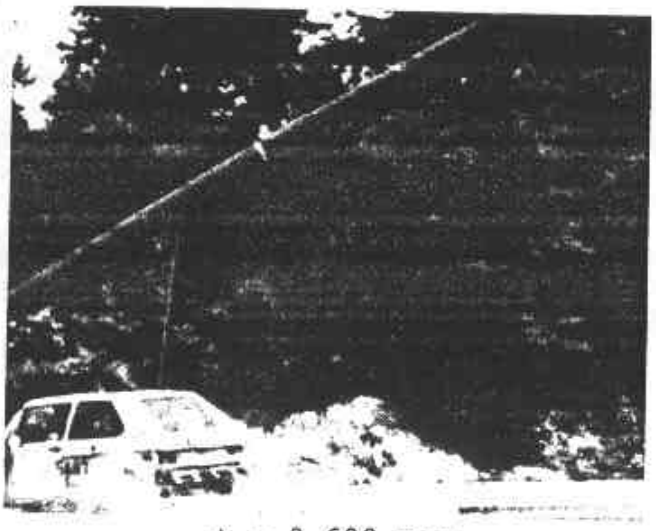
t = 0.060 sec

t = 0.150 sec

Figure 10. Test Sequence for the Iniital Collision Event of Full Scale Crash Test Number 1469-5A82

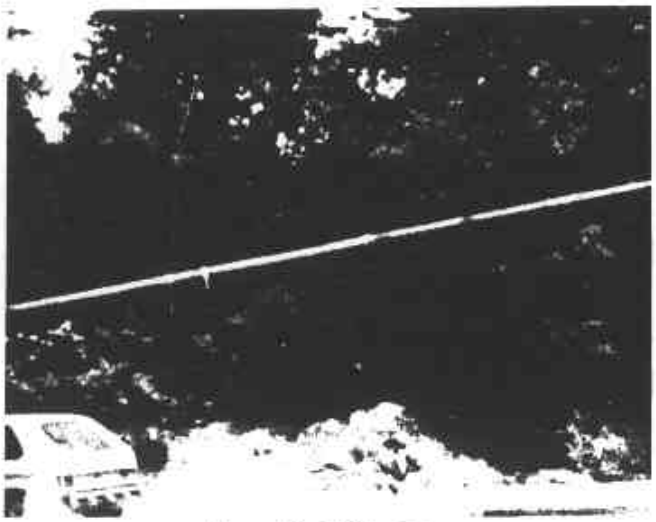


t = 0.00 sec



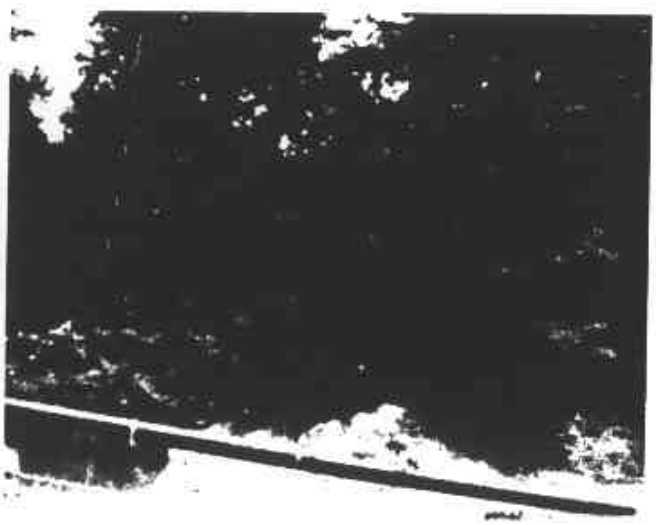
t = 0.600 sec

t = 0.200 sec



t = 0.800 sec

t = 0.400 sec



t = 1.00 sec

Figure 11. Test Sequence of the Entire Collision Event of Full Scale Crash Test Number 1469-5A82

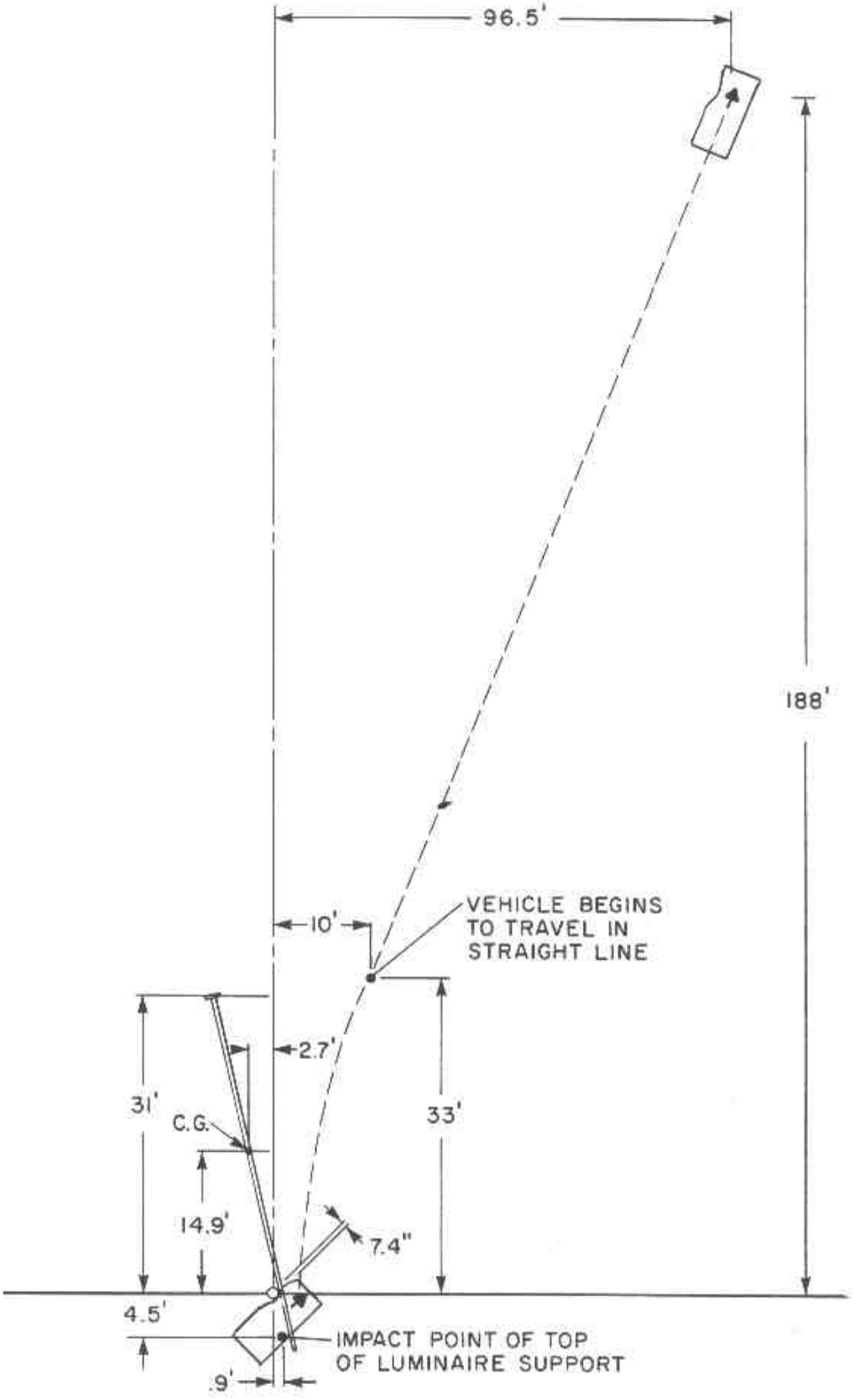


Figure 12. Dimensional Relationships for Full Scale Crash Test Number 1469-5A82

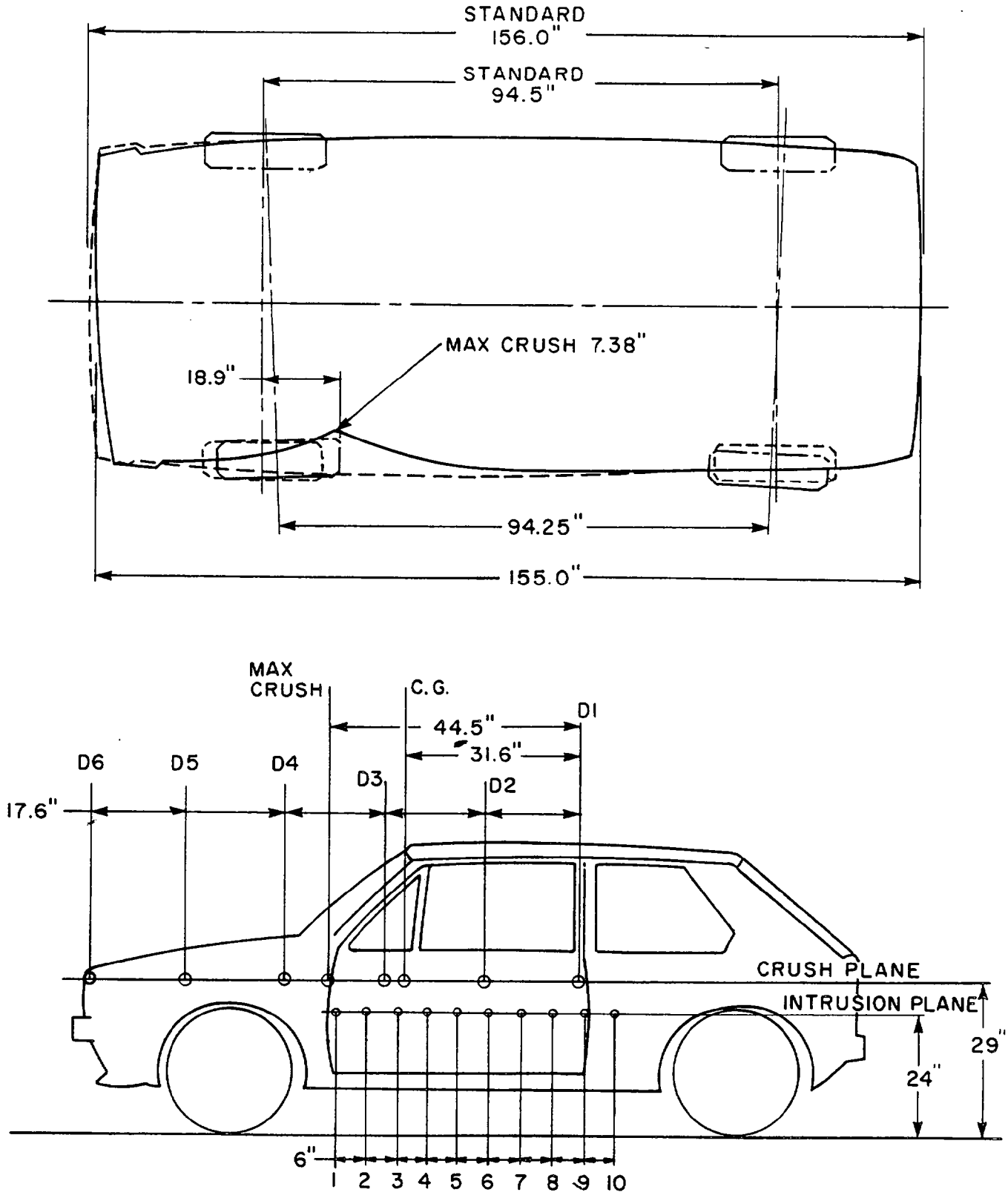


Figure 13. Vehicle Crush Diagram and Crush Measurement Matrix

TABLE 8

VEHICLE CRUSH AND INTRUSION MEASUREMENTS

CRUSH (inches)

Location	D-6	D-5	D-4	MAX	D-3	C.G.	D-2	D-1
Crush 29" Above Ground	0.0	1.75	5.13	7.38	5.38	3.88	1.38	0.00

INTRUSION (inches)

Location	1	2	3	4	5	6	7	8	9	10
24" Above Ground	7.5	4.38	3.00	2.63	1.13	.75	.50	0.00	0.00	0.00

Note: 1) Definitions for measurement locations are given in Figure 13.

7.0 TEST ANALYSIS

Data from this test were evaluated using several techniques. The pre-impact speed was determined from the high speed film information. The signals from the accelerometers mounted at the center of gravity of 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.[1,2] The signals from the accelerometers mounted at the center of of gravity of 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 on the left door of the vehicle were debiased and filtered at SAE Class 180 and are presented to characterize the acceleration environment on the door at the impact location.

The data from the triaxial accelerometer sensor assembly in the head of the test dummy was filtered at SAE Class 1000 and used to evaluate the HIC as specified in FMVSS 208 and by reference in NCHRP 230. The data obtained from the triaxial accelerometer sensor assemblies located in the upper and lower parts of the spine and in the pelvis of the occupant were filtered at SAE Class 180 and were used to evaluate severity indices and maximum sustained accelerations experienced by the occupant in the respective locations in accordance with SAE Information Report J885a, FMVSS 208 and by reference NCHRP 230. The data obtained from the accelerometers located on the ribs and sternum of the occupant were filtered at SAE Class 180 and were used to evaluate the maximum sustained acceleration experienced by the occupant in the respective locations using the technique described in FMVSS

208. In addition, thoracic injury parameters associated with side impact conditions were analyzed using processing techniques specified by Eppinger[19] and Robbins[18]. Finally an AIS and modified AIS were evaluated using the approach outlined by Robbins[18] from a relatively new thoracic injury parameter evaluated from the left upper rib accelerometer signal which was located on the side of the impact.

7.1 FILM IMPACT VELOCITY ANALYSIS

The speed that the test vehicle impacted the surrogate support was determined from the high speed films. Results from the speed analysis of the film data are contained in Table 9. Based upon the results of this analysis, the speed of the vehicle upon impacting the surrogate support was 30.0 mph (13.39 m/sec).

TABLE 9

TEST VEHICLE IMPACT SPEED EVALUATION
USING HIGH SPEED FILM ANALYSIS

Camera	Position	Impact Speed (ft/sec)	Impact Speed (mph)
2	Left Side	42.42	28.92
5	Overhead	45.45	30.99
		43.94	29.96

1 ft/sec = .3048 m/sec
1 mph = .44704 m/sec

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 obtained from the location of the center of gravity of the vehicle 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 14 through 22. The acceleration traces and resultants obtained with the use of the SAE Class 180 (f_c = 300 Hz) filtering technique are presented in Figures 23 through 30.

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.

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	-7.74	11.500	-12.33	11.000
Y Axis	-14.31	11.125	-25.36	11.125
Z Axis	-15.48	70.750	-19.71	70.375
Resultant, X and Y	16.24	11.250	28.17	11.125
Resultant, X,Y and Z	17.07	11.375	28.27	11.125
Left Door, Upper Ctr	64.71	45.250	100.40	44.875
Left Door, Middle For.	-93.53	15.625	-225.85	16.500
Left Door, Middle Rear	16.05	48.375	27.16	18.290
Left Door, Lower Ctr	-128.40	20.375	-210.13	20.125

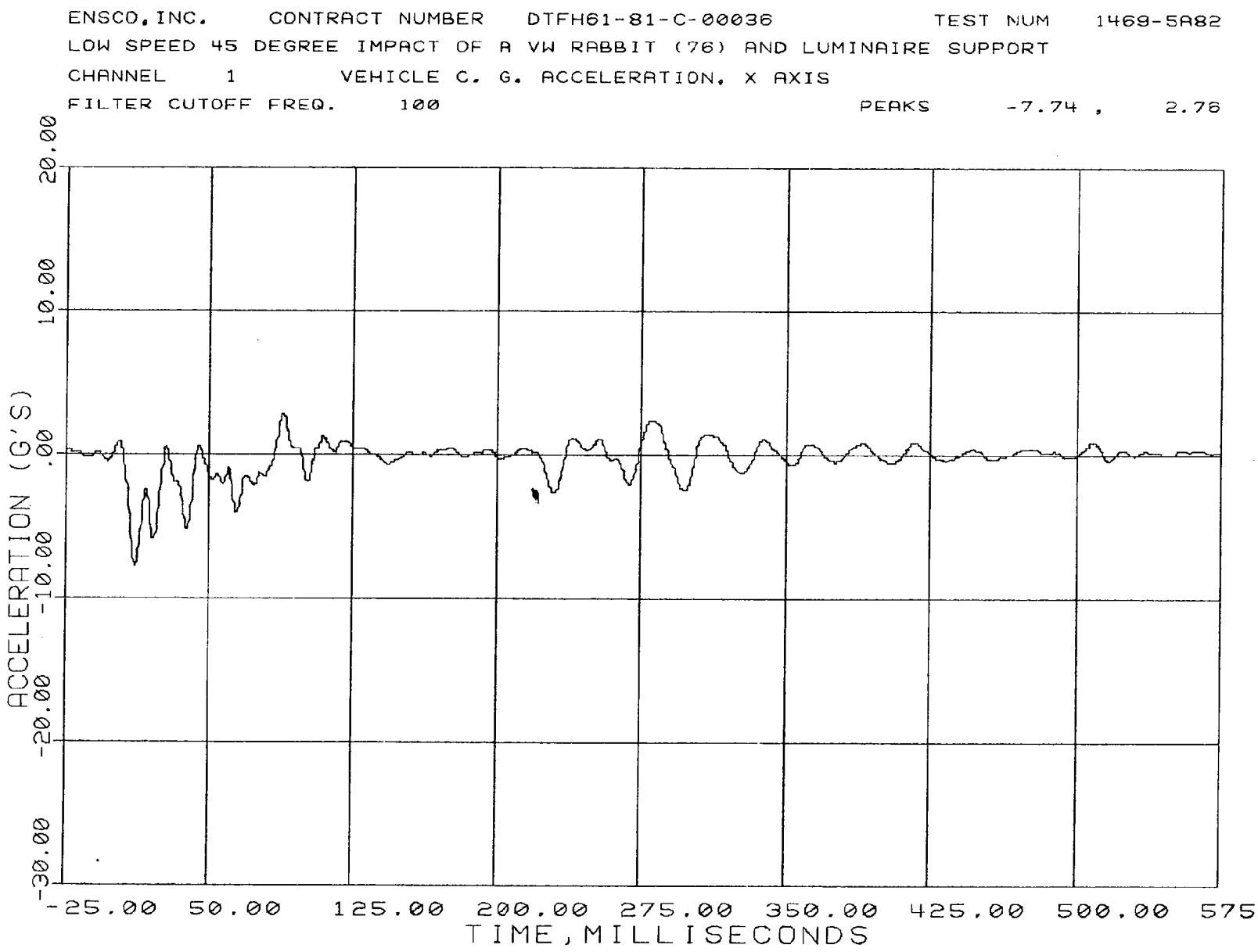


Figure 14. Vehicle C.G. Acceleration, X Axis (SAE Class 60)

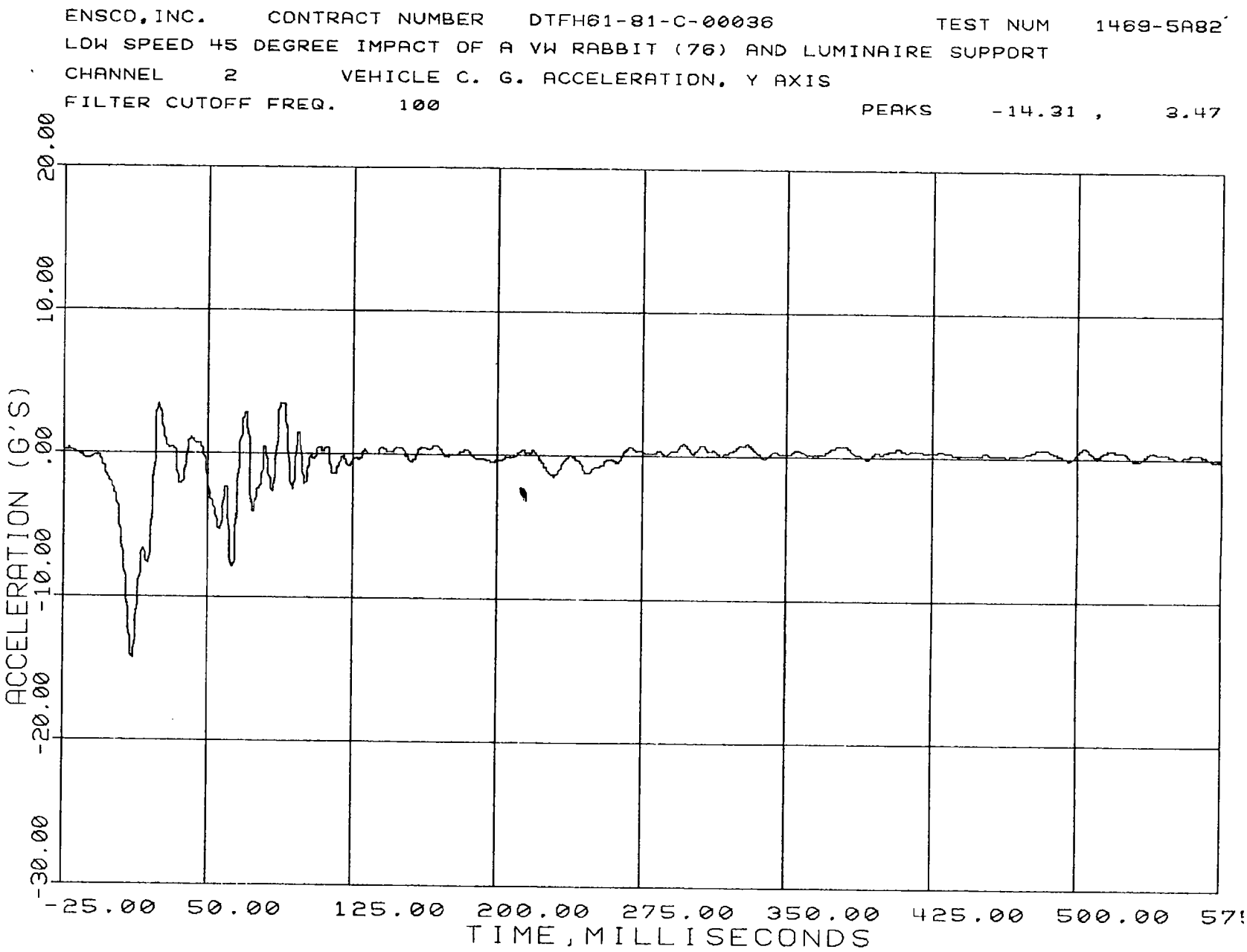


Figure 15. Vehicle C.G. Acceleration, Y Axis (SAE Class 60)

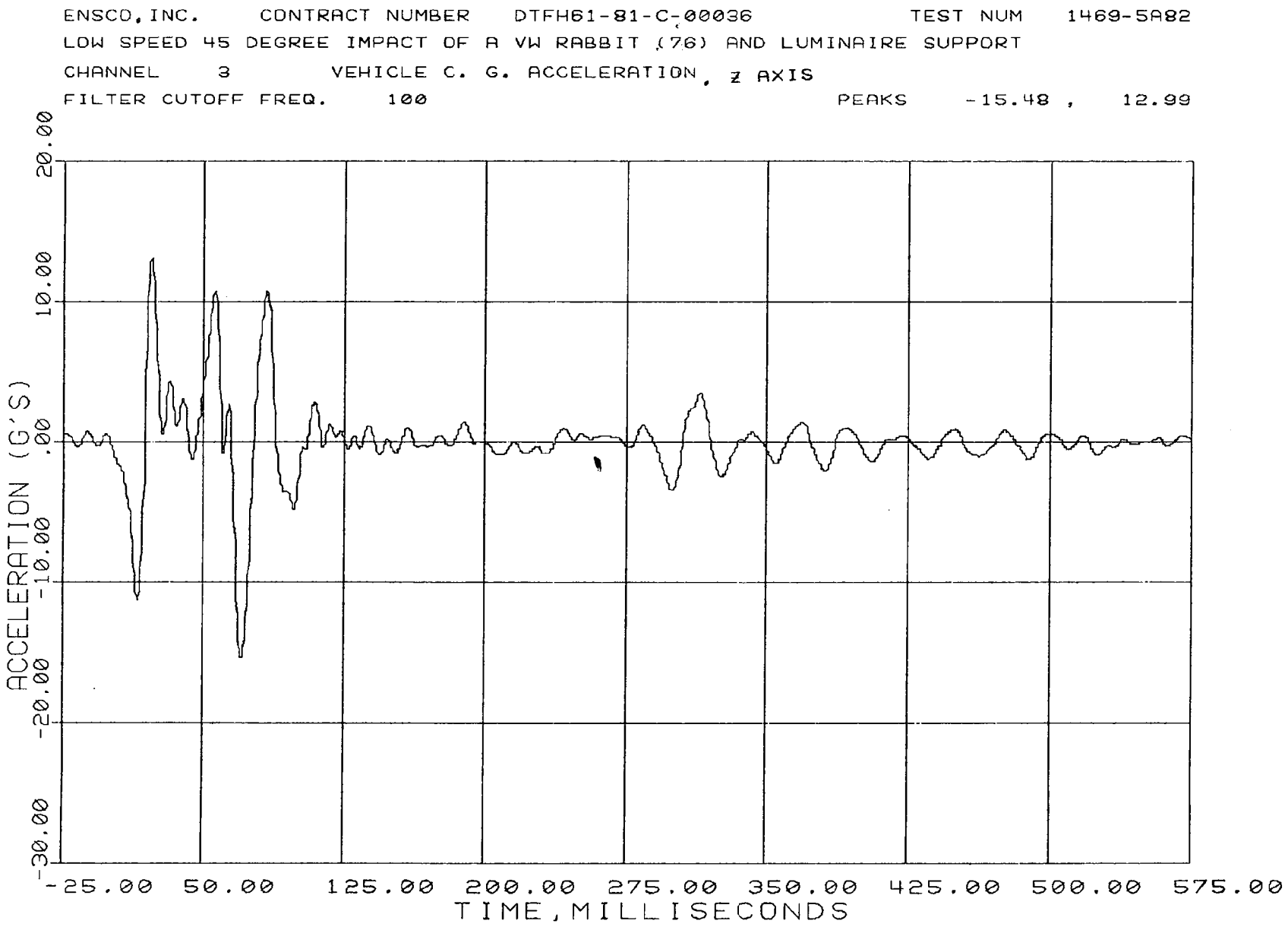


Figure 16. Vehicle C.G. Acceleration, Z Axis (SAE Class 60)

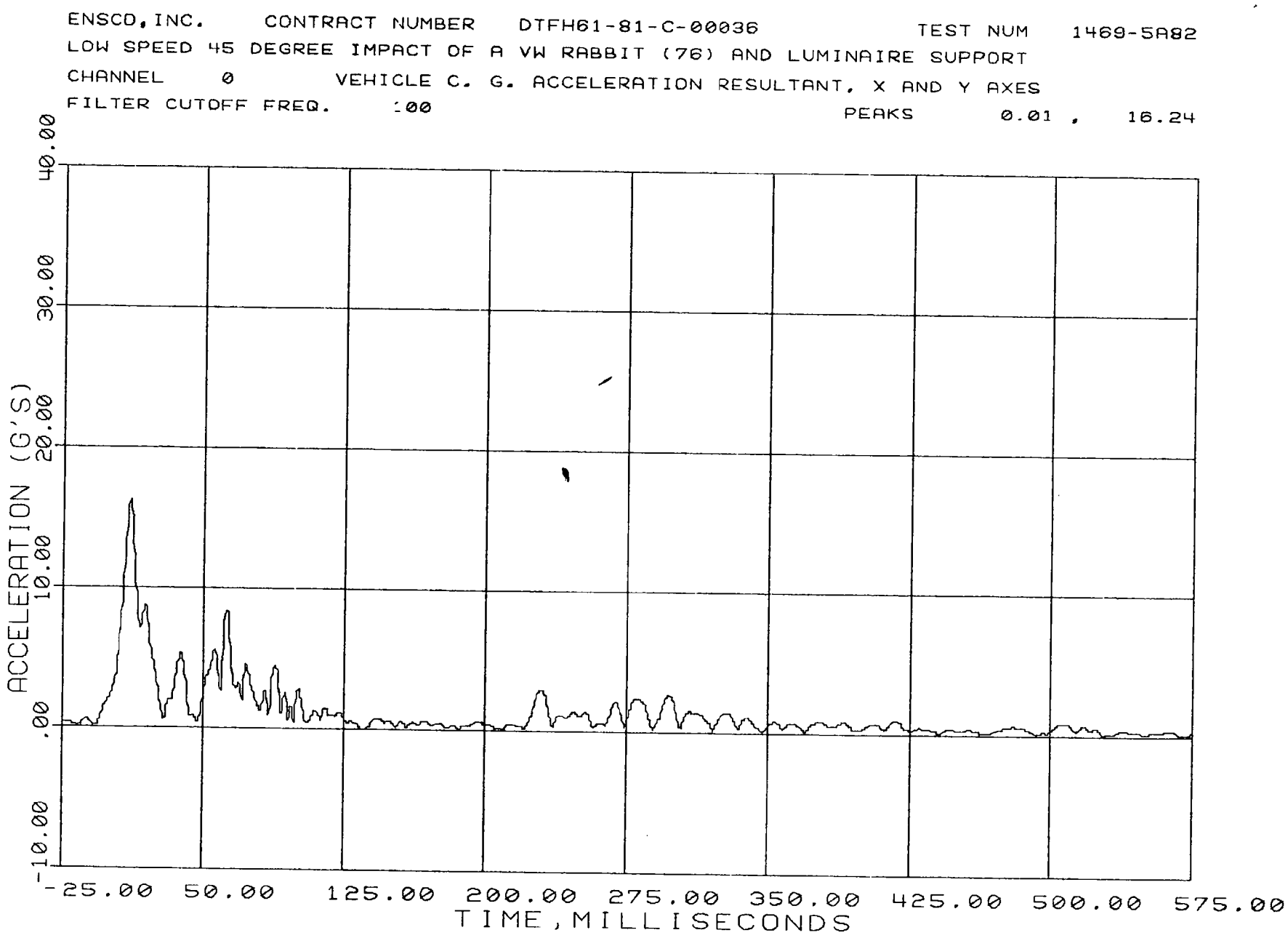


Figure 17. Vehicle C.G. Acceleration, X and Y Axes (SAE Class 60)

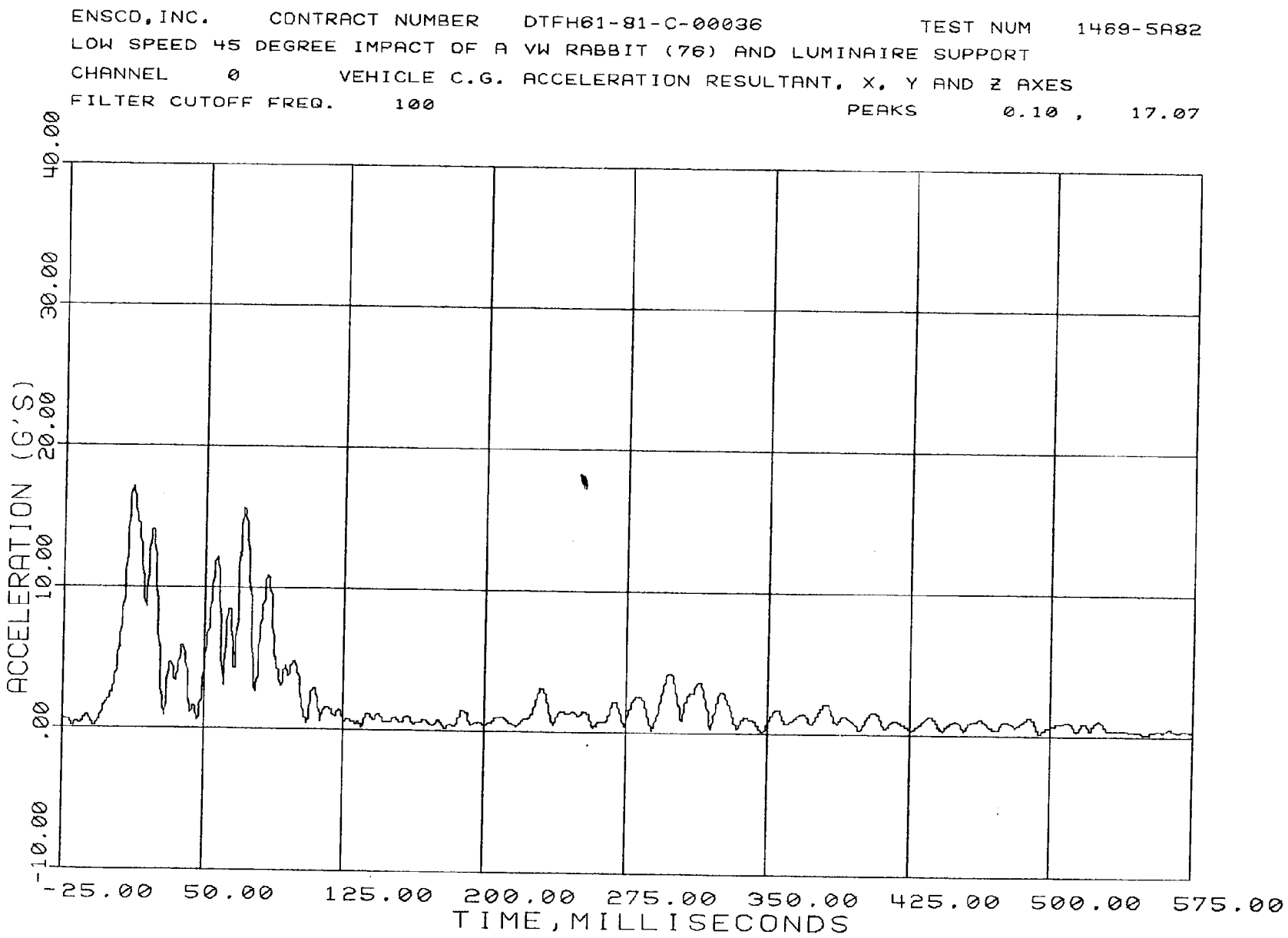


Figure 18. Vehicle C.G. Acceleration, X, Y and Z Axes (SAE Class 60)

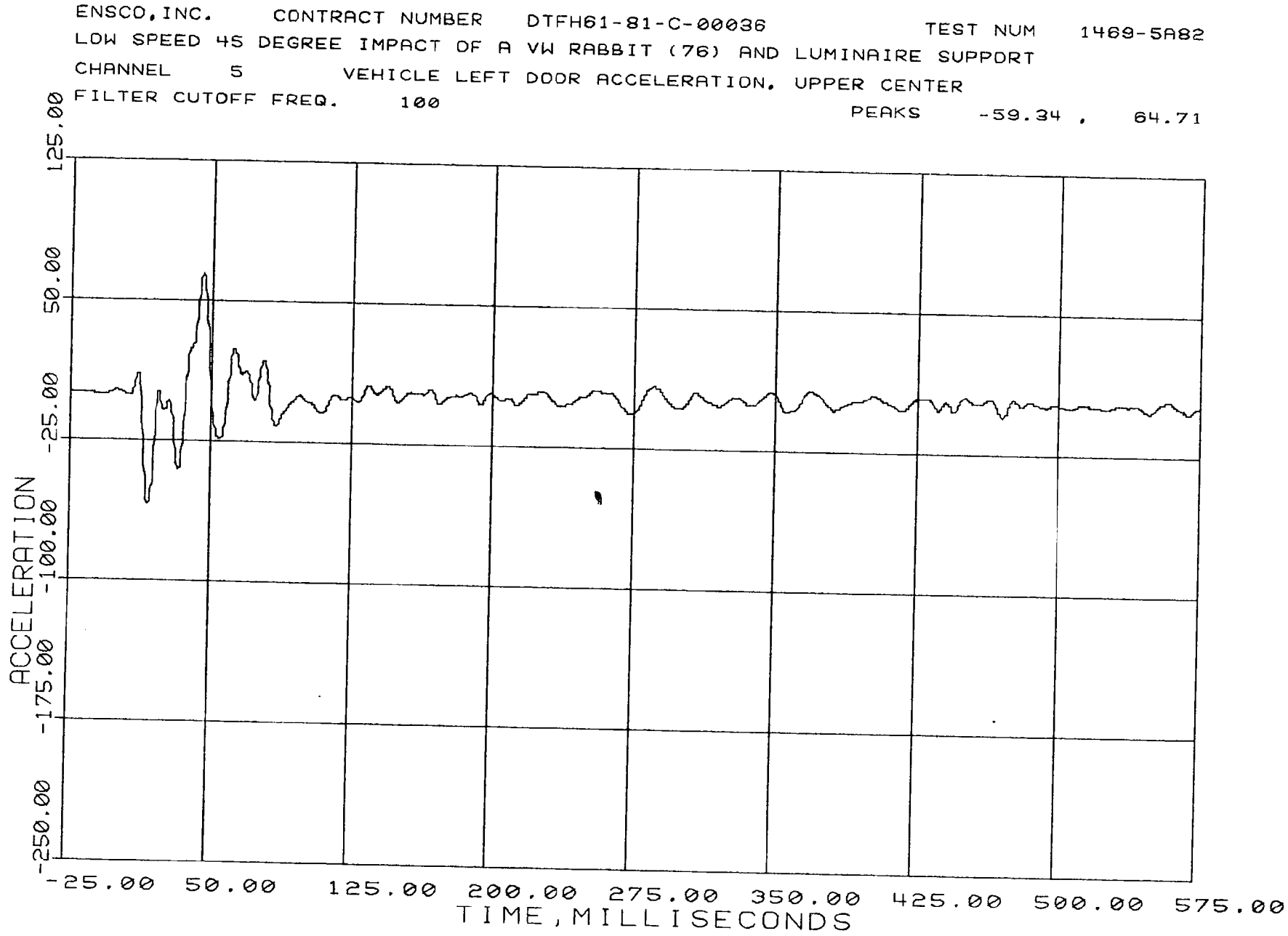


Figure 19. Vehicle Left Door Acceleration, Upper Center (SAE Class 60)

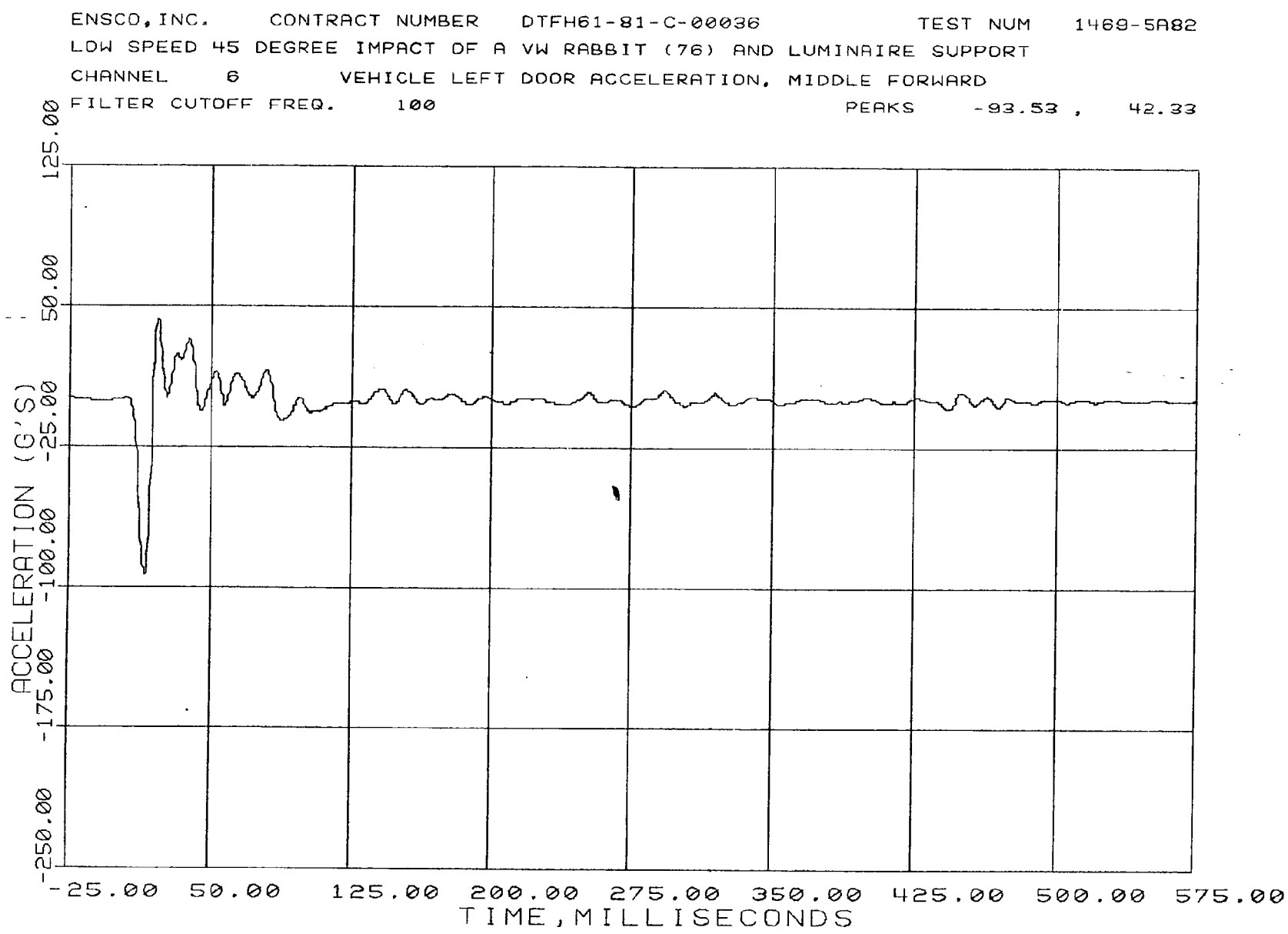


Figure 20. Vehicle Left Door Acceleration, Middle Forward (SAE Class 60)

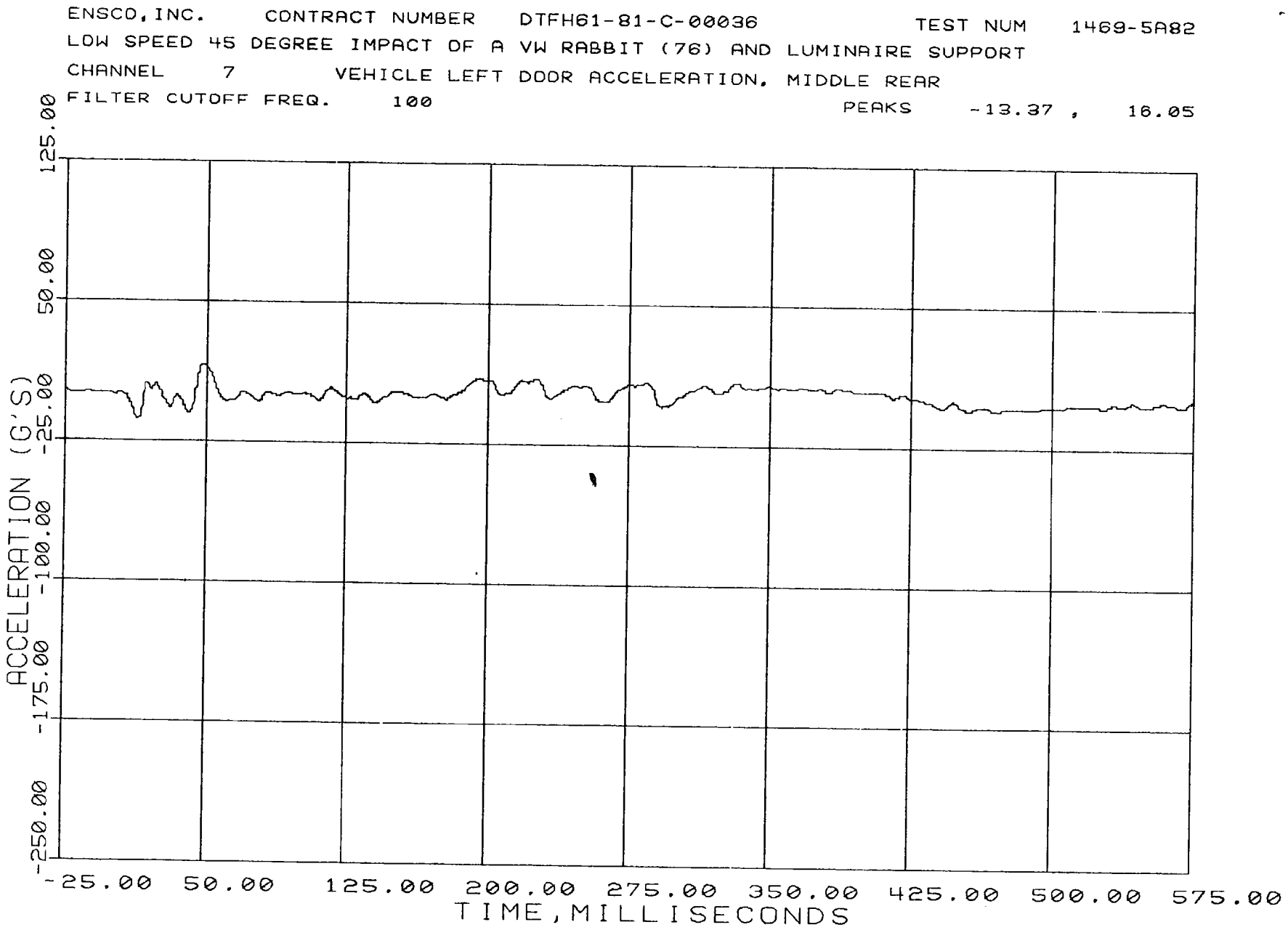


Figure 21. Vehicle Left Door Acceleration, Middle Rear (SAE Class 60)

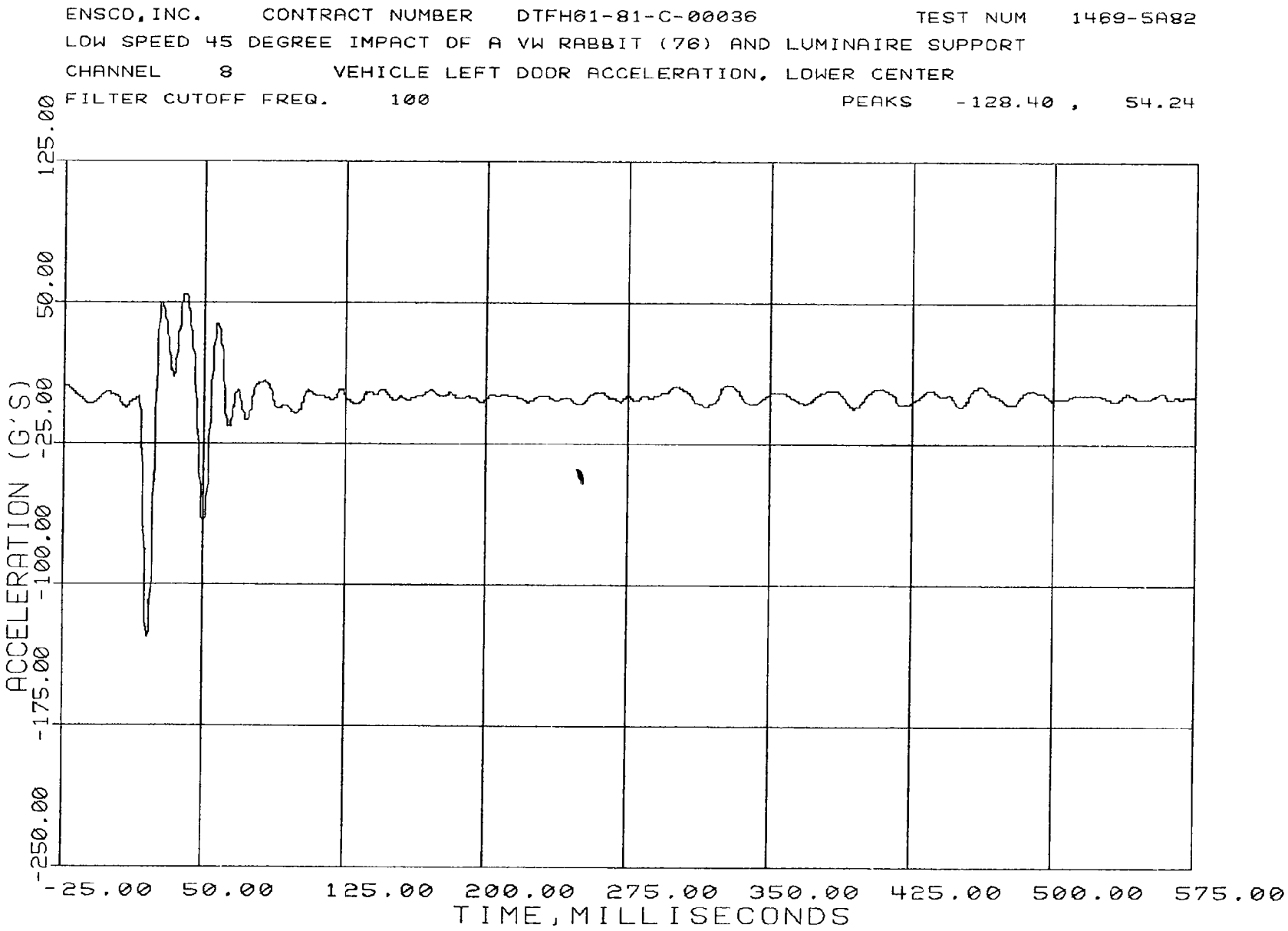


Figure 22. Vehicle Left Door Acceleration, Lower Center (SAE Class 60)

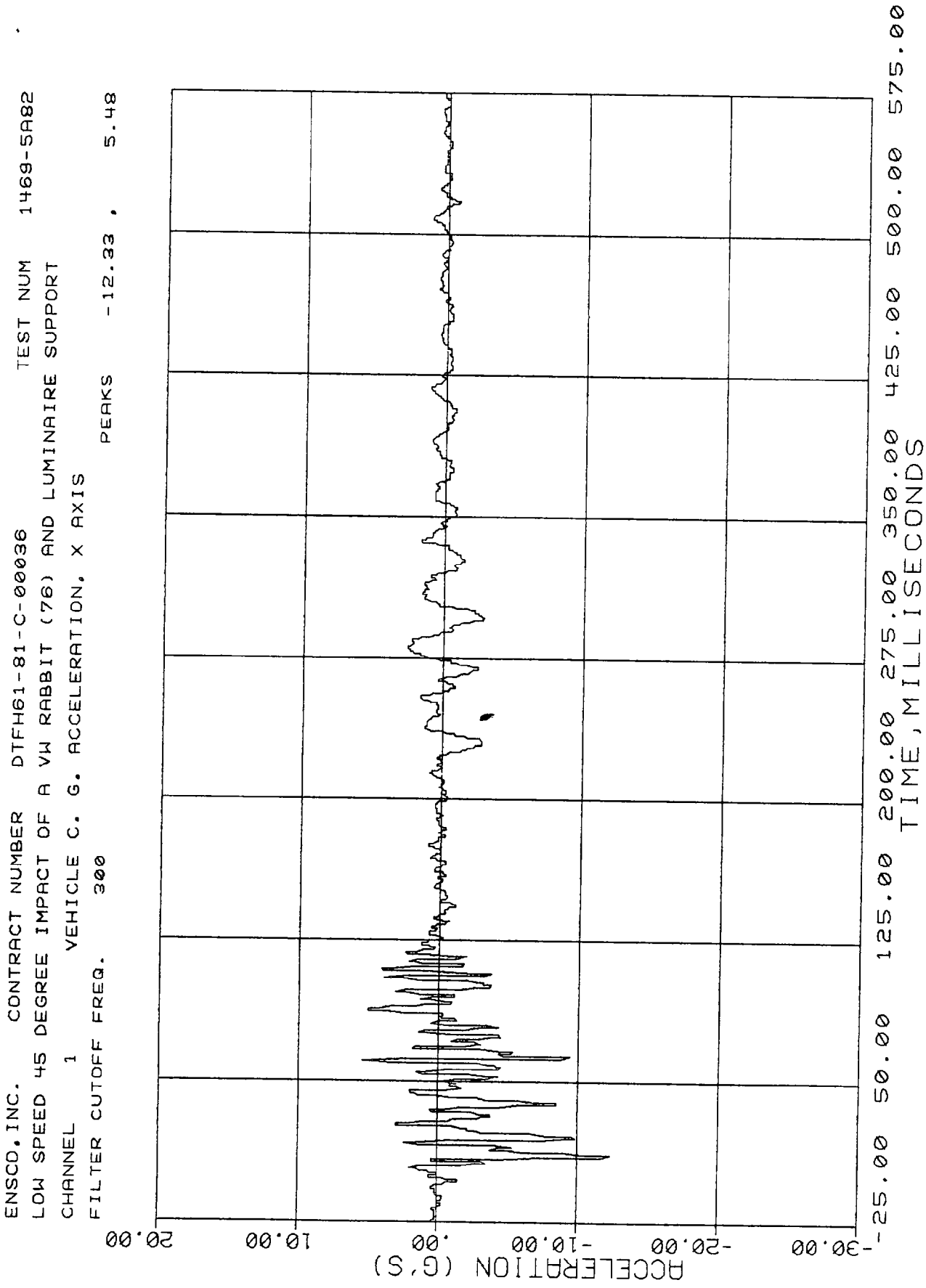


Figure 23. Vehicle C.G. Acceleration, X Axis (SAE Class 180)

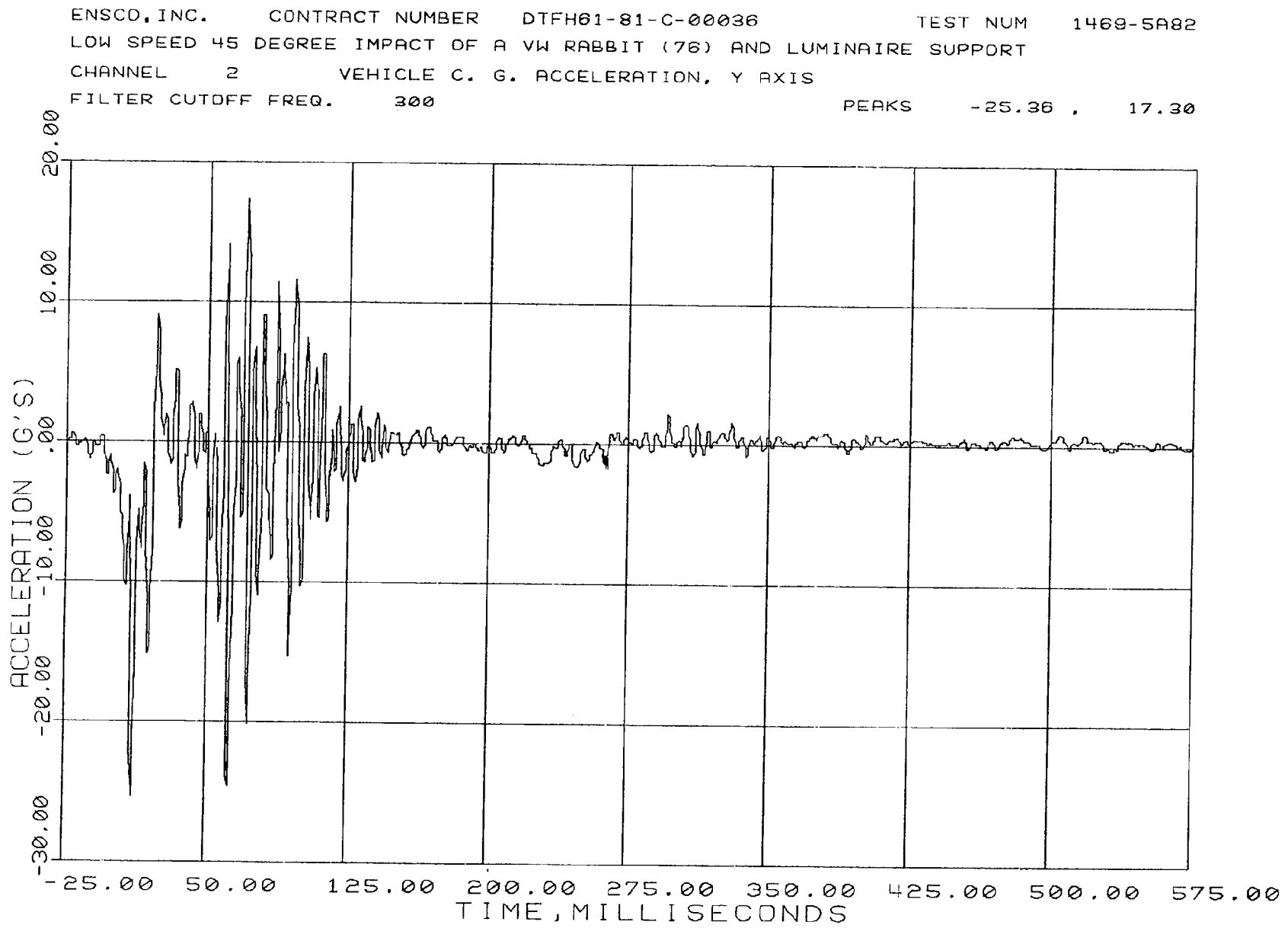


Figure 24. Vehicle C.G. Acceleration, Y Axis (SAE Class 180)

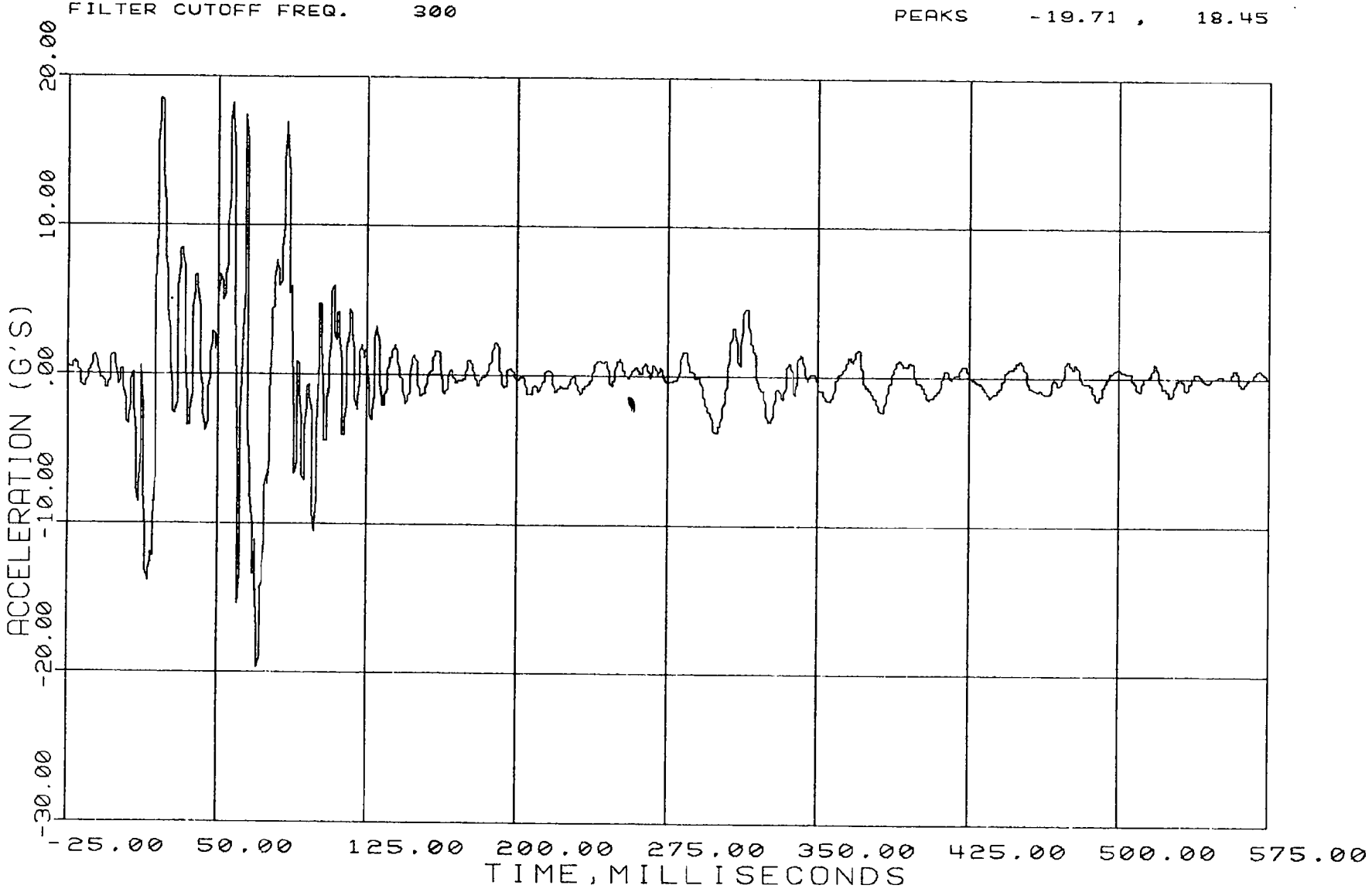


Figure 25. Vehicle C. G. Acceleration, Z Axis (SAE Class 180)

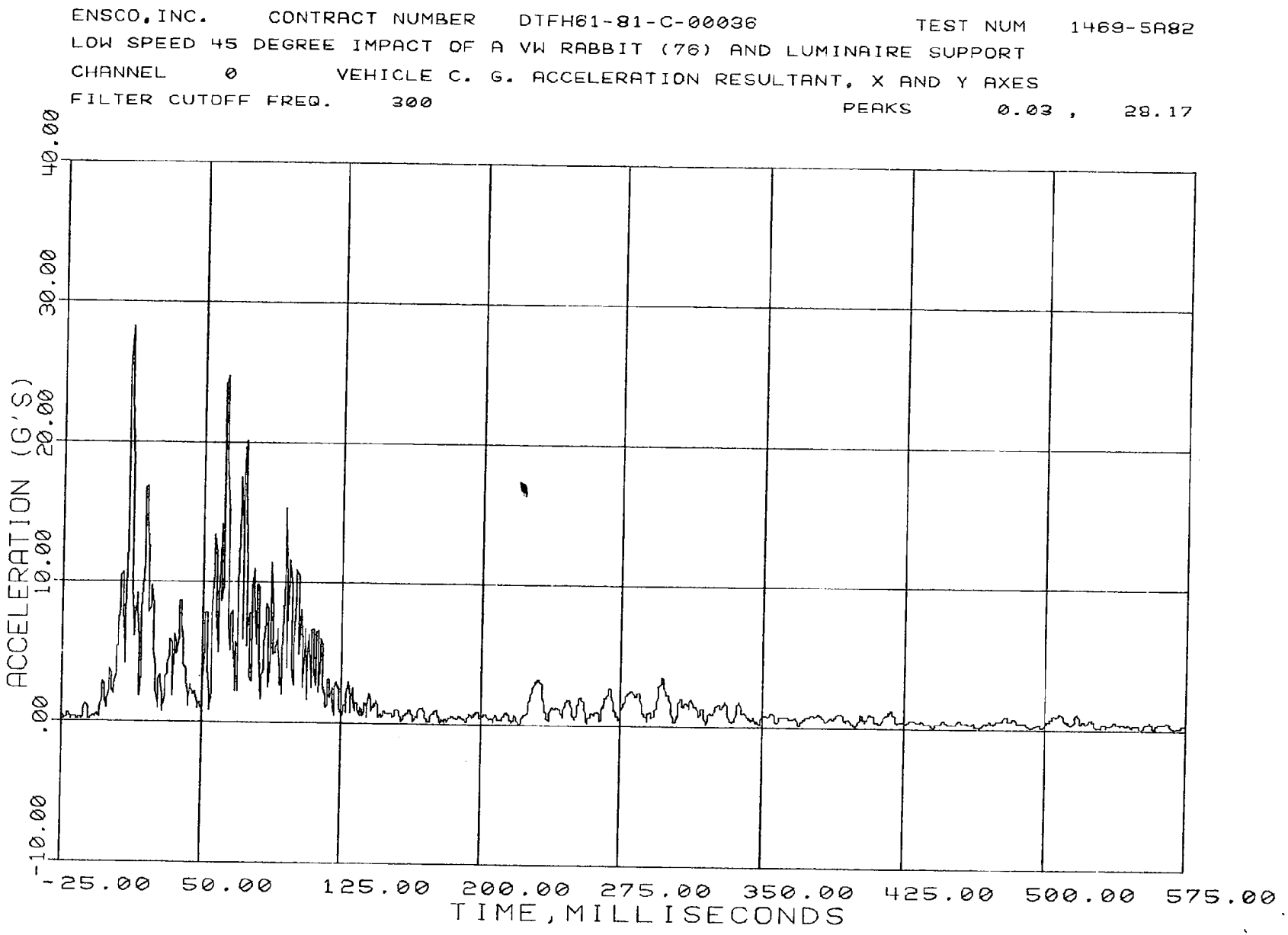


Figure 26. Vehicle C. G. Acceleration, X and Y Axes (SAE Class 180)

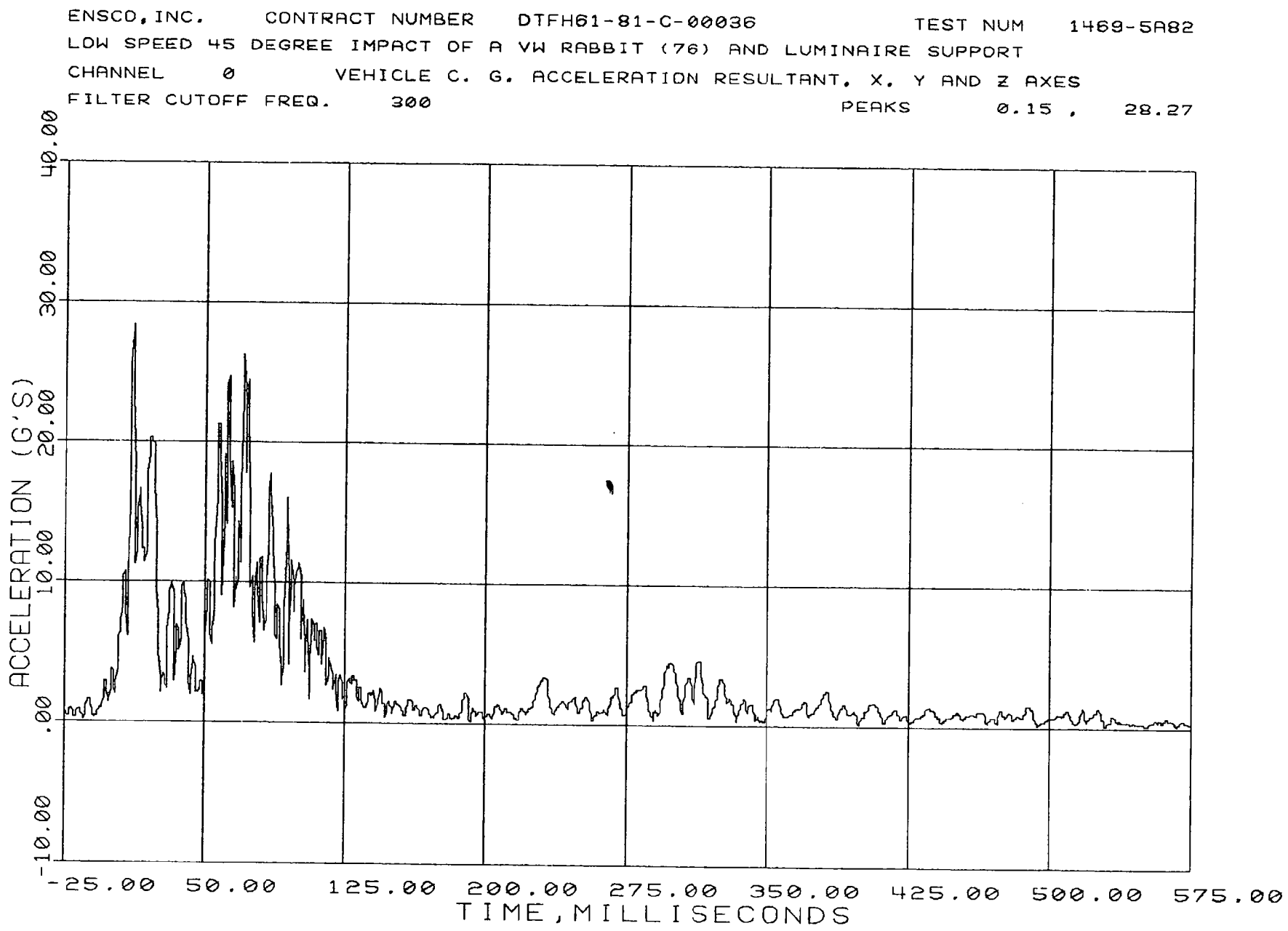


Figure 27. Vehicle C. G. Acceleration, X, Y and Z Axis (SAE Class 180)

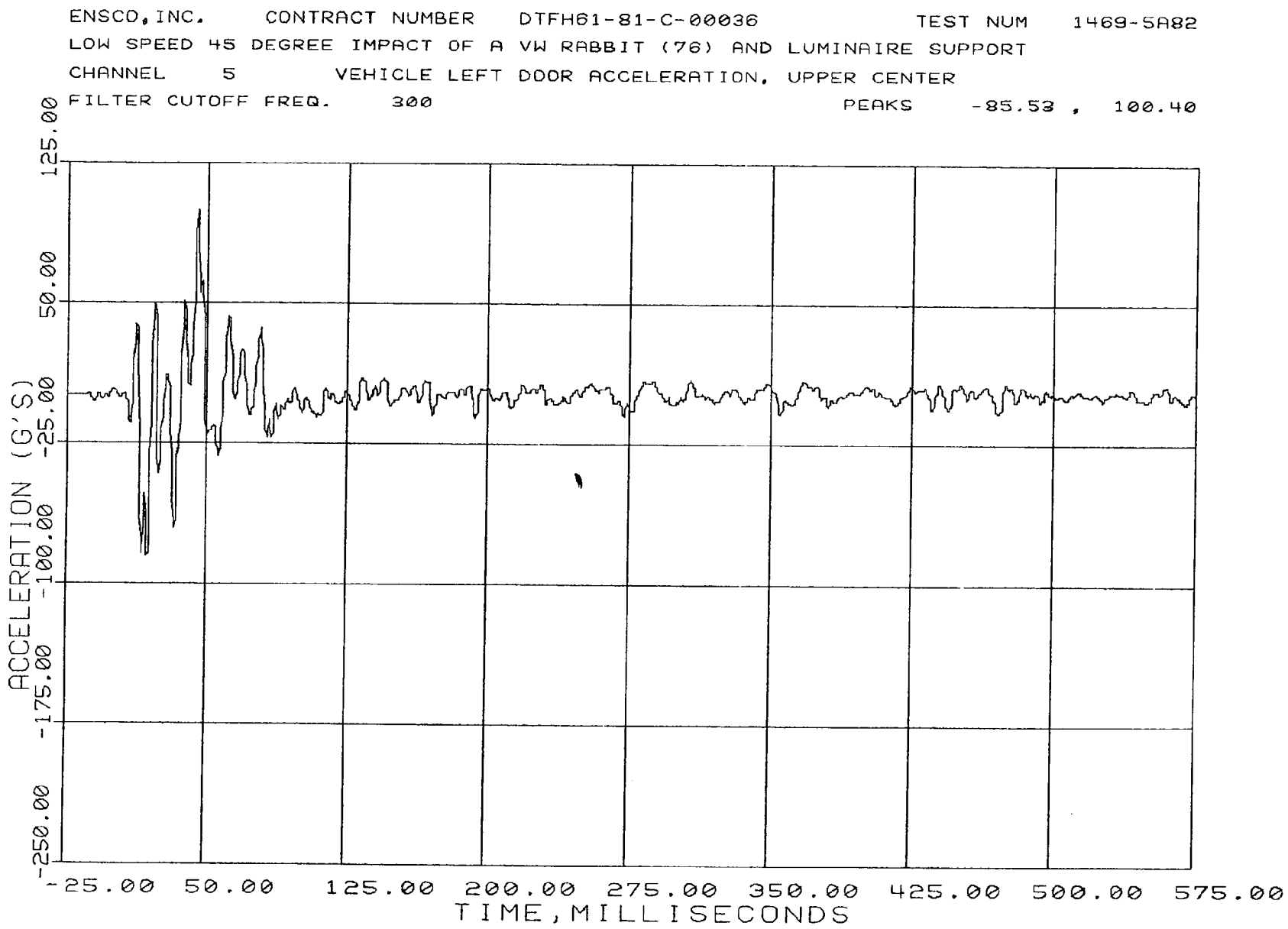


Figure 28. Vehicle Left Door Acceleration, Upper Center (SAE Class 180)

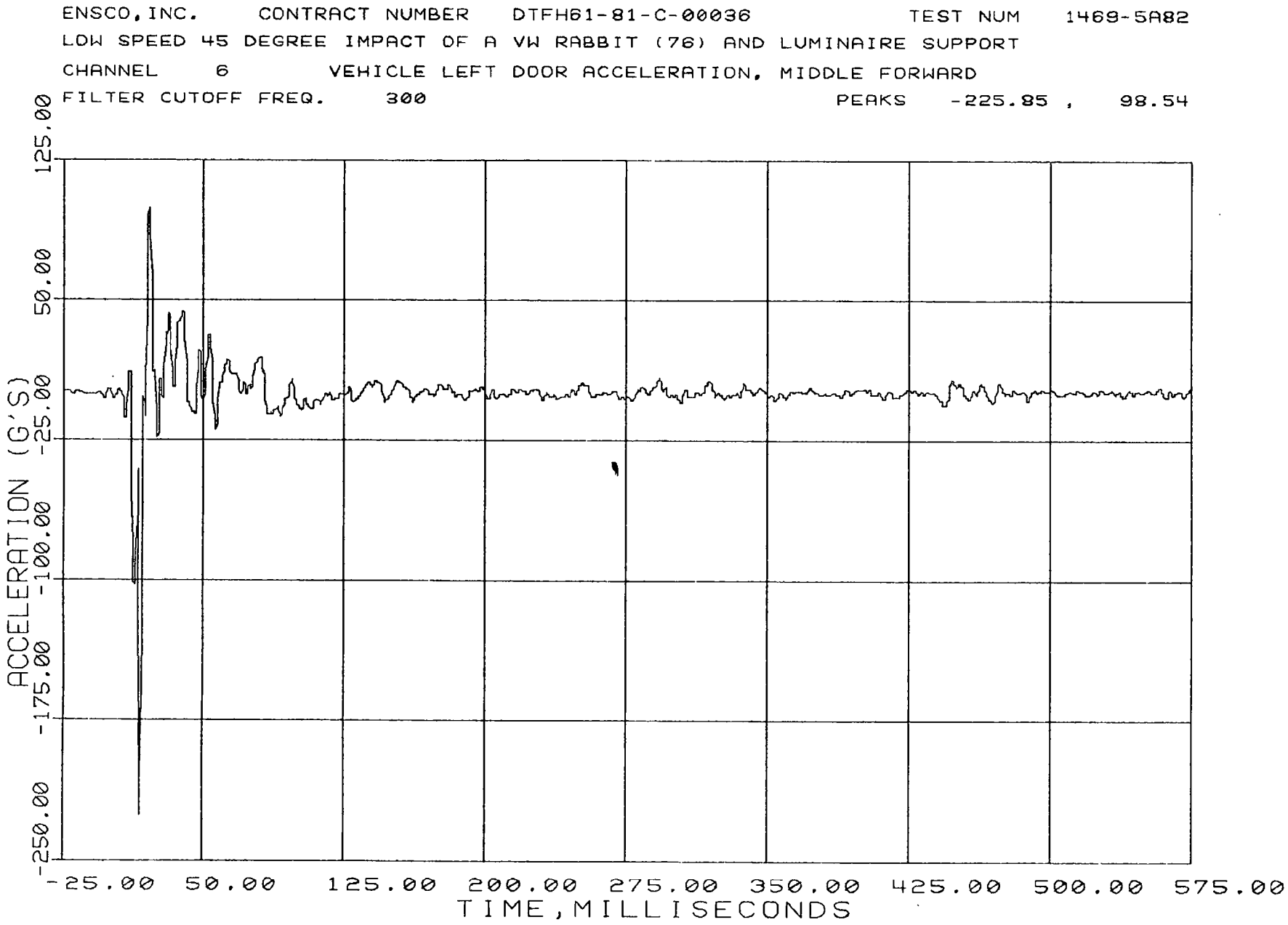


Figure 29. Vehicle Left Door Acceleration, Middle Forward (SAE Class 180)

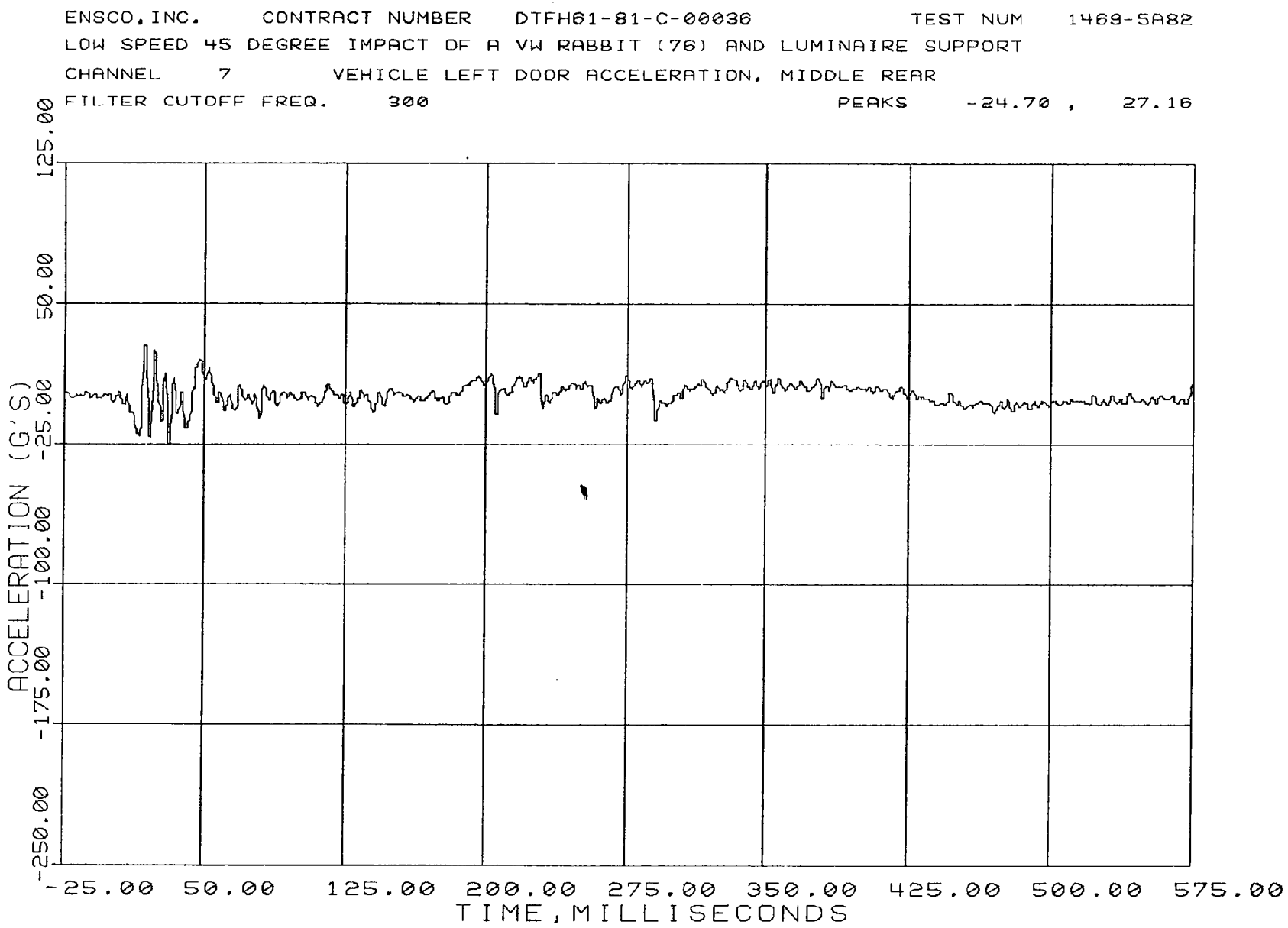


Figure 30. Vehicle Left Door Acceleration, Middle Rear (SAE Class 180)

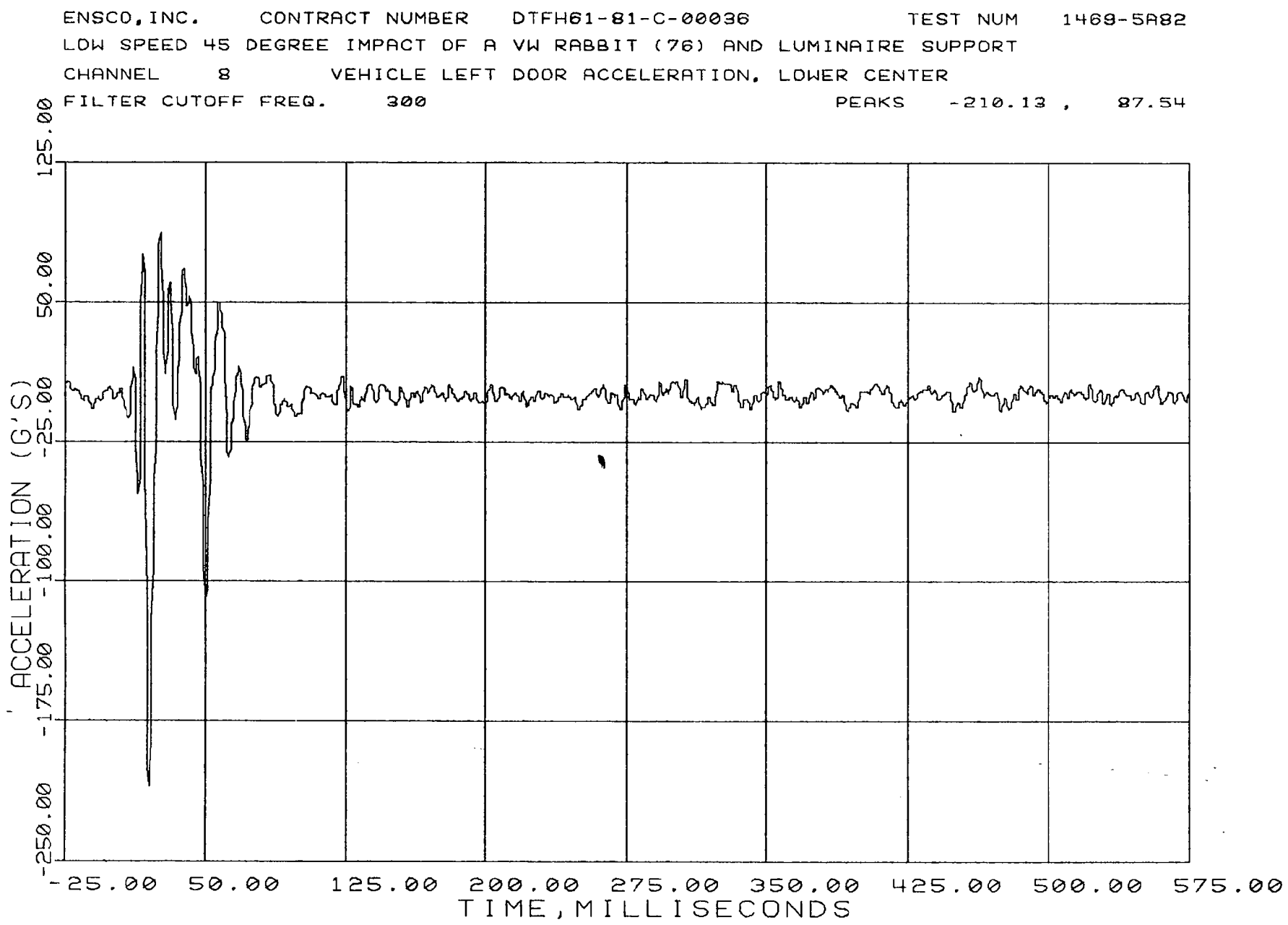


Figure 31. Vehicle Left Door Acceleration, Lower Center (SAE Class 180)

TABLE 11

VEHICLE VELOCITY AND MOMENTUM
CHANGE OCCURRING DURING IMPACT EVENT

	SAE Class 60 Data[a]	SAE Class 180 Data[b]
X Axis	-3.60 mph	-3.60 mph
Y Axis	-5.21 mph	-5.22 mph
M_s V(30.0 mph)	552 lb-sec	552 lb-sec

1 mph = .44704 m/sec

NOTE: a. Time duration used for integrating acceleration data based on 12 in. lateral flail space distance for hypothetical occupant using filters set for SAE Class 60.

b. Time duration used for integrating acceleration data based on 12 in. lateral flail space distance for hypothetical occupant using filters set for SAE Class 180.

Analysis of the impact velocity of a hypothetical front seat passenger against the vehicle interior, calculated from the vehicle accelerations and a 12 in (0.30 m) lateral displacement, yielded the results shown in Table 12. A hypothetical front seat occupant would have impacted the interior of the vehicle in the lateral direction at an approximate impact velocity of 7.6 ft/sec (2.33 m/s) based upon data filtered at both SAE Class 60 and 180. This lateral impact velocity is within the design limit of 20 ft/sec (6.10 m/s) specified for other forms of highway safety appurtenances in NCHRP 230. Further, this lateral impact velocity is within the limit of 30 ft/sec (9.14 m/s) specified for occupants in FMVSS 214 and by reference in NCHRP 230.

The highest ride down acceleration after the hypothetical front seat passenger impacted the interior of the vehicle was -1.14 g's

TABLE 12

LATERAL IMPACT VELOCITIES AND RIDEDOWN ACCELERATIONS 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
v = -7.642 ft/sec	v = -7.649 ft/sec
t(v) = .16138 sec	t(v) = .16125 sec
a_{max} = -1.14 g	a_{max} = -1.19 g
t(a_{max}) = .22863 sec	t(a_{max}) = .22813 sec

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

occurring at 228.6 ms and -1.19 g's occurring at 228.1 ms using 10 ms averages of the lateral acceleration data filtered at SAE Class 60 or 180, respectively. Both of these ride down decelerations were within the design limits of 15 g's specified in NCHRP 230 for lateral inpacts into other forms of highway safety appurtenances.

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. 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 32. The expression for the momentum change in the three phase description is given by:

$$M\Delta V = \int_{t_0}^{t_3} F_c dt$$

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

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

$$\triangleq I_1 + I_2 + I_3$$

where the terms in the above equation are given in Figure 32.

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,

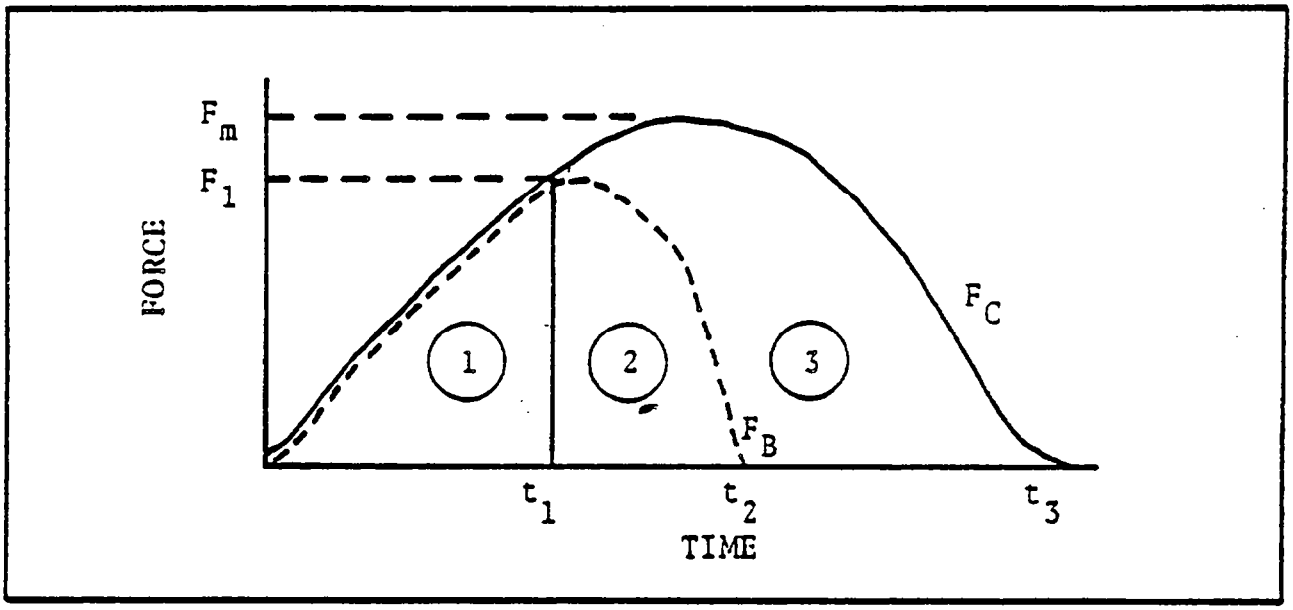


Figure 32. Graphic Representation of Three Phase Analysis of Momentum Change Occurring During the Impact of a Vehicle with a Breakaway Support

I_p = mass moment of inertia of the luminaire support

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

From the film data $\dot{x}_{cg}$ = 13.11 f/s (3.996 m/s) and $\dot{\theta}$ = 1.88 rad/sec. Using these two numbers the momentum change occurring during Phase 3 is given by

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

$$= 408 \text{ lb-sec } (1815 \text{ N-s})$$

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

$$= 403 \text{ lb-sec } (1793 \text{ N-s}).$$

The average momentum change associated with the third phase of the vehicle momentum change is 406 lb-sec (1804 N-s).

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 mechanism 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.

7.4 HEAD INJURY CRITERIA EVALUATION

The data obtained from the three accelerometers located in the head of the occupant during the test were filtered at SAE Class 1000 and combined to yield a resultant acceleration occurring

TABLE 13

EXAMINATION OF THE MOMENTUM
TRANSFER DURING THE COLLISION EVENT

		Class 60 (lb-sec)	Class 180 (lb-sec)
I_T	=	552[a]	552[b]
I_3	=	-406[c]	-406[c]
$I_{1\&2}$	=	146	146
I_2	=	- 62	- 61
I_1		84	85
I_1	=	92[d]	75[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.

during the impact event. The HIC was evaluated in accordance with the procedures outlined in FMVSS 208.[8] The acceleration traces and resultant obtained with the use of the SAE Class 1000 (f_c = 1,650 Hz) filtering techniques are presented in Figures 33 through 36. The results of the HIC evaluation calculated for the occupant 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 and within the design limits specified in FMVSS 208 and by reference those specified in NCHRP 230.

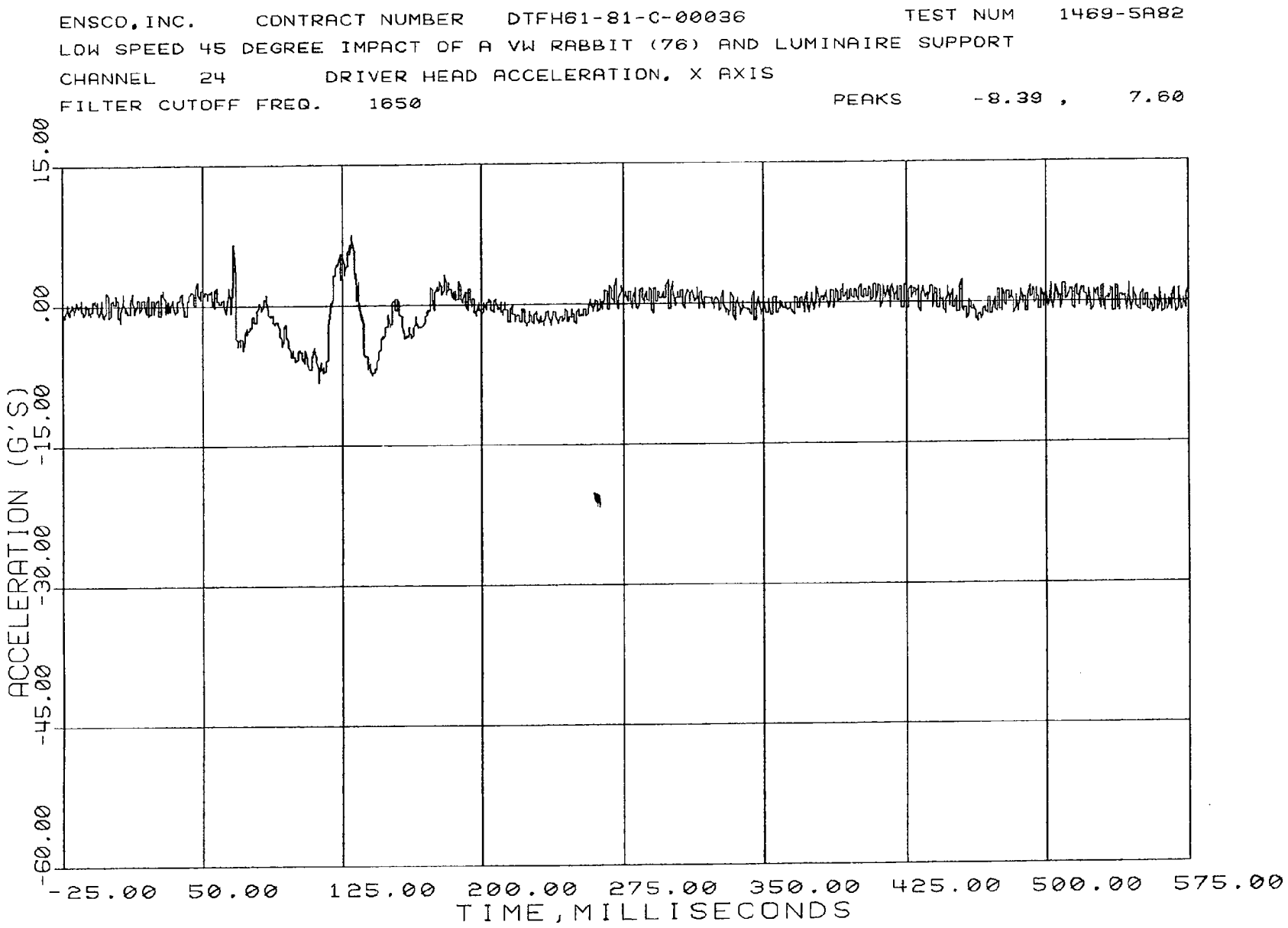


Figure 33. Driver Head Acceleration, X (A-P) Axis (SAE Class 1000)

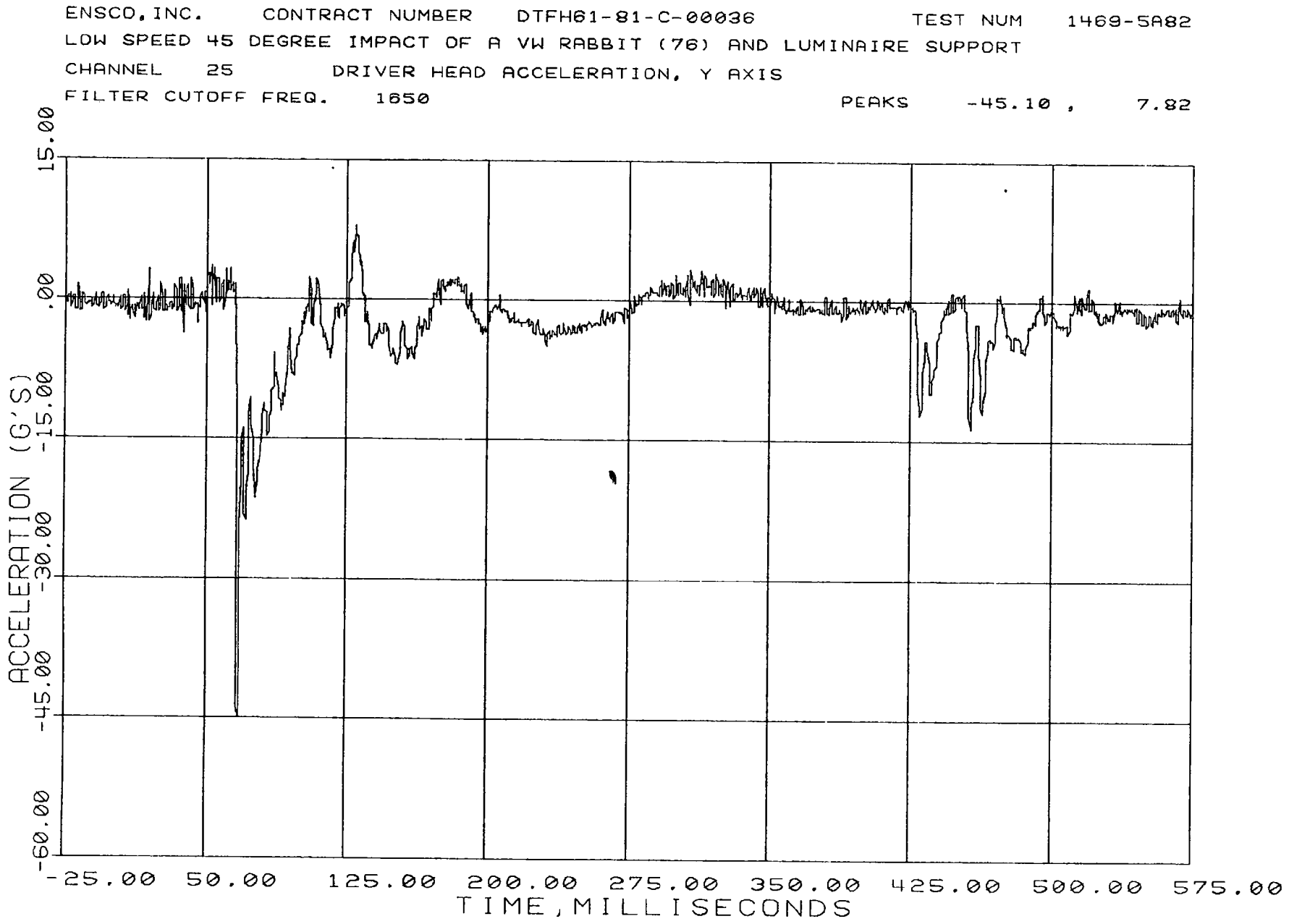


Figure 34. Driver Head Acceleration, Y (M-L) Axis (SAE Class 1000)

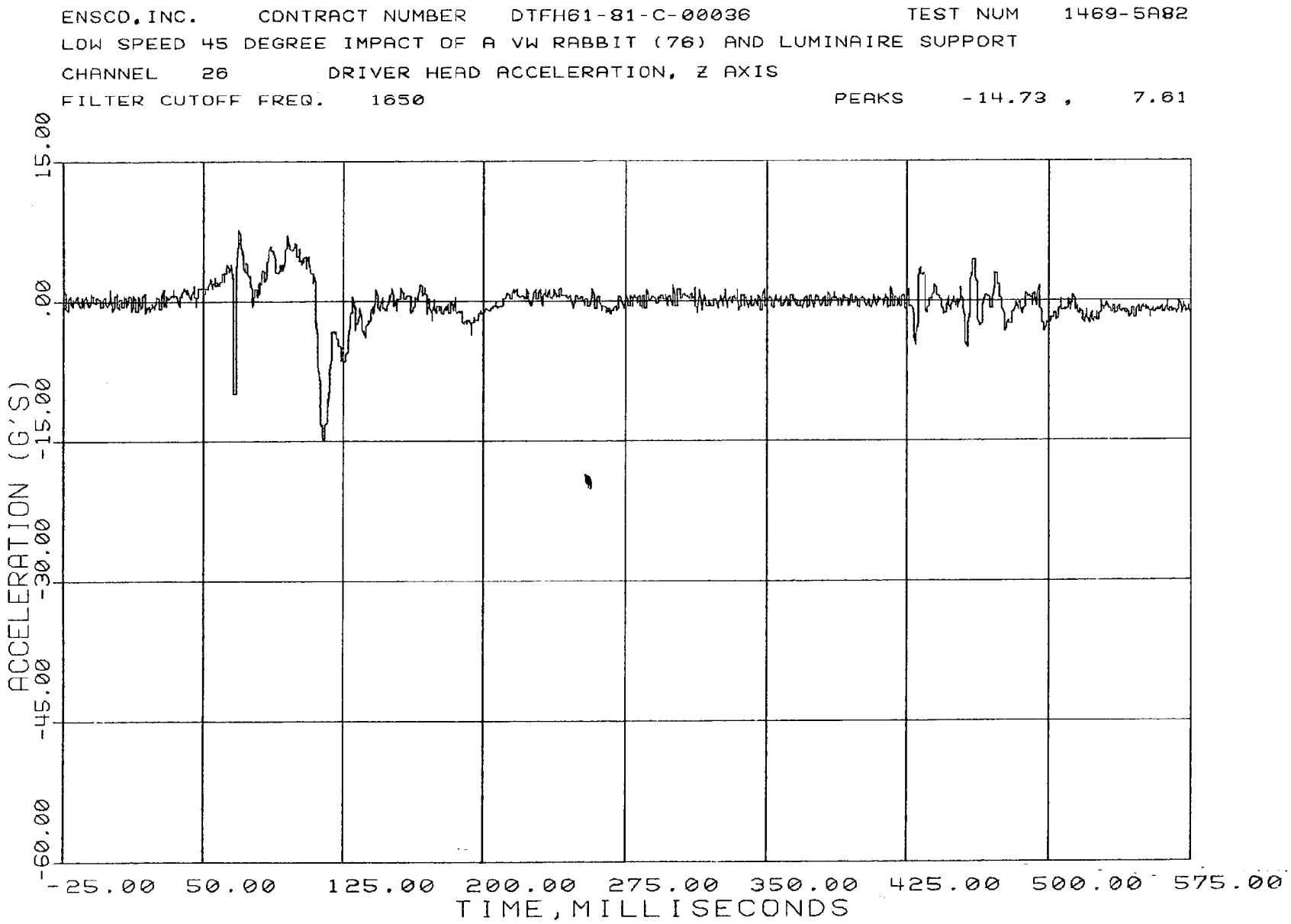


Figure 35. Driver Head Acceleration, Z (I-S) Axis (SAE Class 1000)

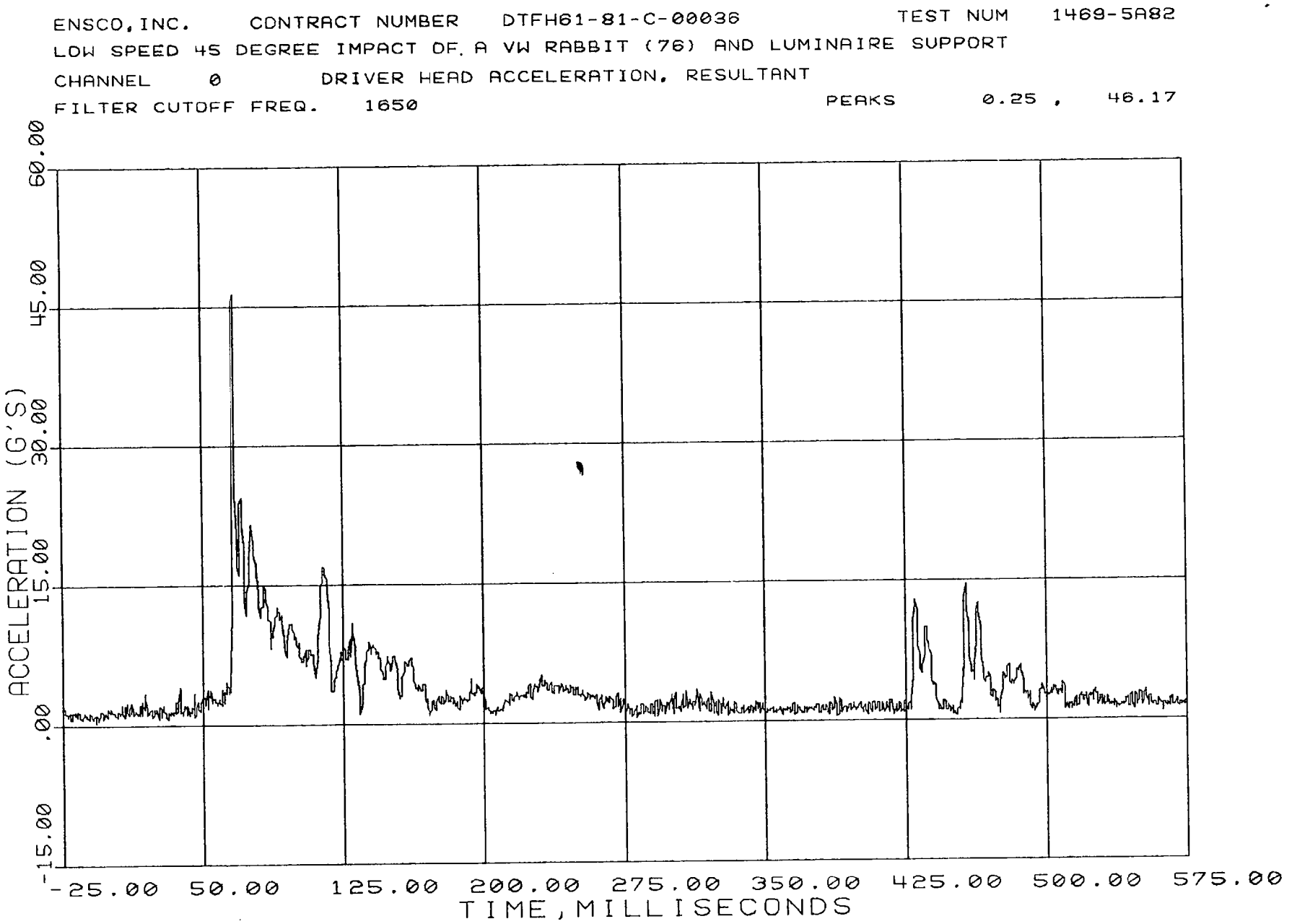


Figure 36. Driver Head Acceleration, Resultant (SAE Class 1000)

TABLE 14
HEAD INJURY CRITERIA EVALUATED FOR FULL
SCALE CRASH TEST 1469-5A82

	Driver
HIC	29
t(Start)	66.00 ms
t(Stop)	118.13 ms
t(Duration)	52.13 ms

7.5 OCCUPANT SEVERITY INDEX EVALUATION

The data obtained from the triaxial accelerometer packages located in the upper and lower parts of the spine and in the pelvis of the occupant were filtered at SAE Class 180 and combined to yield a resultant acceleration occurring during the impact event for each of the respective locations. The severity index for each location was evaluated in accordance with SAE Information Report J885a. In addition, the maximum resultant acceleration whose cumulative duration is not less than 3 milliseconds was evaluated for each location in accordance with FMVSS 208 and by reference NCHRP 230. A weighting factor of 2.5 was applied in the evaluation of the severity index for each location. The acceleration traces and associated resultants obtained with the use of the SAE Class 180 (f_c = 300 Hz) filtering techniques are presented in Figures 37 through 40 for the upper spine location, Figures 41 through 44 for the lower spine location and Figures 45 through 48 for the pelvis location. The results of the severity index and sustained acceleration analysis are given in Table 15. These results should not be compared directly with the design limits for the severity index of 1000 and sustained acceleration level of 60g specified in FMVSS 208 since none of the accelerometers are located at the center of gravity of the

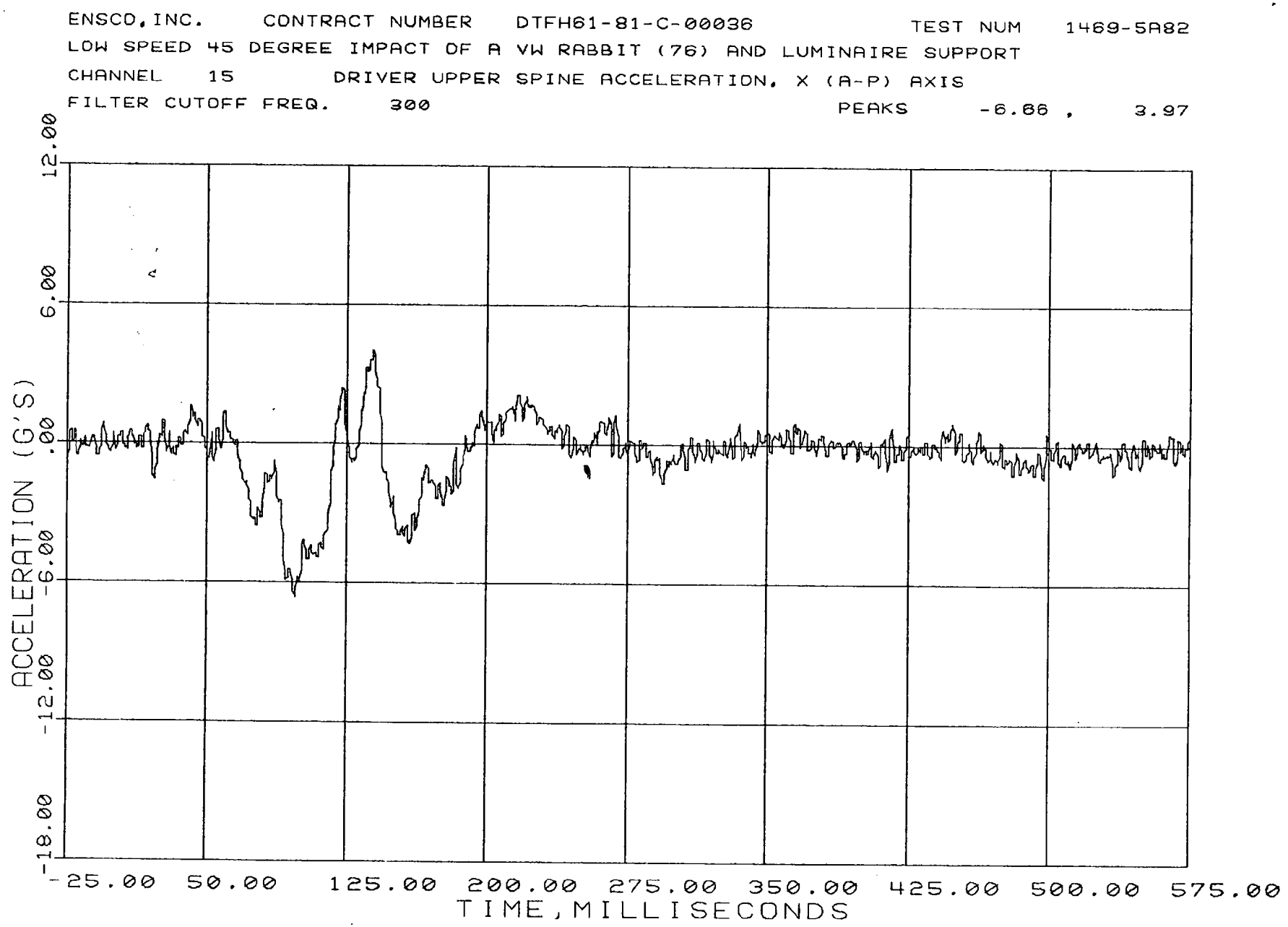


Figure 37. Driver Upper Spine Acceleration, X (A-P) Axis (SAE Class 180)

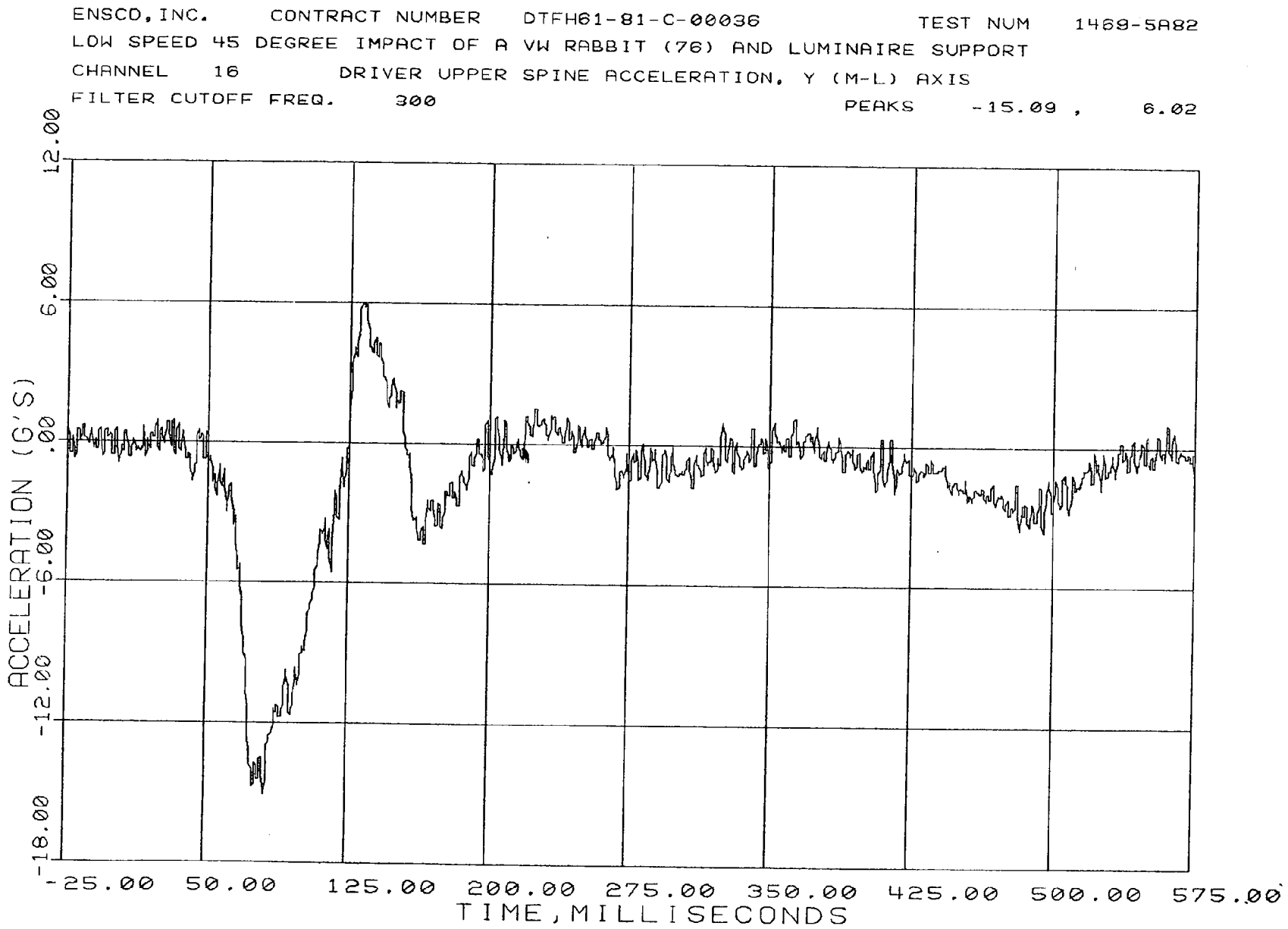


Figure 38. Driver Upper Spine Acceleration, Y (M-L) Axis (SAE Class 180)

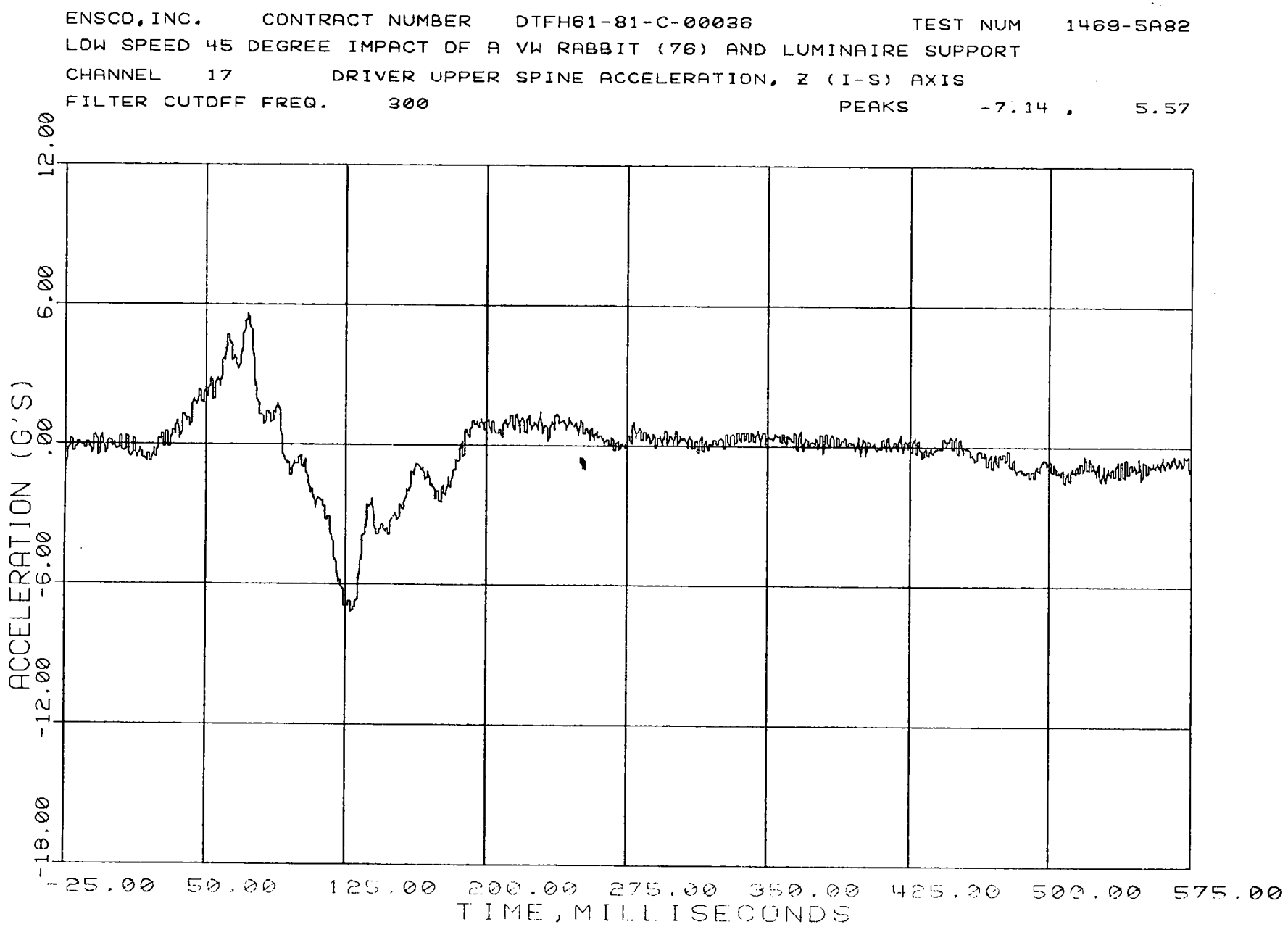


Figure 39. Driver Upper Spine Acceleration, Z (I-S) Axis (SAE Class 180)

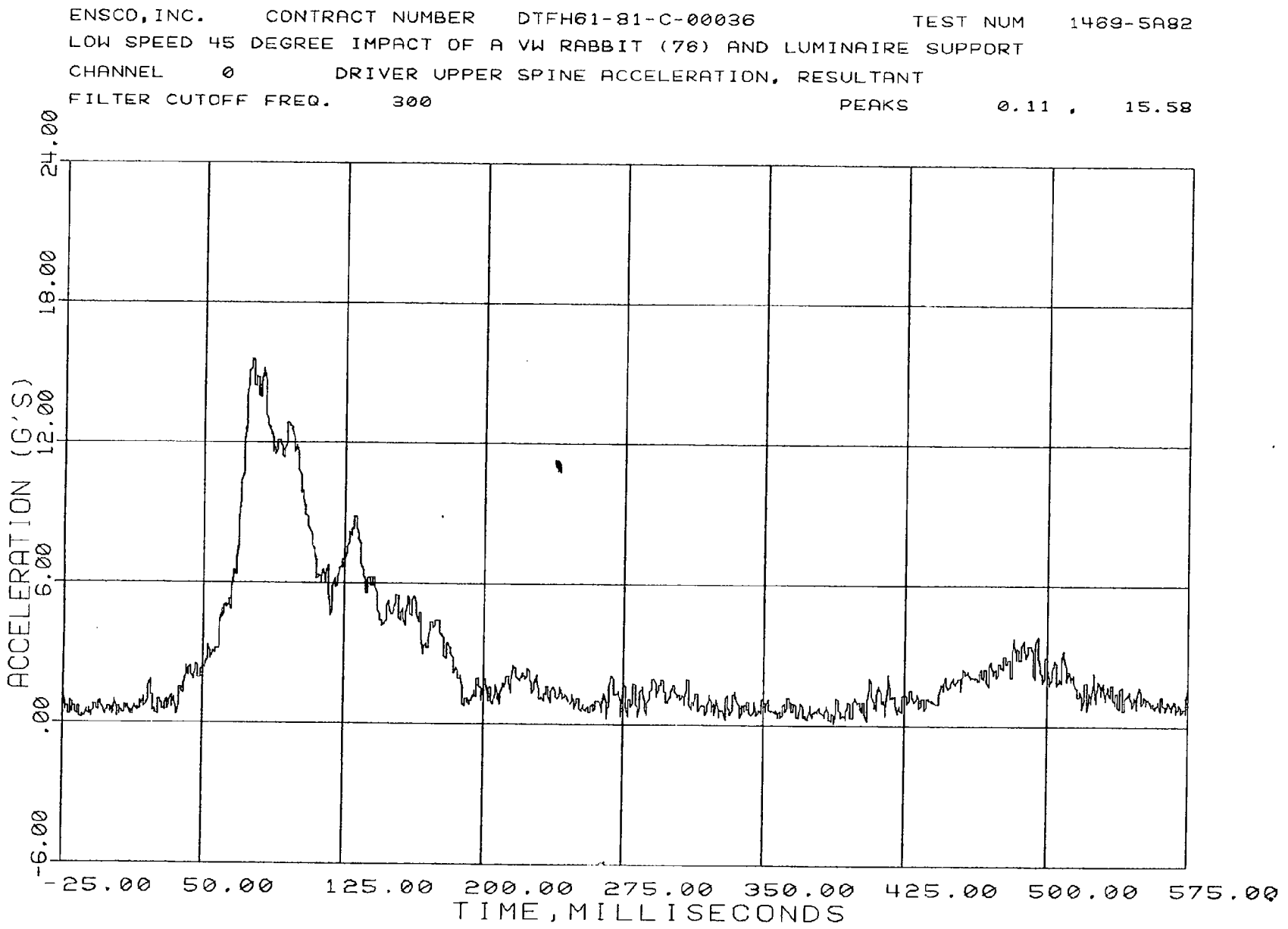


Figure 40. Driver Upper Spine Acceleration, Resultant (SAE Class 180)

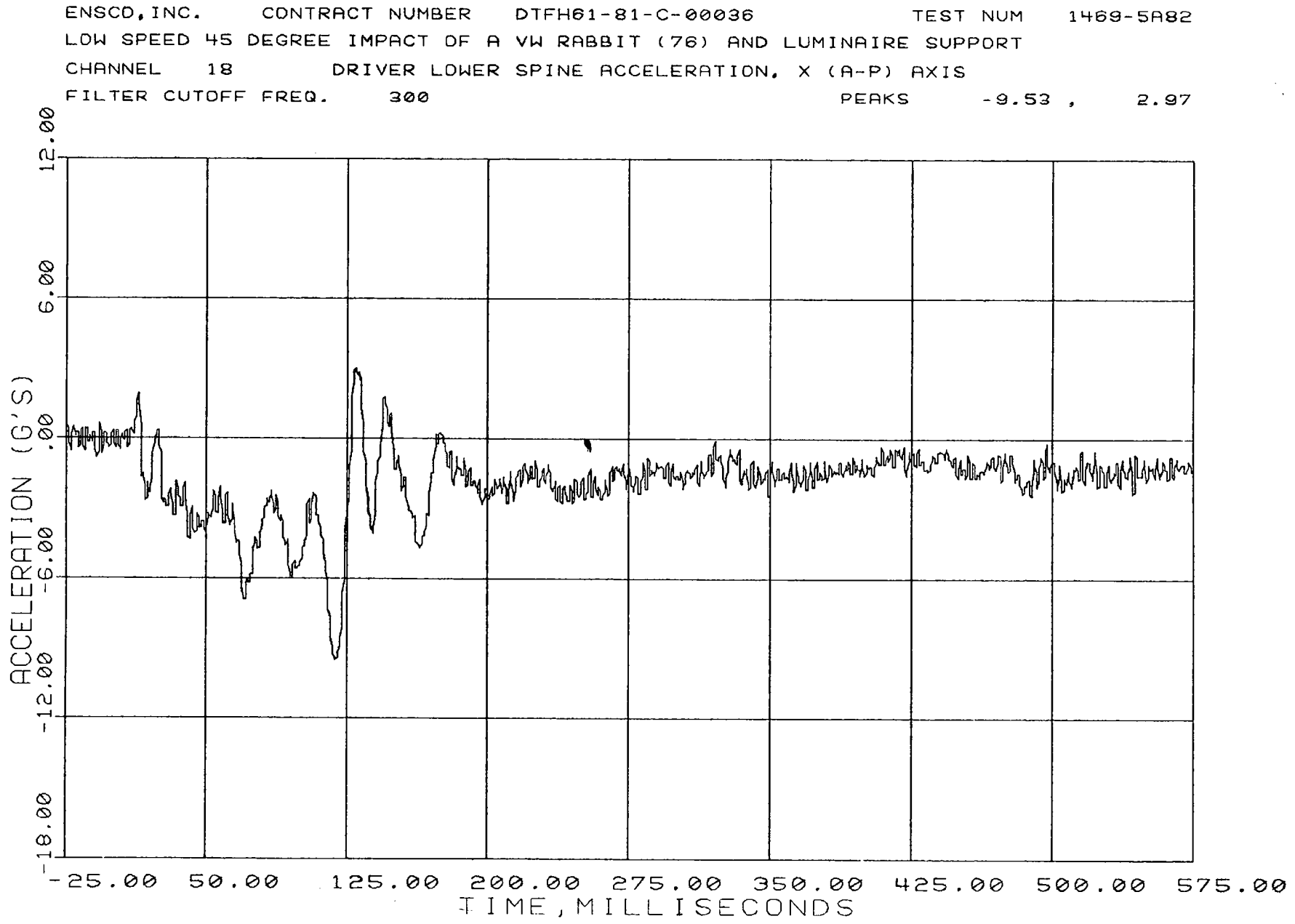


Figure 41. Driver Lower Spine Acceleration, X (A-P) Axis (SAE Class 180)

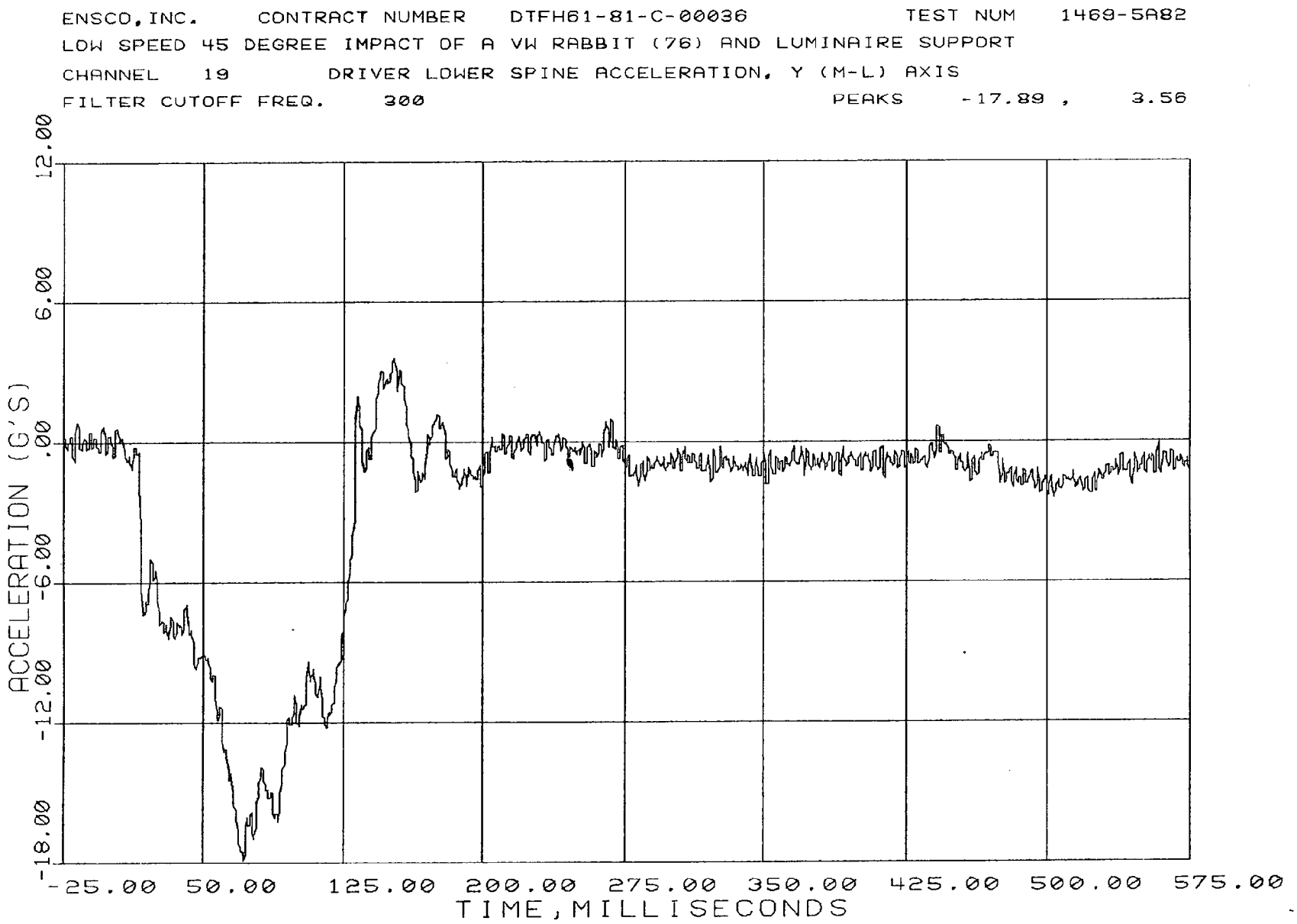


Figure 42. Driver Lower Spine Acceleration, Y (M-L) (Axis) (SAE Class 180)

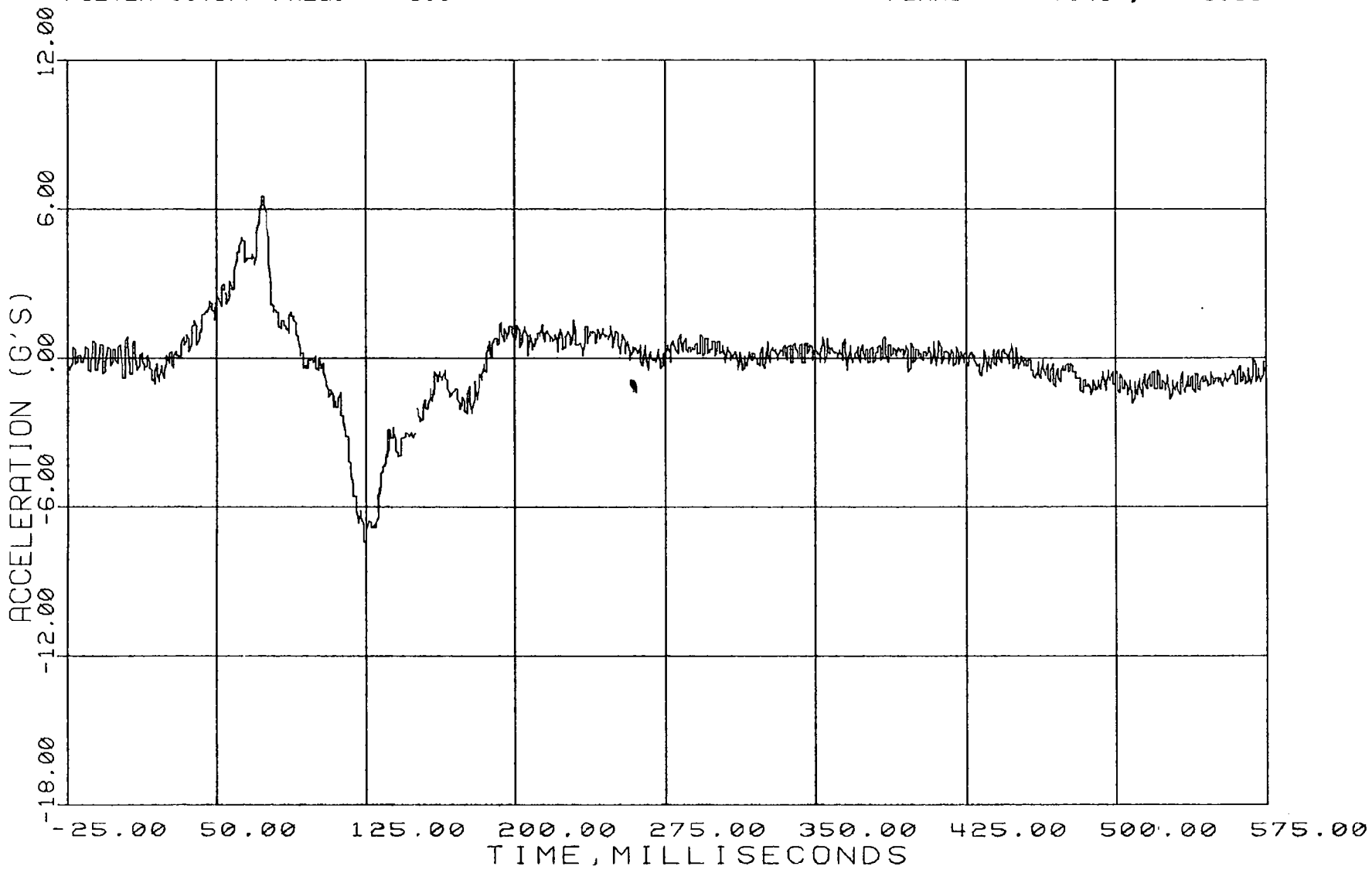


Figure 43. Driver Lower Spine Acceleration, Z (I-S) (Axis) (SAE Class 180)

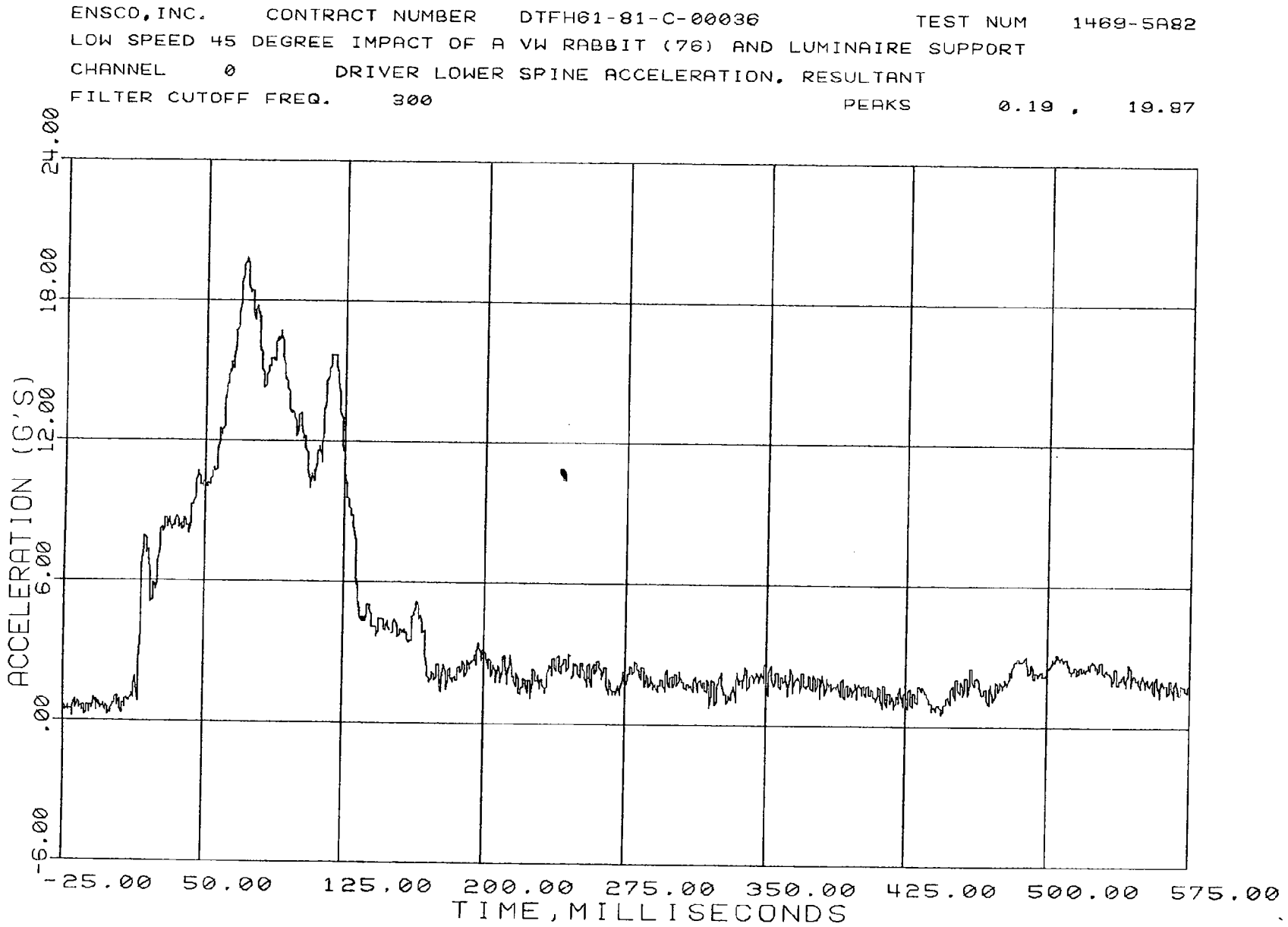


Figure 44. Driver Lower Spine Acceleration, Resultant (SAE Class 180)

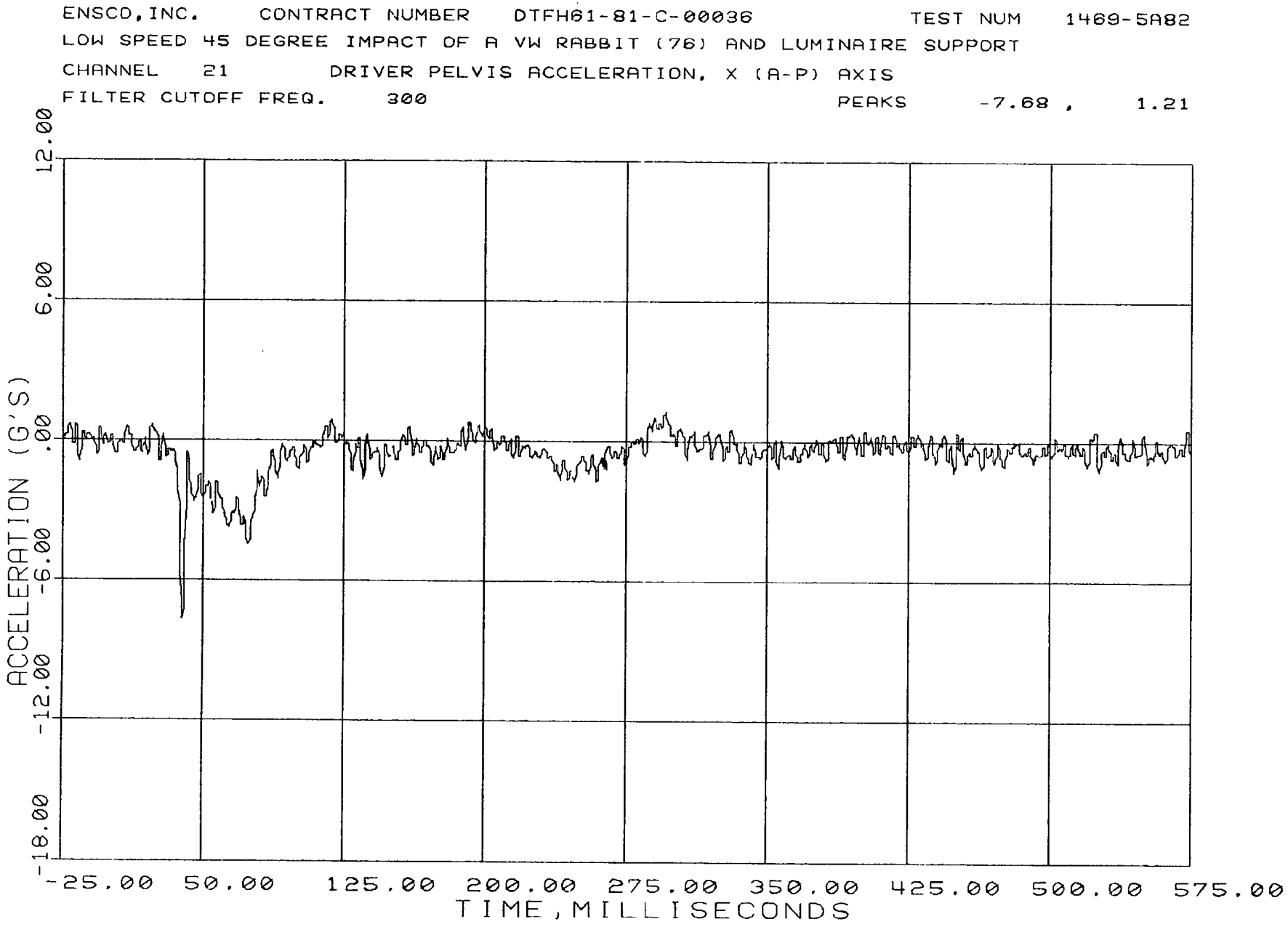


Figure 45. Driver Pelvis Acceleration, X (A-P) Axis (SAE Class 180)

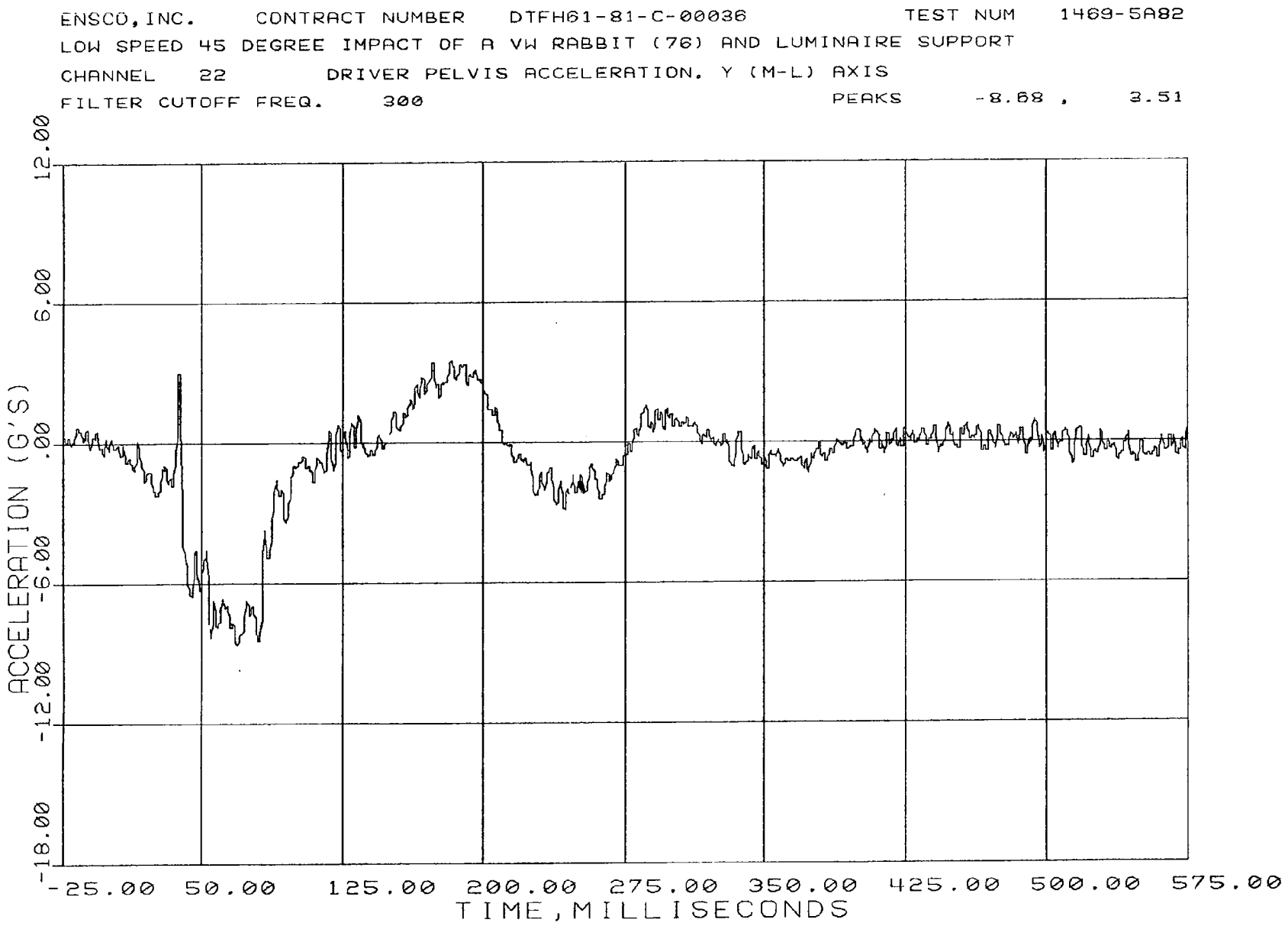


Figure 46. Driver Pelvis Acceleration, Y (M-L) Axis (SAE Class 180)

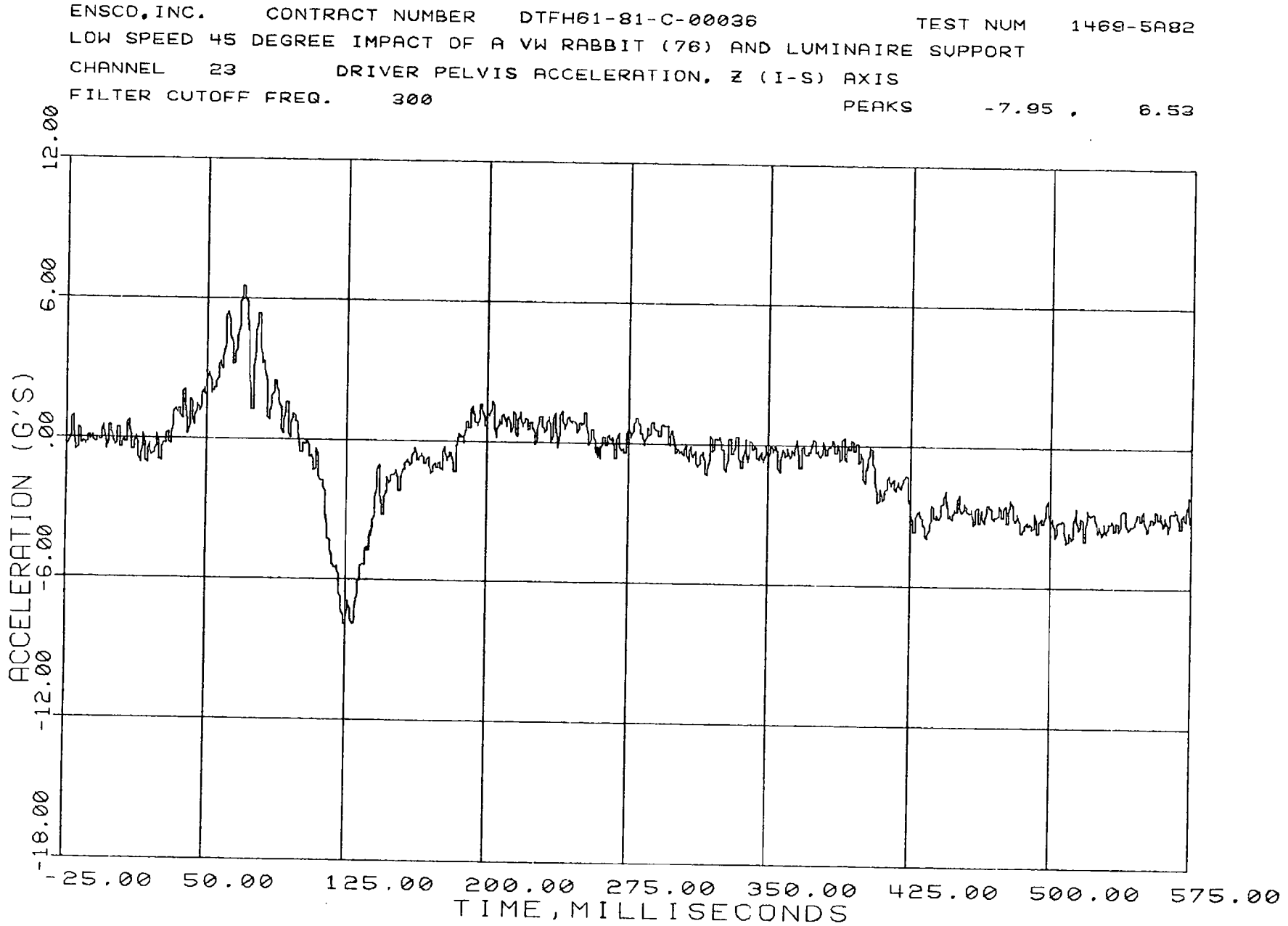


Figure 47. Driver Pelvis Acceleration, Z (I-S) Axis (SAE Class 180)

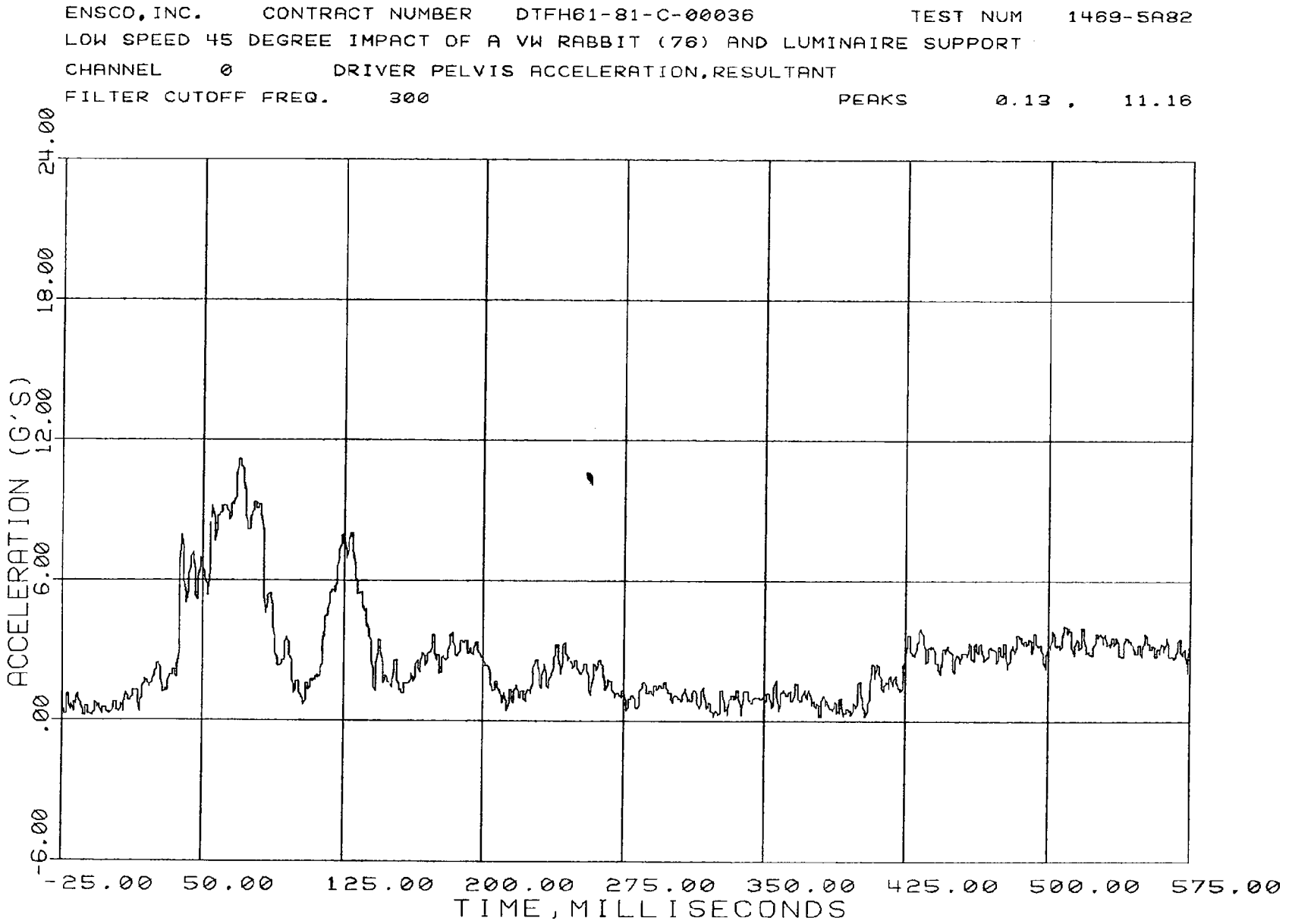


Figure 48. Driver Pelvis Acceleration, Resultant (SAE Class 180)

TABLE 15

SEVERITY INDEX AND MAXIMUM SUSTAINED RESULTANT ACCELERATION EVALUATION

Location	SI	a_{max} (Dur $\geq$ 3 ms)	$t(a_{max})$
Spine, Upper	28	15.57g	75.75 ms
Spine, Lower	72	19.86g	71.50 ms
Pelvis	16	11.15g	69.50 ms

upper thorax location. These resultants are presented for relative comparison purposes only.

7.6 THORACIC INJURY EVALUATION

The data obtained from the accelerometers mounted on the ribs and sternum within the thorax of the occupant were filtered at SAE Class 180 and are presented in Figures 49 through 53. In accordance with contractual requirements the following thoracic injury parameters were evaluated for the upper and lower left rib location and for the upper and lower spine locations using the accelerometer signals aligned with the Y (M-L) axis:

Q = The maximum value of the first integral of the acceleration trace,

V1050 = The time interval between 10% and 50% of Q,

V1090 = The time interval between 10% and 90% of Q,

RVS = V1090 divided by V1050,

and

$$B = \ln\left[\text{Maximum}\ (|F_1|, |F_2|)\right]$$

where

F_1 = net velocity change achieved over 20 ms of maximum positive acceleration, and

F_2 = net velocity change achieved over 20 ms of maximum negative acceleration.

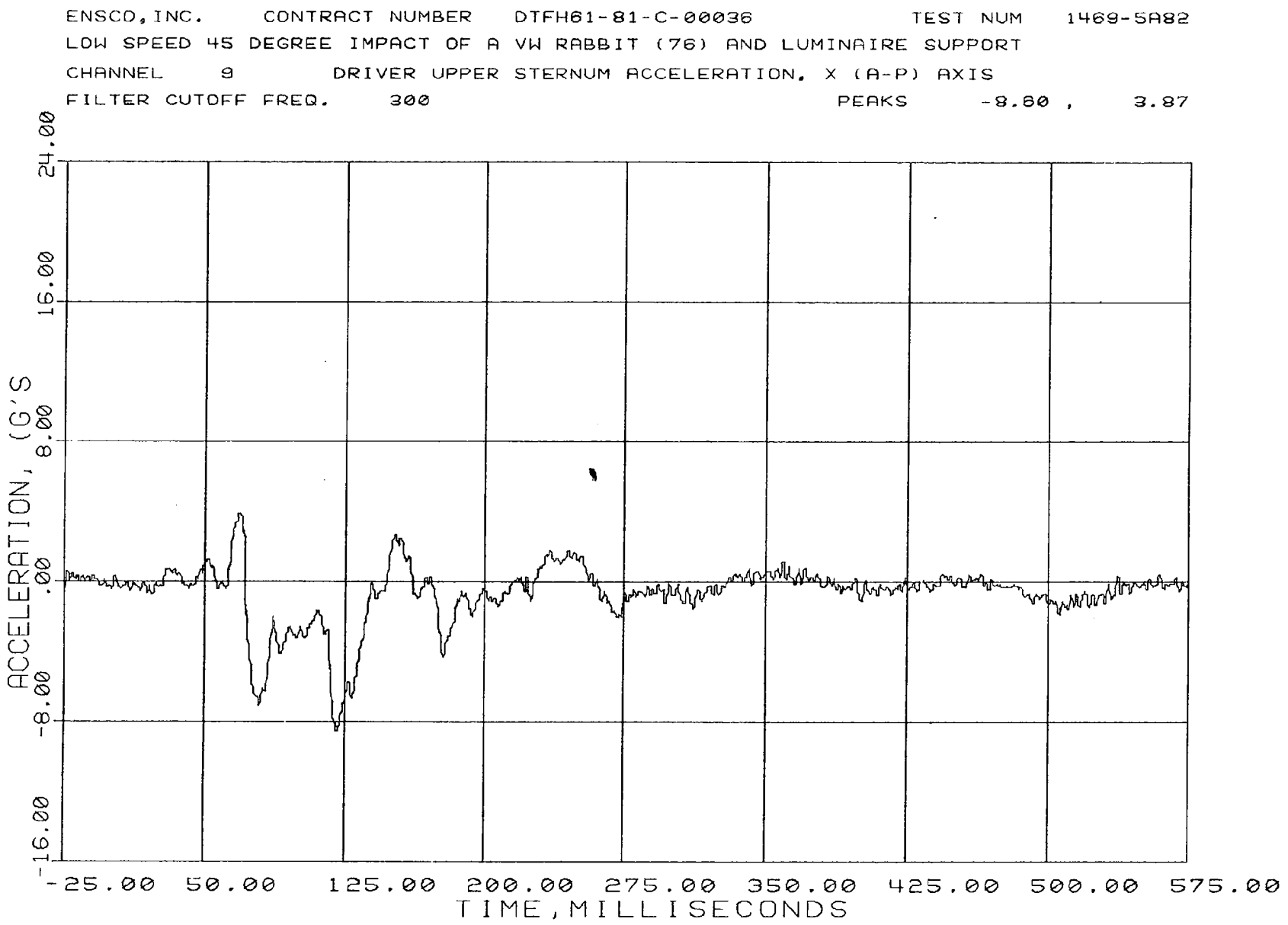


Figure 49. Driver Upper Sternum Acceleration, X (A-P) Axis (SAE Class 180)

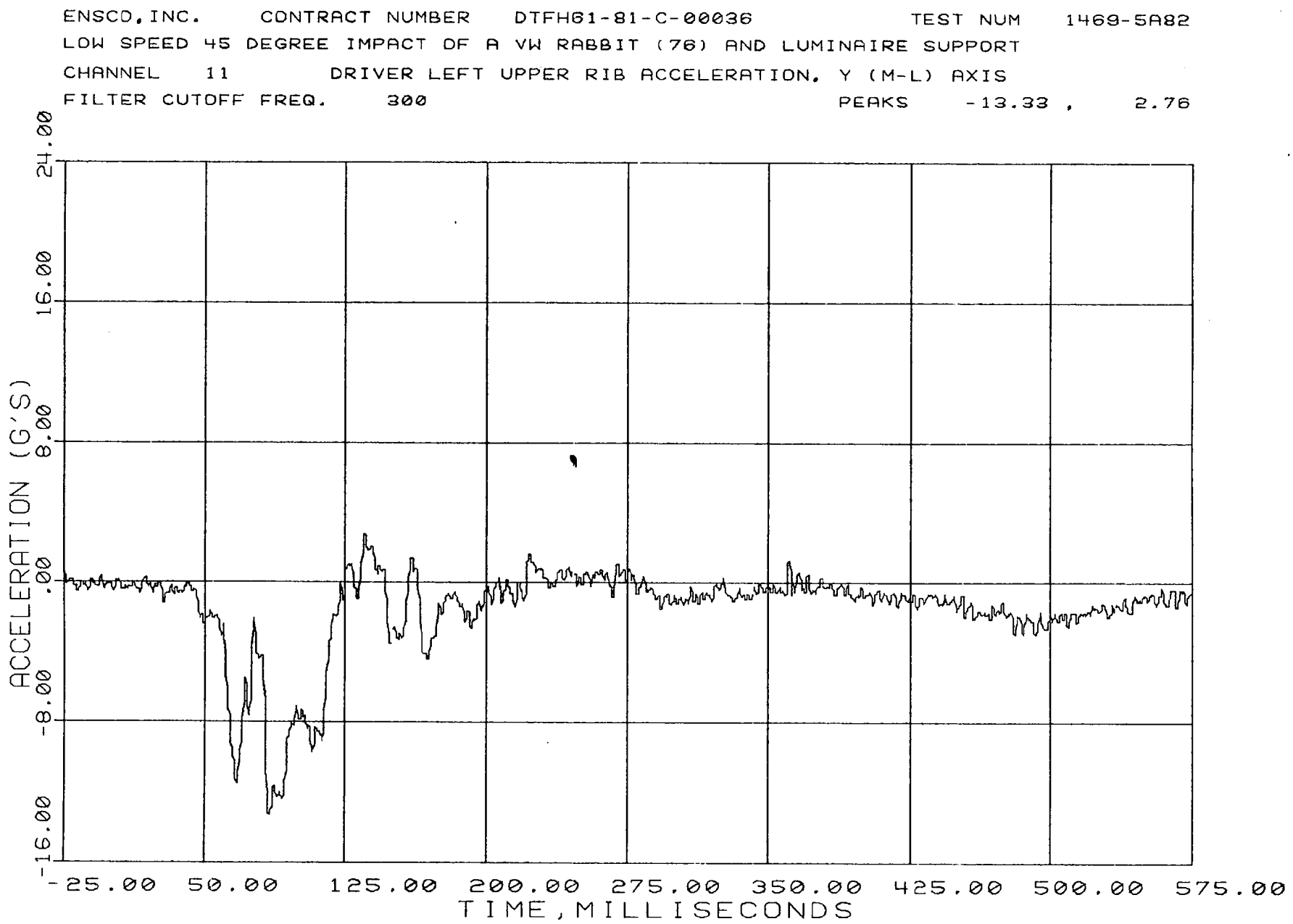


Figure 50. Driver Left Upper Rib Acceleration, Y (M-L) Axis (SAE Class 180)

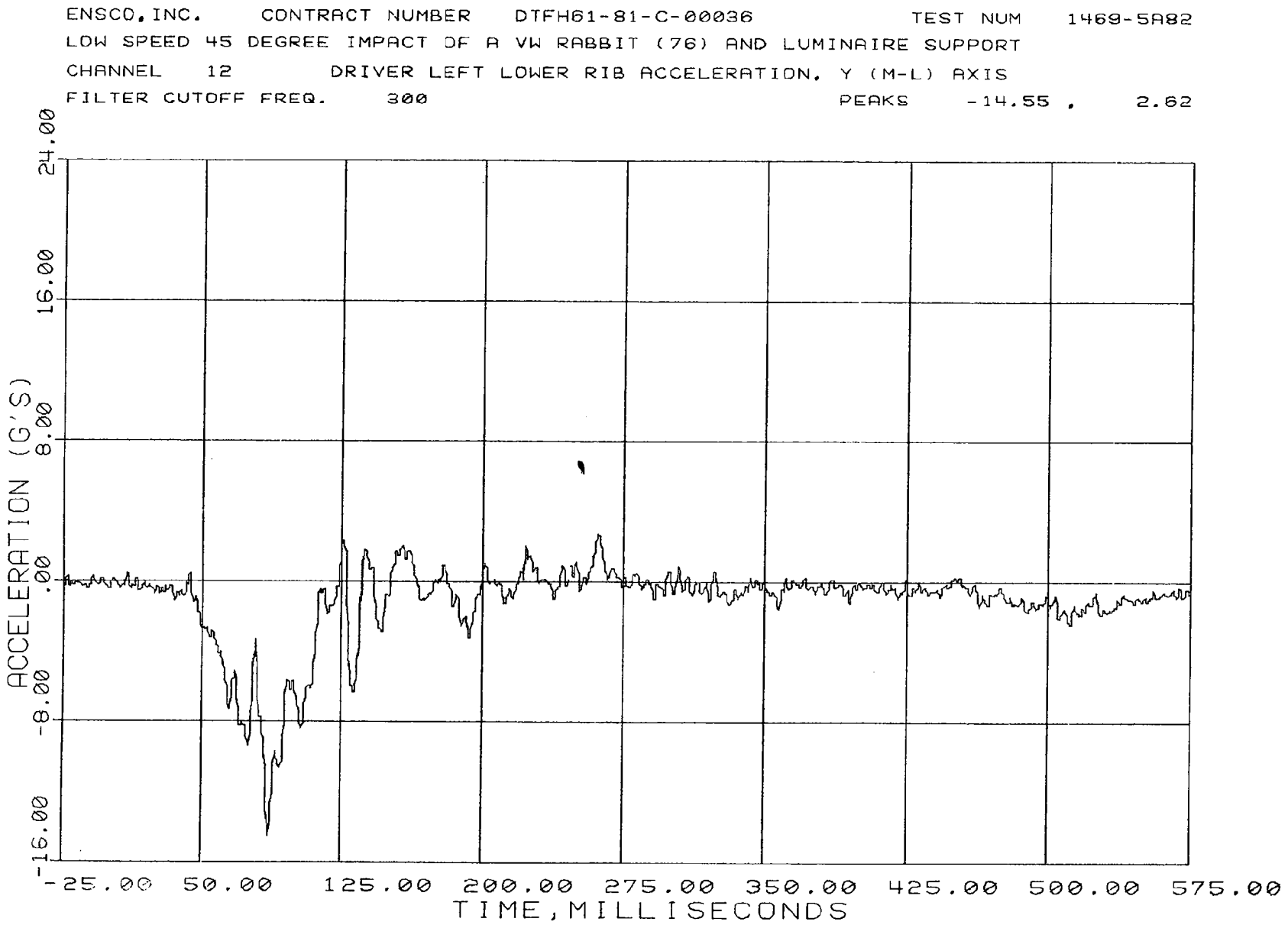


Figure 51. Driver Left Lower Rib Acceleration, Y (M-L) Axis (SAE Class 180)

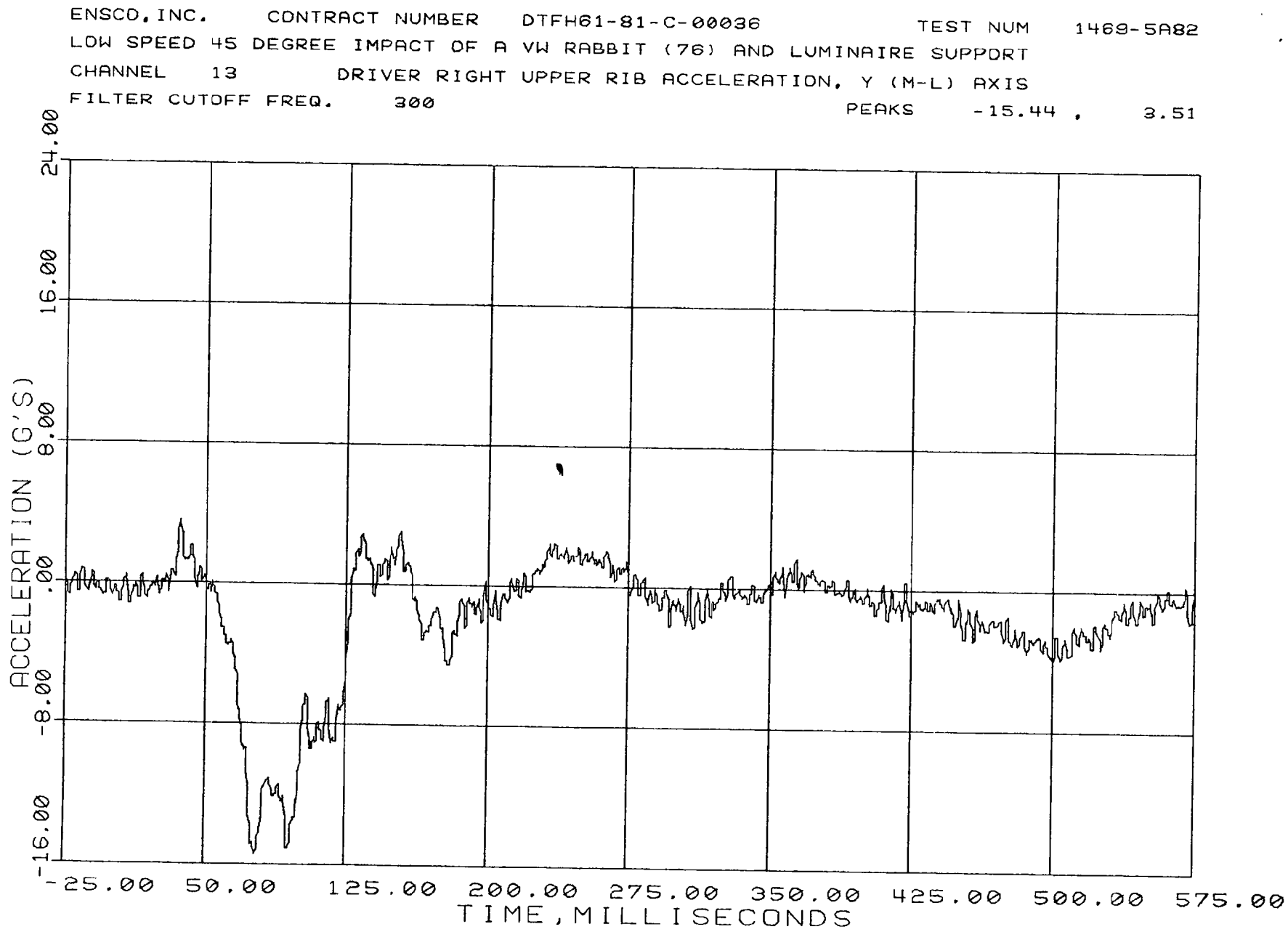


Figure 52. Driver Right Upper Rib Acceleration, Y (M-L) Axis (SAE Class 180)

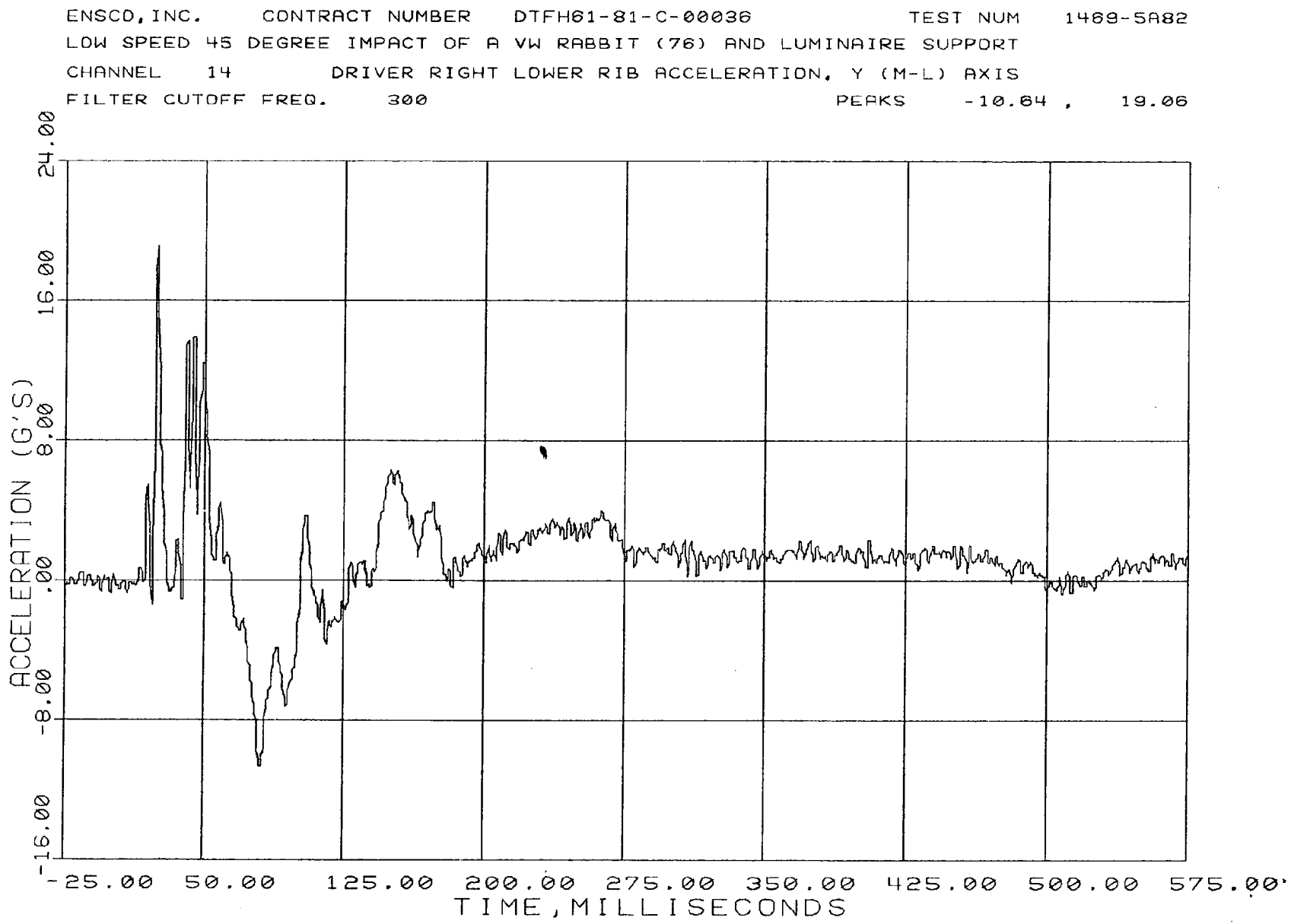


Figure 53. Driver Right Lower Rib Acceleration, Y (M-L) Axis (SAE Class 180)

To evaluate the above parameters the signals for each of the four data channels to be analyzed were first filtered at SAE Class 180 using a noncausal digital filter, decimated to an equivalent digitizing rate of 1600 Hz and filtered again using a finite impulse response filter having a pass band frequency to 100 Hz. The results for the thoracic injury evaluation are given in Table 16. Using the B parameter for the left upper rib and the models proposed by Robbins[19], the AIS and modified AIS number for the occupant for this full scale crash test were .75 and 0.00, respectively.

TABLE 16

THORACIC INJURY PARAMETER EVAUATION

	Q	V1050	V1090	RVS	B
L, Upper Rib	15.72 ft/sec	25.000ms	46.875ms	1.88	5.243
L, Lower Rib	14.49 ft/sec	25.000ms	48.125ms	1.93	5.179
Spine, Upper (Y Axis)	23.99 ft/sec	23.750ms	415.00ms	17.47	5.405
Spine, Lower (Y Axis)	40.14 ft/sec	43.125ms	81.875ms	1.90	5.586

1 ft = .3048 m

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