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ABSTRACT

SAND78-0065C

# RADIOACTIVE FUEL CASK RAILCAR HUMPING STUDY

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The purpose of this study was to determine shock spectra for testing cask tiedowns for railcar shipment. Eventhough radioactive shipments are not to be humped, it can happen. The response of two radioactive shipping casks due to railroad humping shocks was calculated using a spring-mass model. The two railcars for these casks had different coupling mechanisms and different tiedown arrangements. Humping tests had been performed on one of the railcars (ATMX-600) and the resulting shock spectra was used to adjust the spring-mass model to get matching results. One car (designed for cask shipment) was equipped with Freightmaster E-15 end of car coupler and had about 1/8 in. free travel of the cask skid relative to the car. The other car, (ATMX-600) equipped with Miner RF-333 draft gear was designed for nuclear weapon shipment and adapted to nuclear waste shipment by fastening the casks to the floor. Both car frames were built by the same manufacturer and are very similar.

The response of the casks was put in shock spectra format and a parametric study was performed with various cask weights. Additional studies were done on the effects of fastening the loose cask, and using the Freightmaster end of car coupler on the ATMX car. Half-sine response spectra were overlaid to include the natural frequency of the cask tiedown. The resulting shock amplitude was plotted against the cask weight for each car.

The results show a constant acceleration level for all the weights on the car with hydraulic end-of-car coupler which results from constant force at that impact velocity. The cask acceleration can be reduced by fastening it to the car, rather than allowing it to move freely through some small space. This study also shows that the cask response can be optimized on railcars without hydraulic draft gear by adjusting the tiedown stiffness to keep the tiedown frequency different than car frequencies.

The utility of using shock spectra allows the cask designer the flexibility of choosing dynamic or static test levels that are based on the total system.

## DISCLAIMER

# RADIOACTIVE FUEL CASK RAILCAR HUMPING STUDY

## INTRODUCTION

The designer of radioactive fuel casks must provide for shipping loads during transportation. Due to the size and weight of the larger casks, rail transportation is used. It also happens to contain the most severe shock environment if humping loads are considered. The DOT Code of Federal Regulations, Part 49 (49CFR - para. 174.84 dtd. 1976) states that "placarded flatcars may not be coupled into with more force than is necessary to complete the coupling." In spite of this regulation, there is a consensus among shippers that violations may occur and that it would be prudent to design for humping loads. Records from the Sandia Environmental Data Bank show that 99.8% of humping velocities are below 11 mph (17.7 km/hr). This velocity is just below the level where damage becomes apparent on most railcars. Consequently, the 11 mph impact is used as the maximum test velocity.

This analytical study was done to determine shock spectra for testing cask tiedowns for railcar shipment. Mathematical models of two railcars were prepared. One car was an ATMX-600 car (DOE weapon shipping railcar) which had been used to ship radioactive wastes. Humping shock spectra (obtained from tests) were available for this car. Detailed knowledge of the car helped in adjusting the coupler spring stiffnesses to match the test shock spectra. Load-deflection information on couplers is both non-linear and scarce. The other railcar that was modeled was designed to transport a nuclear-fuel cask. Its frame is very similar to the ATMX car frame and was constructed and built by the same company. This car, however, had a hydraulic end-of-car cushion behind the coupler designed by Freightmaster. Force-velocity curves were available and were used for the coupling spring.

This study was performed using a code called GENRE, which solves a single axis spring-mass model with nonlinear spring capability. The cars and casks were impacted into another car of similar weight at four velocities. The highest was 11 mph which is reported here.

## RAILCARS

The ATMX-600 railcar is a hopper car built on an as-cast steel frame of a flatcar and equipped with Miner RF-333 draft gear. The other car was a flatcar with cast steel frame and equipped with a Freightmaster E-15 hydraulic end of car coupler. This coupler provides a constant force during coupler deflection. The coupling force varies with impact velocity. This car is hereafter called the cushioned car.

## CASK AND TIEDOWNS

The radioactive shipping casks shipped in the ATMX-600 cars were designed by Dow Chemical Company and reported in Reference 1. The casks were held to the floor by large bolted brackets. The cask on the cushioned car was mounted to a skid which fit around a shear structure on the car, with no additional restraint. There was about 1/8 inch (3.2mm) gap between the skid and shear structures which was modeled as a nonlinear spring.

## MODELING

The railcars were divided into 7 masses each about 8 feet in length. The spring-mass model of the ATMX-600 and casks is shown in Figure 1, and for the cushioned car and cask in Figure 2. The weights of the casks were varied in four steps to determine the effect of weight on response. The acceleration-time response of the car mass that supported the cask was input to the code PSPECMO to obtain a shock spectrum of the driving point for the cask(s).

## RESULTS

A half-sine spectrum was overlaid to envelop the natural frequency of the tiedowns and the peak acceleration of the half-sine was graphed versus the four cask weights. The curves showed an increasing acceleration level with weight for the cask with the 1/8 inch free travel so the cask was tied down and analyzed. This produced a constant acceleration vs. weight curve as shown in Figure 3. The curve for the ATMX-600 showed that the draft gear produces the lowest acceleration for 160,000 lb. cargo weight and began to bottom out with greater weight. A comparison was made by replacing the Miner draft gear with the Freightmaster E-15 gear. This produced a constant acceleration vs. weight curve as shown in Figure 4. From the foregoing, it is obvious that, if a railcar is dedicated to moving casks, ~~that~~ a cushioned car is the better drafting method. It also shows the need for compatibility between the end-of-car coupler and the tiedown stiffnesses. Figures 5 - 8 are the response spectra for the 200,000 lb. cargo weight to the conditions mentioned above.

Tieing down the loose cask resulted in lowering the responses in the 50 to 60 Hz region and increasing it in the 30 to 40 Hz region. Cushioning the ATMX car lowered the 6 and 400 Hz responses and increased the 10 to 20 Hz response.

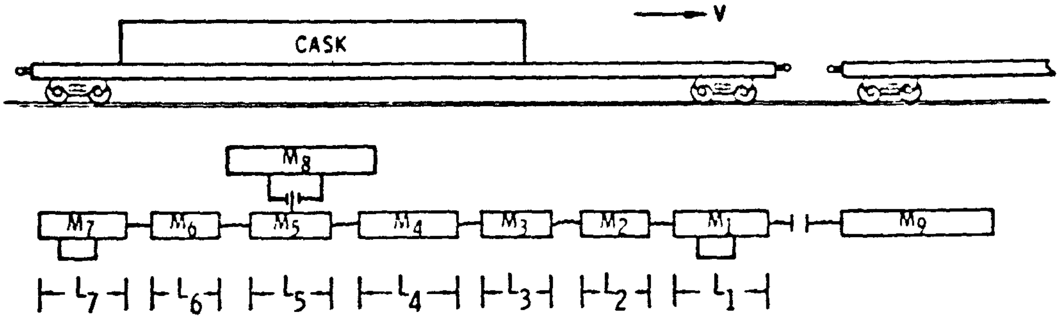
The value in using spring mass modeling and using test shock spectra is that it permits parametric studies to be performed to optimize the overall car, cask, tiedown design. The utility in using shock spectra for cask tiedowns alone is that it permits a judgment of whether to test the cask statically or dynamically if the cask tiedown natural frequencies and cask-cargo natural frequencies are known.

For a fuller treatment of this analysis see Reference 2.

# REFERENCES

1. ATMX-600 Railcar, A New Concept in Radioactive Waste Shipments, Frank E. Adcock, Proceedings from Third International Symposium on Packaging and Transportation of Radioactive Materials, Aug.16 - 20, 1971, 71501 (Vol. 1), Richland, Washington Conference.

2. Shock and Vibration Environments for Large Shipping Containers on Rail Cars and Trucks, Clifford F. Magnuson and Leonidas T. Wilson, Ref: SAND76-0427, Sandia Laboratories, Albuquerque, New Mexico.




## MODEL CHARACTERISTICS

| WEIGHT* | | (N) | (lbs) |
|---|---|---|---|
| $M_1$ | = | 78100 | (17553) |
| $M_2$ | = | 22600 | (5079) |
| $M_3$ | = | 23600 | (5301) |
| $M_4$ | = | 41100 | (9237) |
| $M_5$ | = | 23600 | (5301) |
| $M_6$ | = | 22600 | (5079) |
| $M_7$ | = | 78100 | (17553) |
| $M_8$ | = | (1) 178000 | (40000) |
| | = | (2) 445000 | (100000) |
| | = | (3) 712000 | (160000) |
| | = | (4) 890000 | (200000) |
| $M_9$ | = | 801000 | (180000) |

| LENGTH | | (m) | (in) |
|---|---|---|---|
| $L_1$ | = | 2.67 | (105) |
| $L_2$ | = | 2.44 | (96) |
| $L_3$ | = | 1.83 | (72) |
| $L_4$ | = | 2.44 | (96) |
| $L_5$ | = | 1.83 | (72) |
| $L_6$ | = | 2.44 | (96) |
| $L_7$ | = | 2.67 | (105) |

## SPRING RATES

$K_{1-2}$ = $8.98 \times 10^9$ N/M (.5130 x $10^8$ lb/in)

$K_{2-3}$ = $9.95 \times 10^9$ N/M (.5684 x $10^8$ lb/in)

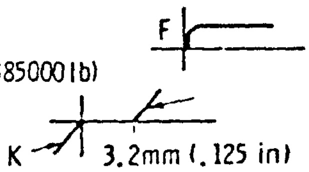
$K_{3-4}$ = $16.21 \times 10^9$ N/M (.9256 x $10^8$ lb/in)

$K_{4-5}$ = $16.21 \times 10^9$ N/M (.9256 x $10^8$ lb/in)

$K_{5-6}$ = $9.95 \times 10^9$ N/M (.5684 x $10^8$ lb/in)

$K_{6-7}$ = $8.98 \times 10^9$ N/M (.5130 x $10^8$ lb/in)

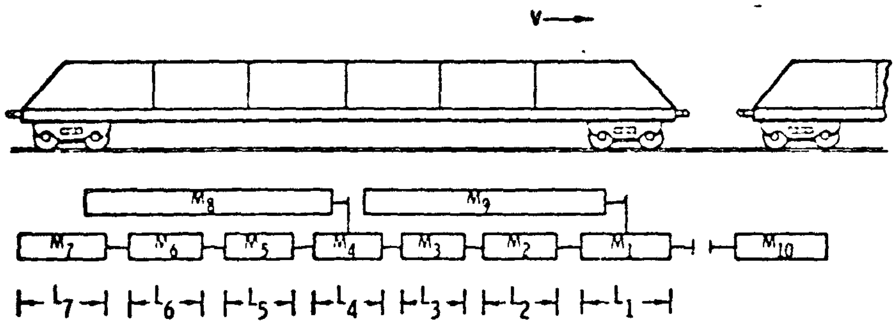
$K_{1-9}$ @ 17.78 km/hr (11.05 mph) F = 1712570 N (385000 lb)




$K_{5-8}$ = $1.75 \times 10^9$ N/M (.1000 x $10^8$ lb/in)

*SEE PAGE 4, PAR. 3.4.1.2 OF ASTM METRIC PRACTICE GUIDE E330-72

Figure 1. Spring-Mass Model; Spent Fuel Cask System




## MODEL CHARACTERISTICS

| | WEIGHT* (N) | WEIGHT* (lbs) |
|---|---|---|
| $M_1$ = | 91200 | (20500) |
| $M_2$ = | 68900 | (15500) |
| $M_3$ = | 68900 | (15500) |
| $M_4$ = | 68900 | (15500) |
| $M_5$ = | 68900 | (15500) |
| $M_6$ = | 68900 | (15500) |
| $M_7$ = | 91200 | (20500) |
| $M_8 = M_9$ = (1) | 89000 | (20000) |
| (2) | 225300 | (50650) |
| (3) | 356000 | (80000) |
| (4) | 445000 | (100000) |
| $M_{10}$ = | 890000 | (200000) |

| | LENGTH (m) | LENGTH (in) |
|---|---|---|
| $L_1$ = | 2.90 | (114) |
| $L_2$ = | 2.44 | (96) |
| $L_3$ = | 2.77 | (109) |
| $L_4$ = | 2.13 | (84) |
| $L_5$ = | 2.77 | (109) |
| $L_6$ = | 2.44 | (96) |
| $L_7$ = | 2.90 | (114) |

### SPRING RATES

$K_{1-2}$ = $1.75 \times 10^{10}$ N/M(.1000 x $10^9$ lb/in)

$K_{2-3}$ = $2.10 \times 10^{10}$ N/M(.1200 x $10^9$ lb/in)

$K_{3-4}$ = $2.98 \times 10^{10}$ N/M(.1700 x $10^9$ lb/in)

$K_{4-5}$ = $2.98 \times 10^{10}$ N/M(.1700 x $10^9$ lb/in)

$K_{5-6}$ = $2.10 \times 10^{10}$ N/M(.1200 x $10^9$ lb/in)

$K_{6-7}$ = $1.75 \times 10^{10}$ N/M(.1000 x $10^9$ lb/in)

$K_{1-10}$ $k_a$ = $7.00 \times 10^8$ N/M(.4000 x $10^7$ lb/in)

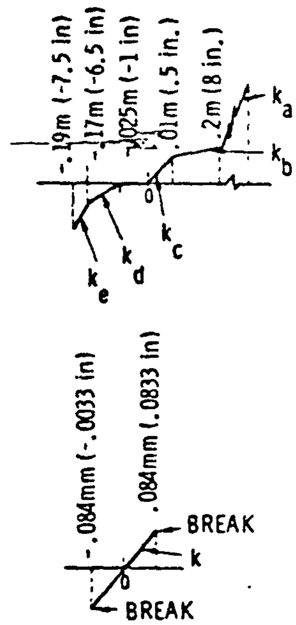
$k_b$ = $2.10 \times 10^7$ N/M (.1200 x $10^6$ lb/in)

$k_c$ = $10.51 \times 10^7$ N/M (.6000 x $10^6$ lb/in)

$k_d$ = $8.76 \times 10^7$ N/M (.5000 x $10^6$ lb/in)

$k_e$ = $12.26 \times 10^7$ N/M (.7000 x $10^6$ lb/in)

$K_{1-9}$, $K_{4-8}$ = $4.95 \times 10^{10}$ N/M (.2827 x $10^9$ lb/in)




*SEE PAGE 4, PAR. 3.4.1.2 OF ASTM METRIC PRACTICE GUIDE E380-72

Figure 2. Spring-Mass Model; ATMX-600 Rail Car with Two Fuel Casks.

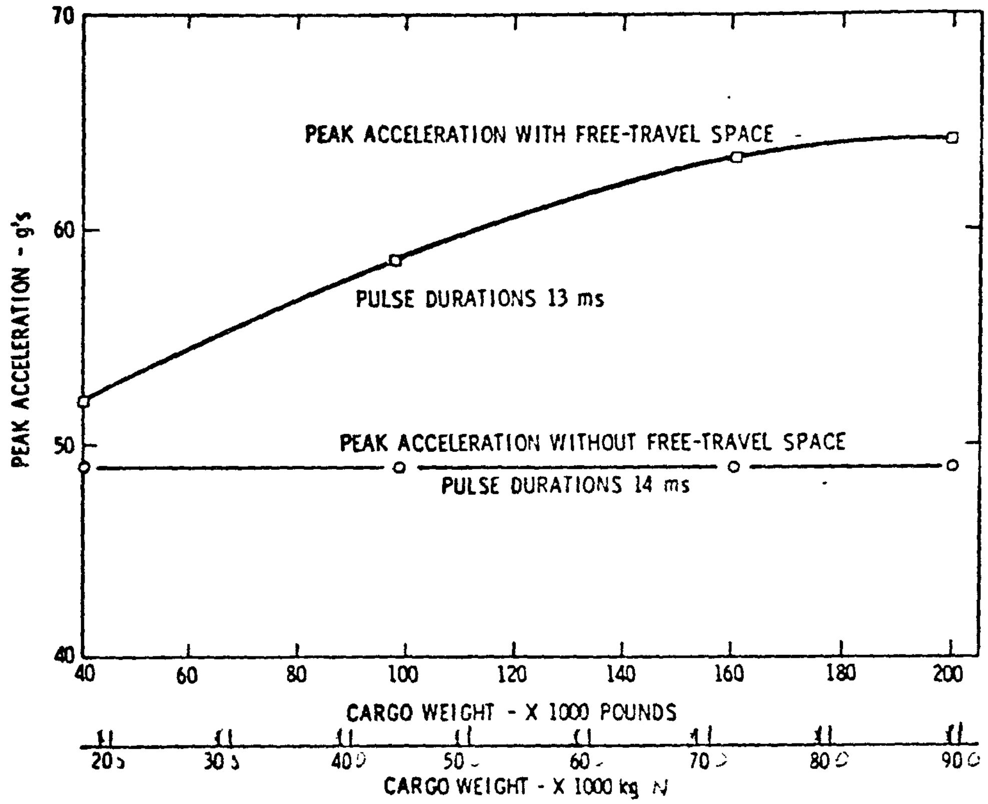



Figure 3. Peak Acceleration and Pulse Duration Half-Sine Pulses - Spent Fuel Cask System Longitudinal Axis.

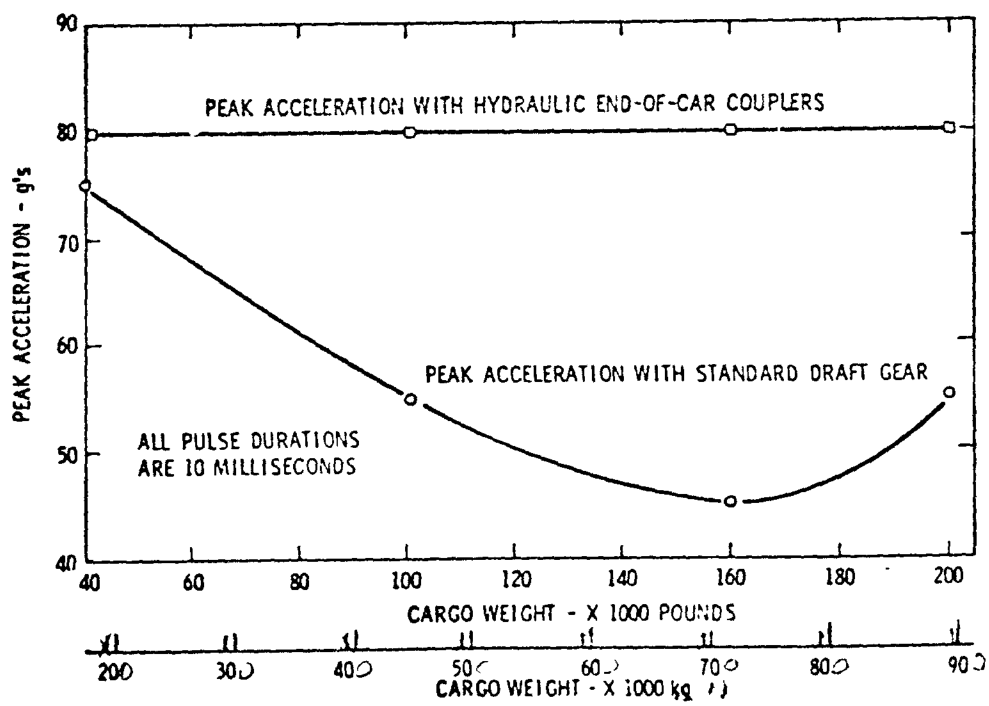



Figure 4. Peak Acceleration and Pulse Duration Half-Sine Pulses - ATMX System Longitudinal Axis.

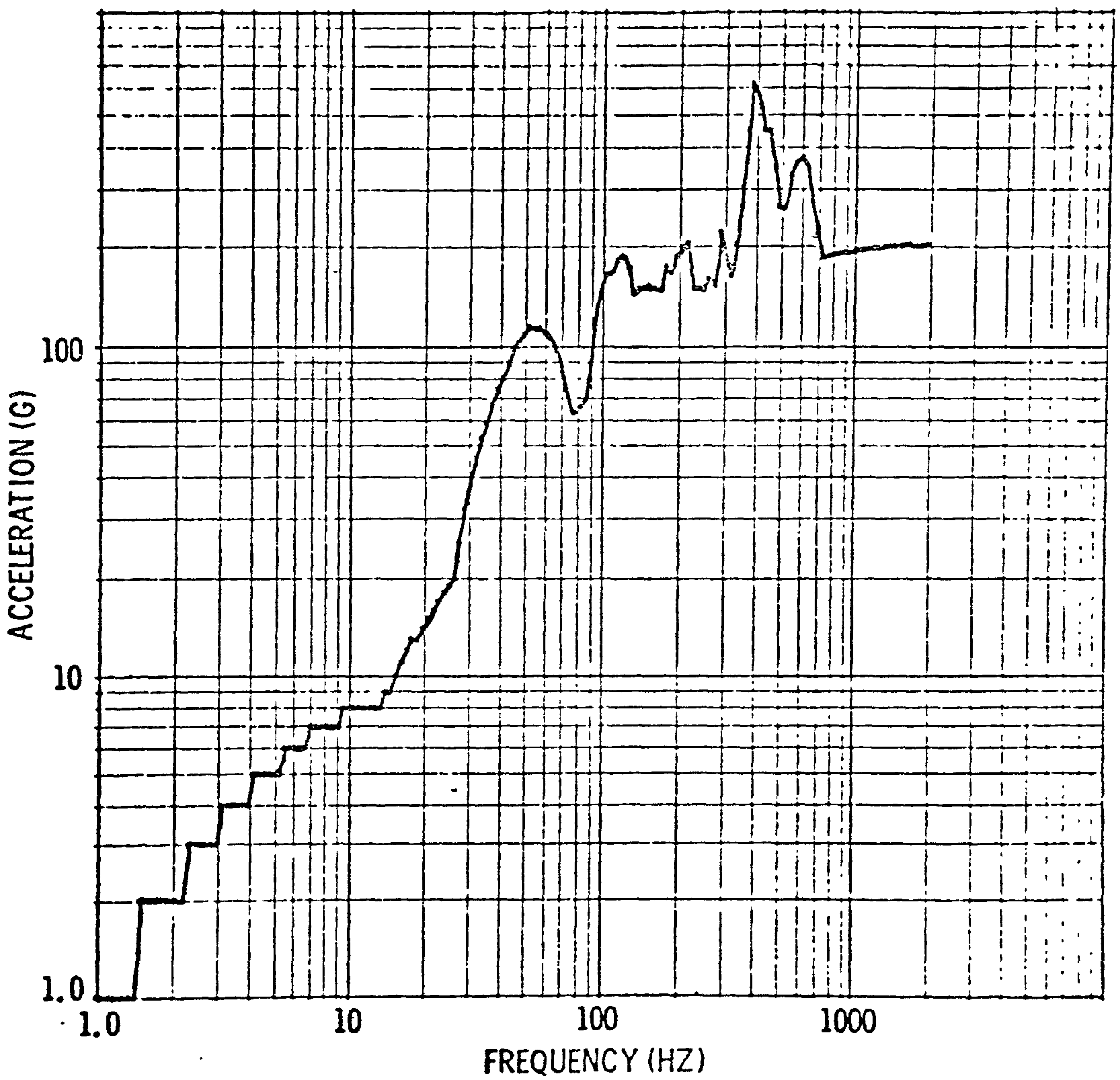



Figure 5. Response Spectrum Analytical Results.

Spent Fuel Cask System with 3.2 mm (1/8 inch) Spacing, 890,000 N (200,000 pound) Cargo, 17.78 km/hr (11.05 mph) Impact Velocity, 3 percent Damping, Longitudinal Axis

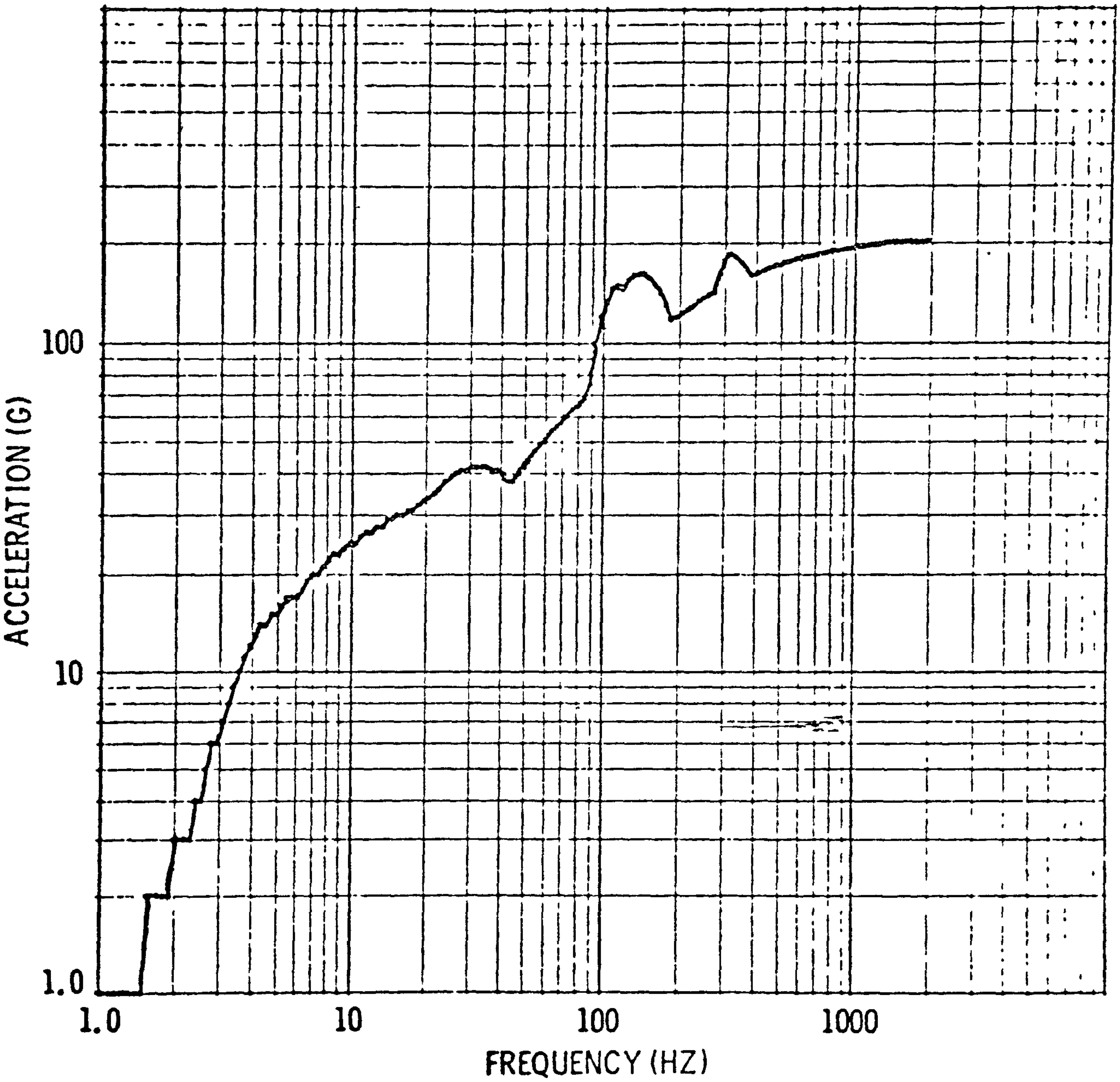



Figure 6. Response Spectrum Analytical Results.

Spent Fuel Cask System, Cargo Tied Down, 890,000 N (200,000 pound) Cargo, 17.78 km/hr (11.05 mph) Impact Velocity, 3 percent Damping, Longitudinal Axis

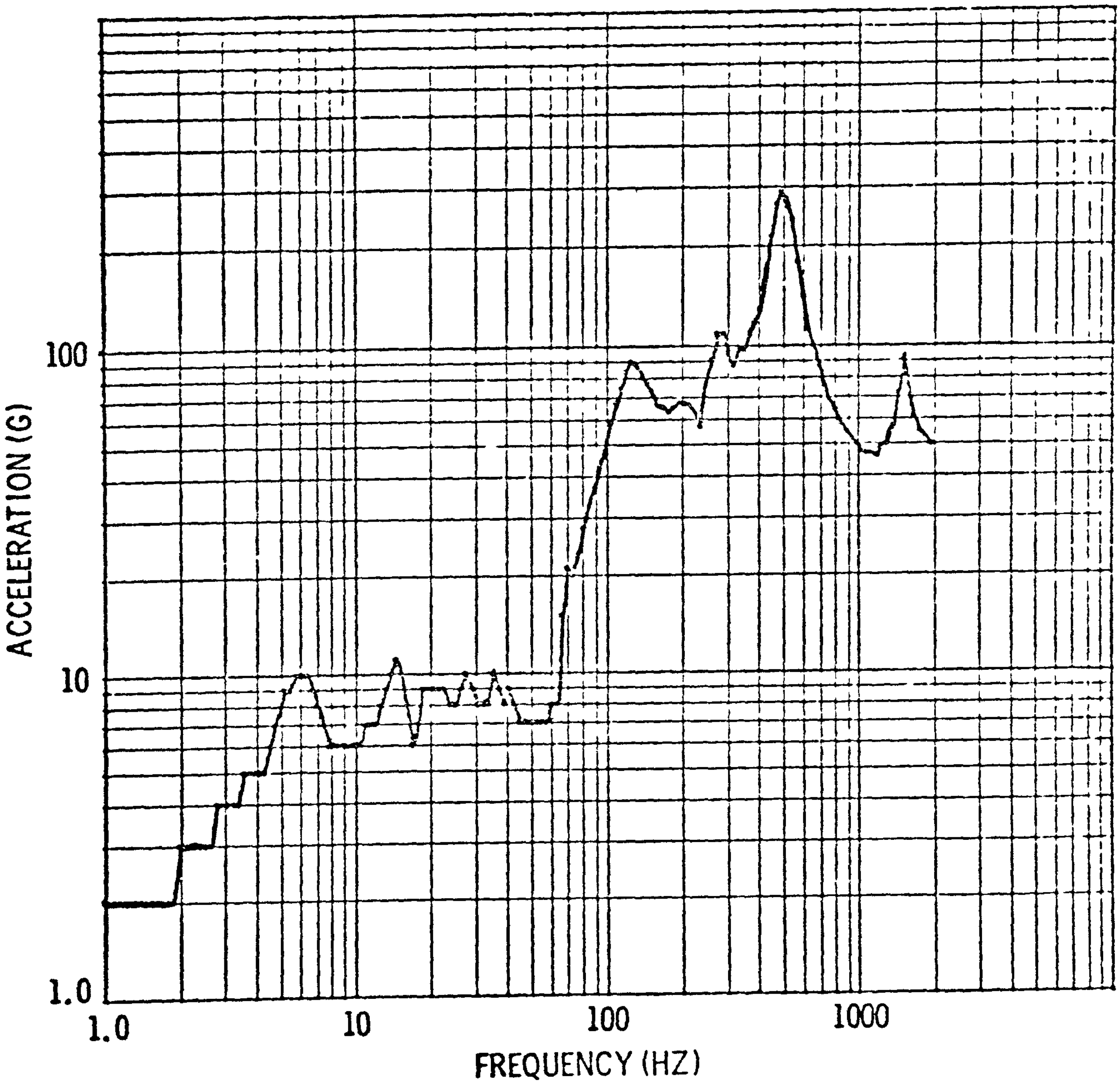



Figure 7. Response Spectrum Analytical Results.

ATMX Car, Standard Draft Gear, 890,000 N (200,000 pound) Cargo, 17.78 km/hr (11.05 mph) Impact Velocity, 3 percent Damping, Longitudinal Axis

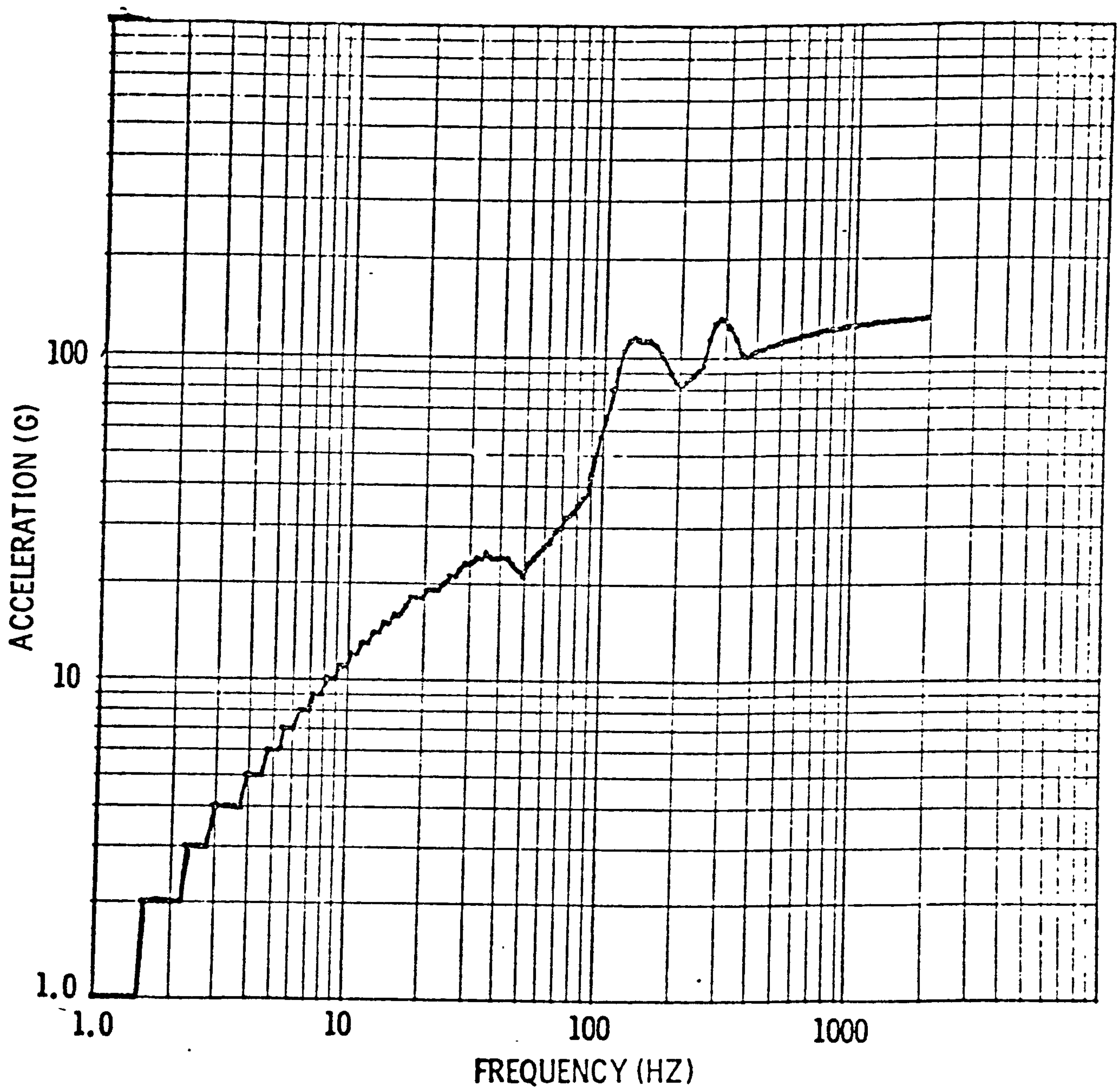



Figure 8. Response Spectrum ANalytical Results.

ATMX Car, Shock Attenuating Couplers, 890,000 N (200,000 pound) Cargo, 17.78 km/hr (11.05 mph) Impact Velocity, 3 percent Damping, Longitudinal Axis