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SHOCK ENVIRONMENTS FOR LARGE SHIPPING CONTAINERS DURING RAIL COUPLING OPERATIONS

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ABSTRACT

Sandia National Laboratories participated in a study to define the shock environments to which large, fissile material shipping containers may be exposed during rail-coupling operations. Tests were conducted using impact velocities up to 17.98 km/h (11.17 mph). The cargo on the rail cars consisted of a 36-tonne (40-ton) cask mounted on a skid or a 64-tonne (70-ton) cask. The rail cars were equipped with either standard draft gear, hydraulic end-of-car draft gear, or a sliding center sill cushion underframe. The maximum peak acceleration and its pulse duration were determined for the longitudinal, transverse, and vertical axes of the two casks.

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SUMMARY

This report defines the shock environments to which heavy shipping containers may be exposed during rail coupling operations if rail cars carrying containers are permitted to roll freely into other cars. The environments defined occur at the car/container interface.

The descriptions of the environments are based on data from a series of rail-coupling tests that were conducted at the Savannah River Plant (SRP) near Barnwell, SC. The tests were conducted with cargo weighing 36 tonne (40 tons) and 64 tonne (70 tons). The test cars were equipped with a standard draft gear, a 0.38 m (15 in.) hydraulic end-of-car device, or a 0.51-m (20-in.) sliding center sill coupling device. The impact velocity of the cars ranged from 4.44 km/h (2.76 mph) to 17.98 km/h (11.17 mph).

The shock data show the following simple half-sine input pulses that conservatively represent the maximum shock intensities:

Cargo Weight	Coupling Device	Axis	Peak Accel. (g)	Pulse Duration (ms)
36 tonne (40 tons)	Standard	Longitudinal	34	14
		Transverse	8	11
		Vertical	31	13
64 tonne (70 tons)	Standard	Longitudinal	21	20
		Transverse	8	8
		Vertical--3-35 Hz	17	50
		35-90 Hz	17	10
36 tonne (40 tons)	Hydraulic End-of-car	Longitudinal	30	23
		Transverse	4.4	8
		Vertical	20	14
36 tonne (40 tons)	Sliding Center Sill	Longitudinal	5.3	45
		Transverse	2.5	13
		Vertical	4.4	24

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Introduction

The packaging and transportation of fissile radioactive materials are regulated by the US Nuclear Regulatory Commission by means of the Code of Federal Regulations Title 10, Part 71. Appendix A of these regulations specifies the environmental conditions of transport to be applied to determine their effects on packages of radioactive material. However, the Appendix does not specify numerically the frequencies or amplitudes of vibration and shock environments, nor does it give their expected occurrence as a function of shipment time and/or mileage. As a result, when evaluating a package for licensing applications, assumptions regarding these environments must be made by each applicant.

To provide guidance in this area, the US Nuclear Regulatory Commission (NRC) contracted with Sandia National Laboratories (SNL) to gather and evaluate data regarding the truck and rail shock and vibration environments normally encountered when transporting large shipping containers. The project was divided into three tasks:

1. Extract, review, and reduce the shock and vibration environment definitions currently on file in both the DOE/DOD and DOE Transportation Data Banks. Determine the best, simply stated estimates of environments for large shipping containers on trucks and railroad cars.

2. Conduct dynamic analyses of the shock environment experienced by cargo during rail switching and coupling to identify the dependence of the shock environment on heavy cargo weights and on shock attenuation couplers. Use the results to refine further the shock load description. Existing mathematical models of freight cars were altered in order to study these specific concerns.

3. Identify, during the performance of Tasks 1 and 2, the need for additional data; plan the tests necessary to obtain these additional data. Any measurements needed were to be made on a "piggyback" basis.

Tasks 1 and 2 were reported in Reference 1. Subsequently, measurements were obtained during truck shipments of two different spent-fuel shipping containers that weighed 20 tonne (44,000 lb) and 25 tonne (56,000 lb). The data obtained from these shipments were reported in References 2 and 3. Reference 3 also compared shock and vibration data from these shipments with data from truck shipments with cargo weights varying from 0 (no-load) to 14 tonne (30,000 lb) that were reported in Reference 1.

While performing the studies for Tasks 1 and 2, the paucity of measured data from rail shipments of heavy cargo became obvious. Existing data covered cargo weights of approximately 5 tonne (10,000 lb) for rail coupling operations, while vibration data and data for shock which is superimposed on vibration (crossing rail joints, travel through switches, run-in and run-out) covered a shipment of a 14 tonne (30,000-lb) fuel cask. The investigation described in this report concerns the generic definitions of shock environments at the interface between the rail car and cargo that result from rail coupling operations with cargo weighing approximately 36 tonne (40 tons) and 64 tonne (70 tons). It is hoped that these data ultimately will contribute to the definition and quantification of meaningful cask tie-down design specifications.

All data used in this report were based on English units. The metric (SI) values presented result from rounding of the English units to the nearest SI unit.

Test Planning

In March 1977, Savannah River Laboratory (SRL) had prepared a draft of Reactor Division Technology (RDT) Standard F8-12, "Fuel Shipping Container Tiedown for Rail Transport"; this was based upon an approximate, analytical approach developed by members of the American National Standards Institute (ANSI) Subcommittee N-582. It was expected that the RDT standard would also become an ANSI standard. The members of the N-582 subcommittee felt that the tiedown requirements resulting from rail-coupling operations stated in that draft were excessively conservative and economically impractical. The conservatism resulted from a lack of test data about heavy cargo on a rail car.

To provide the test data necessary to develop a less conservative tiedown standard, SRL planned a series of field tests using cable and bolt tiedowns for attaching shipping containers to railcars. Later in 1977 the test plans were expanded to accommodate the data needs of closely related programs being supported by NRC. These related programs were being conducted by SNL and Hanford Engineering Development Laboratory (HEDL). A program similar to that conducted by HEDL was underway at Los Alamos National Scientific Laboratory (LANSL); it was funded by the Department of Energy (DOE). SRL accepted responsibility for conducting the redefined test program and for providing part of the instrumentation. SNL agreed to provide part of the instrumentation and to gather and record data for all the participating laboratories. HEDL and LANSL provided part of the instrumentation and served in advisory capacities. Each participating laboratory was responsible for reducing the data which met its specific program needs.

Test Description

The rail-coupling tests were conducted in the Classification Yard of SRL near Barnwell, SC. A loaded test rail car was accelerated by a locomotive to the desired speed and then released and allowed to roll freely into four anvil cars that had a total weight of 316 tonne (695,440 lb). The railroad track was graded so that the test car had about the same speed at impact with the anvil cars as it had when released from the locomotive. The mechanical brakes were set on the four anvil cars and coupler slack was removed from them before each test.

Test Rail Cars

Three rail cars were used in the tests. Two cars, which were leased from Seaboard Coastline (SCL) by SRL, were flat bulkhead types with a capacity of 64 tonne (70 tons) each. The third car, which was provided by Union Carbide Corporation (UCC), had been an overseas US Army car used to transport tanks; UCC had converted it for use in transporting canisters and had upgraded the nominal capacity to 73 tonne (80 tons). One SCL car was equipped with standard draft gear having about 0.06 m (2.5 in.) coupler travel. The second SCL car was equipped with a sliding sill cushion underframe having about 0.51 m (20 in.) coupler travel. The car that had been converted by UCC was equipped with standard draft gear on one end and a 0.38 m (15 in.) travel hydraulic end-of-car (EOC) device (manufactured by Freightmaster) on the other end. The test cars were extensively modified by SRP to accommodate the tiedown instrumentation.

Four hopper cars were leased by SRL from SCL for use as anvil cars.

Cargo Casks

Two casks were used for the tests; they were the heaviest avail-able. One was a cylindrical Hallum cask which was mounted in a skid. The cask and skid weighed approximately 36 tonne (40 tons). The other cask was a rectangular box-shaped cask which is used for on-site scrap shipments at SRP; it weighed about 64 tonne (70 tons).

Test Velocities

The maximum impact velocity of the test car relative to the anvil cars was limited to approximately 17.7 km/h (11 mph) because this velocity covered 99.8% of 15,648 observed coupling operations (Reference 1).

Cargo Tiedowns

Except for the special tests that used cables as the only tiedown mechanism, all tiedown configurations included rigid stops welded to the railcar structure for longitudinal restraint. Either tiedown bolts or cables provided vertical and lateral restraint for the Hallum cask and skid; bolts provided vertical and lateral restraint for the SRP cask. Three parallel bumper beams were placed laterally on the rail car between the cask or skid and the rigid welded stops. These beams were reinforced 0.36 m (14 in.), 76 kg (167 lb), wide-flange beams which were 2.4 m (8 ft) long. In order to study the effect on cask response caused by varying the natural frequency of a tiedown system, on one of the tests the middle 2.4-m-long beam was replaced with a 0.3-m (1-ft)-long beam which was placed in the middle of and between the other two beams.

Instrumentation

The instrumentation used on the tests was selected by the participating laboratories during pretest coordination meetings. Data gathering was limited to 28 channels. IRIG time code and velocity measurements were provided on separate data tracks at the receiving and recording station because these did not require telemetry transmission from the test car to the receiving station.

Force Measurements -- The force measuring devices were provided by SRL. An instrumented coupler was leased from National Castings Division of Midland Ross Corporation; it provided force/time histories at the coupler. The coupler was designed to measure forces up to 5 560 000 N (1,250,000 lb).

The longitudinal forces exerted on the rigid stops by the casks were measured by load cells; the cells were designed and calibrated at SRL.

Instrumented bolts were fabricated for SRL by the Strainsert Co; they were 0.05 m (2 in.) in diameter and 0.18 m (7 in.) long and measured the vertical forces exerted on the rail car by the casks. To avoid shear stresses in the bolts, the holes in the bases of the casks through which the bolts passed were made considerably larger in diameter than the bolts.

Instrumented pins were used in specially fabricated clevises to measure forces when cables were used for tiedowns. The clevises were designed and fabricated by SRL. The Strainsert Co. instrumented the clevis pins.

Photography -- SRL, with assistance from SNL, provided photometric and still photographic coverage of the tests. Four hundred frames-per-second cameras were used for the photometrics. One camera was focused on the couplers of the test car and the first anvil car. The other camera was focused on the top of the cask to monitor vertical motion of the cask at impact. A reference grid background was used for both of the movie cameras; the white squares on the grid measured 0.3 m (12 in.). Still photographs were taken to record instrument mountings and test-car configurations.

Accelerometers -- Nine accelerometers were mounted on the rail car structure; six were mounted on the Hallum cask and four were mounted on the Hallum cask skid (for tests with the SRP scrap cask, all ten of these accelerometers were mounted on the cask); and two were mounted on the rail trucks. The accelerometers were manufactured by ENDEVCO: 9 of them were Model 2262-200 piezoresistive accelerometers and 12 were Models 2221 M1A, 2224-C, and 2225 piezoelectric accelerometer; they were provided by LANSL, HEDL, and SNL.

Coupler Displacement -- Displacement/time records of the coupler were obtained by Celesco PT-101 RX displacement instruments that were provided by SNL.

Data Gathering

Signals from each of the instruments used were fed into two signal-conditioning packages. The output from these packages was transmitted by radio-frequency (RF) link to the instrumentation trailer for recording on magnetic tape. Transmission frequencies were 2204.5 and 2250.5 MHz. Fourteen data channels were multiplexed on each of the transmission frequencies. The subcarrier frequencies on each transmission frequency were 16, 24, 32, 40, 48, 56, 64, 80, 96, 112,128, 144, 160, and 176 kHz. Two tape recorders were used for data recording: one was for a master tape and the other was for playback at the test site to determine the validity of the data recorded on each test. Playback capability was provided, and it allowed examination of each data channel following each test.

Impact velocity was determined by break rods which were placed at known distances apart on the side of the rail. As the test car moved toward the impact point, the rods were broken; this caused an open circuit and, in conjunction with the known IRIG-B time code, the velocity at impact was determined. The IRIG-B time code and the break-rod signals were recorded on separate tracks at the recording station.

The data-gathering equipment was housed in an SNL field-test instrumentation trailer. The 208 V, 3-phase power needed for operating the instrumentation trailer was provided by SRP. The cables from the individual instruments to the signal-conditioning packages, the transmitters, and the receiving/recording/playback equipment were provided by SNL.

Passive Measurements

Several passive measurements were recorded. The distances each of the anvil cars moved as the result of the impact and the cask movements were recorded. Simple displacement gages were devised to measure the maximum compression and extension of the test-car springs. The distance from the coupler horn to the striker plate was measured on each end of each anvil car before and after the tests. The distance that the anvil cars were displaced was also measured. The loaded test cars were weighed in their final test configurations.

Test Results

Eighteen individual tests were conducted during the test program. They are described briefly below.

Test 1

The Hallum cask and skid were loaded onto the standard SCL rail car that was equipped with standard draft gear (Figures 1 and 2). Eight tiedown bolts, of which three were instrumented, provided vertical restraint of the cask and skid. Each of the bolts was pretorqued to 169.5 N•m (125 ft-lb). Twenty-eight channels of data were obtained during this test. Table 1 lists the instrumentation for Test 1.

The impact velocity for this test was 13.36 km/h (8.3 mph). All four crossbeams under the rail car frame (through which the tiedown bolts passed) moved forward during impact, so the tiedown bolts did not remain vertical as intended. One instrumented bolt galled and was destroyed. The coupler on the anvil car nearest the test car bottomed in a manner which led to the assumption that it was badly worn.

The records from this test were played back, and the calibration levels were adjusted for the next test.

Test 2

This test was conducted using the same general test setup and arrangement as in Test 1. The order of the anvil cars was rearranged so that the car with what appeared to be the best draft gear would be struck by the test car.

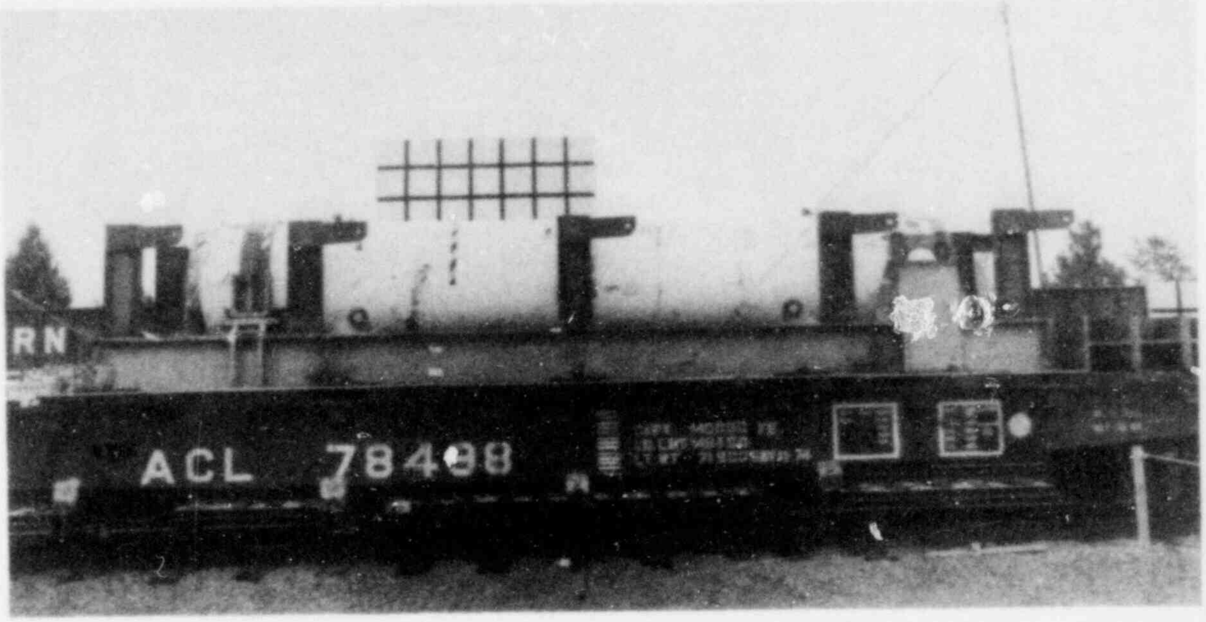

Figure 1. Hallum Cask and Skid Mounted on SCL Rail Car - Tests 1-4

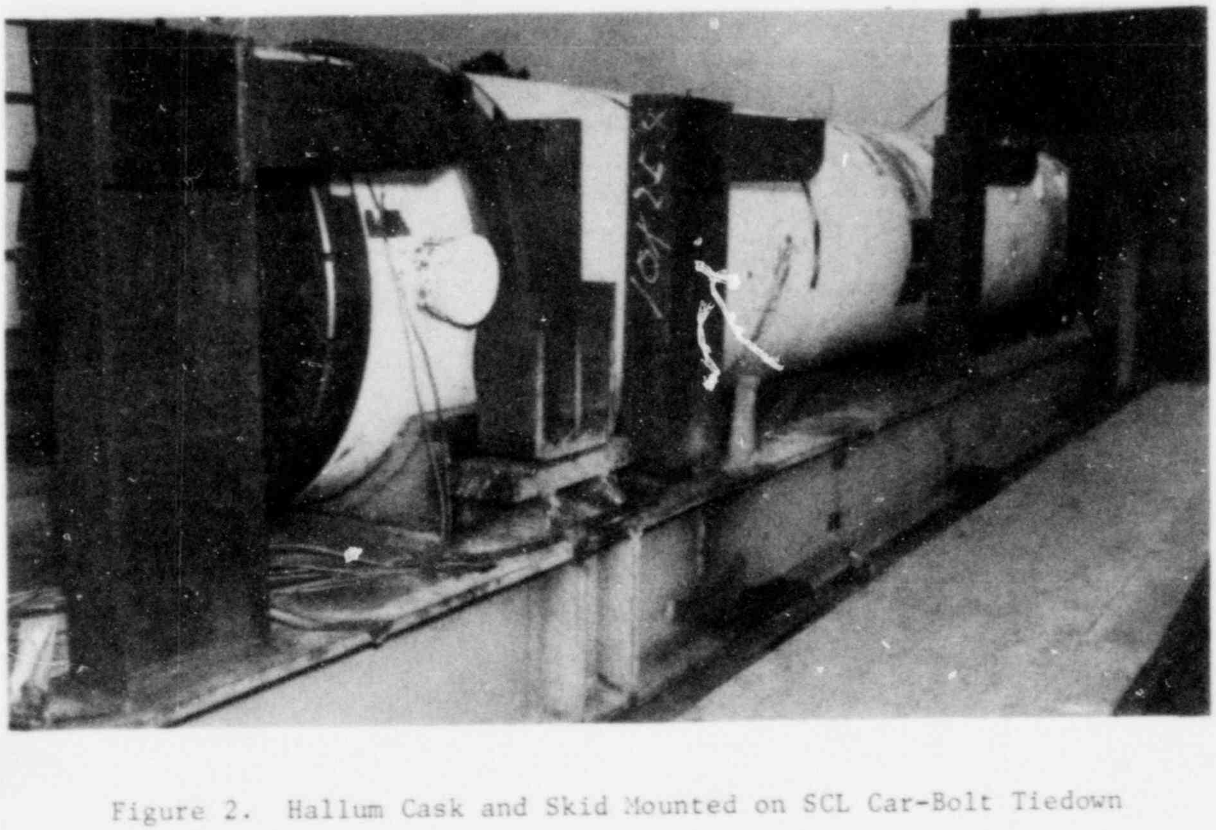

Figure 2. Hallum Cask and Skid Mounted on SCL Car-Bolt Tiedown

Table 1.

Instrumentation for Test 1

Instrument No.	Instrument Location	Instrument Type	Axis Measured*	Figure No.
1	Tiedown Bolt FE**	Strain	V	3
2	Tiedown Bolt Mid	Strain	V	4
3	Coupler	Strain	L	5
4	Coupler	Displacement	L	5
5	Car Structure SE	PR*** Accelerometer	L	6
6	Car Structure SE	PR Accelerometer	V	6
7	Car Structure SE	PE Accelerometer	L	6
8	Cask Top SE	PR Accelerometer	L	7
9	Cask Top SE	PR Accelerometer	V	7
10	Cask Top FE	PR Accelerometer	L	8
11	Cask Top FE	PR Accelerometer	V	8
12	Car Structure Mid	PR Accelerometer	L	9
13	Car Structure Mid	PR Accelerometer	T	9
14	Car Structure Mid	PR Accelerometer	V	9
15	Cask Skid SE	PE Accelerometer	L	10
16	Cask Skid SE	PE Accelerometer	V	10
17	Cask Skid FE	PE Accelerometer	L	11
18	Cask Skid FE	PE Accelerometer	V	11
19	Cask Top CG	PE Accelerometer	V	12
20	Cask Side CG	PE Accelerometer	T	13
21	Car Structure FE	PE Accelerometer	L	14
22	Car Structure FE	PE Accelerometer	V	14
23	Truck SE	PE Accelerometer	L	15
24	Truck FE	PE Accelerometer	L	16
25	Car Structure SE	PE Accelerometer	V	17
26	Tiedown Bolt FE	Strain	V	18
27	Rigid Stop SE	Load Cell	L	19
28	Rigid Stop SE	Load Cell	L	20

*V = vertical; L = Longitudinal; T = transverse
**FE = far end; Mid = middle; SE = struck end; CG = center of gravity
***PR = piezoresistive; PE = piezoelectric

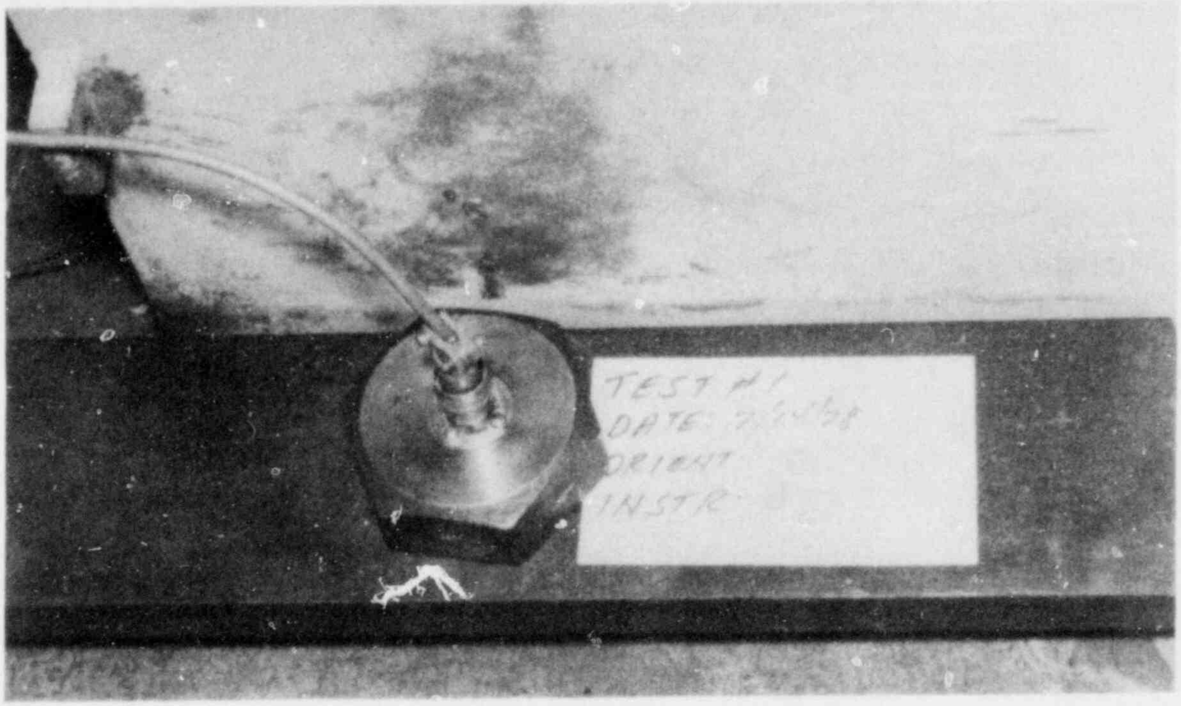

Figure 3. Vertical Tiedown Bolt at Far End of Hallum Cask Skid - Tests 1-4

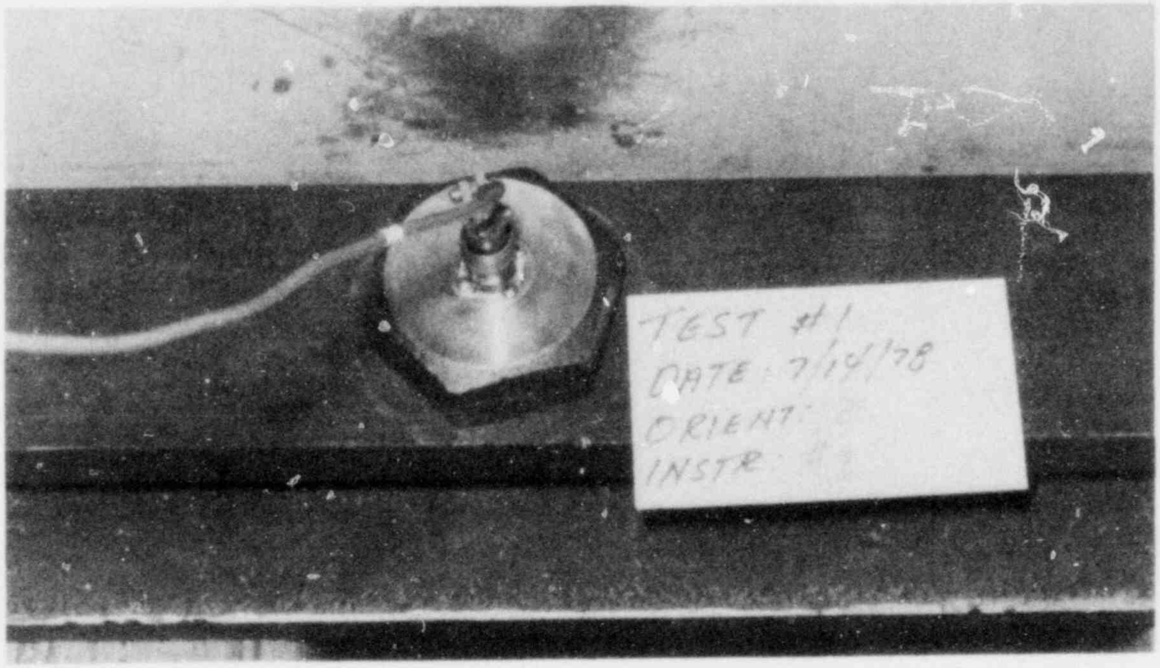

Figure 4. Vertical Tiedown Bolt at Near Middle of One Side of Hallum Cask Skid - Test 1

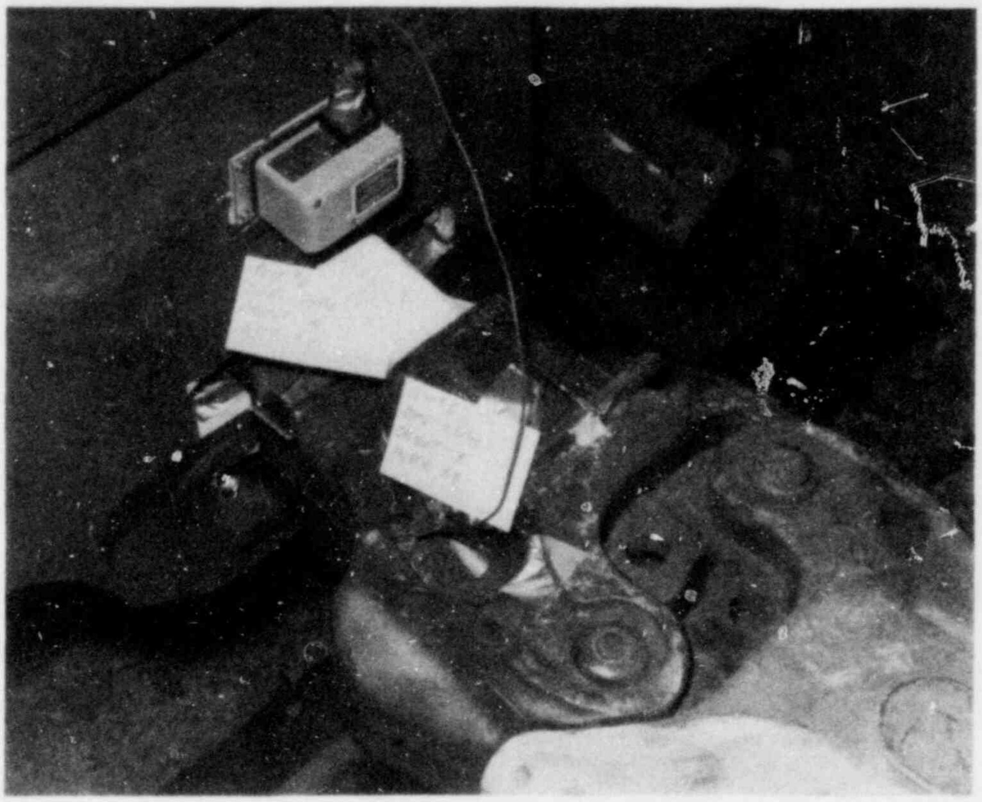

Figure 5. Coupler Force and Displacement Instrumentation at Struck End of Car - Tests 1-5

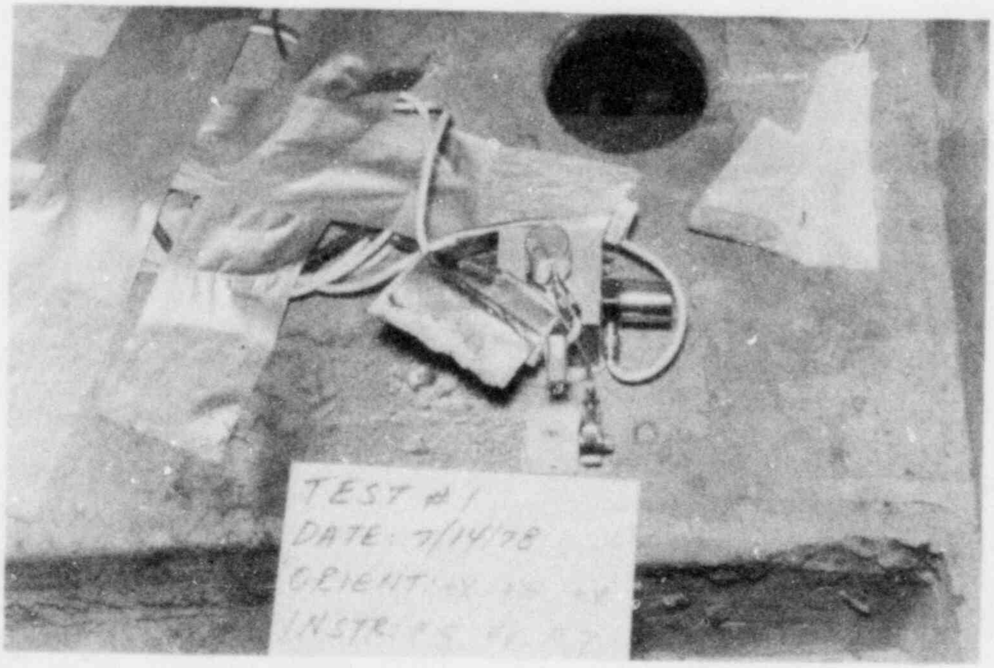

Figure 6. Accelerometer Placement on Car Structure at Struck End of Car - Tests 1-5

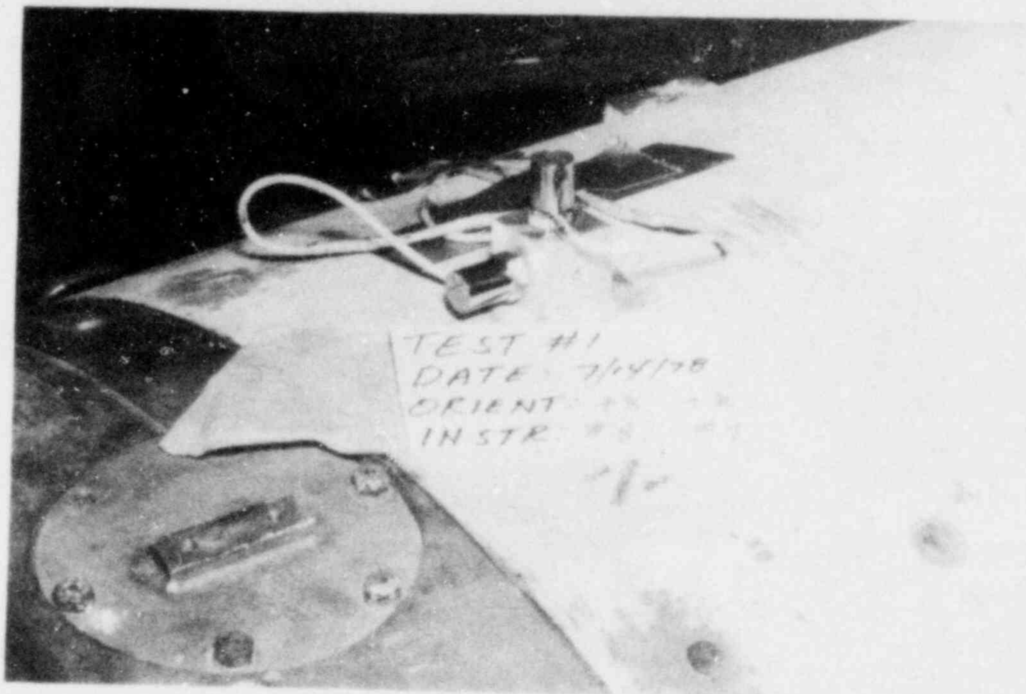

Figure 7. Accelerometer Placement on Top of Hallum Cask at Struck End of the Car - Tests 1-5

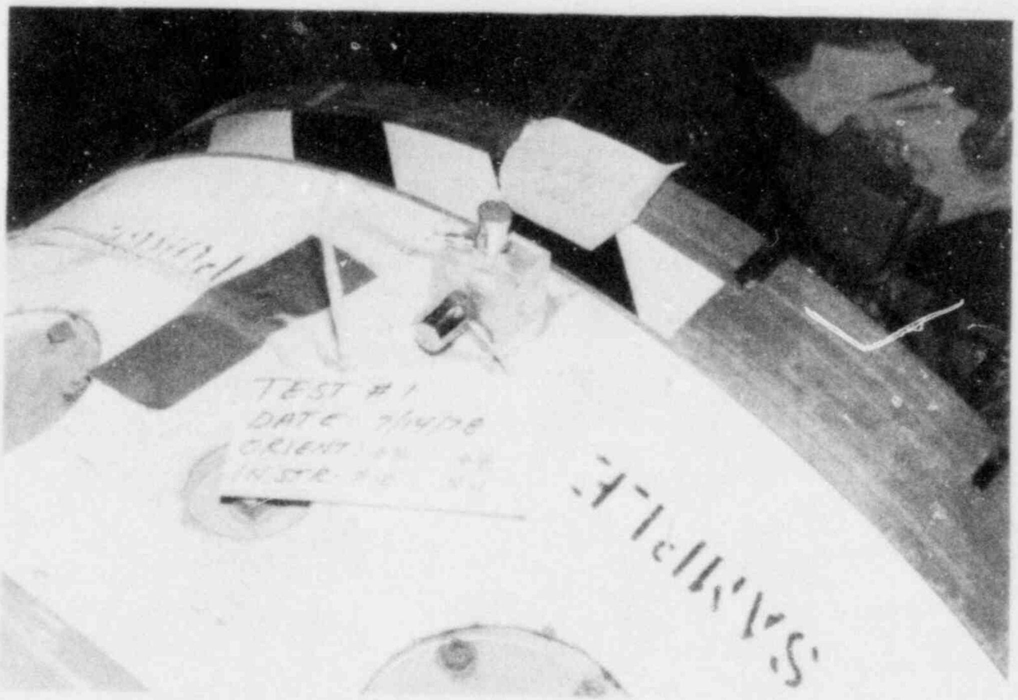

Figure 8. Accelerometer Placement on Top of Hallum Cask at Far End of the Car - Tests 1-5

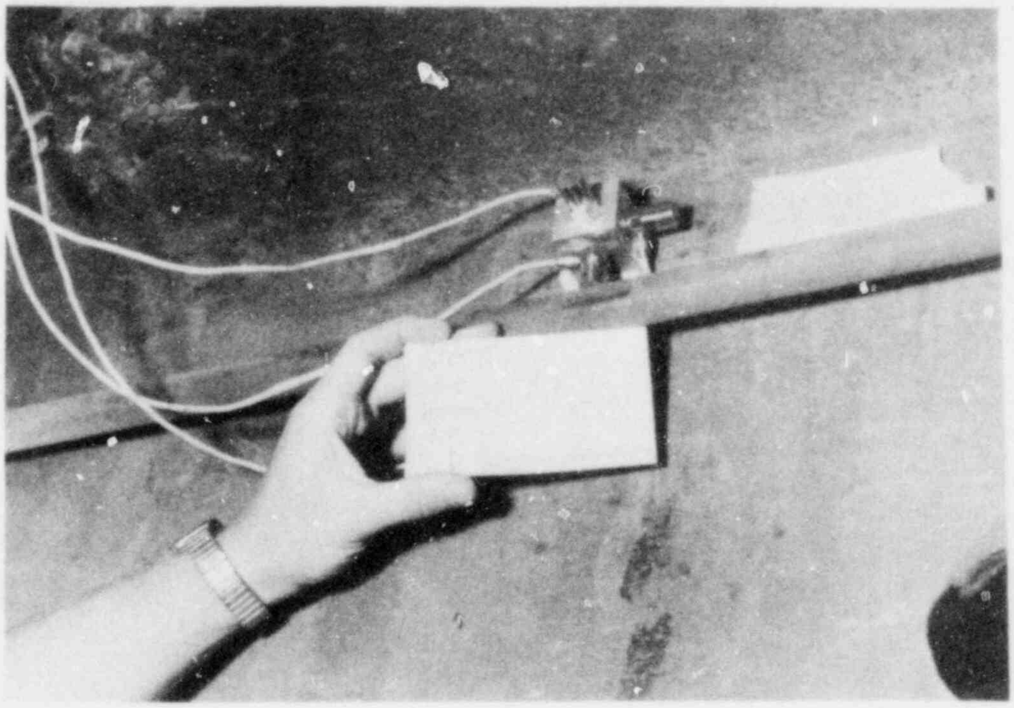

Figure 9. Accelerometer Placement on Longitudinal Structural Rail Car Members Near Middle of Car - Tests 1-5

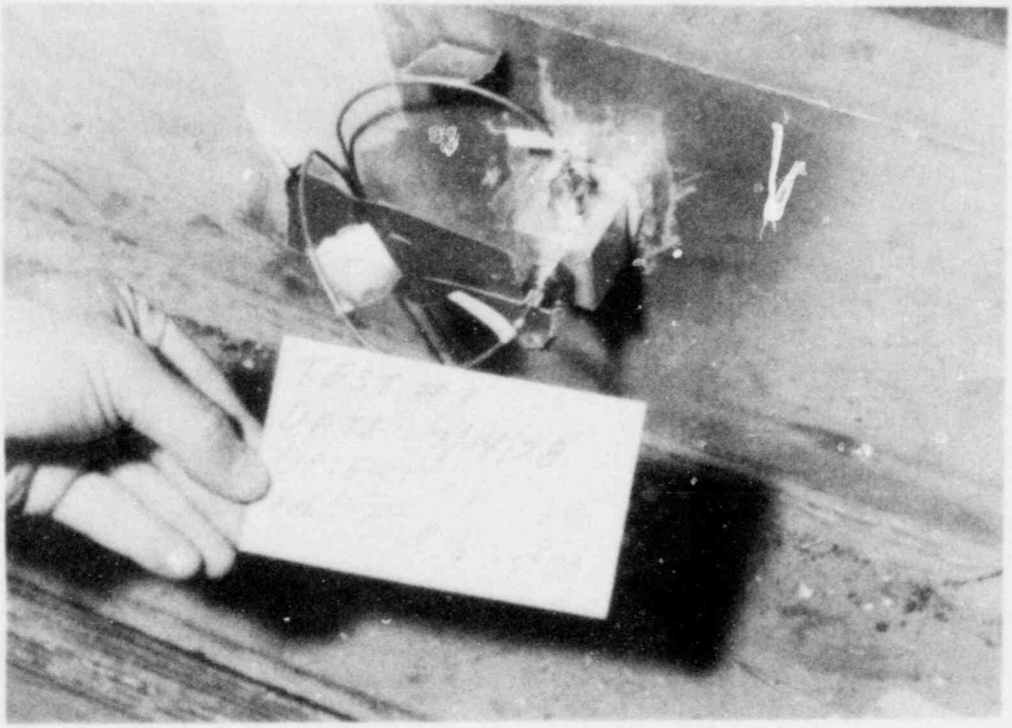

Figure 10. Accelerometer Placement on Hallum Cask Skid Cross Member at Struck End of Skid - Tests 1-5

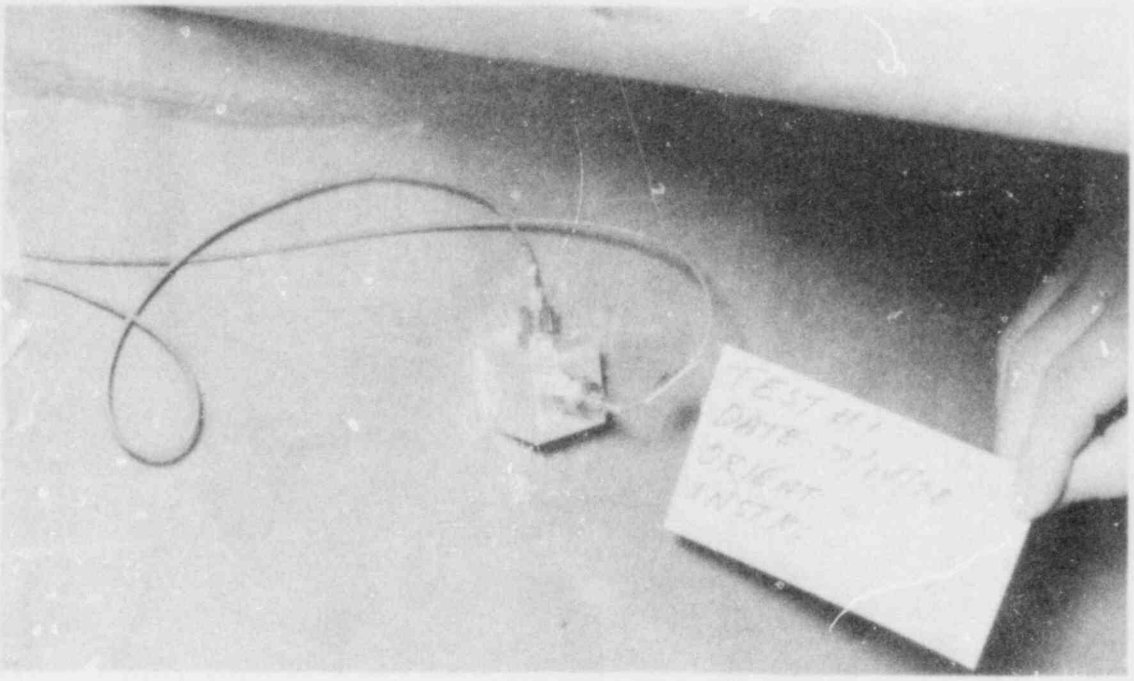

Figure 11. Accelerometer Placement on Hallum Cask Skid
Cross Member at Far End of Skid - Tests 1-5

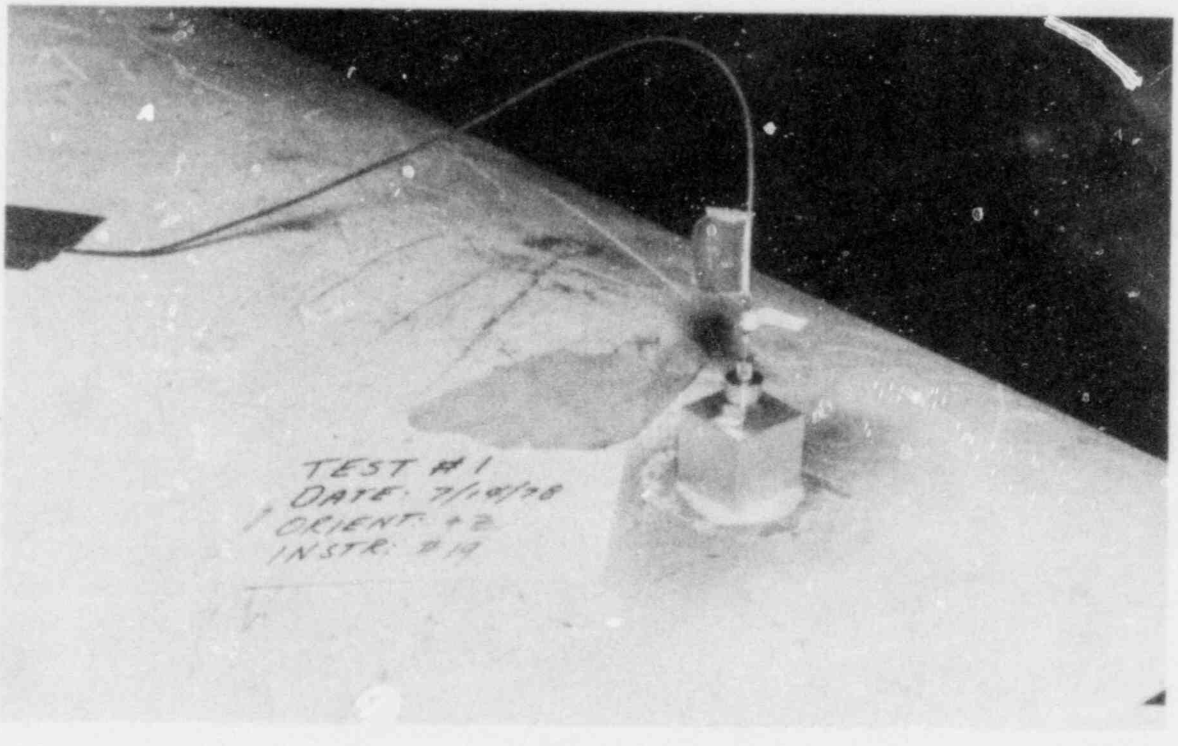

Figure 12. Accelerometer Placement on Top of Hallum Cask
Near Center of Gravity of Cask - Tests 1-5

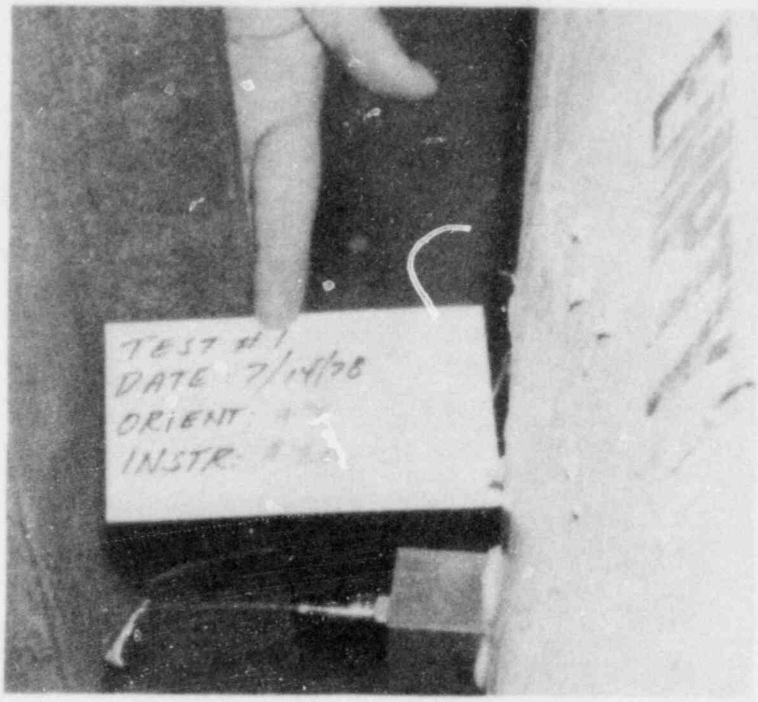

Figure 13. Accelerometer Placement on Side of Hallum Cask Near Center of Gravity of Cask - Tests 1-5

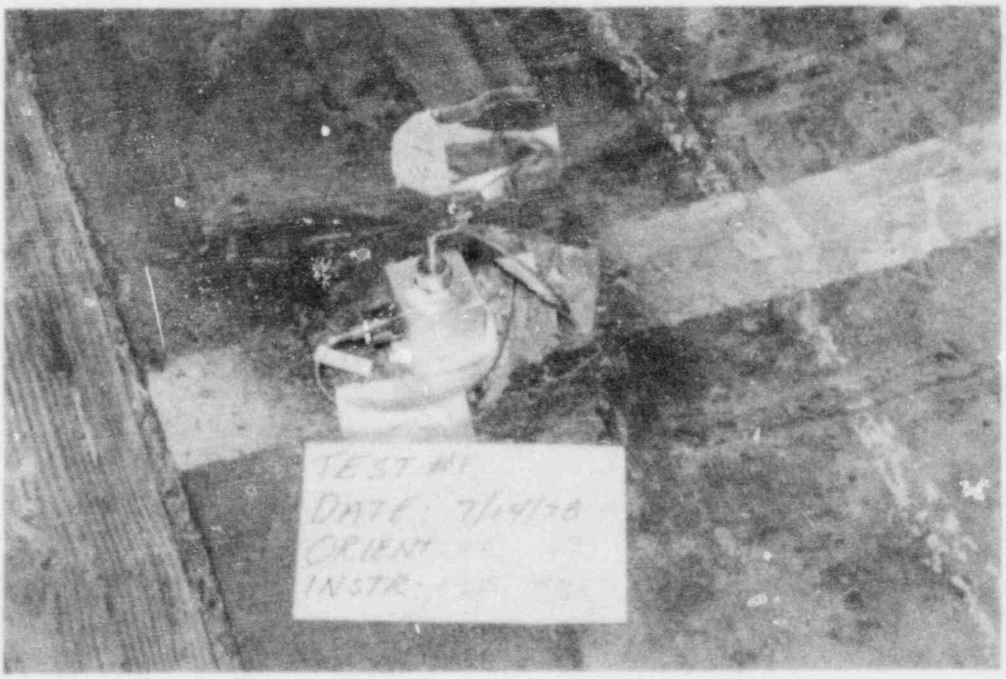

Figure 14. Accelerometer Placement on Car Structure at Far End of Car - Tests 1-5

Figure 15. Accelerometer Placement on Rail Truck Structure at Struck End or Car - Tests 1-5

Figure 16. Accelerometer Placement on Rail Truck Structure at Far End of Car - Tests 1-5

Figure 17. Accelerometer Placement on Car Structure at Struck End of Car - Tests 1-5

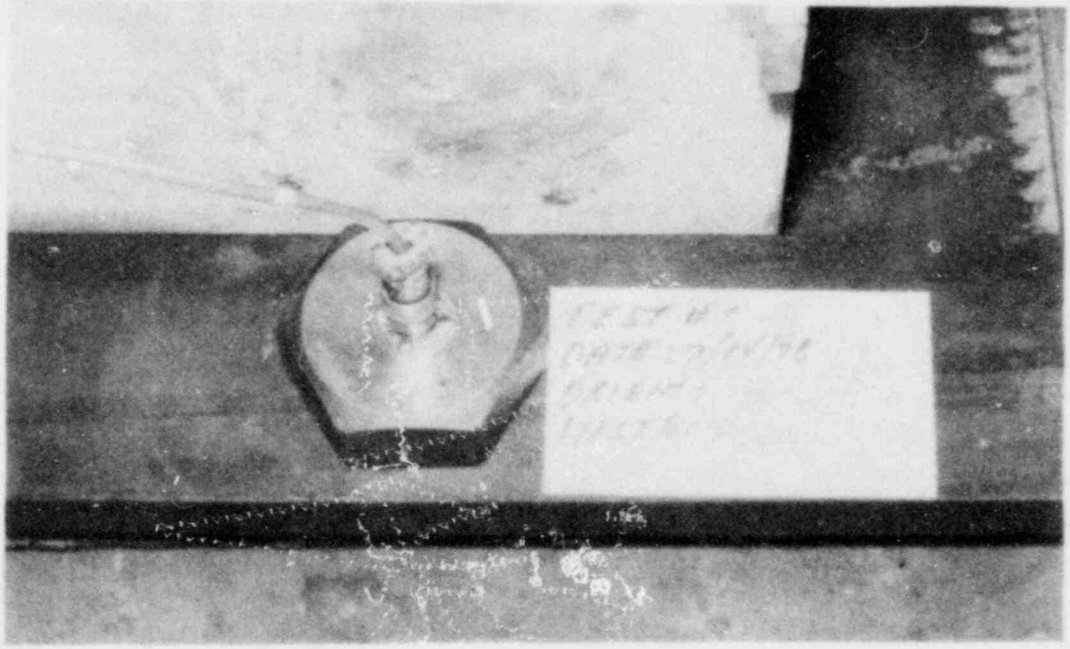

Figure 18. Vertical Tiedown Bolt at Far End of Hallum Cask Skid - Tests 1-4

Figure 19. Load-Cell Placement Between I-Beam Bumpers and Rigid Stop at Struck End of Car - Tests 1-5

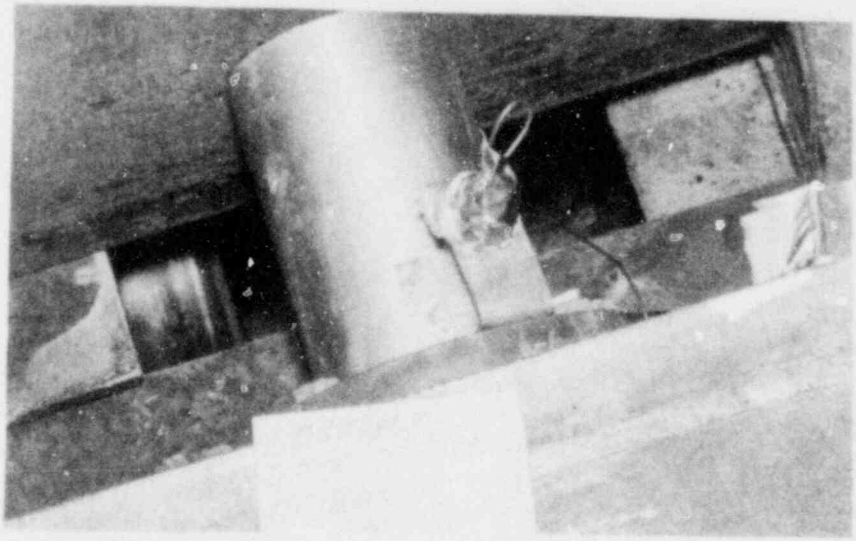

Figure 20. Load-Cell Placement Between I-Beam Bumpers and Rigid Stop at Struck End of Car - Tests 1-5

Three crossbeams under the frame of the rail car were reinforced prior to Test 2. The beams were prevented from moving forward during impact by welding stops to the car frame. Six tiedown bolts, two of which were instrumented, were used for vertical and lateral restraint of the Hallum cask and skid. These bolts passed through the three crossbeams. The bolts again were torqued to 169.5 N•m (125 ft-lb) prior to the test. The load cells between the bumpers and the rigid stops were unloaded by moving the cask before the test.

The instrumentation for Test 2 was the same as for Test 1 (Table 1), except that the instrumented bolt on the side of the skid (instrument 2) was not used. The impact velocity for this test was 14.65 km/h (9.1 mph).

Test 3

Test 3 was conducted using the same test configuration and instrumentation as in Test 2, except that a new instrumentation yoke was installed in the coupler assembly. The impact velocity for this test was 16.9 km/h (10.5 mph).

Test 4

The test configuration and instrumentation for Test 4 was the same as for Test 3, except that the middle long [2.4-m (8-ft)] bumper beam was replaced by a short [0.3-m (1-ft)] bumper beam; this was done to lower the natural frequency of the tiedown system. The impact velocity for Test 4 was 17.22 km/h (10.7 mph). After the test, one of the long bumper beams had taken a permanent bow of approximately 3.2 mm (0.125 in.).

Test 5

The general test configuration and instrumentation for Test 5 were the same as for Test 3, except that vertical restraint of the Hallum cask and skid was provided by six cables instead of six bolts (Figures 21 and 22). Instrumented clevis bolts were used to measure the vertical force exerted by the cask and skid (all turnbuckles were pretorqued to 101.7 N•m

(75 ft-lb). The instrumented cable tiedowns became instruments number 1 and 26 and were located at the most distant location from the struck end of the skid. The impact velocity of Test 5 was 16.9 km/h (10.5 mph).

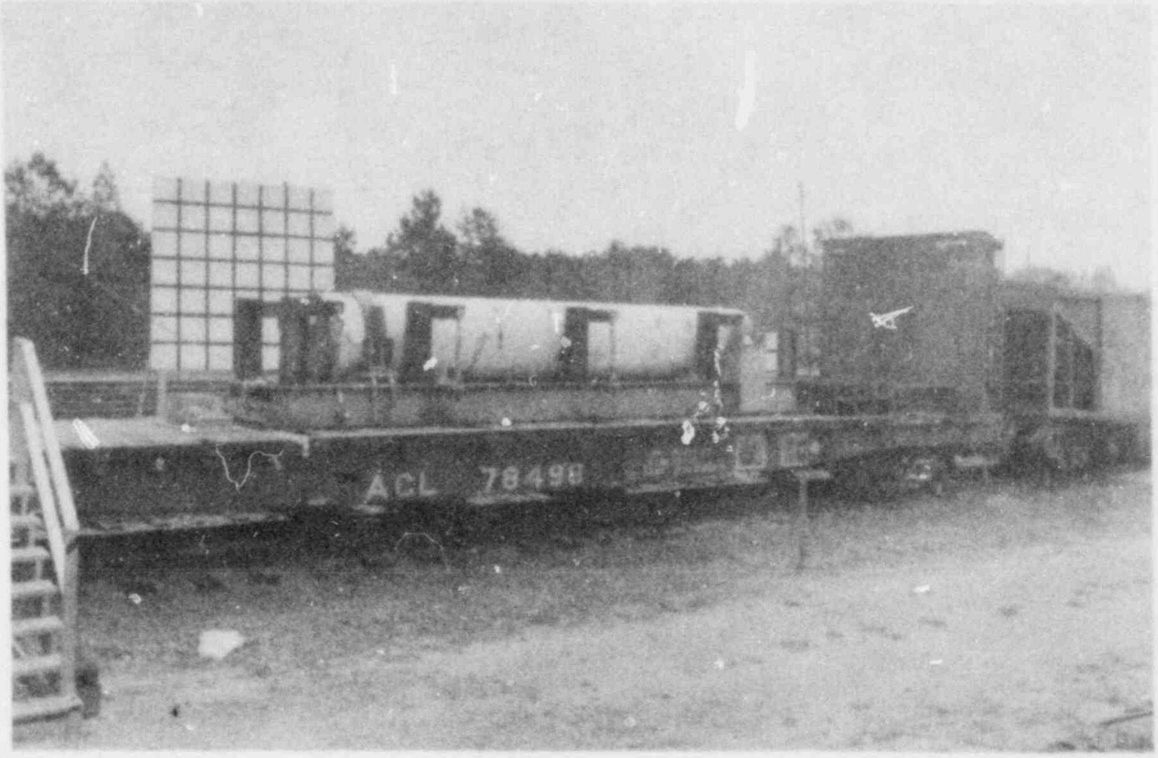

Figure 21. Hallum Cask and Skid Mounted on SCL Rail Car - Test 5

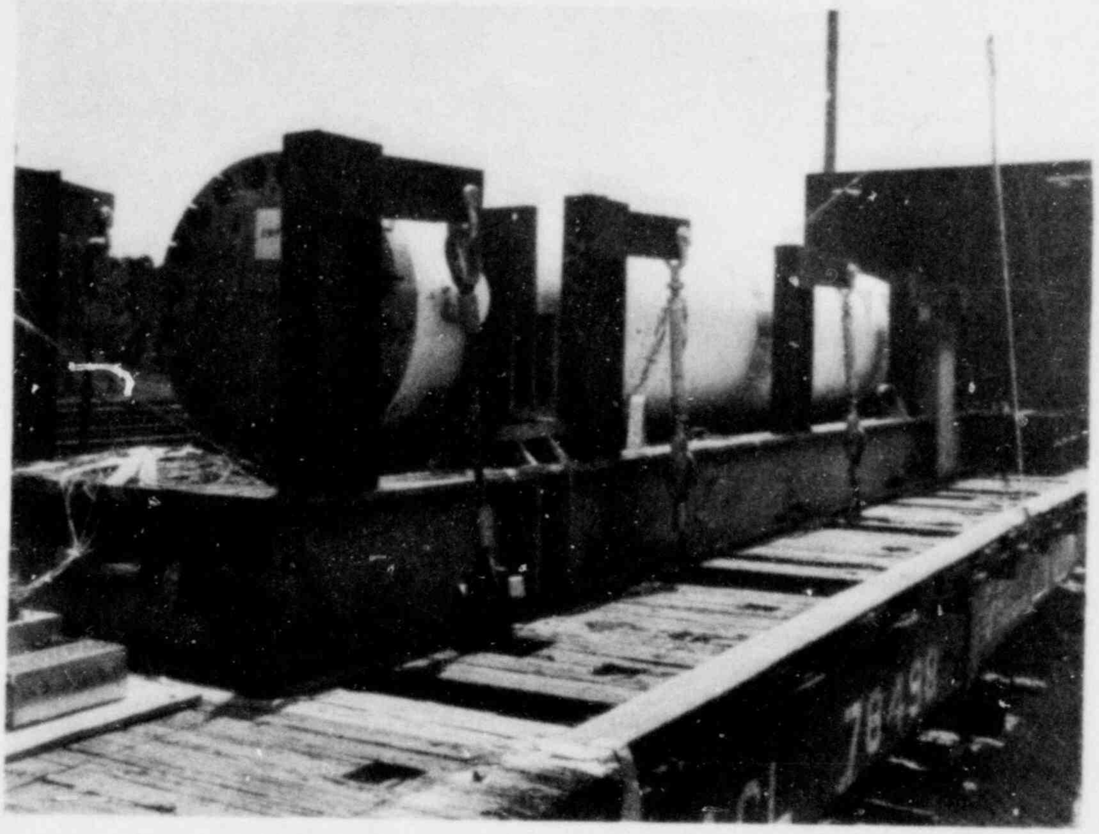

Figure 22. Hallum Cask and Skid Mounted on SCL Rail Car - Cable Tiedown - Test 5

Tests 6, 7, 8, 9

These tests were conducted with the Hallum cask and skid mounted on the railcar that has been modified by UCC. The longitudinal, lateral, and vertical restraint of the cargo was provided by cables only. The cask skid was not in contact with the bumper beams or the rigid stops (Figure 23).

The railcar was positioned on the track so that the 0.38 m (15 in.) hydraulic EOC coupling device was at the impact end of the test car. The ten cables, two of which were instrumented, were pretorqued to 101.7 N•m (75 ft-lb), except for Test 9. The only instrumentation on these tests was the two instrumented cables located at the most distant tiedowns from the struck end of the car.

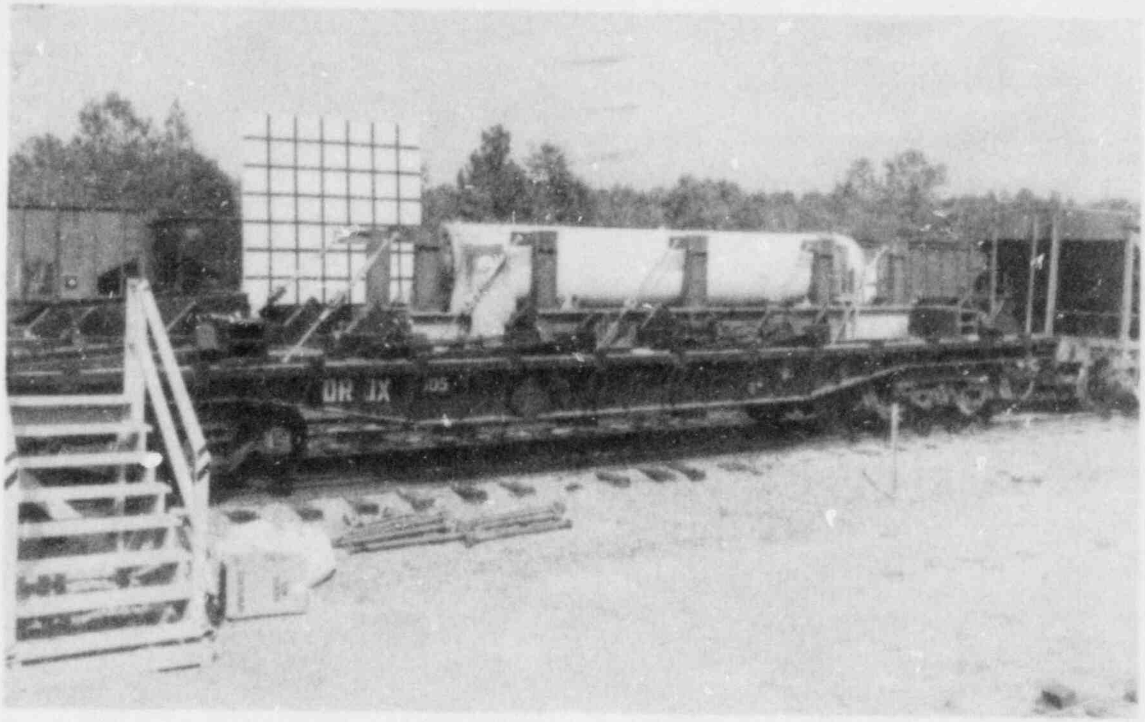

Figure 23. Hallum Cask and Skid Mounted on Union Carbide Car - Cable Tiedown Only - Tests 6-9

The impact velocity for Test 6 was 4.44 km/h (2.76 mph). At this low velocity, there was no detectable load applied to the tiedown cables. The impact velocity for Test 7 was 9.06 km/h (5.63 mph); the cask slid forward approximately 6.4 mm (0.25 in.) at impact. Prior to Test 8 the tiedown cables were retorqued to 101.7 N•m (75 ft-lb); the impact velocity for Test 8 was 14.73 km/h (9.15 mph), and the cask slid forward about 15.9 mm (0.63 in.) at impact.

Test 9 was conducted to learn the effect on tiedown loading when tiedown cables become slack and there are no other longitudinal estraints. This apparently is a common occurence in rail transportation. The tiedown cables were made slack by first tightening each turnbuckle until the cable was snug and then loosening it two turns of the turn-buckle. The impact velocity for Test 9 was 14.73 km/h (9.15 mph); the cask slid forward about 50.8 mm (2 in.), and the cables became taut at impact.

Tests 10,11

For these tests the SRP scrap cask was loaded onto the standard SCL rail car that was equipped with standard draft gear (Figure 24). The cask was restrained longitudinally by stops as was done in Tests 1-4. Six tie-down bolts, two of which were instrumented, provided vertical and lateral restraint of the cask. Each of the bolts were pretorqued to 169.5 N•m (125 ft-lb). Twenty-seven channels of data were obtained during the test. The test car was the same car used for Tests 1 through 5, and the instrument mounting points on the car were the same as for those tests. Table 2 lists the instrumentation for Tests 10 and 11.

The impact velocity for test 10 was 12.91 km/H (8.02 mph); the impact velocity for Test 11 was 17.98 km/H (11.17 mph). The anvil cars were moved 4.83 m (190 in.) as a result of impact during test 11.

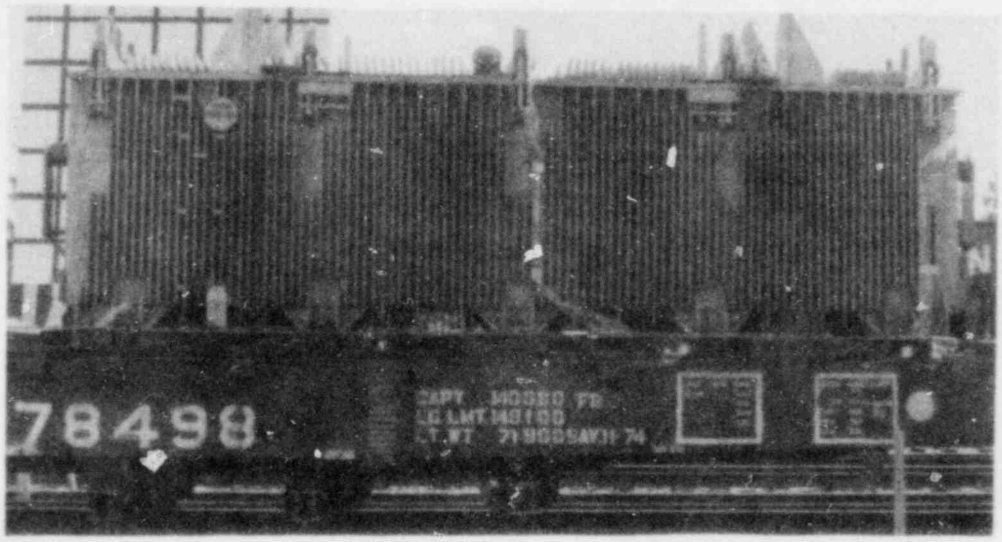

Figure 24. SRP Cask Mounted on SCL Car for Tests 10 and 11

Table 2

Instrumentation for Tests 10 and 11

Instrument No.	Instrument Location	Instrument Type	Axis Measured*	Figure No.
1	Tiedown Bolt FE**	Strain	V	25
2	Not Used			
3	Coupler	Strain	L	26
4	Coupler	Displacement	L	26
5	Car Structure SE	PR Accelerometer***	L	27
6	Car Structure SE	PR Accelerometer	V	27
7	Car Structure SE	PE Accelerometer	L	27
8	Cask Top SE	PR Accelerometer	L	28
9	Cask Top SE	PR Accelerometer	V	28
10	Cask Top FE	PR Accelerometer	L	29
11	Cask Top FE	PR Accelerometer	V	29
12	Car Structure Mid	PR Accelerometer	L	9
13	Car Structure Mid	PR Accelerometer	T	9
14	Car Structure Mid	PR Accelerometer	V	9
15	Cask Top Mid	PE Accelerometer	L	30
16	Cask Top Mid	PE Accelerometer	V	30
17	Cask Top Mid	PE Accelerometer	L	31
18	Cask Top Mid	PE Accelerometer	T	31
19	Cask Top Mid	PE Accelerometer	V	31
20	Cask Top Mid	PE Accelerometer	T	30
21	Car Structure FE	PE Accelerometer	L	32
22	Car Structure FE	PE Accelerometer	V	32
23	Truck SE	PE Accelerometer	L	33
24	Truck FE	PE Accelerometer	L	34
25	Car Structure SE	PE Accelerometer	V	35
26	Tiedown Bolt FE	Strain	V	36
27	Rigid Stop SE	Load Cell	L	37
28	Rigid Stop SE	Load Cell	L	38

*V = vertical; L = Longitudinal; T = transverse

**FE = far end; SE = struck end; Mid = middle; CG = center of gravity

***PR = piezoresistive; PE = piezoelectric

Figure 25. Vertical Tiedown Bolt at Far End of Scrap Cask - Tests 10 and 11

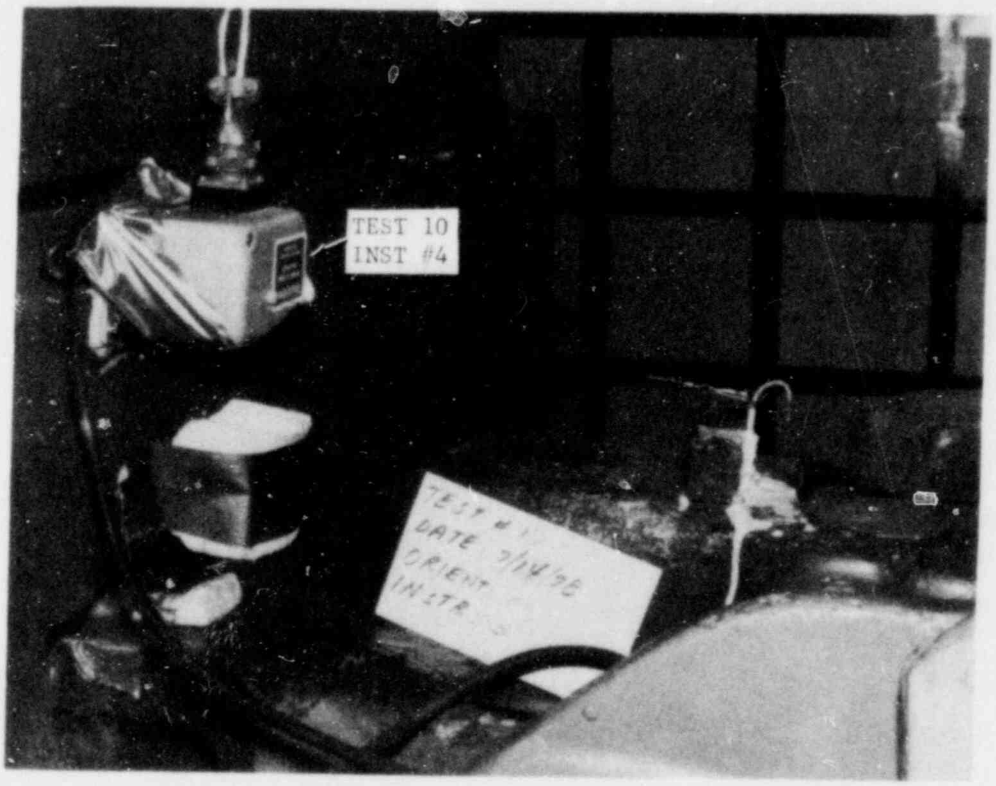

Figure 26. Coupler and Displacement Instrumentation at Struck End of Car - Tests 10 and 11

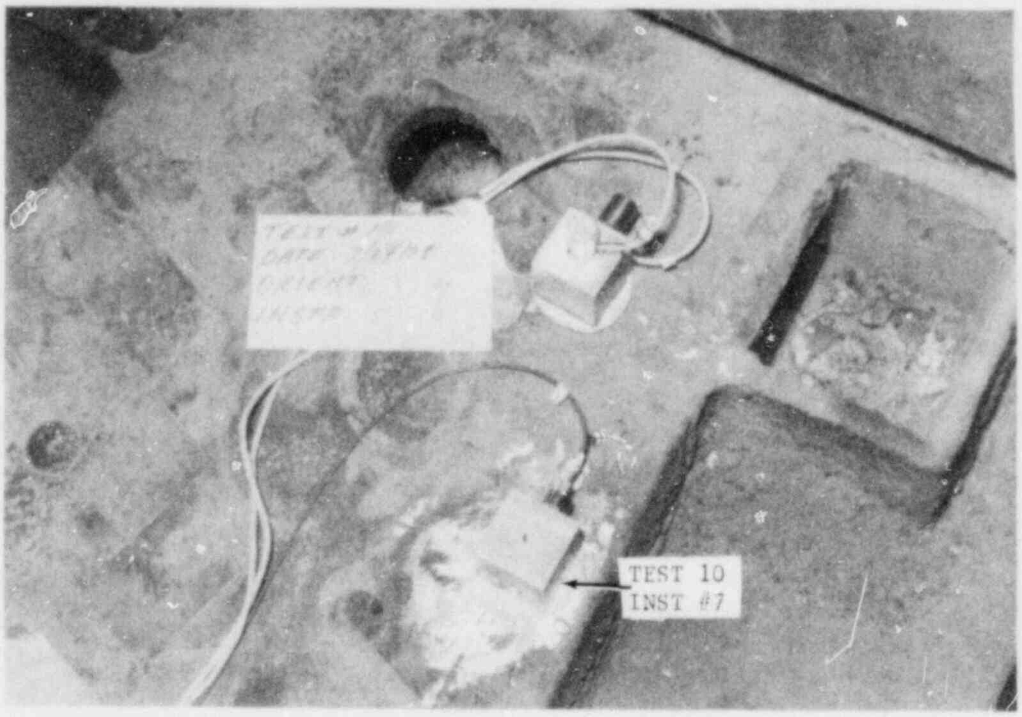

Figure 27. Accelerometer Placement on Car Structure at Struck End of Car - Tests 10 and 11

Figure 28. Accelerometer Placement on Top of Scrap Cask at Struck End of Car - Tests 10 and 11

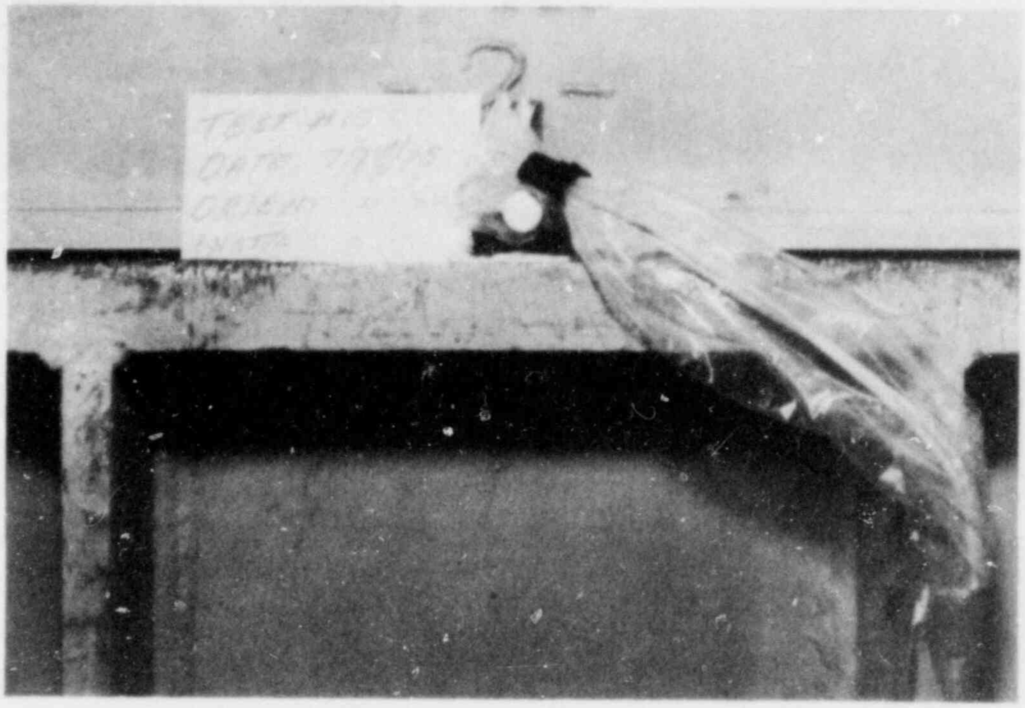

Figure 29. Accelerometer Placement on Top of Scrap Cask at Far End of Cask - Tests 10 and 11

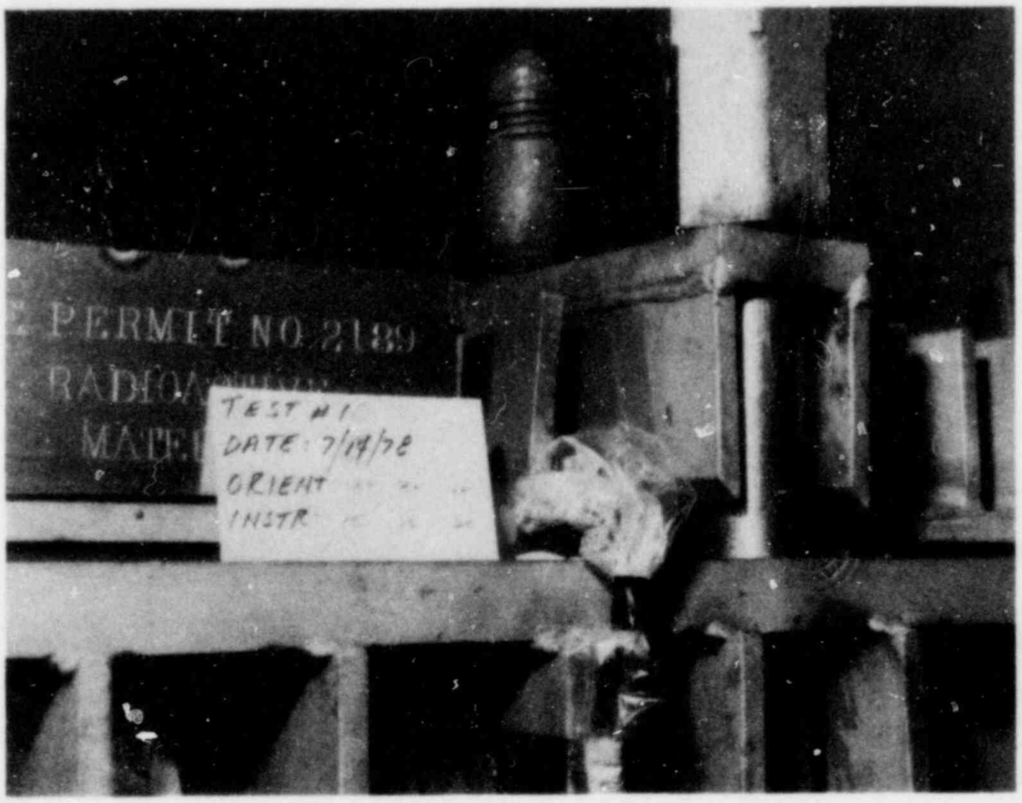

Figure 30. Accelerometer Placement on Top of Scrap Cask Near Middle of Cask - Tests 10 and 11

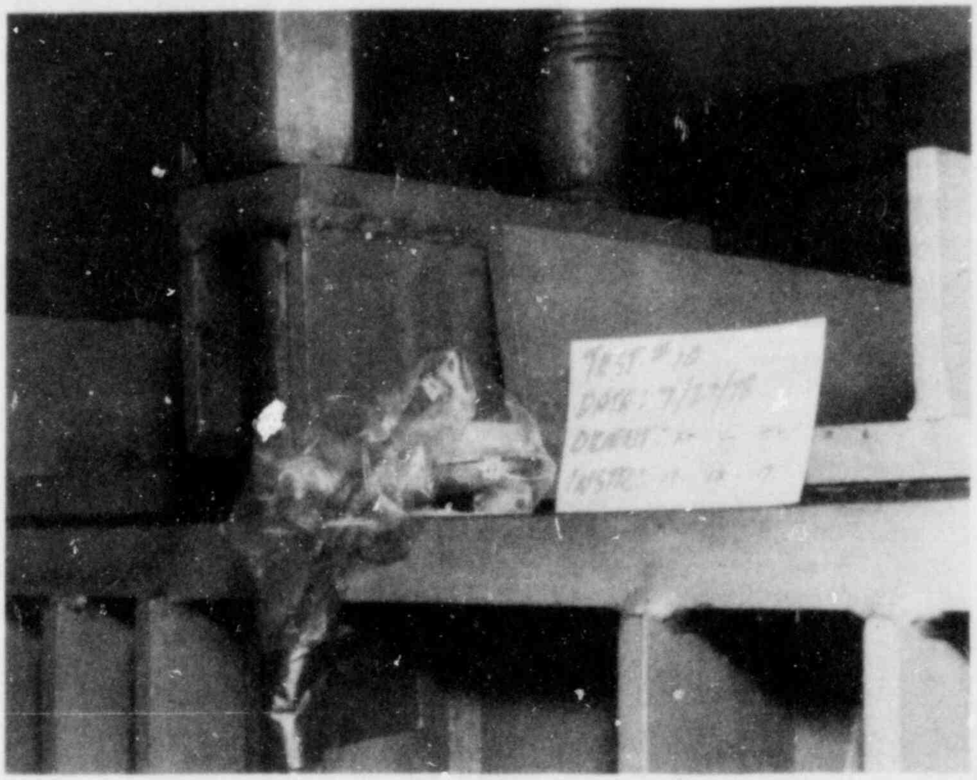

Figure 31. Accelerometer Placement on Top of Scrap Cask Near Middle of Cask - Tests 10 and 11

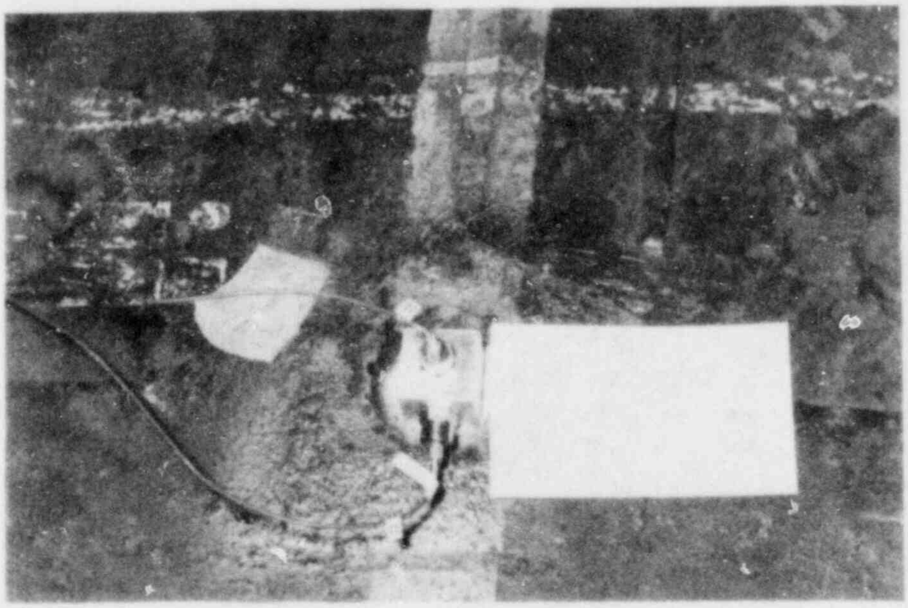

Figure 32. Accelerometer Placement on Car Structure at Far End of Car - Tests 10 and 11

Figure 33. Accelerometer Placement on Rail Truck Structure Near Struck End of Car - Tests 10 and 11

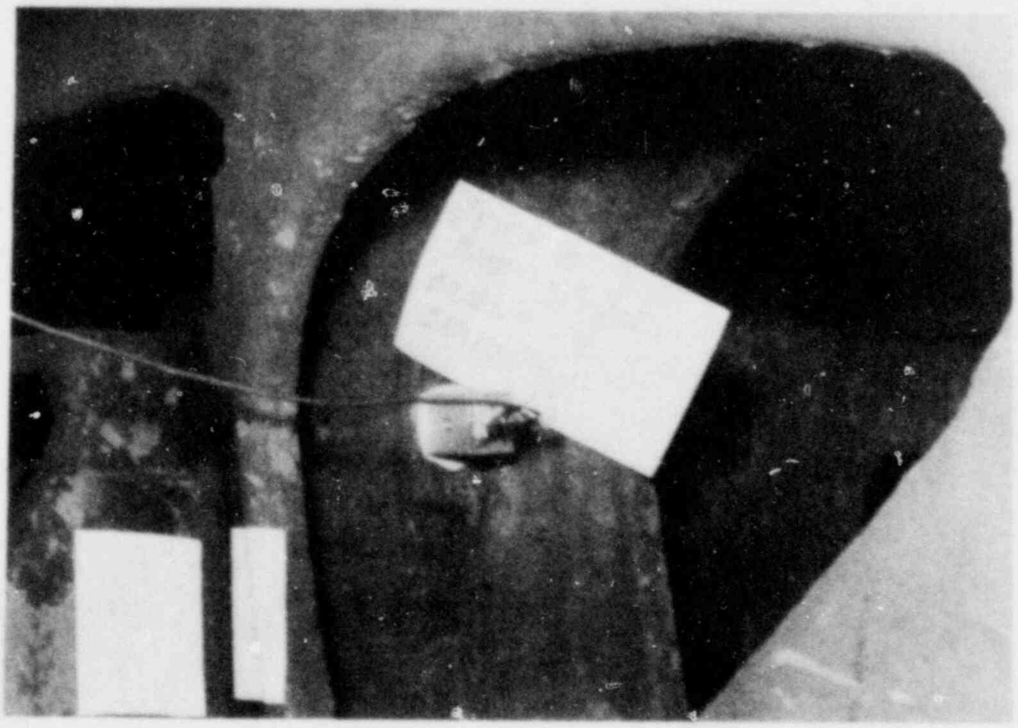

Figure 34. Accelerometer Placement on Rail Truck Structure at Far End of Car - Tests 10 and 11

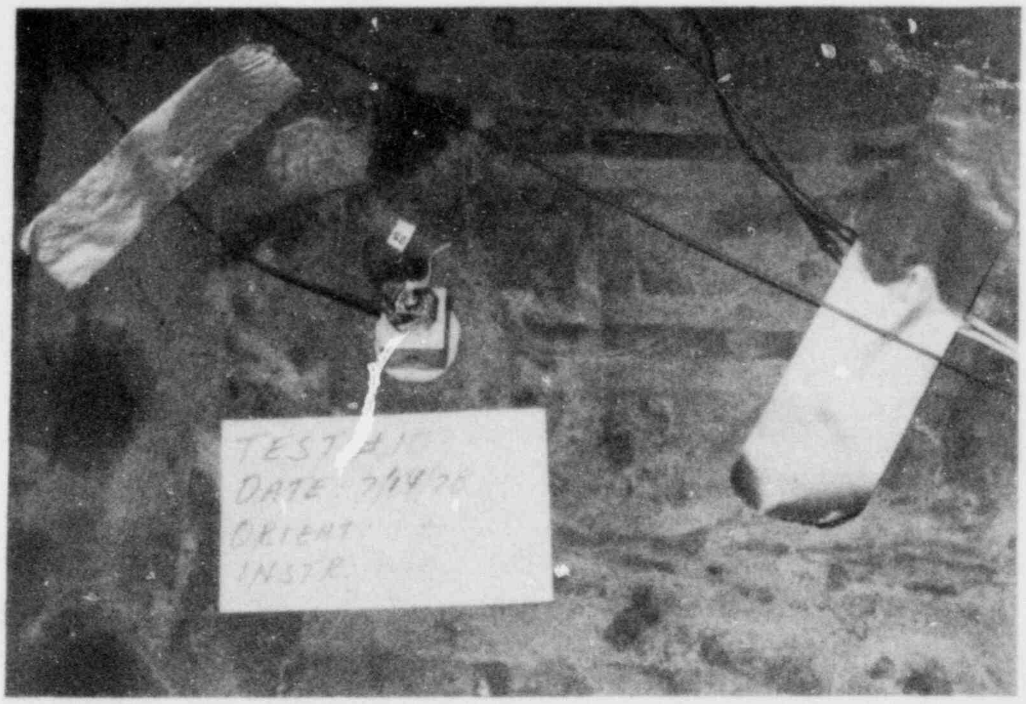

Figure 35. Accelerometer Placement on Car Structure Near Struck End of Car - Tests 10 and 11

Figure 36. Vertical Tiedown Bolt at Far End of Scrap Cask - Tests 10 and 11

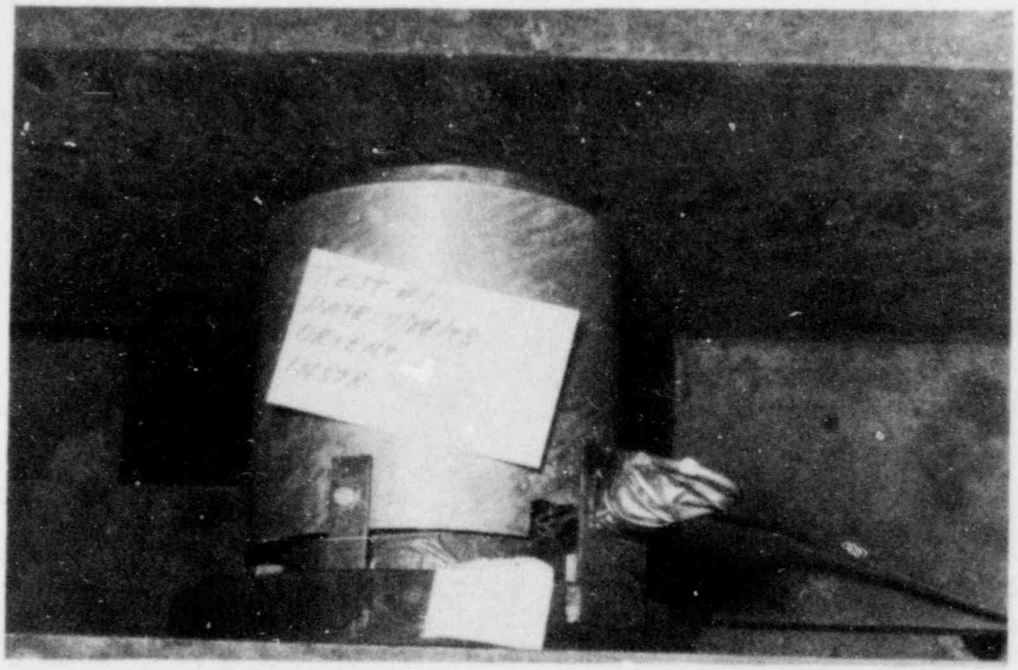

Figure 37. Load Cell Placement Between I-Beam Bumpers and Rigid Stop at Struck End of Car - Tests 10 and 11

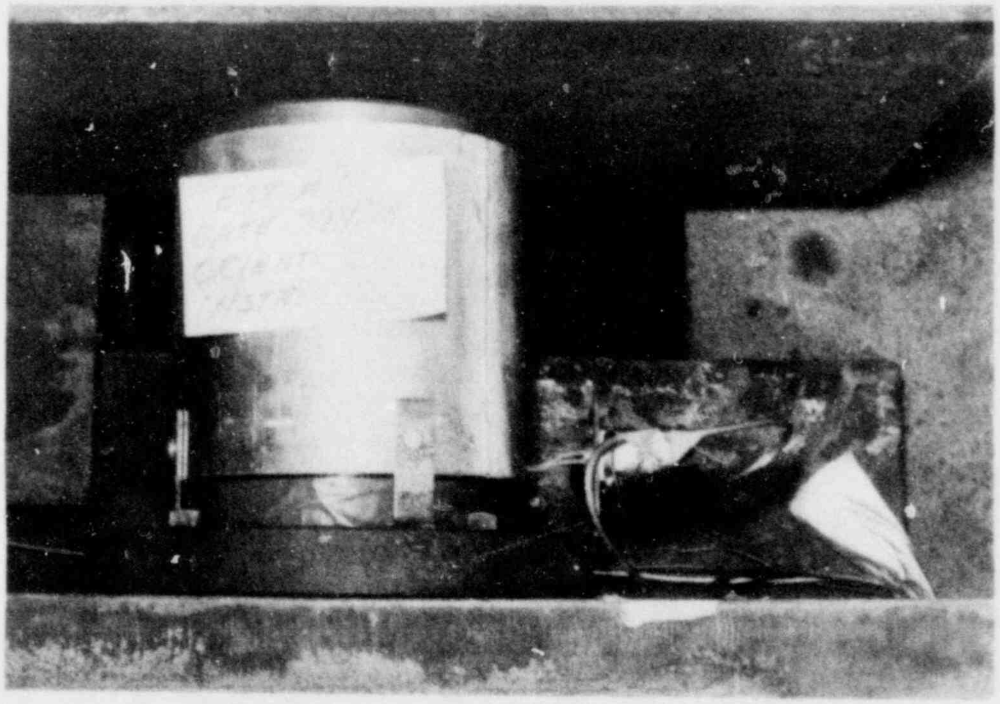

Figure 38. Load Cell Placement Between I-Beam Bumpers and Rigid Stop at Struck End of Car - Tests 10 and 11

Tests 12, 13

For these tests the Hallum cask and skid were loaded on the UCC rail car. The car was positioned on the rail so that the 0.38 m (15 in.) hydraulic EOC coupling device was at the impact end of the test car (Figure 39). The tests were conducted to provide data for comparison between the environments experienced when standard draft gear is used (Tests 1 through 5) and when EOC devices are used. Vertical restraint of the cask and skid was provided by six cable tiedowns, two of which were instrumented. The cables were mounted as near to vertical as the car and cask structure permitted. The turnbuckles on the cables were pretorqued to 101.7 N•m (75 ft-lb). Horizontal restraint was provided by welded, rigid stops in much the same way as on the standard SCL cars. The instrumentation for these tests and the instrument locations were essentially the same as those for Test 1 (Table 1), with the following exceptions.

Instrument No.	Instrument Location	Instrument Type	Axis Measured	Figure No.
1	Cable Tiedown Far End	Strain	Vertical	40
2	Not Used			
26	Cable Tiedown Far End	Strain	Vertical	41

The impact velocity for Test 12 was 18.02 km/h (11.2 mph). Problems were encountered with the data receiving and recording equipment. When the problems were corrected, the test was repeated as Test 13. The impact velocity for Test 13 was 17.86 km/h (11.1 mph).

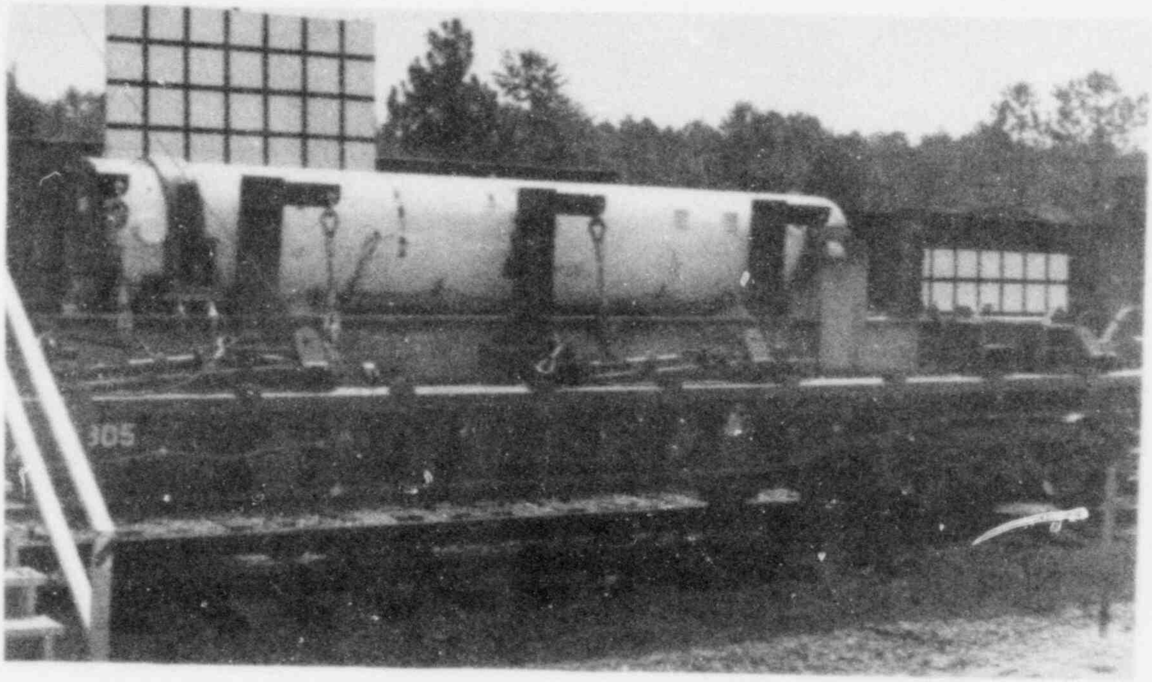

Figure 39. Hallum Cask and Skid Mounted on Union Carbide Rail Car - Tests 12 and 13

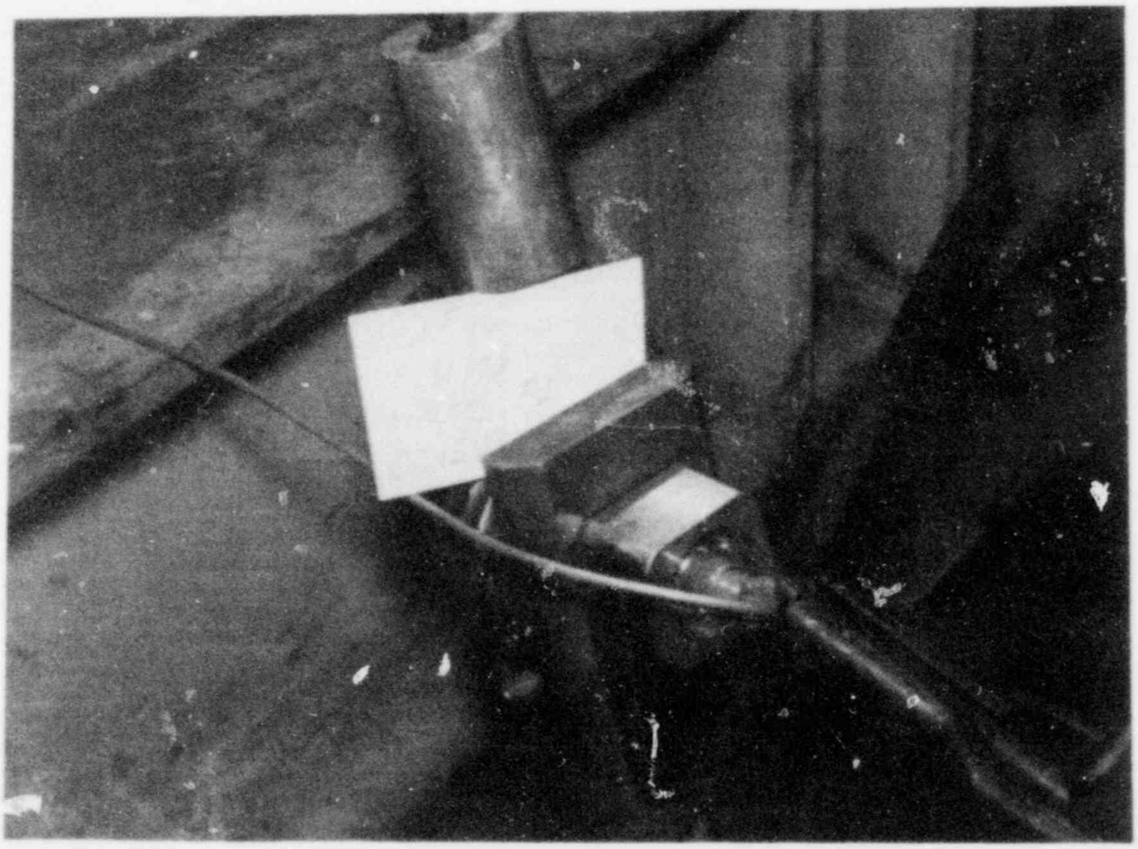

Figure 40. Instrumented Clevis Bolt Placement at Far End of Hallum Cask Skid - Tests 12 and 13

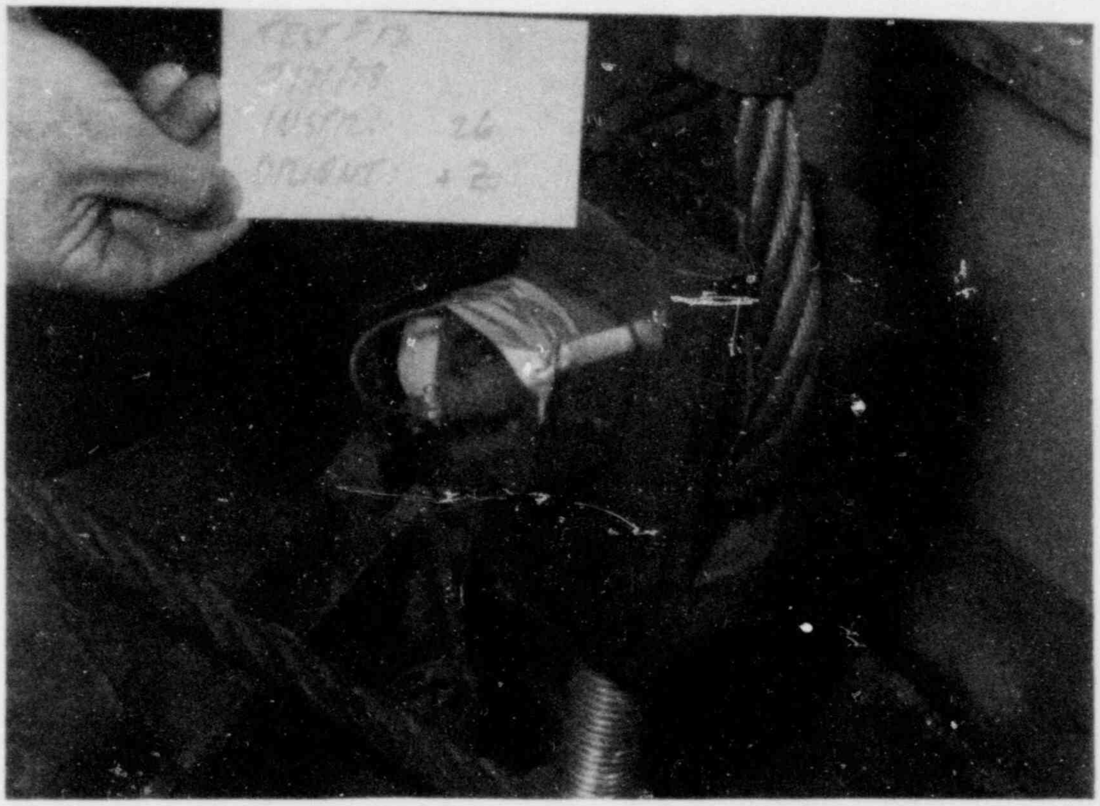

Figure 41. Instrumented Clevis Bolt Placement at Far End of Hallum Cask Skid - Tests 12 and 13

Tests 14, 15

These tests were conducted with the Hallum cask and skid mounted on the UCC rail car. The car was positioned on the rail so that the impacting end was equipped with standard draft gear. These tests were similar to Tests 6 through 9 in that only cables were used for vertical, lateral, and longitudinal restraint of the cask and skid. The tests were conducted to provide data for comparisons of tiedown forces for standard draft gear and EOC devices. For Test 14 the turnbuckles in the ten cables were torqued to 101.7 N•m (75 ft-lb) before the test, as was done for Tests 6 through 8. Test 15 was conducted with the cables slack, as in Test 9. For Tests 14 and 15 the instrumentation consisted of equipping the two cables farthest from the impact end with clevises that incorporated instrumentation pins and instrumenting the coupler. The impact velocity for Test 14 was 8.69 km/h (5.4 mph); the cask and skid slid forward about 38.1 mm (1.5 in.) at impact. The impact velocity for Test 15 was 10.46 km/h (6.5 mph); the cask and skid slid forward about 88.9 mm (3.5 in.) at impact. The anchoring stanchions on the cask skid were deformed (Figure 42).

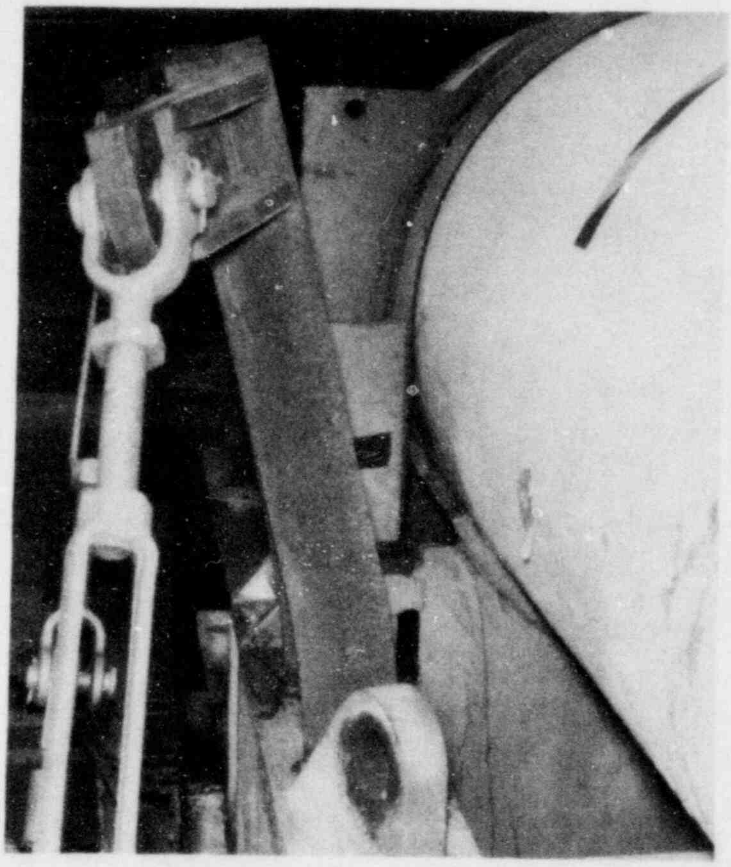

Figure 42. Deformed Anchoring Stanchion on Hallum Cask Skid After Test 15

Test 16

Test 16 was designed to provide comparison of data obtained when an EOC coupler (Test 13) is used on a rail car with data obtained when standard draft gear is used on the same car. The Hallum cask and skid were mounted on the UCC rail car. The standard draft gear was on the impact end of the car. Lateral and vertical restraint and the instrumentation mounting were essentially the same as that used for Test 13. The impact velocity for Test 16 was 17.38 km/h (10.8 mph).

Tests 17, 18

For Tests 17 and 18 the Hallum cask and skid were mounted on the SCL rail car that was equipped with a 0.51 m (20 in.) sliding center sill cushion underframe draft gear. Six tiedown cables, two of which had instrumented clevis pins on the turnbuckles, were used for lateral and vertical restraint of the cask and skid. The turnbuckles were torqued to instrumented clevis pins on the turnbuckles, were used for lateral and vertical restraint of the cask and skid. The turnbuckles were torqued to 101.7 N•m (75 ft-lb) before the tests. Longitudinal restraint was provided by rigid stops which were welded to the test car structure. The test configuration and instrumentation were essentially the same as for Test 1, except that instruments 1 and 26 were instrumented clevis pins (Figures 40 and 41) and instrument 2 was not used. The impact velocity for Test 17 was 9.50 km/h (5.9 mph). For Test 18 it was 17.22 km/h (10.7 mph).

Summary

Table 3 contains a summary of the test configuration and impact velocities.

Table 3

Summary of Test Configurations and Impact Velocities

Test No.	Test Car*	Coupler	Cask Weight tonne	(Ton)	Impact Velocities km/h	(mph)
1	A	Standard	36	40	13.36	8.3
2	A	Standard	36	40	14.65	9.1
3	A	Standard	36	40	16.90	10.5
4	A	Standard	36	40	17.22	10.7
5	A	Standard	36	40	16.90	10.5
6	B	End-of-Car	36	40	4.44	2.76
7	B	End-of-Car	36	40	9.06	5.63
8	B	End-of-Car	36	40	14.73	9.15
9	B	End-of-Car	36	40	14.73	9.15
10	A	Standard	64	70	12.91	8.02
11	A	Standard	64	70	17.98	11.17
12	B	End-of-Car	36	40	18.02	11.2
13	B	End-of-Car	36	40	17.86	11.1
[illegible]	B	Standard	36	40	8.69	5.4
15	B	Standard	36	40	10.46	6.5
16	B	Standard	36	40	17.38	10.8
17	C	Cushion	36	40	9.50	5.9
18	C	Cushion	36	40	17.22	10.7

*A = SCL car; standard couplers
B = UCC car; mixed couplers
C = SCL car; cushion underframe

Test Data

After the tests were completed, each of the participating laboratories was supplied with data tapes in the format compatible with its data reduction system. This allowed each laboratory to reduce the data in the manner best suited to its reason for participating in the test program. Sandia National Laboratories participated in the test program to gather data from which generic definitions of the shock environments could be developed. These environments might be experienced by heavy containers during rail-coupling operations if a rail car were to roll free into other cars during switching. The forces measured at the couplers, load cells, and tiedown members are discussed in Reference 4.

The data provided in this report are those that define the shock environment at the car structure/container interface as measured on the car structure. The data are presented in a single-degree-of-freedom response format. In these response spectra, 3% damping was used because it is very representative of the response of metal-to-metal connections.

Response spectra computations require continuous acceleration/time records that do not overrange the instrumentation calibration. While examining records during data reduction, we found evidence that at frequencies greater than 2 kHz some of the piezoelectric accelerometers experienced high amplitude excitation that may have overranged the charge amplifiers in the data gathering system. Some of the records produced by piezoelectric accelerometers also showed evidence of major excitations at very low frequencies which were inconsistent with time constants of the recording electronics, so the data became suspect. There also were records from piezoresistive accelerometers that exceeded instrumentation band edge and made the records unacceptable for computing response spectra.

A further test for good data was conducted wherein Fourier transforms of the event data time windows were compared with Fourier transforms of an equal time window on the same data channel preceding the coupling event. These comparisons were used to determine which data were sufficiently above the background noise to be considered valid for producing response spectra. The comparisons also were used to bound the upper frequencies to which the spectra were reduced. An upper bound of 500 Hz was selected. Data at frequencies above this valve were judged to be dominated by the background noise of steady-state car motion during its approach before coupling impact.

Response spectra were later combined using computer program ZSHAIL. This program combines up to 150 individual response spectra. The plots produced by this program present the combined data in three curves: (1) the mean or average amplitude of the accelerations at discrete frequencies of all the records combined; (2) the absolute peak amplitude of the accelerations at discrete frequencies of all the records combined; and (3) the statistical mean plus three standard deviations of the accelerations at discrete frequencies. The three standard deviation values at each frequency are equal to

$$3\left[\frac{\Sigma x^2 - \frac{(\Sigma x)^2}{n}}{n - 1}\right]^{1/2}$$

where

x = acceleration amplitude at a discrete frequency
n = number of records being combined.

Comparison of Data Based on Cargo Weight

The test program provided an opportunity to compare the response of rail car structures when two different weights of cargo are involved in rail-coupling operations. The cargo weights were 36 tonne (40 tons) and 64 tonne (70 tons). The spectra presented in this section are from measurements taken during tests conducted with rail cars that were equipped with standard draft gear. There were fewer spectra records available from the two tests conducted with the 64 tonne (70 ton) cask than from the six tests conducted with the 36 tonne (40 ton) cask. A small number of records with variations in acceleration amplitudes produces a mean +3 standard deviation plot that lies considerably above the plot of the absolute peaks of the combined records. Therefore, it seems prudent to base comparisons on the plots which envelop the absolute peaks of the combined records. The comparisons discussed are based on the peak acceleration amplitude envelope of the combined records.

Longitudinal Axis -- The envelope of responses in the longitudinal axis was slightly higher for the 36 tonne (40 ton) cargo than for the 64 tonne (70 ton) cargo across the entire frequency spectrum from 3 to 500 Hz (Figures 43 and 44).

Transverse Axis -- In the transverse axis the responses obtained with the lighter cargo dominated in most frequencies across the 3 to 500 Hz spectrum; however, the response from the heavier cargo dominated in the very low frequencies (3 to 8.5 Hz) and again in the mid frequencies (52 to 82 Hz) (Figures 45 and 46).

Vertical Axis -- The dominance of response acceleration amplitude in the vertical axis was mixed. The response was higher in this axis when the heavier cargo was on the rail car rather than the lighter cargo up to about 35 Hz. From 35 Hz to 500 Hz, the response was higher for the lighter cargo (Figures 47 and 48).

Composites of Longitudinal Axis -- Response spectra for all tests in which cars equipped with standard draft gear were combined. These combinations include data from tests with both the 36 tonne (40 ton) and the 64 tonne (70 ton) cargo. The composite spectra combine all records used for the previous comparisons in this section. Dominance by the lighter cargo response in the longitudinal axis become obvious in comparing the peak response curve of Figure 49 with the peak response curve of Figure 43 for the 36 tonne (40 ton) responses.

Composites of Transverse Axis -- When compared with the spectra of peak responses shown in Figures 45 and 46, the composite spectrum of the peak responses for the transverse axis (Figure 50) shows the general dominance of the responses experienced during tests with the lighter cargo over the heavier cargo. Only between 3 and about 8.5 Hz and between 52 and 82 Hz do the responses from the tests with the heavier cargo dominate.

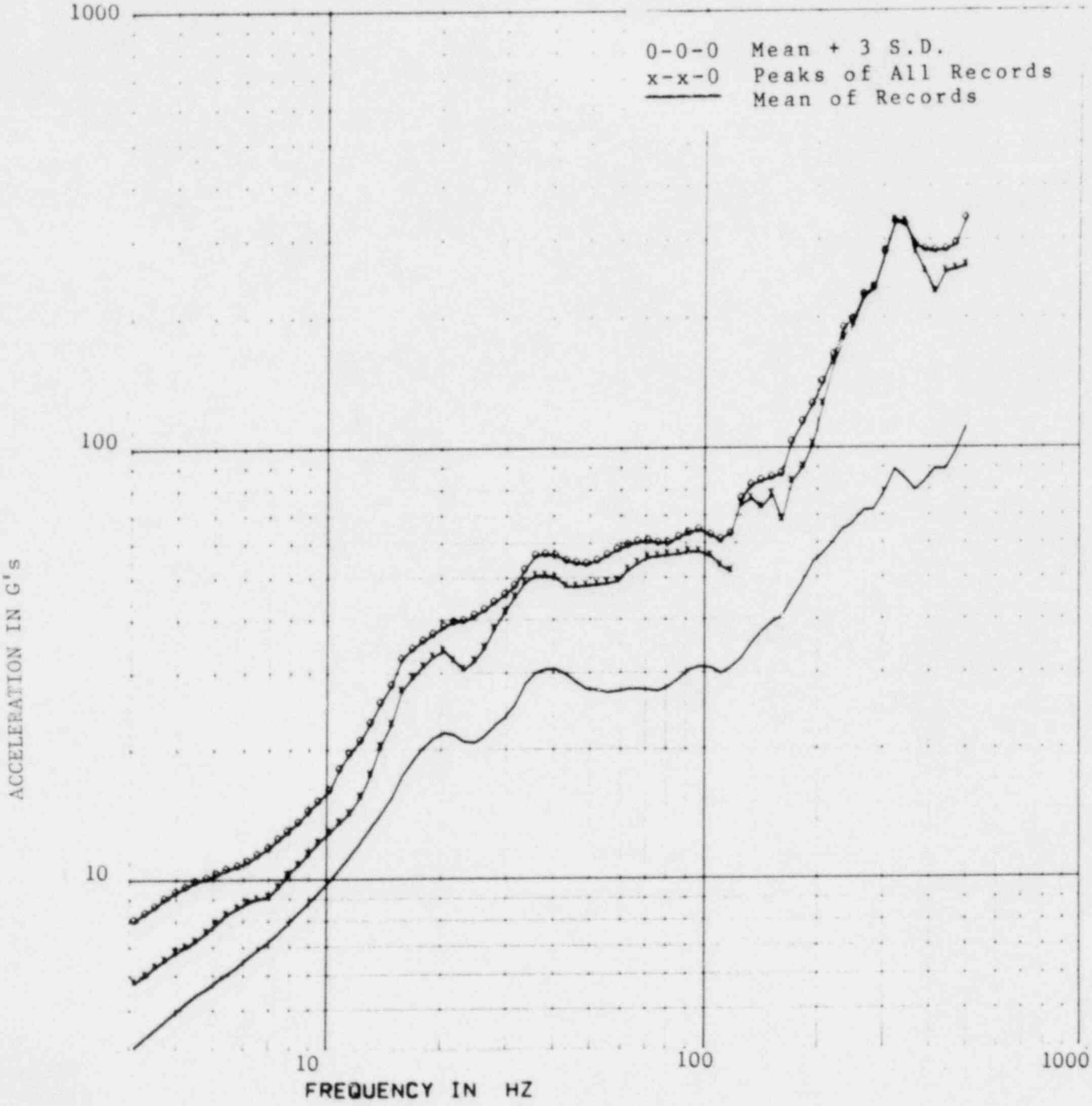

Figure 43. Response Spectra From Measurements on Rail Car Structure: Standard Draft Gear; 36 tonne (40 Ton) Cask and Skid; 13.36-17.38 km/h (8.3-10.8 mph) Impact Velocity; Longitudinal Axis; 3% Damping

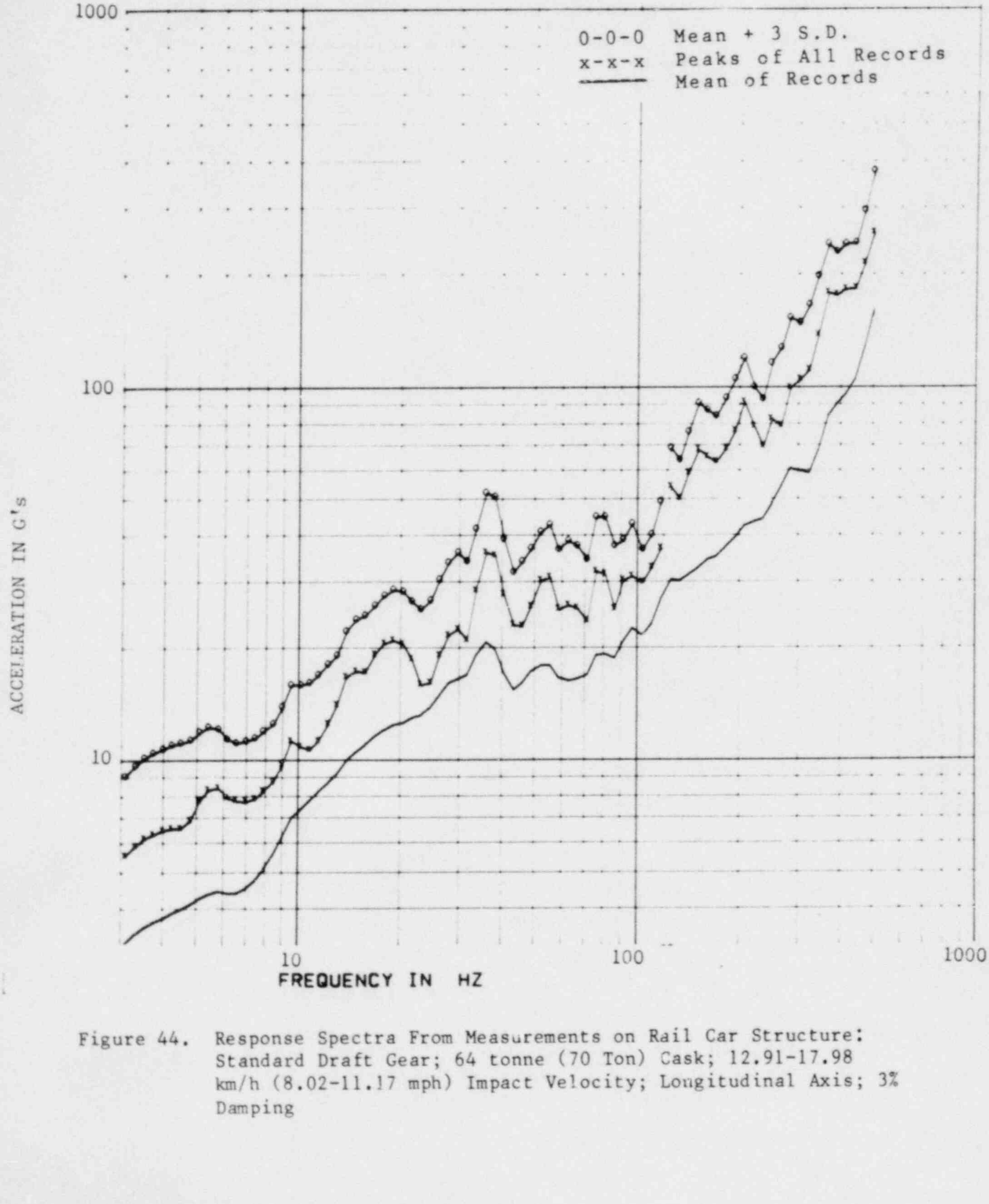

Figure 44. Response Spectra From Measurements on Rail Car Structure: Standard Draft Gear; 64 tonne (70 Ton) Cask; 12.91-17.98 km/h (8.02-11.17 mph) Impact Velocity; Longitudinal Axis; 3% Damping

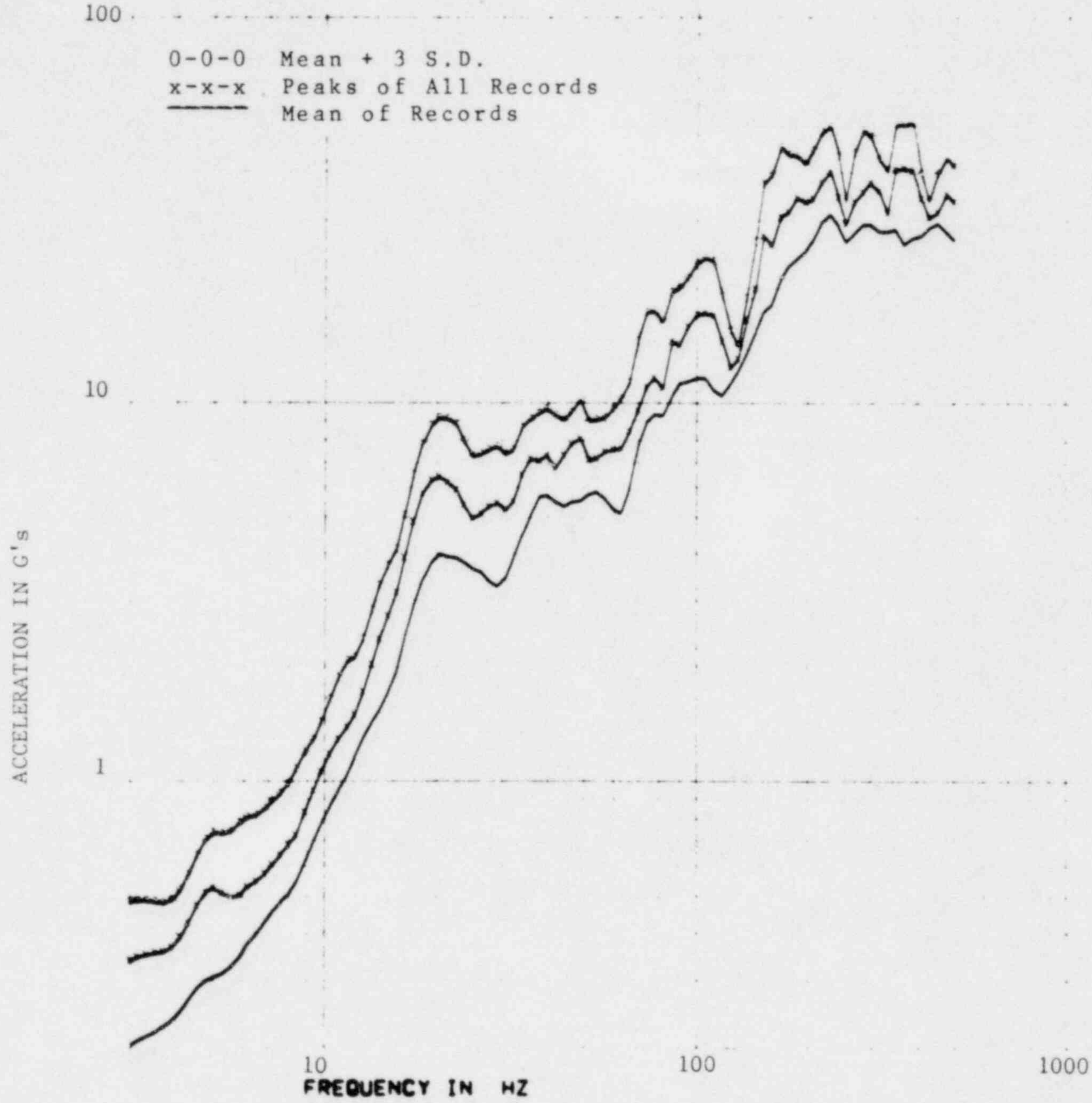

Figure 45. Response Spectra From Measurements on Rail Car Structure: Standard Draft Gear; 36 tonne (40 Ton) Cask and Skid; 13.36-17.38 km/h (8.3-10.8 mph) Impact Velocity; Transverse Axis; 3% Damping

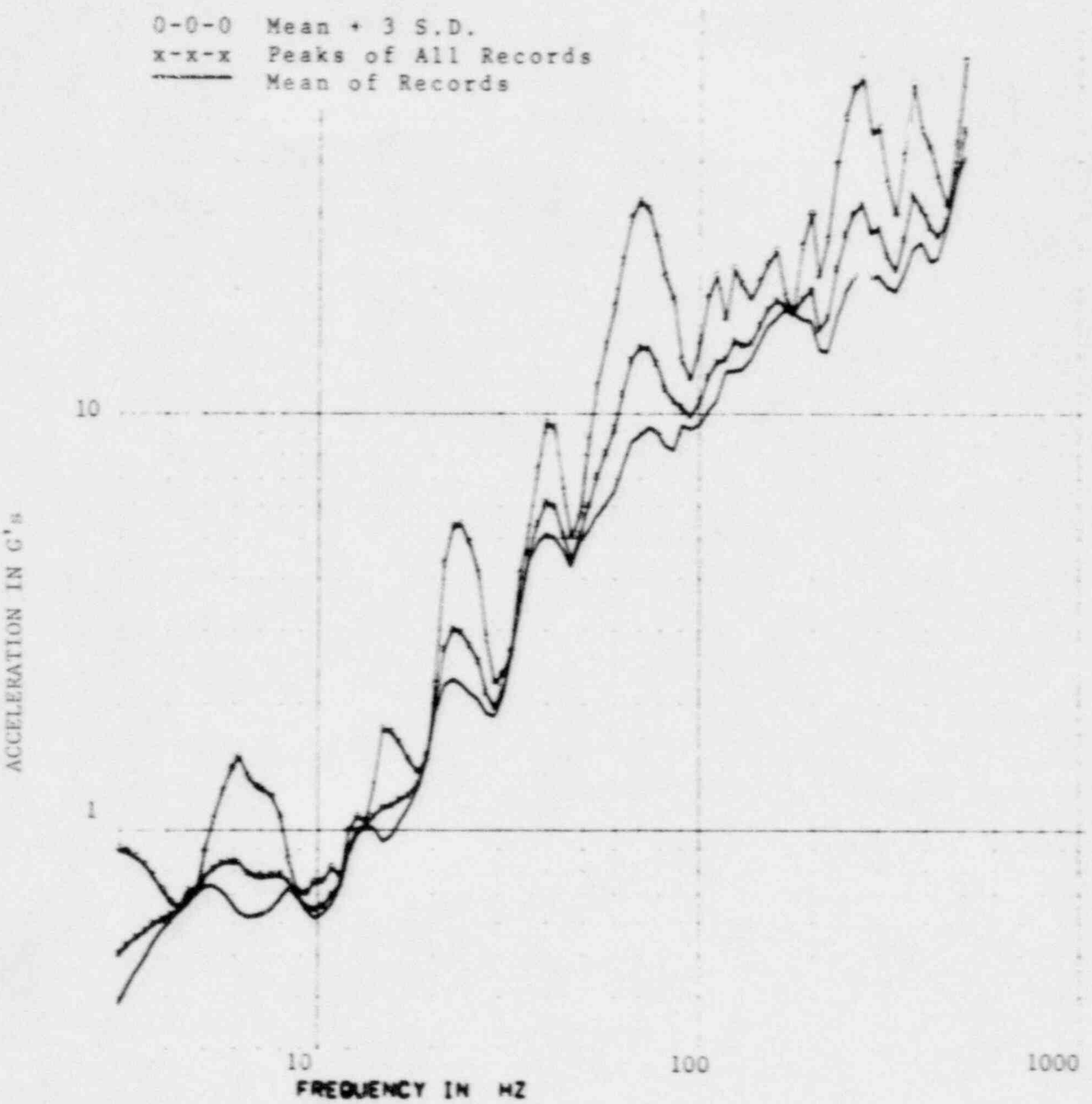

Figure 46. Response Spectra From Measurements on Rail Car Structure: Standard Draft Gear; 64 tonne (70 Ton) Cask; 12.91-17.98 km/h (8.02-11.17 mph) Impact Velocity; Transverse Axis; 3% Damping

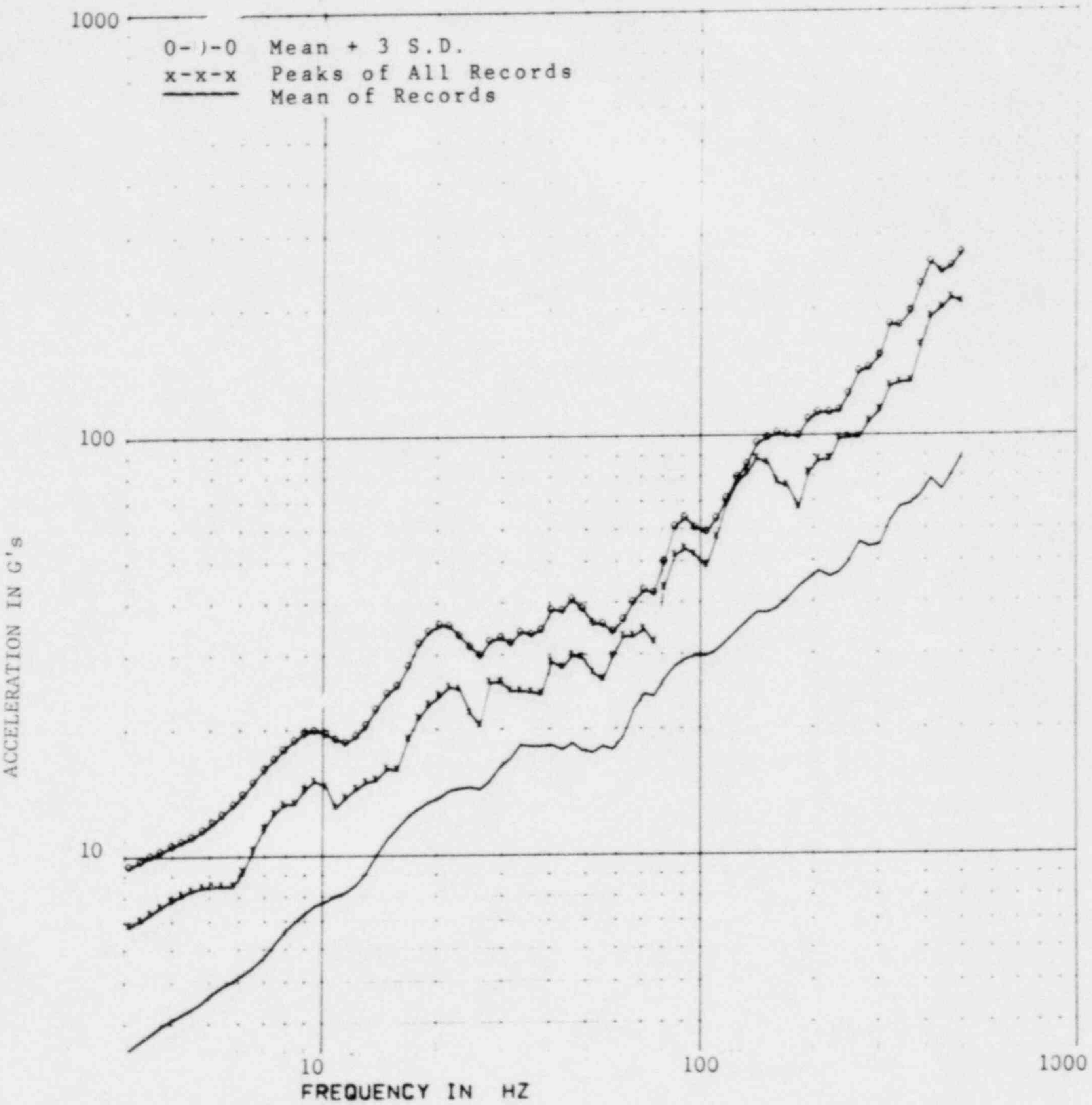

Figure 47. Response Spectra From Measurements on Rail Car Structure: Standard Draft Gear; 36 tonne (40 Ton) Cask and Skid; 13.36-17.38 km/h (8.3-10.8 mph) Impact Velocity; Vertical Axis; 3% Damping.

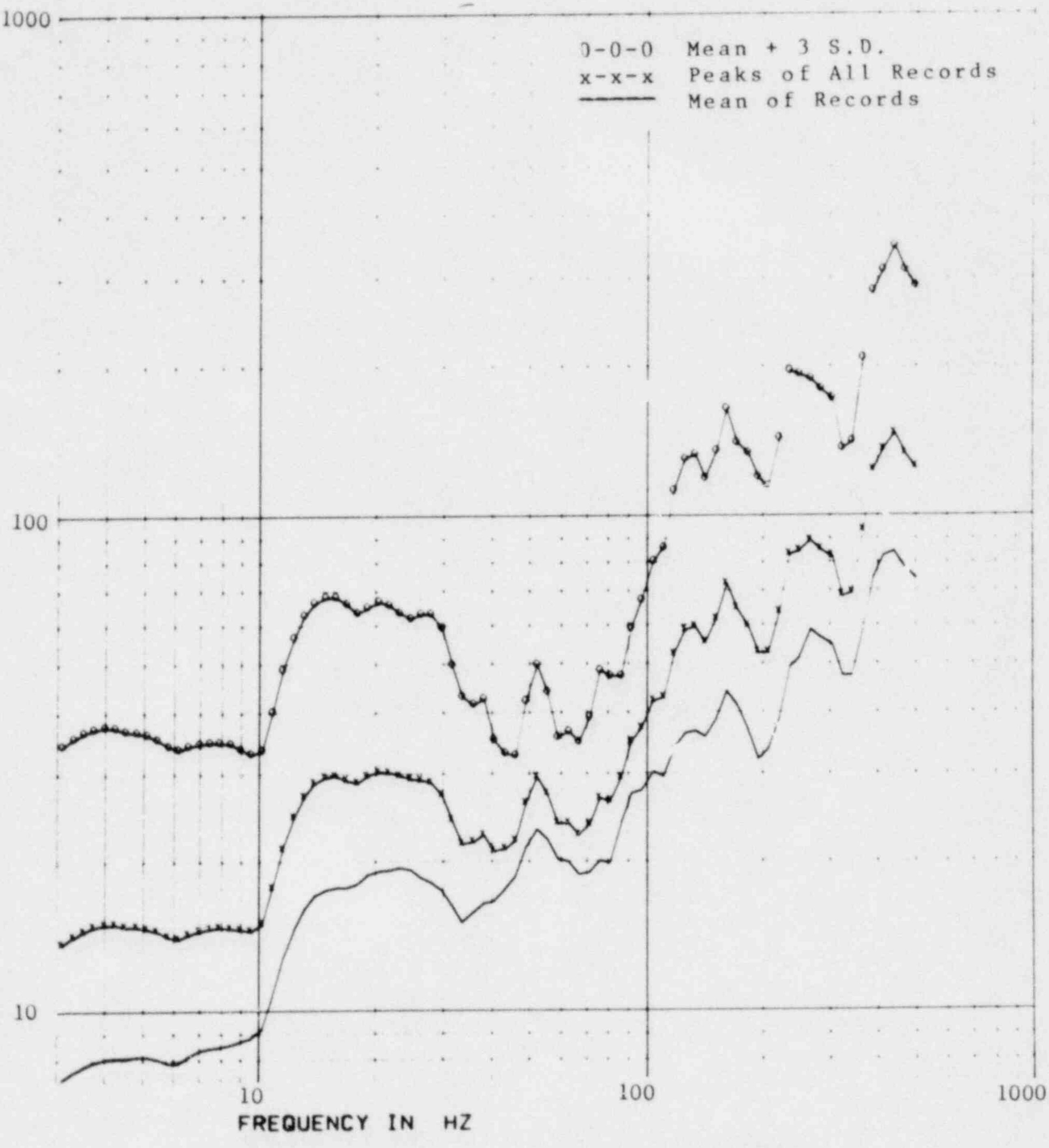

Figure 48. Response Spectra From Measurements on Rail Car Structure: Standard Draft Gear; 64 tonne (70 ton) Cask; 12.91-17.98 km/h (8.02-11.17 mph) Impact Velocity; Vertical Axis; 3% Damping

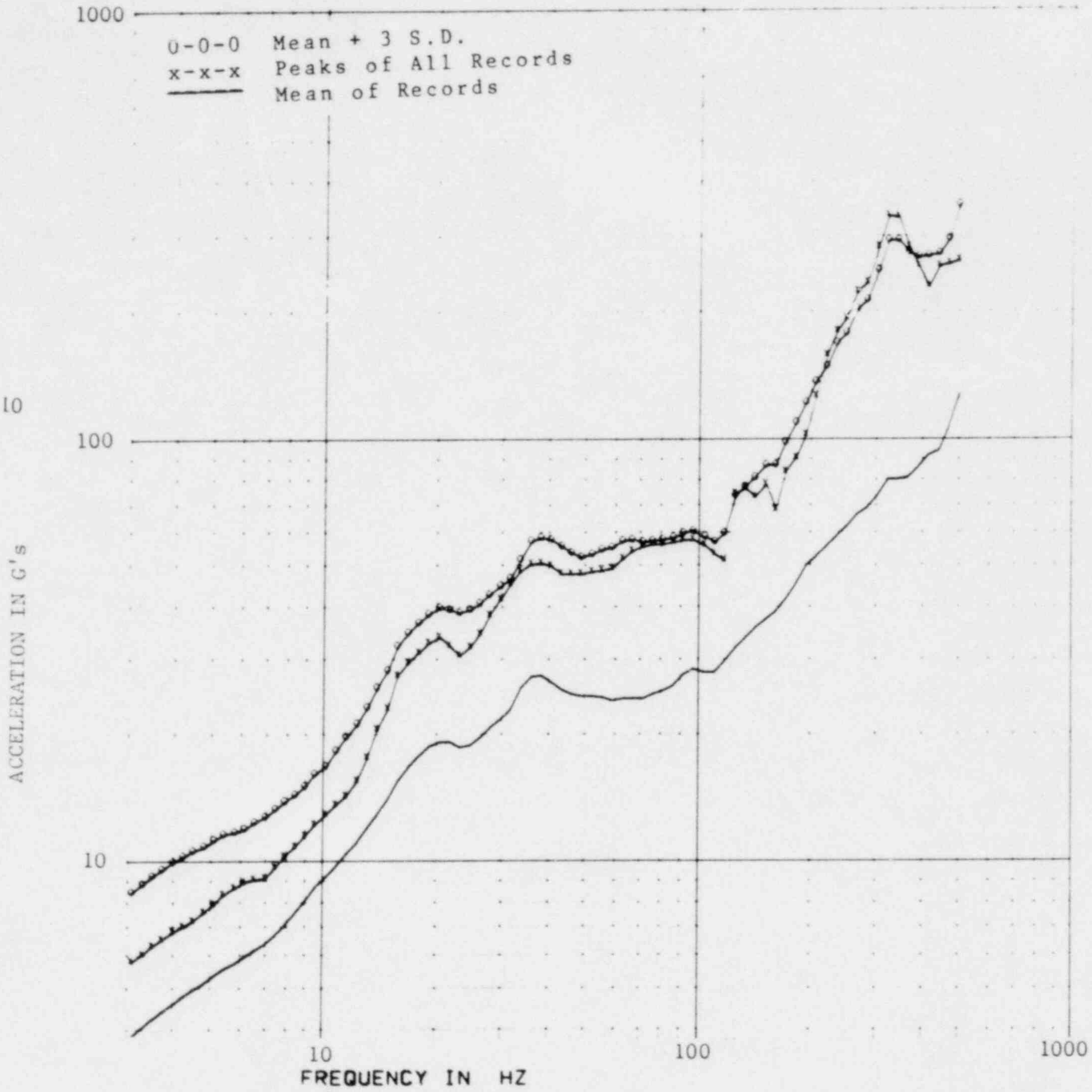

Figure 49. Composite Response Spectra of Rail Car Structure: Standard Draft Gear; 36 tonne (40 ton) and 64 tonne (70 ton) cargo; 12.91-17.98 km/h (8.02-11.17 mph) Impact Velocity; Longitudinal Axis; 3% Damping

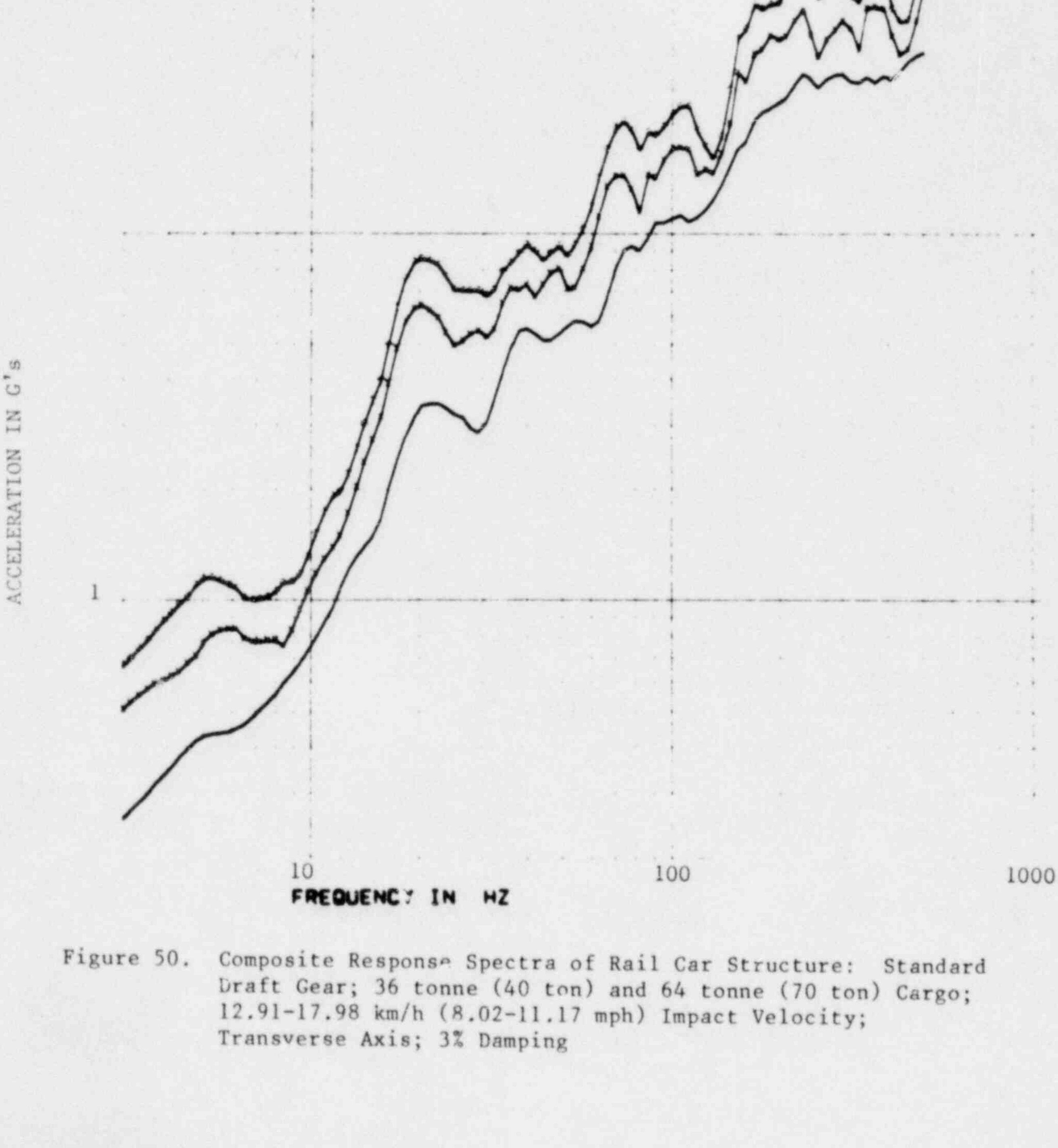

Figure 50. Composite Response Spectra of Rail Car Structure: Standard Draft Gear; 36 tonne (40 ton) and 64 tonne (70 ton) Cargo; 12.91-17.98 km/h (8.02-11.17 mph) Impact Velocity; Transverse Axis; 3% Damping

Composites of Vertical Axis -- Composite response spectra for the vertical axis are shown in Figure 51. A comparison of those spectra with the peak acceleration amplitudes of Figures 47 and 48 shows the domination of the acceleration amplitudes obtained from tests with the 64 tonne (70 tons) cargo up to about 35 Hz. Above 35 Hz the responses are dominated by the lighter cargo.

Comparison of Data Based on Different Shock Attenuating Couplers

Test 13 provided accelerometer data from which response spectra could be developed for coupling operations of a rail car equipped with hydraulic EOC coupling devices. Two tests were conducted with the 0.51 m (20 in.) sliding center sill cushion underframe coupling devices. This section of the report presents comparisons of the data obtained from rail cars equipped with standard draft gear (presented in the previous section), hydraulic EOC coupling devices, and sliding center sill coupling devices. The same 36 tonne (40 tons) cask and skid was used for each of these tests.

Longitudinal Axis -- Peak amplitudes of acceleration responses in the longitudinal axis from these tests became lower as the permissible travel distance of the coupling device became longer. This is true for the entire frequency spectrum from 3 to 500 Hz (Figures 43, 52, and 53).

Transverse Axis -- Only one record for the transverse axis contained "good" data for the car equipped with the hydraulic EOC coupling device. The response of the car structure was slightly higher in amplitude up to about 250 Hz for the car equipped with standard draft gear than for the cars equipped with the other couplers. Between 250 and 500 Hz there is little difference in the excitations experienced by the rail cars in the transverse axis regardless of the type of coupler used. There also was little difference in the response amplitude in this axis between the hydraulic EOC and the sliding center sill coupling devices across the frequency spectrum from 3 to 500 Hz (Figures 46, 54, and 55).

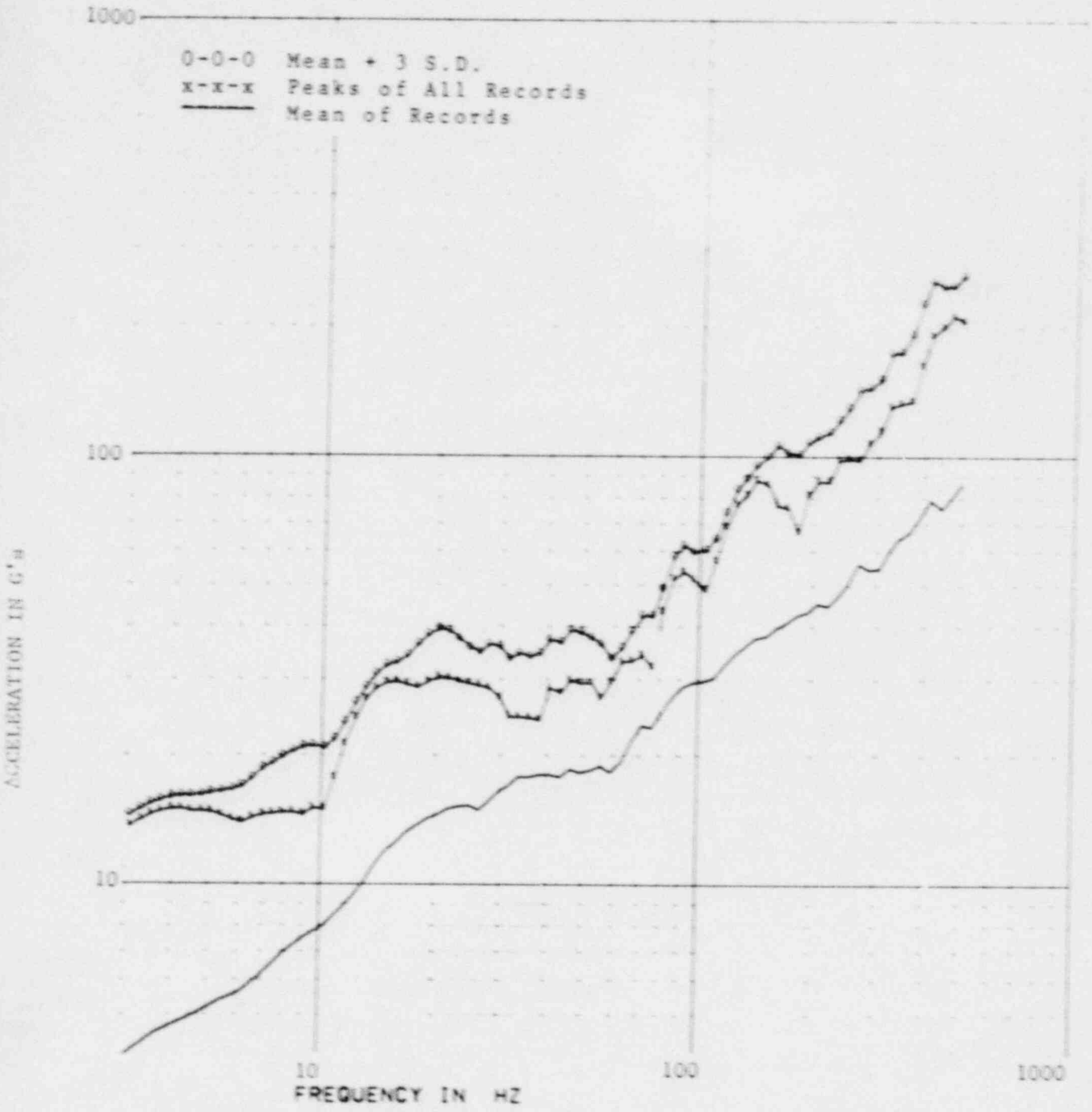

Figure 51. Composite Response Spectra of Rail Car Structure: Standard Draft Gear; 36 tonne (40 ton) and 64 tonne (70 ton) Cargo; 12.91-17.98 km/h (8.02-11.17 mph) Impact Velocity; Vertical Axis; 3% Damping

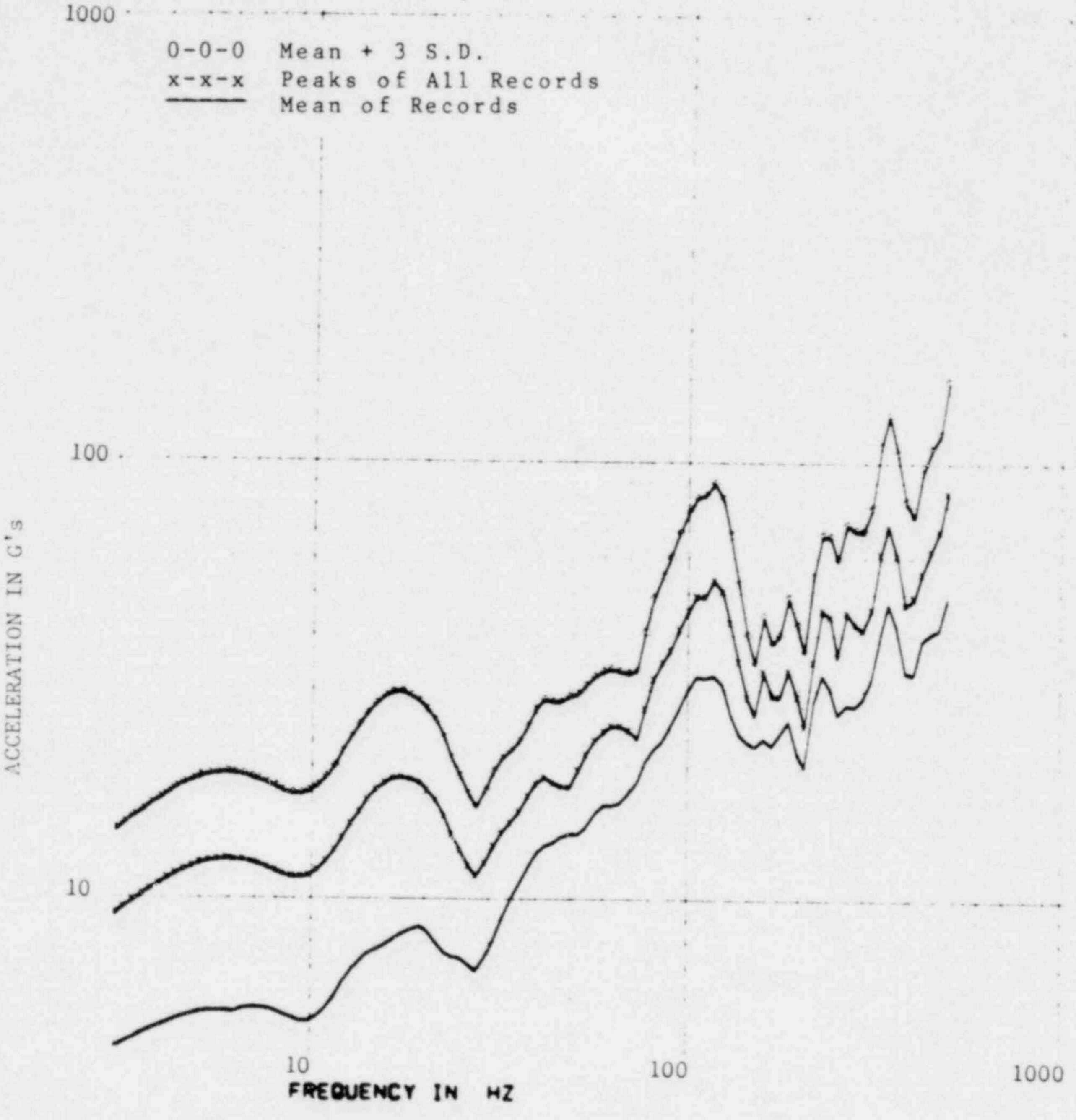

Figure 52. Response Spectra From Measurements on Rail Car Structure: 0.38 m (15-in.) Hydraulic End-of-Car Coupler; 36 tonne (40 ton) Cask and Skid; 17.86 km/h (11.1 mph) Impact Velocity; Longitudinal Axis; 3% Damping

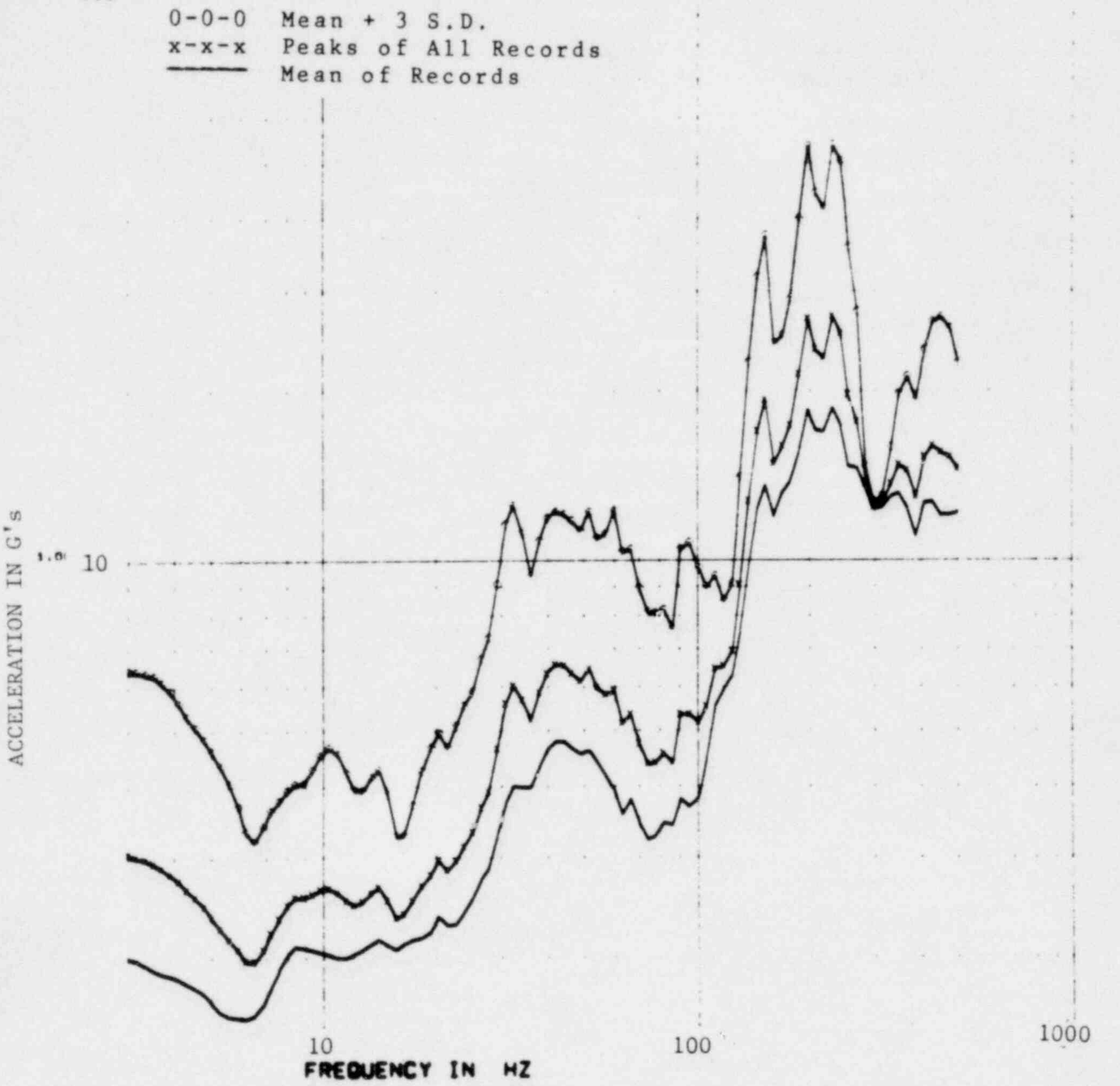

Figure 53. Response Spectra From Measurements on Rail Car Structure: 0.51 m (20-in.) Sliding Center Sill Coupler; 36 tonne (40 ton) Cask and Skid; 9.5-17.22 km/h (5.9-10.7 mph) Impact Velocity; Longitudinal Axis; 3% Damping

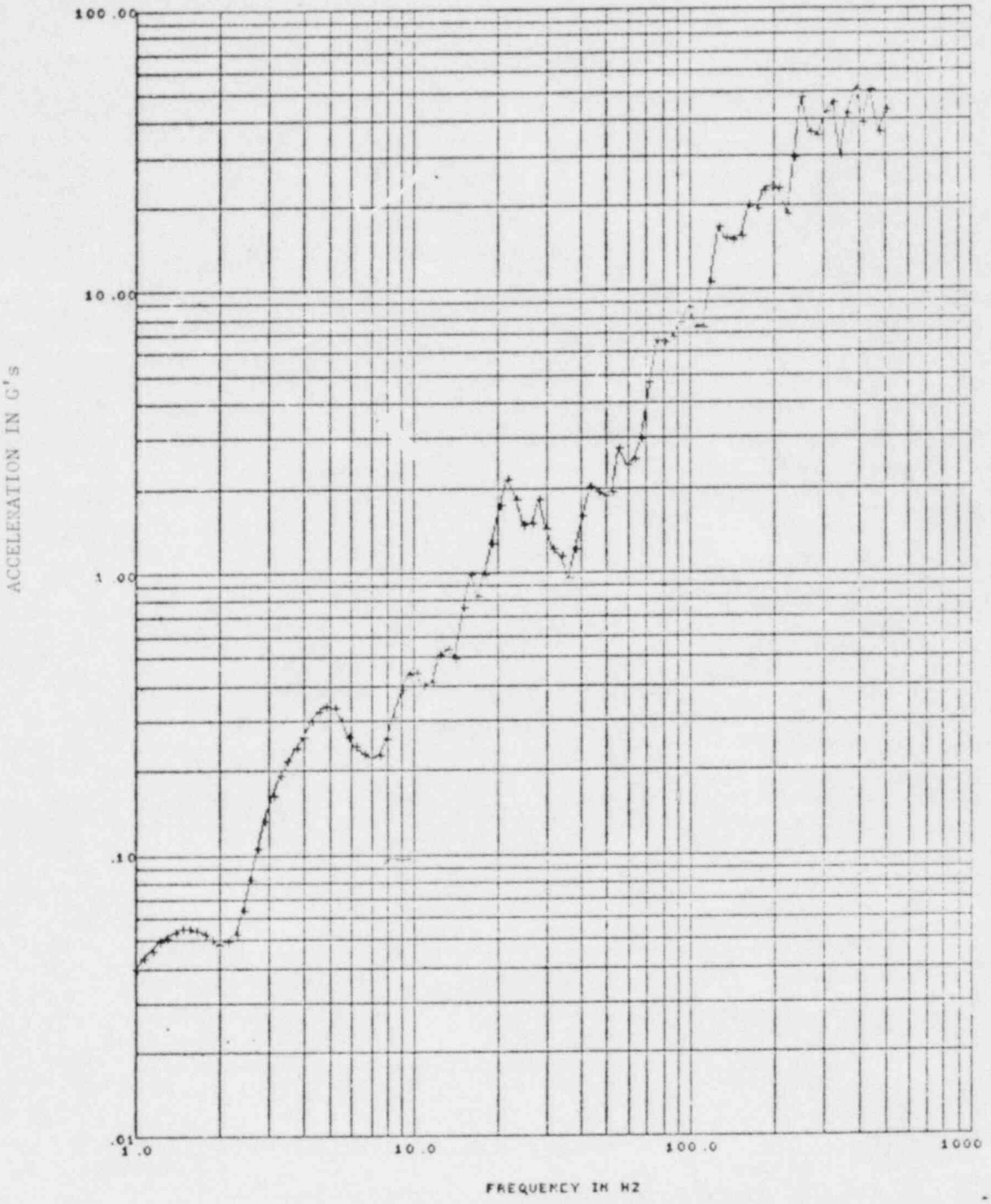

Figure 54. Response Spectrum From Measurements on Rail Car Structure: 0.38-m (15-in.) Hydraulic End-of-car Coupler; 36 tonne (40 ton) Cask and Skid; 17.86 km/h (11.1 mph) Impact Velocity; Transverse Axis; 3% Damping

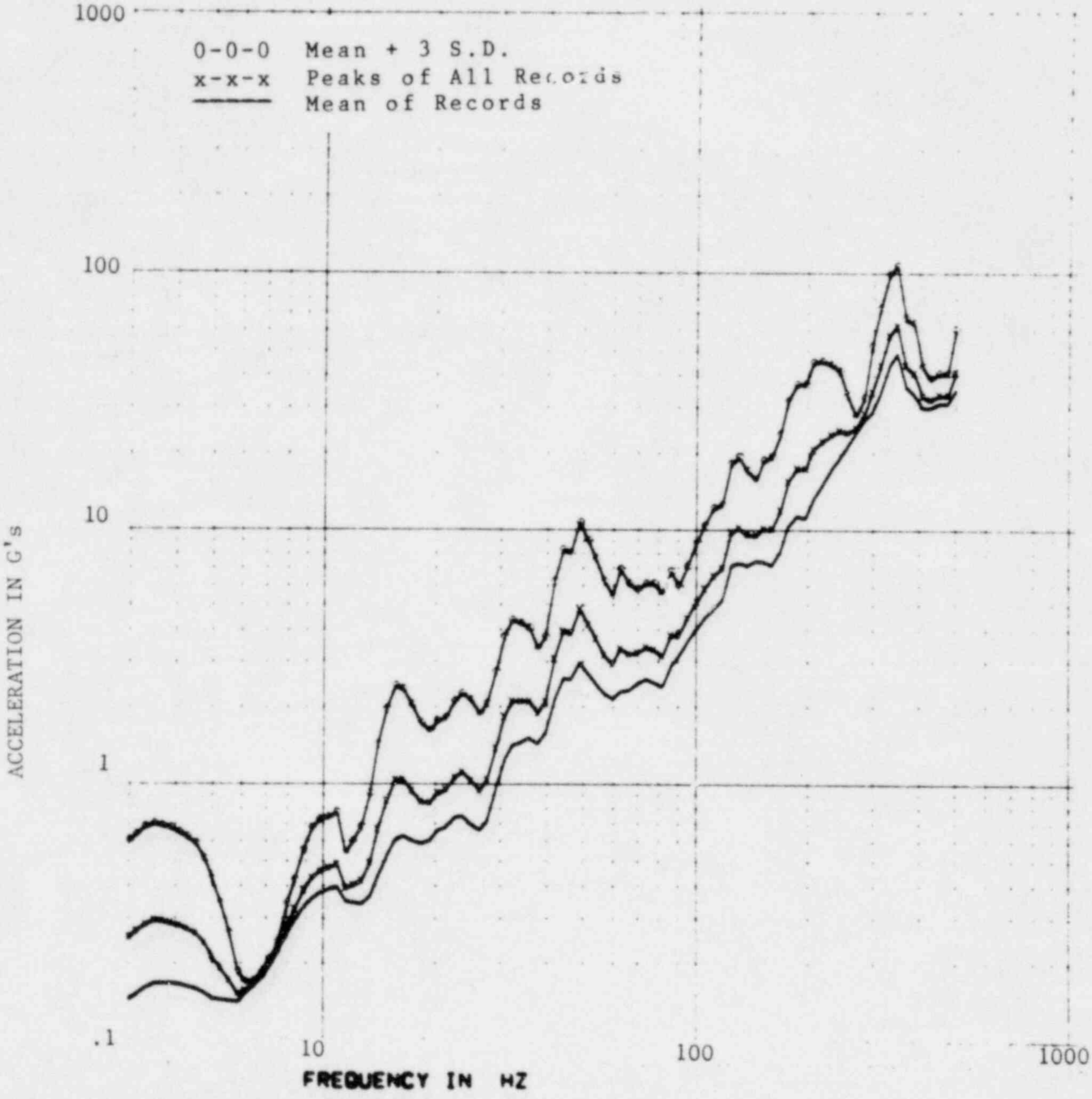

Figure 55. Response Spectra From Measurements on Rail Car Structure: 0.51 m (20 in.) Sliding Center Sill Coupler; 36 tonne (40 ton) Cask and Skid; 9.5 - 17.22 km/h (5.9-10.7 mph) Impact Velocity; Vertical Transverse Axis; 3% Damping

Vertical Axis -- Peaks of acceleration responses in the vertical axis showed the same trend in amplitudes as seen in the longitudinal axis, i.e, as the coupling device travel increased, the acceleration response amplitudes decreased. (Figures 47, 56, and 57).

Single-Pulse Representation of Shock

As discussed in Reference 1, it is often convient to approximate the complex inputs to a system which are caused by shock by using single, simple pulses. Simple pulses used to represent input shock are derived by comparing response spectra generated from test data or analysis with the response spectrum from a single pulse. This comparison usually introduces conservatism because the response spectra from test data are enveloped by the single-pulse response spectrum up to the highest frequencies of interest.

For the comparison presented here, response spectra from test data are enveloped to 90 Hz with response spectra from single, simple pulses. Enveloping to 90 Hz allows for uncertainty in the natural frequency of the tiedown system under consideration and permits using the pulses for systems whose natural frequencies lie within the 0 to 90 Hz range. Several simple pulse shapes can be selected to define an input pulse. In this report, as in References 1, 2, and 3, half-sine pulses are used.

In the longitudinal axis, the peak amplitude of accelerations of single half-sine pulses having spectra which envelop the spectra from test data are lower in amplitude for the heavier cargo than for the lighter cargo. However, the duration of the pulse is slightly longer for the heavier cargo.

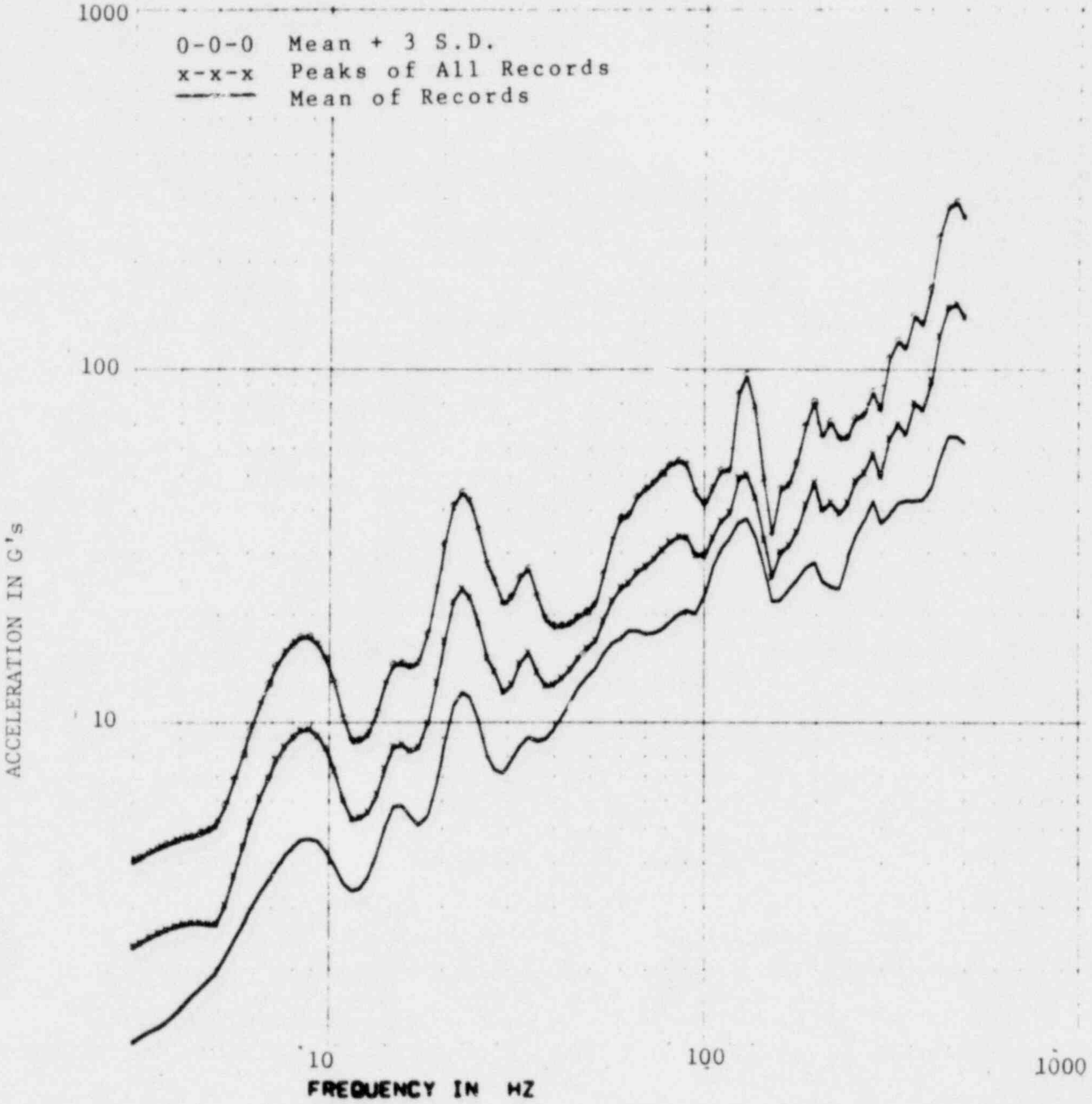

Figure 56. Response Spectra From Measurements on Rail Car Structure: 0.38 m (15 in.) Hydraulic End-of-Car Coupler; 36 tonne (40 ton) Cask and Skid; 17.86 km/h (11.1 mph) Impact Velocity; Vertical Axis; 3% Damping

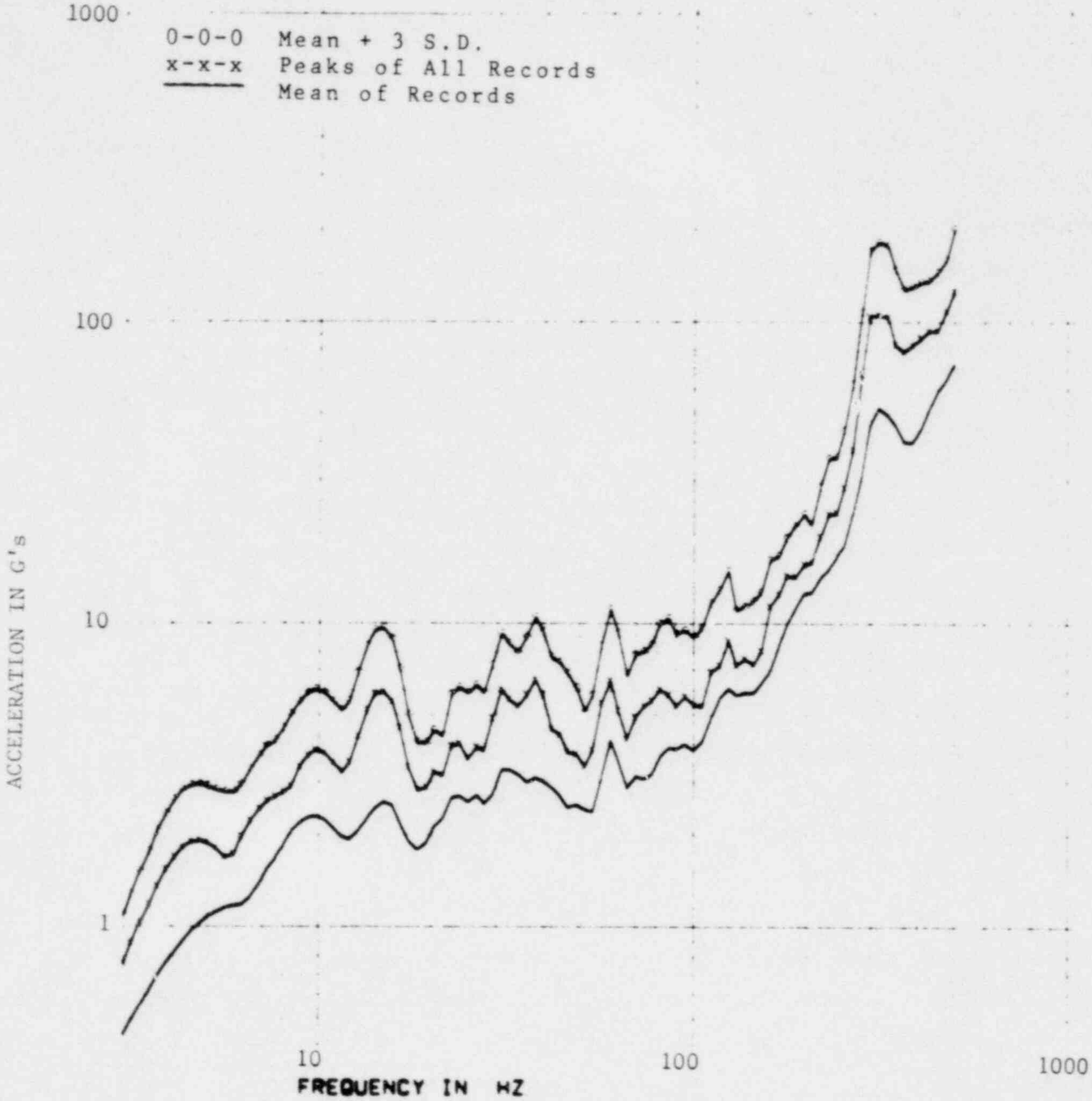

Figure 57. Response Spectra From Measurements on Rail Car Structure: 0.51 m (20-in.) Sliding Center Sill Coupler; 36 tonne (40 ton) Cask and Skid; 9.5-17.22 km/h (5.9-10.7 mph) Impact Velocity; Vertical Axis; 3% Damping

In the transverse axis, the peak amplitude of accelerations for the single half-sine pulses which envelop spectra from test data are the same for both cargos. In this case, the duration of the single pulse is shorter for the heavier cargo.

In the vertical axis using a single simple pulse to cover the entire frequency spectrum for the 64 tonne (70 ton) cargo introduces an unusual amount of conservatism. This results from fitting the spectrum from a test pulse to cover the relatively high amplitude of response in the lower frequencies and at the same time enveloping the responses at 90 Hz. To reduce this conservatism, two simple pulses are used to define the input shocks. Both simple pulses have a peak amplitude of 17 g, but one pulse has a duration of 50 ms to envelop test data from 3 to 35 Hz while the other pulse has a duration of 10 ms to envelop test data between 35 and 90 Hz. These pulses can be compared with one single half-sine pulse which has a spectrum that envelops the spectrum from test data with the 36 tonne (40 ton) cargo. This pulse has a peak acceleration amplitude of 31 g and a duration of 13 ms.

Definitions of single simple input pulses are presented for comparing responses produced by the different couplers used on the rail cars. The cargo was the same 36 tonne (40 tons) cask and skid for all of the definitions derived from the test data.

In the longitudinal axis the peak accelerations of single simple half-sine pulses whose spectra envelop the spectra developed from test data decreased as the length of coupler travel increased. At the same time, as the coupler travel increased so did the duration of the single, simple pulses.

In the transverse axis the peak acceleration of single, simple pulses decreased with increased travel, as they did for the longitudinal axis. The pulse durations did not increase in this axis with increased coupler travel.

In the vertical axis the peak accelerations of single, simple half-sine pulses also decreased as coupler travel increased; however, the duration of the simple pulses increased.

Table 4 presents definitions of simple pulses whose response spectra envelop spectra of the peak responses from test data. The table also presents definitions of single simple half-sine pulses which envelop the spectra of peak responses of composites of the spectra from data for the 36 tonne (40 ton) and 64 tonne (70 ton) cargo when the rail cars were equipped with standard draft gear.

Table 4

Coupling Shock Represented by Single Half-Sine Pulses

km/hr	Coupling Velocity (mph)	Coupler	Cargo Weight*	Axis**	Peak Acceleration (g)	Pulse Duration (ms)	Velocity Change m/s	(fps)
13.36	(8.3	Standard	A	L	34	14	3.0	9.7
to	to			T	8	11	0.6	1.8
17.38	10.8)			V	31	13	2.5	8.2
12.91	(8.02	Standard	B	L	21	20	2.6	8.5
and	and			T	8	8	0.4	1.3
19.98	11.17)			V 3-35 Hz	17	50	5.2	17.2
				V 35-90 Hz	17	10	1.1	3.5
12.91	(8.02	Standard	C	L	34	14	3.0	9.7
to	to			T	8	11	0.6	1.8
17.98	11.17)			V 3-35 Hz	17	50	5.2	17.2
				V 35-90 Hz	28	8	1.4	4.5
17.86	(11.1)	End-of-Car	A	L	30	23	4.3	14.0
				T	4.4	8	0.2	0.7
				V	20	14	1.7	5.7
9.5	(5.9	Sliding	A	L	5.3	45	1.5	4.8
and	and	Center		T	2.5	13	0.2	0.7
17.22	10.7)	Sill		V	4.4	24	0.6	2.1

*A = 36 tonne (40 ton); B = 64 tonne (70 ton); C = composite for A and B
**L = longitudinal; T = transverse; V = vertical

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