DOT ϕ 442

[redacted]

ENSCO, INC.®

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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 broadside 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 30.4 mph (13.59 m/s) was 792 lb-sec (3,523 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 8.63 mph (3.86 m/s). The integrity of the vehicle was maintained throughout the test. Maximum residual intrusion into the vehicle passenger compartment was 8.75 inches (0.22 m). Maximum residual crush of the side of the vehicle was 11.4 inches (0.29 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 apprach was 12.66 ft/sec (3.86 m/s) which occurred 123 ms 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. However, the actual impact velocity of the occupant with the interior of vehicle was approximately 44 ft/sec (13.4 m/s) since the occupant impacted the area where the luminaire support was deforming the interior of the vehicle compartment. This lateral impact velocity exceeds both of the limits discussed eariler in this paragraph.

The acceleration data from the anthropometric 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 3.9 to 4.0. This exceeds 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 anthromorphic dummy yielded a Head Injury Criteria (HIC) of 780 which is fifteen times those attained during frontal impacts with similar test conditions. However, this result is still within the limit 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 1469-4A82

1.	Contract Number	DTFH61-81-C-00036
2.	Date of Test	April 28, 1982
3.	Test Vehicle	Volkswagon Rabbit, 1976
4.	Vehicle Weight, Original Conf.	1,913 lbs
5.	Vehicle Weight, Test Inertial Planned Actual	 1,800 ±50 lbs 1,845 lbs
6.	Vehicle Weight, Gross Static Actual (One Occupant)	 2,013 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 1469-4A82

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	25 mph
	Observed	30.4 mph
23.	Exit Speed, Observed	
	Acceleration Data, NCHRP 230	21.75 mph[6]
	Acceleration Data, TRC 191	21.74 mph[7]
24.	Speed Reduction, Observed	
	Acceleration Data, NCHRP 230	8.63 mph[6]
	Acceleration Data, TRC 191	8.64 mph[7]
25.	Impact Point	
	Planned	Left Door, Driver Location, (15.3 in. behind C.G.)
	Observed	Left Door, Driver Location, (15.8 in. behind C.G.)
26.	Impact Angle of Vehicle 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	11.4 in.
29.	Max. Interior Compartment Intrusion	8.75 in.
30.	Traffic Accident Data, TAD[10]	9-LP-5
31.	Vehicle Damage Index, VDI[11]	09LPAN3

TABLE 1 (Cont'd)
SUMMARY OF TEST CONDITIONS AND
RESULTS FOR TEST NUMBER 1469-4A82

32.	Hypothetical Occupant Impact Velocity	
	Design Limit (Redirectional Barriers)	20 ft/sec[6]
	Observed	12.66 ft/sec[6]
33.	Hypothetical Occupant Ride-down Acceleration	
	Design Limit (Redirectional Barriers)	15.00 g[6]
	Observed, NCHRP 230	1.99 g[6]
	Observed, TRC 191	2.06g[7]
34.	Actual Occupant Impact Velocity	
	Limit	30 ft/sec[6]
	Observed	44 ft/sec
35.	Head Injury Criteria (HIC)	
	Design Limit	1000[8]
	Driver, Observed	780
36.	Peak Resultant Thorax/Pelvis Acceleration with Duration >.003 sec	
	Spine, Upper	74.13g
	Spine, Lower	152.74g
	Pelvis	124.90g
37.	Severity Index (SI)[12]	
	Spine, Upper	404
	Spine, Lower	1108
	Pelvis	916
38.	Thoracic Injury Results[18]	
	Fatal Injury	6.00
	AIS	4.02
	MAIS	3.88
39.	Momentum Change	
	Acceleration Data, NCHRP 230	792 lb-sec[6]
	Accelerations Data, TRC 191	792 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 severity of a minicompact sedan (1,800S) during a low speed broadside collision with a surrogate breakaway luminaire support. This test is the fourth 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 at the impact location. The vehicle also was instrumented with a contact switch mounted on the left door 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. 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	14.83 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 1,913 pounds. The test inertial weight for the vehicle was 1,845 pounds and the gross static weight when the occupant was included in the vehicle was 2,013 pounds. The longitudinal center of gravity of the vehicle without the occupant was located 33.4 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	646	629	1,275
Rear	316	322	638
Subtotals	962	951	1,913

1 lb. = .454 kg

TABLE 4

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

	Left (lbs)	Right (lbs)	Subtotal (lbs)
Front	578	615	1,193
Rear	323	329	652
Subtotals	901	944	1,845

1 lb = .454 kg

TABLE 5

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

	Left (lbs)	Right (lbs)	Subtotal (lbs)
Front	634	640	1,274
Rear	410	329	739
Subtotals	1,044	969	2,013

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 door 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 Side View

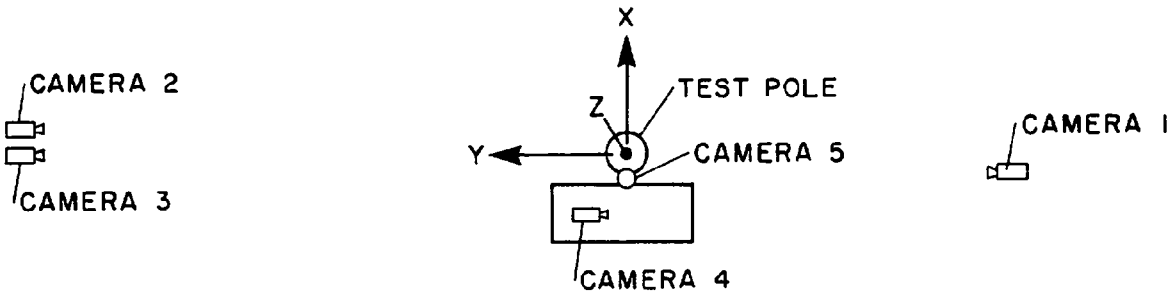
Figure 5. Pretest Photograph of Test Vehicle Shown Next to Surrogate Luminaire Support, Front View

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 1.4 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 1469-4A82



Camera	Model	Position	Placement X(ft),Y(ft),Z(ft)	Speed Setting	Lens
1	Redlake Locam	Rt. Side	0, -47, 3	500 pps	50 mm
2	Redlake Hycam	Lt. Side	3, 75, 3	500 pps	50 mm
3	Redlake Locam	Lt. Side	0, 84, 3	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 1469-4A82

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/Contact
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 30.4 mph (13.58 m/s) at a point on the left door in line with the occupant 15.8 in (.40 m) behind 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 11.4 inches (.29 m). The maximum residual intrusion into vehicle compartment was 8.75 in (.22 m). 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 .020 seconds after impact. The force levels at the time of initiation of the breakaway fracture mechanism of the luminaire support were 25,600 pounds and 31,600 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 14.2 f/s (4.33 m/s) with a rotation rate of 2.15 rad/sec. The luminaire support rotated up and over the test vehicle without any secondary impacts. As the support rotated away, vehicle yawed counter clockwise and rolled up on its left tires and wheels. The maximum roll angle was less than 10°. The vehicle then settled back on all 4 tires and continued forward away from the impact area after yawing a total of about 72°. The final resting position was about 13 feet to the right of the impact approach path and 44.6 feet down stream. The top of the luminaire support impacted the ground 3.3 feet behind and .4 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 1469-4A82 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

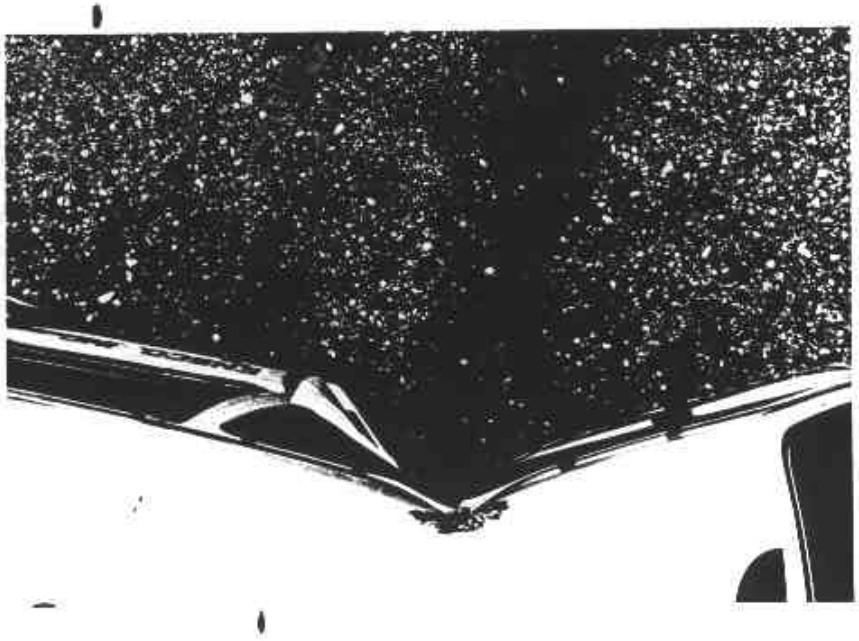


Figure 9. Post-Test Photograph of Test Vehicle, Overhead View

t = 0.00 sec

t = 0.090 sec

t = 0.030 sec

t = 0.120 sec

t = 0.060 sec

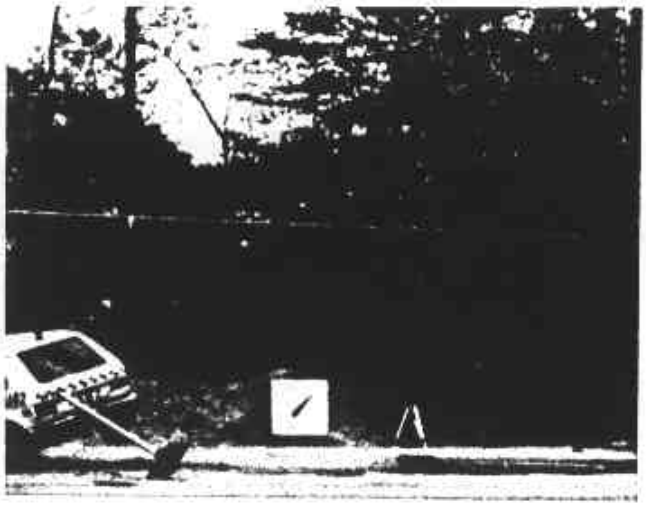
t = 0.150 sec

Figure 10. Test Sequence for the Initial Collision Event of Full Scale Crash Test Number 1469-4A82

t = 0.00 sec

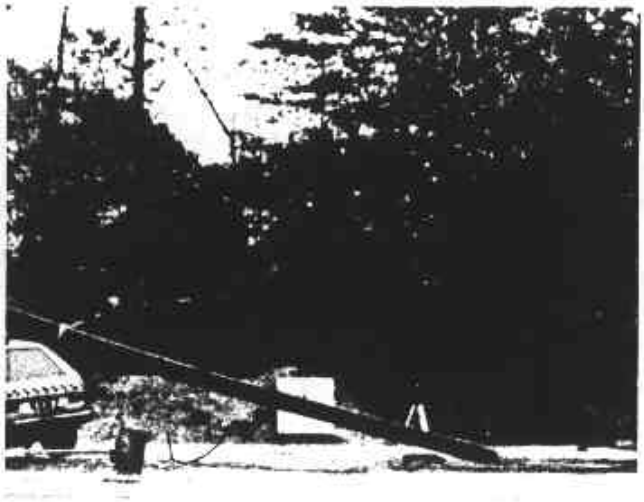
t = 0.600 sec

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 for Full Scale Crash Test Number 1469-4A82

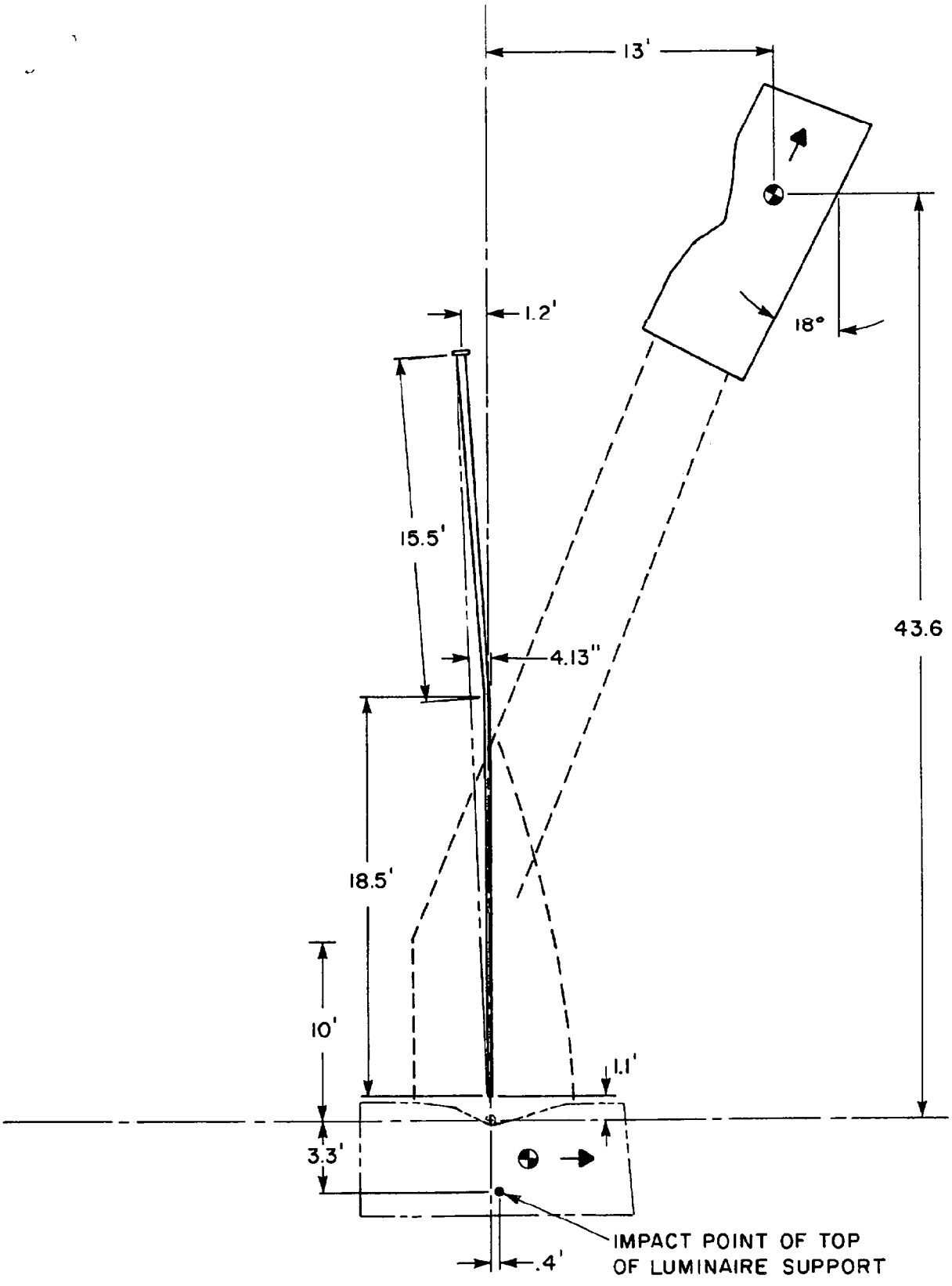


Figure 12. Dimensional Relationships for Full Scale Crash Test Number 1469-4A82

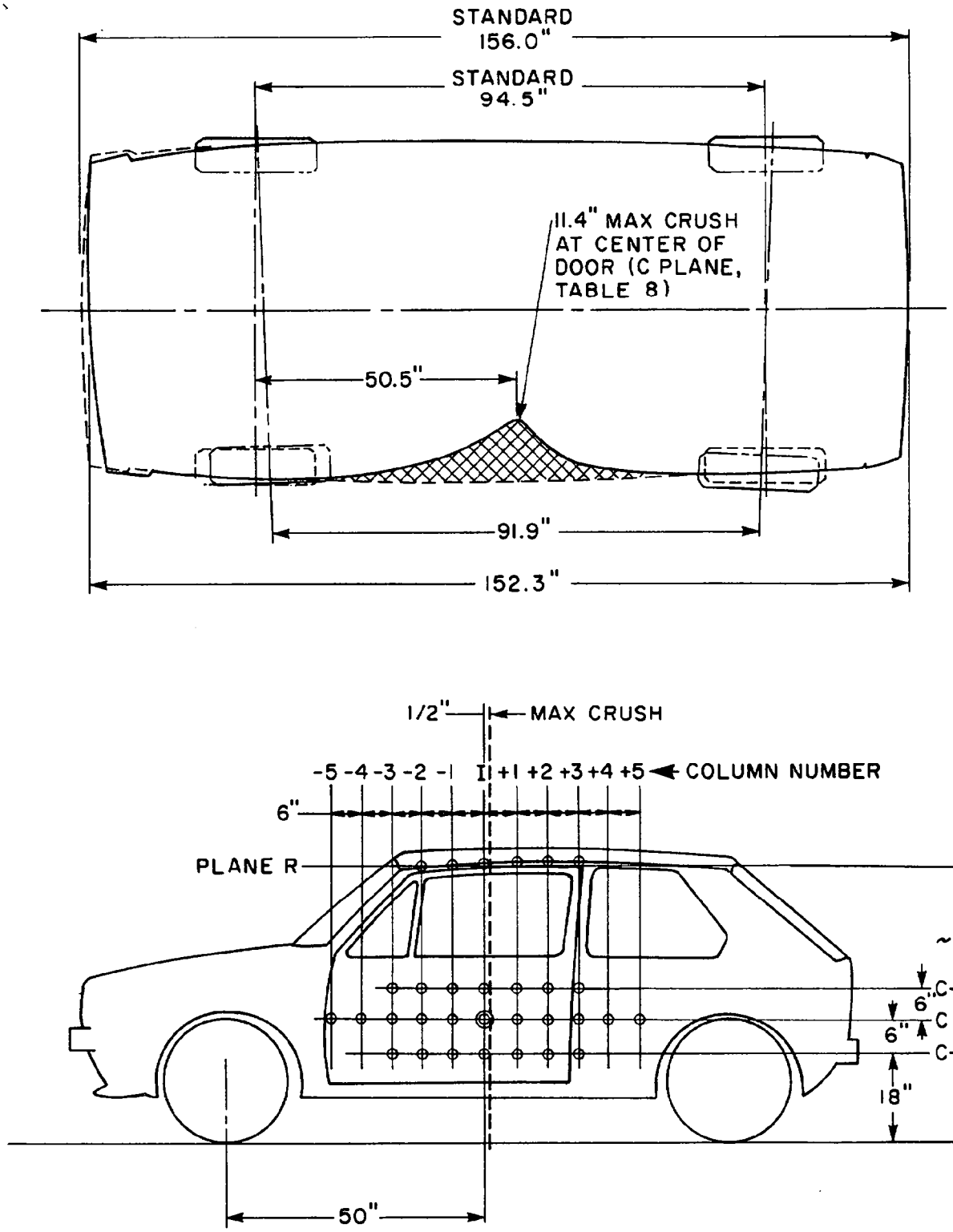


Figure 13. Vehicle Crush Diagram and Crush Measurement Matrix

TABLE 8

VEHICLE CRUSH AND INTRUSION MEASUREMENTS

	FORWARD						REARWARD					
Location	-5	-4	-3	-2	-1	I	MAX	+1	+2	+3	+4	+5
R	-----	-----	-----	1.00	3.00	5.25	6	3.50	2.38	1.75	-----	-----
C + 1 (30")	-----	-----	3.88	5.50	8.13	10.63	11.38	6.13	3.13	2.38	-----	-----
C (24")	0.0	1.63	3.75	5.38	8.13	10.75	11.38	5.25	3.00	2.13	1.13	.88
C - 1 (18")	-----	-----	3.25	4.38	7.13	10	10.68	4.88	3.13	2.80	-----	-----
Intrusion	-----	2.25	3.88	5.69	7.25	8.50	8.75	7.13	3.75	1.50	1.25	1.25

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

2) Intrusion made on inside of vehicle at the C-Plane.

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 30.4 mph (13.58 m/sec).

TABLE 9

TEST VEHICLE IMPACT SPEED EVALUATION
USING HIGH SPEED FILM ANALYSIS

Camera	Position	Impact Speed (ft/sec)	Impact Speed (mph)
1	Right Side	42.4	28.91
2	Left Side	45.7	31.16
3	Left Side	45.7	31.16
5	Overhead	44.4	30.27
		44.55	30.38

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 accelerometer located on the rear of the left door was damaged during the test and the data associated with this accelerometer is not included in this report. 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 21. The acceleration traces and resultants obtained with the use of the SAE Class 180 (f_c = 300 Hz) filtering technique are presented in Figures 22 through 29.

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	-7.39	13.250	-9.23	11.875
Y Axis	-18.52	22.875	-27.86	24.250
Z Axis	7.25	44.750	-15.53	26.875
Resultant, X and Y	18.79	22.875	28.66	24.375
Resultant, X, Y and Z	18.81	22.875	28.71	24.375
Left Door, Upper Ctr	-226.82	7.500	419.26	19.125
Left Door, Middle For.	-214.94	6.125	-365.53	6.625
Left Door, Lower Ctr	-367.04	35.875	-436.61	34.750

TABLE 11

VEHICLE VELOCITY AND MOMENTUM
CHANGE OCCURRING DURING IMPACT EVENT

	SAE Class 60 Data[a]	SAE Class 180 Data[b]
X Axis	.18 mph	.18 mph
Y Axis	-8.64 mph	-8.63 mph
$M_s\Delta V$(30.4 mph)	792 lb-sec	792 lb-sec

1 mph = .44704 m/sec

NOTE: a. Time duration used for integrating acceleration data based on 12 in. 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. 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 12.66 ft/sec (3.86 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. However, the actual impact velocity of the occupant with the interior of vehicle was approximately 44 ft/sec (13.4 m/s) since the occupant impacted the area where the luminaire support was deforming the interior of the vehicle compartment. This lateral impact velocity exceeds both of the limits discussed earlier in this paragraph.

The highest ride down acceleration after the hypothetical front seat passenger impacted the interior of the vehicle was -1.99 g's occurring at 126.5 ms and -2.06 g's occurring at 126.13 ms using 10 ms averages of the lateral acceleration data filtered at SAE Class 60 and 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.

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
Δv = -12.661 ft/sec	Δv = -12.656 ft/sec
$t(\Delta v)$ = .12288 sec	$t(\Delta v)$ = .12300 sec
a_{max} = -1.99g	a_{max} = -2.06g
$t(a_{max})$ = .12650 sec	$t(a_{max})$ = .12613 sec

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

The difference in the results for the hypothetical and anthromorphic occupant are due to the fact that the passenger compartment conformed to the struck object in the lateral impact case and remains generally intact for the frontal impact situation. Based upon this analysis NCHRP 230 indicates that the accident was within design limits for the hypothetical occupant and outside the design limits for the anthromorphic dummy.

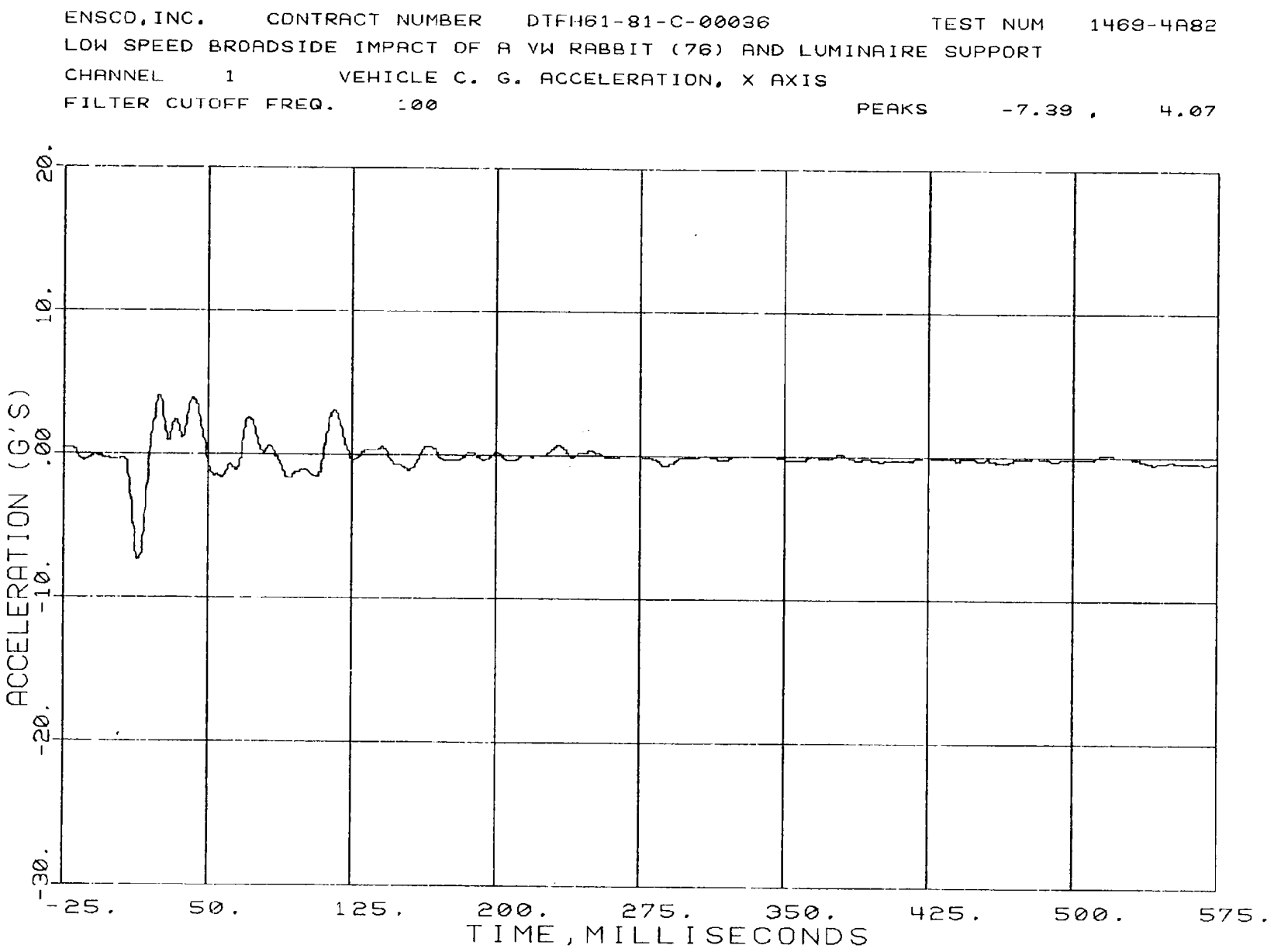


Figure 14. Vehicle C.G. Acceleration, X Axis (SAE Class 60)

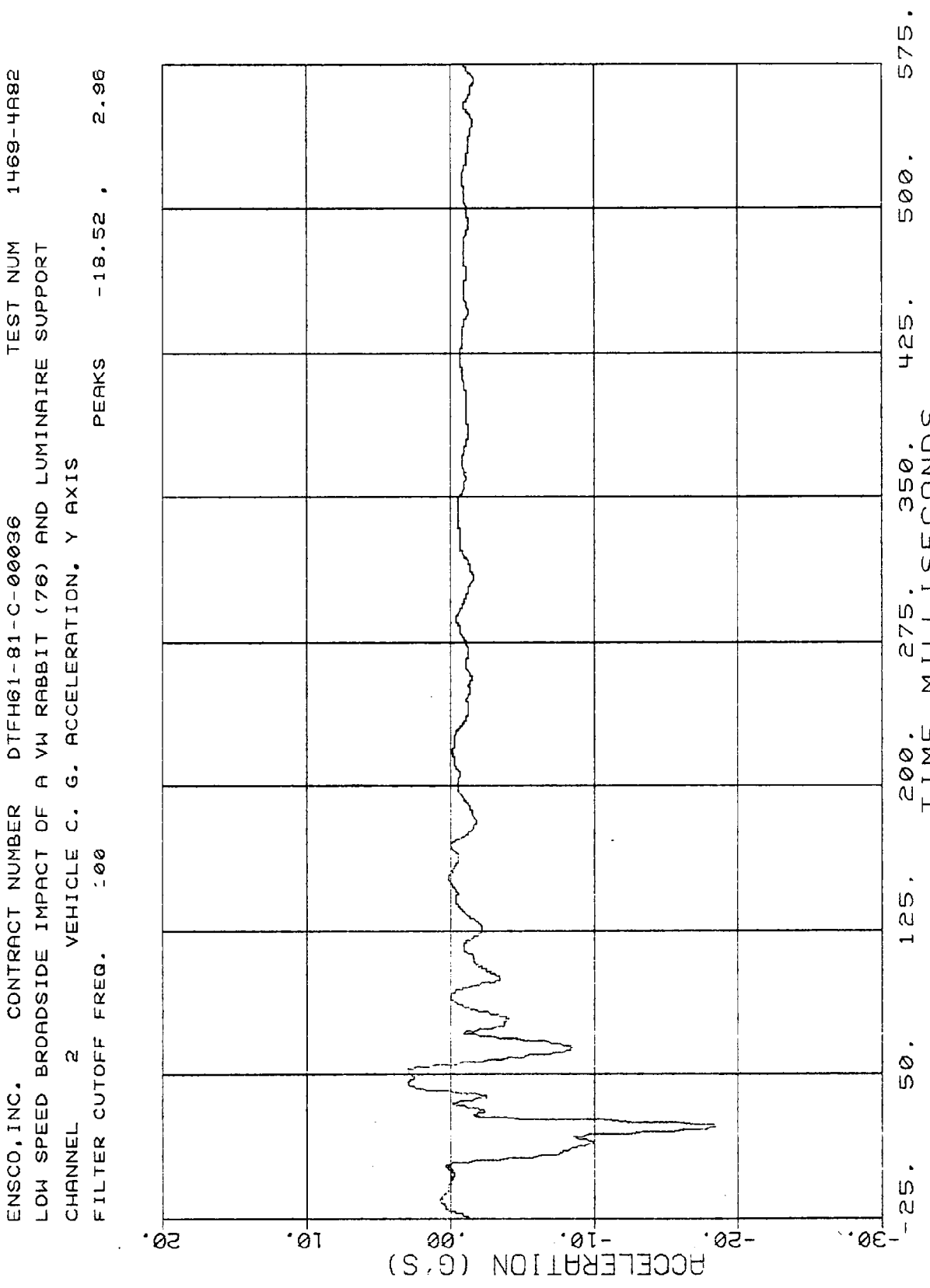


Figure 15. Vehicle C.G. Acceleration, Y Axis (SAE Class 60)

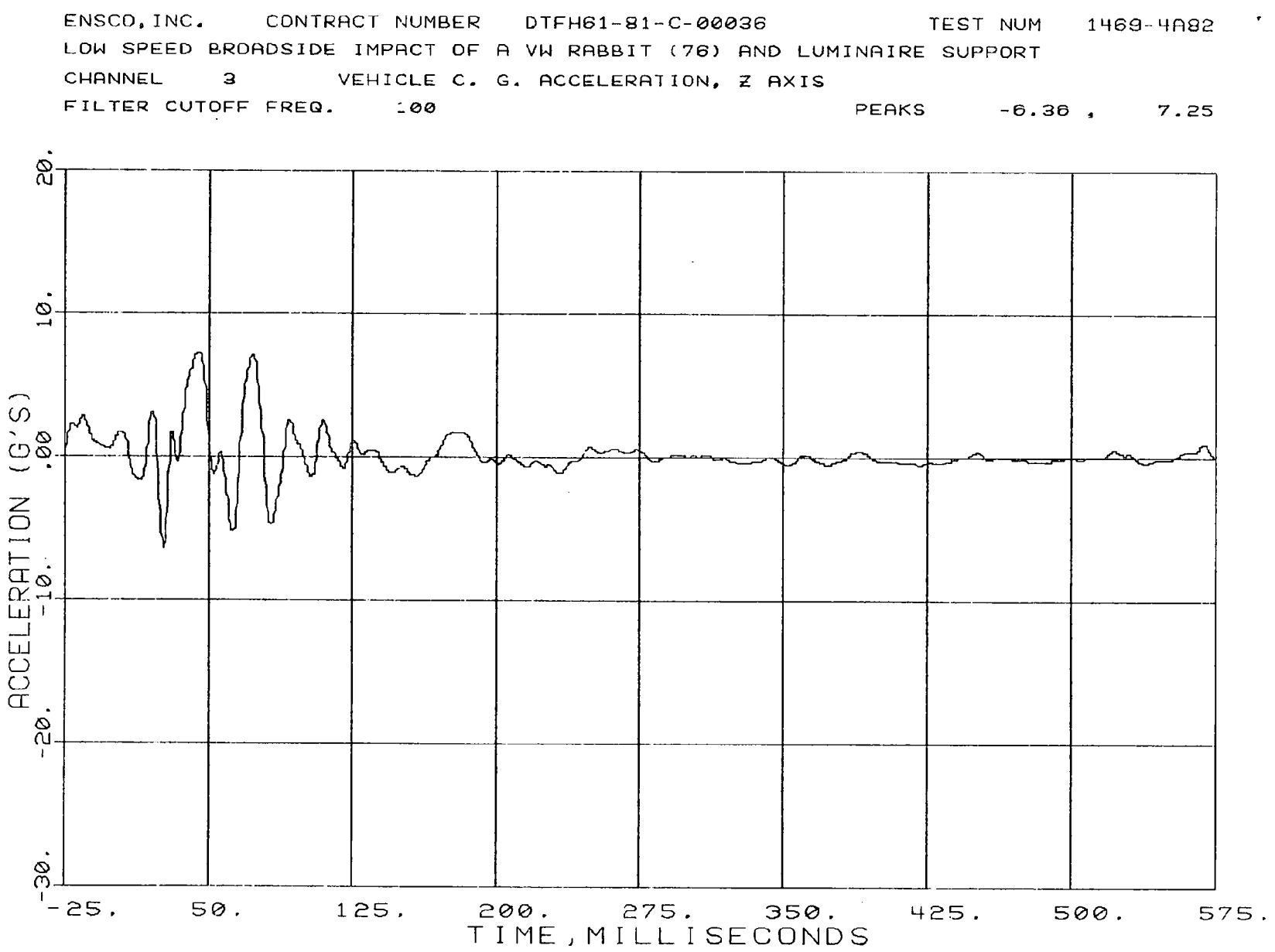


Figure 16. Vehicle C.G. Acceleration, Z Axis (SAE Class 60)

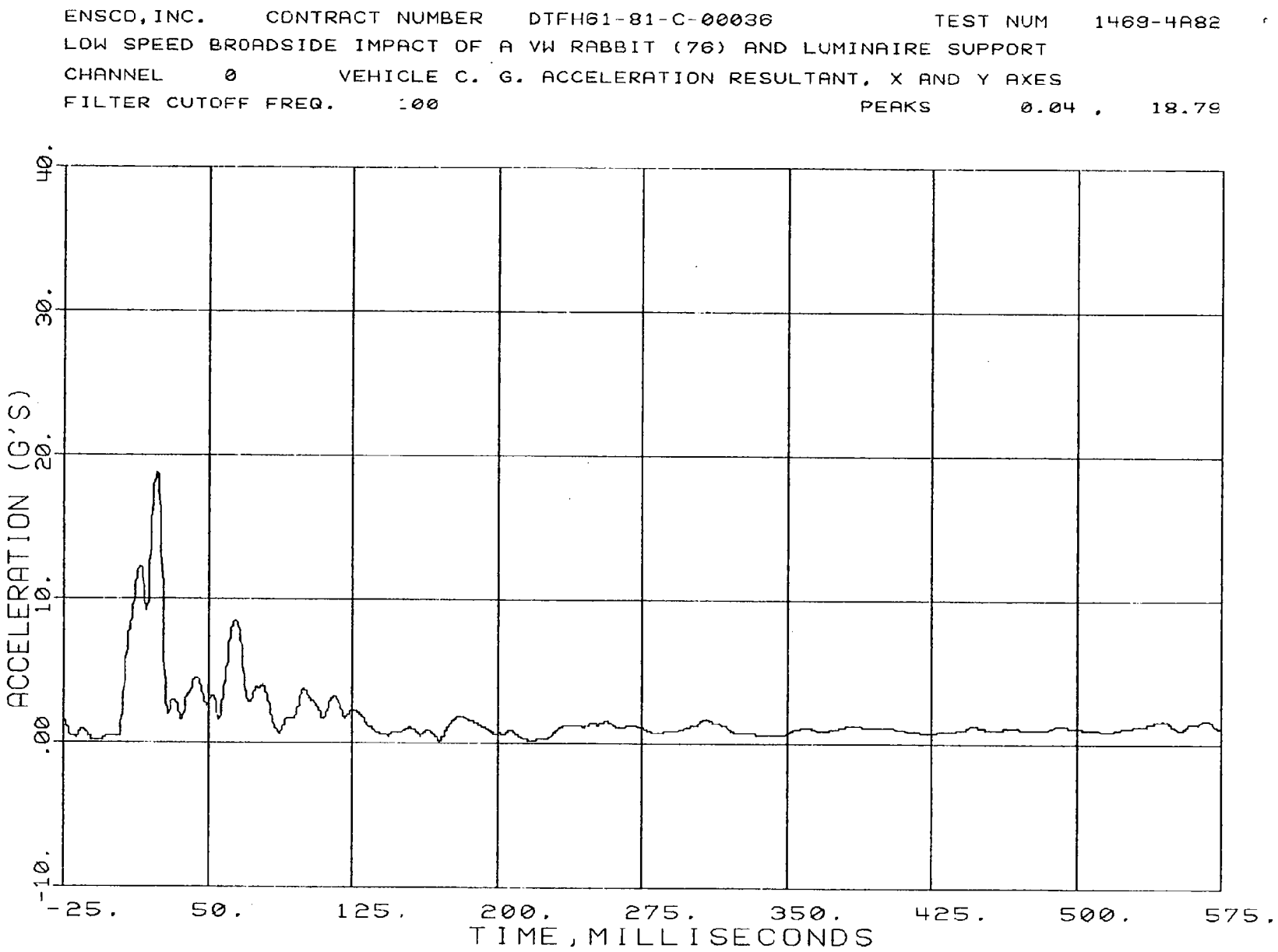


Figure 17. Vehicle C.G. Acceleration, X and Y Axes (SAE Class 60)

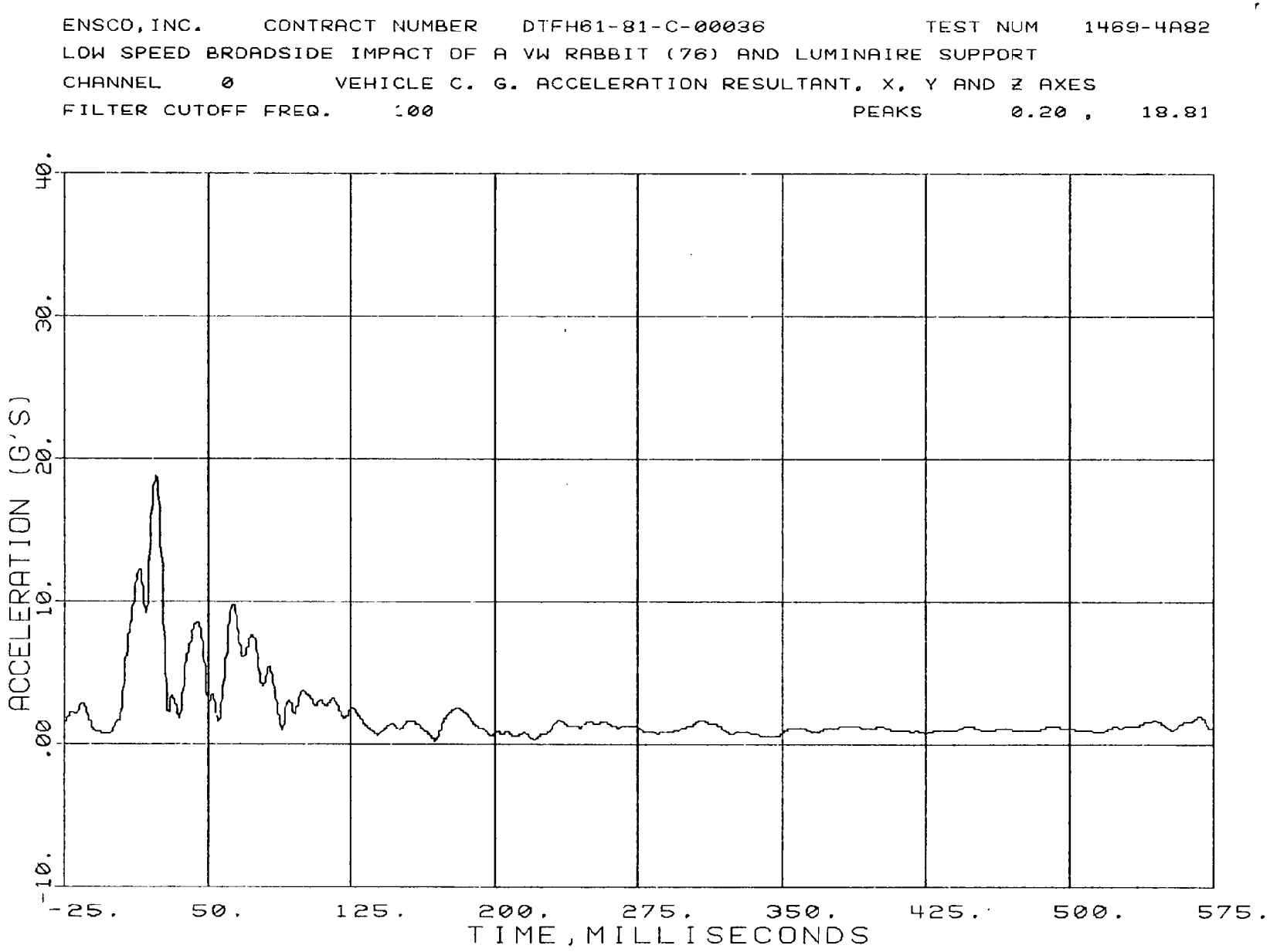


Figure 18. Vehicle C.G. Acceleration, X, Y and Z Axes (SAE Class 60)

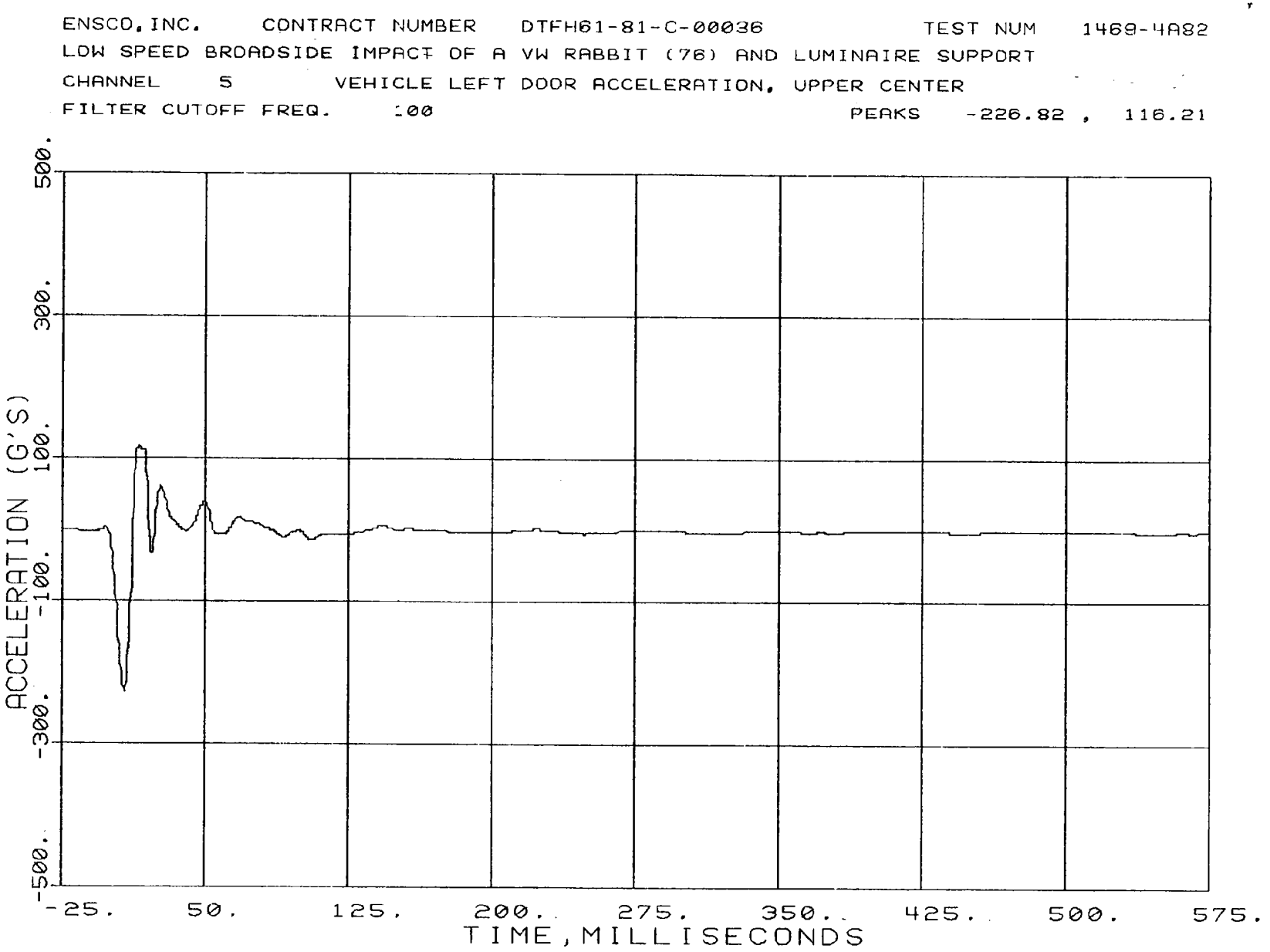


Figure 19. Vehicle Left Door Acceleration, Upper Center (SAE Class 60)

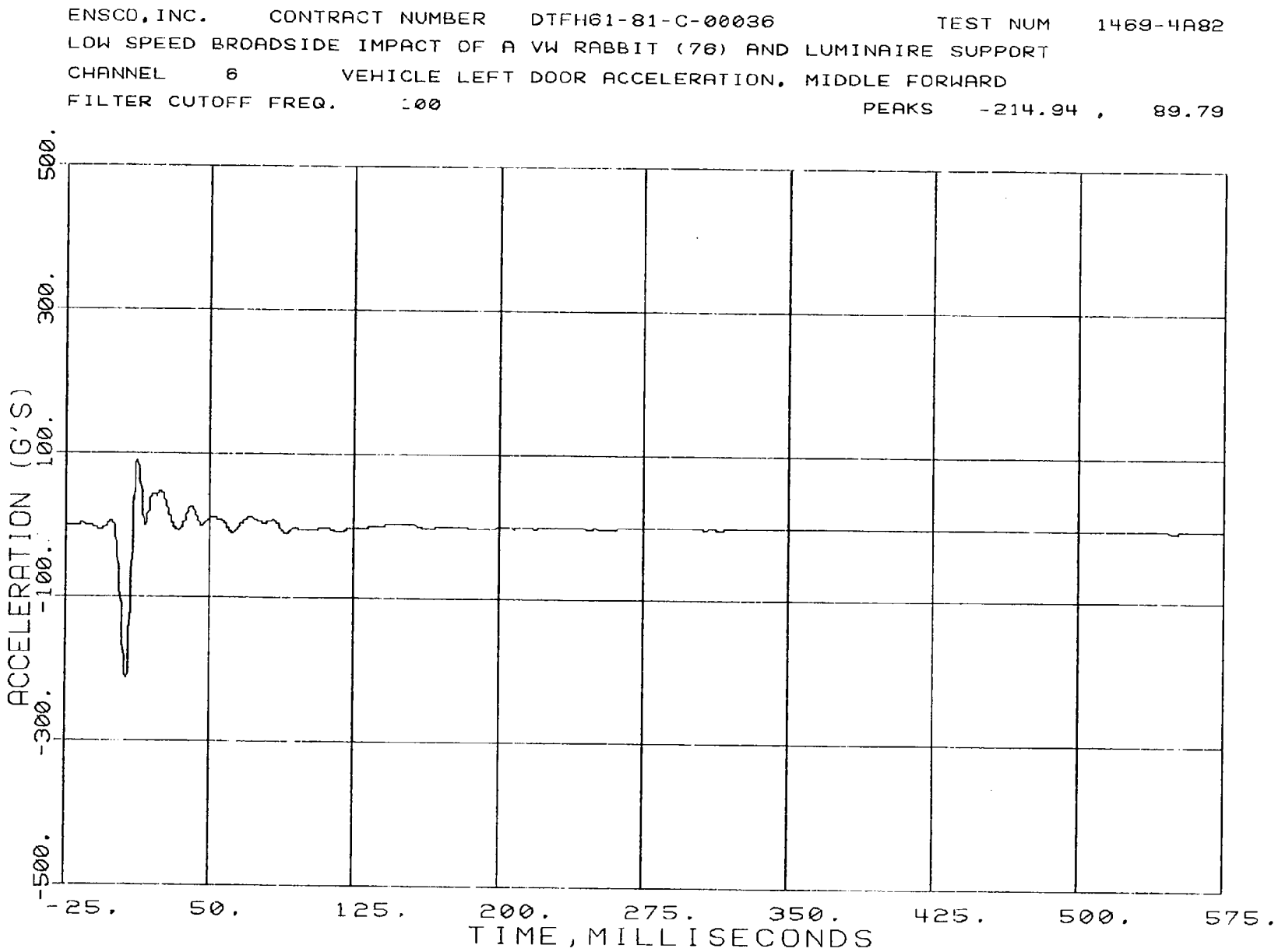


Figure 20. Vehicle Left Door Acceleration, Middle Forward (SAE Class 60)

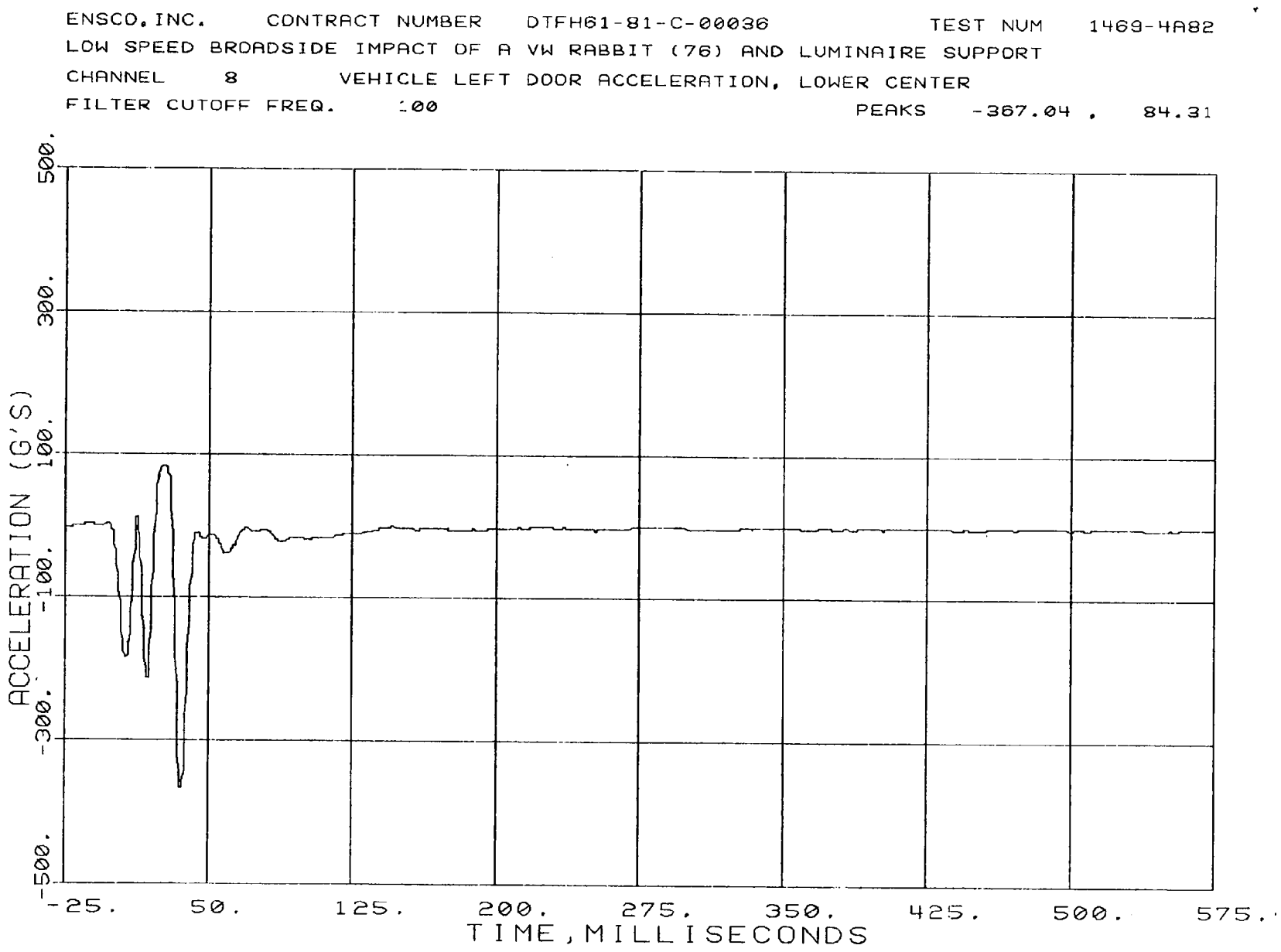


Figure 21. Vehicle Left Door Acceleration, Lower Center (SAE Class 60)

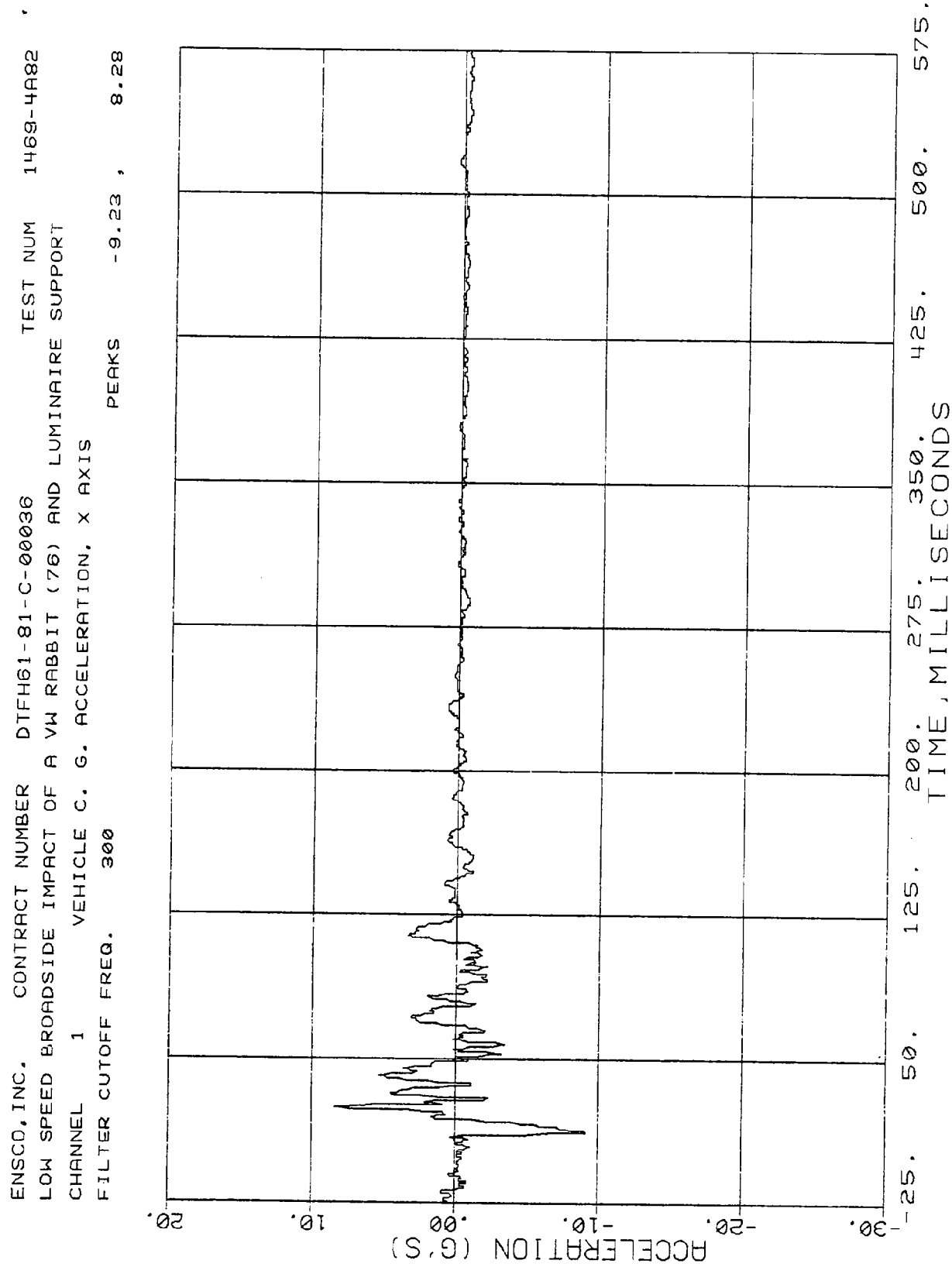


Figure 22. Vehicle C.G. Acceleration, X Axis (SAE Class 180)

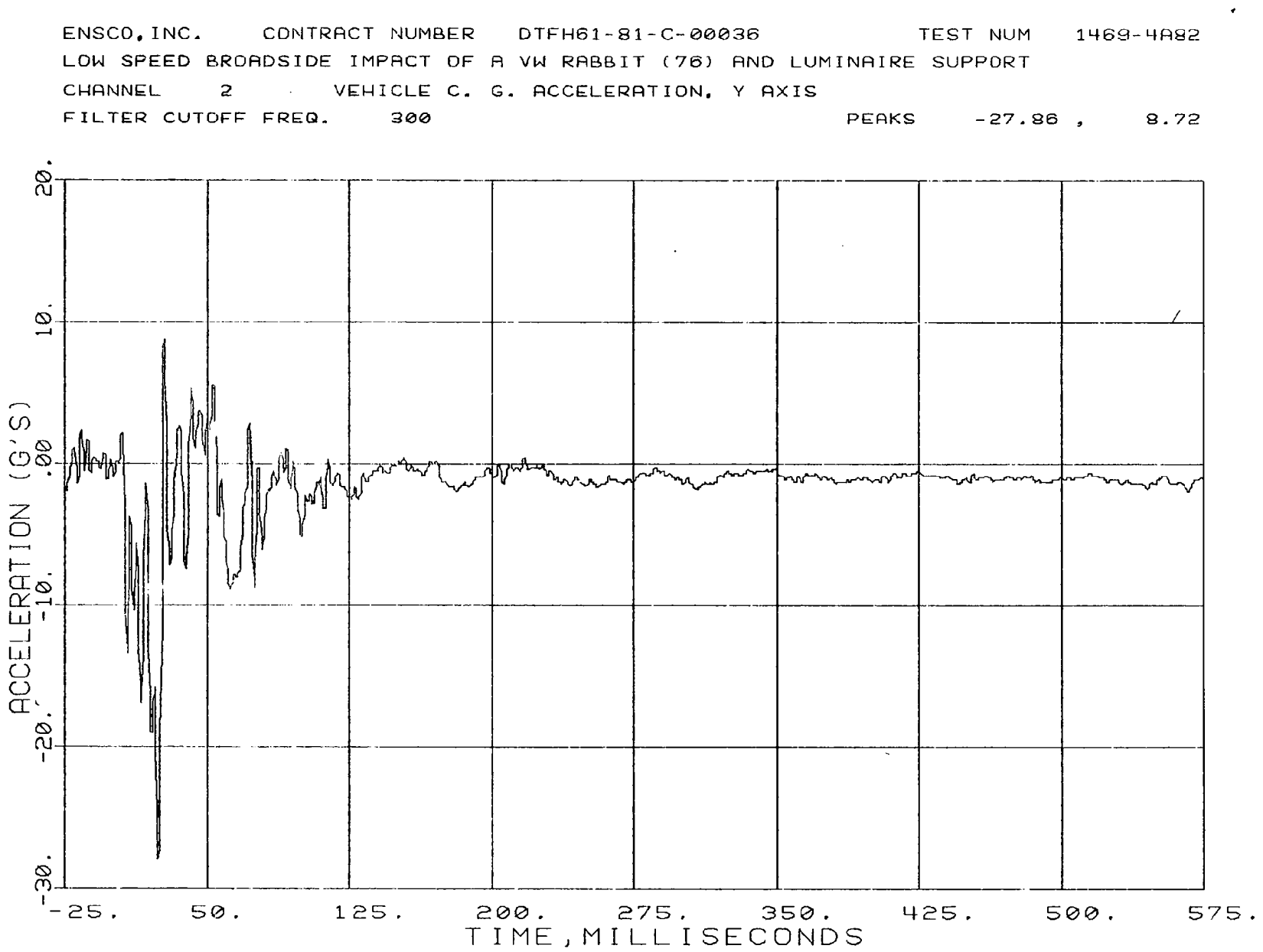


Figure 23. Vehicle C.G. Acceleration, Y Axis (SAE Class 180)

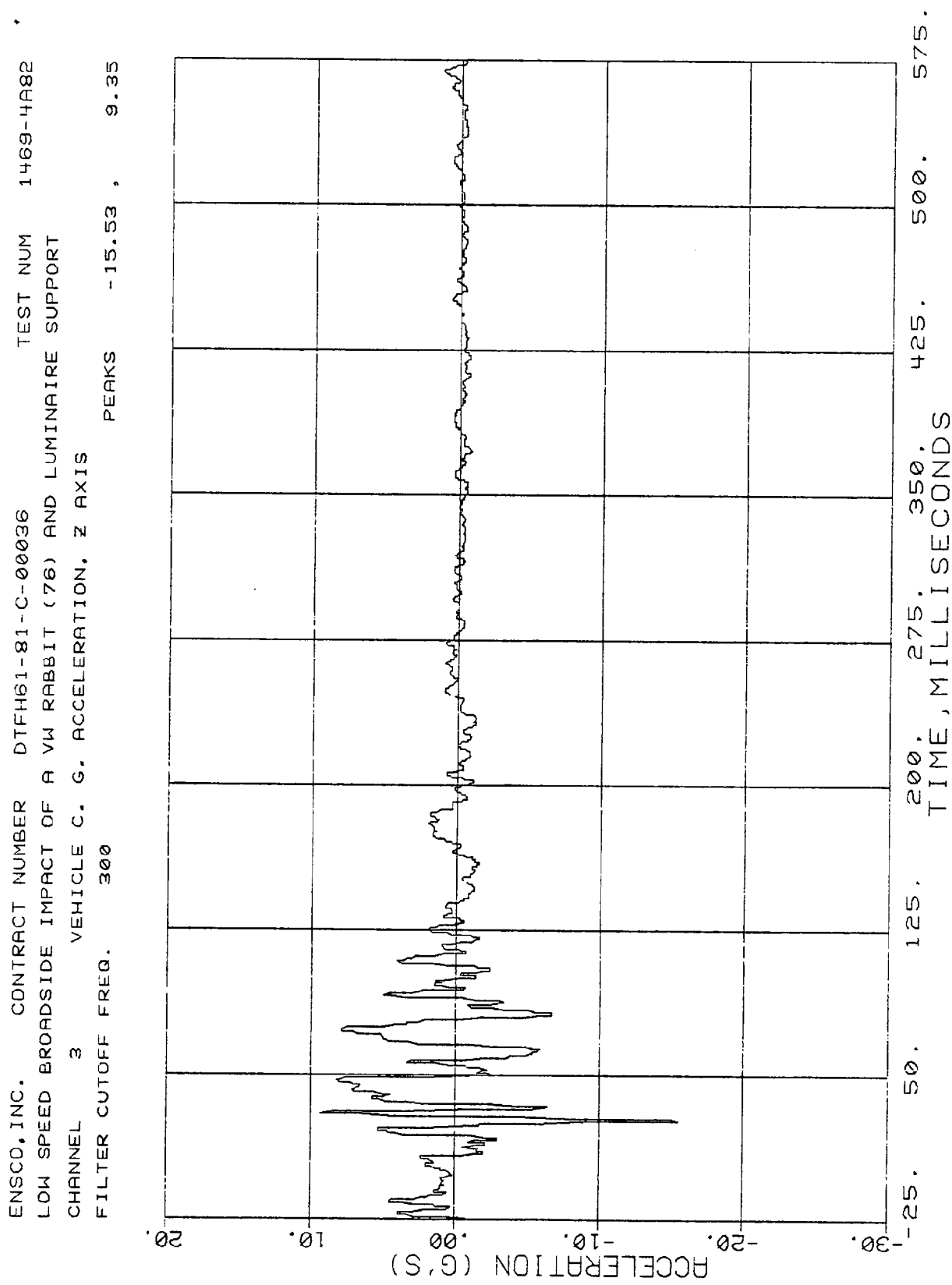


Figure 24. Vehicle C. G. Acceleration, Z Axis (SAE Class 180)

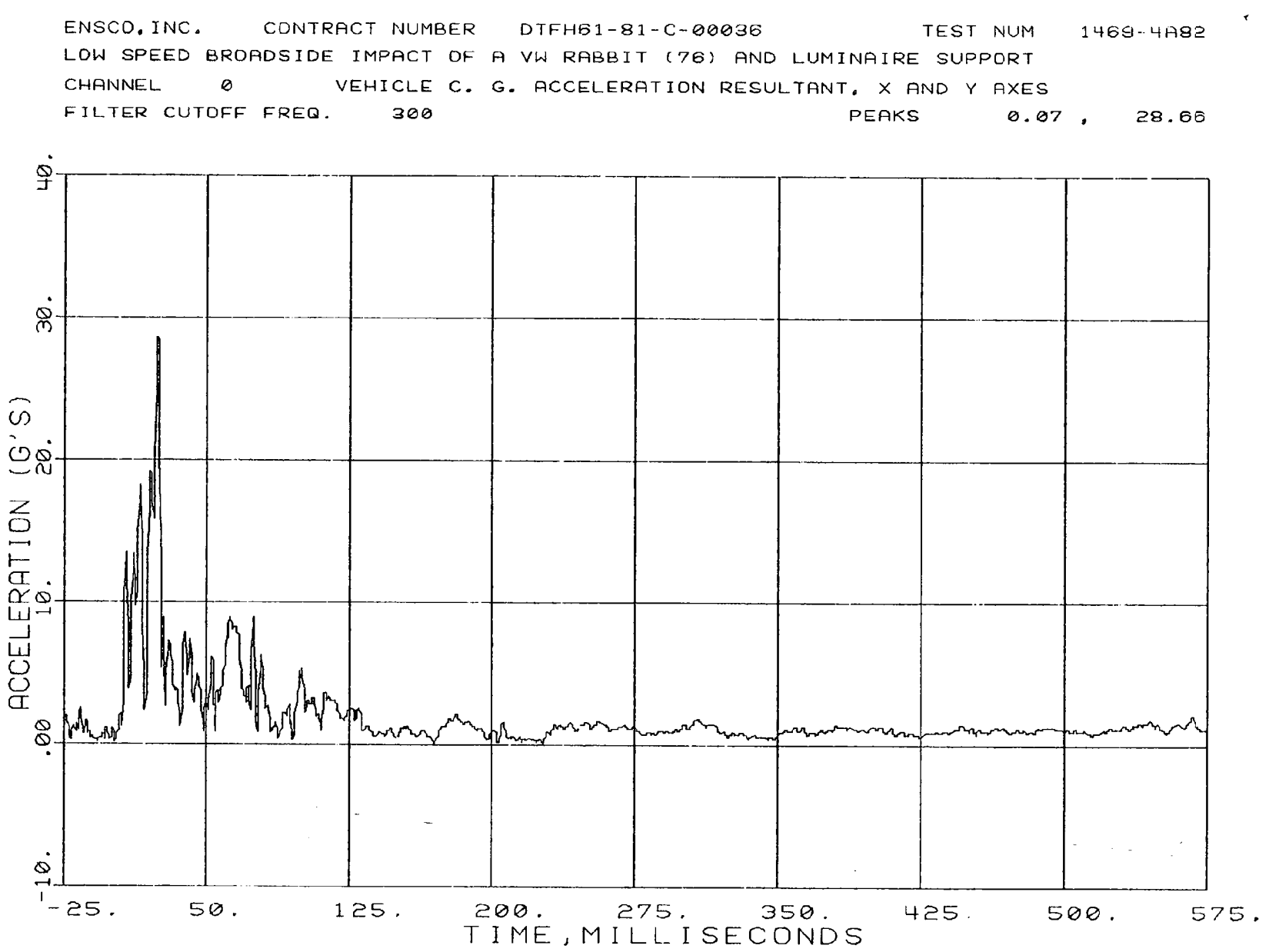


Figure 25. Vehicle C. G. Acceleration, X and Y Axes (SAE Class 180)

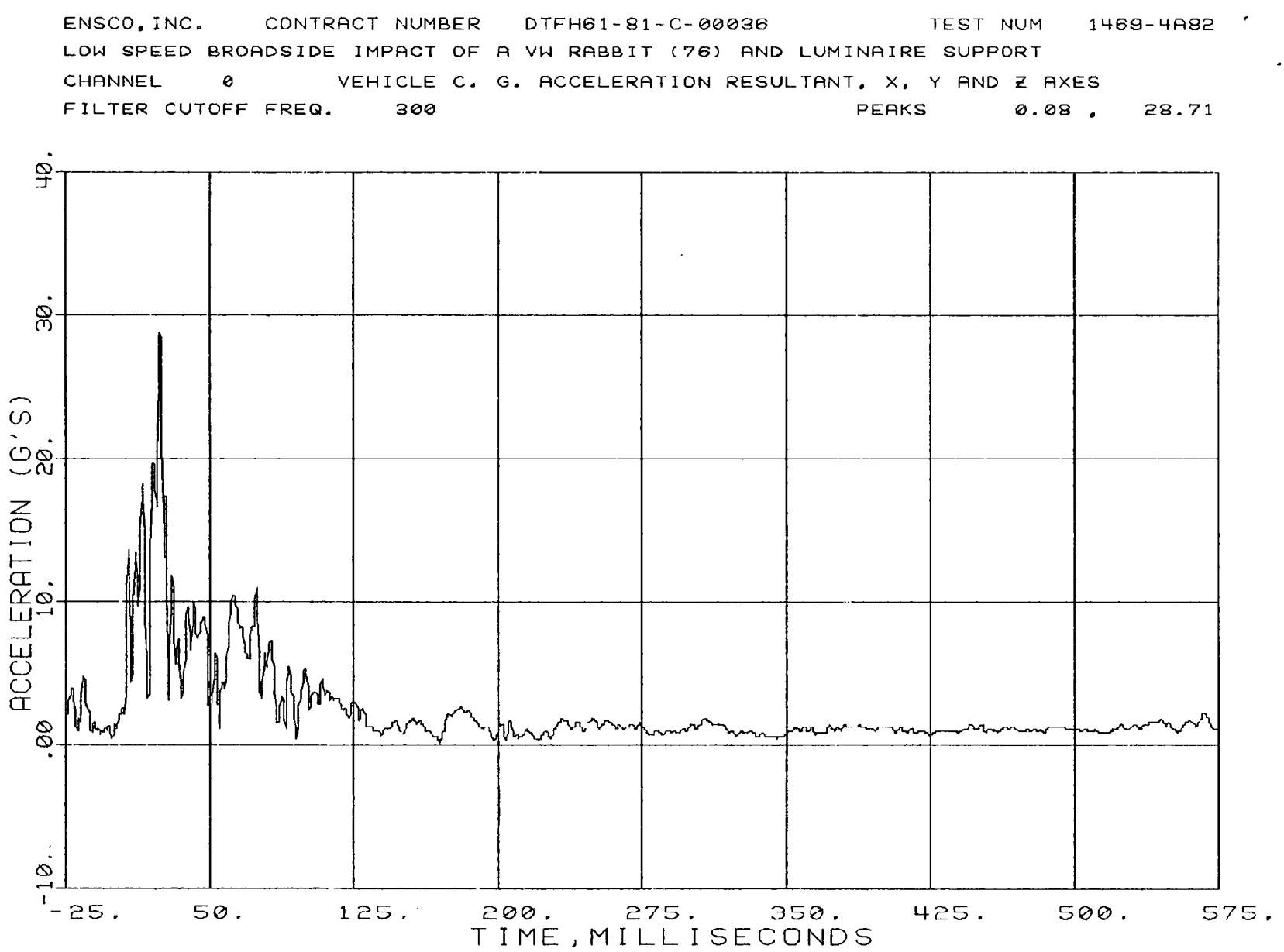


Figure 26. Vehicle C. G. Acceleration, X, Y and Z Axes (SAE Class 180)

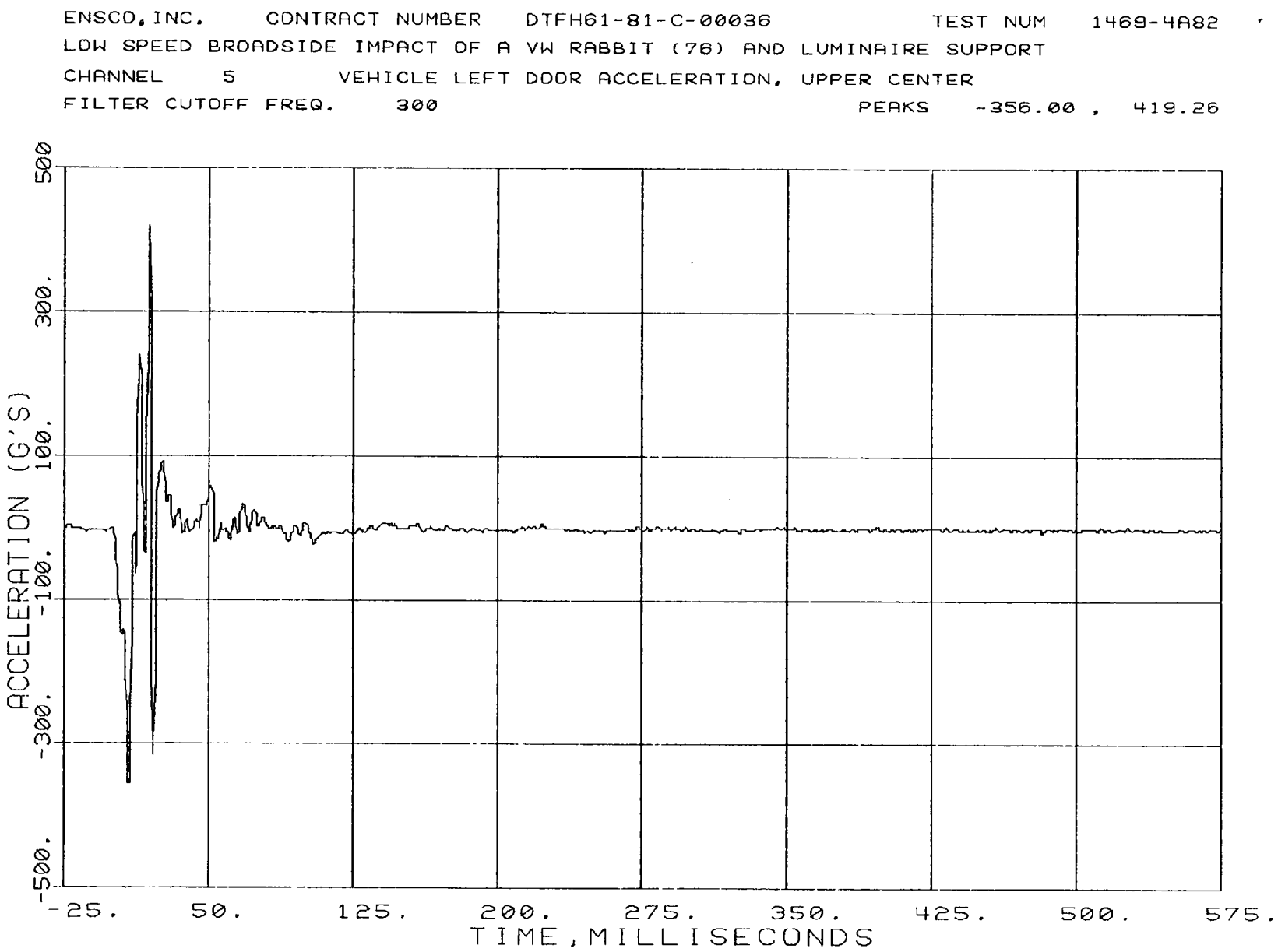


Figure 27. Vehicle Left Door Acceleration, Upper Center (SAE Class 180)

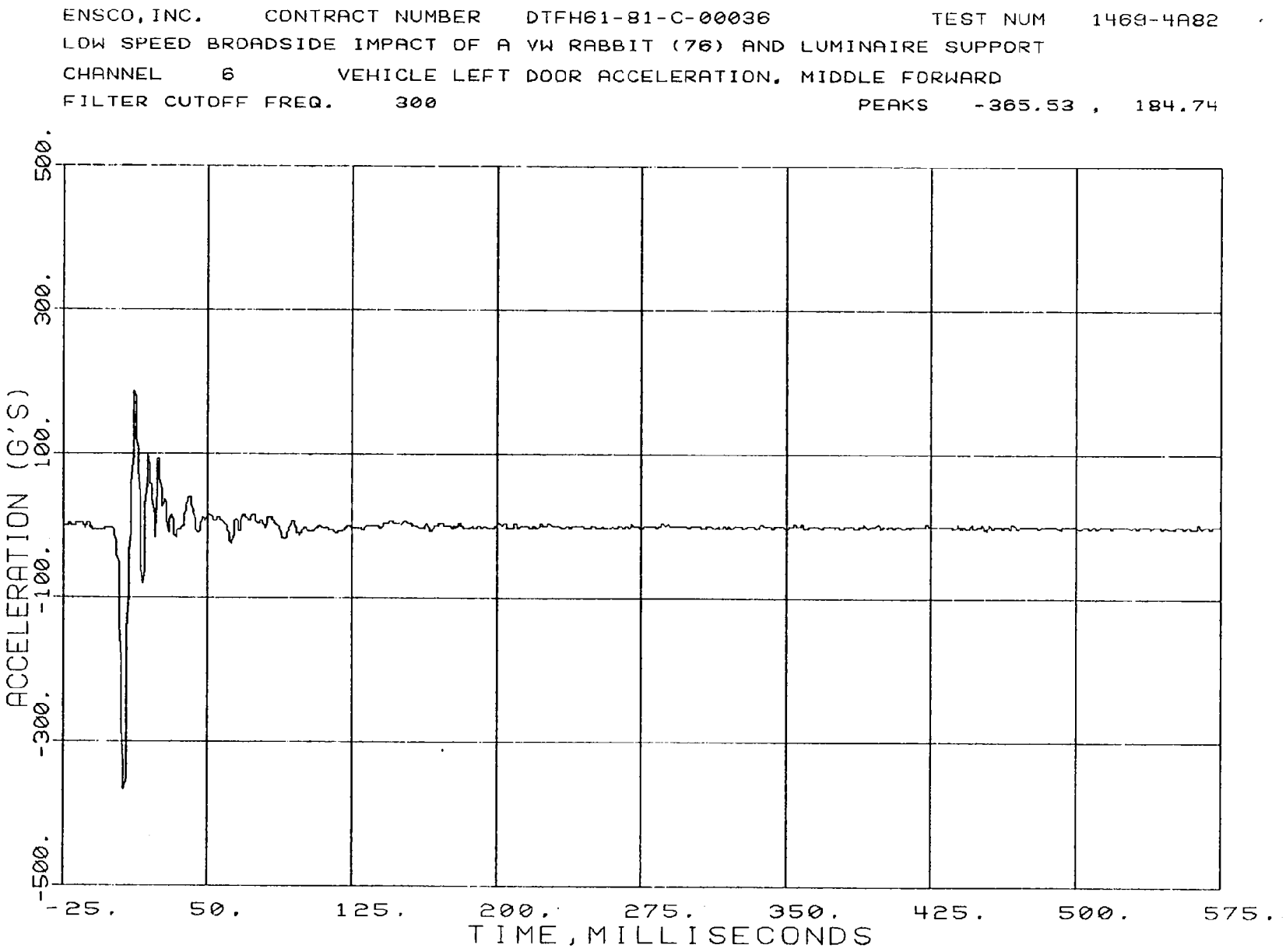


Figure 28. Vehicle Left Door Acceleration, Middle Forward (SAE Class 180)

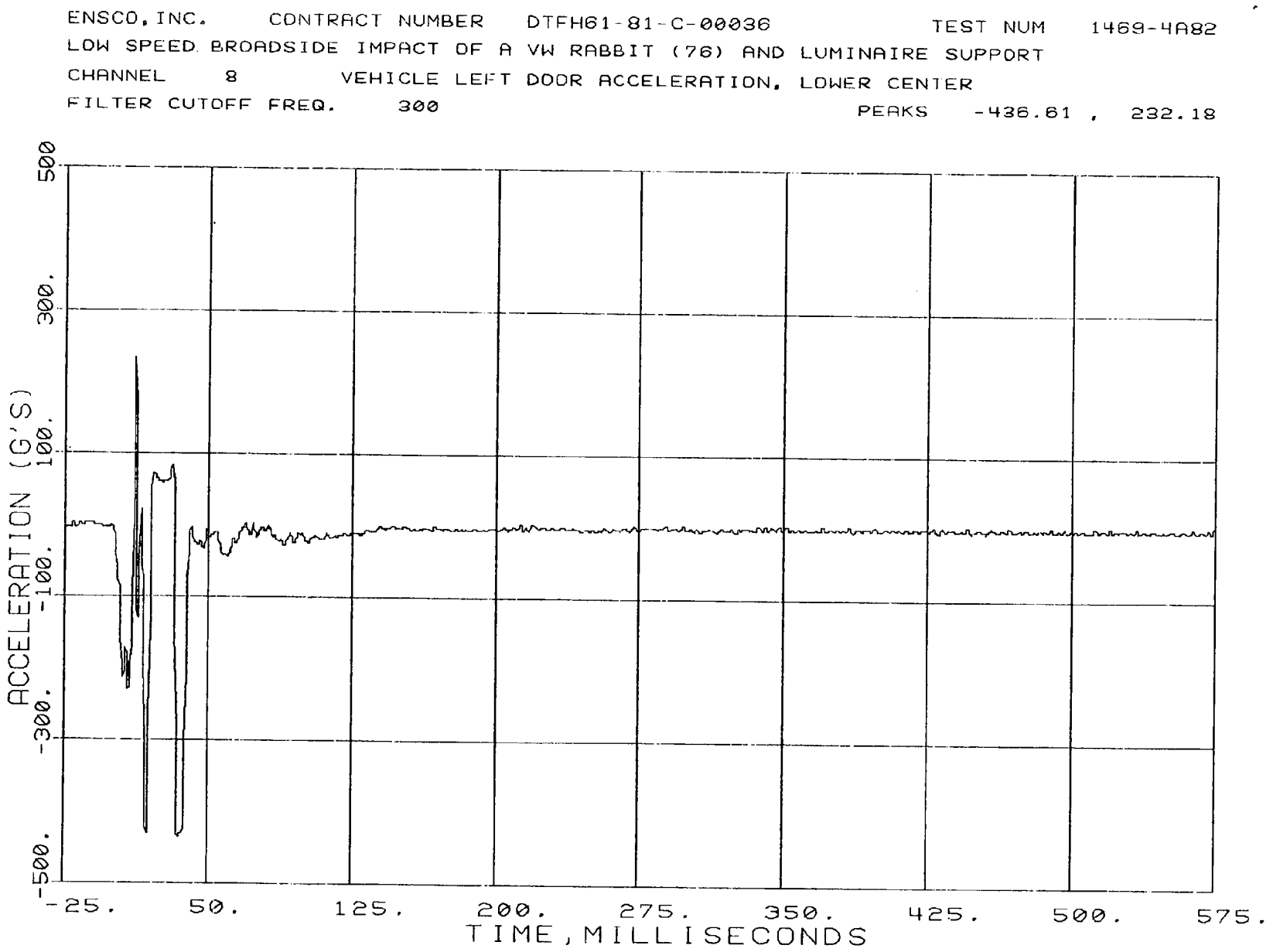


Figure 29. Vehicle Left Door Acceleration, Lower Center (SAE Class 180)

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

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

$$= \int_{0}^{t_1} F_c\,dt + \int_{t_1}^{t_3} F_b\,dt + \int_{t_1}^{t_3} (F_c - F_b)\,dt$$

$$= \int_{0}^{t_1} F_c\,dt + \int_{t_1}^{t_2} F_b\,dt + \int_{t_1}^{t_3} (F_c - F_b)\,dt$$

$$= I_1 + I_2 + I_3$$

where the terms in the above equation are given in Figure 30.

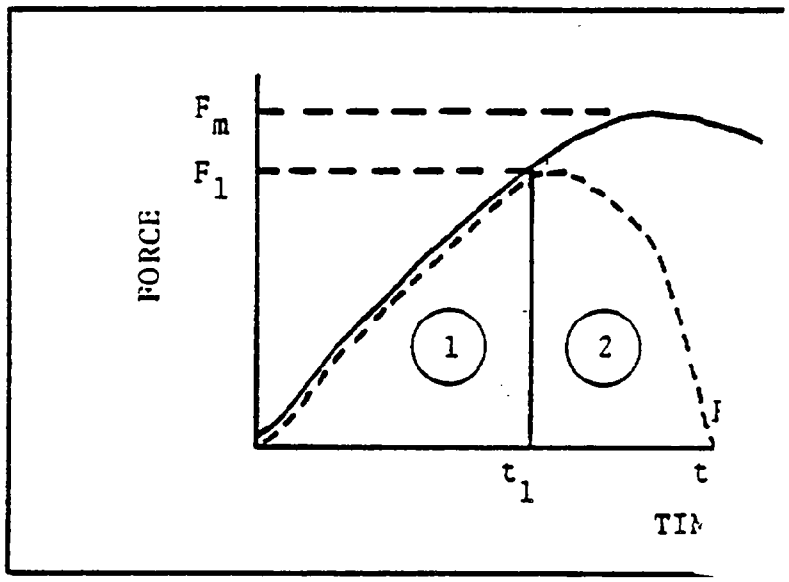


Figure 30. Graphic Representation of Three Phase Analysis of Momentum Change Occurring During the Impact of a Vehicle with a Breakaway Support

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 = mass moment of inertia of the luminaire support,

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

From the film data $\dot{x}_{cg}$ = 14.2 f/s (4.33 m/s) and $\dot{\theta}$ = 2.15 rad/sec. Using these two numbers the momentum change occurring during Phase 3 is given by

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

= 182 lb-sec (808 N-s)

or

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

= 131 lb-sec (583 N-s).

The average momentum change associated with the third phase of the vehicle momentum change is 452 lb-sec (2010 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.

TABLE 13

EXAMINATION OF THE MOMENTUM TRANSFER DURING THE COLLISION EVENT

		Class 60 (lb-sec)	Class 180 (lb-sec)
I_T	=	792[a]	792[b]
I_3	=	-452[c]	-452[c]
$I_{1\&2}$	=	340	340
I_2	=	- 64	- 64
I_1		276	276
I_1	=	235[d]	225[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.

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 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 31 through 34. 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 severe but within the design limits specified in FMVSS 208 and by reference those specified in NCHRP 230.

TABLE 14
HEAD INJURY CRITERIA EVALUATED FOR FULL SCALE CRASH TEST 1469-4A82

	Driver
HIC	780
t(Start)	44.250 ms
t(Stop)	45.875 ms
t(Duration)	1.625 ms

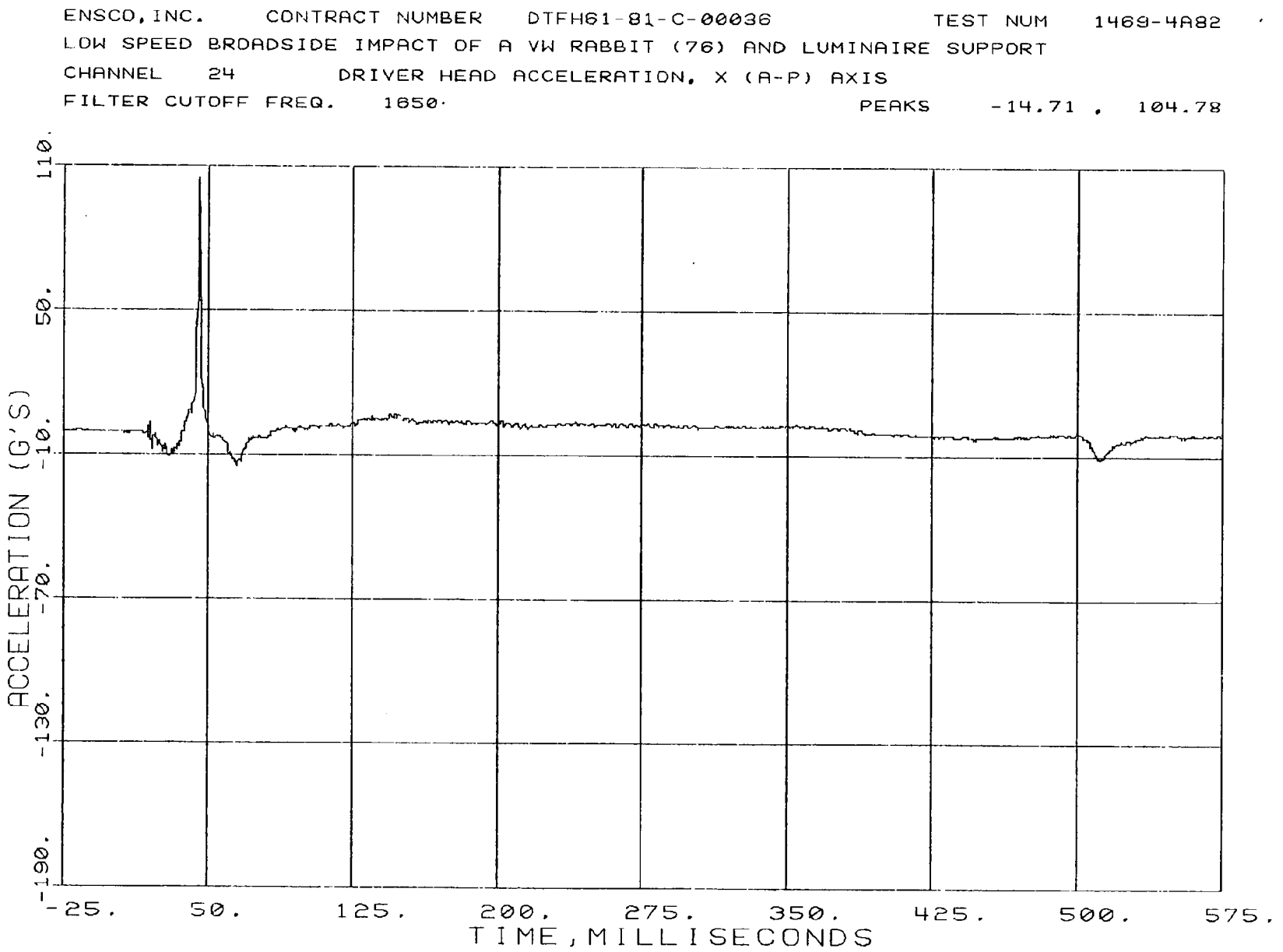


Figure 31. Driver Head Acceleration, X Axis (SAE Class 1000)

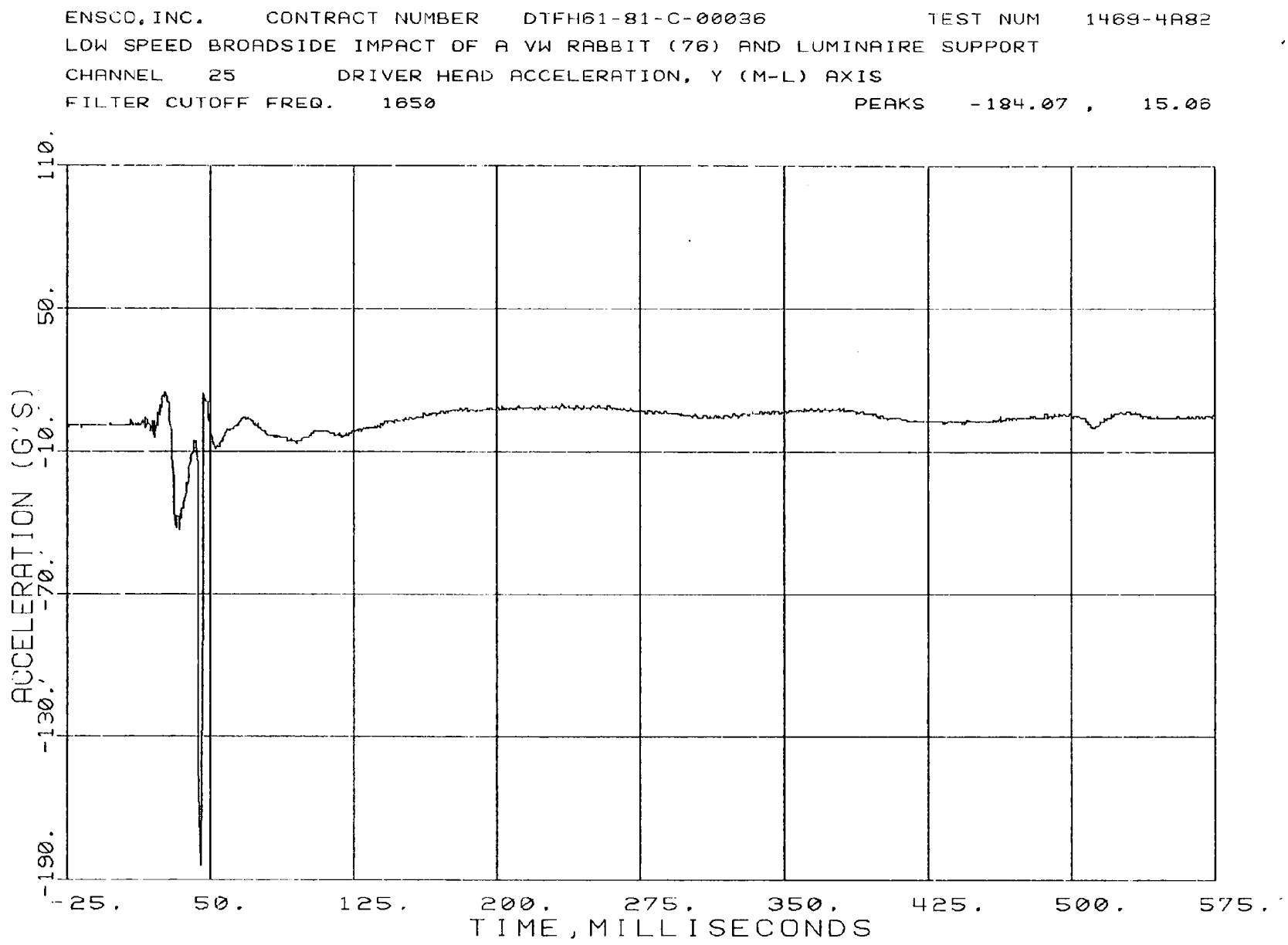


Figure 32. Driver Head Acceleration, Y Axis (SAE Class 1000)

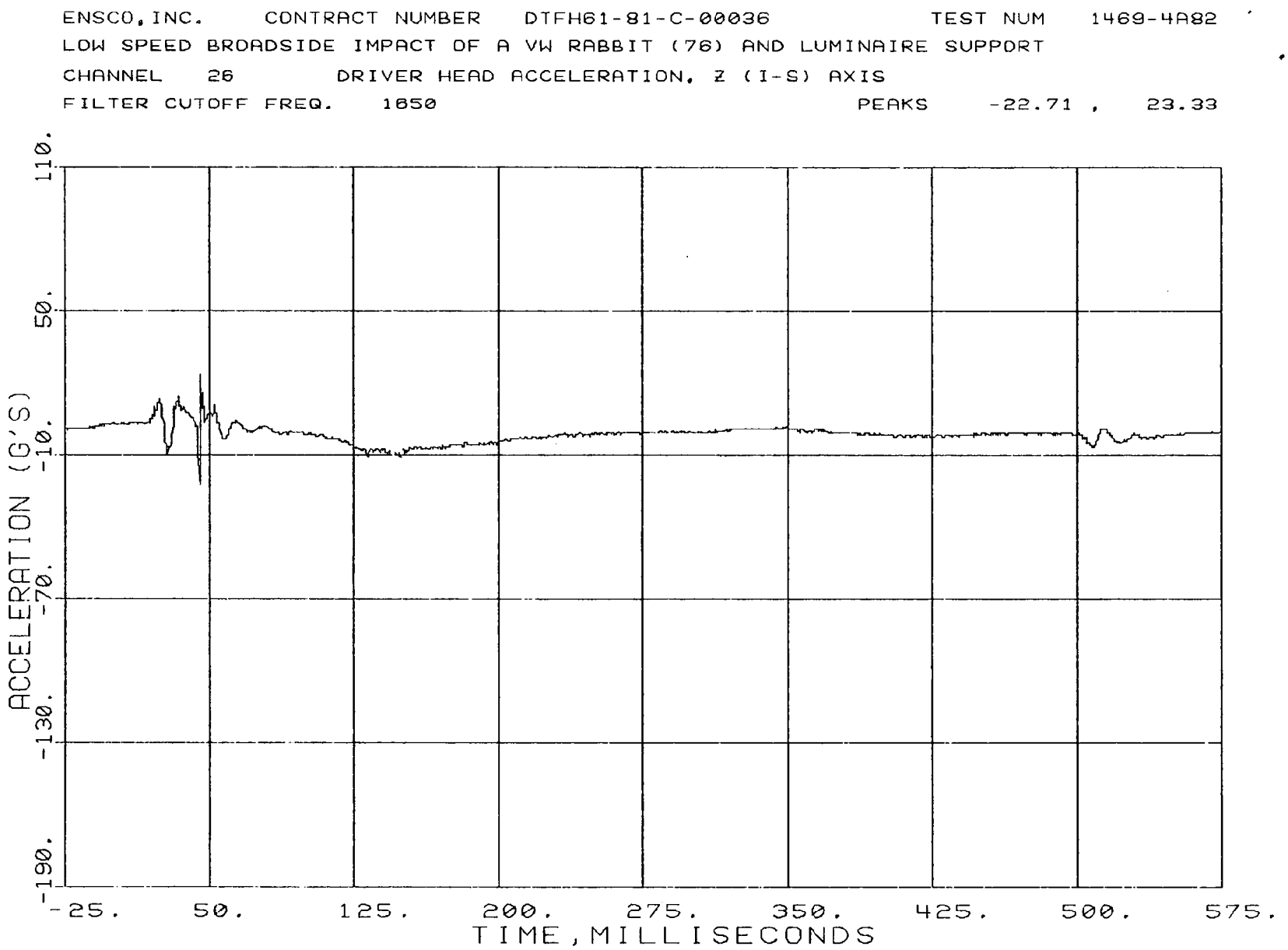


Figure 33. Driver Head Acceleration, Z Axis (SAE Class 1000)

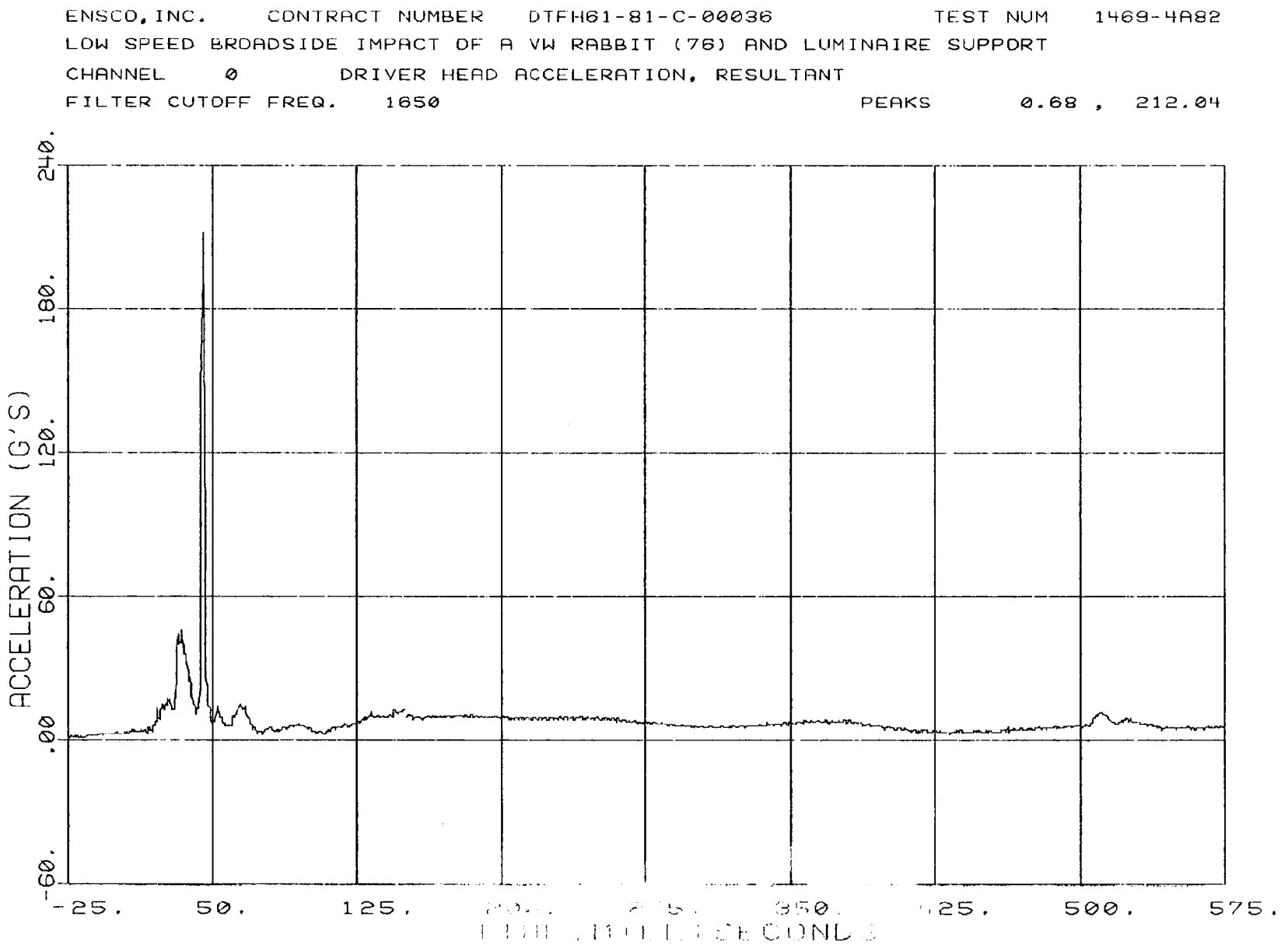


Figure 34. Driver Head Acceleration, Resultant (SAE Class 1000)

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 thechniques are presented in Figures 35 through 38 for the upper spine location, Figures 39 through 42 for the lower spine location and Figures 43 through 46 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 upper thorax location. These resultants are presented for relative comparison purposes only.

TABLE 15

SEVERITY INDEX AND MAXIMUM SUSTAINED RESULTANT ACCELERATION EVALUATION

Location	SI	a_{max} (Dur $\geq$ 3 ms)	$t(a_{max})$
Spine, Upper	404	74.13g	35.75 ms
Spine, Lower	1108	152.74g	24.50 ms
Pelvis	916	124.90g	21.50 ms

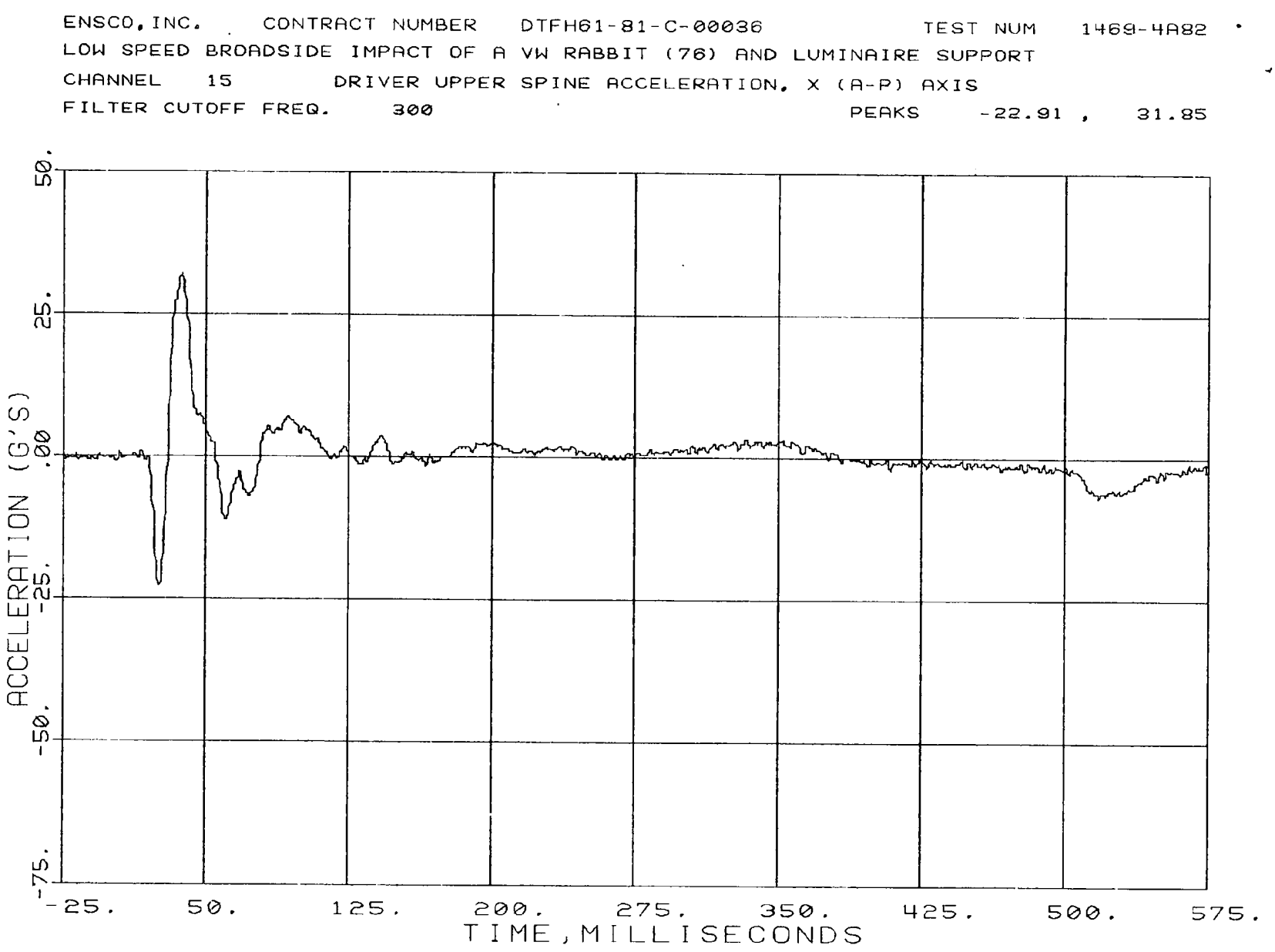


Figure 35. Driver Upper Spine Acceleration, X (A-P) Axis (SAE Class 180)

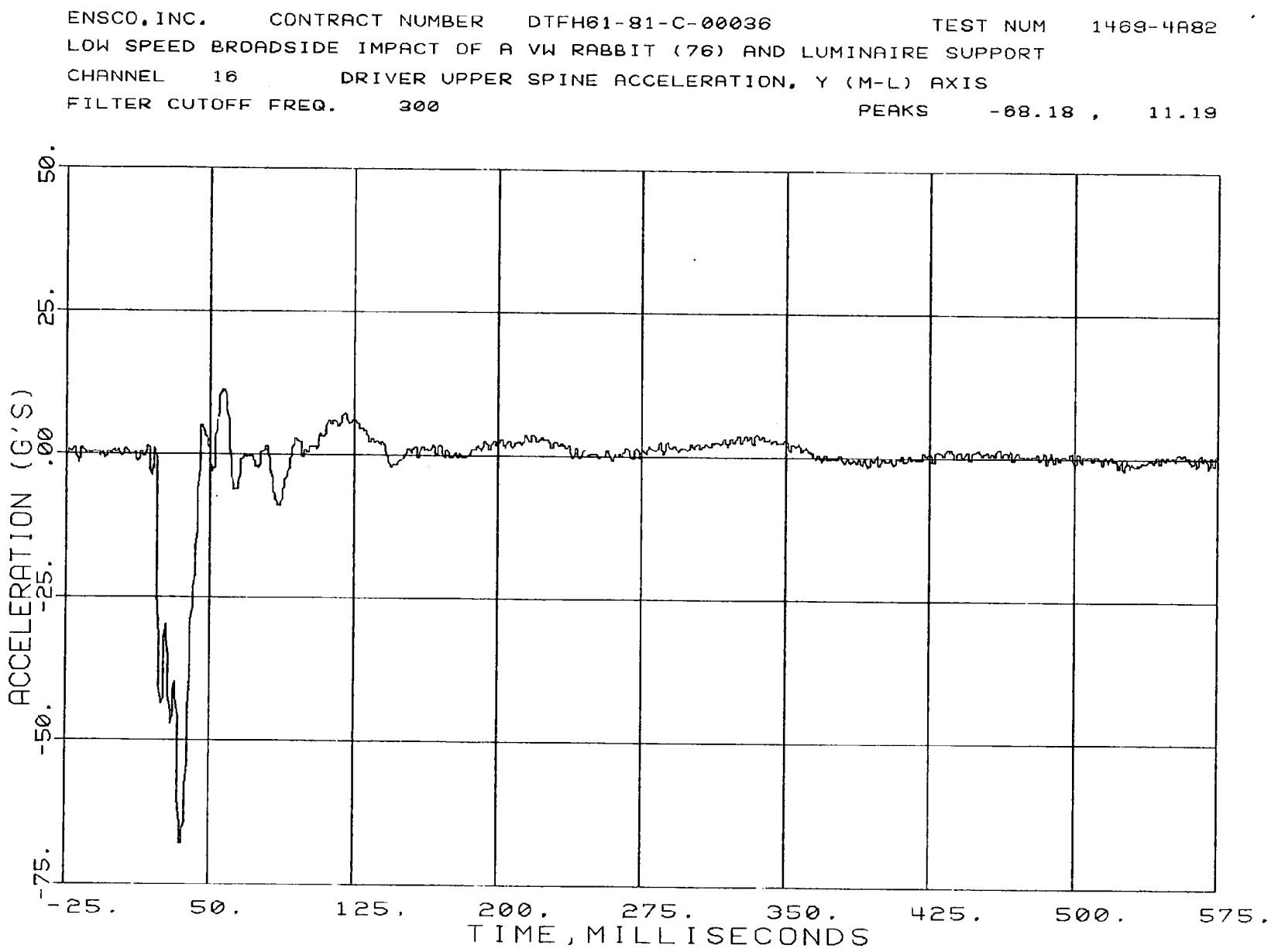


Figure 36. Driver Upper Spine Acceleration, Y (M-L) Axis (SAE Class 180)

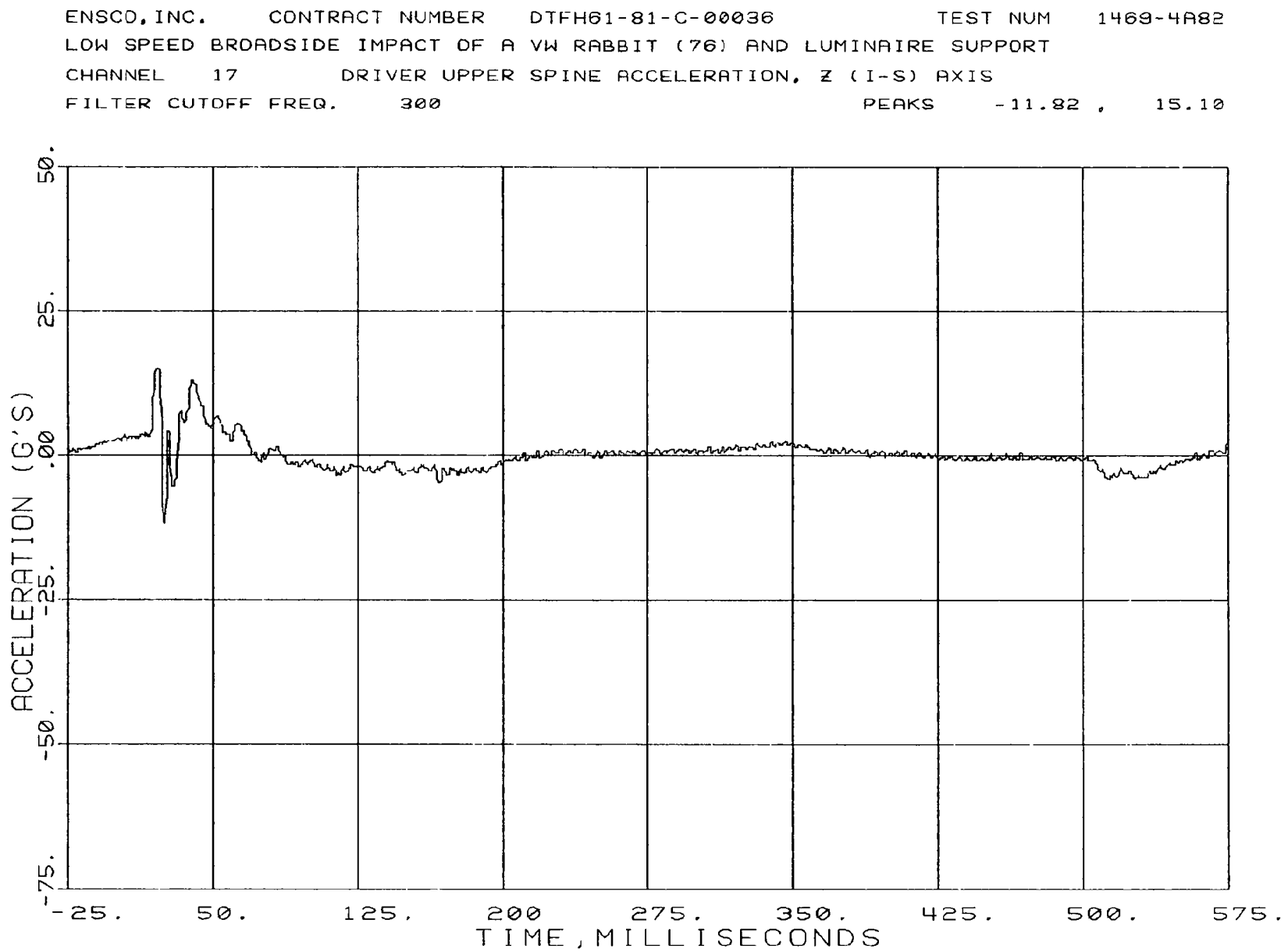


Figure 37. Driver Upper Spine Acceleration, Z (I-S) Axis (SAE Class 180)

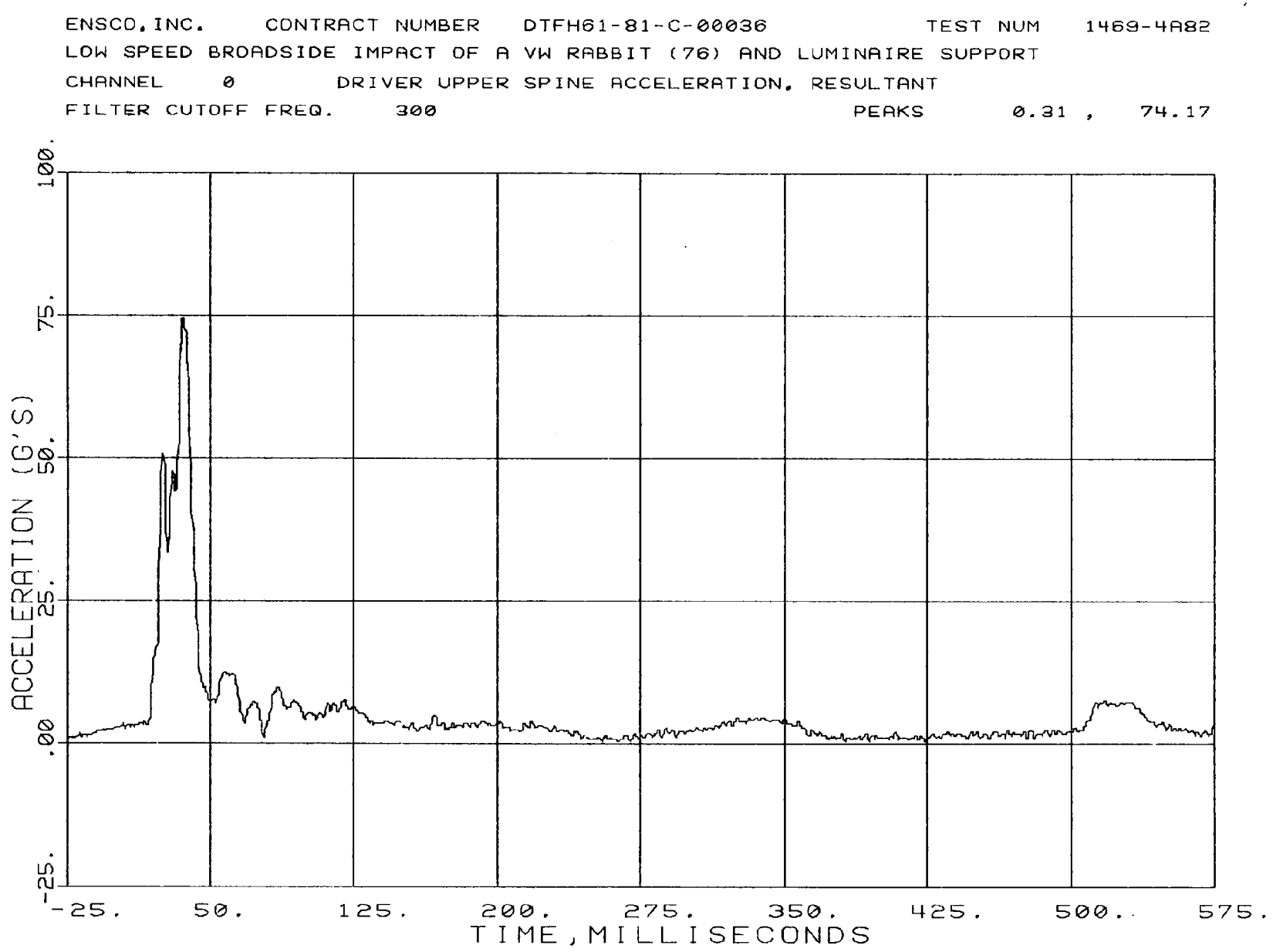


Figure 38. Driver Upper Spine Acceleration, Resultant (SAE Class 180)

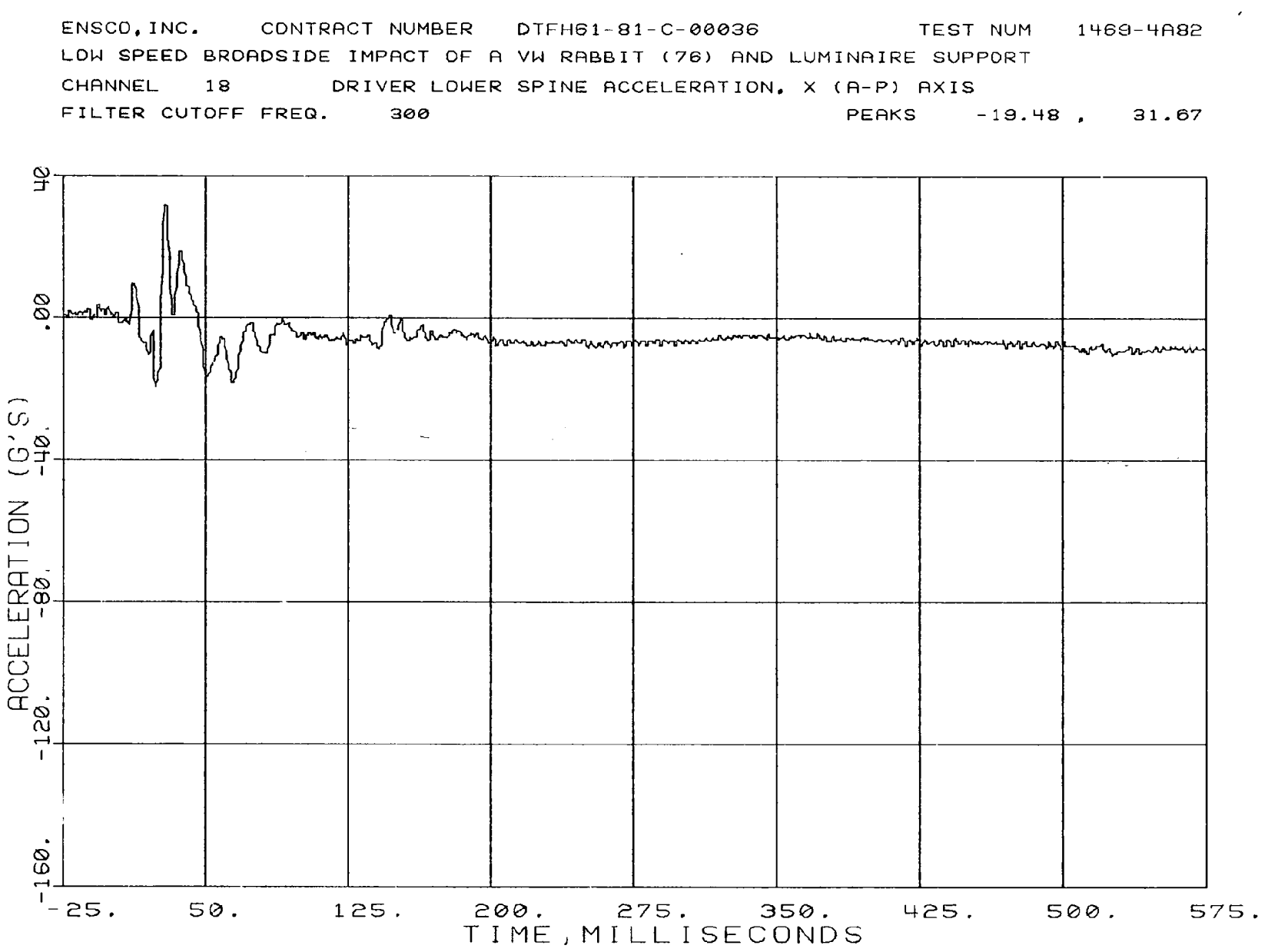


Figure 39. Driver Lower Spine Acceleration, X (A-P) Axis (SAE Class 180)

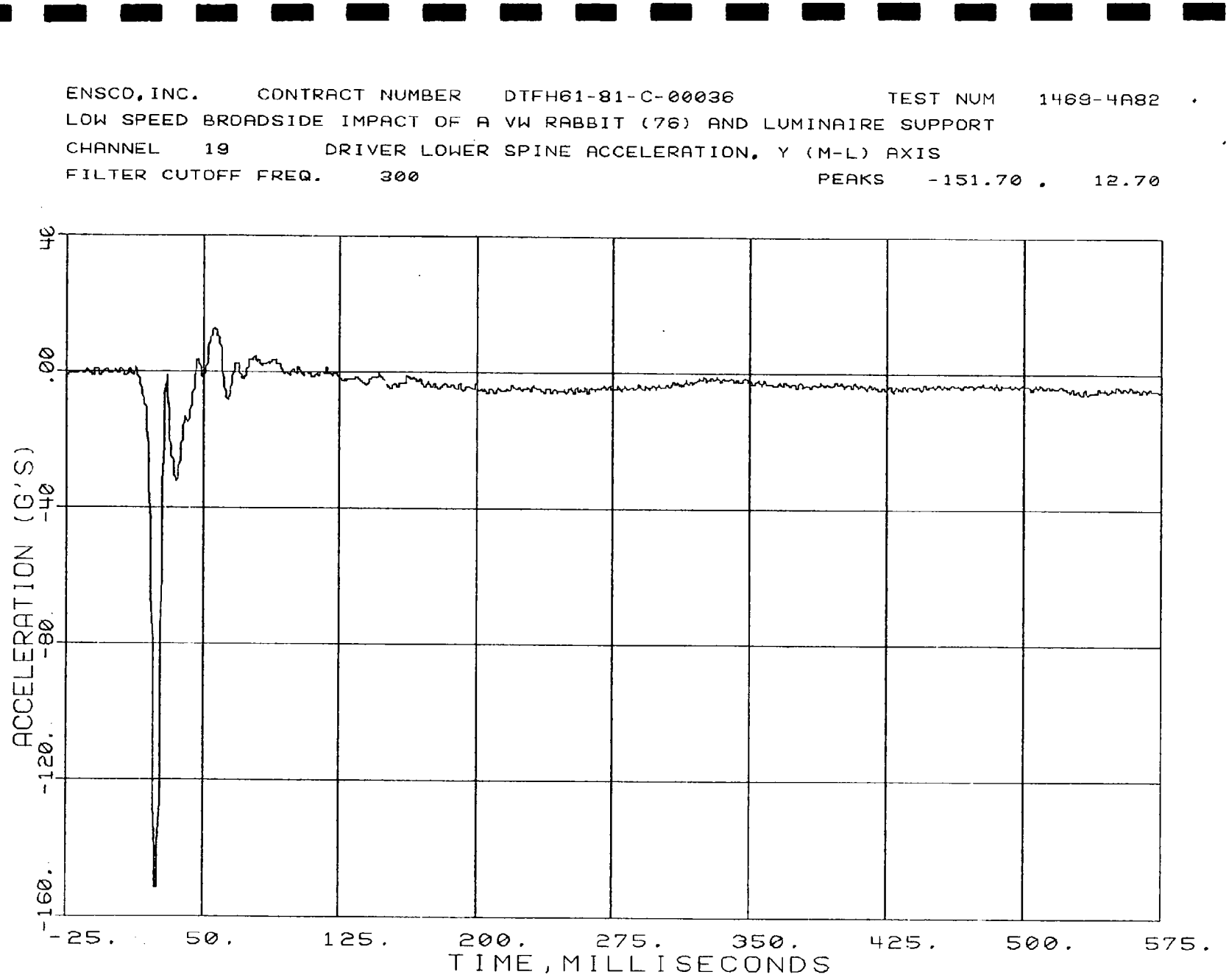


Figure 40. Driver Lower Spine Acceleration, Y (M-L) (Axis) (SAE Class 180)

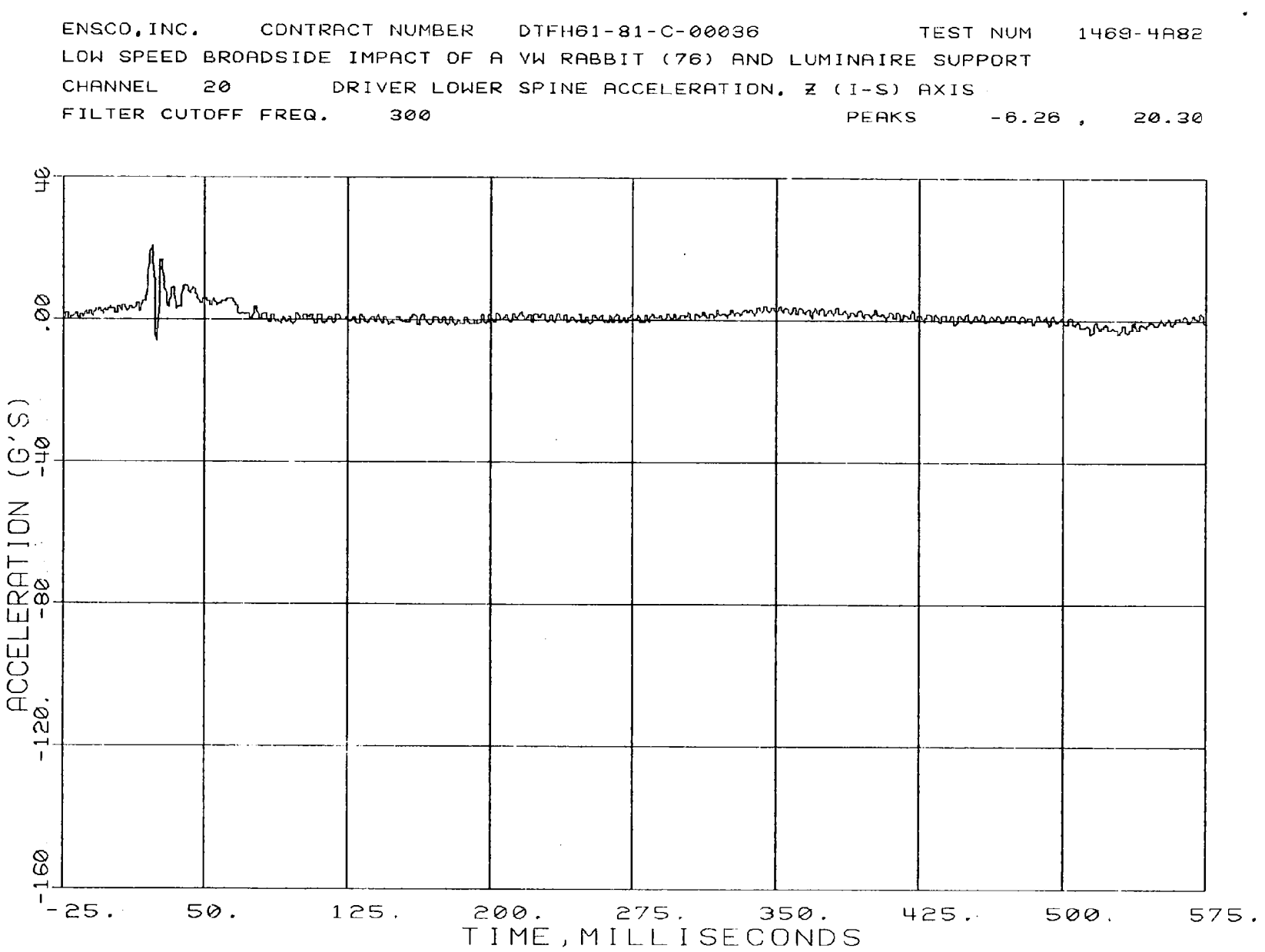


Figure 41. Driver Lower Spine Acceleration, Z (I-S) (Axis) (SAE Class 180)

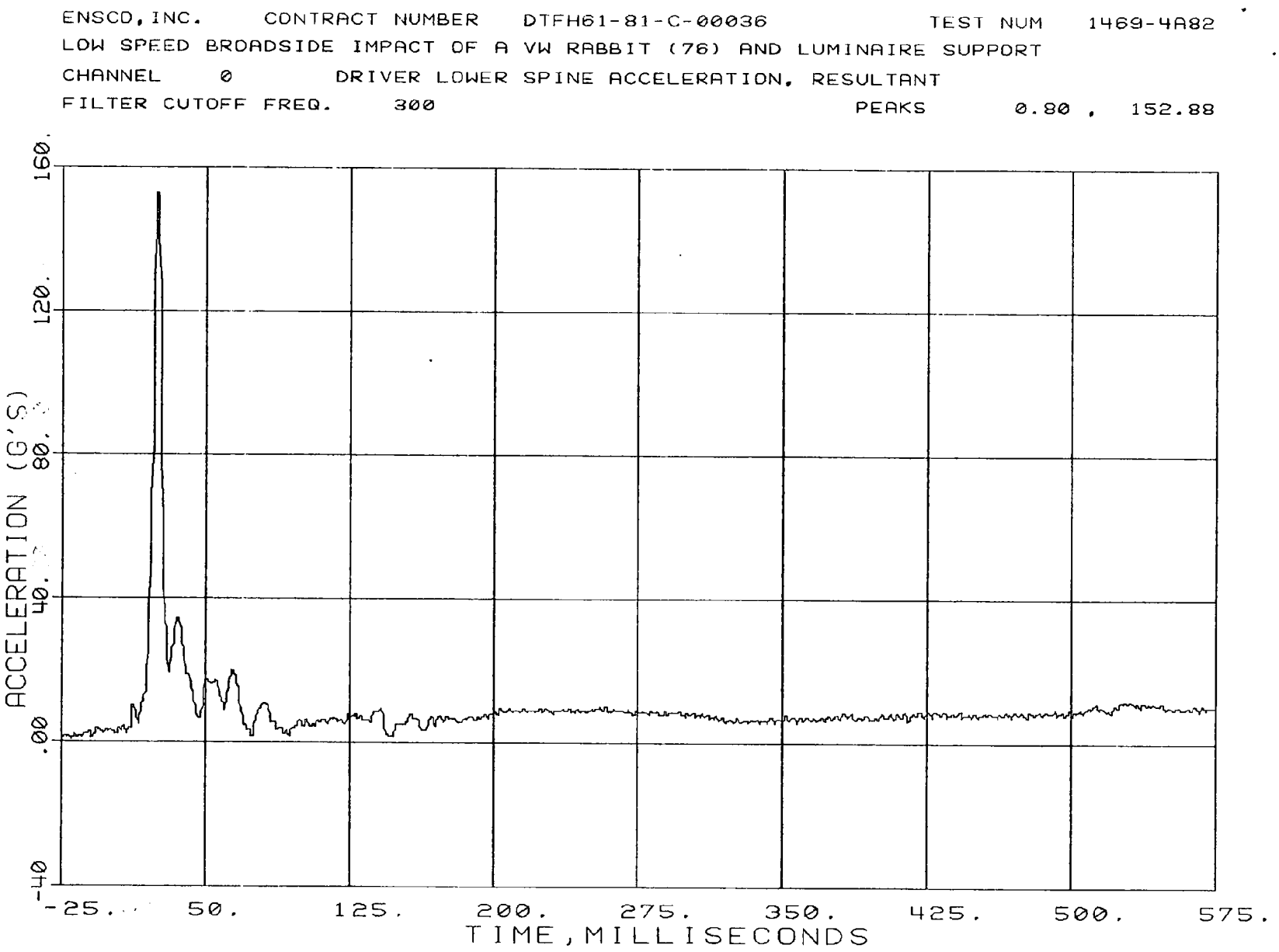


Figure 42. Driver Lower Spine Acceleration, Resultant (SAE Class 180)

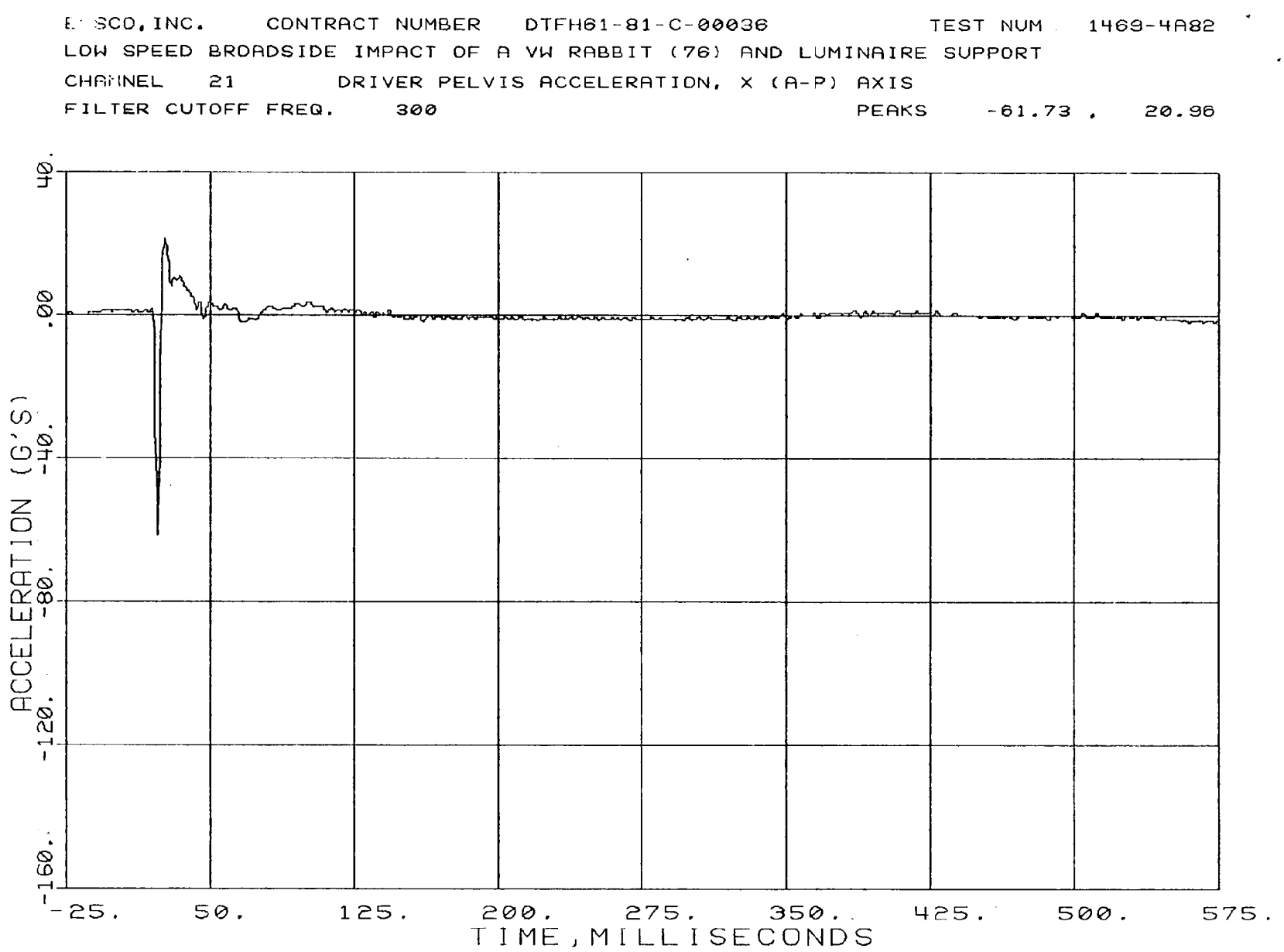


Figure 43. Driver Pelvis Acceleration, X (A-P) Axis (SAE Class 180)

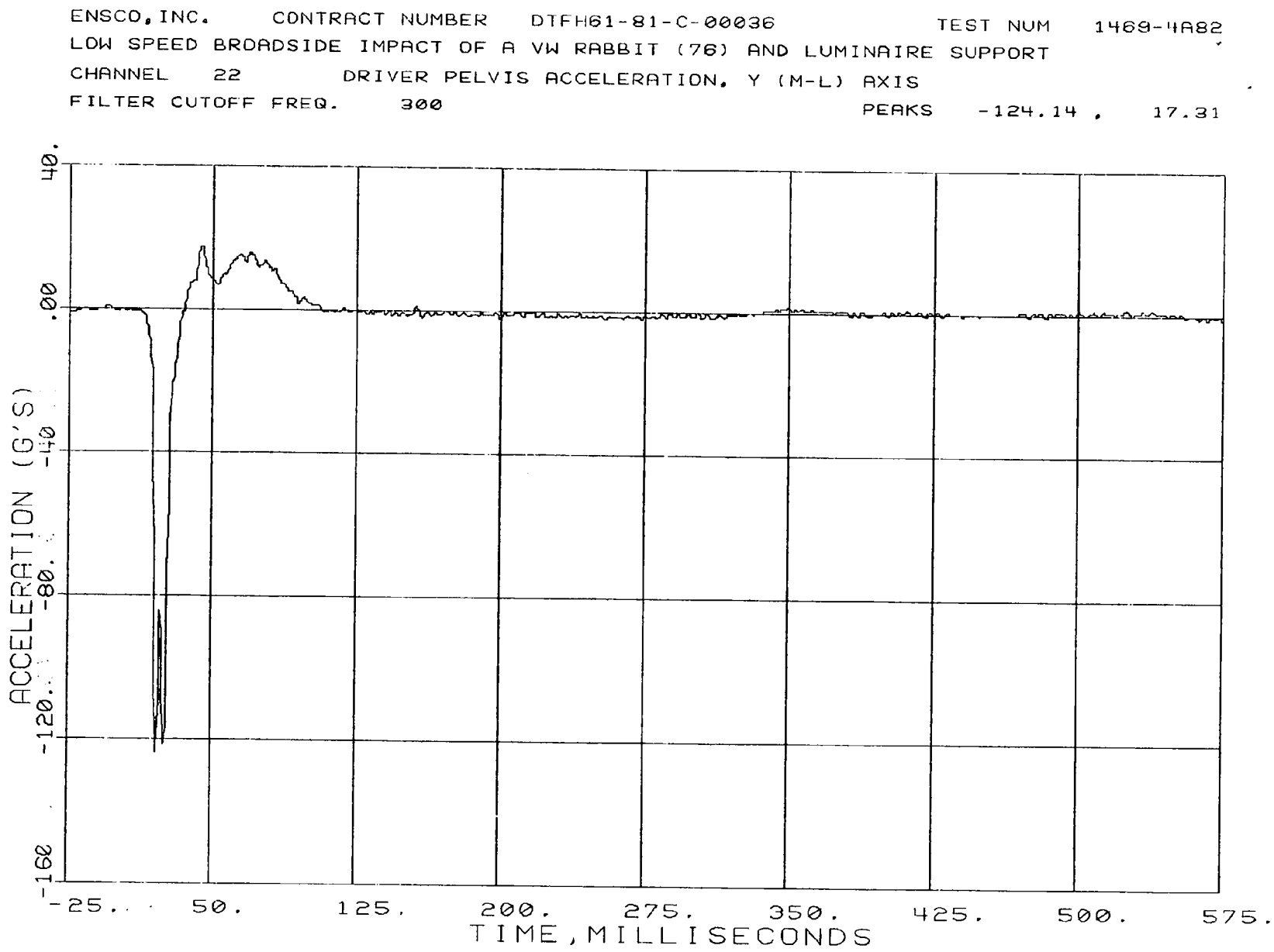


Figure 44. Driver Pelvis Acceleration, Y (M-L) Axis (SAE Class 180)

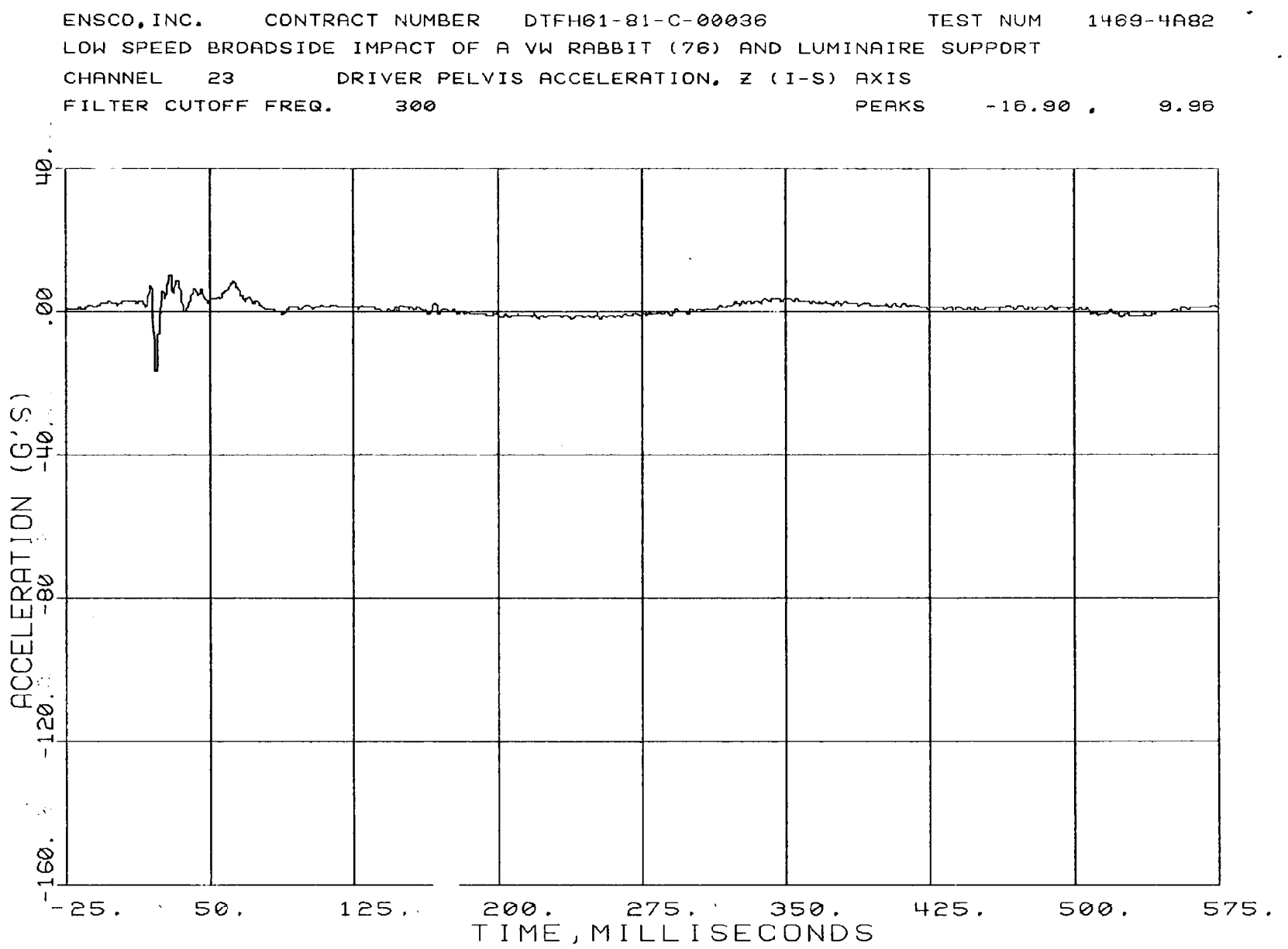


Figure 45. Driver Pelvis Acceleration, Z (I-S) Axis (SAE Class 180)

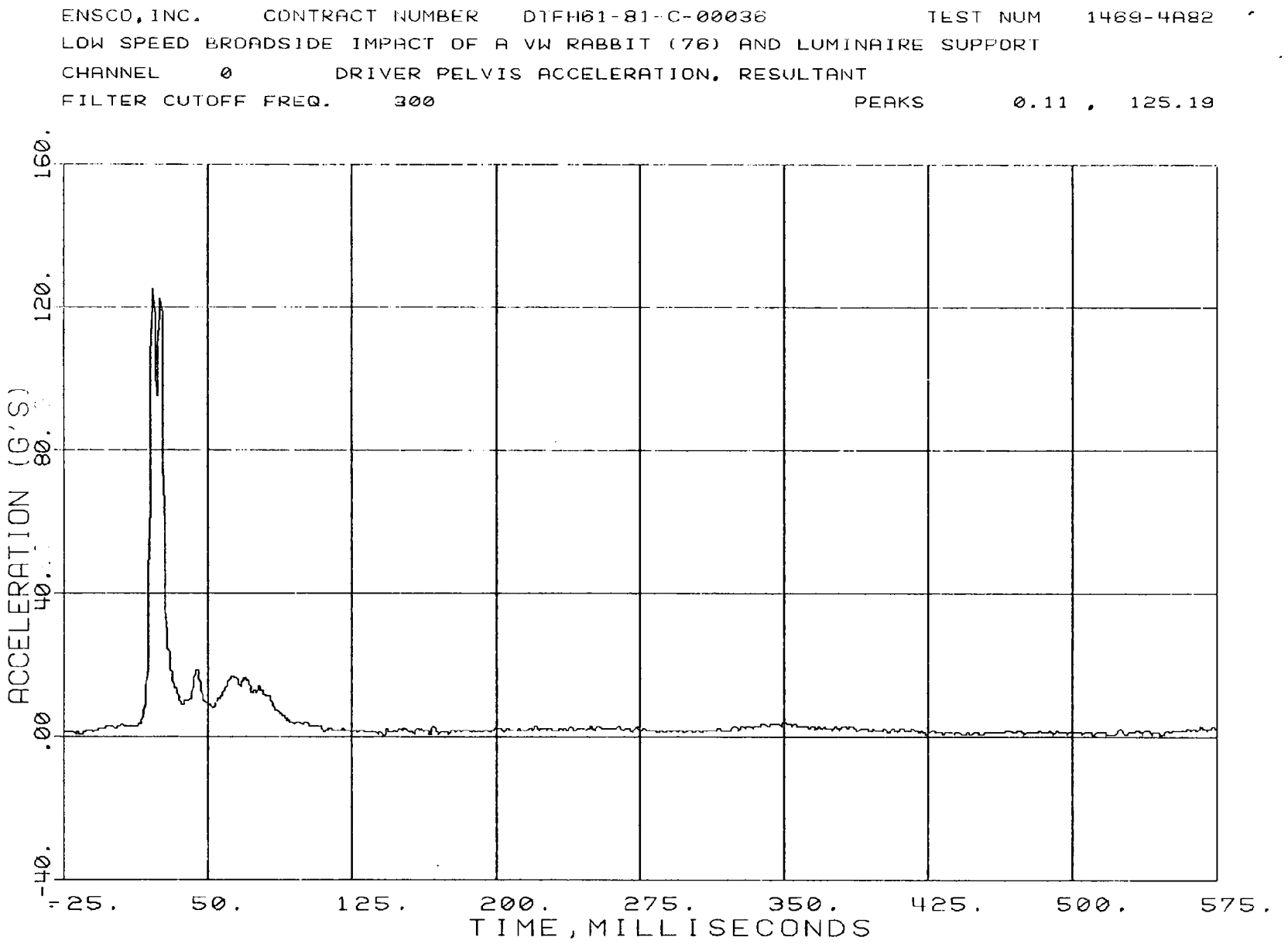


Figure 46. Driver Pelvis Acceleration, Resultant (SAE Class 180)

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 47 through 52. 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

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

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.

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 4.02 and 3.88, respectively.

TABLE 16

THORACIC INJURY PARAMETER EVAUATION

	Q	V1050	V1090	RVS	B
L, Upper Rib	27.17 ft/sec	2.500ms	4.375ms	1.75	7.29
L, Lower Rib	20.44 ft/sec	1.875ms	3.750ms	2.00	7.04
Spine, Upper (Y Axis)	28.19 ft/sec	8.125ms	14.375ms	1.77	6.73
Spine, Lower (Y Axis)	26.73 ft/sec	3.125ms	6.250ms	2.00	7.17

1 ft = .3048 m

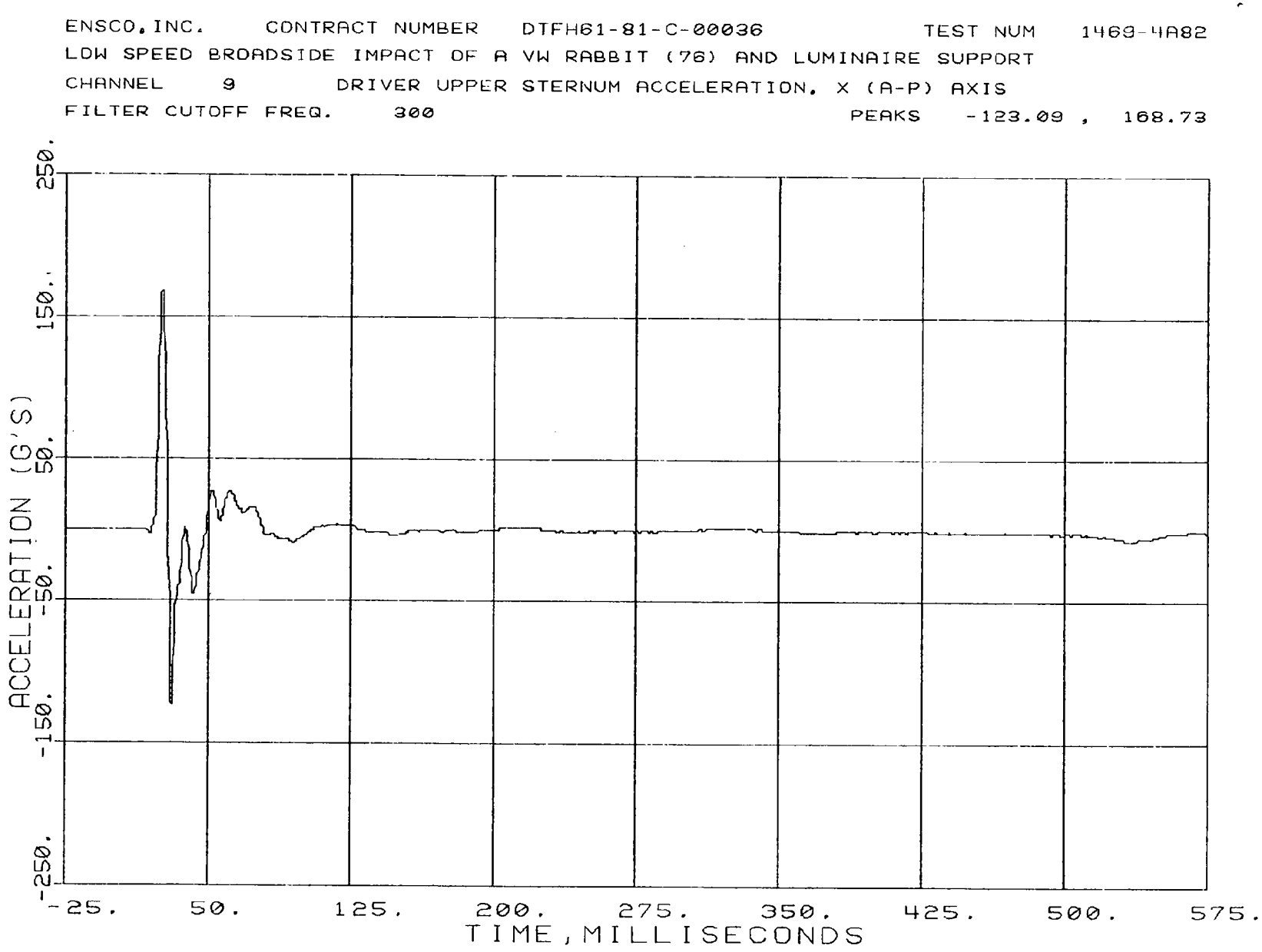


Figure 47. Driver Upper Sternum Acceleration, X (A-P) Axis (SAE Class 180)

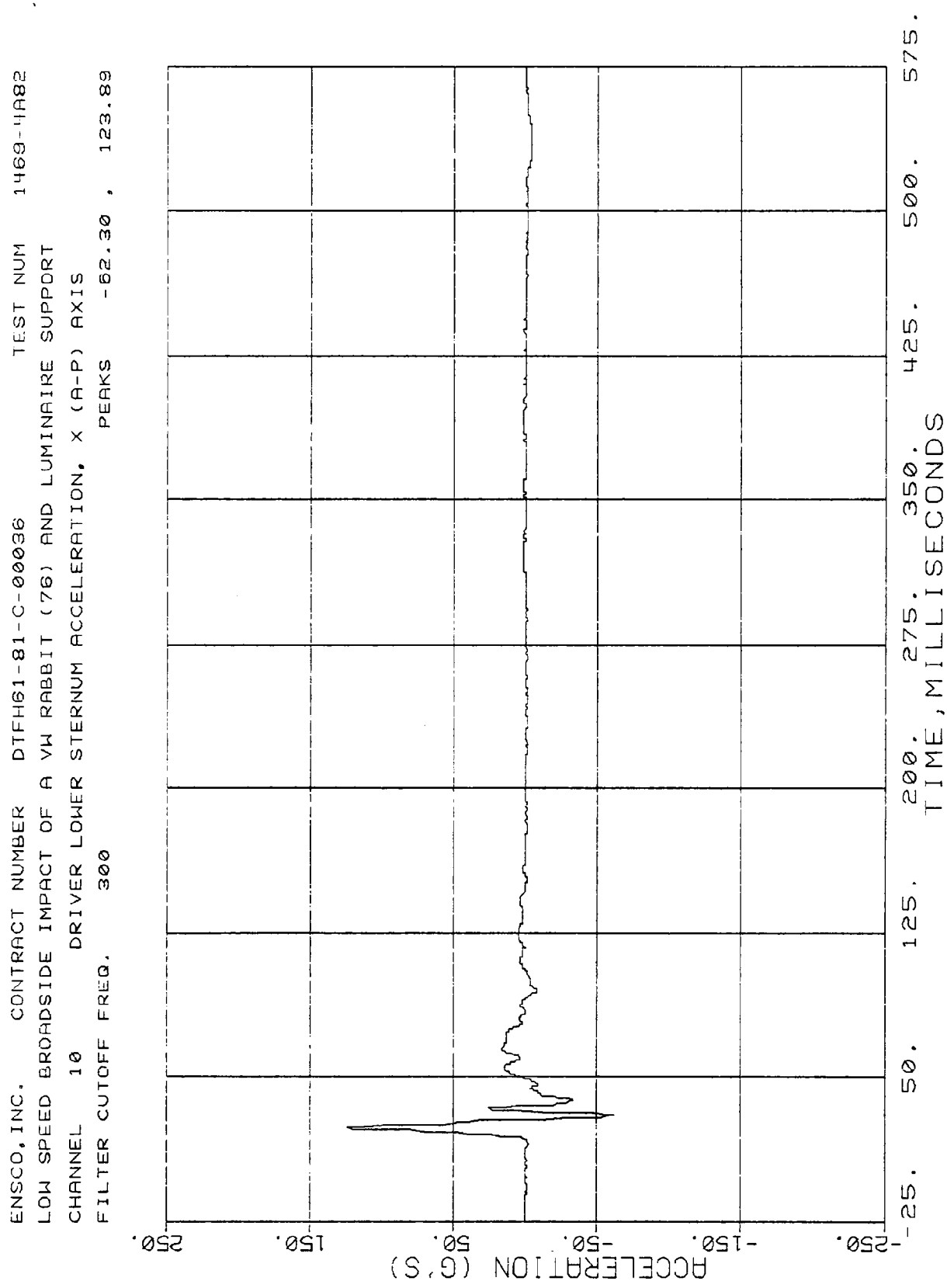


Figure 48. Driver Lower Sternum Acceleration, X (A-P) Axis (SAE Class 180)

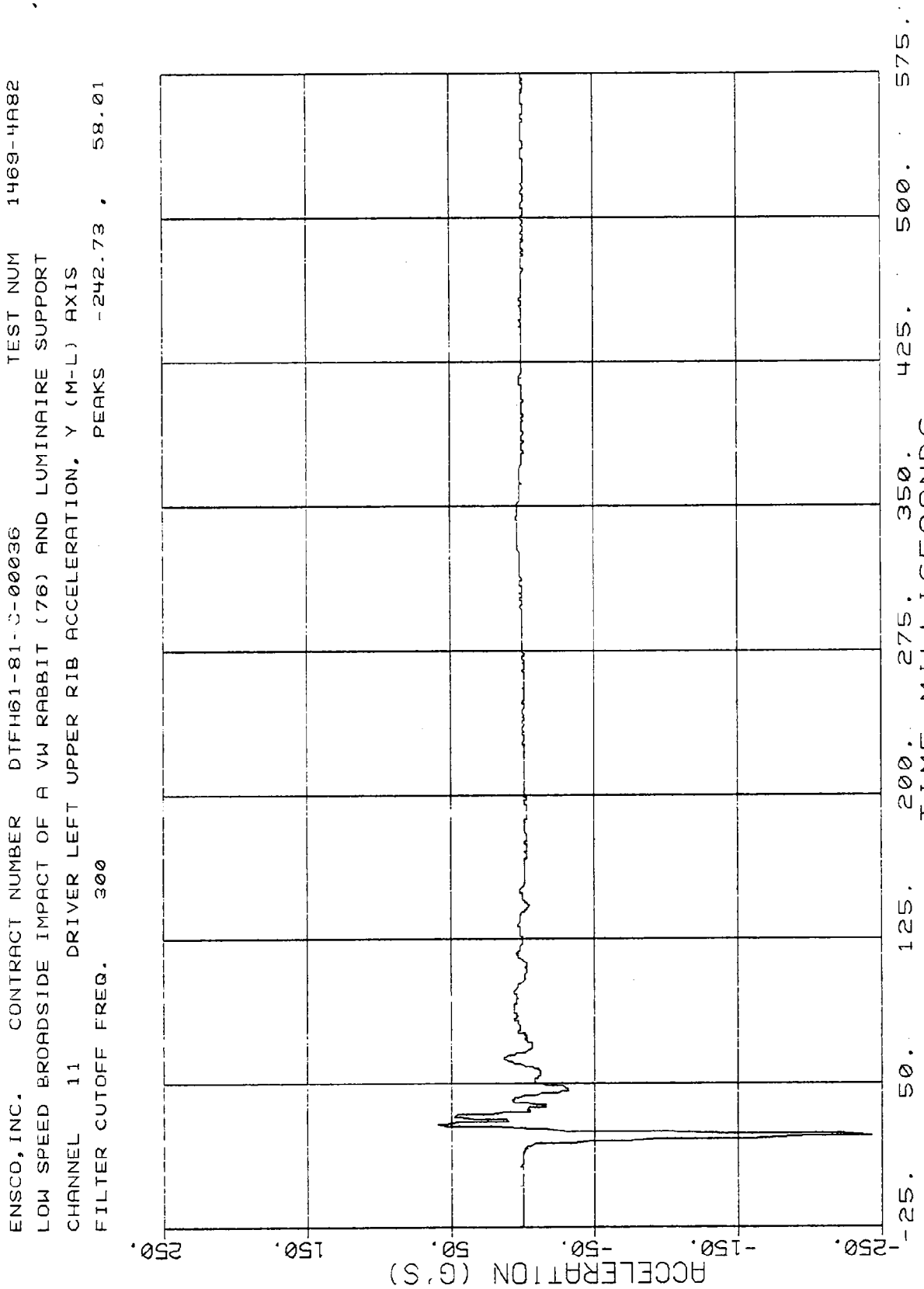


Figure 49. Driver Left Upper Rib Acceleration, Y (M-L) Axis (SAE Class 180)

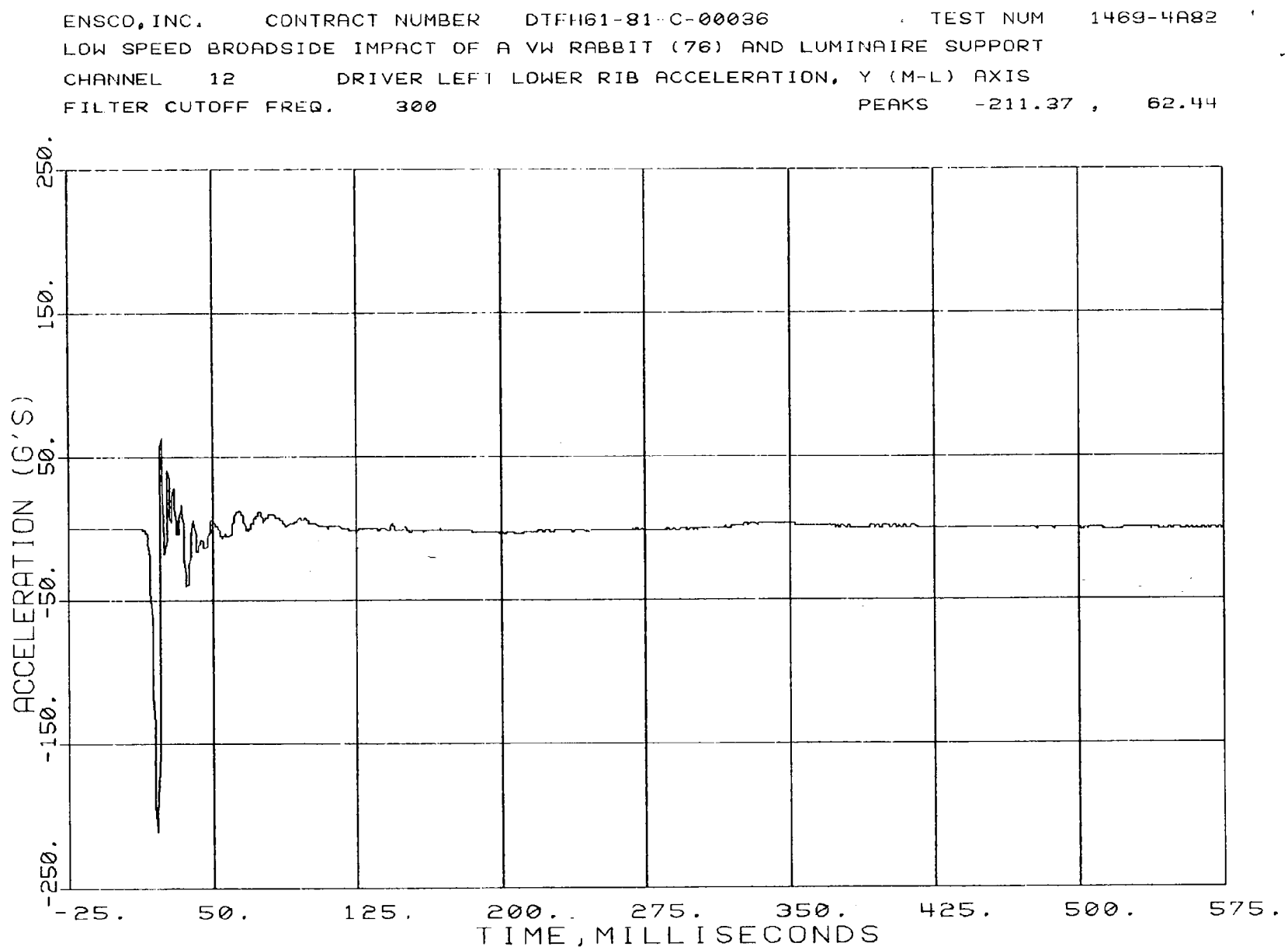


Figure 50. Driver Left Lower Rib Acceleration, Y (M-L) Axis (SAE Class 180)

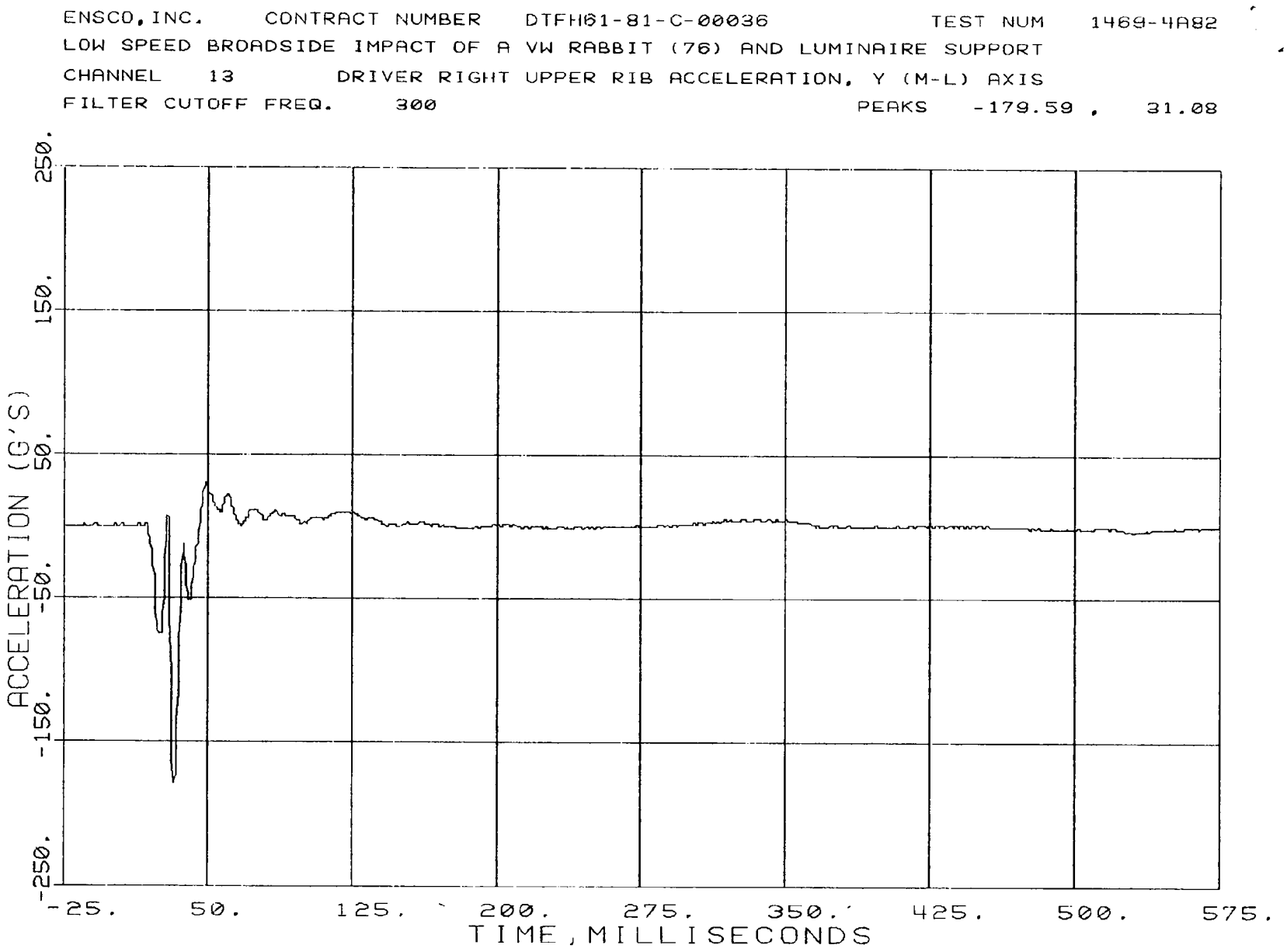


Figure 51. Driver Right Upper Rib Acceleration, Y (M-L) Axis (SAE Class 180)

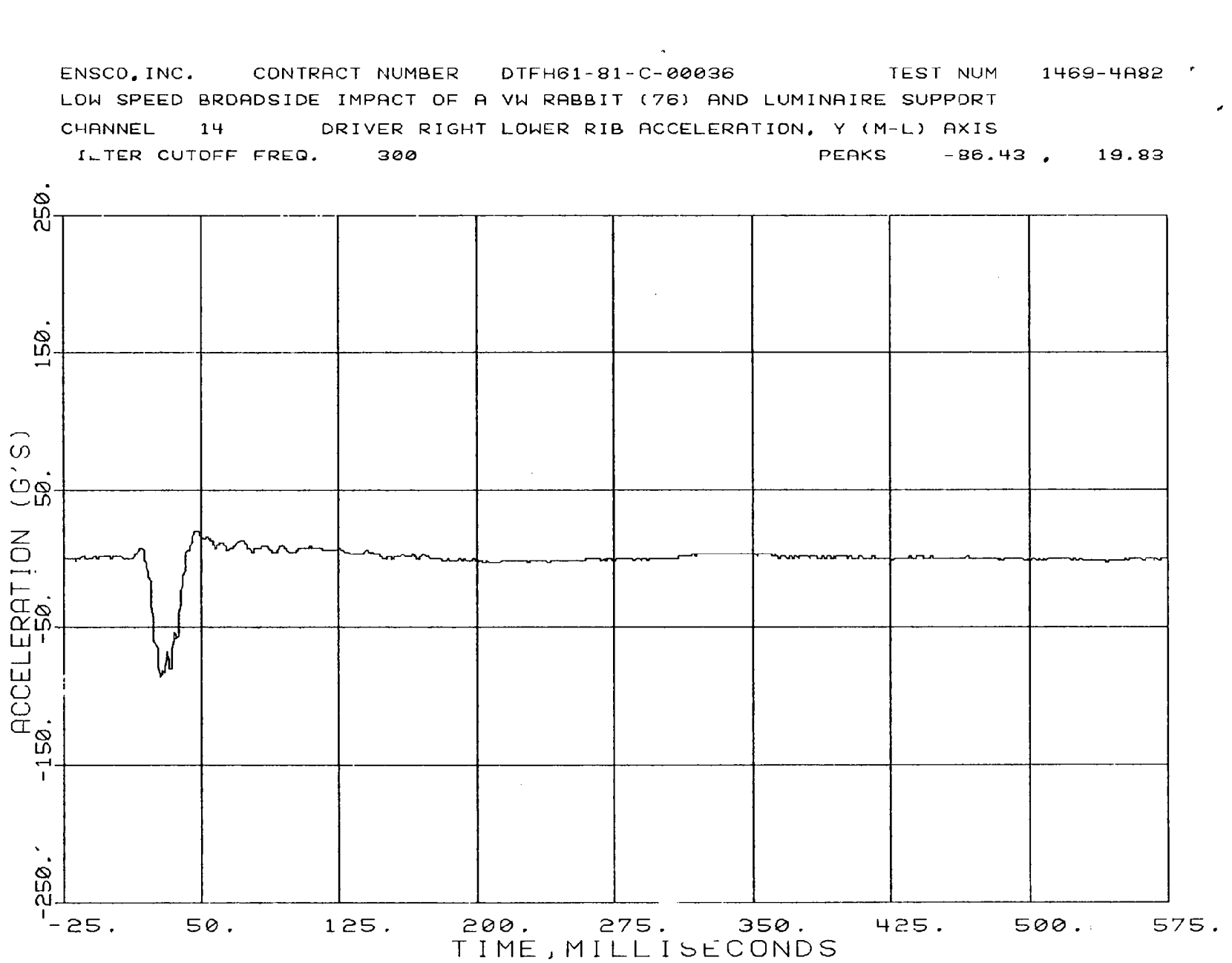


Figure 52. Driver Right Lower Rib Acceleration, Y (M-L) Axis (SAE Class 180)

8.0 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, 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.

18. Prediction of Theracic Injuries as a Function of Occupant Kinematics", Robbins, D. H., Lehman, R. J., Augustyn, K., Proceedings of the 7th International Technical Conference in Experimental Safety Vehicles, Paris, France, June 5-8, 1979, pp. 374-383.

19. "Development of a Promising Universal Thoracic Trauma Prediction Methodology," Eppinger, R. H., Augustyn K., and Robbins, D. H., Proc. 22nd Strapp Car Crash Conference, Society of Automotive Engineers, Warrendale, PA, 1978, pp. 211-268.