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TANK CONTAINER IMPACT STANDARD PHASE II REPORT

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September 1998

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16. Abstract

This report describes work to further develop a proposed International Organization for Standardization (ISO) rail impact standard for tank containers. The standard is based on a concept called shock response spectrum (SRS). A test level is proposed, derived directly from rail impact testing conducted on two different container designs. The effects of various test parameters were also evaluated during the impact testing phase and recommendations are made to improve the proposed standard based on those parametric evaluations. An evaluation of various mass scaling factors to correct for containers tested at an under-weight condition is made using computational methods. Data from rail test agencies in France, Germany and South Africa are evaluated against the proposed test level.

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16\. Résumé

Ce rapport rend compte des travaux de mise au point d'un avant-projet de norme concernant l'essai au choc des conteneurs-citernes destinés au service ferroviaire et susceptible d'être adopté par l'Organisation internationale de normalisation (ISO). La norme proposée est basée sur le concept de spectre de réponse au choc. Elle propose des conditions minimales d'essai établies à partir des résultats d'essais effectués sur deux différents modèles de conteneurs-citernes. L'effet de divers paramètres sur le spectre de réponse au choc a également été étudié, et les résultats ont permis de formuler des recommandations en vue d'améliorer la norme proposée. Divers facteurs de correction applicables à l'essai de conteneurs-citernes qui ne sont pas remplis au maximum de leur capacité (en poids) ont été évalués à l'aide de modèles informatiques. Les conditions d'essai proposées ont été comparées aux données de différents laboratoires d'essai de France, d'Allemagne et d'Afrique du Sud.

17\. Mots clés

Conteneur-citerne, spectre de réponse au choc, conditions d'essai, essai au choc de matériel ferroviaire, Organisation internationale de normalisation (ISO), norme, facteur de correction de masse, fréquence, accélération

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Centre National d’Essais de Tergnier, SNCF (France)
Forschungs und Technologie Zentrum DB (Germany)
Engineering Development Center, SPOORNET (South Africa)

Tank Container Manufacturers

Containers and Pressure Vessels Limited
Welfit-Oddy Limited

Container Lock Manufacturer

Holland Company

EXECUTIVE SUMMARY

This project is the second phase of an initiative to develop a performance standard for impact testing of tank containers, equivalent to that currently described by CSA.B620 or AAR.600, as a proposed International Organization for Standardization (ISO) requirement for certification for rail transport.

The work conducted in the course of this project involved the following key aspects:

- Performing impact testing on two different tank containers to evaluate the effect of different parameters, including container design, impact velocity and restraint configuration, on the shock response spectrum (SRS);
- Developing a minimum SRS test level for the draft impact standard based on the testing conducted at the Centre for Surface Transportation Technology (CSTT);
- Assessing the Mass Correction Factor proposed in the draft standard using simulation results; and
- Analysing impact data from foreign test agencies for comparison with the proposed Minimum SRS curve.

This report summarizes the results of the impact testing conducted by CSTT, the computer simulations performed by TES and the foreign test agency data gathered by TES.

The principal recommendations stemming from this investigation are as follows:

- The loaded tank container should be impact tested on a rail car with container locks conforming to ISO 1161 and the container should be tested with a no gap condition at the front locks;
- The shock response spectrum should span 0.5 to 250 Hz and should be derived from a complete input acceleration time history 2.05 seconds in length and sampled at 1 kHz;
- The Minimum SRS Test Level should be defined by the logarithmic curve defined by 0.55 g at 1 Hz and 27 g at 250 Hz;
- In addition to CSTT, the test agencies in France, Germany and South Africa are all capable of conducting impact testing as per the draft standard; therefore, the proposed standard could be put forth as a basis for an international tank container rail impact standard.

SOMMAIRE

Ce rapport présente les résultats de la deuxième phase d'un projet visant l'élaboration d'une norme d'essai au choc des conteneurs-citernes, égale dans ses exigences à la norme CSA B620 ou à la norme 600 de l'AAR, et susceptible de devenir une norme ISO d'homologation pour le service ferroviaire.

Les travaux menés durant cette phase du projet comportaient plusieurs aspects :

- essais sur deux différents modèles de conteneurs-citernes en vue de déterminer l'effet sur le spectre de réponse au choc de divers paramètres, notamment la configuration du conteneur-citerne, la configuration du dispositif d'immobilisation sur le wagon porte-conteneur et la vitesse d'impact;
- détermination des conditions minimales d'essai à prescrire, sur la base des résultats d'essais effectués par le Centre de technologie des transports de surface (CTTS);
- validation du facteur de correction de masse proposé dans l'avant-projet de norme, au moyen de simulations sur ordinateur;
- examen des données fournies par des laboratoires d'essai étrangers en regard des conditions minimales d'essai proposées.

On trouvera dans ce rapport un résumé des résultats des essais au choc menés par le CTTS, des simulations sur ordinateur effectuées par la société TES et des données recueillies par cette dernière auprès de laboratoires d'essai étrangers.

Cette phase de l'étude a permis de formuler les recommandations suivantes :

- pour les essais au choc, les conteneurs-citernes chargés devraient être arrimés aux wagons porte-conteneurs au moyen de dispositifs de fixation conformes aux exigences de la norme ISO 1161, et les dispositifs de fixation avant ne devraient pas avoir de jeu;
- le spectre de réponse au choc devrait englober la plage de 0,5 à 250 Hz et être établi à partir d'un enregistrement complet de l'accélération impartie d'une durée de 2,05 secondes, échantillonné à une fréquence de 1 kHz;
- les conditions minimales d'essai devraient être définies par la courbe logarithmique reliant les points 0,55 g à 1 Hz et 27 g à 250 Hz;
- les laboratoires d'essai en France, en Allemagne et en Afrique du Sud, comme le CTTS, sont équipés pour réaliser les essais au choc selon les exigences définies dans ce projet de norme; par conséquent, celui-ci pourrait être proposé comme base d'une norme internationale d'essai au choc des conteneurs-citernes en vue de l'homologation pour le service ferroviaire.

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ABBREVIATIONS AND DEFINITIONS

Accelerometer
A transducer designed to convert acceleration into an electrical signal.

Anvil Car
The car that is held stationary and subjected to impact by the moving or hammer car. CSTT used two tank cars as anvil cars during impact testing.

COFC
Container-on-flat-car, rail flat car used for transport of intermodal containers.

Corner castings
Those parts that are normally present at each of the eight corners of the tank container and are designed to interface with the corner fittings.

Corner/securement fittings
The positive lock mechanisms (hereafter referred to as the corner fittings or corner pegs), used to secure a tank container to the bed of a railway car, which within the context of this standard must meet the requirements of ISO 1161.

Coupling (Railway)
The physical linking of one rail car to another by means of either manually operated or automatic linkages (couplers).

Coupling (Vibrational)
The situation where vibrational modes are not independent of one another but where energy can be transferred from one mode to the other.

CSTT (Centre for Surface Transportation Technology)

Damping Ratio
The ratio of actual damping coefficient to the critical damping coefficient.

Draft Gear
The equipment (typically North American), connecting the coupler at each end of the rail car to the sill, which is intended to receive the shocks incidental to train movement and coupling.

Gravitational Units (g's)
Unit of acceleration equal to approximately 9.81 m/s^2.

Hammer Car/Wagon
The device, normally a rail car/wagon, used to either impact directly the test car conveying the tank container under test, or to carry the tank container under test. In the context of this report, the hammer car carries the tank container.

Hertz (Hz)
Unit of measurement related to frequency which is equal to the number of cycles per second.

IMO (International Maritime Organization)
A UN body which monitors and recommends regulations published in the IMDG.

ISO (International Organization for Standardization)
A worldwide federation of national standards institutes that develops international standards through its technical committees.

Octave
A doubling of frequency.

SDOF (Single Degree Of Freedom system)
A system for which only one co-ordinate is required to completely describe the configuration of the system at any instant of time.

SRS (Shock Response Spectrum)
A plot of the maximum response experienced by a Single Degree Of Freedom system, as a function of its own natural frequency, in response to an applied shock.

Tank Container
A container suitable for the carriage of gases, liquids and solid substances which within the context of this standard meets the requirements of ISO 1496-3.

T E S (T E S Limited)

Test Car
The device, normally a railway flat car, used to support the tank container under test, typically called the test car.

Twistlock
An automatic container-locking device that twists and holds a container corner casting in place on a rail car, which within the context of this standard must meet the requirements of ISO 1161.

2DOF (Two-Degree-Of-Freedom)
Referring to a system that requires exactly two co-ordinates to completely define the position of the system at any instant.

1. INTRODUCTION

1.1 Phase I

In 1997, the Transport Dangerous Goods Directorate (TDG) of Transport Canada undertook to develop a performance standard for impact testing of tank containers, equivalent to that presently described by CSA.B620 or AAR.600, as a proposed International Organization for Standardization (ISO) requirement for certification for rail transport. A study was commissioned to investigate and report on a test procedure that would be repeatable, reproducible, and ensure that tank containers would survive the impacts normally sustained in freight yards during switching operations.

The main conclusions and results of the initial study (Ref. 1) were:

- Acceleration measured at the corner castings is the closest representation of the shock input to the system (i.e. independent of container design).
- Within the expected range of system parameters, reduction of the acceleration time history data to the shock response spectrum (SRS) represents the best compromise in characterizing the damage potential without unnecessarily complicating the test procedure.
- A simple algorithm was presented that provided a conservative correction factor for testing tank containers not loaded to their maximum payload capacity (by weight).
- A proposed draft standard was presented for longitudinal rail impact testing of tank containers.

Not included in the proposed draft standard was a test level; the first phase of the program did not include physical testing and therefore a test level could not be developed. It was decided by TDG to submit the draft report and draft standard to the Working Group 4 of ISO TC/SC2 studying this issue and convene a meeting between TDG and Working Group 4 in March 1998.

1.2 March 1998 ISO Meeting and Demonstration of Test Method

In March 1998, the convenor of Working Group 4, and other representatives from Working Group 4, met with TDG to make editorial changes to the first draft standard and to witness a demonstration of the data reduction method (reduction to SRS). The demonstration achieved its objective in verifying that the data reduction method was feasible. The demonstration was limited to impacts on a single container at moderate speeds and therefore there was insufficient data from which to develop a final test level.

The end result was a new draft that was sent to the ISO committee members for review and comment. The main outstanding item of the draft standard was the Minimum SRS curve. With the support and participation of other committee members, TDG indicated that they would undertake the development of a testing and data analysis program to produce a valid Minimum SRS curve. Two container manufacturers agreed to provide a tank container each for the test program.

1.3 Phase II

Phase II of the program was commissioned by TDG in July 1998; it included in its scope of work an extensive series of physical tests to be performed on two (2) different tank containers at various speeds and in various configurations. In addition, it was decided to solicit existing test data from various foreign rail impact test centres to compare with the results of the tests on the two (2) tank containers to be tested at the Centre for Surface Transportation Technology (NRC) in Canada.

A test plan was developed by TDG and submitted to CSTT who were commissioned, along with TES Ltd., to conduct the tests, collect and analyse all data (both national and foreign), and to develop the final test level. The purpose of this report is to describe the test plan in detail, the physical tests which were conducted in August 1998 on the two (2) tank containers, the foreign data collected from the various test agencies, and the development of the final draft ISO standard and test level.

2. TEST OBJECTIVES

The objectives of the tank container rail impact testing conducted at CSTT between July 28 and September 1, 1998, were developed according to Transport Canada's Statement of Work dated June 16, 1998, and are as follows:

- to perform a series of tank container rail impacts, on two tank containers, using the procedures in the proposed draft ISO dynamic longitudinal impact test standard that uses the SRS;

- to analyse impact data coming from other test facilities or organizations for comparison with the proposed Minimum SRS curve;

- to validate and adjust as necessary the Minimum SRS curve, to be equivalent to the 4 g and 8 mph impacts described in CSA B620 or AAR 600, that is being proposed for the draft ISO dynamic longitudinal impact test standard; and,

- to fully develop and specify the reduction procedures for transforming the measured acceleration time-history data to the SRS domain.

3. TEST SET-UP

3.1 Container Securing Methodology

To comply with the proposed test methodology, a set of container securing devices were designed and manufactured. For tests not employing front load cells that included all tests except Tests A3 and B1, a fixed twistlock arrangement was required for both of the impact end corner castings and a sliding twistlock design was required for both of the rear corner castings. The twistlocks were positioned as per ISO 1161 with the exception that the rear twistlocks were free to slide longitudinally, except for the last three series of tests during which they were also fixed. Drawings of the securing devices are shown in Appendix A along with the positioning drawing supplied by Holland Company, which supplied the four automatic twistlocks.

For installation, the front twistlock supports were braced against their respective end plates and then bolted to the flat car. The rear twistlock supports were welded in place. For Tests A3 and B1 utilizing front load cells, the standard CSTT sliding block arrangement was used at the car impact end, while the sliding locks were employed at the rear.

Tests were also performed in which all the twistlocks were welded in place to restrain any longitudinal movement. This is the configuration proposed in the standard.

3.2 Instrumentation

The test plan required two accelerometers to be mounted on the impact end bottom corner castings of the tank container under test and aligned in the longitudinal direction. CSTT decided to mount a third accelerometer at the opposite end of the tank container to evaluate the shock input at the rear of the structure, while a fourth accelerometer was held in reserve. Kistler piezoelectric accelerometers (Ref. 2) were used and were powered by a piezotron coupler. Steel mounting plates for the accelerometers measuring 2” x 2” x 3/8” were made, and were centre-drilled and tapped to fit a 10-32 thread. A mounting plate was epoxy-bonded to either of the inner faces of the four bottom corner castings in the case of the Container and Pressure Vessels (CPV) container or to the vertical beam just above the inner faces of the four bottom corner castings in the case of the Welfit container. Figure 3.1 shows the location and the numbering convention for each of the three installed accelerometers. If the container required turning during the test, the accelerometers were simply unscrewed and reinstalled at the same positions relative to the flat car. The accelerometer signals were recorded using an Optim Electronics MegaDac and stored on an optical disk drive. A Panasonic laptop computer was used to view the signals in real time and to perform data post-processing. A complete equipment list is presented in Table 3.1. The transducer mounting arrangement can be seen in Figure 3.2.

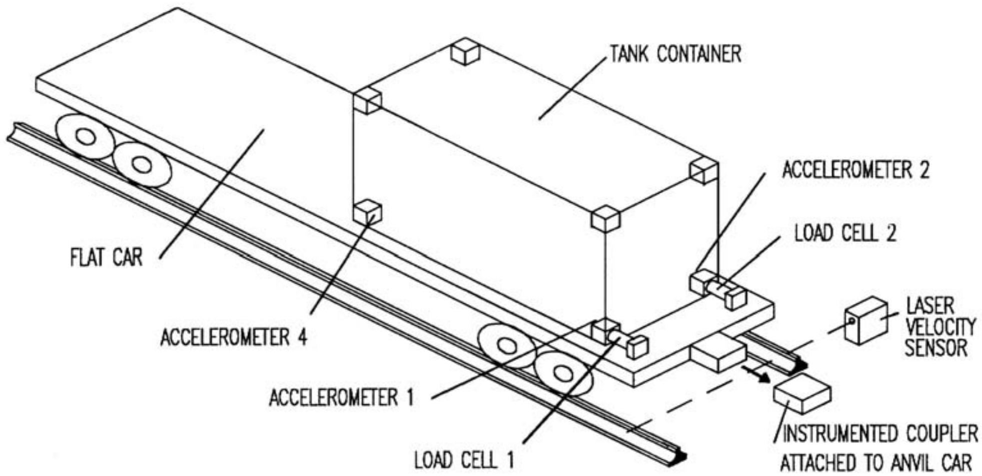

Figure 3.1 – Transducer Set-up Schematic

Figure 3.2 – Typical Accelerometer Mounting Arrangement

For Tests A3 and B1, load cells were installed in the load cell pockets of the flat car. CSTT used two custom-built 200 kip load cells manufactured by Sensordata. Thin lead sheets were placed between the load cells and slider plate to improve the load cell accuracy. An instrumented coupler was installed in the first anvil car to measure the coupling forces between the flat car with the tank container and the first anvil tank car. The velocity of the flat car was measured using a customized laser velocity sensor. The load cell, instrumented coupler, and velocity sensor signals were all recorded using CSTT's PCI PC-based data acquisition system. Figure 3.1 also shows the load cell, instrumented coupler and velocity sensor locations. In light of test results, ±200 g accelerometers would have been preferable to the ±100 g/54 kHz accelerometers used.

Item	Decription	Quantity	Model Number	Serial Number
1	Optim Electronics MegaDac Data acquisition system	1	5108AC	SO2994
2	Optim Electronics optical drive	1	AC Ext Lsr Dr	SO3415
3	Kistler Piezotron Coupler	1	5126A	C32166
4	Kistler accelerometers	4	8704B100M1	C123080 C123081 C123082 (Rsv) C123083
5	Sensordata 200 kip load cells	2		95017 95018
6	Laser1 velocity sensor	1		
7	PCI data acquisition system	1		
8	Instrumented coupler	1		No. 1
9	Panasonic laptop	1	CF-25	CF-25FJF4CAM 7GKSA03130

Table 3.1 – Instrumentation Equipment List

3.3 Car and Tank Container Configurations

The typical test configuration used for the impact testing of the tank containers was a rolling 55 ft flat car (CP521590) upon which the tank container was mounted and a stationary two-car consist comprising an empty tank car (Tank car 2) and a concrete-filled tank car (Tank car 664). Figure 3.3 shows the standard test configuration used during impact testing and the CSTT impact facility. The only exceptions to this rule were for Test A6 where the concrete-filled tank car was moving and the flat car was stationary and for Test B7 where Tank car 1 was substituted for Tank car 2. The flat car was equipped with NY-11F standard draft gear and all the tank cars were equipped with Type 50 draft gear. Lead ballast weighing 11,080 kg was placed on the flat car for Tests A2 and A3. The ballasting was done to assess the influence of flat car mass on the SRS curve.

Figure 3.3 – Standard Test Configuration

Containers and Pressure Vessels Ltd. of Ireland, loaned CSTT a beam-type tank container and Welfit-Oddy Ltd. of South Africa, loaned CSTT a frame-type container for testing purposes. The Welfit-Oddy container's tank was mounted to its frame via a suspension system. The Welfit container represented a suspension-mounted tank design and the CPV container represented a more standard design, together representing a broad stiffness spectrum for evaluation purposes. The following table summarizes the containers and cars used in the impact testing at CSTT. The CPV and the Welfit-Oddy tank containers are featured in Figures 3.4 and 3.5, respectively.

Item	Description	Serial Number	Test Weight lb (kg)	Tare Weight lb (kg)	Rated Weight lb (kg)
1	CPV beam-type tank container	TABU 240307 6	59,040 (26,800)	7,760 (3,520)	74,890 (34,000)
2	Welfit-Oddy frame-type tank container	UTCU 459 000 3	59,820 (27,200)	8,488 (3,850)	74,890 (34,000)
3	Flat car – 55 ft	CP521590	45,260 (20,550)		
4	Tank car 1	1	53,200 (24,000)		
5	Tank car 664	664	260,000 (118,000)		
6	Tank car 2	2	52,900 (24,150)		

Table 3.2 – Container and Car Equipment List

Figure 3.4 – CPV Beam Tank Container

Figure 3.5 – Welfit-Oddy Frame Tank Container

4. RESULTS OF TESTING AT CSTT

4.1 Testing Performed and Data Acquired

The actual impact testing conducted at CSTT differed from the plan proposed by Transport Canada. The scope of the actual testing expanded to allow for the evaluation of the effect of tank container weight, tank restraint boundary conditions, and anvil car effects. Three sets of results are presented in this section:

- Averaged impact speeds, coupler forces, and load cell forces (tabular format)
- Averaged container diagonal measurements (tabular format)
- Averaged shock response spectrum results and parametric plots (see Appendix B)

The actual testing that was performed is listed in Table 4.1. However, the order in which individual runs were performed differs from the order presented below.

Test	Description	Speed m/s(mph)	Runs	Test	Description	Speed m/s(mph)	Runs
	Tank Container A (CPV)				**Tank Container B (Welfit-Oddy)**		
A1	Front twistlocks – no-gap	2.68 (6)	3	B1	Load cells – no-gap	2.68 (6) 3.58 (8) 3.80 (8.5)	5 3 1
A2	Ballasted flat car – front twistlocks – no-gap	2.68 (6)	3	B2	Front twistlocks – gap	1.79 (4) 2.68 (6) 3.58 (8)	5 5 2
A3	Ballasted flat car – load cells – no-gap	2.68 (6) 3.58 (8) 4.47 (10)	5 1 1	B3	Front twistlocks – no-gap	1.79 (4) 2.68 (6) 3.58 (8)	5 5 3
A4	Front twistlocks – gap	1.79 (4) 2.68 (6) 3.58 (8)	5 5 1	B4	Rear twistlocks fixed – no-gap	2.68 (6) 3.58 (8)	3 3
A5	Front twistlocks – no-gap	1.79 (4) 2.68 (6) 3.58 (8)	5 5 3	B5	Rear twistlocks fixed – no-gap – container empty	3.44 (7.7)	1
A6	Front twistlocks – no-gap – stationary flat car	2.68 (6)	3	B6	Rear twistlocks fixed – no-gap – container empty – orig. anvil	2.68 (6) 3.53 (7.9)	2 1
A7	Front twistlocks – no-gap – container empty	2.68 (6)	3				
	Total number of impacts:		43		Total number of impacts:		44

Table 4.1 – Testing as Conducted

4.2 Test Procedure

Preparation for testing required that the tank container be mounted on the CSTT flat car and the car-container unit was then weighed empty. The tank container was filled with water to 97% volumetric capacity and the car-container unit was again weighed to determine the weight of the water aboard the tank container.

Prior to each test, the two anvil cars were pushed together to remove any slack in their draft gear; their brakes were then set. These steps ensured that the impacts were generating repeatable shocks and that the shock potential for each impact was as high as possible. The test procedure involved pulling the loaded flat car up the impact ramp to a prescribed release point that would generate a particular impact velocity. Once the test chief established that all personnel were in position, the track was clear and the instrumentation was ready, the car release command was given. Once the impact occurred, the data were analysed, the diagonal measurements were made as required, and any necessary equipment inspections were made.

4.3 Impact Speeds and Forces

The average recorded impact speeds, coupler forces and corner casting forces are listed in Table 4.2.

Test	Description	Avg Speed m/s (mph)	Avg Coupler Force kN (kip)	Avg Load Cell Force KN (kip)	Container G-load wrt Rated Wt.
	Tank Container A (CPV)				
A1	Front twistlocks – no-gap	2.77 (6.2)	1,032 (232)		
A2	Ballasted flat car – front twistlocks – no-gap	2.68 (6.0)	1,166 (262)		
A3	Ballasted flat car – load cells – no-gap	2.72 (6.1) 3.62 (8.1) 4.47 (10.0)	1,228 (276) 2,358 (530) 4,138 (930)	418 (93.9) 751 (168.7) 1,114 (250.1)	1.3 2.3 3.3
A4	Front twistlocks – gap	1.79 (4.0) 2.68 (6.0) 3.62 (8.1)	721 (162) 1,010 (227) 1,259 (283)		
A5	Front twistlocks – no-gap	1.83 (4.1) 2.68 (6.0) 3.62 (8.1)	792 (178) 1,032 (232) 1,633 (367)		
A6	Front twistlocks – no-gap – stationary flat car	2.72 (6.1)	2,149 (483)		
A7	Front twistlocks – no-gap – container empty	2.72 (6.1)	949 (213)		
	Tank Container B (Welfit-Oddy)				
B1	Load cells – no-gap	2.68 (6.0) 3.58 (8.0) 3.80 (8.5)	1,019 (229) 1,882 (423) 2,314 (520)	483 (108.5) 776 (174.3) 1,046 (234.9)	1.4 2.3 3.1

B2	Front twistlocks – gap	1.83 (4.1) 2.68 (6.0) 3.62 (8.1)	747 (168) 952 (214) 1,357 (305)		
B3	Front twistlocks – no-gap	1.79 (4.0) 2.68 (6.0) 3.62 (8.1)	752 (169) 965 (217) 1,878 (422)		
B4	Rear twistlocks fixed – no-gap	2.68 (6.0) 3.62 (8.1)	1,099 (247) 1,757 (395)		
B5	Rear twistlocks fixed – no-gap – container empty	3.44 (7.7)	1,713 (385)		
B6	Rear twistlocks fixed – no-gap – container empty – orig. anvil	2.77 (6.2) 3.53 (7.9)	979 (220) 2,180 (490)		

Table 4.2 – Averaged Impact Speeds and Forces

A quick review of the averaged coupler force results shows a definite correlation between impact speed and coupler force: the higher the impact speed the higher the coupler force. It is worthwhile to note that the no-gap condition (Tests A5 & B3) results in higher coupler forces than the gap condition (Tests A4 & B2) for all speeds between 4 and 8 mph. The corner casting g-loading was calculated for Tests A3 and B1 by dividing the total corner casting force by the rated container weight. The CPV container achieved loadings of 1.3 g at 6 mph, 2.3 g at 8 mph and 3.3 g at 10 mph, while the Welfit-Oddy container achieved loadings of 1.4 g at 6 mph, 2.3 g at 8 mph and 3.1 g at 8.5 mph.

4.4 Post-Impact Tank Container Diagonal Measurements

Container diagonal measurements were taken during the testing to quantify the deformation performance of the containers under testing. The results are in no way predictive of the performance of the individual containers under the proposed test standard. This is because the CSTT test configuration with sliding rear twistlocks represented a very severe test condition, as did the 8 mph and 10 mph impacts conducted with ballast. The results are presented for information purposes only.

The diagonals in question are shown as D3 and D4 in Figure 4.1. All eight corner castings of each container were centre-punched prior to testing at the indicated locations to establish a datum for subsequent measurements. Note that the CPV container was turned around after Test A3 such that the valve was facing away from the impact end. Note that the D3 and D4 dimensions on the opposite side were also measured for the Welfit-Oddy tank container, and are averaged in the results. The dimensions are always referenced with respect to the valve end of the tank container.

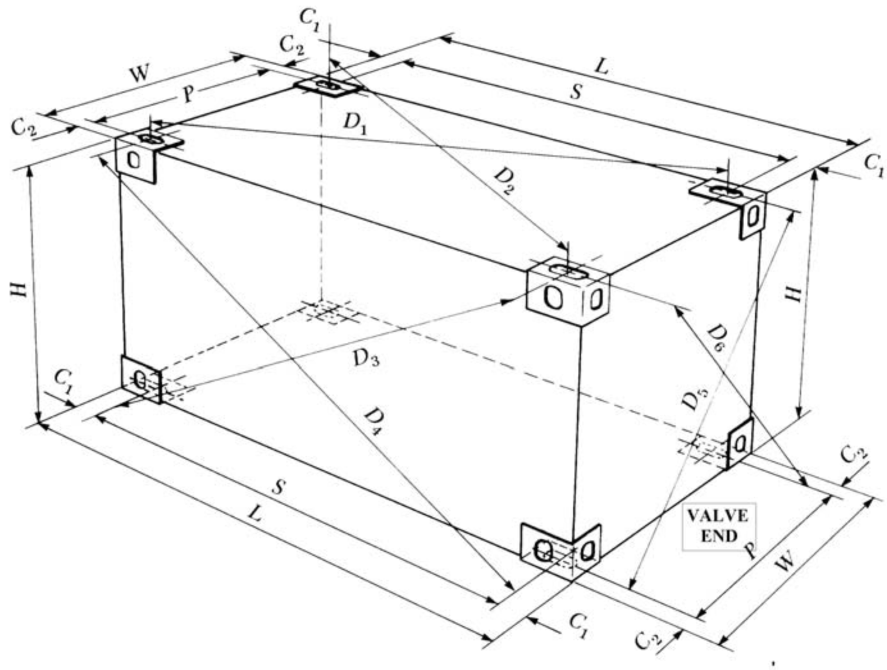

Figure 4.1 – Tank Container Dimensional Reference (Ref. 3)

Tank Container A (CPV)			Tank Container B (Welfit-Oddy)		
Msmt After Test/Run	D3 (mm)	D4 (mm)	Msmt After Test/Run	D3 (mm)	D4 (mm)
Baseline	6,408	6,393	Baseline	6,411	6,388
A1/R3	6,408	6,393	B1/R5	6,412	6,388
A2/R3	6,408	6,393	B1/R6	6,411	6,388
A3/R5	6,409	6,393	B1/R7	6,412	6,389
A3/R6	6,407	6,390	B2/R10	6,411	6,385
A3/R7	6,408	6,362	B2/R11	6,410	6,384
A4/R10 (Turned)	6,407	6,364	B3/R10	6,411	6,383
A5/R10	6,404	6,363	B3/R13	6,411	6,384
A6/R3	6,399	6,361	B4/R3	6,411	6,384
A5/R13	6,399	6,363	B4/R6	6,411	6,383
A4/R12	6,398	6,364	B5/R1	6,411	6,383
A7/R3	6,399	6,362	B6/R3	6,411	6,383

Table 4.3 – Container Diagonal Measurements

Looking at the progressive deformation of the CPV container, the D4 dimension shrank by 3 mm from baseline to Test A3/Run R6 while the D3 dimension remained relatively unchanged in that period. The 10 mph impact with load cells (A3/R7) resulted in a 28 mm reduction in D4. Before proceeding with testing, the tank container was turned around, which resulted in an 8 mm reduction of the D3 dimension through to the end of testing; D4, however, remained the same. Some pillowing deformation on the rear faces of the front corner castings was also noted. The resulting deformations that were recorded were not a result of poor container design, but rather due to severe test conditions.

The D3 dimension of the Welfit-Oddy container was unchanged through all of the impact testing. The D4 dimension was reduced by 5 mm over the course of the impacts, with the largest reduction of approximately 3 mm occurring after B2/R10 which was a gap impact at 8 mph. A slight progressive bulge was noted in a left-side frame beam at the impact end of the container, with left and right being defined with respect to the direction down the track. Once again, the resulting deformations that were recorded were not a result of poor container design, but rather due to severe test conditions.

4.5 SRS Results and Parametric Comparisons

4.5.1 Data Reduction Methodology

The SRS was calculated for all of the channels, using a Fortran executable program (see Appendix G) based on the algorithm found in the ISO draft standard (see Appendix F). CSTT gathered the data at 10 kHz and processed the data at the same sample frequency. The processing involved using a data post-processing software package installed on CSTT's laptop to view the unfiltered data and then selecting the time segment as the input excitation for the shock algorithm. The primary impact pulse, typically 0.2 to 0.3 seconds of data, was selected for SRS processing. However the approach recommended for the standard has been subsequently modified (see Section 6.2). This impact pulse-based SRS calculation provided very comparable results to the approach prescribed in the proposed standard, which calls for the full impact data segment including transients (2.05 seconds) sampled at 1 kHz to be transformed into SRS. The damping ratio used in the transformation was 5% and the natural frequency range was 0.5 to 250 Hz. This methodology was used for all data reduction, unless otherwise indicated. The natural frequency breakpoints used in all of CSTT's data reduction are as follows:

Frequency Range (Hz)	Breakpoints (Hz)
0.5 – 1.0	0.1
1 – 20	0.2
20 – 50	0.5
50 – 100	1
100 – 200	2
200 – 250	5

Table 4.4 – SRS Breakpoints versus Frequency Range

Due to the extensive number of plots comprising the SRS results from the impact testing and the parametric comparisons, it was deemed preferable to place all the SRS plots in an appendix; therefore, please refer to Appendix B for these results.

Figures B.1 through B.11 are a summary of all of the impact SRS results for all 87 impacts for both containers. Figures B.1 through B.6 represent the CPV container results, while Figures B.7 through B.11 represent the Welfit-Oddy container results. Because of the large number of plots that would have been required to plot every channel for every run, it was decided that the shock curves from both Accelerometers 1 and 2 would be averaged across each natural frequency. The curves for each set of runs at a given velocity were then averaged. This approached greatly rationalized the presentation of the data.

Figures B.12 through B.24 contain the results from evaluating the effects of mass, impact speed, accelerometer location and fixation, and sampling frequency on the SRS. The results presented for this series of curves are based on the evaluation of a single channel, typically Accelerometer 1 unless otherwise indicated.

4.5.2 Summary of Test Results

Figure B.1 shows the results for Tests A1 and A2 using front twistlocks for the CPV container without ballast and with 11,080 kg of lead ballast respectively on the flat car. The ballasted condition resulted in a reduced SRS compared to the unballasted condition.

Figure B.2 shows the effect of testing the CPV container at various impact velocities with corner casting load cells in place (Test A3), with velocity increasing the SRS beyond 2 Hz.

The results from Test A4, front twistlock gap condition are shown in Figure B.3. Increasing velocity again generally increases the SRS across all natural frequencies. The same observation can be made in Figure B.4 for Test A5, the front twistlock no-gap condition.

The shock curve for the stationary flat car test (A6) and the empty tank container test (A7) with the front twistlock no-gap condition can be seen in Figures B.5 and B.6, respectively.

Figure B.7 is the first plot with results from impact testing of the Welfit-Oddy container. The figure shows results from testing with load cells as per Test B1. It is interesting to note that while the 8 mph curve is higher that the 6 mph curve, the 8.5 mph curve is somewhat lower than the 8 mph curve. See Section 4.6.2 for explanation of this phenomenon.

The results from Tests B2 and B3, which are the front twistlock gap and no-gap tests, are shown in Figure B.8 and B.9, respectively. The trend to increasing shock response with increasing impact velocity is apparent in both plots.

For Test B4, the rear twistlocks were welded in place according to the dimensions specified in ISO 1161. As expected, the higher impact velocity manifested itself with a higher shock response, as shown in Figure B.10.

Finally, the results from Tests B5 and B6, the empty container with fixed rear constraints using Tank car 2 and the empty container with identical constraints and the original anvil arrangement using Tank car 1, respectively, are shown in Figure B.11. It can be seen that the tank car or anvil arrangement has some influence on the SRS.

4.5.3 Summary of Parametric Comparisons

Figure B.12 is the first of the parametric plots and shows the effect of tank container and flat car mass on the shock input seen by the tank container. Interestingly, the SRS for Accelerometer 1 of the full CPV container with a weight of 26,000 kg is very similar to that of the empty container with a weight of 3,520 kg. The curve for the 31,630 kg ballasted flat car is markedly less than the curve for the 20,550 kg unballasted flat car.

The effect of impact velocity on the SRS of Channel 1 is clear in Figure B.13. This trend towards increasing SRS with increasing impact speed, and consequently increasing energy, was previously observed in Figures B.2–B.4 and Figures B.7–B.9.

The accelerometer mounting arrangement had an effect on the shock value recorded, as shown in Figure B.14. Mounting directly to the rear face of the corner casting resulted in a lower SRS than mounting the accelerometer on a side plate bolted to the corner casting.

Whether the front twistlocks or the load cell slider mounts were used under the no-gap condition did not appear to significantly affect the shock response, as demonstrated in Figure B.15.

Comparison of the SRS for a moving flat car to a stationary flat car shows no significant difference in the 0.5 to 10 Hz natural frequency range; however, the SRS curve does increase somewhat for the stationary flat car beyond 10 Hz as shown in Figure B.16.

Figure B17 shows that the CPV and Welfit-Oddy containers have different SRS results, and consequently shock inputs in the 0.5 to 10 Hz range. In the range above 10 Hz, the difference is less pronounced.

The effect of accelerometer position on SRS of the Welfit-Oddy container is shown in Figure B.18 (see Figure 3.1 for the transducer locations). The shock curves for Channels 2 and 4 are virtually identical, while the curve for Channel 1 is somewhat higher, suggesting that the corner casting upon which Accelerometer 1 was attached was subjected to slightly more impact shock.

Figure B.19 shows the effect of the maximum gap condition 19 mm or ¾" versus the no-gap condition for the Welfit-Oddy container. The gap SRS curve is more linear on the log-log plot than the no-gap curve, resulting in a lower shock response below 5 Hz and higher shock response above 5 Hz with respect to the no-gap SRS curve.

The shock curves for three different runs at 8 mph with the Welfit container at the no-gap front twistlock condition gave very similar results, as shown in Figure B.20.

Figure B.21 shows that the SRS for the impact with a fully-loaded tank container (27,200 kg) with the rear twistlocks free to slide is similar to the SRS for an impact with an empty container (3,850 kg) with rear twistlocks fixed. The SRS for the condition with rear twistlocks fixed and a fully-loaded container is much lower up to 6 Hz as compared to the other two conditions. Note that under the rear twistlocks fixed condition, no-gap existed between the rear lugs and the rear corner casting faces.

The shock response using Tank car 1 (July-August first anvil car) and Tank car 2 (March demo first anvil car) was very similar up to 10 Hz, with the SRS of Tank car 2 arrangement increasing beyond that frequency point, as shown in Figure B.22.

Figure B.23 presents the effects of sampling frequency and sample length on the SRS. Note that sampling frequency is the frequency at which the raw data is acquired and filtering frequency is the frequency to which a signal is resolved. It is worth noting that the 1 kHz and 10 kHz SRS curves are essentially identical for a given sample period. At both 1 kHz and 10 kHz, the curves are very similar whether a 0.2 second impact time-history pulse or the full 2.05 second impact time-history signal is used to generate the SRS. The only real difference is in the range of 0.5 to 1.5 Hz, where the pulse-based curves are lower that the full signal-based curves.

The effect of applying the scaling factor (see Section 7 and Appendix E) to the acceleration time-history signal to compensate for the difference in rated and test masses is shown in Figure B.24. The scaling factor reduces the SRS linearly in the 0.5 to 10 Hz range, but the effect of the scaling factor is reduced at the higher frequencies.

4.6 Discussion

4.6.1 Corner Casting Force and Deformation Results

The CPV beam tank container underwent impact testing with load cells at the front corner castings with 11,080 kg of lead ballast placed on the rear deck of the flat car. The ballast reacted against the car crossbeam via two wooden planks. This arrangement probably reduced the car deceleration somewhat and consequently the shock input the tank container experienced at a given impact velocity. Significant frame deformation in the order of 28 mm along diagonal D4 occurred during the 10 mph impact. It was decided not to conduct future tests beyond 8 mph and the container was turned around such that the undamaged end faced down the track. It is clear that stress overloads resulting from longitudinal load transfer through the front corner castings alone caused deformation of the container’s front frame. The rear corner castings were not restrained in the longitudinal direction, but this requirement has been added to the proposed standard. Repeated impacts from Tests A4 through A7 caused a further 8 mm of deformation in diagonal D3, through the same overloading process.

The Welfit-Oddy frame tank container was tested without ballast on the flat car and achieved a maximum corner casting load cell loading of 3.1 g based on its rated mass at 8.5 mph. Deformation was limited to 5 mm in diagonal D4 over the course of the testing. It was decided not to test beyond 8.5 mph as the container was specially instrumented and could not be damaged without incurring significant financial loss.

Based on the test results, there is no longer a requirement that the flat car weigh more than the tank container. In addition, the rear twistlocks are to be fixed in order to restrain the tank container in all directions.

4.6.2 Shock Response Results

The most significant result arising from the SRS is the way in which tank container mass and tank container boundary conditions relate. Based on Figure B.12, the SRS is unaffected whether the tank container is loaded (26,800 kg) or not (3,520 kg) when there is a no-gap condition at the front twistlocks, i.e. the container reaction loads pass through the front twistlocks only. The reason for the SRS invariance likely due to the flat car and the tank container effectively acting as a single lumped mass during the impact event because of the front twistlock no-gap condition. Therefore if the impact reaction is to occur at the front twistlocks, it is important to prescribe in the standard that the tank container under test be loaded so that realistic reaction forces are generated by the impact.

Note that the lower shock response of the ballasted flat car with respect to unballasted flat car was not due to the additional mass per se, but due to the mass shifting slightly during impact.

The importance of boundary conditions to the shock response is clear in Figure B.21. When the container was restrained via fixed rear twistlocks, i.e. the loaded container SRS was significantly less than that for the unloaded container. In fact, the unloaded container restrained by rear twistlocks produced an SRS similar to that of a loaded container constrained by front twistlocks. Rear restraint of a loaded tank container causes the container and the flat car to act as a two degree-of-freedom system joined by the spring equivalent to the tank container's longitudinal stiffness. This system was less stiff than a lumped mass system, thereby reducing the impact shock seen by the flat car. In order to avoid the system acting as a 2 degree-of-freedom (2DOF) system, the tank container must be positioned such that there is no gap between the rear faces of the front lugs and those rear faces of the front corner castings.

As expected, impact velocity increased the shock input seen by the flat car and consequently the SRS calculated for the tank container as seen in Figure B.13. This result was expected, and, as for the given test configuration, a higher impact speed resulted in a higher flat car deceleration.

Based on the results in Figure B.14, the accelerometer mounting arrangement has some effect on the resulting SRS. Mounting the accelerometers to the casting via a bonded plate produces a lower SRS than mounting accelerometers via a bolted plate. It is important to prescribe the mounting arrangements explicitly in the standard so that all test results are comparable and consistent. The SRS results for impacts performed with the front twistlocks are comparable to those performed with the front load cell slider (see Figure B.15). This means that there is shock or test equivalency between impacts conducted with load cells and front twistlocks. The same can be said for impacts conducted using a moving or stationary flat car (see Figure B.16); the results, especially in the important 0.5 to 10 Hz range, are similar.

Referring to Figure B.17, there appears to be some influence of tank container design on the shock input that they experience. The CPV beam design tank container with its two end frames, had a lower shock input and, therefore lower shock response than the Welfit-Oddy frame design. This is probably because the overall longitudinal flexibility of the CPV container at 8 mph was slightly less than that of the Welfit-Oddy tank container. However, it is likely that at higher impact speeds, the difference would diminish, as the suspended tank mounting arrangement of the Welfit container would then start to have some effect (see Figure B.7). In Figure B.7, the SRS curve was slightly lower for the 8.5 mph impact as compared to the 8.0 mph impact. This was likely due to the tank suspension system of the Welfit tank container becoming activated above 8.0 mph and thereby slowing the acceleration of the overall system.

Accelerometer location does produce different shock response results, as seen in Figure B.18. Invariably, the impact event will not be symmetric and therefore one restraining point will experience more shock than another.

The effect of gap between the rear face of the front twistlock lugs and the rear face of front corner casting is significant as seen in Figure B.19. The gap condition causes the container to slide initially and strike the twistlock lugs with dynamic force. This sequence of events would delay the onset of lower frequency shock, but would increase the higher frequency shock with respect to the no-gap condition. For the sake of consistency in testing, it is important to control this condition with the no-gap condition being prescribed.

Despite the quasi-random nature of impact acceleration time-history, Figure B.20 shows that for three impacts at 8 mph without gap at the front twistlocks, the shock response in the frequency spectrum is very repeatable. This confirms that the frequency spectrum is an appropriate technique with which to evaluate impact events.

The effect of the anvil arrangement was evaluated by conducting impacts with the empty Welfit container with fixed rear constraints using Tank car 1 and then Tank car 2, which was used during the March 1998 demonstration, as the first anvil cars in the anvil consist. Based on Figure B.22, the two slightly different anvil cars produced very similar shock curves up to 10 Hz. Beyond 10 Hz the shock response of the impact using Tank car 2 is higher; this may be due to the fact that the brakes on Tank car 2 were in better condition than those of Tank car 1.

The comparison of sample period and sample frequency effects can be seen in Figure B.23. At both 1 kHz and 10 kHz, the effect of processing the primary 0.2 second pulse of the acceleration time-history data was very similar to processing the entire 2.05 second impact signal. The 2.05 second time segment is the length called for in the ISO standard. The only difference was in the 0.5 to 1.5 Hz range, where the longer data segment produced a higher shock. This is understandable in that more data in time would reveal lower frequency excitation modes. The 1 kHz and 10 kHz pulse-based SRS curves are identical, as are the 1 kHz and the 10 kHz full data length-based curves. This suggests that the SRS results are not sampling frequency dependent in the 1 kHz to 10 kHz range.

Finally, the scaling factor proposed in the draft standard and discussed in Section 5 does have an effect on the shock response. The objective of the scaling factor was to reduce the test-time history signal to compensate for a container that is tested at less than its rated mass. The objective of the scaling factor is to reduce the test signal, thereby requiring a higher test speed, which would in turn increase the corner casting reaction loads to match those experienced by a container tested at its rated mass condition. Figure B.24 shows that the scaling factor applied in the time domain translates well to the frequency domain in the 0.5 to 10 Hz range. Therefore, the scaling factor approach to correct for rated mass is feasible. Summarizing the results in tabular format, we can subjectively characterize how different variables affect the shock response:

Effect on SRS	Variable/Condition
No effect	• Tank container mass with no-gap at front twistlocks • No-gap testing with load cells or twistlocks • Sampling frequency in the 1 – 10 kHz range
Slight effect	• Container design • Accelerometer mounting arrangement & location • Moving vs. stationary flat car • Condition of brakes on first anvil car • Sample period in the 1 – 10 kHz range
Significant effect	• Impact velocity • Tank container mass with no-gap at rear fixed twistlocks • No-gap vs. gap at the front twistlocks • Scaling factor applied to time-domain data

Table 4.5 – Summary of Parameter Effects on SRS

5. SCALING FACTOR DEVELOPMENT AND VALIDATION

5.1 Methodology

The purpose of this effort was to investigate and report on a suitable scaling factor for incorporation into the draft standard. The approach taken in the scaling factor development involved the following steps:

- Identify the problem
- Identify all assumptions
- Formulate a model for the system
- Test the model
- Present results
- Discuss results

5.2 Problem Identification

To prescribe an impact severity independent of container design, and which does not require changes to the normal container mountings, the logical impact severity criterion is acceleration measured at the corner castings. Recent (July-August 1998) impact tests performed on two different containers under a variety of situations (e.g. different mounting points, different anvil car arrangements) have shown that acceleration measured at the corner castings is primarily dependent upon the following:

- Velocity at time of impact; and,
- Total mass of the tank container/restraint combination.

Conversely, acceleration measured at the corner castings appears relatively insensitive to changes in container mass or container stiffness in the front twistlock no-gap condition. This has both advantages and disadvantages. The advantage is that an impact severity criteria can be synthesized, and is repeatable and reproducible. The disadvantage is that the measured signal does not correlate simply with changes in container mass and therefore cannot be scaled in direct proportion.

No discussion has been presented thus far regarding damage potential. A given corner casting force resulting from impact will produce stresses within the structure and framework of the container. The peak force at the corner casting resulting from one impact on the container at test mass (water) conditions will produce stresses in the container and framework. An equivalent peak corner casting force resulting from a different impact on the same container at rated mass (high density payload) will generally produce a different stress time history if only because the structure has changed and will have different modal response. This is only to illustrate that the two test situations are physically different even if the peak corner casting force was coincidentally equal. In short, the optimum test situation would be to test the container at its rated mass using a suitable density medium (not necessarily water). However, this does not seem practical (but should not be overlooked) for reasons of human safety, environmental damage, and cost.

The challenge is to describe a method by which adjustment of the test response (corner casting acceleration) will adequately compensate for a test mass that is invariably less than the rated mass. Before pursuing the subject further, it is worthwhile to examine the underlying assumptions regarding the current physical situation (i.e. switch yard impacts of tank containers).

5.3 Assumptions

It is instructive to enumerate the assumptions that were used in the scaling factor analysis, namely:

- The maximum gross mass allowable for any certifiable tank container is 36,600 kg.
- The minimum test mass achievable with water for a 36,600 kg rated container would be 10,000 kg (roughly commensurate with a 7,000 L container having a 3,000 kg tare mass).
- The maximum tare flat car mass would be 40,000 kg.
- The minimum tare flat car mass would be 10,000 kg.
- All container-on-flat-cars, used either in practice or as the test car, are equipped with some form of cushioning device roughly corresponding to standard draft gear.
- The nominal impact velocity is approximately 3.5 to 4.0 m/s.
- The maximum longitudinal stiffness of the test car would be 40 MN/m.
- The minimum longitudinal stiffness of the test car would be 3 MN/m.
- The maximum longitudinal stiffness of the container support framework would be 900 MN/m.
- The minimum longitudinal stiffness of the container support framework would be 15 MN/m.
- Surge effects due to sloshing can be neglected.

The aforementioned assumptions describe the scope of the problem and also iterate the range of parameter values used in the modeling analysis.

5.4 System Model

A system model was constructed to investigate the problem. The system model used for the computer simulation was a 2DOF model comprising a flexible component mounted on a primary system with isolator between the input and primary system. The input was simplified to a step velocity change. The system model is shown diagrammatically in Figure 5.1.

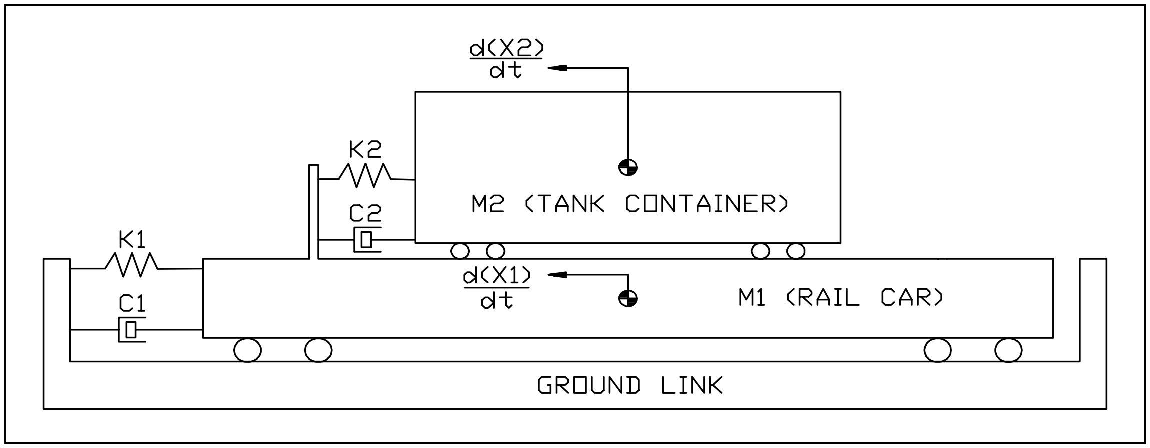

Figure 5.1 – 2DOF System Model for Rail Impact Simulation

In the computer simulation model the flexible component is represented by the tank container, which is considered a rigid body (container) mounted on a flexible support (framework). The primary system is represented by the flat car which is considered to be a rigid body isolated by a longitudinal spring/damper arrangement (draft gear). The input to the system is a step velocity change. The 2DOF model was allowed to rebound but stayed attached (coupling present).

5.5 Proposed Scaling Factors

There are currently a number of existing rail impact test procedures that specify a scaling factor in the following form:

$$\text{Test Acceleration Required} = \frac{\text{Rated Mass(R)} \times \text{Acceleration Required}}{\text{Test Mass(T)}}$$

The assumption is that the corner casting force, which is equated with damage potential to the container, will scale in direct proportion to the difference in mass. This approach does not account for the fact that the acceleration transmitted to the container (shock transmissibility) will vary with the container's mass. As reference, equation 31.40 in the third edition of the Shock and Vibration Handbook (Ref. 4) shows that the acceleration transmitted to the tank container is dependent on three major parameters:

- The input velocity shock (dU/dt)
- The principal natural frequency of the test car (ωn1)
- A mass factor $(1+ m2/m1)^{0.5}$

For a given velocity shock (change) and a given test car, it would appear that the major influence on the maximum acceleration of the tank container would be the mass factor.

For a given change in mass of the tank container, ΔM, the new transmitted acceleration could then be estimated using the following equation:

$$\left(\frac{d^2(X2)}{dt^2}\right)_{new} \approx \left(\frac{d^2(X2)}{dt^2}\right)_{original} \times \frac{1}{\sqrt{1+\frac{\Delta M}{M1+M2}}}$$

Where: ΔM = (Rated Mass) - (Test Mass)

A third possible scaling factor approach would be to take the product of the mass ratio, R/T, and the mass factor, $([1+(\Delta M/m1+m2)]^{0.5})$, since both mass and acceleration combine to produce force (F=ma).

Finally, a fourth possible scaling factor approach would be to take the product of R/T and $(T/R)^{0.5}$ which equals $(R/T)^{0.5}$. The rationale for this approach would be that the first term, R/T, accounts for the mass change while the second term, $(T/R)^{0.5}$, accounts for the change in the tank container's principal frequency.

To determine the accuracy of applying the proposed mass factors to actual test situations, a series of computer simulations were performed on the 2DOF model. These simulations and the results are described in the following section.

5.6 2DOF Computer Simulations

To test the various scaling factors, a number of 2DOF computer simulations were performed, all having the following in common:

- All models had 2DOF (in the longitudinal direction).
- Input to the model was a step velocity change.

The results of the computer simulations are available in Appendix C. For each modeling simulation the following variables and results are listed:

- Peak coupler force.
- Peak corner casting force.
- Peak test car (centre of gravity) acceleration.
- Peak container (centre of gravity) acceleration.
- Input velocity (to the system).
- Tank container mass as used in the simulation.
- Theoretical natural frequency (uncoupled) for the test car.
- Theoretical natural frequency (uncoupled) for the container.

The simulations are presented in the order in which they were performed. The first simulation was always performed on a nominal test mass, usually 20 t. The second simulation was usually performed on a 10 t container. The third simulation within a series was usually performed on a hypothetical container loaded to the gross mass, usually 40 t; this simulation is highlighted by the shaded band across the table. The remaining simulations were performed at various impact velocities but otherwise keep the same values as for the first simulation.

The purpose of the simulations was to estimate the effect on hypothetical corner casting force as the tank container mass and/or impact velocity was varied. In all, ten model series were simulated. In all ten cases the corner casting force increased as the test mass increased. However, the percentage change in corner casting force was not proportional to the change in container mass (for a given velocity). Impacts at various speeds show that in general, only a relatively small increase in velocity is required on the smaller container to achieve the same corner casting force as with the larger container. These results are summarized in Table 5.1.

Model	R / T Factor	Mass Factor	Total Factor	$[R/T]^{.5}$ Factor	F_{rated} / F_{test}	$F_{R/T}$ / F_{Rated}	F_{MF}/ F_{rated}	F_{Total}/ F_{Rated}	$F_{[R/T]^{.5}}$/ F_{rated}	Corr Coeff
80	2.0	1.29	1.55	1.41	1.27	1.56	1.01	1.21	1.10	.99999
90	2.0	1.29	1.55	1.41	1.24	1.61	1.04	1.25	1.14	.99999
10	1.25	1.07	1.17	1.12	1.15	1.09	0.93	1.02	0.97	.99998
50	2.0	1.23	1.63	1.41	1.43	1.39	0.86	1.13	0.98	.99999
60	2.0	1.23	1.63	1.41	1.43	1.41	0.86	1.15	0.99	.99993
70	2.0	1.16	1.73	1.41	1.68	1.19	0.69	1.03	0.84	.99995
38	2.0	1.23	1.63	1.41	1.62	1.26	0.76	1.01	0.88	.99992
47	2.0	1.23	1.63	1.41	1.41	1.42	0.87	1.16	1.00	.99996
45	2.0	1.23	1.63	1.41	1.40	1.42	0.88	1.16	1.00	.99998
99	1.36	1.10	1.24	1.17	1.13	1.20	0.97	1.09	1.03	.99989

Table 5.1 – 2DOF Computer Simulation Results

Legend:
R = Rated (container) mass.
T = Test (container) mass.
F_{rated} = Corner casting force result using rated mass.
F_{test} = Corner casting force result using test mass.
$F_{R/T}$ = Corner casting force result using R/T scaling factor approach.
F_{MF} = Corner casting force result using mass factor approach.
F_{Total} = Corner casting force result using mass factor x R/T factor.
Corr Coeff = Correlation coefficient from linear regression analysis.

The first column in the table indicates the model series. Columns 2 through 5 present the calculated scaling factors previously discussed. The sixth column presents the ratio of the corner casting forces for the rated mass and test mass simulations. Columns 7 through 10 present the results of the simulations using the various scaling factors, normalized with respect to the corner casting forces that resulted from those simulations using the actual rated mass. Therefore, columns 7 through 10 represent the accuracy (at least in the modeling domain) of the various scaling factors. The last column presents the correlation coefficient for the linear regression analysis used to interpolate the results for the estimated speeds.

5.7 Results

From Table 5.1 it appears that applying R/T as a correction factor overestimates the increase in acceleration required to achieve the equivalent peak corner casting force. The “overtest” amount is as high as 62%. Conversely, the mass factor approach always produces an “undertest” by as much as 26% but never produces an overtest. The third scaling factor is always too conservative, by as much as 25%. The fourth and final scaling factor is remarkably accurate in 6/10, modeling runs but is overly conservative in one case by 14%.

5.8 Discussion

The R/T correction factor appears to be overly conservative based upon the computer simulations. This may be due either to limitations within the model or because the R/T factor is too simplistic. For example, it does not take into account the fact that the system natural frequencies will change as a result of change in mass. Conversely, the mass factor approach is consistently under conservative in achieving equivalent corner casting force; however, the mass factor approach appears to produce closer results. Of all four scaling factors, $(R/T)^{0.5}$ appears to be the most accurate.

None of the scaling factors produced perfect estimates of the speeds required to obtain equivalent peak corner casting force. This is to be expected since the parameters used to derive the scaling factors do not take into account damping either within the test car or tank container structure. Hence, the methodology used in this investigation is more empirical than theoretical. The analysis, therefore, depends primarily on the fidelity and accuracy of the computer simulations. The last model series (model 99) was refined to agree as closely as possible with previous physical test results obtained by CSTT on a similar size and mass container. Interestingly, for this model series the mass factor approach achieves a very good approximation to the acceleration required to achieve an equivalent corner casting force. Unfortunately, the physical evidence is inconclusive in supporting or refuting either correction factor.

In summary, it can probably not be overstated that any “correction” factor is at best only a mediocre substitution for using the correct payload material. The fact that the discrepancy between the rated and test mass is probably less in practice than hypothesized in the computer simulations is of some comfort. Also, it should be noted that using a higher impact velocity to achieve equivalent corner casting force will always produce a higher overall acceleration than would otherwise be experienced in practice if the rated mass was tested.

In consideration of all of the above, the present recommendation is to propose the mass factor approach to scaling the measured acceleration response while emphasizing that the adjusted values represent only an approximation of the real situation.

6. DEVELOPMENT OF THE SRS TEST LEVEL

6.1 Selection of Test Configuration

The basis for the new test level was the 8 mph impact test, as specified in Section A4.2 of CSA B620/1987. The test configuration that would provide the most repeatable results while maintaining boundary conditions similar to the load cell-based testing previously conducted at CSTT was no-gap at the front twistlocks. In terms of the test plan, this was Test A5 for the CPV container and Test B3 for the Welfit-Oddy container. The 8 mph impacts corresponded to three runs for each test (Run 11, Run 12 and Run 13), for a total of six runs.

6.2 Data Reduction

The shock response curves for each of the two accelerometer channels (1 and 2) were produced using the same methodology described in the proposed ISO specification in Appendix F. The only exception was that the frequency breakpoints in Table 4.4 were used. The procedure for each channel was as follows:

1. The acceleration data was filtered from 10 kHz to 1 kHz, meaning that the data was transformed to appear as it had been originally sampled at 1 kHz;
2. Extraction of the time-domain data 0.05 seconds prior to the start of the impact event and 2.0 seconds thereafter was performed, for a total time segment of 2.05 seconds;
3. The shock response algorithm was applied to the data for a natural frequency range of 0.5 to 250 Hz with a damping ratio of 5%.

The acceleration values for Accelerometers 1 and 2 were then averaged for each natural frequency and plotted in Figure D.1 of Appendix D.

6.3 Development of the Test Level

The averaged results for each run were then averaged in turn to create a composite average for all six runs (see Figure D.2). It is worthwhile to note that the resulting mean shows quite linear characteristics on the log-log plot in the 0.5 to 100 Hz range. The standard deviation of the mean was calculated and subtracted from the mean to produce a reduced SRS curve. The proposed test level was then generated by a line-of-best-fit through the mean minus one standard deviation curve. An upper frequency cut-off of 250 Hz was chosen as signal representation of frequencies above 250 Hz becomes difficult with a 1 kHz data sample because of aliasing effects.

The test level based on the impact data gathered at CSTT is shown in Figure D.3. The two defining points are 1g at 0.55 Hz and 27g at 250 Hz.

7. REVIEW OF EXTERNAL DATA

7.1 Test Procedures

Before presenting the data from the various test centres, it is instructive to examine how the data was generated, i.e. what procedures were used in performing the test. Although in many instances the test procedures from the respective countries appear similar, they do, in fact, contain subtle but important differences.

7.1.1 Test Level

The test levels as currently specified in the existing procedures, although superficially similar, have distinct differences. CSA.B620 (Ref. 5 - Canada) specifies in paragraph A4.2 an 8 mph impact in the forward and rearward direction as the highest prescribed speed. In paragraph A4.3 the test level is specified in terms of a measured force equal to four (4) times the weight of the “loaded portable tank”. What constitutes an acceptable payload (e.g. water) is not specified.

The test level specified in AAR.600 (Ref. 6 - US) is similar to the A4.3 clause in CSA.B620 except that the container is “loaded to its rated capacity”. The term “loaded capacity” is not defined (i.e. with respect to volume or mass).

The test level specified in CNEST 001 (Ref. 7 - France) is a peak acceleration of the front two (2) corner castings equivalent to four (4) times the acceleration due to gravity (i.e. 4 g) when the acceleration signal is low-pass filtered down to 16 Hz. Low-pass filtering is accomplished by using a mathematical function that attenuates signals above a particular frequency, in this case 16 Hz.

The test level specified in UIC 592-4 (Ref. 8 - Germany) is a peak acceleration of the front two (2) corner castings equivalent to two (2) times the acceleration due to gravity (i.e. 2 g) when the acceleration signal is low-pass filtered down to 16 Hz.

There are three (3) separate test levels specified in EDC/023/000 (Ref. 9 - South Africa) depending upon the test:

R-Test:	8 mph (measured).
SS-Test:	8 mph (calculated equivalent speed).
SF-Test	4 g at rated load using a 40 Hz low-pass filter frequency.

The operating procedures, used to obtain the test results in accordance with the respective procedures, are discussed in more detail in the following section.

7.1.2 Test Set-Up and Operating Procedures

There are at least three (3) different impact situations that could arise in practice; these situations are approximately in the test procedures, which attempt to reproduce the effects of these normal occurring impacts:

1. Container-on-flat-car (COFC) running into a stationary consist.
2. COFC being impacted by a “hammer” car while the COFC is coupled to a stationary consist.
3. COFC being impacted by a “hammer” car while the COFC is standing stationary on the track without being coupled to adjoining cars.

Paragraph A4.2 of Canadian Standards Association CSA.B620 specifies impacts that fall under category 1; it further specifies that the cars should be configured to allow coupling. In actual test practice, the coupling mechanism is usually disabled. Paragraph A4.3 specifies impacts that fall under category 2 or possibly 3; the paragraph is ambiguous. In actual test practice, the usual procedure is to follow category 1 for satisfying this clause in addition to clause A4.2.

Centre National d’Essais de Tergnier CNEST 001 specifies a test procedure that falls under category 3. Rail cars in most European countries (e.g. France, Germany, England) do not have automatic couplers. The CNEST operating procedure also specifies that the gap between the corner pegs and corner castings is less than or equal to 2 mm. The procedure used in Germany falls under category 3 but the gap is not specified.

Engineering Development Centre EDC/TES/023/000 specifies three (3) distinctly different impacts corresponding to the three (3) situations previously outlined. Test 1 (R mode) is a “run down hill” procedure that falls under category 1. Test 2 (SS mode) involves the COFC being impacted by a “hammer” car while standing coupled to a “buffer” car, corresponding to category 2. Test 3 (SF mode) involves the container being impacted while “standing free”, corresponding to category 3. In all three (3) test modes, the gap is not specified, but in practice there is usually a “settling” shunt that would tend to reduce or close the gap.

7.1.3 Test Procedure Measurements/Checkpoints

The impact specified in clause A4.3 (CSA.B620) requires load cells positioned between the container-on-flat-car corner pegs (twistlocks) and the corner posts on the tank container. In practice, the corner pegs are substituted with an angle bracket which retains the load cell at the front (impact end) of the container-on-flat-car while the rear corner pegs are substituted with flat plates (sliders). As currently configured, the load cells only measure the unidirectional compressive loads.

The CNEST procedure includes a diagram in Annexe 2 which indicates an accelerometer located at the front (impact end) bottom corner of the container. It is assumed that the German instrument set-up is similar.

The Engineering Development Centre (EDC) in South Africa typically instruments the tank container with four (4) accelerometers providing four (4) channels of data. The accelerometers are positioned as follows:

CH1. Non-discharge (B) end, left-hand side (as viewed facing discharge).
CH2. Discharge (A) end, right-hand side (as viewed facing discharge).
CH3 Discharge (A) end, left-hand side (as viewed facing discharge).
CH4 Discharge outlet.

Section 7.2 describes the format of the data received and the methods used to reduce the data to shock response domain.

7.2 Data Collection/Analysis

Data collected from the various test centres was usually sent and received in electronic spreadsheet format as time/acceleration pairs. Each set of test data was logged with respect to date received, sampling rate, filter frequency (if applicable), speed of impact, mass of unladen COFC (test car), and container test mass.

7.2.1 Sample Rate/Filter Frequency

All data received to date from CNEST was sampled at 2 kHz with no low-pass filtering specified. The data from Minden was sampled at 2.5 kHz with low-pass filtering being done at either 999 Hz, 40 Hz, or 16 Hz. Only the 999 Hz filtered data is presented in this report (the 40 Hz and 16 Hz data is considered unusable for the purpose of this investigation). The data from EDC was sampled at 2.4 kHz and 500 Hz. The filter frequency was 200 Hz (for the 2.4 kHz sampled data) and 250 Hz (for the 500 Hz sampled data).

The sampling rates and low-pass filtering were considered within acceptable limits (except for the 16Hz and 40 Hz data).

7.2.2 Data Reduction

All data was reduced to the shock response domain using the same algorithm developed during the first phase of the ISO tank container study. The damping ratio was 5%. The same frequency breakpoints were used as found in Table 4.4. This was to present the various sets of data in a uniform format (some data could only be analysed up to 125 Hz because of the low sampling frequency employed). Since the frequency band of primary interest is in the 10 to 100 Hz region, this was not considered a severe limitation.

7.3 Data Presentation

7.3.1 EDC

The first five graphs represent data collected at EDC (South Africa). The COFC test car used in all instances had a 14,460 kg tare mass. The data was obtained from various containers under different procedures. All data is cross-plotted with the SRS Test Level (as defined in September 1998).

See Appendix E for results.

Figure E.1 – The container was filled to approximately 30,000 kg total mass and then allowed to run down the impact testing hill into a stationary consist; the cars were allowed to couple. The "A" end of the container is the impact end for this procedure. The "B" end (opposite to the discharge end) was the end opposite to the point of impact. The velocity was 3.97 m/s.

Figure E.2 – The container was filled to approximately 23,660 kg and impacted similar to the container presented in Figure D.1. Channels (CH) 2 and 3 are at the "A" impact end whilst CH 1 accelerometer is at the "B" non-impacting end. The impact speed was 2.93 m/s.

Figure E.3 – The container (same container as for Figure E.1) was impacted while in "standing free" mode. Channel 1 accelerometer is at the "B" impact end while Channel 2 is at the "A" non-impacting end. The impact speed was 2.32 m/s.

Figure E.4 – The container (same container as for Figure E.2) was impacted while in "standing free" mode. Channel 1 accelerometer is at the "B" impact end while channel 2 and 3 accelerometers are located at the "A" non-impact end, right-hand side, and left-hand side locations, respectively. The impact speed was 2.15 m/s.

Figure E.5 – The container (same container as for Figure E.2) was impacted while in "standing stationary" mode. Channel 1,2, and 3 locations correspond to those for Figure E.4. The impact speed was 3.1 m/s.

7.3.2 CNEST

Figure E.6 – The container was impacted while in "standing free" mode with no coupling. It is assumed that the two signals at identical speeds indicate the presence of two accelerometers recording the same event. It is also assumed that both accelerometers are at the impact end of the container since this is what CNEST 001 specifies. The impact speeds were between 2.75 and 3.09 m/s.

Figure E.7 – Same as for Figure E.6, but a different container. The impact speeds were between 2.91 and 3.21 m/s.

Figure E.8 – A third container impacted at four (4) different speeds between 3.33 m/s and 3.67 m/s.

Figure E.9 – A fourth container impacted at 3.14 m/s with two accelerometers recording the event.

Figure E.10 – A fifth container impacted at two different speeds, 3.06 m/s and 3.37 m/s.

7.3.3 Minden

Figure E.11 – A container impacted in “standing free” mode at two different speeds, 2.47 m/s and 3.03 m/s.

7.4 Discussion

7.4.1 Comparison of External Data with Physical Tests

The test plan executed at CSTT in August 1998, involved two different containers of approximately same size and mass (27 t) which were tested in “R-mode” without coupling. The test results from these two containers were comparable to the SRS that were generated from the acceleration measured at the corner castings. As baseline data, CSTT used the shock response spectrum obtained from the testing of one of the containers when impacted at 8 mph (3.56 m/s). This baseline data was then used to compare with the external data and presented at the first Review Committee Meeting with Transport Canada.

The data received from France, for containers impacted at comparable speeds (3.33 to 3.67 m/s), was consistent and comparable to the baseline data over a frequency range of 0.5 to 200 Hz.

The data received from Germany plotted (in the response domain) well below the baseline data; this was not unexpected since the test data from Germany was at significantly lower speeds (2.47 and 3.03 m/s). Interestingly, previously obtained impact data involving a tank car impacted at 3.33 m/s, produced an SRS similar to the baseline data.

The data received from South Africa also plotted consistently below the baseline data; again, this was not unexpected since the majority of the test data was obtained at speeds below that of the baseline data. Figure E.1, which was generated from an impact of 3.97 m/s (versus 3.56 m/s for the baseline data), produced an SRS close to or exceeding the baseline spectrum at all frequencies.

7.4.2 Comparison of External Data With Test Level

The only data (reduced to SRS) submitted by EDC in South Africa which has been analysed and meets the present test level criterion is the 3.97 m/s impact presented in

Figure E.1. Again, this not unexpected since the majority of processed data from EDC involves impacts below the 3.56 m/s nominal impact speed.

Figure E.3 (2.32 m/s) indicates that this test run would also qualify since it is above the test level. However, this test data should be considered suspect since it does not reflect the overall trends. One possible explanation for the abnormally high SRS is that it was conducted in “standing free” mode; however, tests performed at CSTT indicate that the mode of impact does not significantly affect the response spectrum. At the present time, Figure E.3, channel 2, must be considered an anomaly. It is possible there was an error in importing and/or reducing the data to the response domain.

With regard to the data from CNEST, the 3.09 m/s (Figure E.6), 3.21 (Figure E.7), and 3.37 (Figure E.10) spectra would all appear to qualify. However, it is assumed these spectra were not “corrected” for mass. If the rated mass was higher than the test mass then the measured signals would have to be de-rated or adjusted by the application of a scaling factor (according to the current draft standard). This would shift the spectra down; since most of the spectra are already very close, an increase in impact severity would be required, which would undoubtedly increase the test velocity close to or exceeding 3.56 m/s.

In the case of the Minden data, neither the 2.47 or 3.03 m/s impacts would qualify; again, this is not surprising since the test level was derived from impacts at 3.56 m/s. Also, it is assumed the Minden data was not de-rated for mass effect.

7.4.3 Comparison of Data from Different Test Centres

Overall, the data obtained from France seemed consistent with the physical testing performed at CSTT in August 1998, and with the derived test level. The data from Minden also appeared to be consistent with the CNEST and CSTT results but contained too few data sets to make a rigorous assessment. The data from South Africa appeared to have the greatest inconsistencies; in other words, it was difficult to see clearly identified trends. There are several possible explanations. First, the test agency uses three different test procedures (R, SS, SF modes) to test the containers. Second, for all test modes, coupling is enabled. It is possible that the presence of coupling tends to produce a greater variation in the test results since the system is made more complex. Also, some of the data was sampled at 200 Hz and some of the data was sampled at 250 Hz (the CNEST data was assumed to be unfiltered while the Minden data was sampled at 999 Hz). Ideally, all data should have been sampled at 1 kHz.

7.4.4 Summary/Conclusions

Overall, the external data appears to support the currently defined test level. In general, the following can be concluded:

- There is no marked evidence to indicate that any of the test agencies, using their existing container-on-flat-cars, should not be able to produce the requisite spectrum as defined by the current draft standard and incorporated test level.
- The data evaluated to date suggests that existing container-on-flat-cars used for rail impact testing have comparable characteristics at equivalent speeds (in other words, spectra produced from impacts at equivalent speeds appear comparable).
- Based upon the limited data, there does not appear to be an indication that one test mode (e.g. “standing free”) would produce significantly different results from another test mode, assuming that all other factors are equal.

8. RECOMMENDATIONS

8.1 Recommendations Based on CSTT Testing

- The container locks should be positioned on the flat car to conform to ISO 1161 in D.2.1 of the draft standard.
- Section D.2.4 of the standard should prescribe the no-gap at the front corner casting condition, as this configuration will provide the most repeatable results.
- No reference to the mass of the test car is required in the standard as the mass of the tank container did not affect the SRS with no-gap at the front container lock condition. Consequently, the mass of the test car will not have an effect on the SRS under similar conditions.
- Accelerometers with a minimum ±200 g capability and a minimum resonant frequency of 20 kHz should be prescribed in D.2.3.2 of the standard.
- Selection of acceleration time-history data should commence 0.05 seconds before the impact and include the 2.0 seconds thereafter, for a total data length of 2.05 seconds. This methodology should be noted in D.2.6.1 of the standard.
- The highest natural frequency analysed using the shock spectrum technique should be 250 Hz in D.2.6.1, based on the limits of signal resolution tied to the sampling frequency.
- The test level presented in Figure D.3 should be prescribed as the Minimum SRS Test Level of the standard. (Note that the acceleration is expressed in gravitational units.)

8.2 Recommendation Based on Modelling Results

- The mass correction scaling factor should be preserved as expressed in D.2.6.2 of the standard.

8.3 Recommendation Based on Evaluation of Foreign Data

- Data evaluation from foreign test agencies indicated that those agencies, in addition to CSTT, would be capable of conducting tank container impact testing as prescribed in the draft standard and, therefore, the proposed standard could form the basis for an international standard.

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APPENDIX A

CONTAINER SECURING DEVICE DRAWINGS

(Not available in electronic format /
Non disponible en format électronique)

APPENDIX B

CSTT IMPACT TEST SRS RESULTS

Figure B.1 - Test A1 & A2 SRS Results

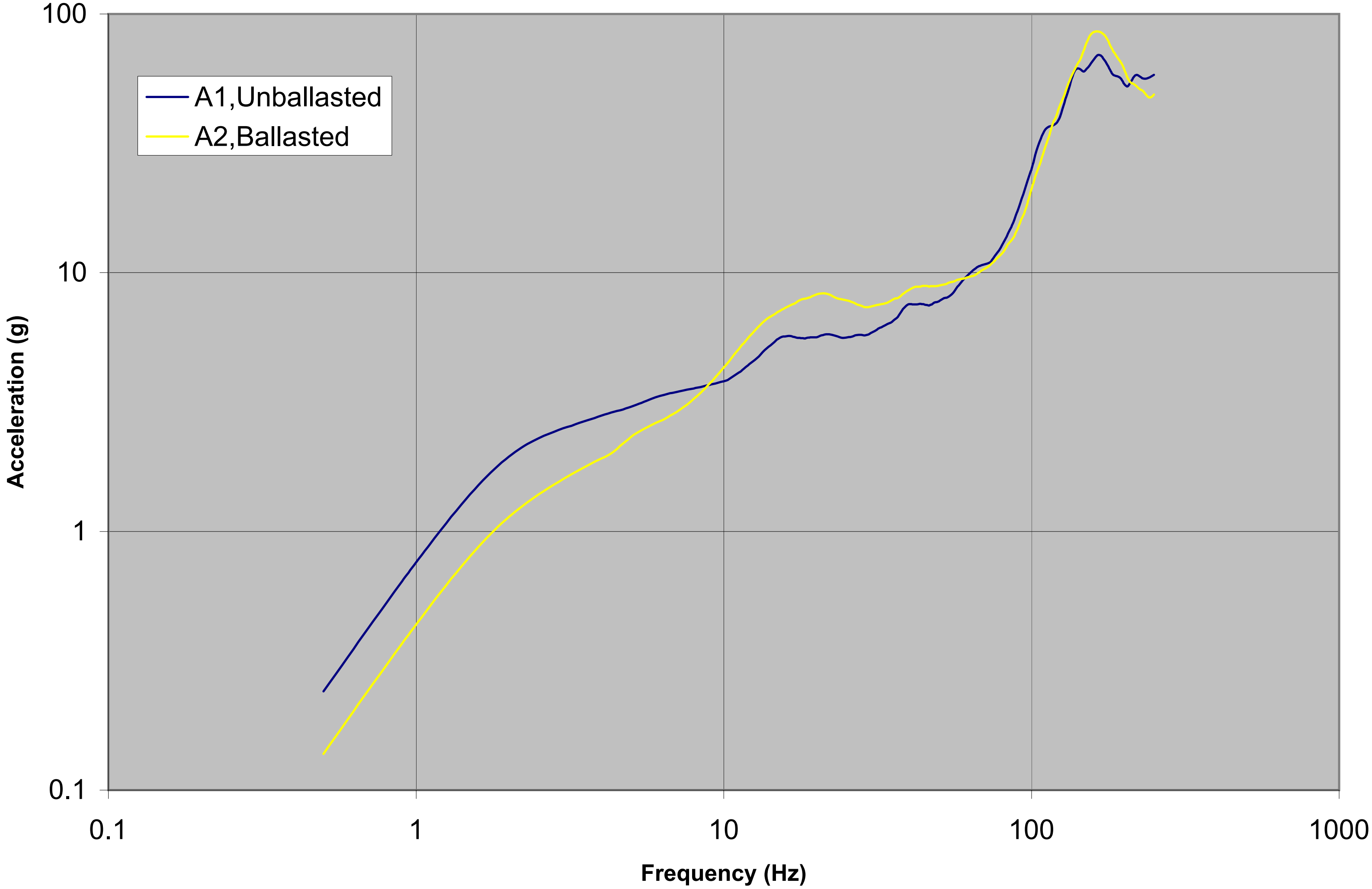


Figure B.2 - Test A3 SRS Results

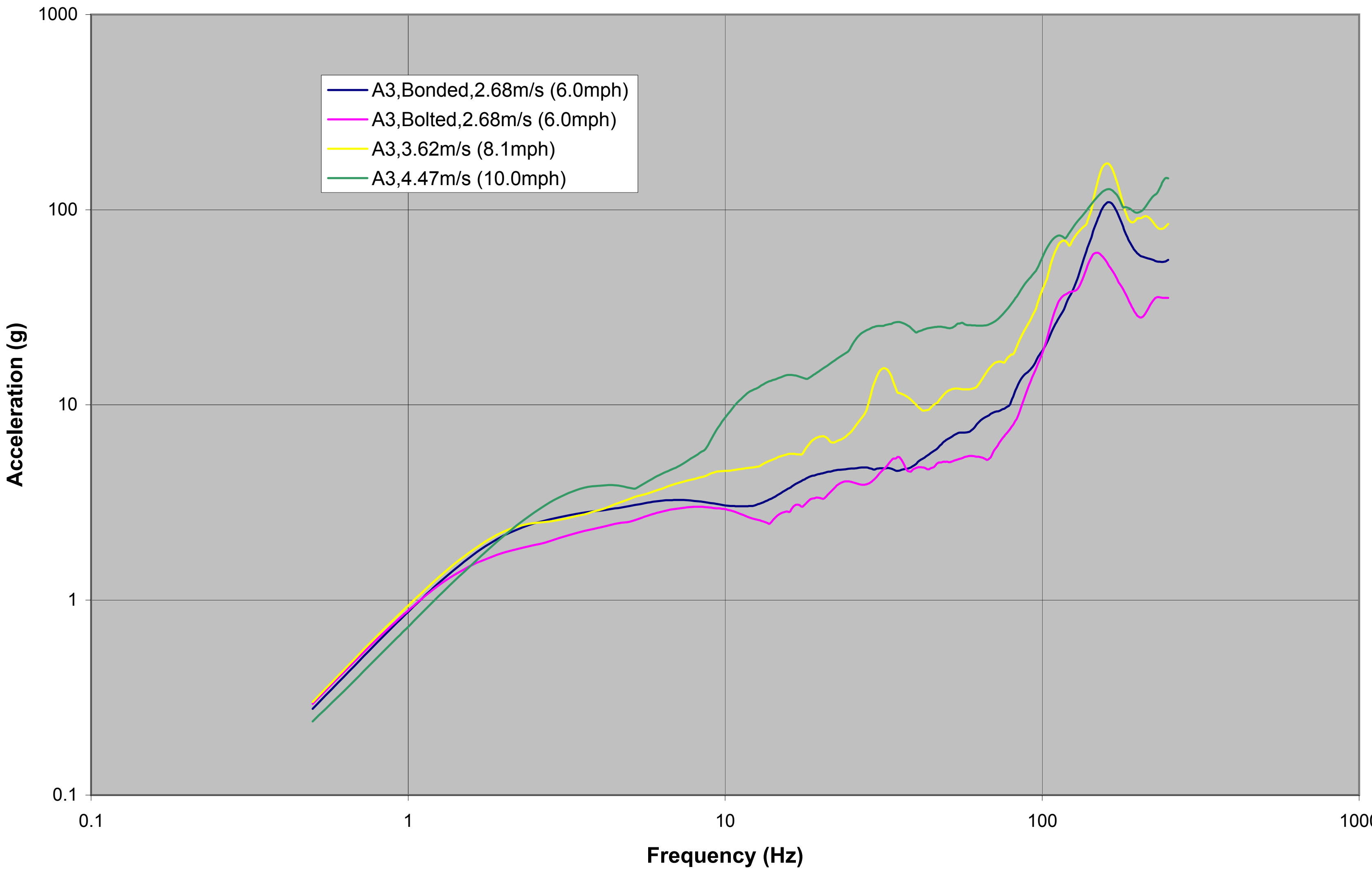


Figure B.3 - Test A4 SRS Results

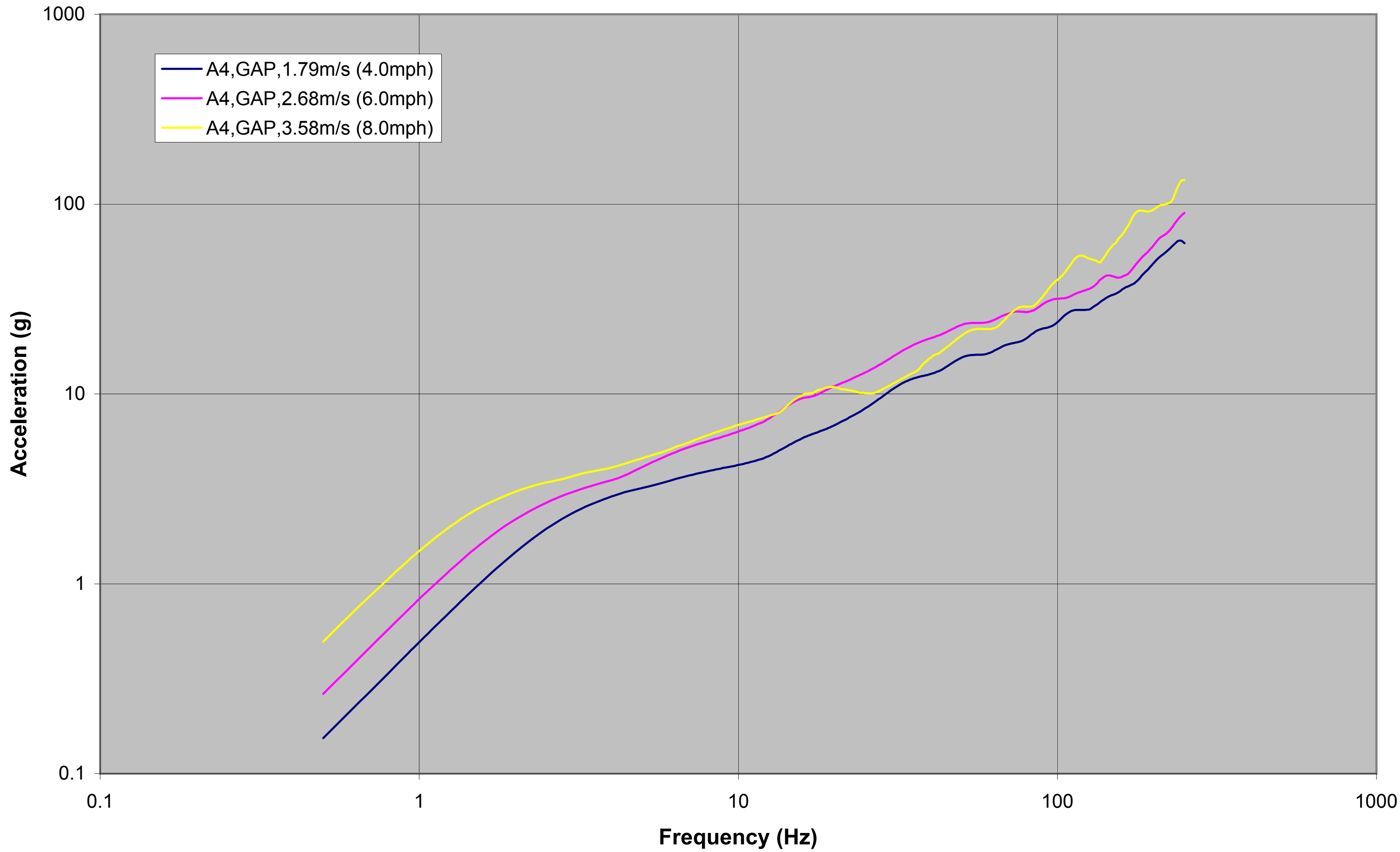


Figure B.4 - Test A5 SRS Results

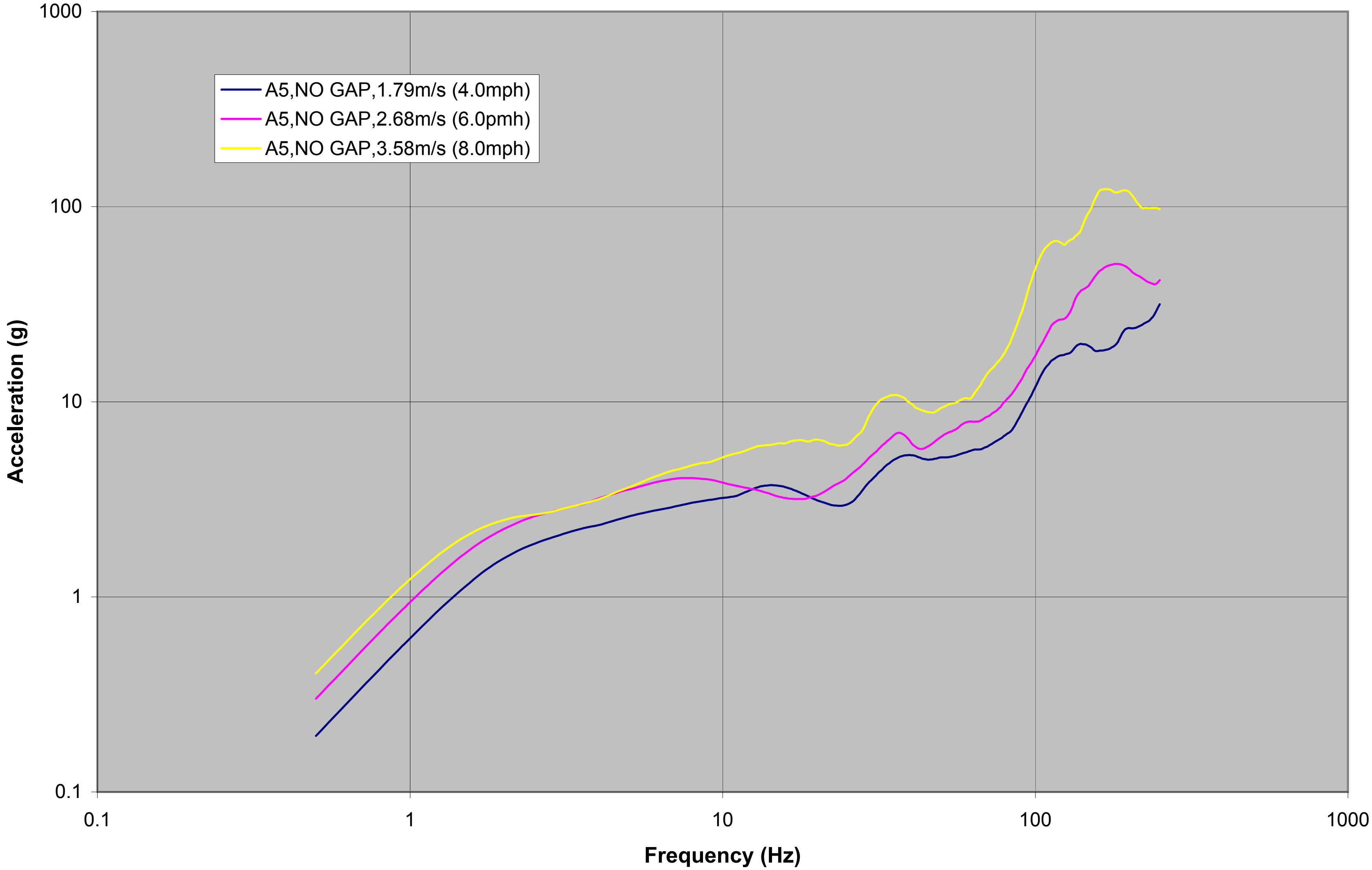


Figure B.5 - Test A6 SRS Results

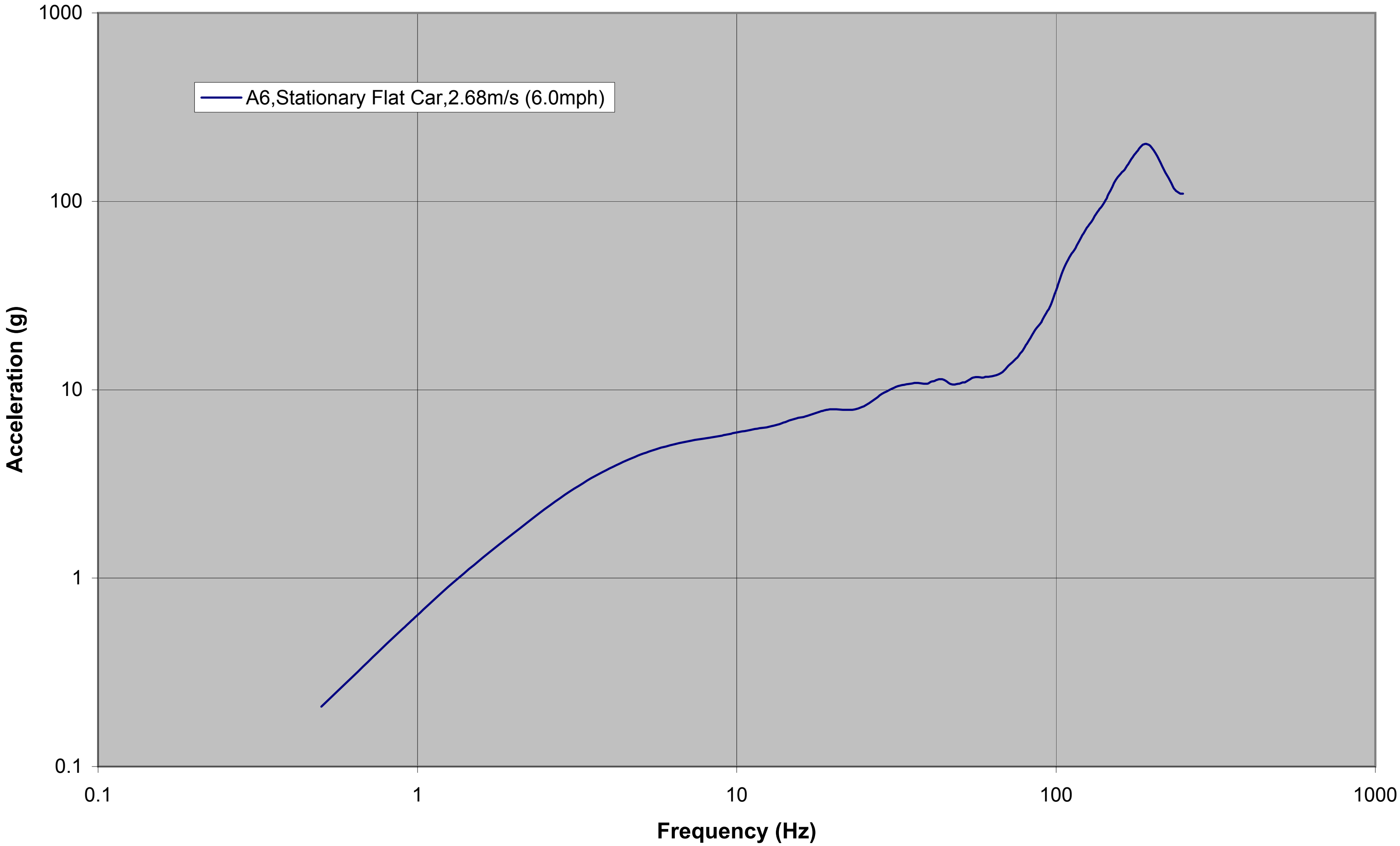


Figure B.6 - Test A7 SRS Results

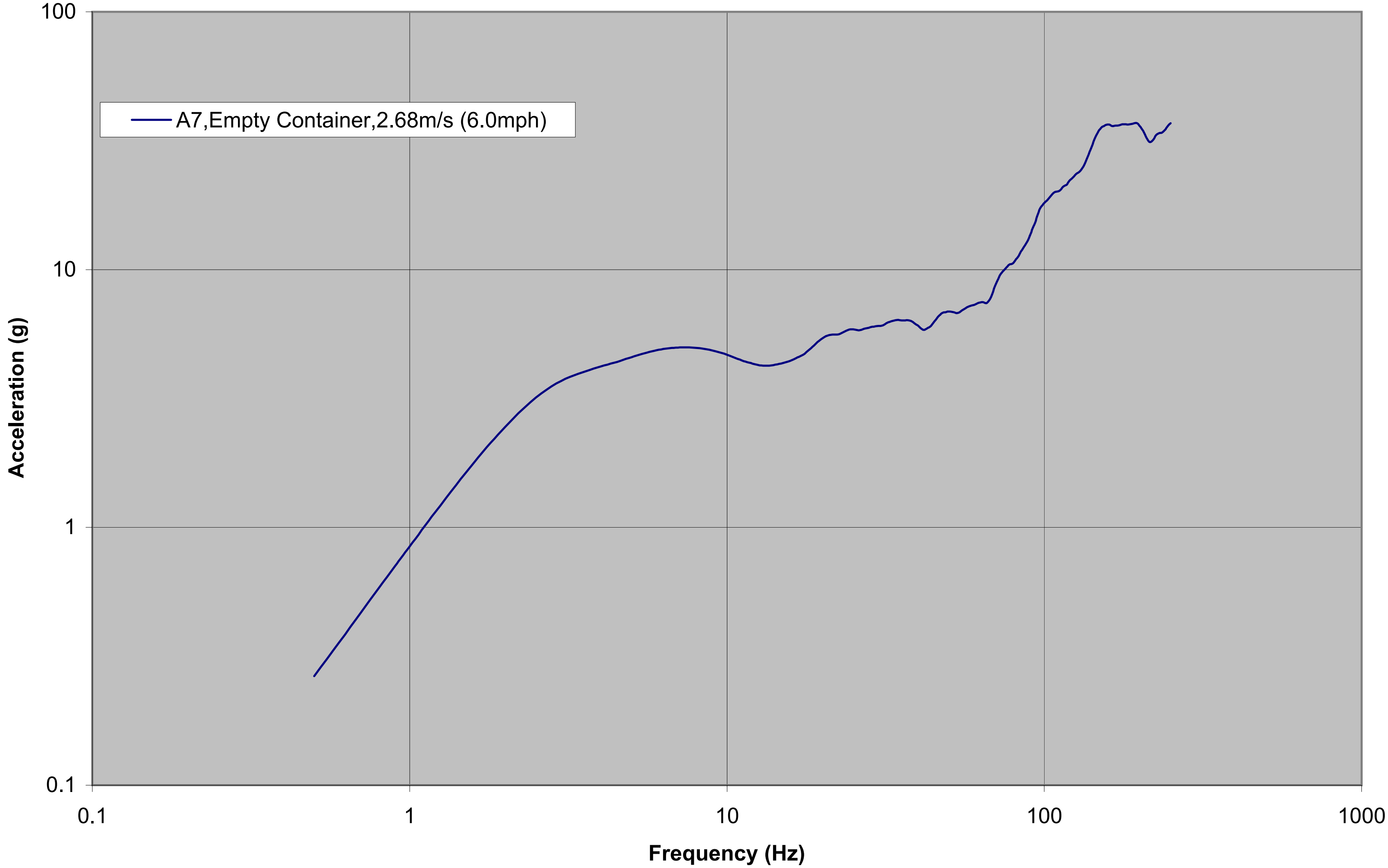


Figure B.7 - Test B1 SRS Results

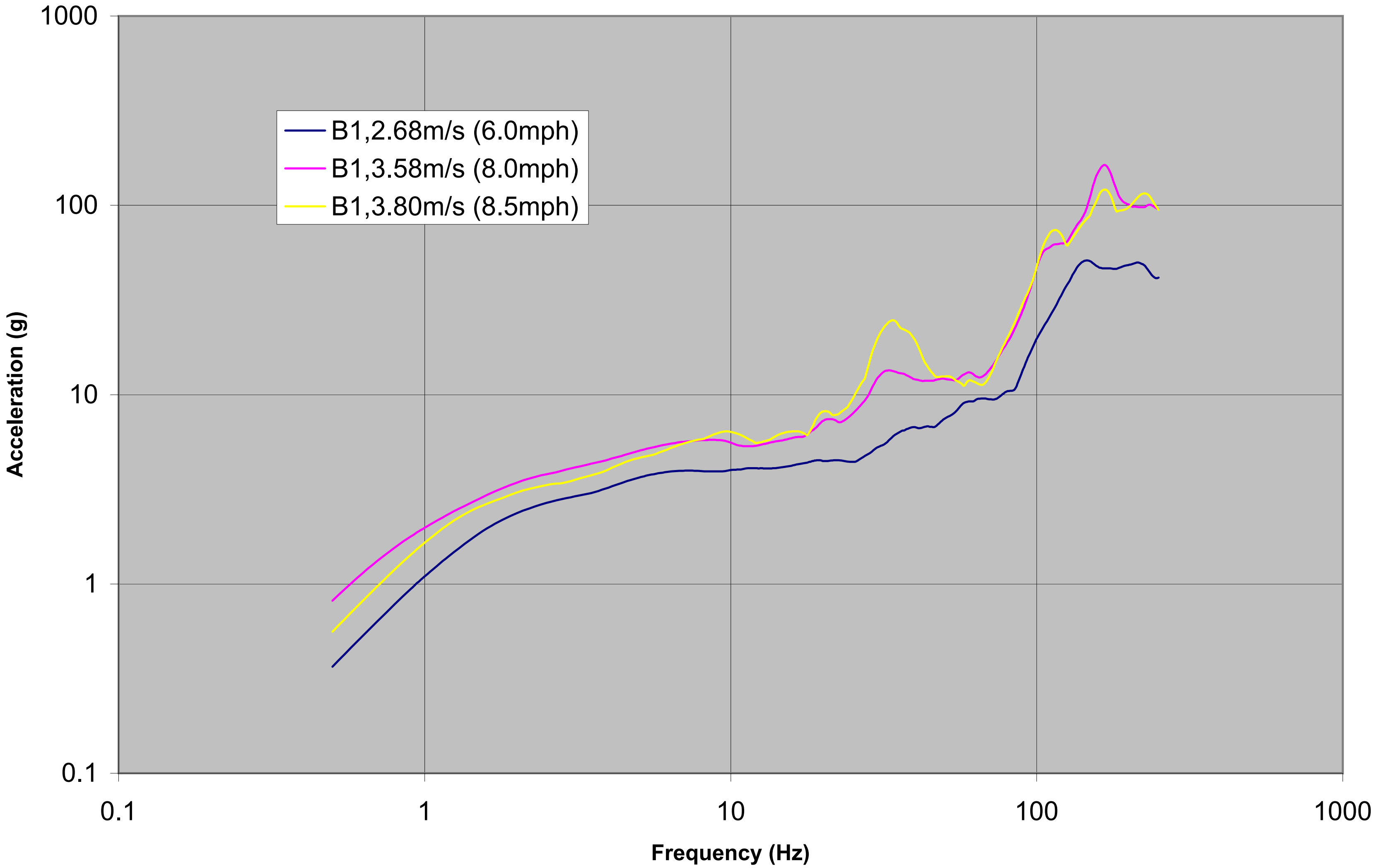


Figure B.8 - Test B2 SRS Results

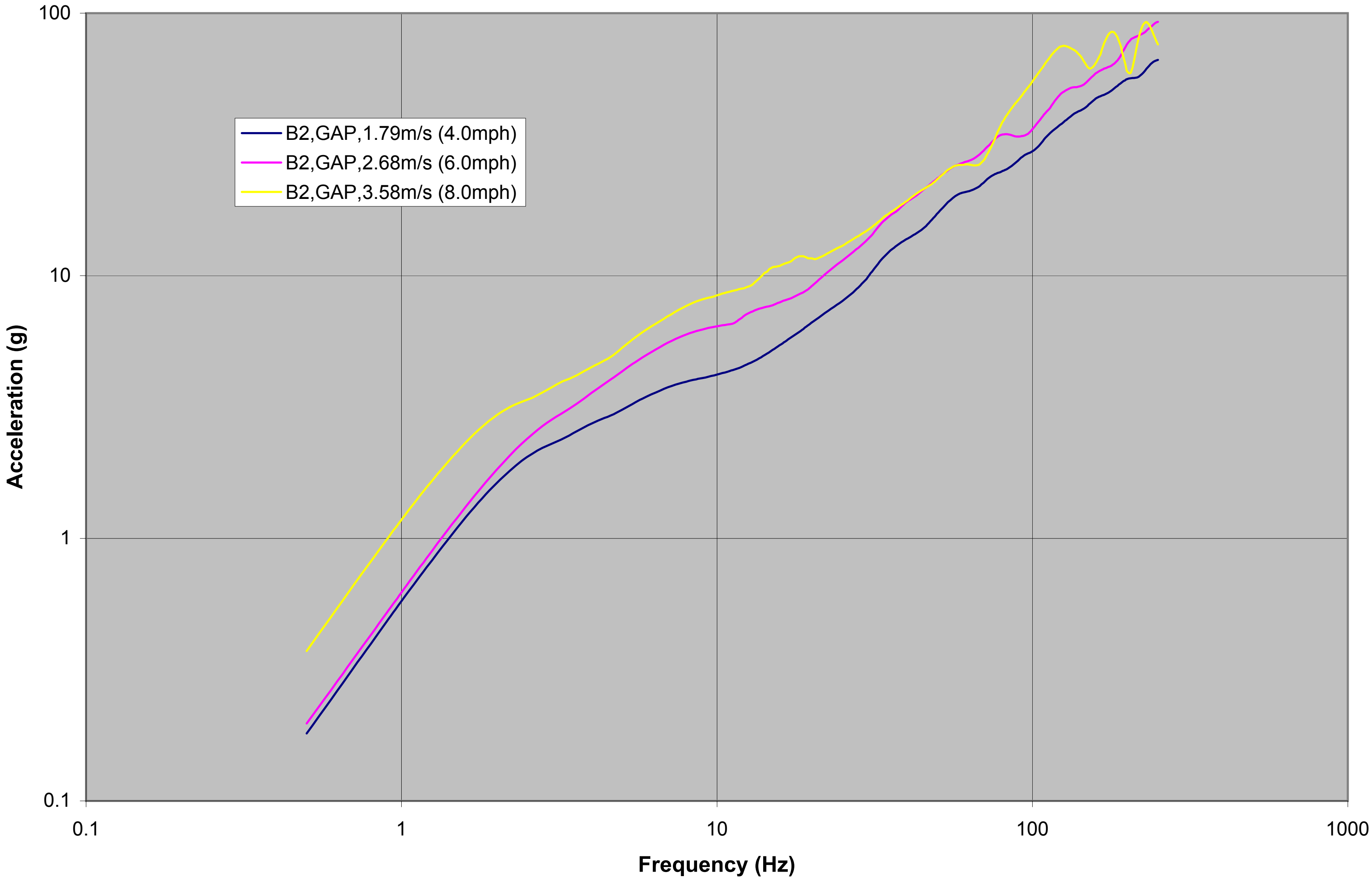


Figure B.9 - Test B3 SRS Results

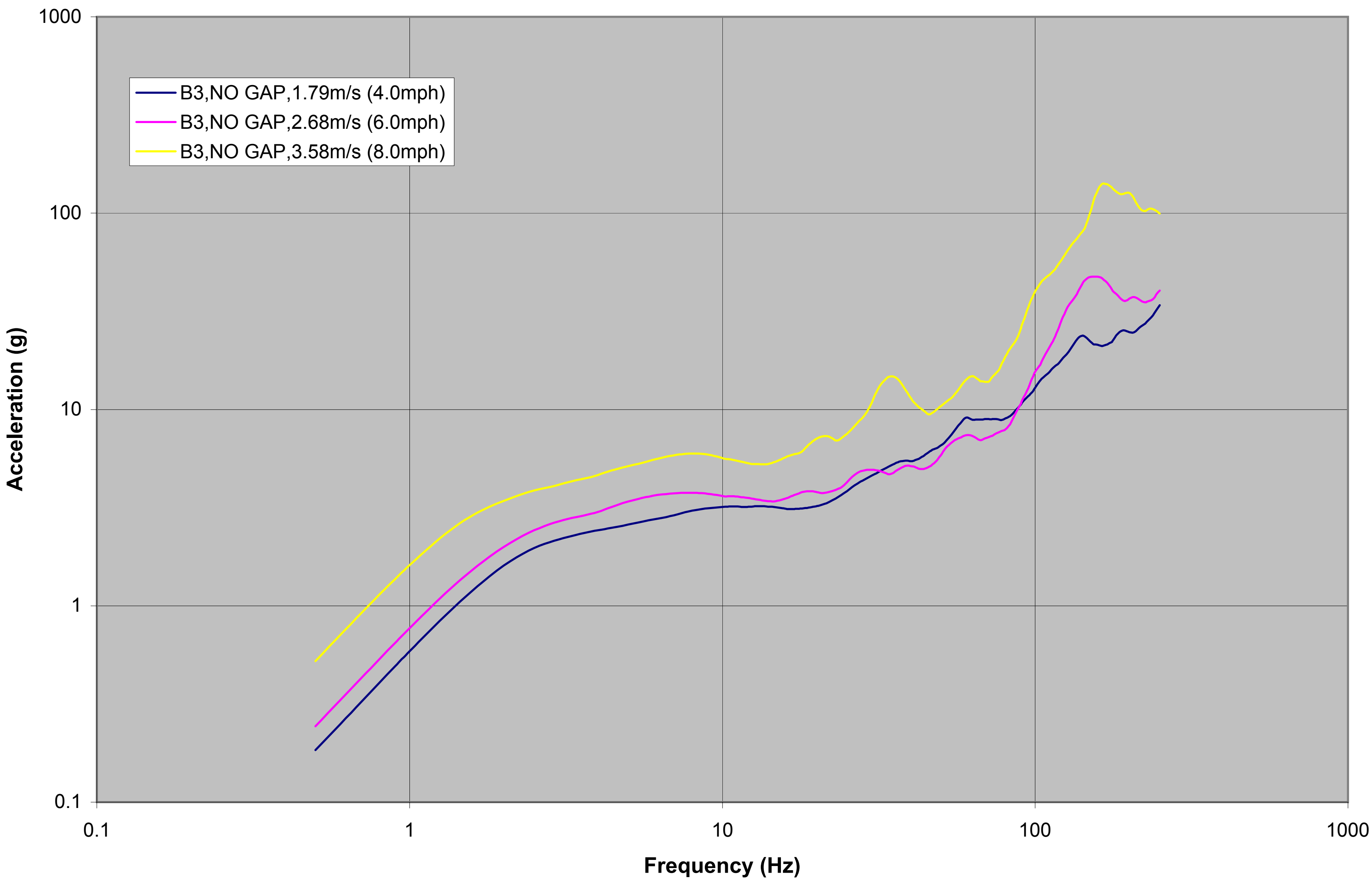


Figure B.10 - Test B4 SRS Results

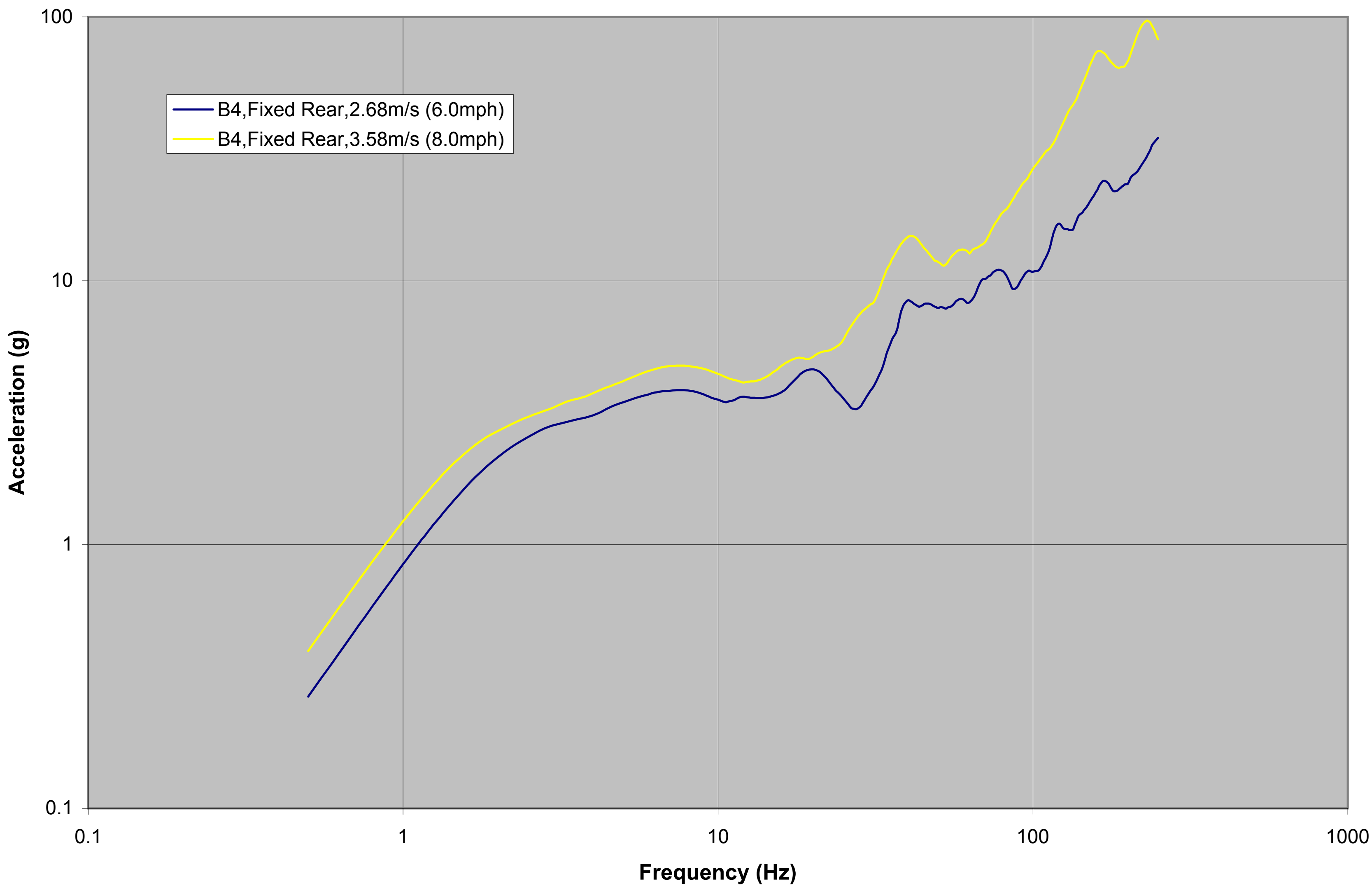


Figure B.11 - Test B5 & B6 SRS Results

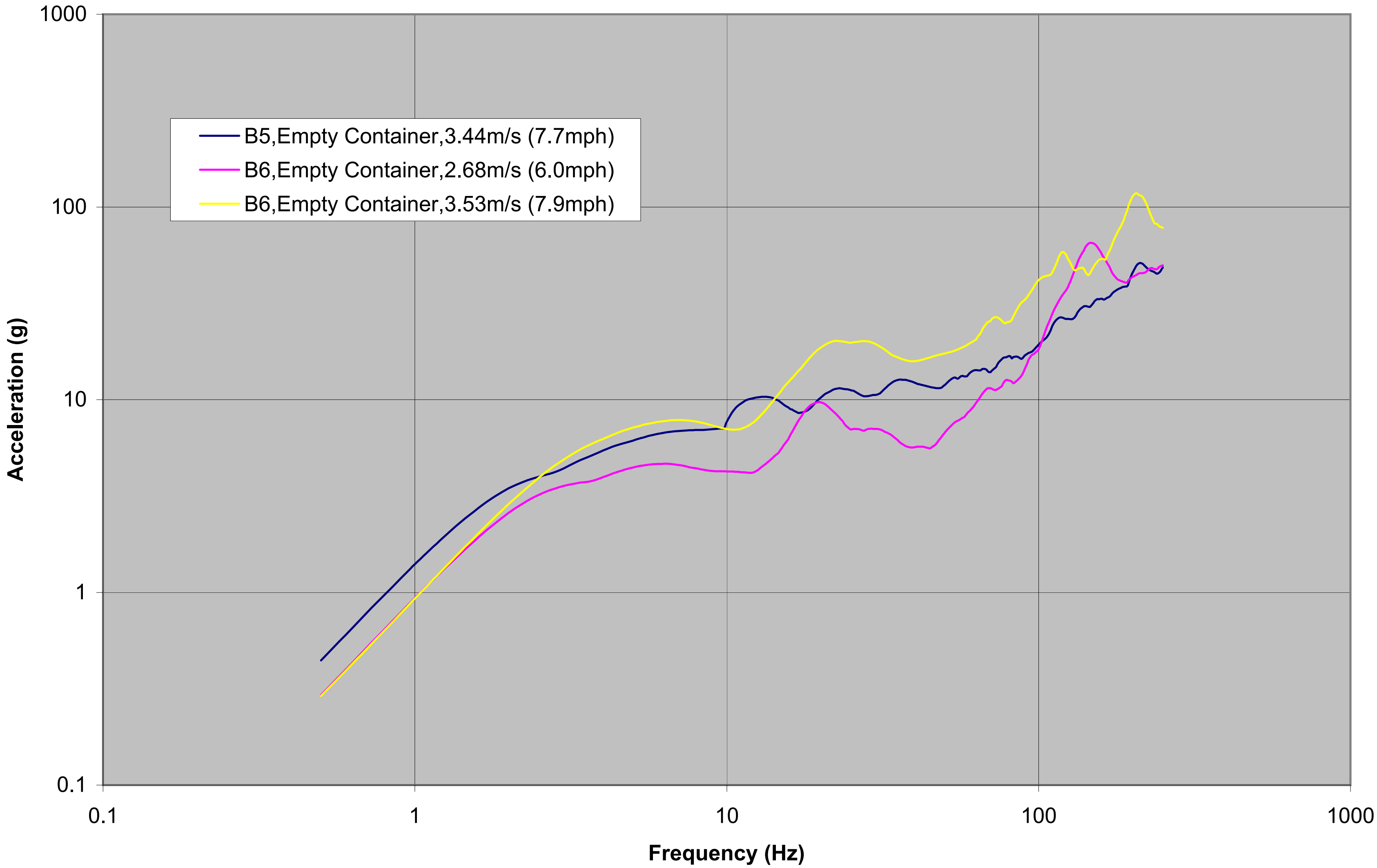


Figure B.12 - Effect of Mass on SRS
CPV Container @ 6 mph w/ Twistlocks + No Gap

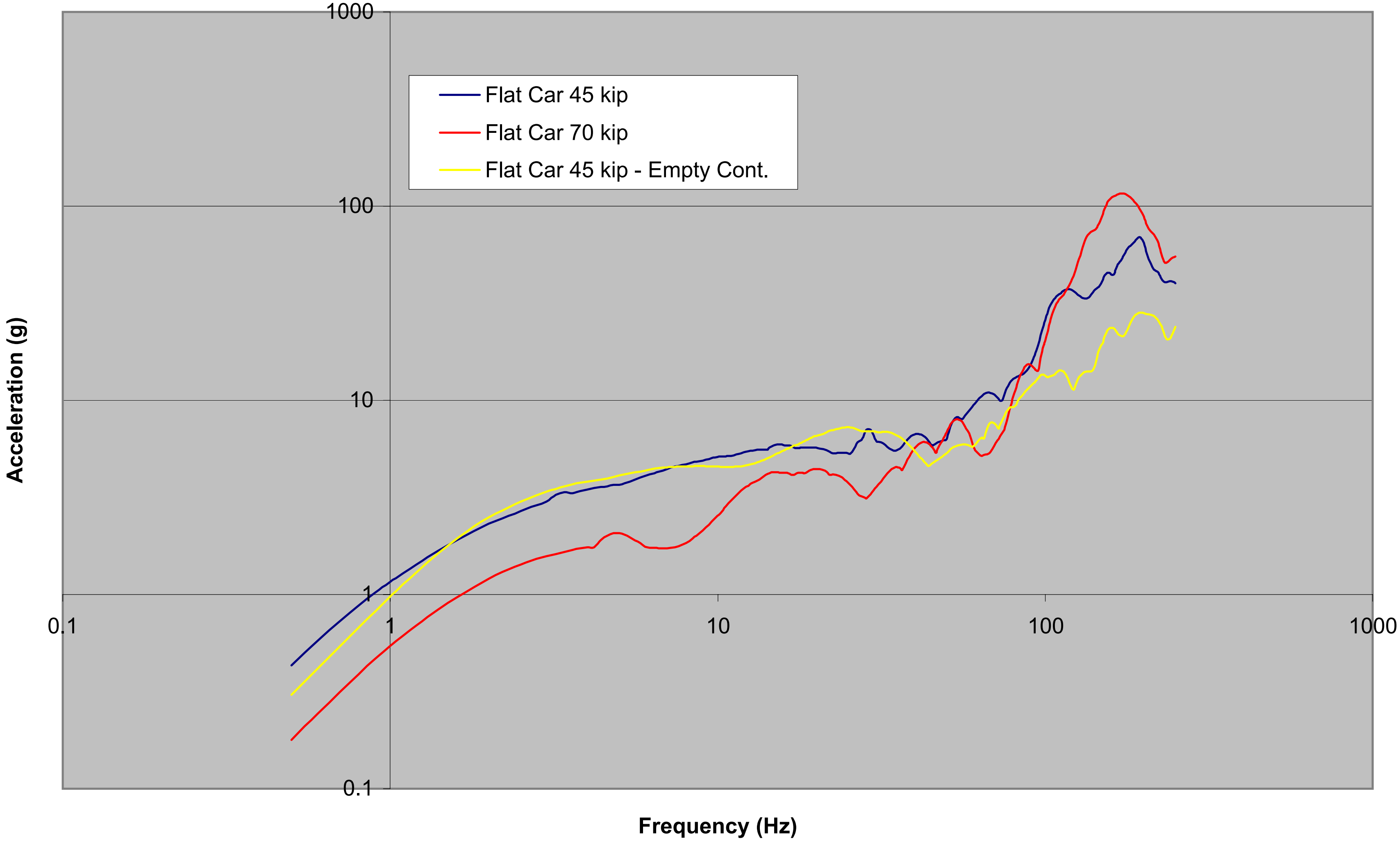


Figure B.13 - Effect of Impact Velocity on SRS

CPV Container w/ Load Cells + 70 kip Flat Car

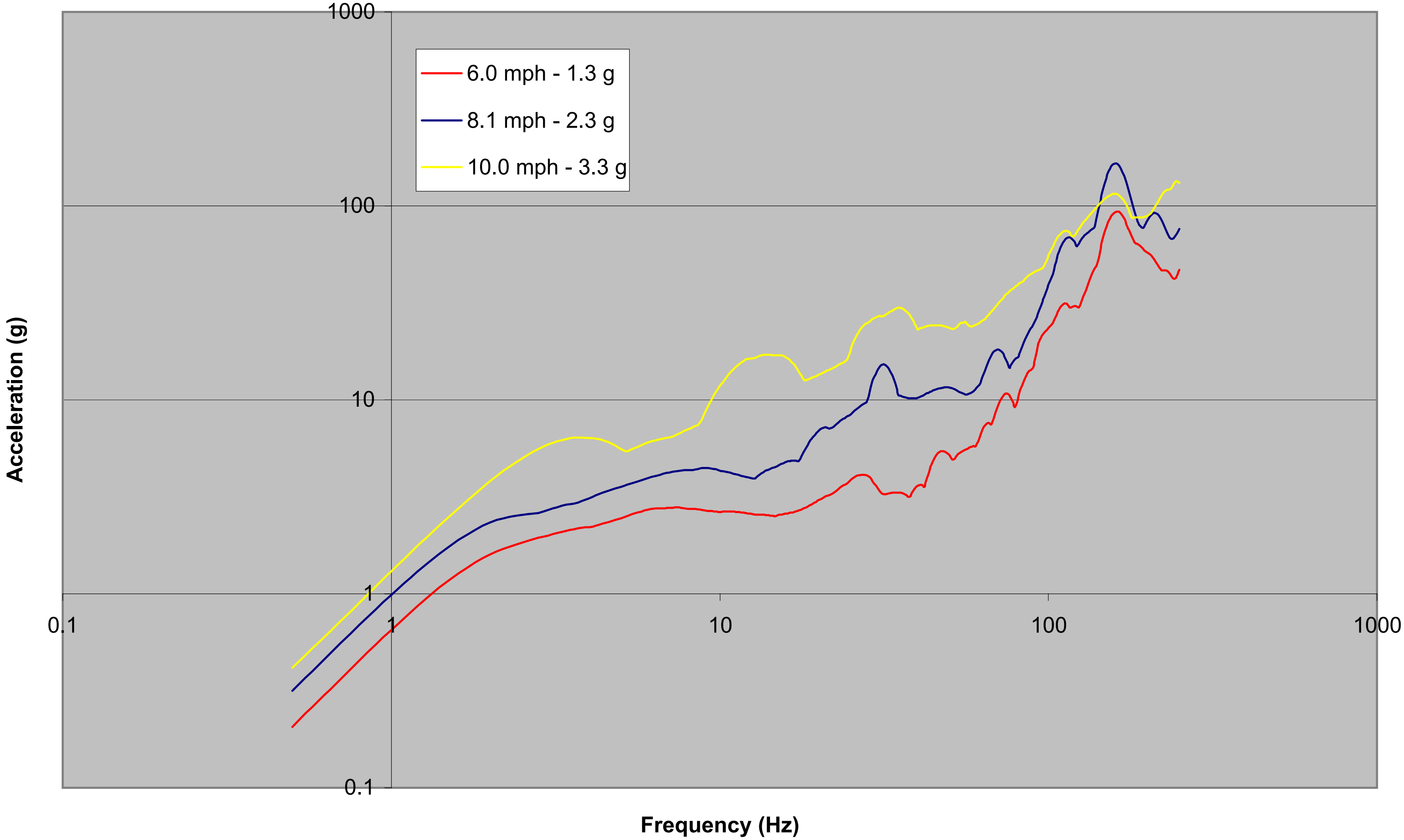


Figure B.14 - Effect of Accelerometer Mounts on SRS

CPV Container @ 6 mph w/ Load Cells + 70 kip Flat Car

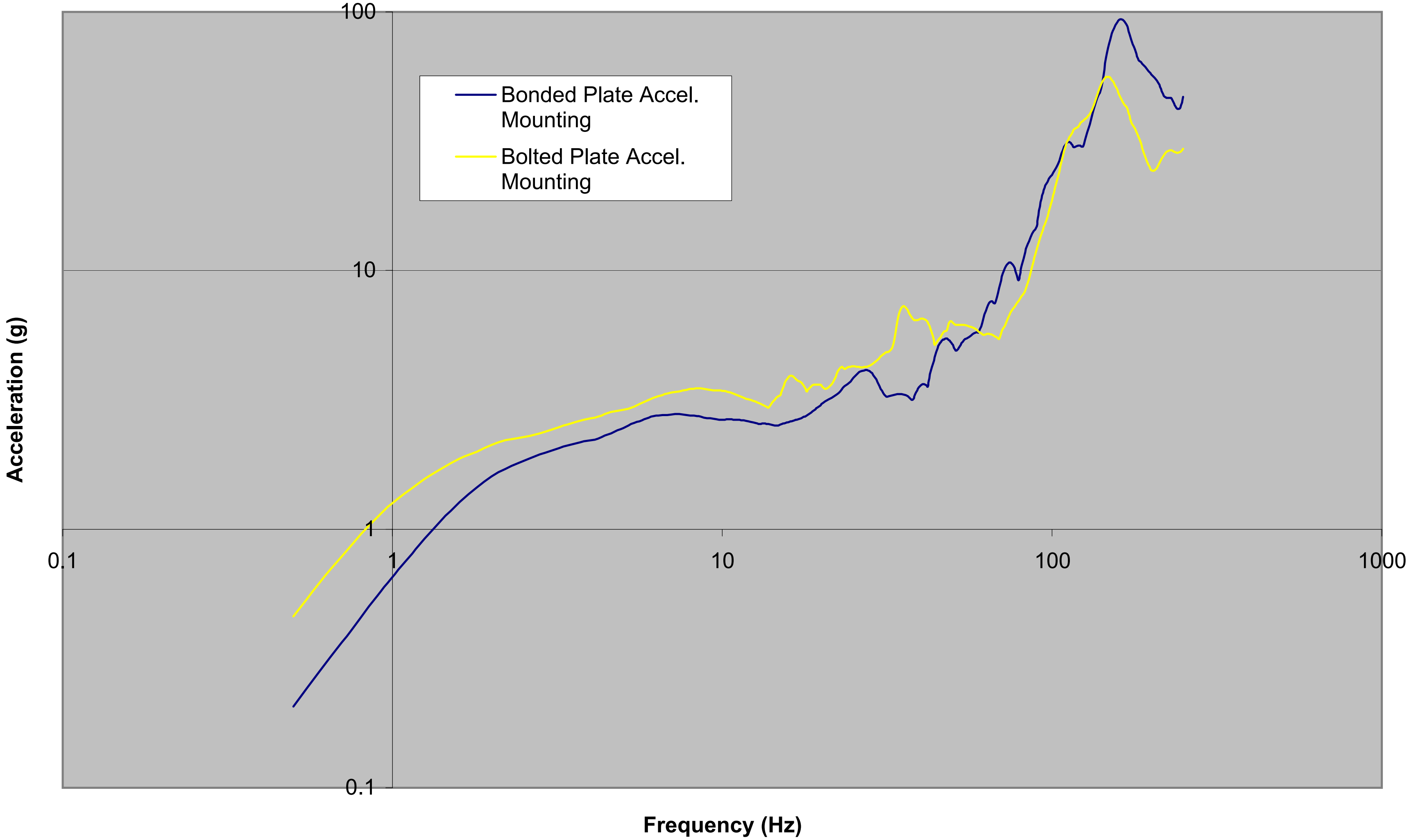


Figure B.15 - Effect of Tank Container Attachment on SRS

CPV Container @ 6 mph w/ 70 kip Flat Car + No Gap

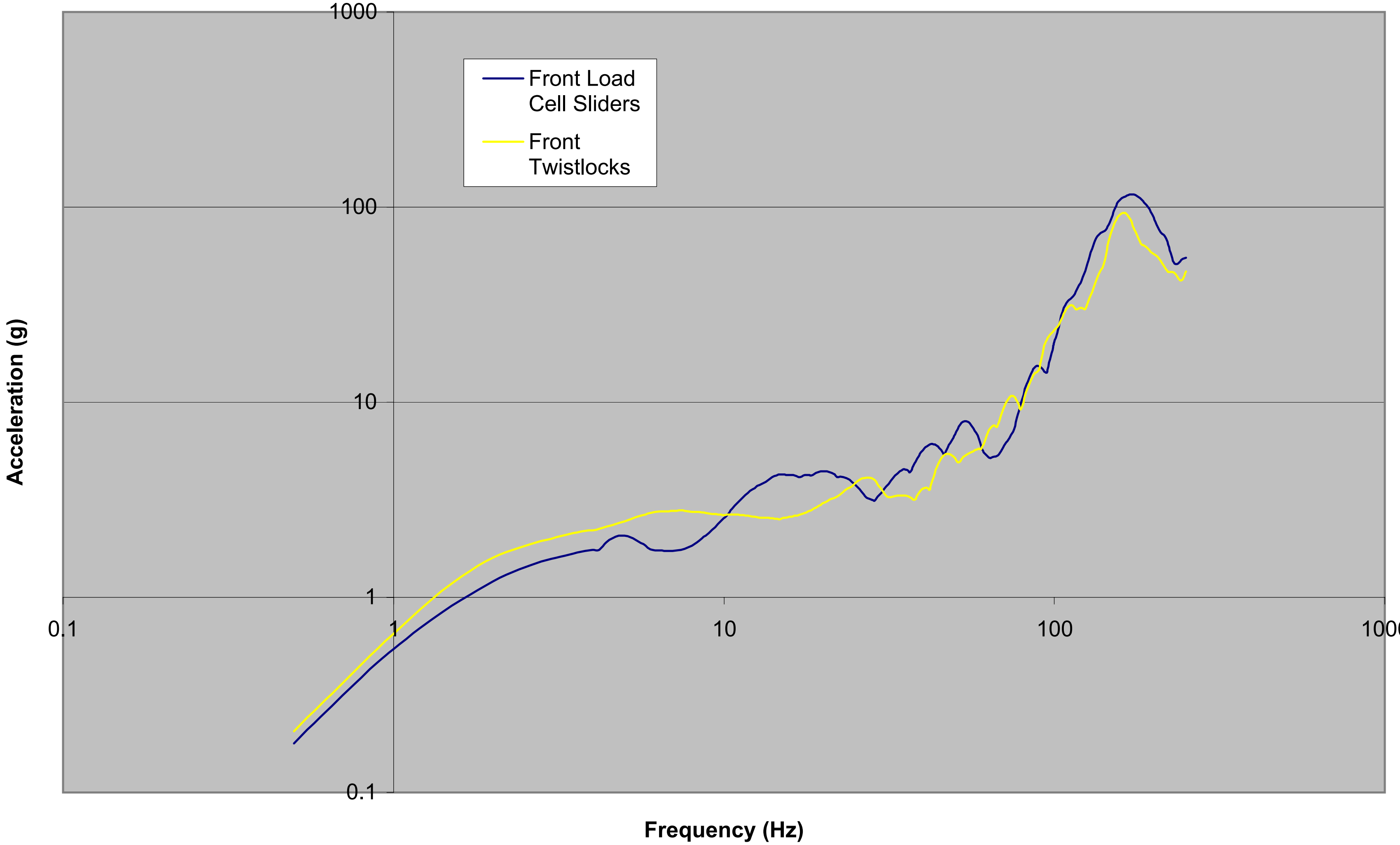


Figure B.16 - Effect of Stationary Flat Car on SRS

CPV Container @ 6 mph w/ 45 kip Flat Car + No Gap

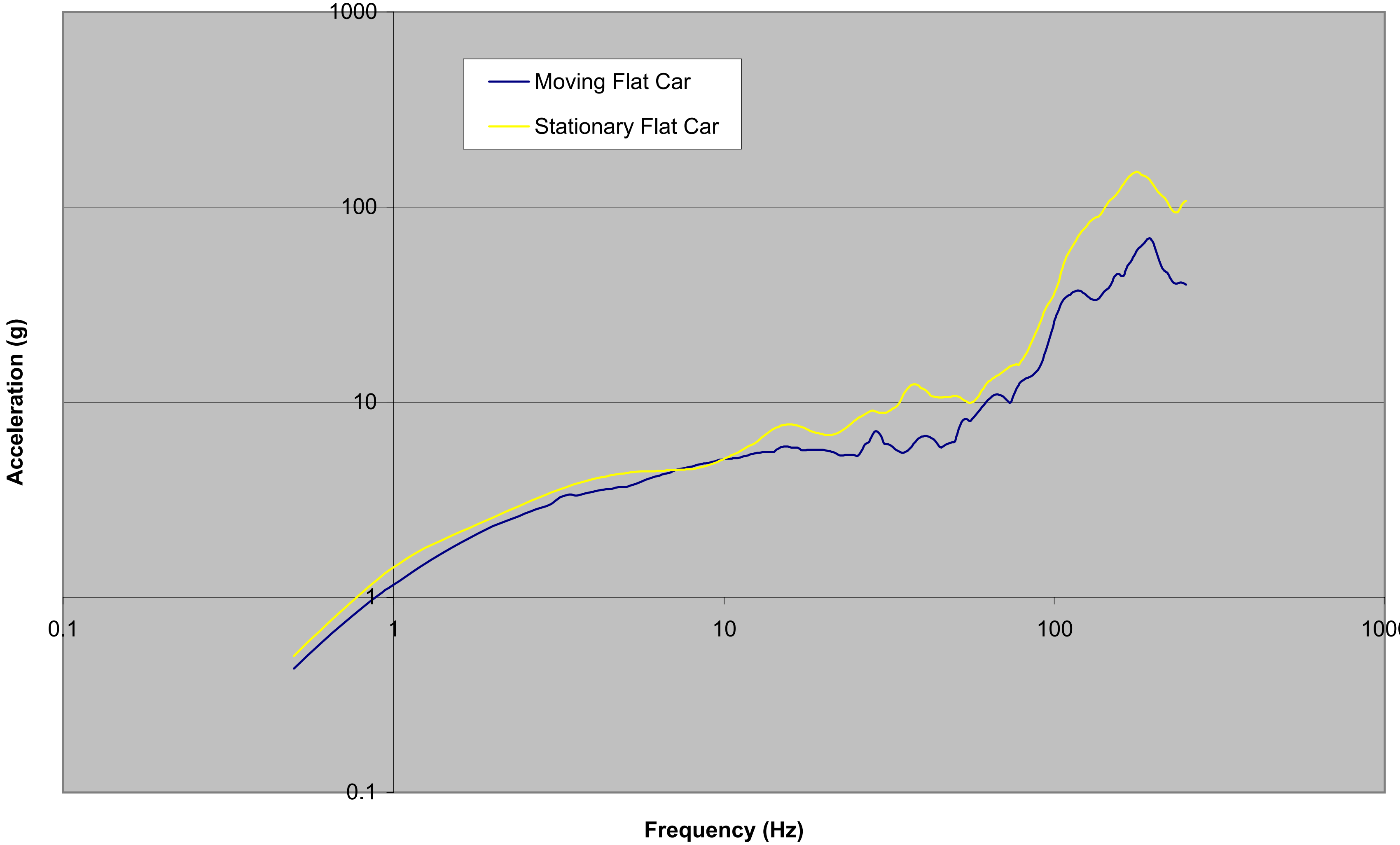


Figure B.17 - Effect of Tank Container Type on SRS

8 mph w/ Twistlocks + No Gap + 45 kip Flat Car

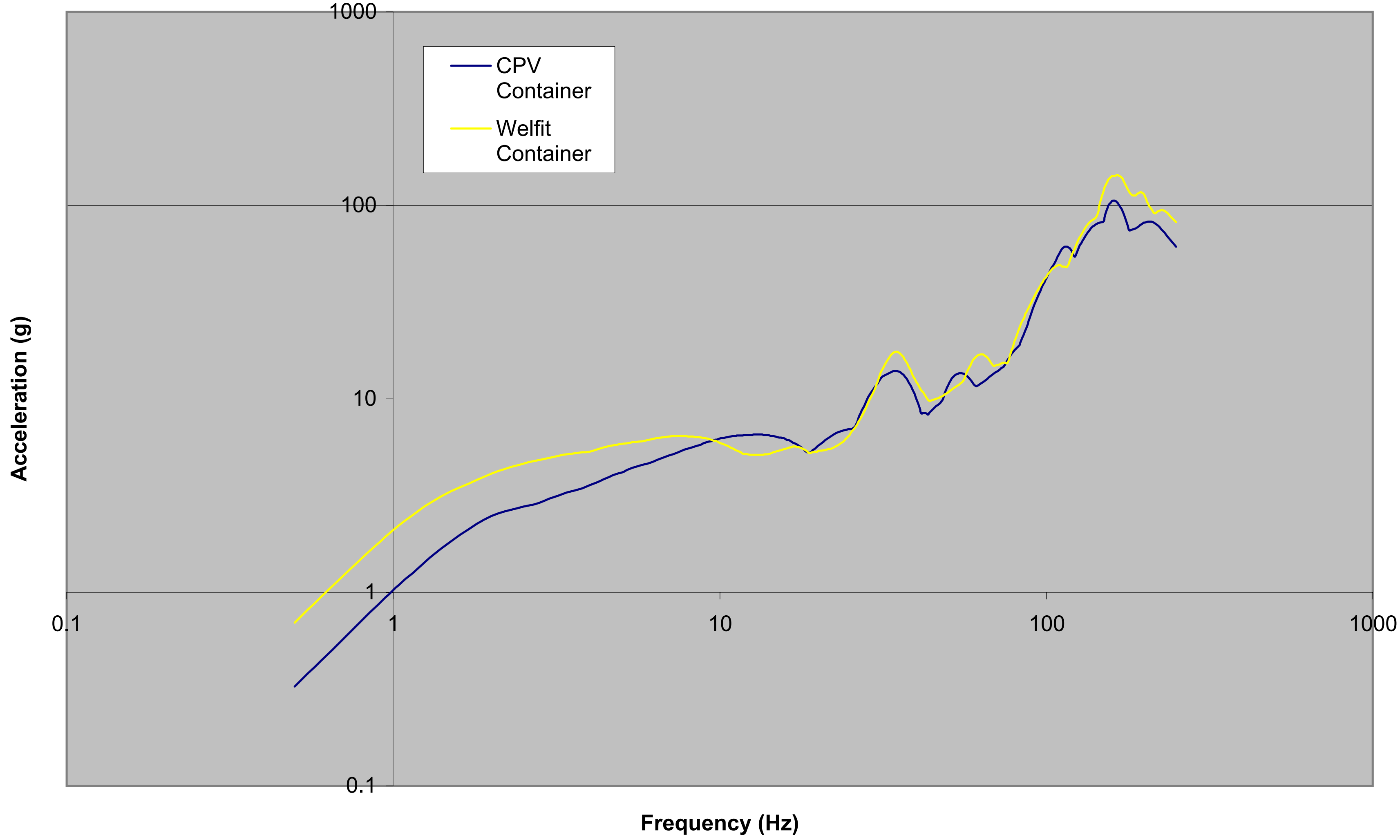


Figure B.18 - Effect of Accelerometer Position on SRS
Welfit-Oddy Container @ 8 mph w/ Twistlocks + No Gap + 45 kip Flat Car

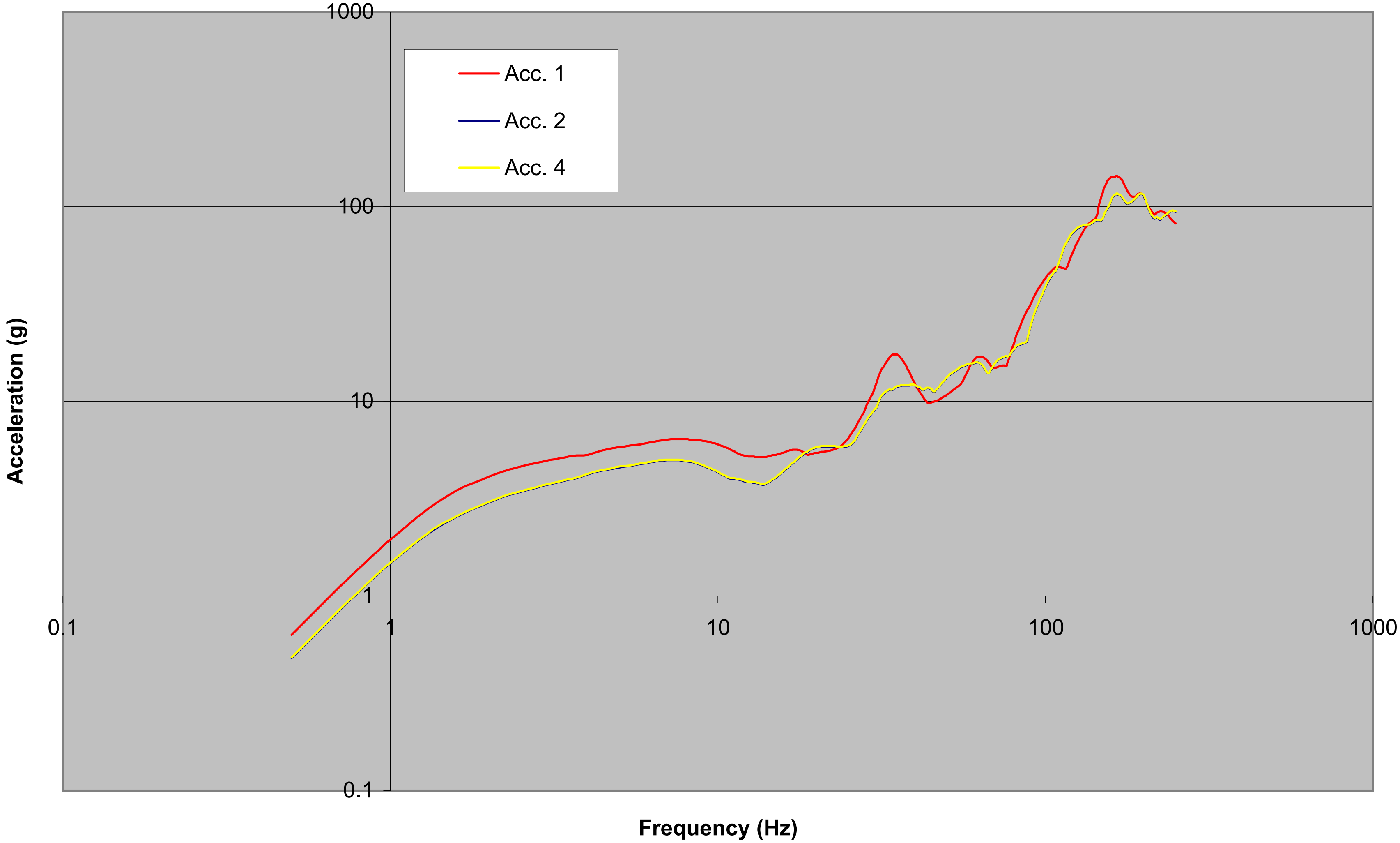


Figure B.19 - Effect of Gap on SRS

Welfit-Oddy Container @ 8 mph w/ Twistlocks + 45 kip Flat Car

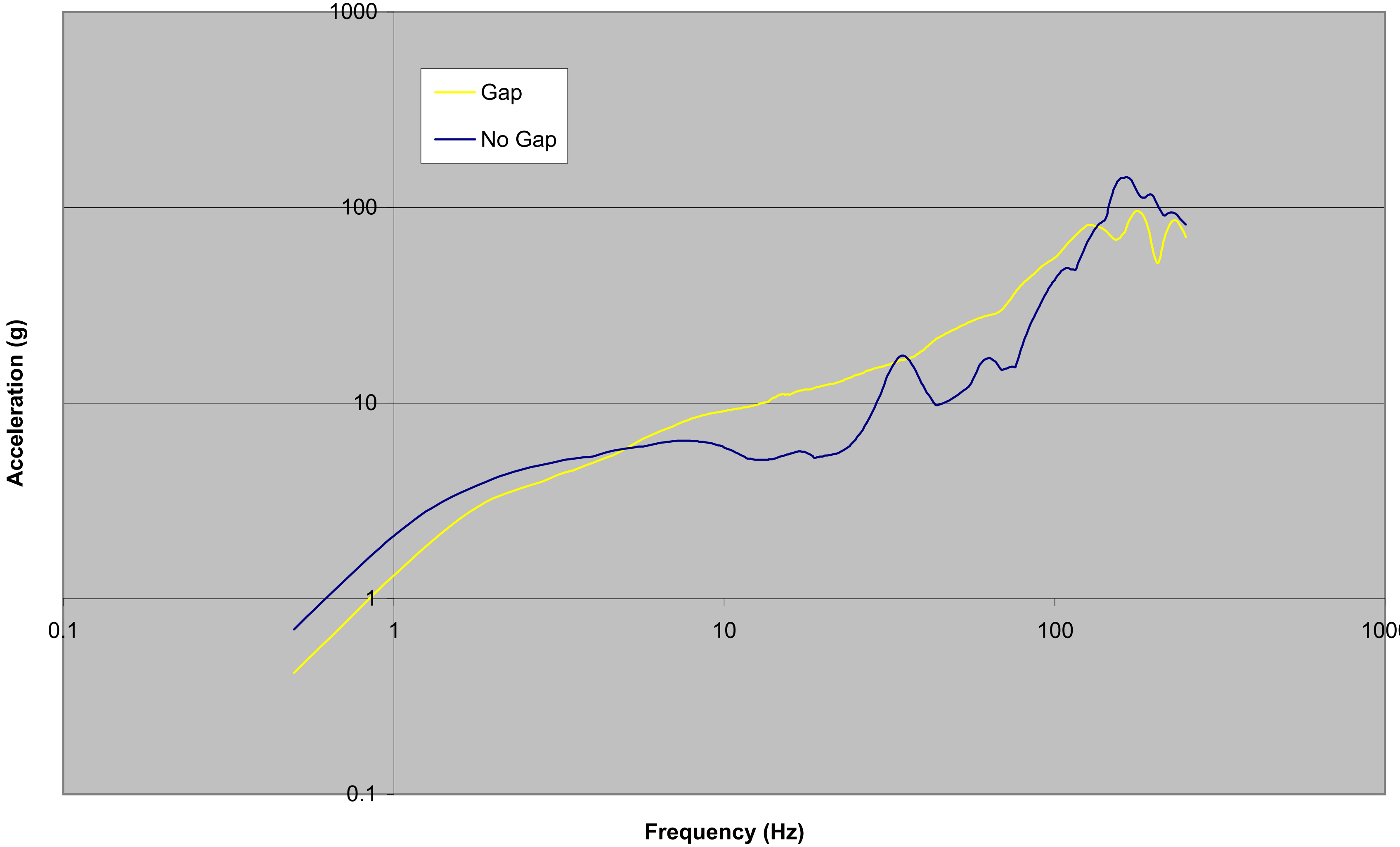


Figure B.20 - Repeatability of SRS

Welfit-Oddy Container @ 8 mph w/ Twistlocks + No Gap + 45 kip Flat Car

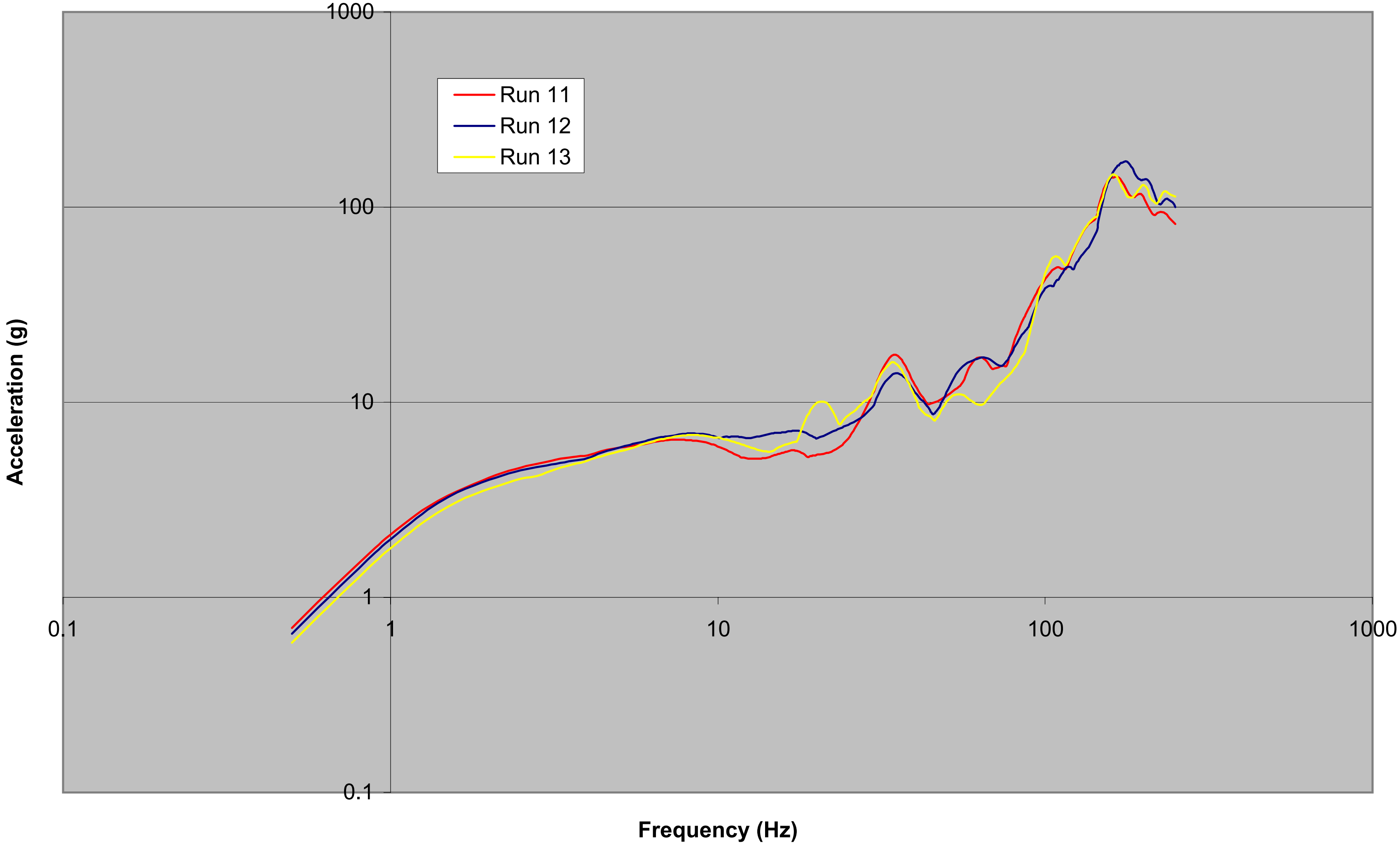
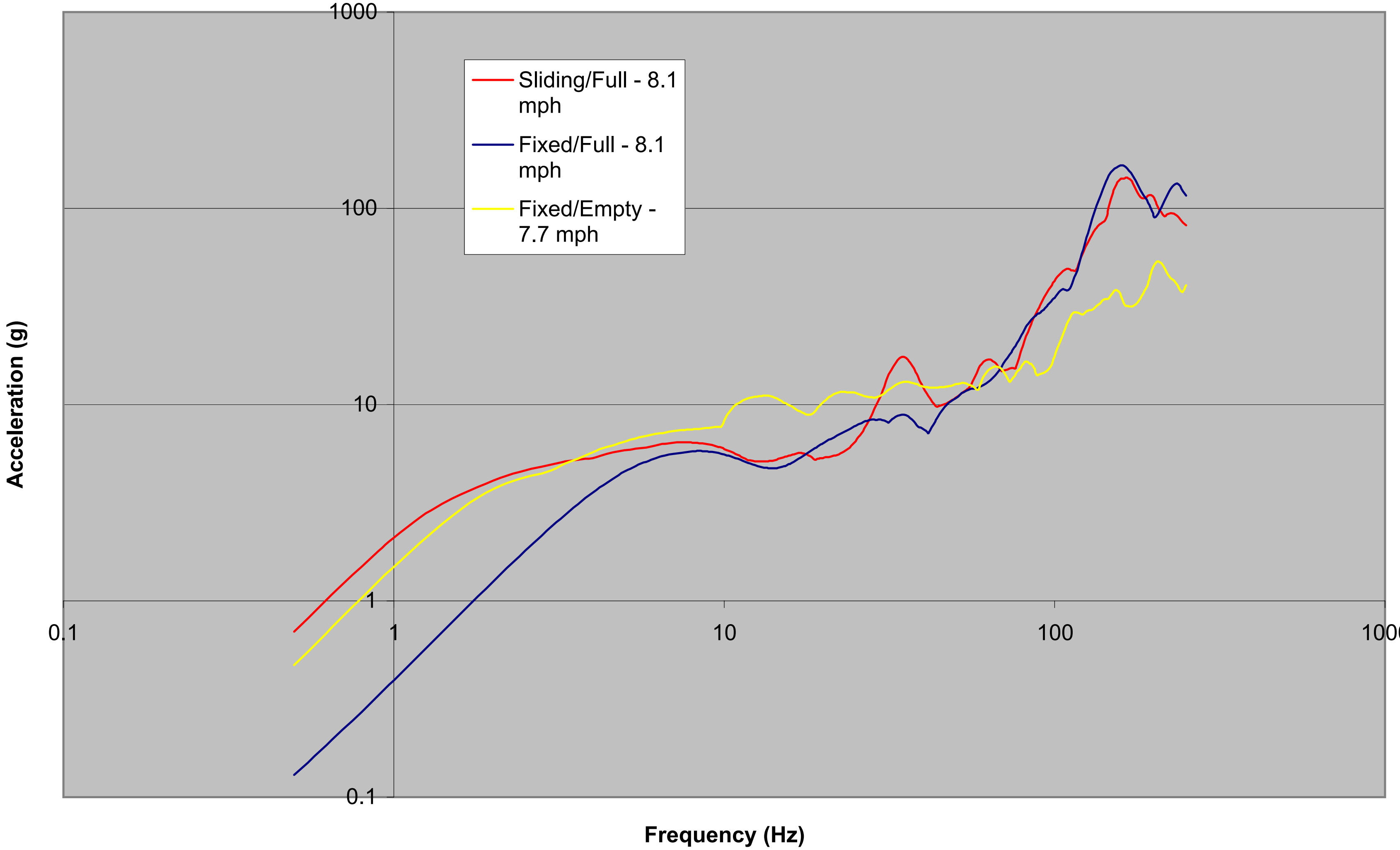


Figure B.21 - Effect of Rear Longitudinal Constraint & Tank Mass on SRS
Welfit-Oddy Container @ 8 mph w/ Twistlocks + No Gap + 45 kip Flat Car



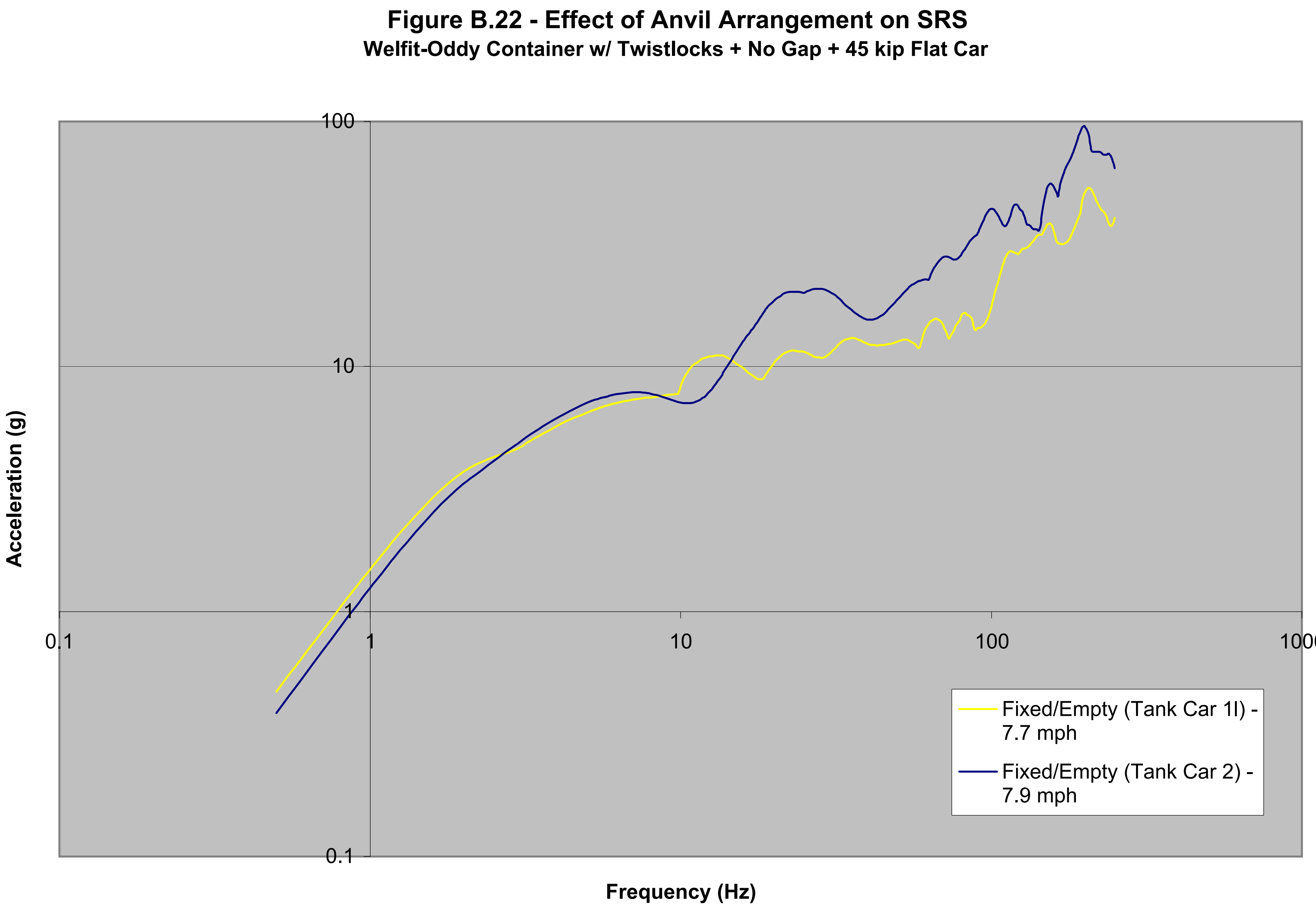


Figure B.22 - Effect of Anvil Arrangement on SRS
Welfit-Oddy Container w/ Twistlocks + No Gap + 45 kip Flat Car
100
10
1
0.1
0.1
1
10
100
1000
Acceleration (g)
Frequency (Hz)
Fixed/Empty (Tank Car 1I) - 7.7 mph
Fixed/Empty (Tank Car 2) - 7.9 mph

Figure B.23 - Effect of Sampling Frequency & Record Length on SRS
CPV Container @ 8 mph w/ Twistlocks + No Gap + 45 kip Flat Car

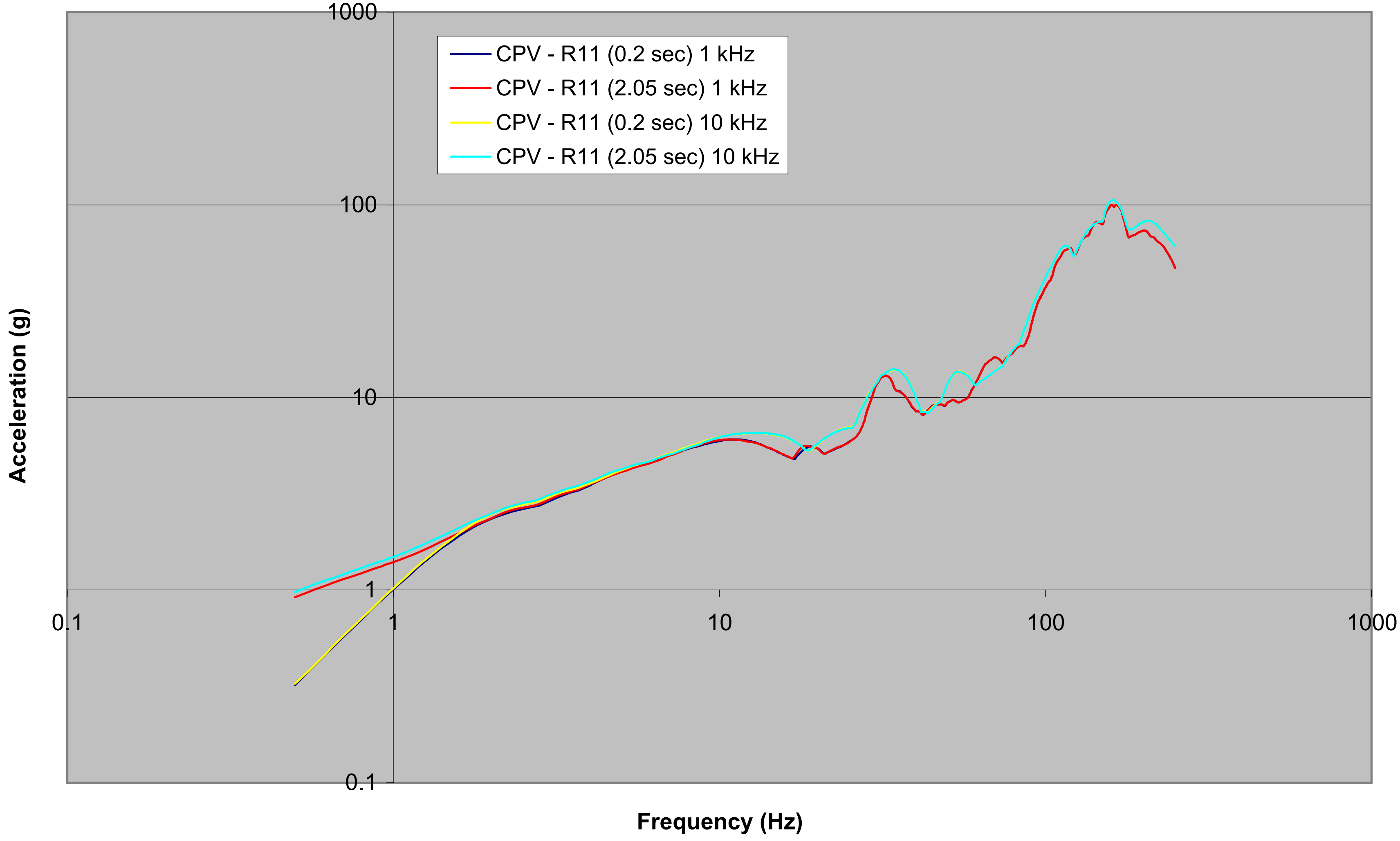
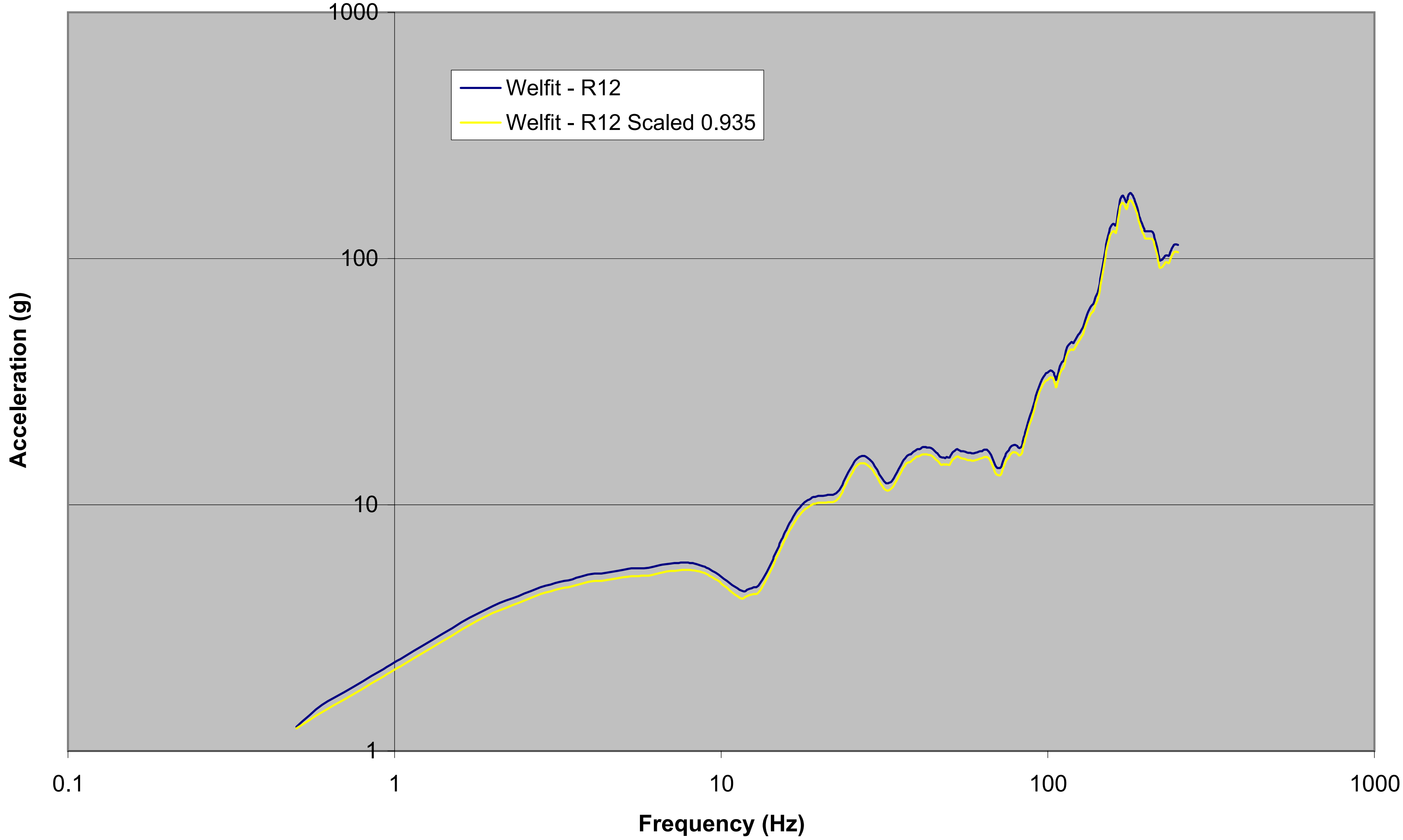


Figure B.24 - Effect of Scaling Factor on SRS

Welfit-Oddy Container @ 8 mph w/ Twistlocks + No Gap + 45 kip Flat Car



APPENDIX C

2DOF SIMULATION RESULTS

TABLE C.1 - RATED VERSUS TEST MASS 2DOF RESULTS

FILE	COUPLER FORCE (N)	CASTING FORCE (N)	TESTCAR ACC (m/s^2)	CONTAINER ACC (m/s^2)	INPUT VELOCITY (m/s)	TEST MASS (tonnes)	$\omega 1$ (Hz)	$\omega 2$ (Hz)
model80	1.96e6	1.86e6	143	93	4.0	20	5.03	10.1
model80b	1.59e6	1.35e6	143	135	4.0	10	5.03	14.2
model80c	2.41e6	2.37e6	143	58	4.0	40	5.03	7.11
model80d	3.68e6	3.48e6	269	174	7.5	20	5.03	10.1
model80e	3.93e6	3.71e6	287	186	8.0	20	5.03	10.1
model80f	2.45e6	2.32e6	179	116	5.0	20	5.03	10.1
model80g	2.75e6	2.60e6	201	130	5.6	20	5.03	10.1
model90	1.94e6	1.90e6	143	95.1	4.0	20	5.03	14.2
model90b	1.63e6	1.39e6	143	139	4.0	10	5.03	20.1
model90c	2.232e6	2.35e6	143	58.8	4.0	40	5.03	10.1
model90d	3.64e6	3.56e6	269	178	7.5	20	5.03	14.2
model90e	3.88e6	3.80e6	287	190	8.0	20	5.03	14.2
model90f	2.42e6	2.37e6	179	119	5.0	20	5.03	14.2
model90g	2.72e6	2.66e6	201	133	5.6	20	5.03	14.2
model10	2.85e6	2.17e6	89.6	81.0	3.576	26.8	5.03	29
model10b	3.07e6	2.50 e6	87.0	74.5	3.576	33.6	5.03	26
model10c	2.14e6	1.63e6	67.2	60.8	2.682	26.8	5.03	29
model10d	1.43e6	1.08e6	44.8	40.5	1.788	26.8	5.03	29
model10e	3.57e6	2.72e6	112.0	102.0	4.48	26.8	5.03	29
model10f	3.05e6	2.32e6	96.0	86.8	3.83	26.8	5.03	29
model10g	3.35e6	2.55e6	105.0	95.2	4.20	26.8	5.03	29

Legend:
model80* = 10T test wagon, high stiffness (10e6 N/m), high stiffness container (80e6 N/m)
model90* = 10T test wagon, high stiffness (10e6N/m), high stiffness container (160e6 N/m)
model10* = 20T test wagon, high stiffness (20e6N/m), high stiffness container (900e6 N/m)

FILE	COUPLER FORCE (N)	CASTING FORCE (N)	TESTCAR ACC (m/s^2)	CONTAINER ACC (m/s^2)	INPUT VELOCITY (m/s)	TEST MASS (tonnes)	ω1 (Hz)	ω2 (Hz)
model50	2.99e6	2.18e6	92.2	109	4.0	20	5.03	10.1
model50b	2.54e6	1.35e6	94.5	136	4.0	10	5.03	14.2
model50c	3.75e6	3.12e6	86.9	78.1	4.0	40	5.03	7.11
model50d	5.60e6	4.08e6	173	204	7.5	20	5.03	10.1
model50e	5.97e6	4.35e6	184	218	8.0	20	5.03	10.1
model50f	3.73e6	2.72e6	115	136	5.0	20	5.03	10.1
model50g	4.18e6	3.05e6	129	153	5.6	20	5.03	10.1
model60	3.01e6	2.05e6	102	103	4.0	20	5.03	14.2
model60b	2.57e6	1.28e6	104	128	4.0	10	5.03	20.1
model60c	3.68e6	2.93e6	93.9	73.4	4.0	40	5.03	10.1
model60d	5.65e6	3.85e6	191	193	7.5	20	5.03	14.2
model60e	6.02e6	4.11e6	203	206	8.0	20	5.03	14.2
model60f	3.76e6	2.57e6	127	129	5.0	20	5.03	14.2
model60g	4.22e6	2.88e6	142	144	5.6	20	5.03	14.2
model70	5.38e6	2.42e6	98.9	121	4.0	20	5.03	14.2
model70b	4.87e6	1.27e6	104	127	4.0	10	5.03	20.1
model70c	6.27e6	4.07e6	93.9	102	4.0	40	5.03	10.1
model70d	10.1e6	4.53e6	185	227	7.5	20	5.03	14.2
model70e	10.8e6	4.83e6	198	242	8.0	20	5.03	14.2
model70f	6.73e6	3.02e6	124	151	5.0	20	5.03	14.2
model70g	7.53e6	3.38e6	138	169	5.6	20	5.03	14.2
model70h	8.74e6	3.93e6	161	197	6.5	20	5.03	14.2

Legend:
model50* = 20T test wagon, high stiffness (20e6 N/m), high stiffness container (80e6 N/m)
model60* = 20T test wagon, high stiffness (20e6 N/m), high stiffness container (160e6 N/m)
model70* = 40T test wagon, high stiffness (40e6 N/m), high stiffness container (160e6 N/m)

FILE	COUPLER FORCE (N)	CASTING FORCE (N)	TESTCAR ACC (m/s^2)	CONTAINER ACC (m/s^2)	INPUT VELOCITY (m/s)	TEST MASS (tonnes)	ω1 (Hz)	ω2 (Hz)
model38	1.12e6	6.22e5	32.0	31.1	4.0	20	1.94	9.42
model38b	9.43e5	3.66e5	32.8	33.9	4.0	10	1.94	13.3
model38c	1.42e6	1.01e6	28.3	25.3	4.0	40	1.94	6.66
model38d	1.59e6	9.32e5	47.4	46.7	5.6	20	1.94	9.42
model38e	2.29e6	1.37e6	68.8	68.8	8.0	20	1.94	9.42
model38f	2.14e6	1.29e6	65.3	64.7	7.5	20	1.94	9.42
model38g	1.42e6	8.16e5	41.9	40.9	5.0	20	1.94	9.42
model47	2.09e6	1.64e6	72.8	82.3	4.0	20	3.56	7.12
model47b	1.77e6	1.05e6	72.8	105.0	4.0	10	3.56	10.1
model47c	2.64e6	2.32e6	72.8	58.0	4.0	40	3.56	5.03
model47d	3.91e6	3.08e6	136	154.0	7.5	20	3.56	7.12
model47e	4.17e6	3.29e6	146	165.0	8.0	20	3.56	7.12
model47f	2.61e6	2.05e6	91.0	103	5.0	20	3.56	7.12
model47g	2.92e6	2.30e6	102	115	5.6	20	3.56	7.12
model45	1.88e6	1.60e6	73.6	79.9	4.0	20	3.56	5.03
model45b	1.62e6	1.03e6	73.6	103.3	4.0	10	3.56	7.11
model45c	2.46e6	2.24e6	73.6	56.1	4.0	40	3.56	3.56
model45d	3.52e6	2.99e6	138.0	150.0	7.5	20	3.56	5.03
model45e	3.75e6	3.19e6	147.0	160.0	8.0	20	3.56	5.03
model45f	2.35e6	1.99e6	92.0	99.9	5.0	20	3.56	5.03
model45g	2.63e6	2.23e6	103	112	5.6	20	3.56	5.03

Legend:
model38* = 20T test wagon, low stiffness (3e6 N/m), high stiffness container (70e6 N/m)
model47* = 20T test wagon, high stiffness (10e6 N/m), medium stiffness container (40e6 N/m)
model45* = 20T test wagon, high stiffness (10e6 N/m), low stiffness container (20e6 N/m)

FILE	COUPLER FORCE (N)	CASTING FORCE (N)	TESTCAR ACC (m/s^2)	CONTAINER ACC (m/s^2)	INPUT VELOCITY (m/s)	TEST MASS (tonnes)	ω1 (Hz)	ω2 (Hz)
model99x	2.47e6	1.48e6	121	55.3	3.53	26.82	2.49	3.76
model99a	2.47e6	1.68e6	121	46.8	3.53	36.60	2.49	3.22
model99b	2.80e6	1.68e6	137	62.7	4.0	26.82	2.49	3.76
model99c	3.15e6	1.89e6	154	70.5	4.5	26.82	2.49	3.76
model99d	3.50e6	2.10e6	171	78.3	5.0	26.82	2.49	3.76
model99e	3.85e6	2.31e6	188	86.2	5.5	26.82	2.49	3.76
model99f	3.22e6	1.93e6	157	72.1	4.6	26.82	2.49	3.76
model99g	3.29e6	1.97e6	161	73.6	4.7	26.82	2.49	3.76
model99h	3.36e6	2.02e6	164	75.2	4.8	26.82	2.49	3.76

Legend:
model99* = 20.45T test wagon, low stiffness (5e6 N/m), low stiffness container (15e6 N/m)

APPENDIX D

SRS TEST LEVEL DEVELOPMENT

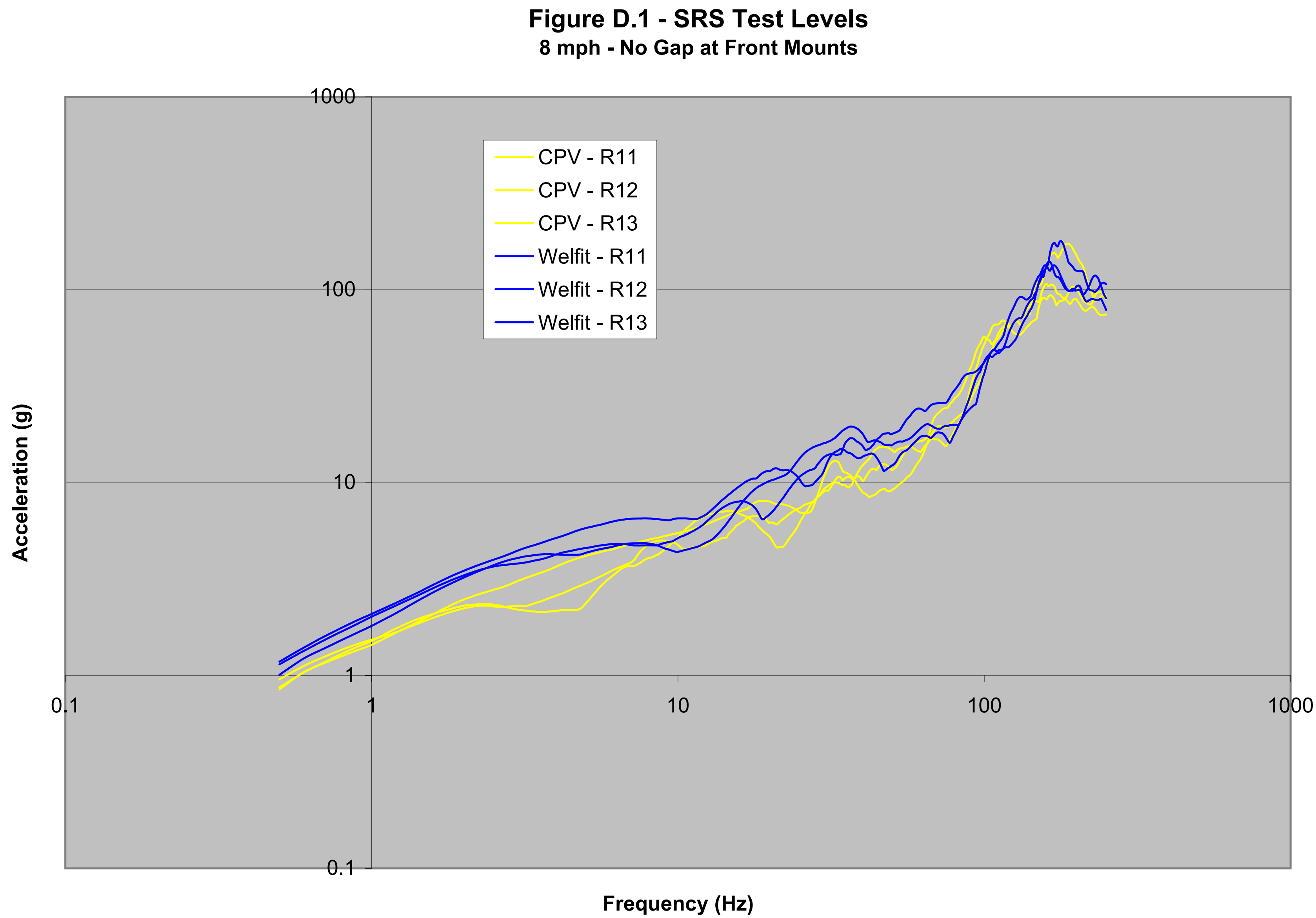


Figure D.1 - SRS Test Levels
8 mph - No Gap at Front Mounts
Acceleration (g)
Frequency (Hz)
1000
100
10
1
0.1
0.1
1
10
100
1000
CPV - R11
CPV - R12
CPV - R13
Welfit - R11
Welfit - R12
Welfit - R13

Figure D.2 - Mean SRS Test Level

8 mph - No Gap at Front Mounts

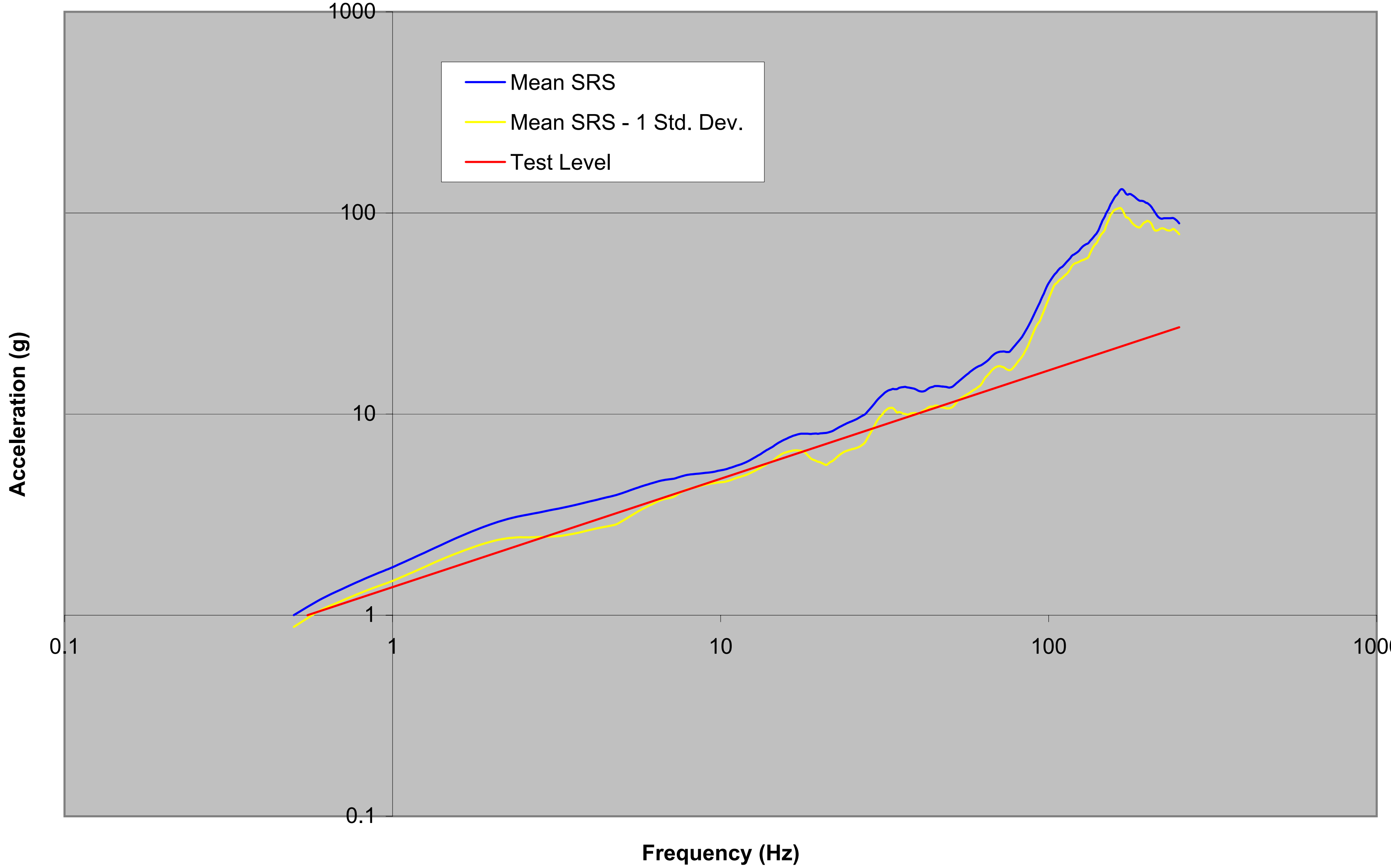
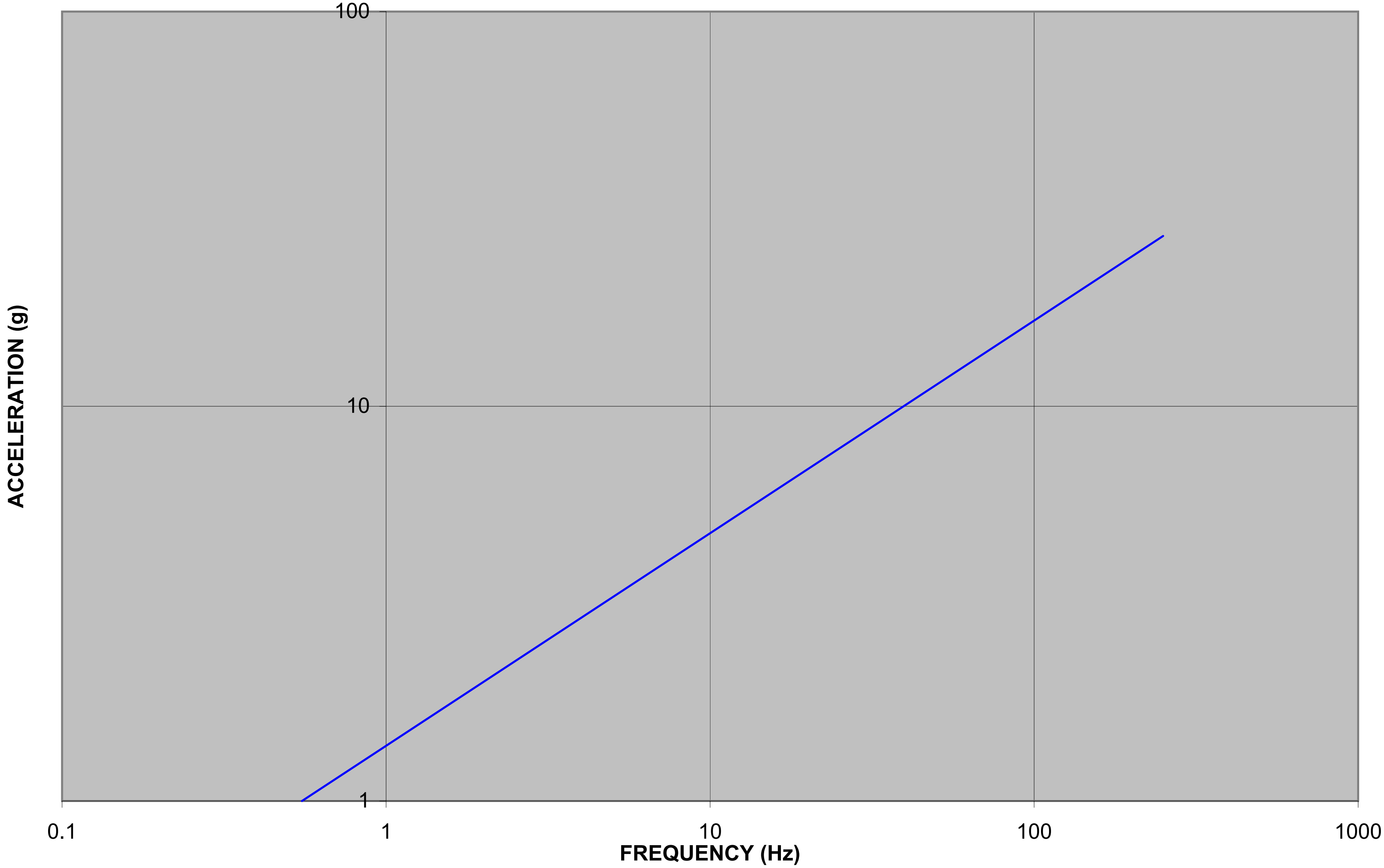


FIGURE D.3 - MINIMUM SRS TEST LEVEL
(5% DAMPING)



APPENDIX E

EXTERNAL TEST AGENCY SRS RESULTS

Figure E.1 - EDC (R TEST)
M1: 14 460 kg, M2: 30 000 kg

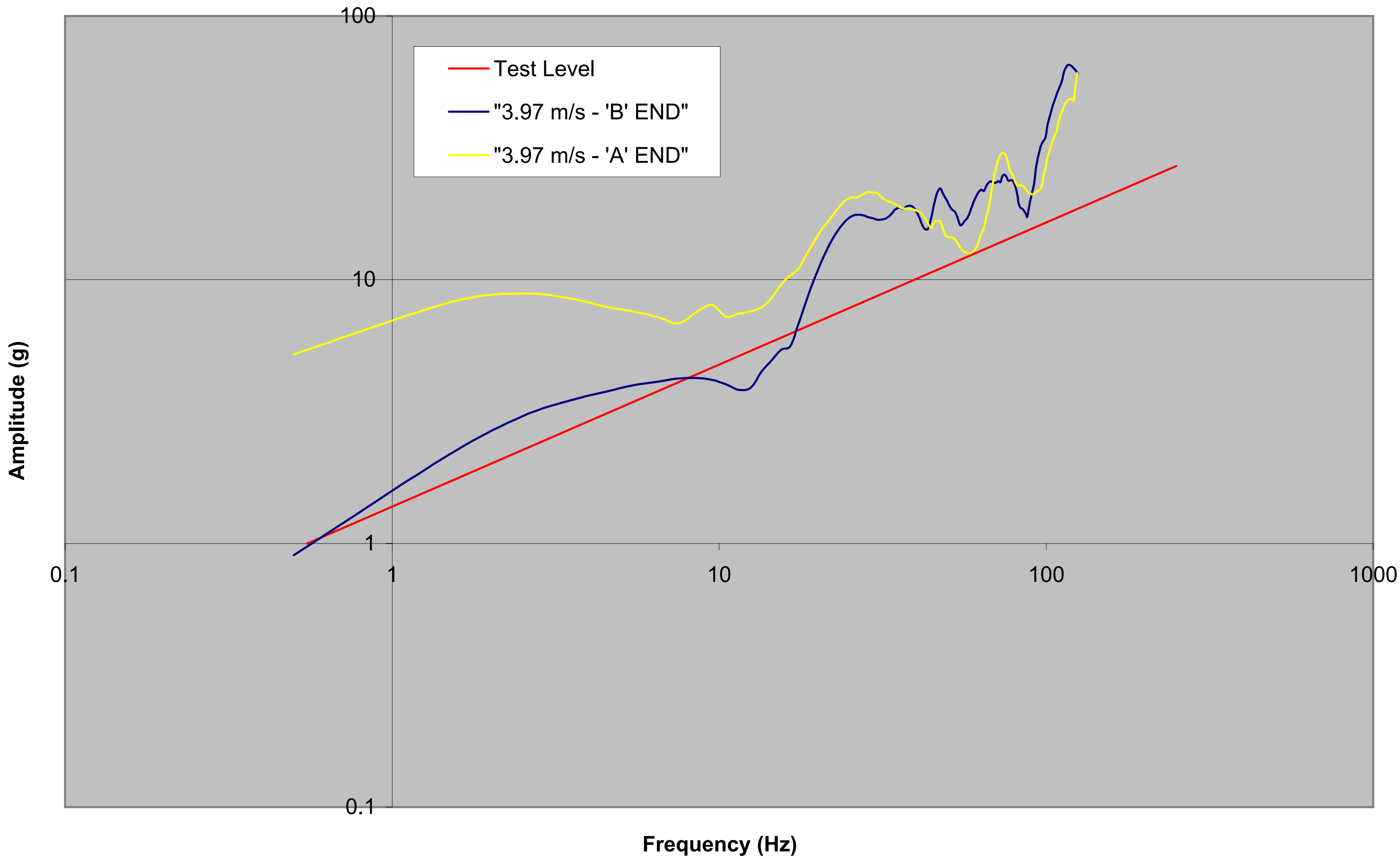


Figure E.2 - EDC (R TEST)
M1: 14 460 kg, M2: 23 660 kg

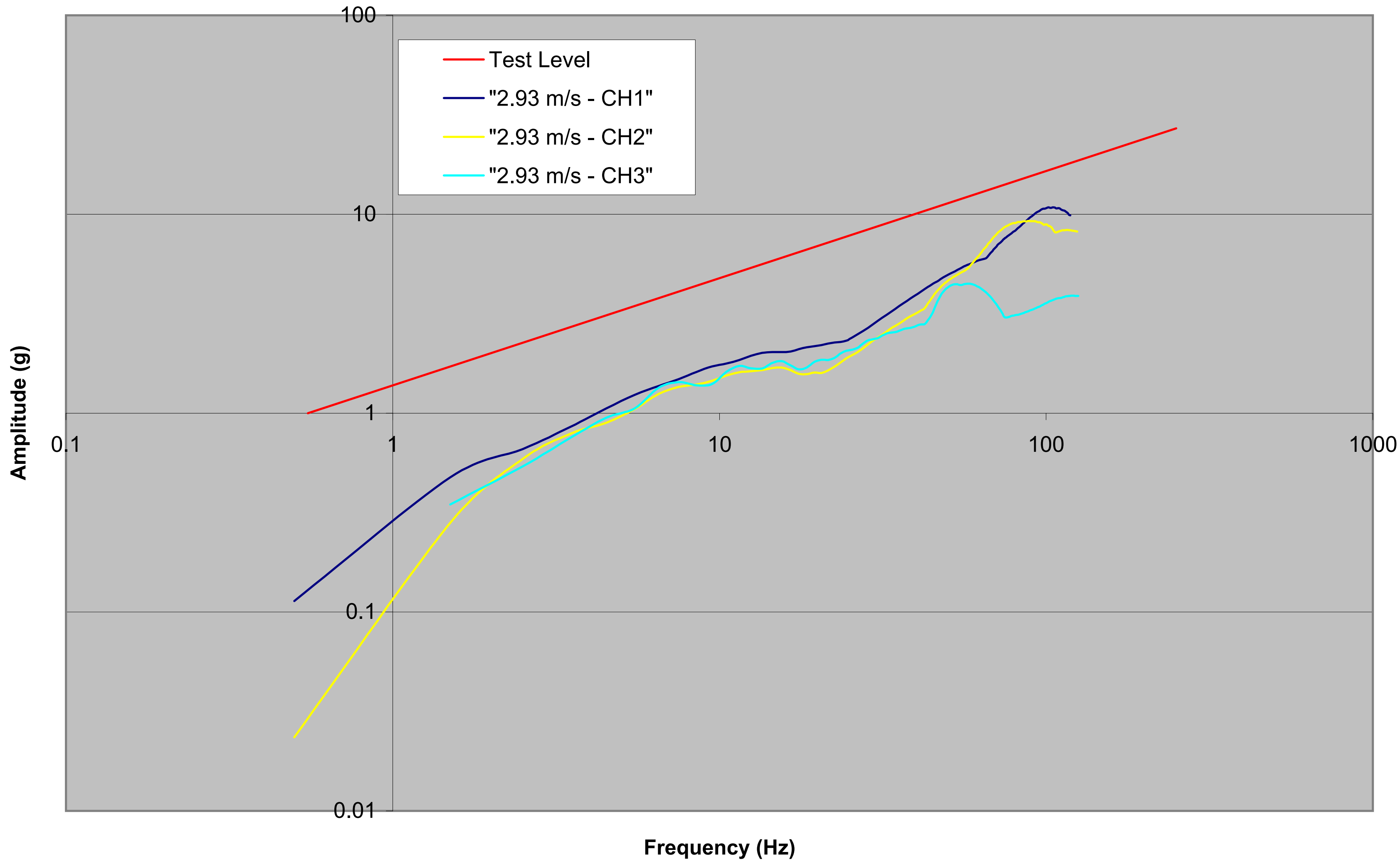


Figure E.3 - EDC (SF TEST)
M1: 14 460 kg, M2: 30 000 kg

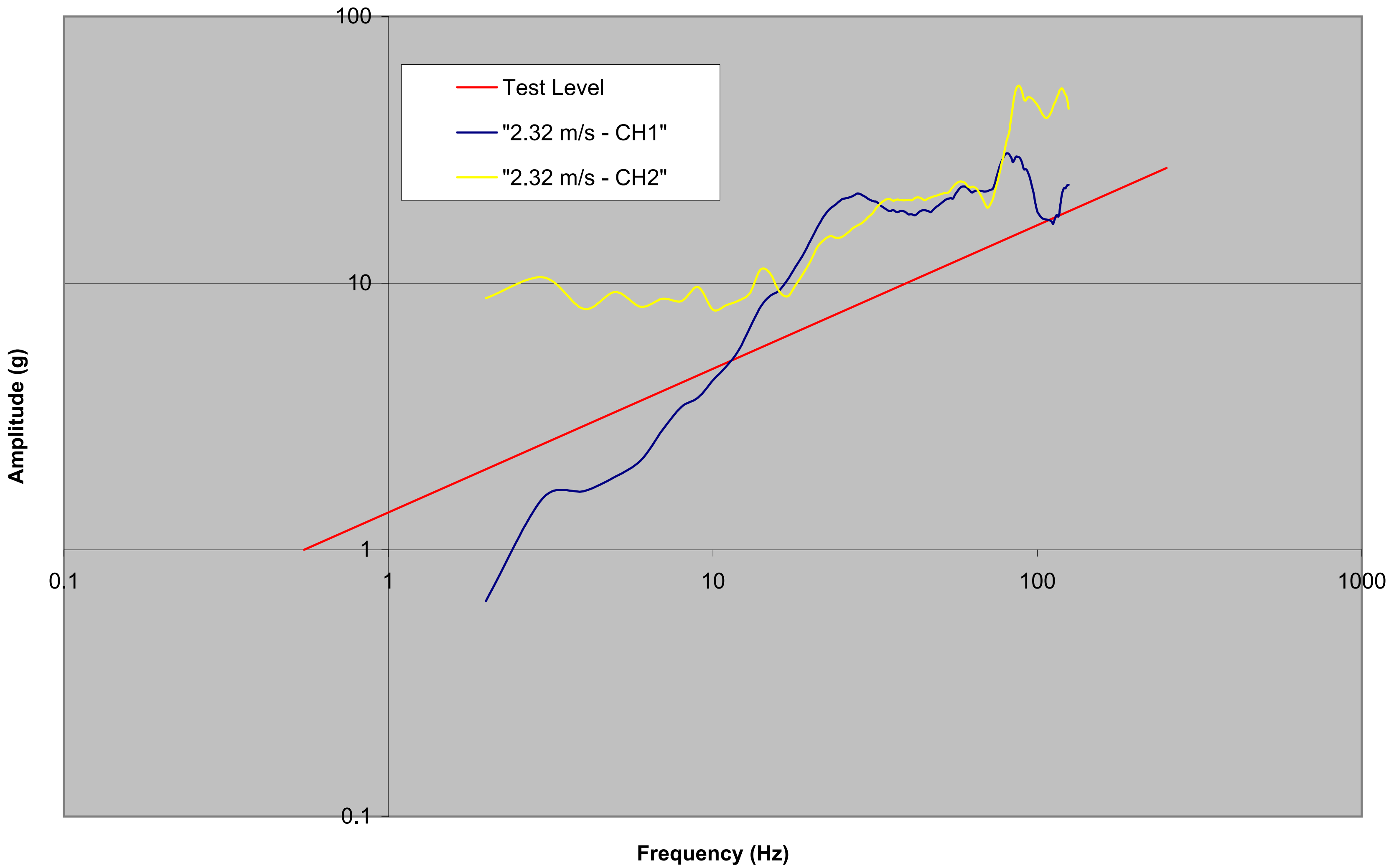


Figure E.4 - EDC (SF TEST)
M1: 14 460 kg, M2: 23 660 kg

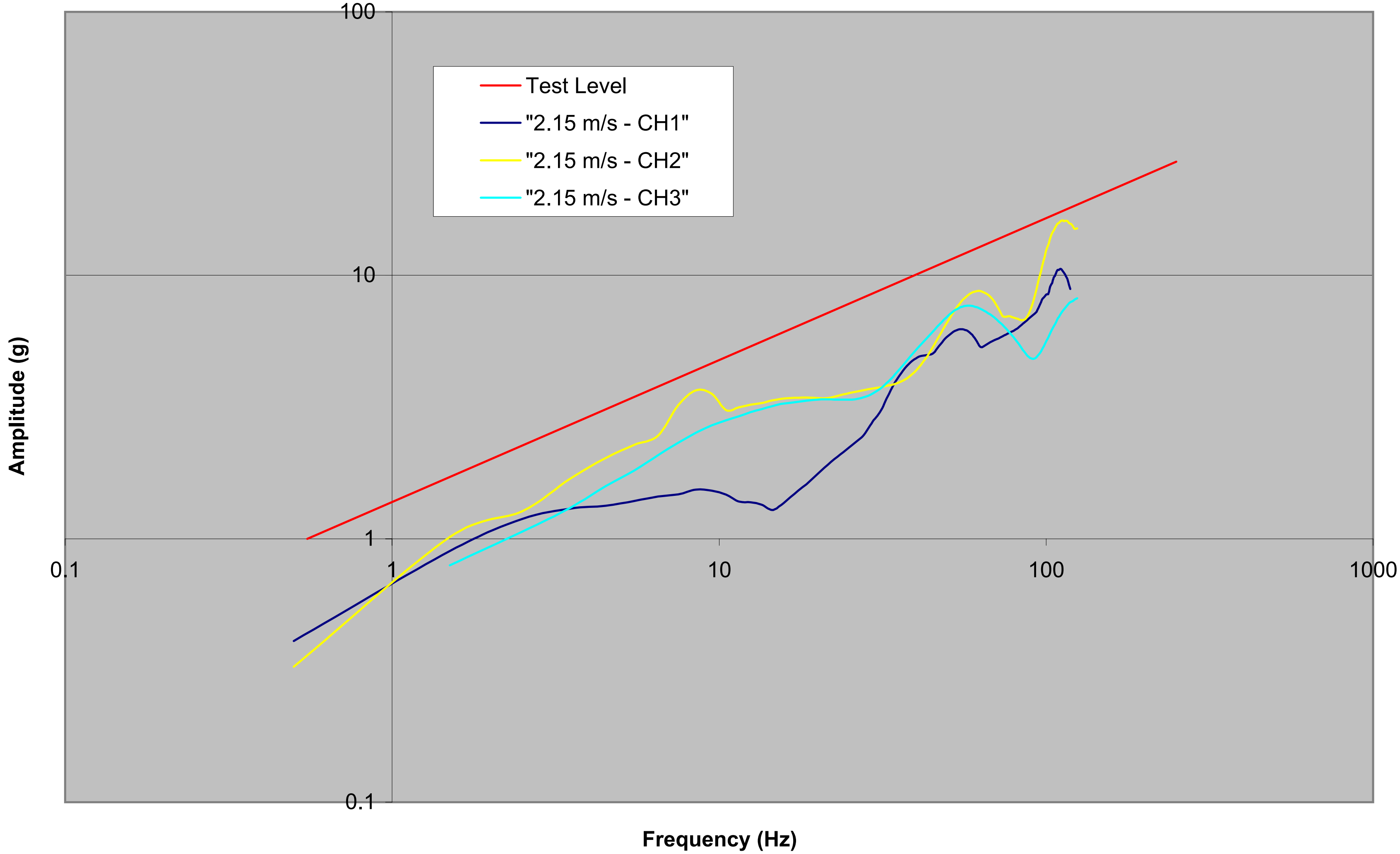


Figure E.5 - EDC (SS TEST)
M1: 14 460 kg, M2: 23 660 kg

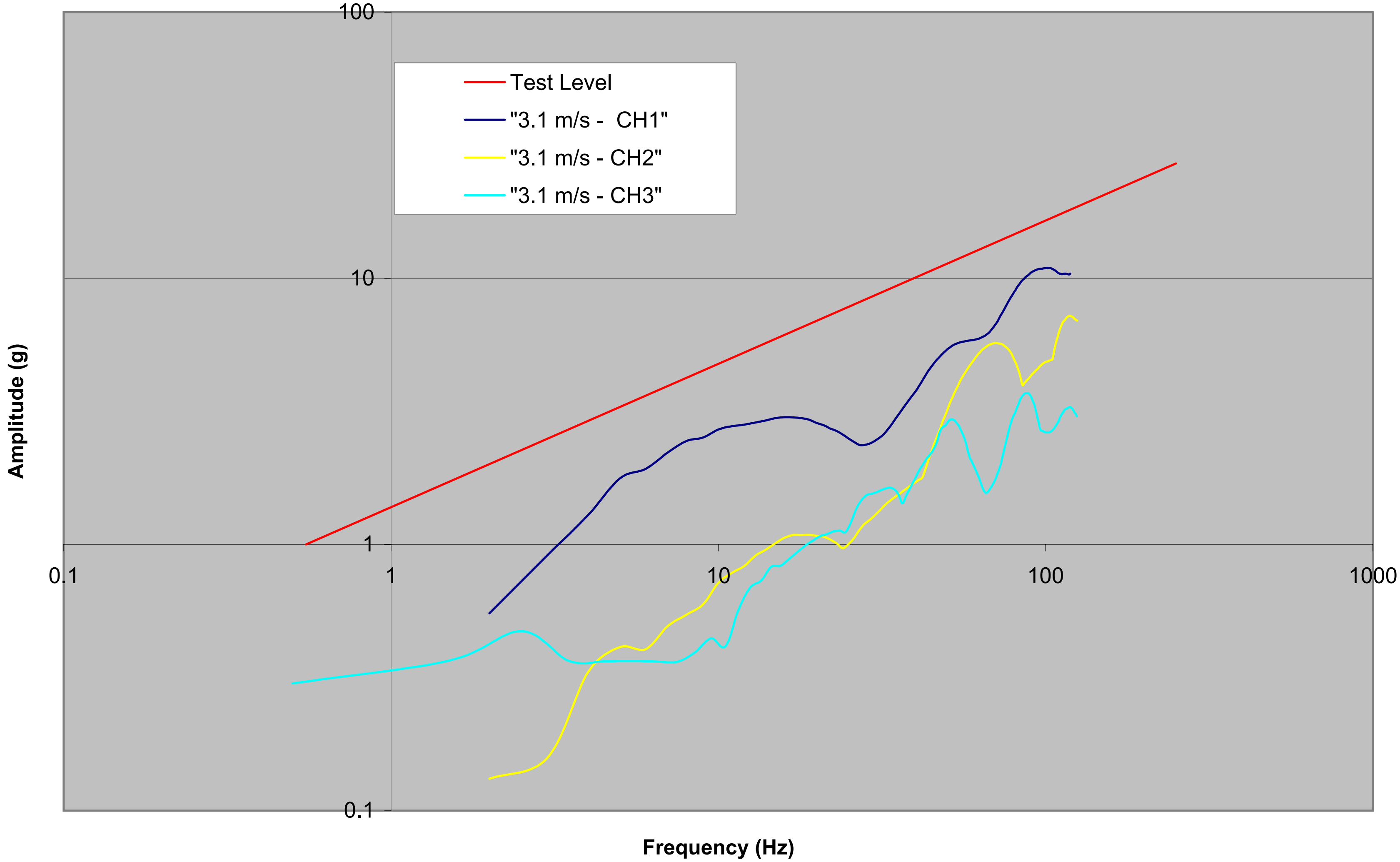


Figure E.6 - CNEST
M1: 24 180 kg, M2: 26 750 kg

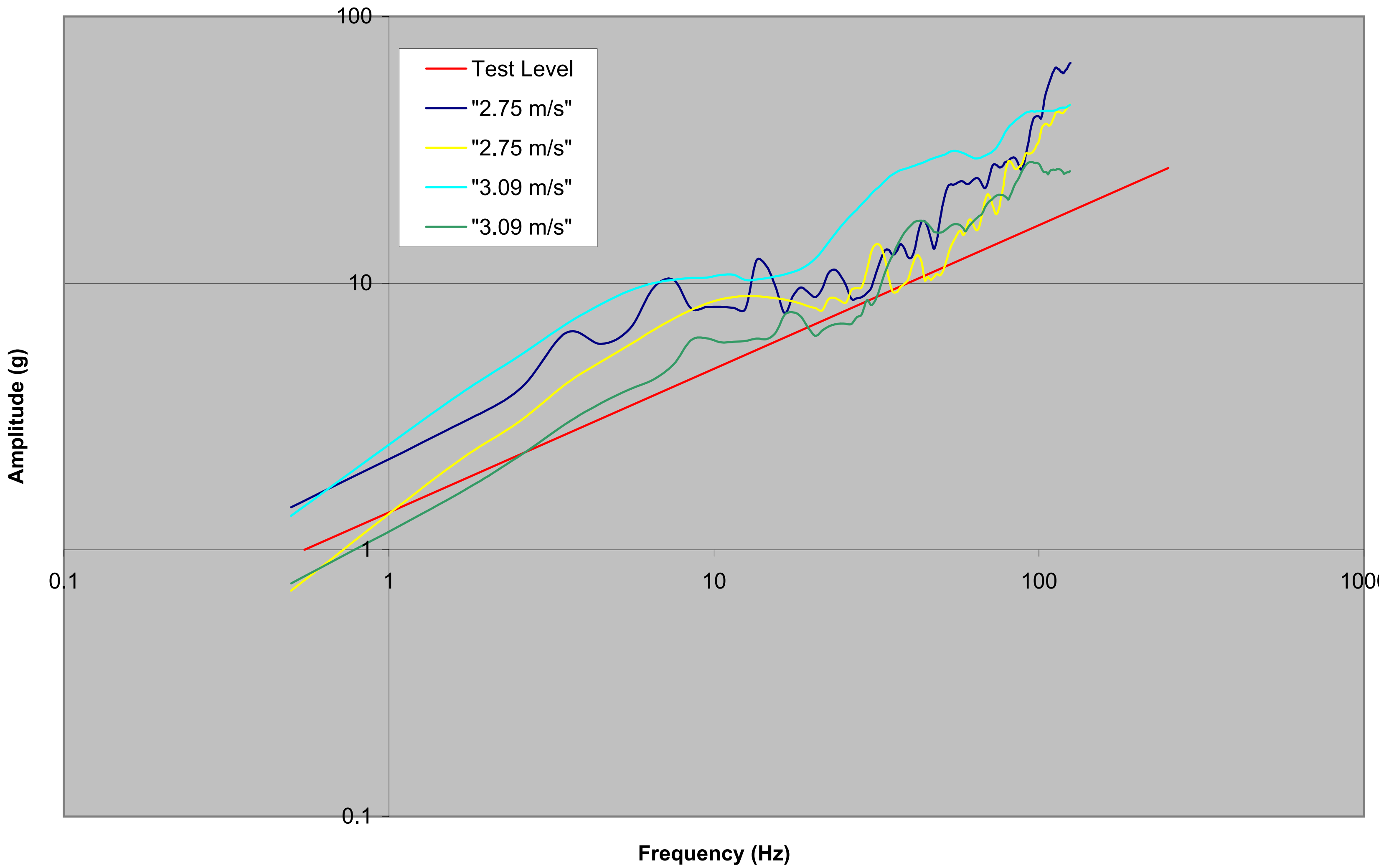


Figure E.7 - CNEST
M1: 24 180 kg, M2: 27 620 kg

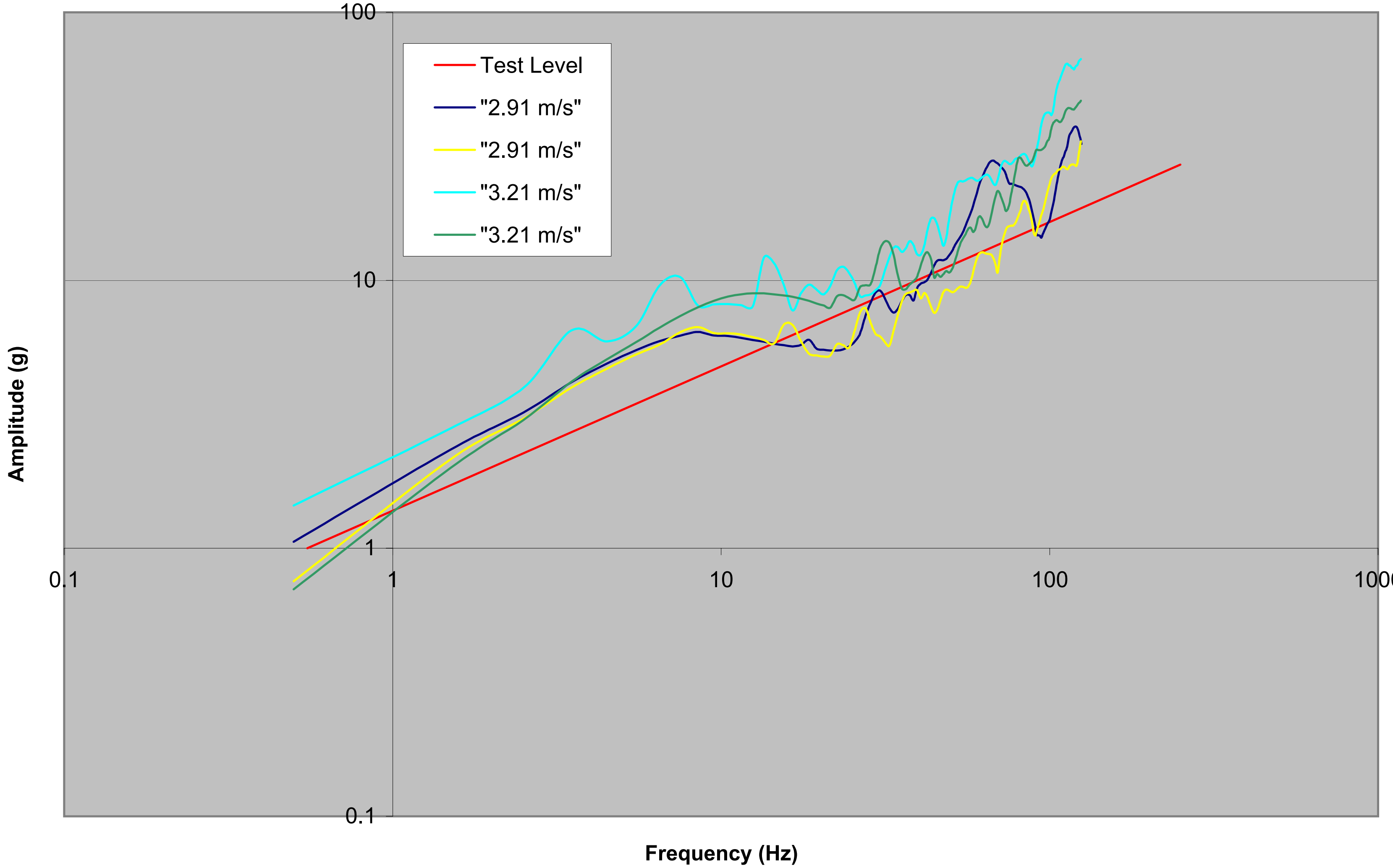


Figure E.8 - CNEST
M1: 24 180 kg, M2: 19 920 kg

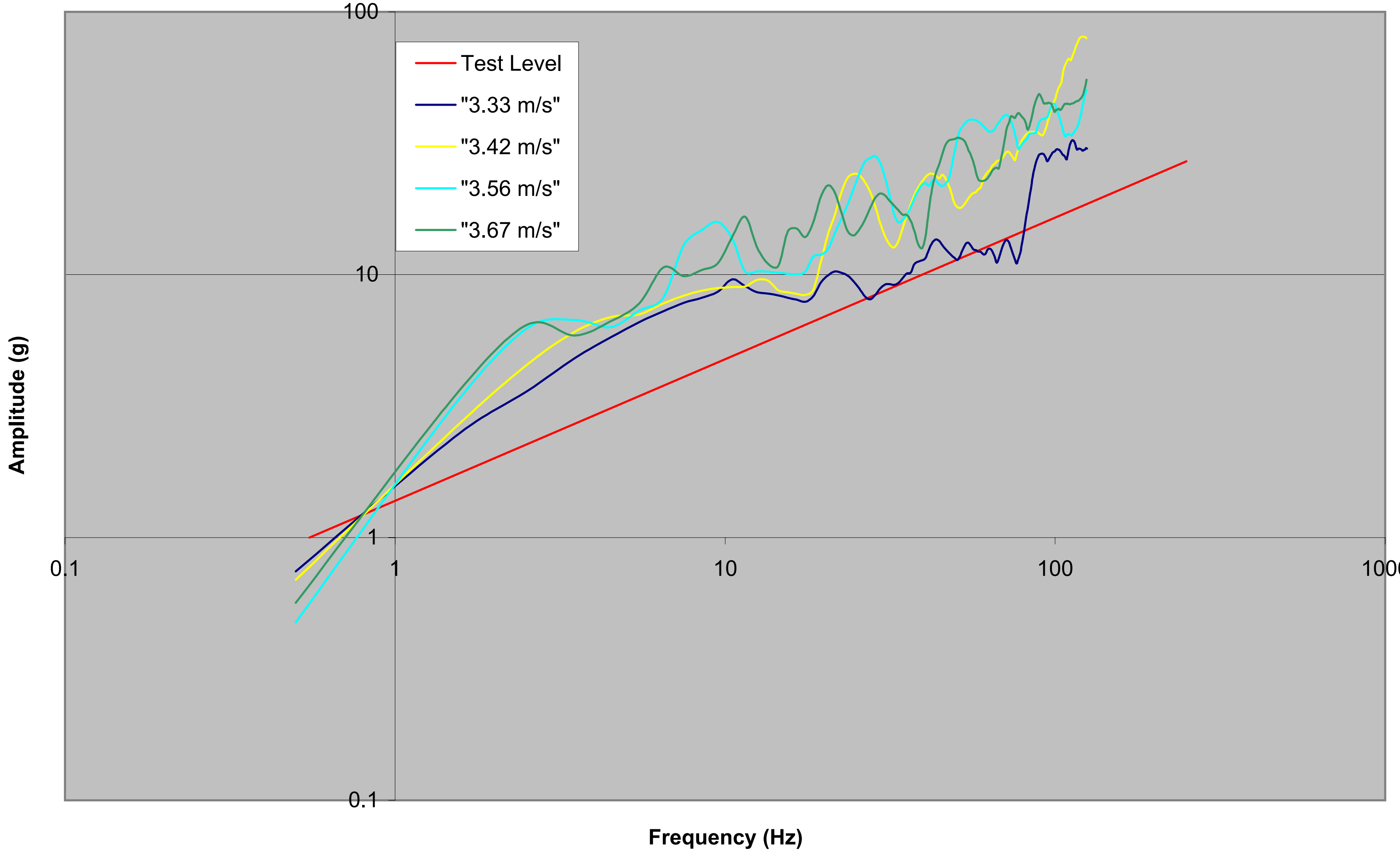
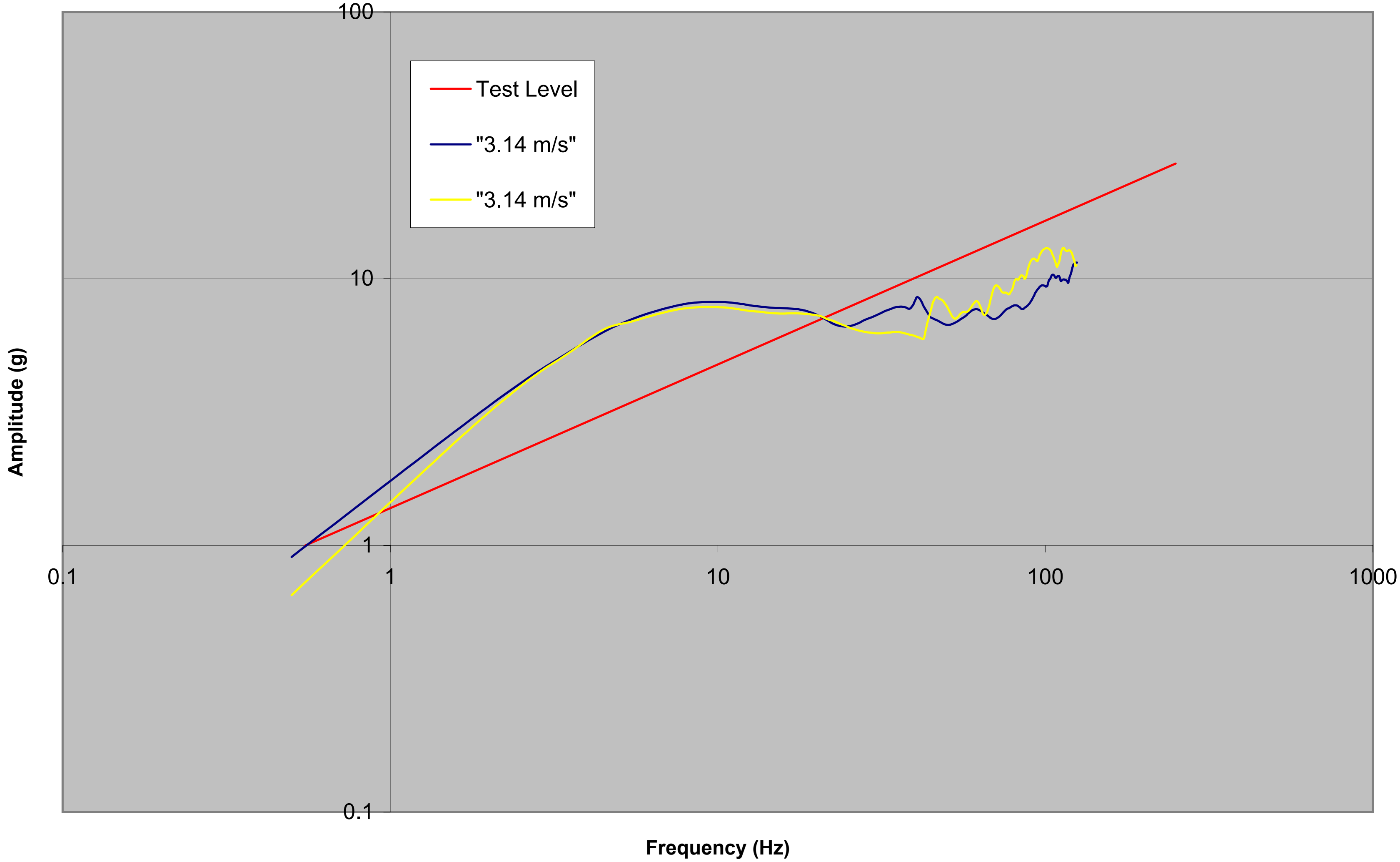


Figure E.9 - CNEST
M1: 24 180 kg, M2: 24 330 kg



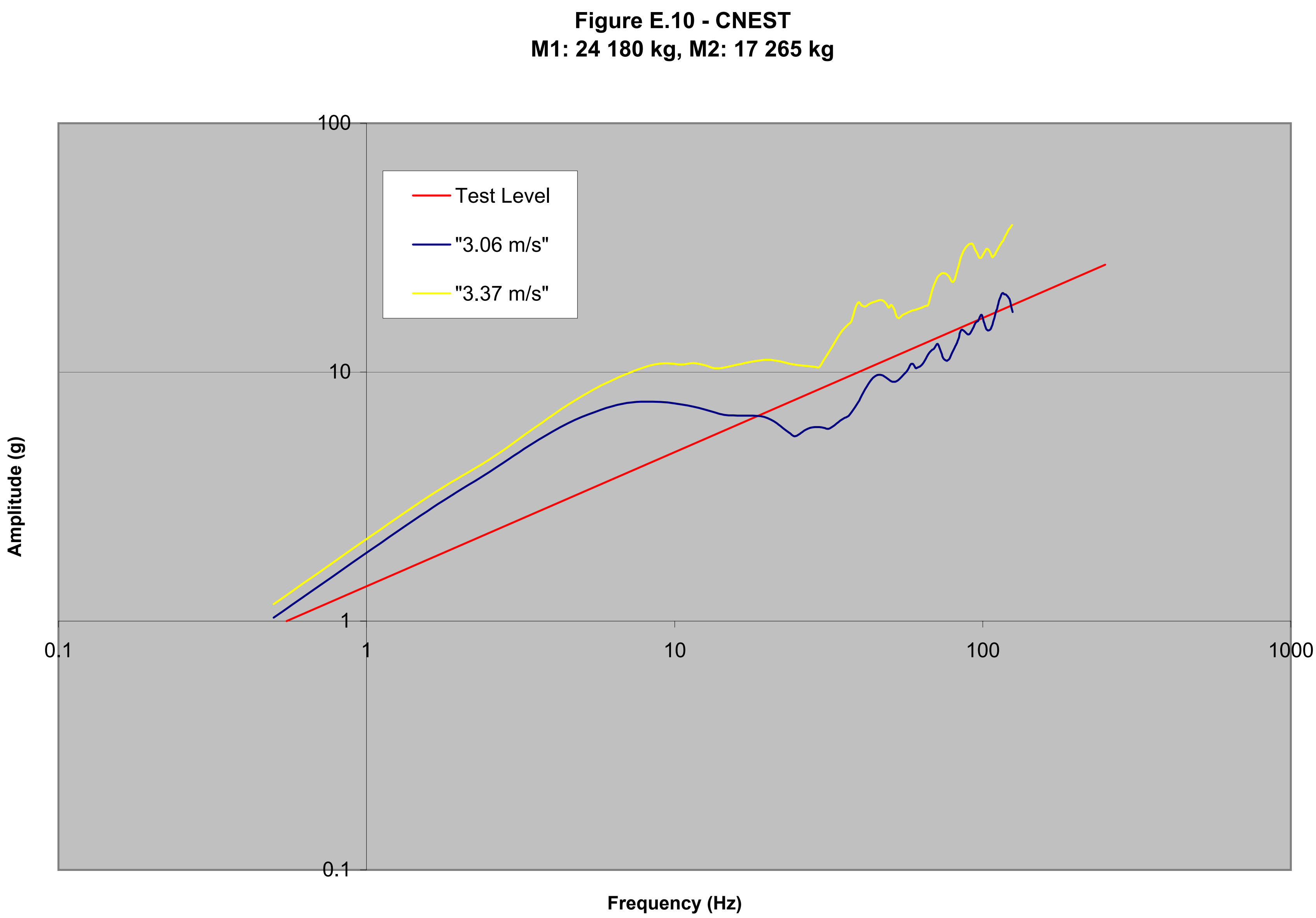
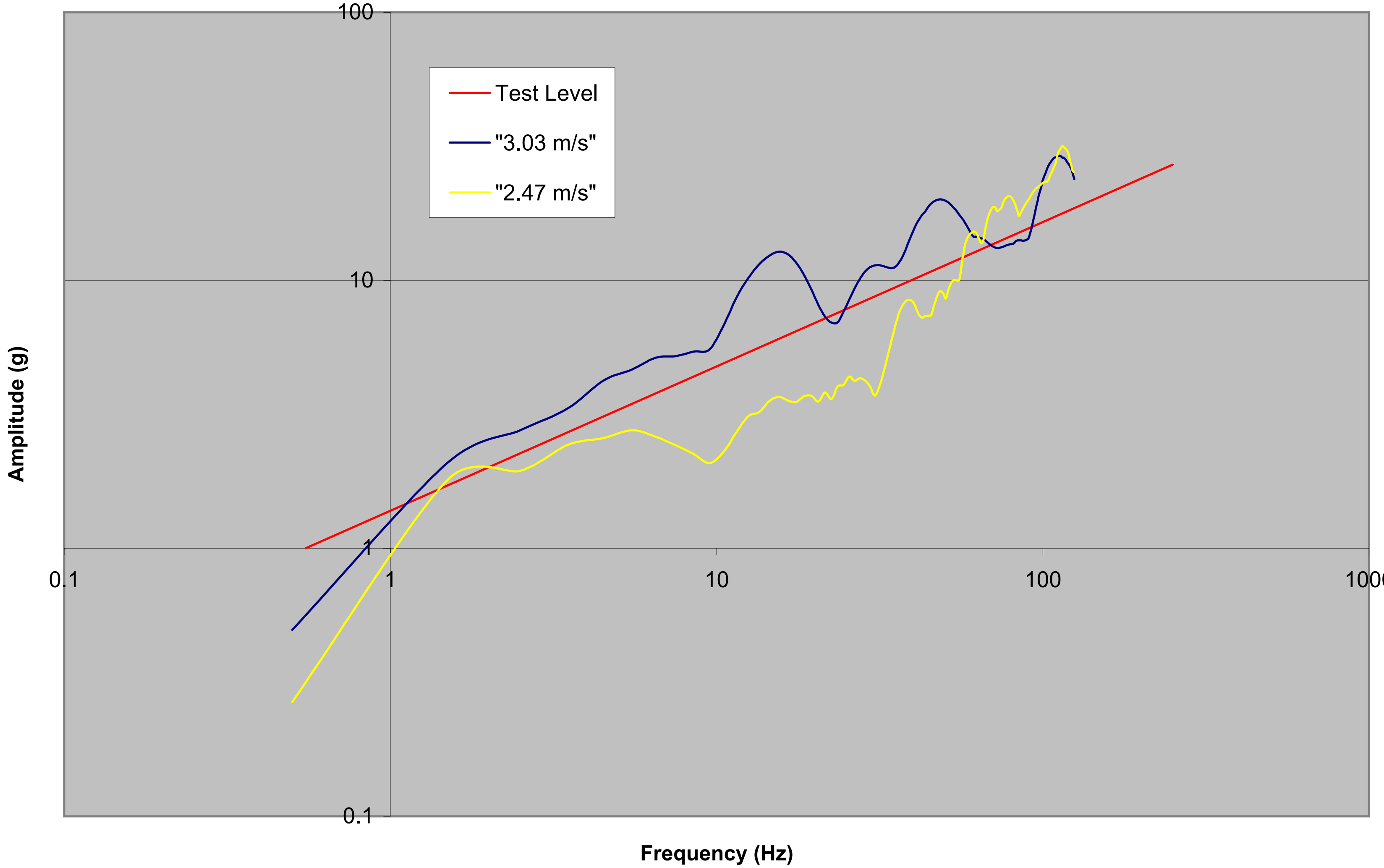


Figure E.10 - CNEST
M1: 24 180 kg, M2: 17 265 kg
Test Level
"3.06 m/s"
"3.37 m/s"
Amplitude (g)
Frequency (Hz)
100
10
1
0.1
0.1
1
10
100
1000

Figure E.11 - MINDEN
M1: 20 000 kg, M2: 34 000 kg



APPENDIX F

TANK CONTAINER RAIL IMPACT TEST
DRAFT STANDARD

TDG Draft for ISO Meeting October 1998
ISO/TC 104/SC 2 N 182
Date: 1998-05-14

ISO 1496-3:/PDAM 1

ISO/TC 104/SC 2/WG 4
Secretariat: BSi

Series 1 freight containers – Specification and testing – Part 3: Tank Containers for liquids, gases and pressurized dry bulk

AMENDMENT 1

Testing – External restraint (longitudinal) – Dynamic

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Document type: International Standard
Document subtype: Amendment
Document stage: (30) Committee
Document language: E

J:\ISO\104\SC2\WG4\N182.DOC ISOSTD ISO Template Version 3.0 1997-02-07

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75% of the member bodies casting a vote.

Amendment 1 to International Standard ISO 1496-3: 1995 was prepared by Technical Committee ISO/TC 104, Freight containers, SC 2, Special purpose containers.

Series 1 freight containers – Specification and testing – Part 3: Tank containers for liquids, gases and pressurized dry bulk

AMENDMENT 1

Testing – External restraint (longitudinal) - Dynamic

Page 1 Normative references.

Add as follows:

ISO 6487: 1987 Road vehicles – Measurement techniques in impact tests – Instrumentation

Page 2 Definitions

3.10 test platform: the device, either stationary or moving, used to support the tank container under test and directly receiving the impact.

3.14 damping ratio: ratio of actual damping coefficient to critical damping coefficient.

3.15 single degree of freedom (SDOF) system: system for which only one coordinate is required to completely describe that system at any instant of time.

3.16 shock response spectrum: a plot of the maximum response experienced by a "single degree of freedom" system, as a function of its own natural frequency, in response to an applied shock.

3.17 minimum shock response spectrum (Minimum SRS): reference curve representing the minimum shock response spectrum for a test to be valid (see figure A.1)

3.19 octave: doubling of frequency

then re-number existing definitions accordingly.

Page 9, clause 6.5

Amend the title to read as follows:

6.5 Tests 4A and 4B – External restraint (longitudinal).

Then re-number the existing clause as:

6.5.1 Test 4A – Static.

6.5.1.1 General

6.5.1.2 Procedure

6.5.1.3 Requirements

Then insert the following:

6.5.2 Test 4B – Dynamic

6.5.2.1 General

This test shall be carried out to prove the ability of tank containers in dangerous goods service to withstand longitudinal external restraint under dynamic conditions of railway operation.

This test is optional for tank containers not in dangerous goods service but where it is applied, test 4A may be omitted

6.5.2.2 Procedure

The test shall be conducted in accordance with the procedure specified in annex D

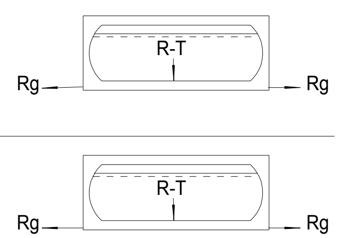
6.5.2.3 Requirements

On completion of the test, the tank container shall not show leakage or permanent deformation or abnormality which will render it unsuitable for use, and the dimensional requirements affecting handling, securing and interchange shall be satisfied.

Page 15, figure A6

Within the figure, replace the reference to "Test Number 4" *by* "Test number 4A"

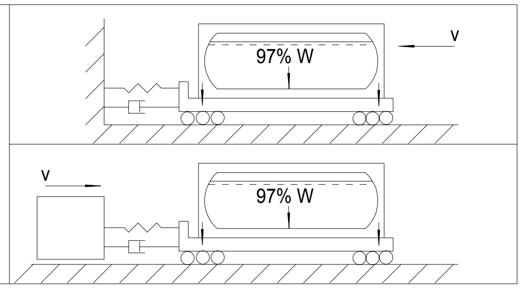
Delete "Applicable to all tank containers" *replace by* "Applicable when test number 4B is not performed" (see graphic below)

A.6	External restraint (longitudinal) Test No. 4 Applicable when Test No.4a is not performed	

Add an additional figure A6A (see graphic below)

<table>
<tr>
<td>A.6a</td>
<td>External restraint (longitudinal)(Dynamic)

Test No. 4A

Applicable to dangerous goods
tank containers.
Optional for non-dangerous goods
tank containers</td>
<td>
</td>
</tr>
</table>

Page 24 insert Annex D as follows and re-reference existing **Annex D (informative) Bibliography as Annex E**

Add to **Annex E** *reference to*

IEC 68-2-27: 1987 Basic environment testing procedures – Part 2: Shock

Annex A
(normative)

Dynamic longitudinal impact test

D.1 Test sample

Ensure the tank container under test (hereafter referred to as container-under-test) is representative of the tank container design for which conformity confirmation is being sought (design type).

A container-under-test may be considered design representative of the tank container being certified if all the following conditions are met:

a) the maximum rated mass of the container-under-test is equal to or greater than that for the design type (see D.2.5.2 for action in the case of exception);

b) the structural configuration of the container-under-test as well as that of its structural members and supports are equivalent or less to those on the tank containers being certified;

c) the vessel equivalent thickness of the container-under-test is equal to or less than that of the design type;

d) the manufacturing location and the processes used to fabricate the container-under-test are the same as those used for design type;

D.2 Test apparatus

D.2.1 Test platform

The test platform may be any suitable structure having securing devices in accordance with ISO 1161, which is capable of achieving and sustaining without permanent damage the prescribed shock severity with the container-under-test mounted securely in place. The test platform shall be:

- configured so as to allow the container-under-test to be mounted as close as possible to the impacting end;
- fitted with securing devices in good condition with no evidence of flaky rust on the surface;
- equipped with a cushioning device for the purpose of achieving a suitable duration of impact;

D.2.2 Impact creation

The impact may be created by:

1) The test platform striking a stationary mass; or

2) The test platform being struck by a moving mass.

D.2.3 Measuring/recording system

D.2.3.1 Unless otherwise specified within this standard, ensure that the measuring system complies with ISO 6487.

D.2.3.2 Ensure that the following equipment is available for the test:

1) 2 accelerometers with a minimum range of ± 200 'g' and a minimum resonant frequency of 20 kHz (fitted to a plate bonded to the container-under-test, one at each of the two bottom adjacent corner castings closest to the impact source and positioned/aligned so as to measure the acceleration in the longitudinal axis);
2) method of measuring the impact velocity;
3) analogue-to-digital data acquisition system incorporating an anti-aliasing filter, capable of recording the shock disturbance as an acceleration-time history at a minimum frequency of 1kHz with aliasing kept to a maximum of 1%;
4) method of permanently storing in electronic format the acceleration-time histories so that they can be subsequently retrieved and analyzed.

D.2.4 Procedure

1) Fill the container-under-test with a quantity of water to approximately 97% volumetric capacity, ensuring that it is not pressurized during the test. Measure and record the as tested payload mass.
   Note. Filling may be undertaken before or after mounting on the test platform.

2) Orientate the container-under-test so as to present it in a manner that will result in the most severe test and mount on the test platform, as close as possible to the impacting end and secured by the corner fittings. In so doing, ensure that any clearance between the corner fittings of the container-under-test and the securing devices at the impacting end of the test platform are minimized. In particular, ensure that impacting masses are free to rebound after impact.

3) Create an impact (D.2.2) such that for a single impact the as tested SRS at both corner fittings equals or exceeds the minimum SRS shown in figure A.1 at all frequencies within the prescribed frequency band.
   Note. Repeated impacts may be required to achieve this result.

4) Examine the container-under-test for evidence of any of the faults identified in 6.5.2.3 and record the result.

D.2.5 Recording of data

Record the following data as a minimum in the application of this procedure:

1) Date, time, ambient temperature, and location of test;
2) Tank container tare mass, maximum rated mass, and as-tested payload mass;
3) Tank container manufacturer, tank type, registration number if applicable, certified design codes and approvals if applicable;
4) Test platform mass;
5) Impact velocity;
6) Direction of impact with respect to tank container;
7) For each impact, an acceleration-time history for each instrumented corner fitting shall be recorded.

D.2.6 Analysis/processing of data

D.2.6.1 Data reduction system

Reduce the acceleration time-history data from each channel to the shock response spectrum, ensuring that the spectra are presented in the form of equivalent static acceleration plotted as a function of frequency. The maximum absolute value acceleration peak will be recorded for each of the specified frequency break points, thus producing what is commonly referred to as the maximax acceleration shock response spectrum. The data reduction will follow the following criteria:

- If required, the corrected impact acceleration time-history data will be generated using the procedure outlined in section D.2.6.2.
- The time-history data will comprise the period commencing 0.05 seconds prior to the start of the impact event and the 2.0 seconds thereafter;
- The analysis will span the frequency range of 0.5 to 250 Hz with a minimum of 1/30 octave break points. Each break point, or bin in the range will constitute a natural frequency; and,
- A damping ratio of 5% will be used in the analysis.

Calculation of the test shock response curve data points will be made as described below. For each frequency bin:

1- Calculate a matrix of relative displacement values using all data points from the shock input acceleration time history using the following equation:

$$\xi_i = \frac{\Delta t}{\omega_d}\sum_{k=0}^{i}\ddot{X}_k e^{-\zeta\omega_n\Delta t(i-k)}\sin\left[\omega_d\Delta t(i-k)\right]$$

where:

Δt = time interval between acceleration values
ω_n = undamped natural frequency (in radians)
ω_d = damped natural frequency = $\omega_n\sqrt{1-\zeta^2}$
$\ddot{x}_k$ = k_{th} value of acceleration input data
ζ = damping ratio
i = integer number, varies from 1 to the number of input acceleration data points
k = parameter used in summation which varies from 0 to the current value of i

2- Calculate a matrix of relative accelerations using the displacement values obtained in step 1 in the following equation:

$$\ddot{\xi}_i = 2\zeta\omega_n\Delta t\sum_{k=0}^{i}\ddot{x}_k e^{-\zeta\omega_n\Delta t(i-k)}\cos\left[\omega_d\Delta t(i-k)\right] + \omega_n^2\left(2\zeta^2-1\right)\xi_i$$

3- Retain the maximum absolute acceleration value from the matrix generated in step 2 for the frequency bin under consideration. This value becomes the SRS curve point for this particular frequency bin. Repeat step 1 for each natural frequency until all natural frequency bins have been evaluated.

4- Generate the test shock response spectrum curve.

D.2.6.2 Method for scaling measured acceleration-time history values to compensate for under mass containers.

Where the sum of the as-tested payload mass plus tare mass of the container-under-test is less than the maximum rated mass of the container-under-test, apply a scaling factor to the measured acceleration-time histories for the container-under-test as follows:

Calculate the corrected acceleration-time values, $Acc(t)_{(corrected)}$, from the measured acceleration-time values by use of the following formula:

$$Acc(t)_{(corrected)} = Acc(t)_{(measured)} \times \frac{1}{\sqrt{\left[1 + \frac{\Delta M}{M1 + M2}\right]}}$$

Where:

a) The $Acc(t)_{(measured)}$ is the actual measured -time value;

b) M1 is the mass of the test platform, without the container-under-test;

c) M2 is the actual test mass (including tare) of the container-under-test;

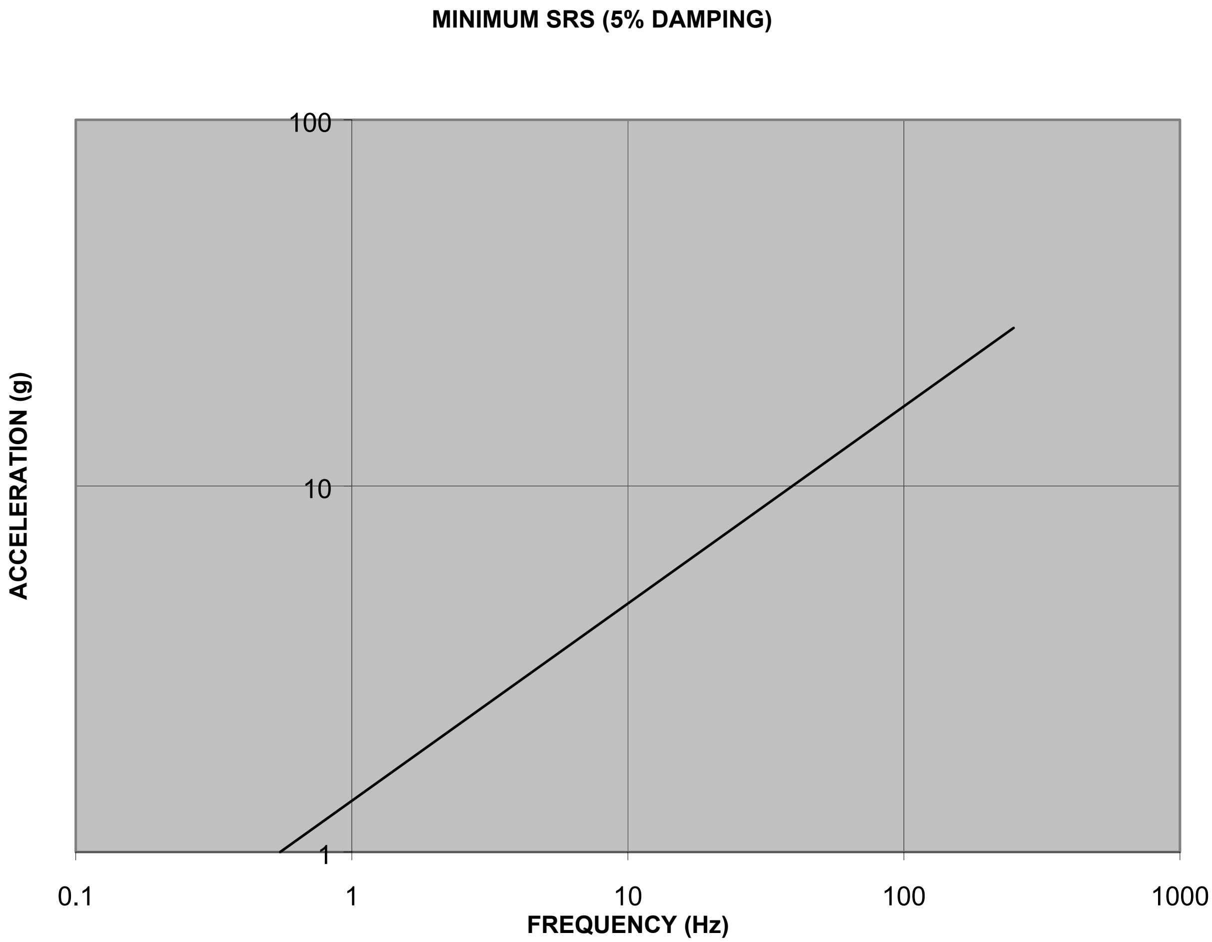
d) R is the maximum rated mass (including tare) of the container-under-test;

e) $\Delta M = R - M2$;

f) The test SRS values must be generated from the $Acc(t)_{(corrected)}$ values.

Figure A.1

Minimum SRS Curve and Table



Equation for generating the above Minimum SRS Curve: $ACCEL = 1.3798\,FREQ^{0.5386}$

Tabular representation of some data points for the minimum SRS curve above.

FREQUENCY (Hz)	ACCELERATION (g)
0.50	0.950
0.55	1.00
1	1.38
10	4.77
100	16.5
250	27.0

APPENDIX G

SHOCK RESPONSE SPECTRUM SOURCE CODE

FORTRAN Source Code

```
      program SRS2A

c
c     SRS2A
c     Shock Response Spectra - version 2, mod "A"
c
c     This test program is used to calculate the maximax shock
c     resonse spectrum (SRS) at several natural frequencies.
c     Input is absolute acceleration, SRS output is derived
c     from the peak relative acceleration.
c
c     Reference:
c     "Principles and Techniques of Shock Data Analysis"
c     R. Kelly & G. Richman
c     The Shock and Vibration Information Center, SVM-5, 1969
c
c
c     MAX_POINTS   =  maximum size of data arrays
c
c     INPUT_FILE   =  name of input acceleration data file
c     DELTA_T      =  time between consecutive points in INPUT_ACC
c                     (1.0 / Sampling_Rate)
c     DAMPING      =  damping factor
c     FREQ_LOW     =  analysis frequency range, lower bound
c     FREQ_HIGH    =  analysis frequency range, upper bound
c     FREQ_STEP    =  analysis frequency, interval between bins
c     OUTPUT_FILE  =  name of output SRS data file
c
c     INPUT_ACC    =  input array, acceleration data
c     NPNTS        =  size of INPUT_ACC
c
c     W_N          =  undamped natural frequency (in radians)
c     W_D          =  damped natural frequency
c     SUM          =  accumulator
c     NBINS        =  number of frequency bins processed
c
c     WORK_EXP     =  work array, exponential term
c     WORK_SIN     =  work array, sine term
c     WORK_COS     =  work array, cosine term
c
c     OUTPUT_DISP  =  output array, calculated relative displacement
c     OUTPUT_ACC   =  output array, calculated absolute acceleration
c     OUTPUT_SRS   =  output matrix, frequency bin / maximax SRS
c

      implicit none

c...  Parameters

      integer*4  max_points
      parameter (max_points = 5000)

      real*4  pi, twopi
```

```
      parameter (pi = 3.141592654)
      parameter (twopi = 2.0 * pi)

c...  Variables

      real*4  input_acc(max_points), work_exp(max_points),
     &        work_sin(max_points), work_cos(max_points),
     &        output_disp(max_points), output_acc(max_points),
     &        output_srs(max_points,2)

      real*4  t1, t2, t3,
     &        freq_low, freq_high, freq_step, freq_bin,
     &        delta_t, w_n, w_d, damping, sum

      integer*4  i, k, n, ierr, nbins, npnts

      character*80  input_file, output_file

cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c
c
c...  Start of main


c
c...  Open parameter file and get run info
c
c     Parameter file should contain:
c       Line 1 = Input data filename
c       Line 2 = Intersample time (delta time)
c       Line 3 = Damping (0% to 99%)
c       Line 4 = Frequency analysis band:
c                  t1 = lower bound
c                  t2 = upper bound
c                  t3 = step
c       Line 5 = Output data filename

      open (unit=1, file='SRS2A.IN', form='FORMATTED',
     &      mode='READ', status='OLD', iostat=ierr)
      if (ierr .ne. 0) then
        write (*,*) '%Error: cannot open input parameter file'
        goto 8000
      endif

c
c...  Get input data filename

      read (1,'(a)',iostat=ierr) input_file
      if (ierr .ne. 0) then
        write (*,*) '%Error reading input data filename'
        close (unit=1)
        goto 8000
      endif

c
c...  Get intersample time
```

```
      read (1,*,iostat=ierr) t1
      if (ierr .ne. 0) then
        write (*,*) '%Error reading delta time parameter'
        close (unit=1)
        goto 8000
      endif

      if (t1 .le. 0.0) then
        write (*,*) '%Error: invalid delta time parameter'
        close (unit=1)
        goto 8000
      endif

      delta_t = t1

c
c...  Get damping

      read (1,*,iostat=ierr) t1
      if (ierr .ne. 0) then
        write (*,*) '%Error reading damping parameter'
        close (unit=1)
        goto 8000
      endif

      if (t1 .lt. 0.0  .or.  t1 .gt. 99.0) then
        write (*,*) '%Error: invalid damping parameter'
        close (unit=1)
        goto 8000
      endif

      damping = t1 / 100.0

c
c...  Get frequency band parameters

      read (1,*,iostat=ierr) t1, t2, t3
      if (ierr .ne. 0) then
        write (*,*) '%Error reading frequency band parameters'
        close (unit=1)
        goto 8000
      endif

      if (t1 .lt. 0.1  .or.  t1 .gt. 250.0) then
        write (*,*) '%Error: invalid lower frequency bound'
        close (unit=1)
        goto 8000
      endif

      if (t2 .lt. t1  .or.  t2 .gt. 250.0) then
        write (*,*) '%Error: invalid upper frequency bound'
        close (unit=1)
        goto 8000
      endif

      if (t3 .lt. 0.1) then
        write (*,*) '%Error: invalid frequency step parameter'
```

```
        close (unit=1)
        goto 8000
      endif

      freq_low  = t1
      freq_high = t2
      freq_step = t3

c
c...  Get output data filename

      read (1,'(a)',iostat=ierr) output_file
      if (ierr .ne. 0) then
        write (*,*) '%Error reading output data filename'
        close (unit=1)
        goto 8000
      endif

c
c...  Close parameter file

      close (unit=1)

cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c
c
c...  Open input data file and read acceleration data

      open (unit=2, file=input_file, form='FORMATTED',
     &      mode='READ', status='OLD', iostat=ierr)
      if (ierr .ne. 0) then
        write (*,*) '%Error opening input data file'
        goto 8000
      endif

      n = 0

1000  read (2,*,iostat=ierr) t1
      if (ierr .lt. 0) goto 1500        ! end of file
      if (ierr .ne. 0) then
        write (*,*) '%Error reading from input data file'
        close (unit=2)
        goto 8000
      endif

      n = n + 1
      if (n .gt. max_points) then
        write (*,*) '%Error: input data buffer overflow'
        close (unit=2)
        goto 8000
      endif

      input_acc(n) = t1

      goto 1000
```

```
1500  close (unit=2)

      if (n .lt. 2) then
        write (*,*) '%Error: too few points in input data file'
        goto 8000
      endif

      npnts = n

ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c
c
c...  Open output data file and write header

      open (unit=4, file=output_file, form='FORMATTED',
     &      mode='WRITE', status='NEW', iostat=ierr)
      if (ierr .ne. 0) then
        write (*,*) '%Error opening output data file'
        goto 8000
      endif

      write (4,*,iostat=ierr) '      Frequency       Amplitude'
      if (ierr .ne. 0) then
        write (*,*) '%Error writing to output data file'
        close (unit=4)
        goto 8000
      endif

      close (unit=4)

ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c

      write (*,*) delta_t
      write (*,*) damping
      write (*,*) freq_low, freq_high, freq_step
      write (*,*) npnts

ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c

c
c...  Loop to generate data at each frequency bin

      nbins = 0
      freq_bin = freq_low

5000  if (freq_bin .gt. freq_high) goto 6000

        nbins = nbins + 1
        write (*,*) '%Processing frequency bin: ', freq_bin, ' Hz'

c
c...    Convert natural frequency from Hz to radians

        w_n = twopi * freq_bin
```

```
c
c...    Calculate damped natural frequency

        w_d = w_n * sqrt(1.0 - damping**2)

c
c...    Generate work arrays

        t1 = -damping * w_n * delta_t
        t2 = w_d * delta_t

        do i=1,npnts
          t3 = float(i-1)
          work_exp(i) = exp(t1 * t3)
          work_sin(i) = sin(t2 * t3)
          work_cos(i) = cos(t2 * t3)
        enddo

c
c...    Calculate relative displacement

        t1 = -delta_t / w_d

        do i=1,npnts
          sum = 0.0
          do k=1,i
            n = i - k + 1
            sum = sum + ( input_acc(k) * work_exp(n) * work_sin(n) )
          enddo
          output_disp(i) = t1 * sum
        enddo

c
c...    Calculate absolute acceleration

        t1 = delta_t * 2.0 * damping * w_n
        t2 = ((2.0 * damping**2) - 1.0) * w_n**2

        do i=1,npnts
          sum = 0.0
          do k=1,i
            n = i - k + 1
            sum = sum + ( input_acc(k) * work_exp(n) * work_cos(n) )
          enddo
          output_acc(i) = (t1 * sum) + (t2 * output_disp(i))
        enddo

c
c...    Scan for acceleration maximums

        t1 = abs(output_acc(1))

        do i=2,npnts
          t1 = max(t1, abs(output_acc(i)))
        enddo

        output_srs(nbins,1) = freq_bin
```

```
        output_srs(nbins,2) = t1

c
c...    And loop for next frequency bin

        freq_bin = freq_bin + freq_step
        if (nbins .lt. max_points) goto 5000

        write (*,*) '%Warning: SRS buffer full'

cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c
c
c...  Save SRS results

6000  open (unit=4, file=output_file, form='FORMATTED',
     &      mode='WRITE', access='APPEND', status='OLD',
     &      iostat=ierr)
      if (ierr .ne. 0) then
        write (*,*) '%Error opening SRS results file'
        goto 8000
      endif

      do i=1,nbins
        write (4,*,iostat=ierr) output_srs(i,1), output_srs(i,2)
        if (ierr .ne. 0) then
          write (*,*) '%Error writing to SRS results file'
          close (unit=4)
          goto 8000
        endif
      enddo

      close (unit=4)

c
c...  Exit

8000  stop
      end
```