PD IEC/TR 62131-3:2011

BSI Standards Publication

Environmental conditions — Vibration and shock of electrotechnical equipment

Part 3: Equipment transported in rail vehicles

National foreword

This Published Document is the UK implementation of IEC/TR 62131-3:2011.

The UK participation in its preparation was entrusted to Technical Committee GEL/104, Environmental conditions, classification and testing.

A list of organizations represented on this committee can be obtained on request to its secretary.

ISBN 978 0 580 52990 0

ICS 19.040

This Published Document was published under the authority of the Standards Policy and Strategy Committee on 31 March 2011.

Amendments issued since publication

Amd. No.	Date	Text affected

IEC/TR 62131-3

Edition 1.0 2011-02

TECHNICAL REPORT

colour
inside

Environmental conditions – Vibration and shock of electrotechnical equipment – Part 3: Equipment transported in rail vehicles

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

PRICE CODE X

ICS 19.040

ISBN 978-2-88912-388-9

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

ENVIRONMENTAL CONDITIONS – VIBRATION AND SHOCK OF ELECTROTECHNICAL EQUIPMENT –

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FOREWORD

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IEC/TR 62131-3, which is a technical report, has been prepared by IEC technical committee 104: Environmental conditions, classification and methods of test.

The text of this technical report is based on the following documents:

Enquiry draft	Report on voting
104/508/DTR	104/537/RVC

Full information on the voting for the approval of this technical report can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2. A list of all the parts in the IEC 62131 series, under the general title *Environmental conditions – Vibration and shock of electrotechnical equipment*, can be found on the IEC website.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this publication will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

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ENVIRONMENTAL CONDITIONS – VIBRATION AND SHOCK OF ELECTROTECHNICAL EQUIPMENT –

Part 3: Equipment transported in rail vehicles

1 Scope

IEC/TR 62131-3, which is a technical report, reviews the available dynamic data relating to electrotechnical equipment transported by rail vehicles. The intent is that from all the available data an environmental description will be generated and compared to that set out in IEC 60721.

For each of the sources identified the quality of the data is reviewed and checked for self consistency. The process used to undertake this check of data quality and that used to intrinsically categorize the various data sources is set out in IEC/TR 62131-1.

This technical report primarily addresses data extracted from a number of different sources for which reasonable confidence exist as to their quality and validity. The assessment also presents data for which the quality and validity cannot realistically be reviewed. These data are included to facilitate validation of information from other sources. The report clearly indicates when it utilizes information in this latter category.

This technical report addresses vibration and shock data from three different measurement exercises, i.e. one on the UK rail system and two on the USA rail system. Although one of these relates to a multimodal system in limited use world wide, data from it are included to facilitate validation of information from other sources. The vast majority of the rail measurements reviewed are from the USA and the remainder from Western Europe. Some of the data sources considered indicate the inclusion of some quite old vehicles. It has not been possible to identify the rail data considered in setting the existing IEC 60721 severities.

Although the majority of the measurement exercises considered in this technical report supplied both vibration and shock information, a number of measurement exercises are biased towards the shock conditions of rail transportation. The severity and incidence of shocks is mostly related to the occurrence shunting of individual wagons. The occurrence of shunting of individual wagons is in turn dependant upon the operational strategy adopted by the national rail systems. A significant number of rail systems no longer adopt methods of operation which assemble train sets when the wagons are carrying sophisticated goods (carriage of bulky raw minerals is a common exception). Other rail systems purposely utilize good quality wagons and/or procedures of operation to significantly mitigate shunting loads. These strategies are intended to minimize shock severities for sensitive equipment such as electrotechnical equipment.

Relatively little of the data reviewed have been available in electronic form. To permit comparison a quantity of the original (non-electronic) data have been manually digitized in this techical report.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60068-2 (all parts), *Environmental testing – Part 2: Tests*

IEC 60721 (all parts), *Classification of environmental conditions*

IEC 60721-3 (all parts), *Classification of environmental conditions – Part 3: Classification of groups of environmental parameters and their severities*

IEC 60721-3-2:1997, *Classification of environmental conditions – Part 3: Classification of groups of environmental parameters and their severities – Section 2: Transportation*

IEC/TR 60721-4-2, *Classification of environmental conditions – Part 4-2: Guidance for the correlation and transformation of environmental condition classes of IEC 60721-3 to the environmental tests of IEC 60068 – Transportation*

3 Data source and quality

3.1 UK rail measurements

The vibration data in [1][1] from the UK rail system are relatively old (1980) and were commissioned by the UK MOD to summarize existing knowledge of the shock and vibration environments experienced by goods exposed to UK rail transit. The report initially sets out the five methods of operation used at that time within the UK. However, several of these are no longer adopted.

The report indicates that the major factors creating vibration environment within a vehicle are as follows:

- vehicle running gear characteristics (suspension, wheelbase, etc.);
- track condition;
- vehicle speed;
- vehicle lading condition.

This techical report contains vibration information indicated as from “worst case” vehicles (two axle, short wheelbase, simple-suspension), intermediate suspension vehicles (longer wheelbase) and advanced suspension vehicles (long wheelbase, bogie good suspension and air brakes). The data are relatively low frequency (less than 100 Hz) but beyond the low pass filter frequency (10 Hz to 20 Hz – the report is not specific as to the actual roll-off frequency). The report admits that higher frequency content does exist but has no general information. Although it does indicate that with a rail sleeper spacing of approximately 0,7 m, a vertical component between 20 Hz and 40 Hz would be expected for speeds of 50 km/h to 100 km/h. The report does not supply any information as to the statistical errors on the measured data including the duration of measurements. Nor are any specific information supplied as to the exact location of the transducers or the specific vehicles used.

The report indicates that shocks, particularly longitudinally, can occur between two vehicles during running as a consequence of vehicle-to-vehicle interaction arising from traction, braking and gradient effects. The severity of such shocks is generally determined by the vehicle coupling arrangement and braking condition. Vehicles may be equipped with vacuum brakes, air brakes or none at all. Coupling between wagons may allow longitudinal movement (loose coupled) or none at all (tight coupled).

The report indicates that major shocks are attributed to heavy impact shunting in marshalling yards. The shocks severity is dependant upon impact speed, buffering gear characteristics and total mass of the wagon. The report explains two types of buffer are used: spring and hydraulic. The older spring buffers limit longitudinal accelerations until the springs close solid, typically at an impact speed of approximate 8 km/h, after which the acceleration levels rise rapidly. As the springs are linear energy storage systems, when the stored energy is released it can cause “shuttling” of the vehicles. As springs are linear, the impact shock is approximate to a classic half sine. Hydraulic buffers are fitted to newer wagons and are specifically intended to mitigate

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[1] References in square brackets refer to the bibliography.

impact shock. They are designed to give a more constant retardation over the entire impact speed range which is usually far greater than for spring systems. The amount of energy released into "shuttling" is also significantly reduced. The impact shock characteristics approximate to a trapezoidal pulse. The report sets out a distribution of actual shunting impact velocities (reproduced in Figure 3).

Overall, the data in the report cannot be considered adequate to meet the required criteria for data quality (single data item). This is largely because the source and statistical quality of the data cannot be established. The report is included, nevertheless, mostly because it sets out a good background to the source and influences on both the rail shock and vibration environment.

3.2 Association of American Railroads – Lengthways shocks

This relatively recent (1995) document (see [2]) from the Association of American Railroads is on the measurement and analysis of lengthwise rail shocks. Although the title of the document infers a description of a measurement and analysis exercise, in reality the majority of the report comprises a general background discussion. As a consequence, it is not a straightforward exercise to determine whether the data source meets the required criteria. The data source relates entirely to shunting shocks on the US system. The report contains tabulated longitudinal shock information relating to impacts between

- standard draft gear cars into standard draft gear cars at velocities of 1,8 m/s – 2,7 m/s (4 mph to 6 mph),
- M921 cushioned cars into standard draft gear cars at velocities of 1,8 m/s – 3,8 m/s (4 mph to 8,6 mph),
- M921D cushioned cars into standard draft gear cars at velocities of 1,8 m/s – 3,6 m/s (4 mph to 8 mph) ,
- M921 cushioned cars into M921 cushioned cars at velocities of 1,8 m/s – 3,6 m/s (4 mph to 8 mph) ,
- M921D cushioned cars into M921 cushioned cars at velocities of 1,8 m/s – 3,7 m/s (4 mph to 8,4 mph) ,
- M921D cushioned cars into M921D cushioned cars at velocities of 1,8 m/s – 3,7 m/s (4 mph to 8,4 mph) ,
- cushioned cars into cushioned cars (type unknown) at velocities of 1,3 m/s – 4,0 m/s (3 mph to 9,0 mph).

The document indicates that the standard draft gear cars are spring buffered with around 85 mm of buffer travel and little damping. The cushioned cars are hydraulic buffered with between 250 mm and 500 mm of buffer travel. The measurements were made at a sample rate of 256 samples per second (sps) and with an anti-aliasing filter set at 60 Hz. For each impact a record of duration 2 s was acquired (although none of the shocks appeared to utilise that record window). It is implied that the measurements were made with only a single tri-axial transducer probably embedded within an EDR-3 digital recorder. The actual location of the transducers / EDR-3 is not indicated. Rail impact velocities were acquired using a radar gun (accuracy unstated). The integral EDR-3 transducer is usually piezo-resistive and able to resolve to DC. As such would be a good choice for the measurement of long duration pulses under consideration by this work.

The report presents peak positive acceleration, peak negative acceleration, r.m.s. and crest factor for 60 Hz filtered data, for 10 Hz filtered data and 3 Hz filtered data. Based upon the 10 Hz and 3 Hz filtered data the shock duration and velocity change are derived. The latter is compared with measured car impact velocity. A considerable proportion of the report is expended in establishing this velocity comparison.

The data in the report is specifically related to the shunting shock conditions. It cannot be considered adequate to meet the required validated criteria for data quality (single data item). This is largely because the source and statistical quality of the data cannot be established. However, the information has a degree of traceability and realistically is the best available.

3.3 Association of American Railroads – Intermodal environment

This relatively recent (1991) work from the Association of American Railroads (see [3]) concerns the measurement and analysis of vibration and shock conditions experienced by standard ISO containers when transported by both rail and road. The objective was clearly to establish the relationship between the vibration and shock conditions experienced during rail and road movements. The technical summary provides a description of a measurement and analysis exercise and presents some of the results. Whilst establishing the validity of the data and quality of the exercise from the technical summary alone is not straightforward, the source is supported by separate technical reports for each of the phases (see [4], [5] and [6]). Further, an “executive summary” report is also available (see [4]), some of which is reproduced below. The data source relates almost entirely to ISO containers on the US and Canadian rail system.

The study was divided into three phases:

- *Phase One:* A standard 27 m (89 foot) trailer on flat car (TOFC) was loaded with two trailers and moved in excess of 14 500 km (9 000 miles) over mountains, rolling hills and level terrain on U.S. and Canadian transcontinental routes.
- *Phase Two:* Four loaded, standard 12 m (40 foot) ISO containers were moved in dedicated intermodal trains over more than 18 000 km (10 900 miles) in principal U.S. rail corridors. The test containers were moved in double-stack rail cars, on articulated container on flat car (COFC) cars and articulated TOFC cars. Articulation is a way of joining rail cars to eliminate slack motion between them.
- *Phase three:* A 14 m (45 foot) intermodal trailer travelled more than 4 200 km (2 600 miles) of interstate highways, 1 900 (3 050 km) miles of primary (non-interstate) highways and 2 253 km (1 400 miles) of urban streets. Data was also collected for lift-on/lift-off operations at several intermodal ramps.

The report indicates differing data recording systems were used in the different phases. For phase 1 both an 18 channel data acquisition system was used as well as six self contained data recorders. Two data recorders were installed on each test trailer and container. The multi-channel system sampled at 128 sps with a filter at 30 Hz. The total record duration was around 11 % of a total of 4 200 km (2 600 miles) of rail transport. The six self contained units measured mostly shocks and adopted a sample rate of 1 600 Hz into 0,5 s files. The remaining two phases utilized two self contained recorders. One recorder was programmed to record random vibration data at preset intervals with a threshold of 0,1 g. The other recorder was set to record only acceleration levels exceeding a preset 0,5 g threshold, providing shock data for each test vehicle. The two pre-programmable data recorders, housed longitudinal, lateral and vertical accelerometers capable of DC measurement (piezoresistive). The sample rate was 250 sps in both cases.

The information in this report is limited to large 12 m (40 foot) ISO containers and the US/Canadian rail systems. However, the quality of the information is good and meets the required validation criteria for data quality (single data item).

3.4 Association of American Railroads – Study of the shock and vibration environment in boxcars

This relatively recent (1992) work from the Association of American Railroads (see [8]) is on the measurement and analysis of vibration and shock conditions experienced in both standard and cushioned boxcars. A lot of commonality exists between this study and that reported above. Data were recorded on some 16 journeys covering nearly 40 000 km (25 000 miles) and encompassed 14 different boxcars. The instrumented boxcars had a range of payloads and were located at different positions within the train set. Each boxcar had between 2 and 4 pre-programmed data recorders each with a single integral triaxial piezoresistive accelerometer. One recorder was programmed to record 4 s of random vibration data at preset intervals with a threshold of 0,1 g. The other recorder was set to record 2 s of data but only when acceleration levels exceeded a preset 0,5 g threshold for 15,6 ms, providing shock data for each test vehicle. In both cases the recorder sample rate was 256 sps. One pair of recorders was positioned as close to the centre of the payload bay floor as possible.

The study report, as was the case also in the previous study, presents amplitude probabilities for the shock data and PSD data for the vibration data.

The information in this report is limited to boxcars on the US rail system. However, the quality of the information is good and meets the required validation criteria for data quality (single data item).

3.5 Association of American Railroads – Study of the railroad shock and vibration environment for railroader equipment

This relatively recent (1992) work from the Association of American Railroads (see [9]) is on the measurement and analysis of vibration and shock conditions experienced by trailers carried on Mk IV and Mk V railroader equipment. A lot of commonality exists between this study and the two previous studies. Data was recorded on two different routes encompassing two types of railroader equipment. Eight different payloads were utilised four for each type of railroader equipment, however, these were not identical in the two cases. Each instrumented trailer had 2 pre-programmed data recorders, each with a single integral triaxial piezoresistive accelerometer. One recorder was programmed to record 4 s of random vibration data at preset intervals with a threshold of 0,1 g. The other recorder was set to record 2 s of data but only when acceleration levels exceeded a preset 0,5 g threshold for 15,6 ms, providing shock data for each test vehicle. In both cases the recorder sample rate was 256 sps. One pair of recorders was positioned as close to the (presumably rear) door threshold laterally centred on the payload bay floor.

The study report, as was the case also in the previous study, presents amplitude probabilities for the shock data and PSD data for the vibration data.

The information in this report is limited to a particular type of equipment which allows road vehicles to be moved by rail on the US rail system. Again the quality of the information is good and meets the required validation criteria for data quality (single data item).

3.6 Supplementary data

The data collection exercise which preceded this assessment also identified relevant sets of information which come from reputable sources but for which the data quality could not be adequately verified. Although, they are included here to facilitate validation of data from other sources, care should be taken when utilizing information in this category.

Johnson. In the mid 1970's G.E. Johnson of Cambridge Consultants in the UK was funded by the UK MOD to review the transportation shock environment. The final report of this work (see [10]) was delivered in 1976 and includes a significant review of available rail shock data. The shocks reported were all from inter-wagon impacts during shunting. The report includes a number of references containing rail shunting shock data. However, these are all pre-1970 and many relate to unobtainable data sources (hence are not reproduced here). Further the information set out by Johnson on shutting practice (Figure 28) are not representative of the practice used on the UK rail system in recent years.

Various US rail vehicles circa 1970. As part of an exercise, in the early 1970's, to authenticate test severities for the US military specification Mil Std 810, J.T. Foley (see [11]) at Sandia National Laboratories in the US undertook an extensive exercise to establish transportation severities on a number of platforms including several rail vehicles. As far as can be determined the vehicles used real US rail roads and conditions. The vibration information included data from 3 journeys and "other" (source unknown) published data. A total of 22 events were summarized up to 350 Hz. Whilst several measurements were considered, the process adopted does not allow information from individual vehicles to be identified. Moreover, the analysis process Foley used throughout his work is relatively unique and not immediately compatible with other information presented in this assessment.

Wagon GDE capacité. Information is contained within the French military specification GAM EG 13 (see [12]) from three different vehicles. The measurements were made on a variety of real rail conditions and speeds (although the exact nature is not known). All the data are presented in the form of PSD's of 1 Hz (or better) frequency resolution. The duration of the records used for the analysis is unknown and hence the analysis random error cannot be determined. Overlaid vibration spectra for the one vehicle are presented for vehicle speeds of 90 km/h, 100/h km and 120 km/h, respectively. Additionally shock response spectra for impacts at 4 km/h and 7 km/h are presented.

Miscellaneous data. During the course of the data search a number of possible data sources were identified for which the data were not traceable to any reasonable extent. These are included here for completeness because they may help support information from more traceable sources. Most of these sources are courtesy of Dr Ulrich Braunmiller and the EC sponsored SRETS work. Vertical responses from two rail vehicles presented in ASTM D4728-91 (see [13]). However, these data may well be those of the Association of American Railroads – Intermodal environment. The SRETS work also documents data from the UK Defence Standard Def Stan 00-35; which are based upon the UK Rail measurements already documented.

4 Intra data source comparison

4.1 General remark

The purpose of the following paragraphs is to review each data source for self consistency. The process for evaluating the vibration data takes into account the variation of vibration due to operational usage and aircraft characteristics. The level of confidence resulting from this review directly influences the levels of factoring and enveloping that are used when deriving environmental severities.

4.2 UK Rail measurements

The report from the UK rail system (see [1]) makes a number of comparisons but does not set out the basis for these. With regard to vibration the report suggests that vertical vibrations are marginally more severe than lateral, whilst longitudinal vibrations are usually insignificant. However, the report does indicate this vehicle possesses simple suspension, which is a lot worse in the vertical axis (these simple vehicles are essentially all used for transportation of minerals). The report contains limited vibration information which are shown in Figures 1 and 2 and relate to vehicle vertical and lateral axes. Summary amplitude information are summarized in Table 1.

The report indicates that longitudinal shocks can occur between two vehicles during running as a consequence of vehicle to vehicle interaction arising from traction, braking and gradient effects. The severity of such shocks is generally determined by the vehicle coupling arrangement and braking condition. Vehicles may be equipped with vacuum brakes, air brakes or none at all. Coupling between wagons may allow longitudinal movement (loose coupled) or none at all (tight coupled). Typical maximum longitudinal shocks are given as

– tight coupled, fully braked	0,2 g,
– loose coupled, fully braked	0,5 g,
– loose coupled, unbraked	2,0 g.

The report indicates that major shocks are attributed to heavy impact shunting in marshalling yards. The shock's severity is dependant upon impact speed, buffering gear characteristics and total mass of wagon. The report explains two types of buffer are used spring and hydraulic. The report indicates the longitudinal shock has the longest duration but not necessarily the greatest amplitude. Due to the position of the wagon centre of gravity (c of g) above the buffer height vertical shocks may be typically one and a half times greater in acceleration amplitude than longitudinal shocks but with a duration of only 10 ms. The severity of lateral shocks is more variable but can have the same greater acceleration amplitude as longitudinal shocks but with a duration of only 20 ms. Typical maximum longitudinal acceleration values are given as

- spring buffers, fully laden wagon until buffers fully compressed = 1,5 g,
- spring buffers, lightly laden wagon until buffers fully compressed = 3,0 g,
- spring buffers, fully laden wagon after buffers fully compressed = >15,0 g,
- hydraulic buffers, fully laden wagon at 8 km/h impact = 2,0 g (double for lightly laden wagon),
- hydraulic buffers, fully laden wagon at 15 km/h impact = 4,0 g (double for lightly laden wagon).

The report does not set out the basis for the derivation of these values.

4.3 Association of American Railroads – Lengthways shocks

This relatively recent (1995) document from the Association of American Railroads is solely on the measurement and analysis of lengthwise rail shocks. Whilst, the report extracts several indicators of a rather obvious nature, it does present a useful selection of summarized data from which the reader to make their own assessment. The information presented includes peaks and r.m.s. values mostly filtered at 3 different frequencies. The report present typical longitudinal shock pulses from impacts with different types car (shown in Figure 4). The report also presents acceleration levels (positive and negative) for some 96 shunting impacts of different cars at a range of speeds (Figures 5 and 6). For the same impacts r.m.s. and crest factors are also presented (Figures 7 and 8). However, a significant observation of the report relates the energy of the longitudinal shock to the impact energy (Figure 9). The reports conclusions imply that better the buffer cushion system the lower the amplitude and longer the duration of the shock (Figure 10).

The shock data presented in this report indicates an underlying relationship between shock amplitude and duration for different vehicle types. However, some data clearly falls outside this trend and the data most notable in this regard are labelled “cushioned vehicle into cushioned vehicle – type unknown”. The report does not comment on this anomalous data although question marks over its applicability exist.

4.4 Association of American Railroads – Intermodal environment

This work from the Association of American Railroads includes measurement and analysis of both vibration and shock conditions experienced by standard ISO containers when transported by both rail and road. Each of the phases was intended to measure vibration and shock conditions on different road and rail vehicles. The clear main intent of the assessment was a comparison between rail and road, but some inter rail vehicle comparisons are also possible. In particular a comparison between axes is included. The report includes a distribution of shock and vibration amplitudes and again this shows the peak amplitudes are part of a reasonable distribution and not based on a few anomalous results.

The findings from the shock measurements (summarized in Table 5) were as follows:

a) The distribution of acceleration shock levels was established for each type of equipment and mode of transport. Accurate comparison is not readily possible from the data presented. However, the summary shown in Table 5 indicates quite high values of standard deviation compared to the mean. This seems to originate from a few (<1%) values that are much greater in amplitude than the remainder. Overall this would suggest a very skewed distribution with extreme values occurring at a relatively low occurrence rate.

b) Lengthways Shocks. Figure 11 and Table 2 show the distribution of longitudinal shocks. As can be seen whilst distribution for the standard 27 m (89 foot) trailer-on-flatcar shock environment was generally the most severe in the lengthwise direction it did not produce the most severe extreme conditions.

c) Lateral shock. Figure 12 and Table 3 show the distribution of lateral shocks. The lateral axis indicates to be the least severe in terms of both shock distributions and extreme conditions.

d) Vertical Shocks. Figure 13 and Table 4 show the distribution of vertical shocks. These are relatively similar to the appropriate longitudinal values.

The findings from the vibration measurements were as follows:

(1) The report indicates that the vertical rail vibrations are comparable or lower than for urban street and primary highways. Peak vibration levels are shown in Table 6. The report includes power spectral densities (PSD's) in terms of both average and peak values. Unfortunately these are plotted on linear – linear scales which difficulties in reproducing them here. The peak PSD for vertical axis is shown in Figure 14. The figure shows the vibrations for the various types of car are relatively consistent over the frequency range for which information is available.

(2) Lateral vibration levels are summarized in Table 6. The peak PSD's for the lateral axis is shown in Figure 15. The consistency of the lateral spectra from the different types of car are not as good as for the vertical axis but a broad trend is still discernible.

(3) Longitudinal vibration levels are summarized in Table 6. The peak PSD's for the longitudinal axis is shown in Figure 16. Quite marked variations exist in the longitudinal measurements for the different vehicle types. No real trends in the data are discernible.

4.5 Association of American Railroads – Study of the shock and vibration environment in boxcars

This study is clearly intended to follow on from the previous study and the author of this study report is also one of the authors of the previous study reports. As a consequence, it is reasonable to expect that the severities have been compared to those of earlier studies. Within this study the report compares, for both shock and vibration, the differences between standard and cushioned cars as well as the location within the overall train set. The work also compares the effect of measurement axis. A major deficiency in the results is the absence of a comparison of shock duration (this was the case for the previous study also). This is a little disappointing as the latter study on longitudinal shock did show that to be relevant.

Figures 17 to 19 show the vertical, lateral and longitudinal vibration responses from the middle and end of both cushioned and standard cars. The figures show the peak hold power spectral densities only as the use of log – linear scales in the report presents difficulties in reproducing the average values here. The vertical responses are consistent for all four measurement summaries up to around 5 Hz above which the difference between cushioned and standard cars is clearly visible. The lateral measurements are less consistent but do show some constancy with the vertical axis. The longitudinal measurements are the least consistent, with the standard cars showing indications that the measurements may be contain some impacting.

Peak-to-peak shock probability distributions are shown in Figures 20, 21, 22 and 23 and are summarized in Table 7. These distributions are for all three axes from the centre and end of standard as well as cushioned boxcars. The data indicates that peak shocks are different at the centre and end of cushioned cars but relatively similar in standard cars. Apparent from the values of extreme measured value (Table 7) the shocks in cushioned boxcars are similar to those in standard boxcars in the vertical and lateral axis. However, the values are nearly three times greater for the standard boxcar in the longitudinal axis.

4.6 Association of American Railroads – Study of the railroad shock and vibration environment for railroader equipment

Once again this study is clearly intended to follow on from the previous study and again the author of this study report is also one of the authors of the previous two study reports. Within this study the report compares, for both shock and vibration, the differences between Mk IV and Mk V trailers and also compares the effect of measurement axis. Again a major deficiency in the results is the absence of a comparison of shock duration.

Figure 24 shows the vibration responses for Mk IV and Mk V trailers in three axes. The figures show the peak hold power spectral densities only as the use of linear – linear scales in the report presents difficulties in reproducing the average values here. The vibration responses show a good degree of consistency and that the vertical/lateral responses are greater than the longitudinal vibration responses.

Figure 25 shows the shock probability distribution for an Mk V filtered at both 10 Hz and 30 Hz. Summary information is included in Table 8.

4.7 Supplementary data

The data collection exercise which preceded this assessment also identified relevant sets of information, which come from reputable sources, but for which the data quality could not be adequately verified. Although, they are included here to facilitate validation of data from other sources, care should be taken when utilizing information in this category.

Johnson. This report includes a number of references containing rail shunting shock data of pre-1970 vintage and many relate to unobtainable data sources. Johnson does present some Shock Response Spectra of rail shocks which are reproduced here at Figures 26 to 27. These figures include shock responses from different velocity impacts for both spring and hydraulic buffers. A clear and consistent difference between the two types of vehicle is apparent in these figures.

Various US road vehicles circa 1970. The vibration analysis process Foley used throughout his work is relatively unique and not immediately compatible with other information presented in this assessment. Foley generated a form of vibration test spectra which permitted ensemble averaging of information from several different vehicles. This was then turned into a “model” (Figure 29) from which test spectra could be derived (mostly by non-quantitative means). The shock response spectra information collected by Foley is comparable with other information presented in this report. He collected two forms of shock, recurrent (crossing rail joints, travel through switches, etc.) and for discrete intermittent events (shunting shocks). These two sets of information are reproduced here as Figures 30 and 31 respectively.

Wagon GDE capacité. Overlaid spectra, from the French military specification GAM EG 13, are presented in Figures 32, 33 and 34 for the fore-aft, transverse and vertical axes respectively. The actual orientation of these axes to those of the vehicle is unknown. Each figure includes information for a mediocre, good and very good rail tracks at different speeds. All these results appear very consistent. Figures 35 and 36 show shock response spectra for the longitudinal and vertical axis each at two different shunting impact velocities. Again these values look very similar with a clear difference between impact speeds.

Miscellaneous data. Vertical responses from two rail vehicles presented in ASTM D4728-91 (see [13]) are shown in Figure 37. However, these data may well be selected values of average PSD from the Association of American Railroads study on the intermodal environment.

5 Inter data source comparison

Superficially, the data from the various sources suggests not only a reasonable degree of self consistency but also a fairly good degree of consistency across the various sources. None of the verified data sources are so obviously significantly different from the remainder that the validity of the whole is called into question. Although a lot of the data are from one rail system and one agency, relatively few items of information can be directly compared.

The trends in shunting shocks are consistent for all the sources addressed. The form and amplitude of shock impact are significantly influenced by the velocity of impact as well the type of buffering system employed. Impact velocity is clearly the most significant parameter but difference between spring and hydraulic systems (also referred to as standard or cushioned in the US reports) is quite marked both in terms of amplitude and type of shock pulse. Broadly, the shock amplitudes appear to fall into the same general trends regardless of source.

However, this is not particularly surprising given the close direct relationship between the shock and the kinetic energy imparted during the impact.

Only a few shock response spectra are presented and those seem relatively similar given consideration of impact velocity and buffer type. Only one study presented information on the shape and duration of the shocks. This study related impact velocity and pulse duration (in the longitudinal direction) – which seems reasonable. The same study also showed that pulse shape (again in the longitudinal direction) is broadly similar to a half sine for spring buffers and relatively similar to a trapezoidal pulse for hydraulic buffers. That broad trend was supported by another study.

A second type of rail shock has also been observed to occur between two running vehicles as a consequence of vehicle-to-vehicle interaction arising from traction, braking and gradient effects. The severity of such shocks appears to be related to vehicle coupling arrangement and braking condition. The shock severity appears to be minimized for braked vehicles when tight coupled and that conditions seems to be the norm. For this type of shock few data items are available for direct comparison. However, of those similar values are indicated.

The broad trends in rail running vibrations are broadly consistent for all the sources addressed. The various sources indicate that the trends and amplitudes are influenced by the type of rail vehicle and particularly its suspension. Much of the data available for inter source comparison are typically up to 30 Hz. In this frequency region the different sources indicate broadly consistent data, although the relationship with the quality of the suspension system is not always easy to identify. The only source which appears different to the others is the supplementary data from the French military specification GAM-EG-EG-13. The main reason for such a difference is that it presents data up to 2 000 Hz rather than up to 30 Hz of the remaining data. In the lower frequency range, the French data is similar if not slightly lower than the remainder.

The analysis of the shock data predominantly adopted the use of probability analysis to define both amplitude and occurrence rate. Additionally a few studies presented the shock in terms of shock response spectra. Both approaches are reasonable but none of the shock data descriptions were ideal. The first consideration in the shock data process was the technique used to identify the occurrence of a shock condition. The main one used in the studies was exceedance of a “trigger” level on either the recorder or any subsequent data analysis. However, to be of any use these identified shock events need to be associated with an appropriate occurrence “rate”. Two of the studies reviewed did this but neither may be applicability to current day rail system practice. Having identified the shocks, statistical analysis of the amplitudes was commonly undertaken. The relationship between mean, standard deviation and extreme value clearly indicate a skewed and non-Gaussian distribution. The shock distributions are clearly influenced by relatively few very severe conditions, a fact which should have been noted by the high value of the standard deviation compared to the mean value. Also, the various probability analysis presented utilized linear scales on the probability axis which does not allow adequate consideration of the skewed distribution of high amplitude/low occurrence events. No error analysis considerations of the latter are addressed in any of the studies.

All the data sources (with the exception of Foley) have utilized acceleration power spectral density as the means of analysing the vibration data. This approach appears valid for the analysis of the long term vibrations occurring when rail transport achieves a steady velocity. However, the approach is not so valid for the analysis of non-stationary vibration, especially when potentially interspaced shock conditions occurring at lower speeds. Given that power spectral density analysis is essentially an ‘averaging’ process, the amplitudes could vary due to these aspect. Several studies reviewed acknowledge this and utilize “peak hold” power spectral density values as well as the usual ‘average’. The large differences between peak and mean values would suggest that these aspects are a significant consideration. In this report mostly peak values have been presented. However, these peak values do not occur all the time and should these peak values be used as the basis for a test severity some form of associated “occurrence rate” will need to be established. Unfortunately, nothing in the studies reviewed readily allows for this. It is notable that the predominant peak amplitudes are commonly noted at around 3 Hz and typically between 1 Hz and 5 Hz. Accurate measurement in this frequency region can be at the limits of capability of certain accelerometer/signal conditioning types and it is not always clear whether suitable accelerometer/signal conditioning types have been utilized. Also, measurements centred in such a low frequency range require very long duration records to achieve good statistical accuracy. None of the measurement exercises appear particularly good in this regard.

6 Environmental description

None of the studies specifically present quantified environmental descriptions of the environment. Moreover, had any done so it is questionable whether the values would have applicability to any other rail systems. Essentially rail transportation can generate three types of environments each from different sources and related to different excitation mechanisms. The primary environmental condition can be the shock arising from shunting, the second is shocks arising during rail movement which occurs as a result of inter-wagon impacts. The third condition is the vibrations that occur during movement over the rails. The various studies reviewed indicate that the actual severity of all three are dependant upon the operational procedures of the rail system and the quality of the wagons utilized.

The severity of the longitudinal shocks arising from shunting is dependant upon the velocity at which the wagons impact as well as the type of buffering mechanism used. A spring buffered wagon potentially produces the greatest amplitude shock with a shock pulse tending toward one with a half sine characteristic. Hydraulic buffers potentially produce less severe amplitudes but with a markedly longer pulse duration. The latter shock pulse shape is tending towards that of a trapezoidal test pulse. In either case pulse amplitude and duration are essentially related to impact velocity. Vertical shocks are around 1.5 times greater in amplitude than longitudinal shocks (but it does depend upon height of equipment above buffer height) but a shorter duration of 10 ms is reported. Lateral shocks are similar in amplitude to longitudinal shocks but with a reported duration of around 20 ms.

The main parameter to the severities of shunting shocks is wagon longitudinal impact velocity. As such, the severity is directly related to the rail system operational procedures causing such impacts. The highest velocities seem to have occurred historically when single loose wagons were propelled at relatively high speed into one another to facilitate rapid shunting operations. This is still common practice for mineral transports but does not appear to be the norm for wagons carrying high value goods. Johnson reported historical information that relates impact velocities of up to 15 km/h and the British Rail report indicates velocities of up to 20 km/h. US documents such as Mil Std 810 suggest upper impact velocities of 11 km/h should be considered (the Mil Std 810 value is believed to originate from a Federal test requirement). Alternative and generally more modern procedures are characterized by wagons remaining attached to locomotives or wagon strings and seems to be that adopted for wagons carrying consumer and high value goods (and also usually adopt hydraulic buffers). In such cases, much lower impact velocities appear to occur with typically values of up to 3 km/h (but with no really traceable evidence of this value). A third case also exists, that is one in which wagons are not shunted at all, specifically when wagons remain permanently assembled as train sets. This is essentially the norm in Western Europe and probably also in many other parts of the world.

Broadly speaking, the available data could allow the derivation of shock amplitudes for a particular impact speed and buffer type. The real problem is identifying actual impact velocities. It is observed that some rail systems no longer undertake rail shunting at all, whilst others only undertake low speed coupled shunting. Some rail systems no longer use vehicles with spring buffers except for mineral transports.

Shocks arising from inter wagon impacts occurring during rail movements arise essentially when the train is loose coupled. Tight coupled trains do not seem to encounter this environment or, probably – more likely – it is encompassed by the vibration condition. Moreover, the environment is diminished with the use of hydraulic buffers as opposed to spring buffers. The vast majority of these shocks do not exceed 1 g in amplitude. The shock severity appears to be minimized for braked vehicles when tight coupled, and that condition seems to be the norm. Again, some rail systems no longer use loose coupled vehicles except for mineral transports.

The vibrations occurring during rail transport are reported to be influenced by the type of wagon suspension system. The most severe conditions arise when utilizing wagons with simple suspension. Whilst mineral transports may adopt this type of wagon, those used to carry higher value goods are now generally fitted with good suspension systems. In either case, the vibration environment is dominated by low frequency components at typically 2 Hz to 3 Hz and, if the majority of the studies reviewed are to be believed, almost all the vibratory energy occurs below 30 Hz. The highest peak power spectral density amplitude noted is around 0,4 g^2/Hz. Typically, the highest value is in the vertical axis, but with lateral response amplitudes only a little lower. Longitudinal vibration amplitudes are for the most part significantly lower than either vertical or lateral axes.

The data reviewed does not suggest the effects of vehicle suspension are as clear as implied above. Almost all the peak amplitudes are in the frequency range 1 Hz to 5 Hz regardless of suspension type. This would suggest suspension frequency is not being used to improve response. At these frequencies, excitations are almost certain to arise from track quality which is related to the rail system and not to the wagon type. Improved suspension probably does reduce higher frequencies and the effects of shock.

7 Comparison with IEC 60721

The environmental levels of IEC 60721-3-2:1997, Table 5, environmental category b) (stationary vibration random), Table 5,environmental category a) (stationary vibration sinusoidal) and Table 5, environmental category c) (non-stationary vibration including shock), are illustrated in Figures 38, 40 and 42 respectively. These are intended for “transport” in general and not specifically for rail transport. No duration or number of applications is specified this is presumably the severities purport to be environmental descriptions.

The test procedures of IEC 60068-2 contain vibration and shock levels related to transport. These are different to those of IEC 60721-3. The severities for stationary vibration random, stationary vibration sinusoidal and shock are illustrated in Figures 39, 41 and 43 respectively. In these cases, the duration of vibration testing and number of shock applications is quoted.

As the amplitudes of IEC 60721-3 differ from those of IEC 60068-2, reconciliation between the two standards is set out in IEC/TR 60721-4-2. For the two vibration conditions IEC/TR 60721-4-2 recommends the IEC 60068-2 amplitudes. However, for the shock condition, a third option is recommended as are illustrated in Figure 44.

The three “transport” categories set out in IEC 60721-3-2 are designated 2M1, 2M2 and 2M3. Only a brief explanation is given as to the conditions these represent but seem to be essentially

2M1 trains with soft suspension,

2M2 trains with soft suspension, trains with specially designed buffers intended to reduce shock,

2M3 trains with hard suspension, including shunting.

From the information reviewed for this assessment, these categories do not appear to be entirely sensible today. The “default” category appears to be 2M3 with 2M2 only used in special cases. However, today a large number of rail systems use tightly coupled wagons with soft suspension and hydraulic buffering gear. In many cases the severity of shunting impact velocities is limited and in some cases shunting does not occur. Essentially it would today be far more realistic for these conditions to use the default category 2M2.

When the levels from IEC 60721 and IEC 60068-2 are reviewed against the information surveyed for this assessment, a number of significant issues arise. These are addressed in the following paragraphs.

The severities from IEC 60721 are split into three headings viz. stationary vibration random, stationary vibration sinusoidal and non-stationary vibration,including shock, these are in fact different test procedures from IEC 60068-2. It is presumed that the two stationary vibration categories (sinusoidal and random) are intended to be alternatives. As such, a review is justified of the various testing categories against today's understanding of the actual dynamic rail transport environment and todays testing facilities.

Random vibration. The dynamic environment is predominantly Gaussian random (although none of the studies reported here intrinsically conclude this). As such, this is probably the most realistic of the two vibration tests. However, the lowest frequency of the test is at the upper end of the range in which the largest rail vibration responses occur. The amplitudes at the lowest frequency are such that displacements and velocities are very low compared with those that can actually occur. The test does not have the ability to exercise potential failure modes associated with either displacement or velocity (and nor does any other test currently specified in IEC 600721 or IEC 60068-2). At the time the tests were originally derived only limited capabilities existed to allow for much greater displacements and velocities than adopted. Today greater displacements are possible.

Sinusoidal vibration. At the time the current severities were set the environment was sufficiently understood to know it was dominantly random. It is suspected that the acceleration test pre-dates the random test and the two were never compatible. As such, the continued use of a sinusoidal sweep test was presumably to allow continued use of older facilities. However, if the sinusoidal seep test was retained to allow continued use of older test facilities, it is difficult to understand why the sinusoidal vibrations are so different from the random. One difference is clearly apparent in that the frequency ranges of the two tests are entirely different (random 10 Hz to 2 000 Hz and sinusoidal 1 Hz to 500 Hz). If the effects of the two tests are compared using techniques such as maximum response spectra and fatigue damage spectra it is found that they are remarkably different. The two tests only producing similar damage effects for a very small range of equipment.

Shock. All the various shock definitions are half sine pulses. In this case this may actually be representative of some of the transient responses actually occurring, although a trapezoidal pulse may be more appropriate in some cases. The duration and the velocity change of the shocks are not representative of those that can occur in a longitudinal shunting shock. However, they are probably representative of vertical and lateral conditions.

The vibration amplitudes set out in IEC 60721 and IEC 60068-2 do not appear particularly representative of actual rail condition nor do they replicate all aspects of the environment exercising potential equipment failure modes. Notably the highest rail vibration amplitudes are in the frequency range 1 Hz to 5 Hz. The random environment and test of IEC 60721 and IEC 60068-2 respectively do not go below 10 Hz and consequently do not encompass the worst case conditions. Moreover, even if the existing amplitudes were extrapolated down to 1 Hz, they would not encompass the worst case conditions identified. The sinusoidal vibration environment of IEC 60721 and IEC 60068-2 go down to 2 Hz and 1 Hz respectively. Consequently they have the potential to encompass actual conditions. In fact comparison suggests the sinusoidal aspects of IEC 60721 and IEC 60068-2 do encompass the worst case conditions identified.

The shock amplitudes and durations set out in IEC 60721 and IEC 60068-2 do not appear particularly representative of actual rail shunting condition nor do they replicate all aspects of the environment exercising potential equipment failure modes. The most significant difference occurs for the duration and velocity change of the longitudinal rail shock. This is a far longer duration event than any of IEC 60721 and IEC 60068 shock conditions. The actual duration is sufficiently long as to render any anti-vibration/shock mount practically ineffective at attenuating the event.

Although this assessment does not include detailed work and has been undertaken to establish equivalent test durations, a basic review indicates that test durations should be much shorter than actual conditions. This is a consequence of the variations that exist in the actual conditions rather than any deliberate attempts to accelerate the test duration.

8 Recommendations

Good data has been identified from three sources, for which a modest amount of information is available by which data validity can be established. The five primary sources and three secondary sources encompass both shock and vibration conditions covering a range of vehicles. The information from these sources was acquired on three different national rail systems although the majority of data are from one rail system. The secondary sources come from reputable agencies, but for which the available information is insufficient for the data quality to be adequately verified.

For the most part, the data from the various sources not only indicates a reasonable degree of self consistency but also a fairly good degree of consistency across the various sources. None of the data sources are obviously significantly different from the remainder, to the extent that their validity of this assessment exercise is called into question. Notwithstanding the above, it is clear from the information reviewed that it does not fully describe the rail transportation dynamic environment.

Whilst the information reviewed would allow an environmental condition to be developed, it is clear that the actual conditions are highly dependant upon the quality of the rail vehicles and the method of operation of the rail service. In recent times, significant changes have occurred in the way some rail services operate to the extent that they have significant effect on the dynamic rail environment. These changes have occurred for a variety of reason (cost, change of role) not necessarily associated with reducing the environmental conditions. However, an underlying message in some of the information reviewed is that ensuring the environmental conditions are less than those of road vehicles is an issue.

The severities of IEC 60721-3-2:1997, Table 5, environmental category b) (stationary vibration random) encompass a variety of transportation conditions as well a transportation by rail vehicles. It seems likely that the dynamic environment arising from rail transportation was not the main condition setting the IEC 60721-3-2:1997 Table 5 severities. The severities of IEC 60721-3-2:1997 Table 5 (stationary vibration) encompass a variety of transportation conditions and are not representative of actual rail conditions. The shocks of IEC 60721-3-2:1995 Table 5, environmental category c) (non-stationary vibration including shock) also encompass a variety of transportation conditions and again do not represent actual rail conditions.

Utilizing the data identified, this assessment has found a number of deficiencies in the current IEC 60721 conditions and the IEC 60721 and IEC 60068-2 severities. These are set out below.

a) The vibration amplitudes set out in IEC 60721 do not appear particularly representative of actual rail condition. Notably the highest rail vibration amplitudes are in the frequency range 1 Hz to 5 Hz. The random environment of IEC 60721 does not go below 10 Hz and consequently does not encompass the worst case conditions. Moreover, even if the existing amplitudes were extrapolated down to 1 Hz they would not encompass the worst case conditions identified. The sinusoidal vibration environment of IEC 60721 goes down to 2 Hz, consequently it has the potential to encompass actual conditions. In fact, comparison suggests the sinusoidal aspects of IEC 60721 do encompass the worst case conditions identified.

b) The shock amplitudes and durations set out in IEC 60721 do not appear particularly representative of actual rail shunting condition. The most significant difference occurs for the duration and velocity change of the longitudinal rail shock. This is a far longer duration event than any of IEC 60721 shock conditions.

c) The current descriptions in IEC 60721 are inadequate as it does not represent the entire damage-inducing potential of the dynamic rail transport environment. Whilst it is acknowledged that not all users will need to exercise all potential damage mechanisms, IEC 60721 should not unnecessarily restrict the scope of the test. The damage mode of particular relevance is for equipment with low frequency resonances (such as those on anti-vibration/shock mounts) whose frequency may coincide with the low dominant excitation frequency occurring during rail transportation of equipment. In fact this encompasses a considerable range of packaged equipment.

d) When no relevant information is available relating to rail vehicle type, the intent appears to be that category should be 2M3 used with 2M2, and 2M1 only used in special cases. Historically, that may have been a reasonable assumption. However, the majority of rail systems currently use only tightly coupled wagons with soft suspension and with hydraulic buffering gear for the carriage of goods. If loosely coupled wagons with no suspension are used, they are usually limited to the carriage of minerals. Few rail systems adopt the shunting of loaded wagons and the majority of the remainder significantly limit shunting impact velocities. As a consequence, it would today be far more realistic to assume category 2M2 applies for the transport of electrotechnical goods and 2M1 applies if rail transport occurs on systems which no longer shunt loaded vehicles.

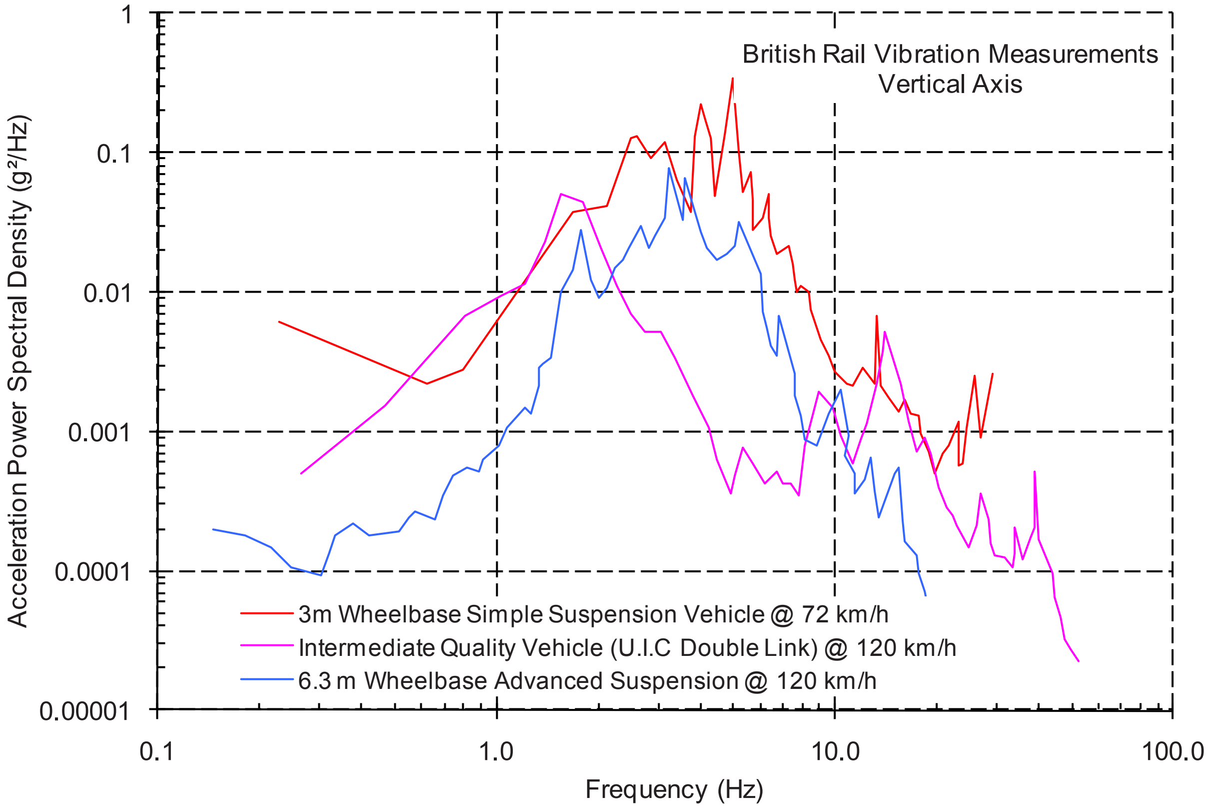

Figure 1 – British Rail measured vertical vibration severities

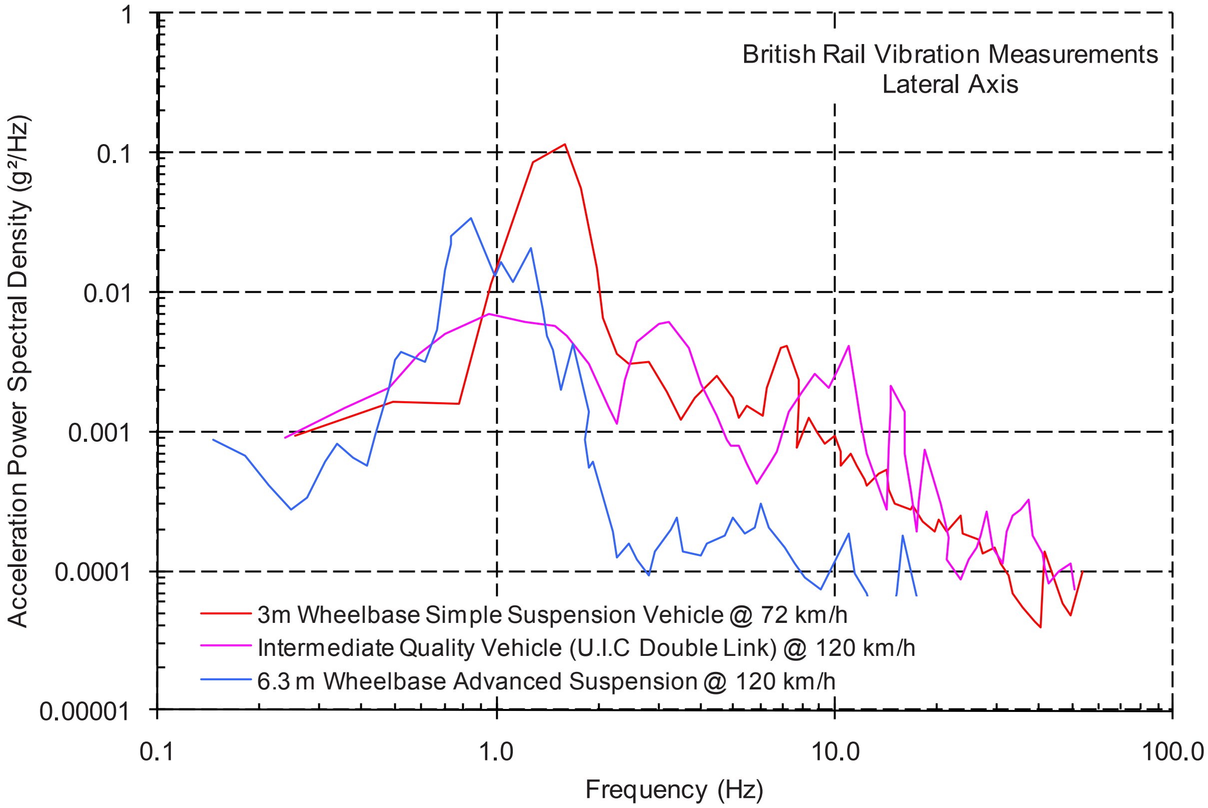

Figure 2 – British Rail measured lateral vibration severities

Table 1 – British Rail measurements summary of vibration measurements

Ride acceleration levels				
VERTICAL AXIS	**Acceleration**		**Frequency of peak value** Hz	**Speed** km/h
Vehicle	**Mean** g	**Maximum** g		
Freightliner (on road)	0,2	0,9	3 to 4	72
Freightliner (on rail)	0,25	0,8	3 to 5	120
4 wheel wagon simple suspension	0,45	1,6	3 to 6	72
4 wheel wagon advanced suspension	0,15	0,75	3 to 4	120
Lateral axis	**Acceleration**		**Frequency of peak value** Hz	**Speed** km/h
Vehicle	**Mean** g	**Maximum** g		
Freightliner (on road)	0,04	0,4	4 to 12	72
Freightliner (on rail)	0,2	0,45	3 to 5	120
4 wheel wagon simple suspension	0,25	1,0	1 to 2	72
4 wheel wagon advanced suspension	0,1	0,5	0,75 to 1,75	120

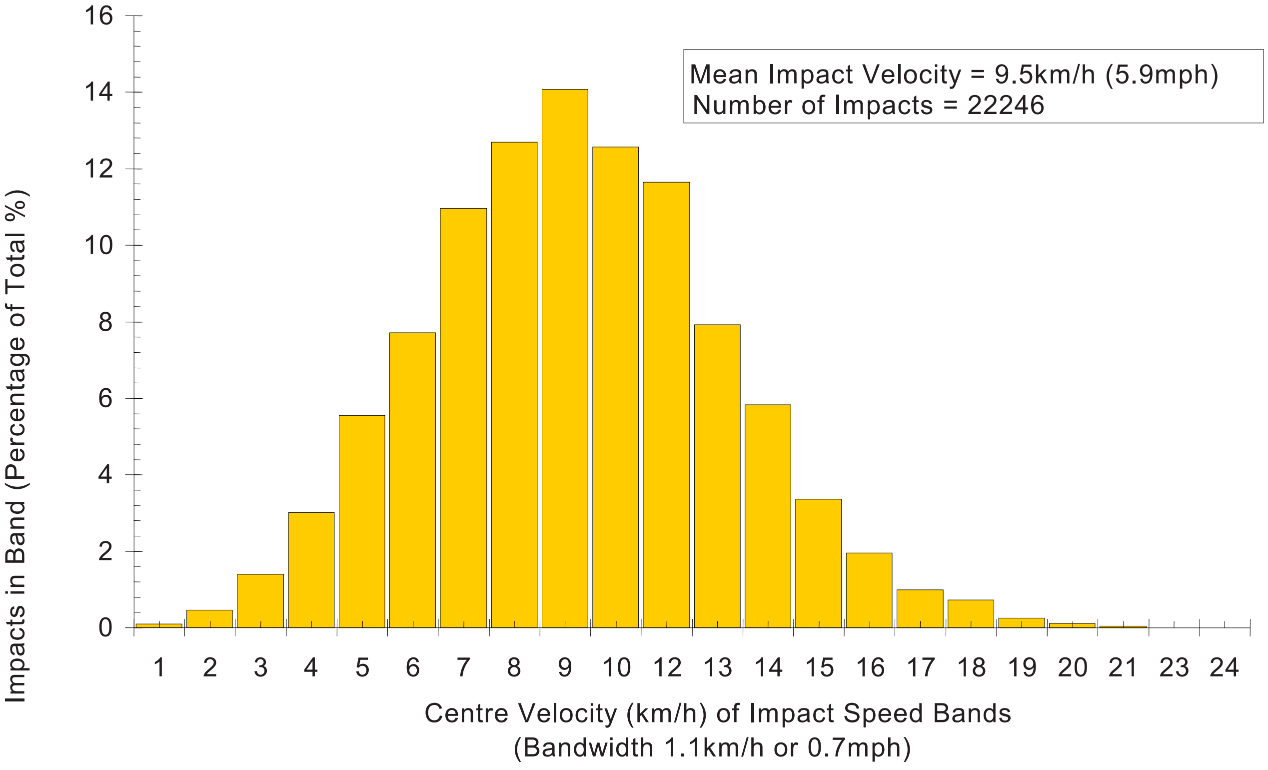

Figure 3 – British Rail measurements distribution of shunting velocities

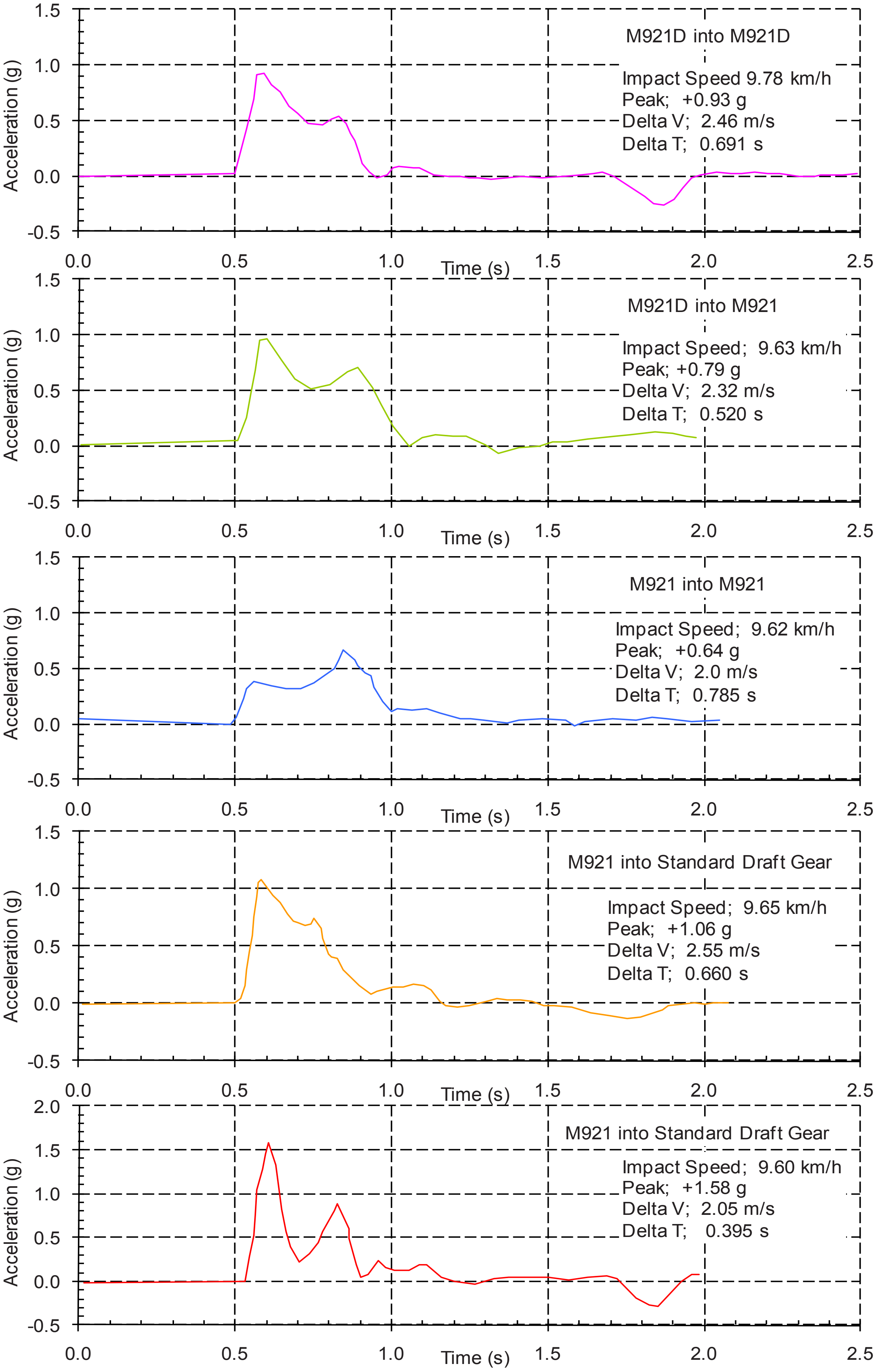

Figure 4 – Association of American Railroads – Lengthways shock measurements – Example shock pulses

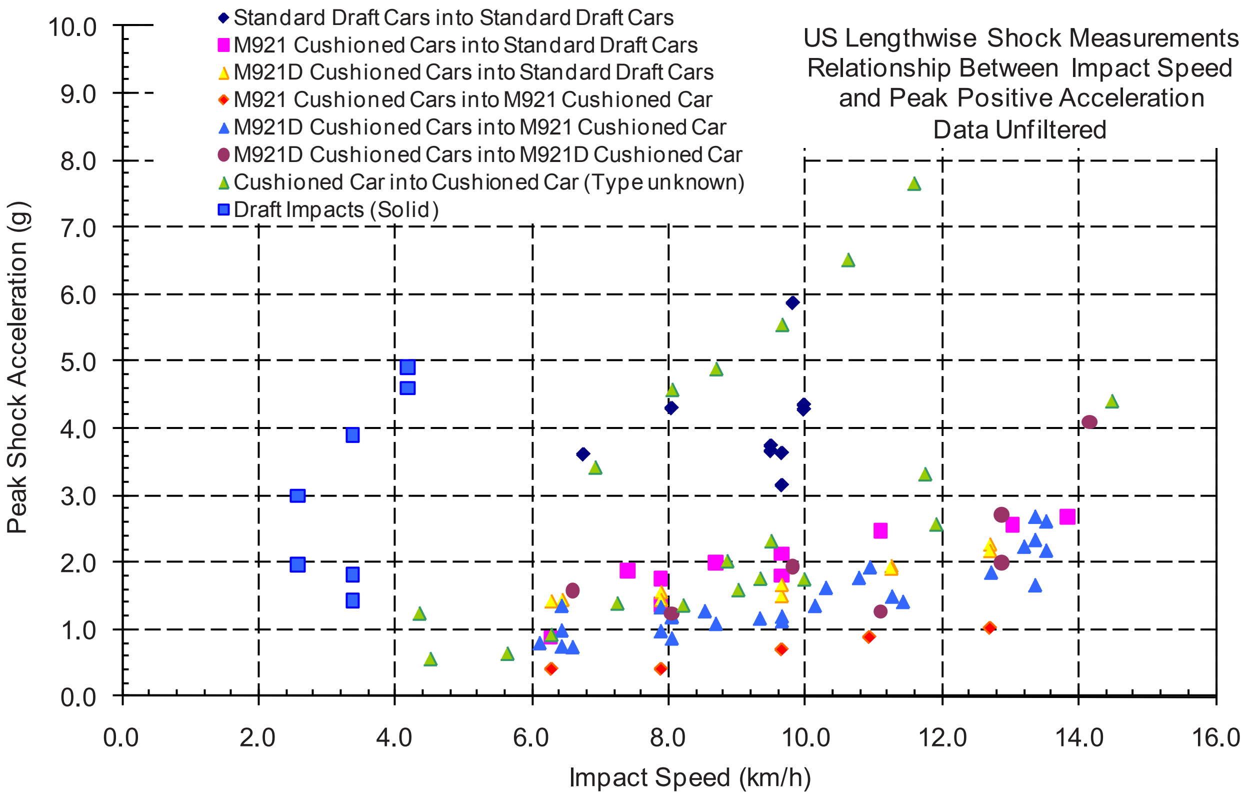

Figure 5 – Association of American Railroads – Lengthways shock measurements – Comparison of positive peak acceleration

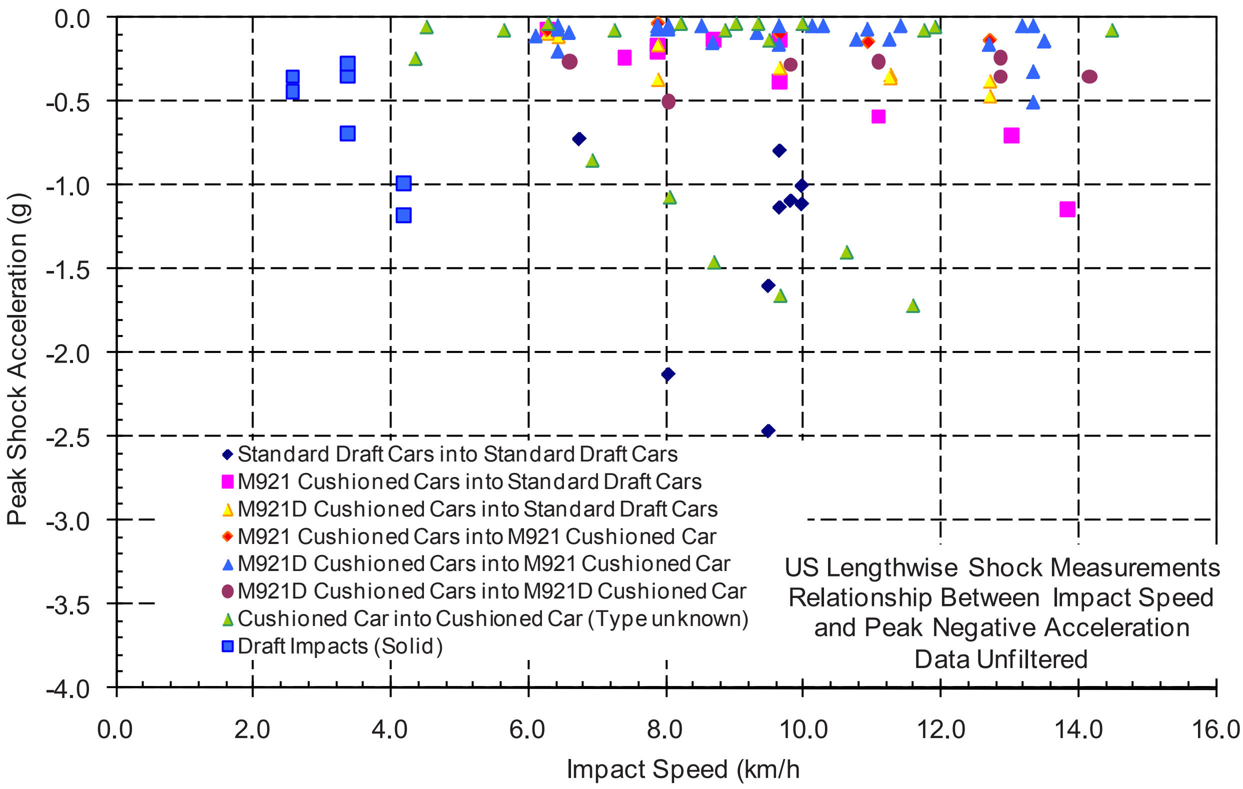

Figure 6 – Association of American Railroads – Lengthways shock measurements – Comparison of negative peak acceleration

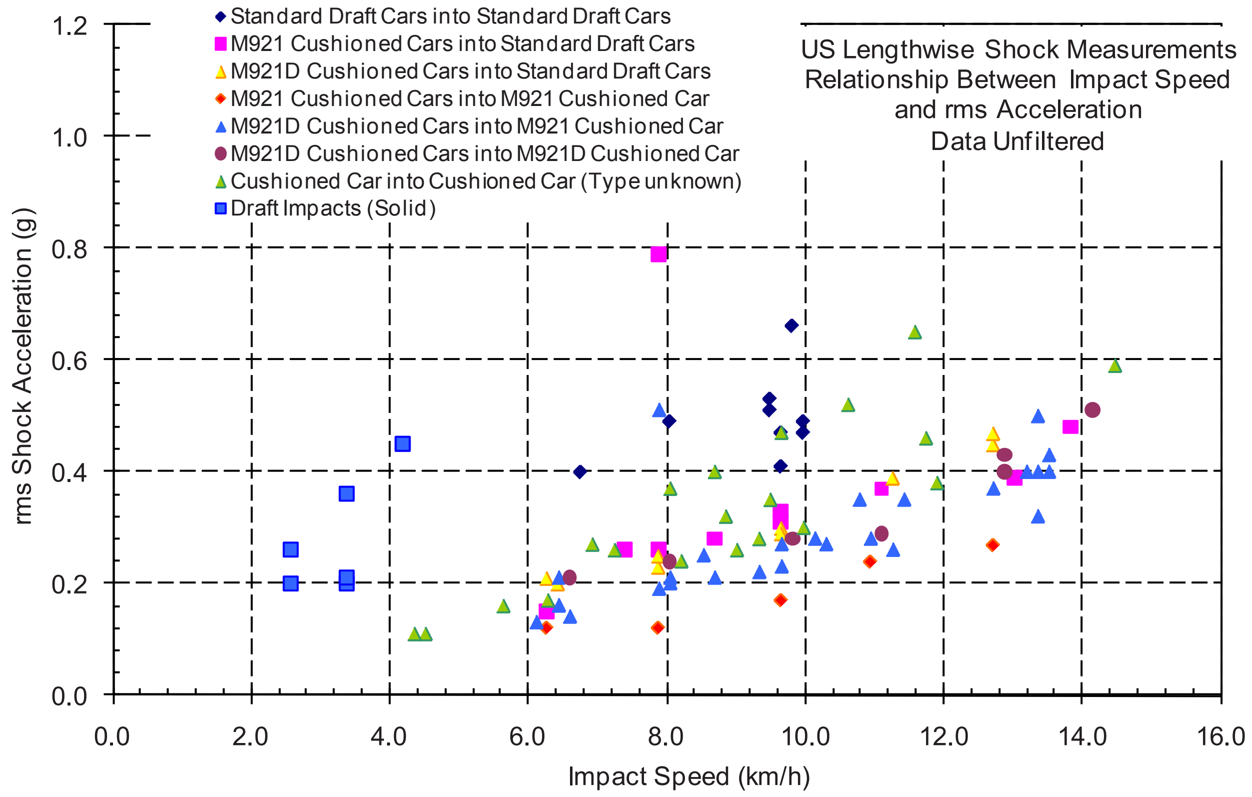

Figure 7 – Association of American Railroads – Lengthways shock measurements – Comparison of RMS acceleration

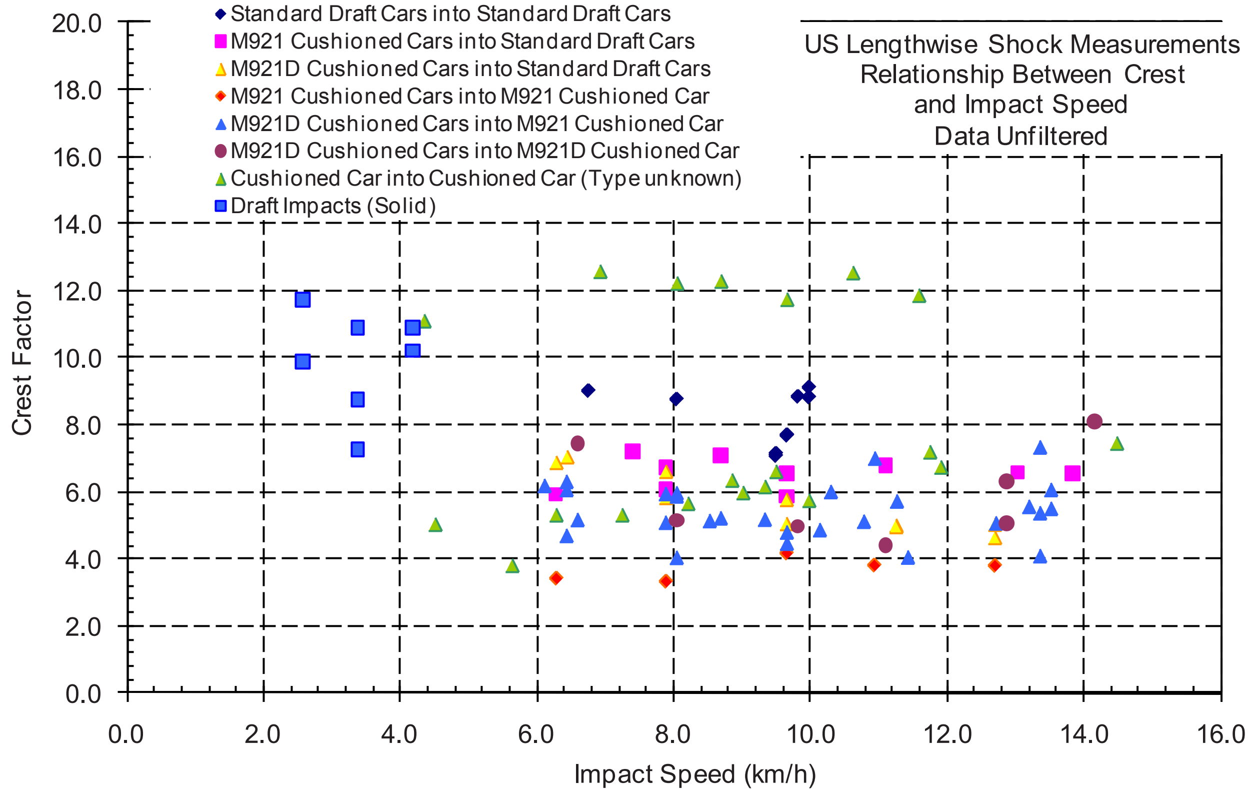

Figure 8 – Association of American Railroads – Lengthways shock measurements – Comparison of crest factor

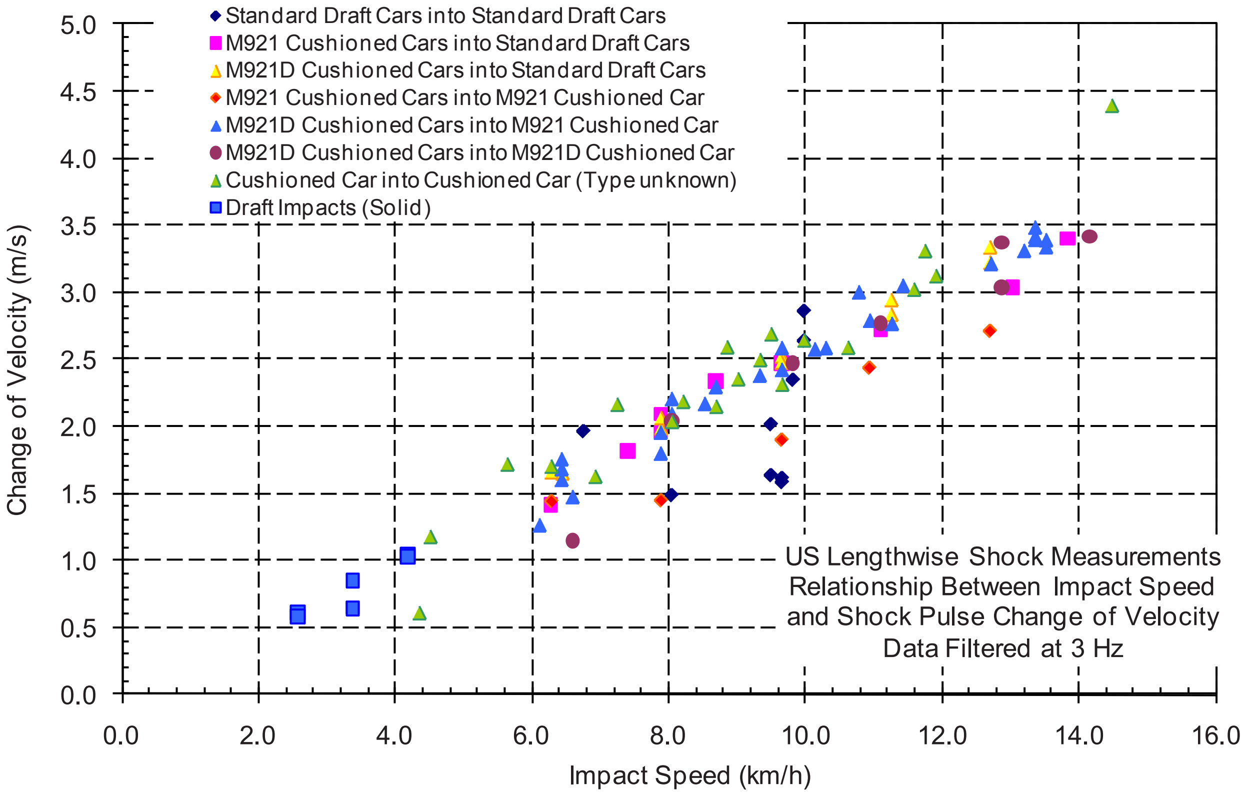

Figure 9 – Association of American Railroads – Lengthways shock measurements – Comparison of change of velocity

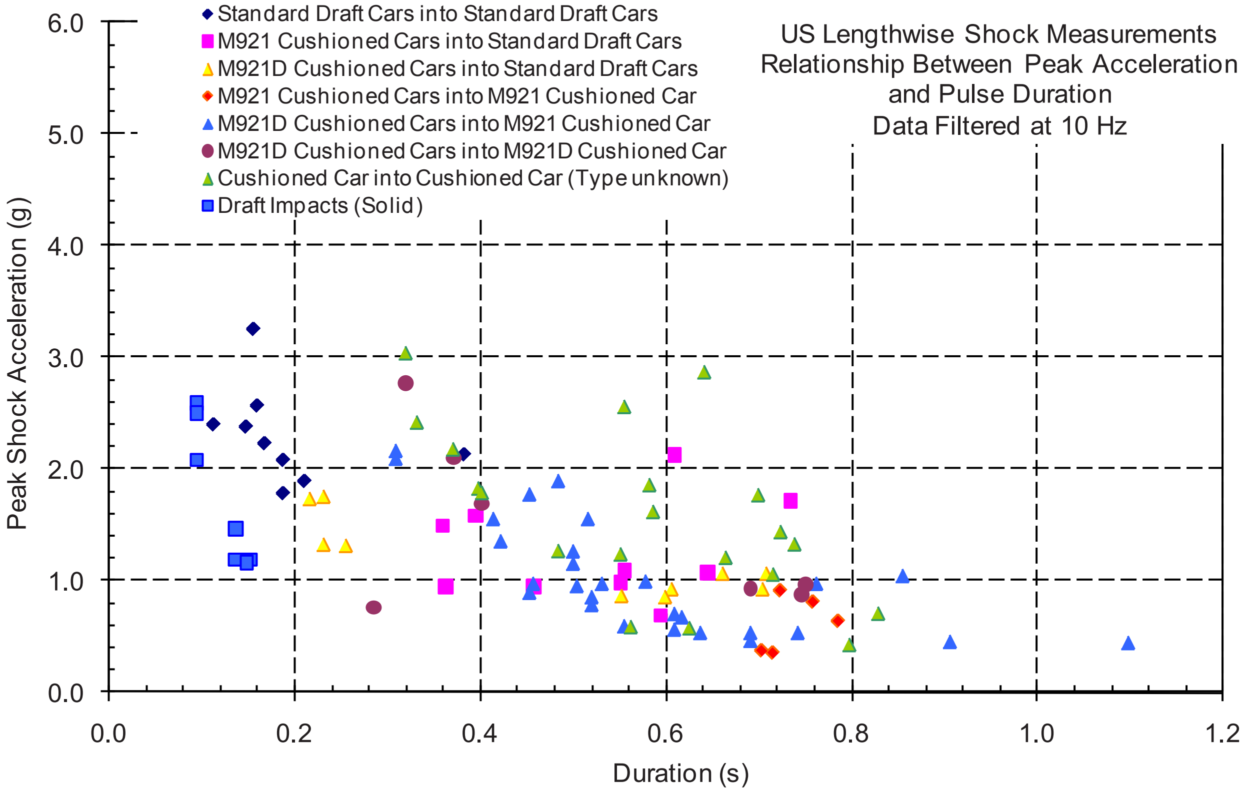

Figure 10 – Association of American Railroads – Lengthways shock measurements – Comparison of filtered peak acceleration

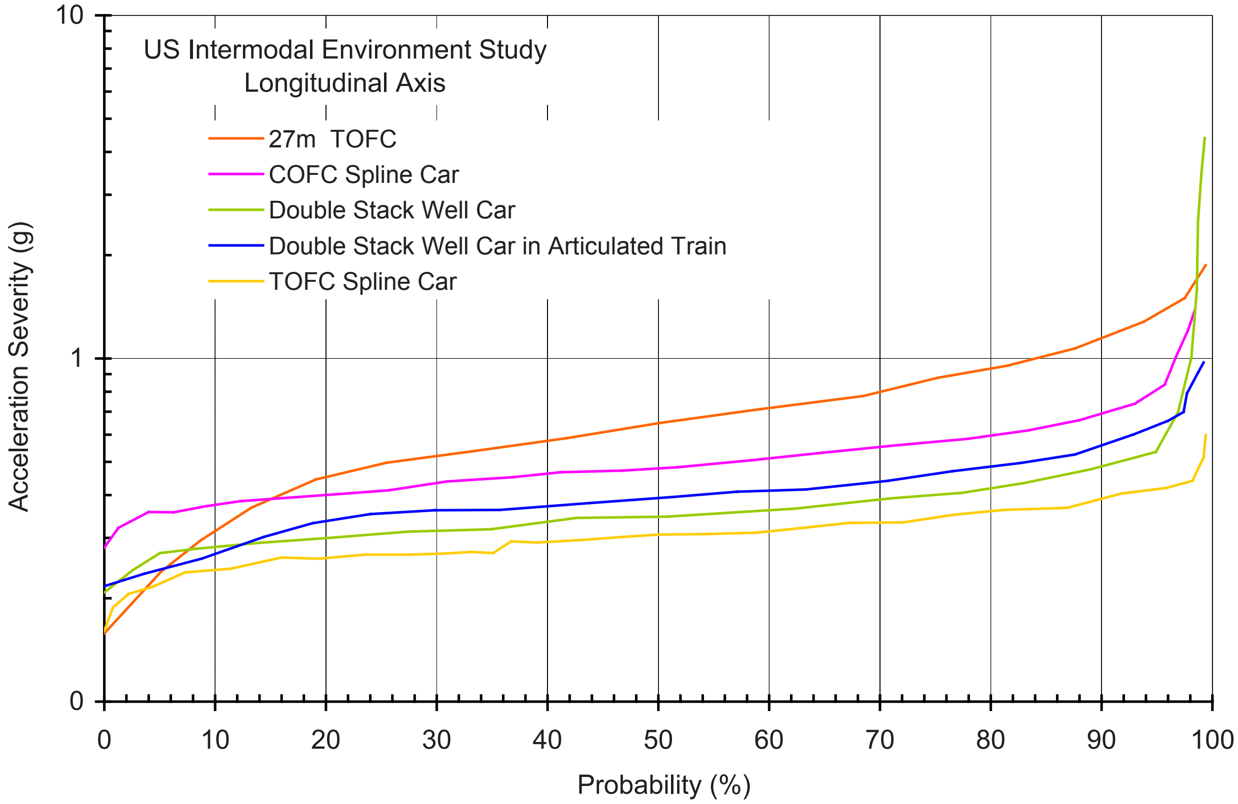

Figure 11 – Association of American Railroads – Intermodal study – Amplitude probability in longitudinal axis

Table 2 – Association of American Railroads intermodal study as it relates to Figure 11

Distribution of longitudinal shocks					
Equipment type		Percentage of shocks			Extreme value measured g
		< 0,3 g	< 0,5 g	< 1,0 g	
Rail	27 m TOFC	9,2	24,5	82,9	1,92
	COFC spine car	0,3	52,0	97,3	6,66
	Double stack well car	14,7	89,9	98,5	4,13
	Double stack well car in articulated train	14,3	82,7	99,9	1,03
	TOFC spine car	44,4	99,4	100	0,64
Truck	Interstate	16,8	64,7	99,2	1,12
	Primary highway	44,4	94,8	100	0,82
	Urban street	56,1	94,8	99,9	1,35

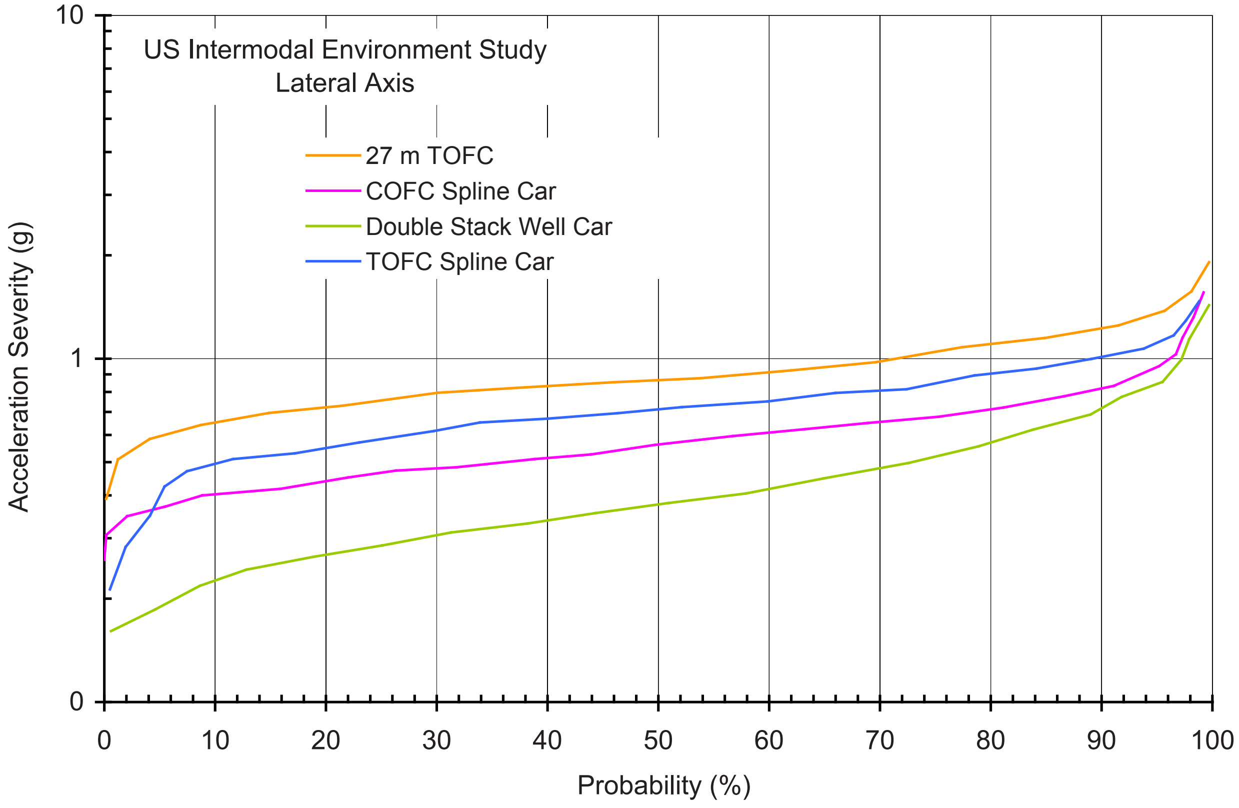

Figure 12 – Association of American Railroads intermodal study – amplitude probability in lateral axis

Table 3 – Association of American Railroads – Intermodal study as it relates to Figure 12

Distribution of lateral shocks					
Equipment type		Percentage of shocks			Extreme value measured g
		< 0,3 g	< 0,5 g	< 1,0 g	
Rail	27 m TOFC	1,4	69,5	97,0	1,76
	COFC spine car	28,6	96,7	99,8	1,69
	Double stack well car	0,5	63,7	97,9	2,20
	TOFC spine car	7,8	86,6	99,8	1,55
Truck	Interstate	4,5	60,0	92,8	3,22
	Primary highway	6,3	78,7	97,3	2,28
	Urban street	17,7	78,7	95,9	2,97

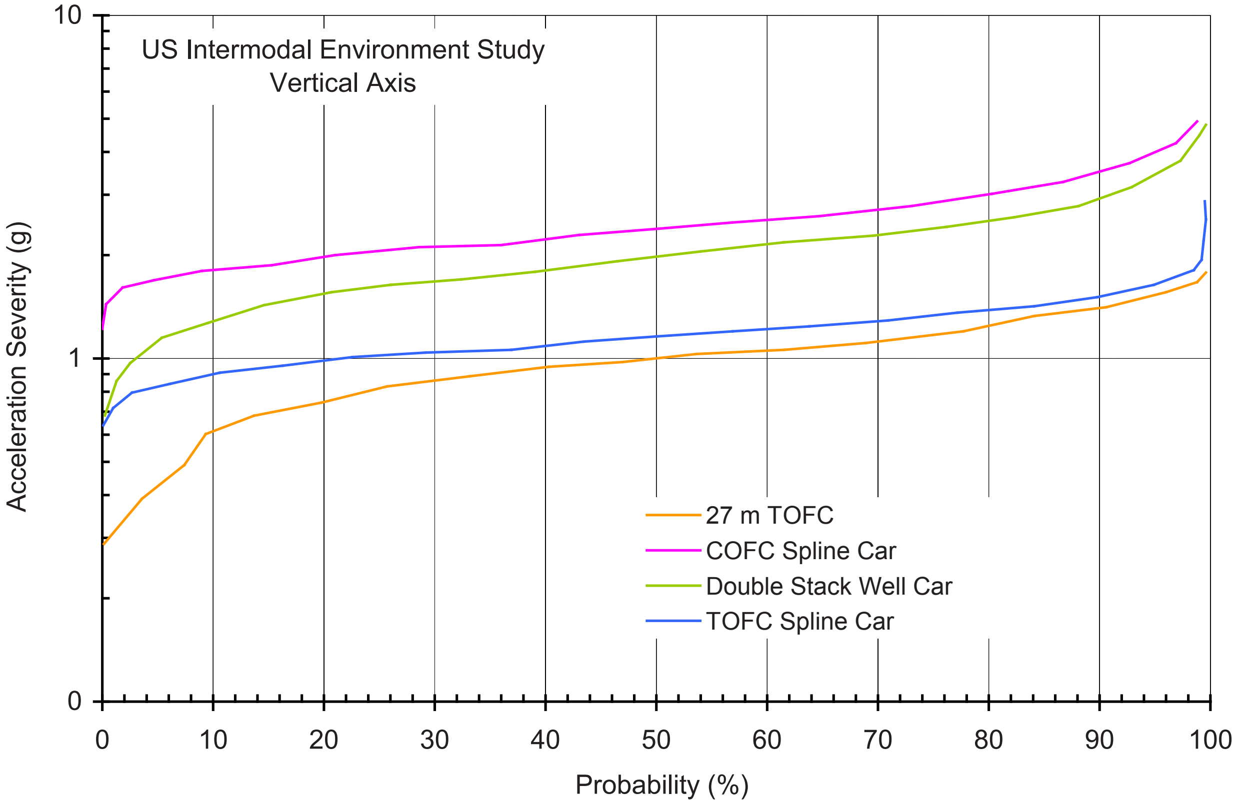

Figure 13 – Association of American Railroads intermodal study – Amplitude probability in vertical axis

Table 4 – Association of American Railroads – Intermodal study as it relates to Figure 13

Distribution of vertical shocks					
Equipment type		**Percentage of shocks**			**Extreme value measured** g
		< 0,3 g	< 0,5 g	< 1,0 g	
Rail	27 m TOFC	95,8	100	100	1,72
	COFC spine car	0,8	82,1	99,2	6,17
	Double stack well car	15,3	90,0	99,3	6,06
	TOFC spine car	90,4	100	100	2,87
Truck	Interstate	8,4	69,8	99,3	5,14
	Primary HIGHWAY	6,5	91,1	94,4	5,58
	Urban StReet	20,2	90,0	98,3	8,32

Table 5 – Association of American Railroads intermodal study – Summary of results from shock measurements

Statistical summary – Shock data files (g pk)										
Equipment type		**Longitudinal**			**Lateral**			**Vertical**		
		Mean	**Standard deviation**	**Mean r.m.s.**	**Mean**	**Standard deviation**	**Mean r.m.s.**	**Mean**	**Standard deviation**	**Mean r.m.s.**
Rail	27 m TOFC	0,31	0,2	0,09	0,2	0,15	0,08	0,41	0,15	0,18
	COFC spine car	0,29	0,23	0,08	0,32	0,1	0,09	1,3	0,34	0,38
	Double stack well car	0,22	0,17	0,06	0,46	0,12	0,15	1,05	0,36	0,3
	TOFC spine car	0,16	0,04	0,06	0,38	0,12	0,17	0,6	0,13	0,21
Truck	Interstate	0,27	0,07	0,08	0,51	0,19	0,15	1,14	0,32	0,34
	Primary highway	0,16	0,05	0,04	0,42	0,17	0,11	1,11	0,34	0,3
	Urban street	0,14	0,06	0,04	0,42	0,18	0,11	1,03	0,44	0,26

Table 6 – Association of American Railroads intermodal study– Summary of results from vibration measurements

Statistical summary – Vibration data files (g pk)										
Equipment type		**Longitudinal**			**Lateral**			**Vertical**		
		Mean	**Standard deviation**	**Mean r.m.s.**	**Mean**	**Standard deviation**	**Mean r.m.s.**	**Mean**	**Standard deviation**	**Mean r.m.s.**
Rail	COFC spine car	0,11	0,12	0,03	0,19	0,11	0,06	0,47	0,30	0,14
	Double stack well car	0,09	0,14	0,04	0,25	0,17	0,09	0,40	0,27	0,12
	TOFC spine car	0,08	0,05	0,03	0,12	0,09	0,04	0,28	0,17	0,10
Truck	Interstate	0,11	0,06	0,03	0,31	0,16	0,09	0,67	0,40	0,20
	Primary highway	0,09	0,05	0,03	0,30	0,18	0,09	0,54	0,54	0,16
	Urban street	0,07	0,05	0,02	0,16	0,13	0,04	0,38	0,38	0,12

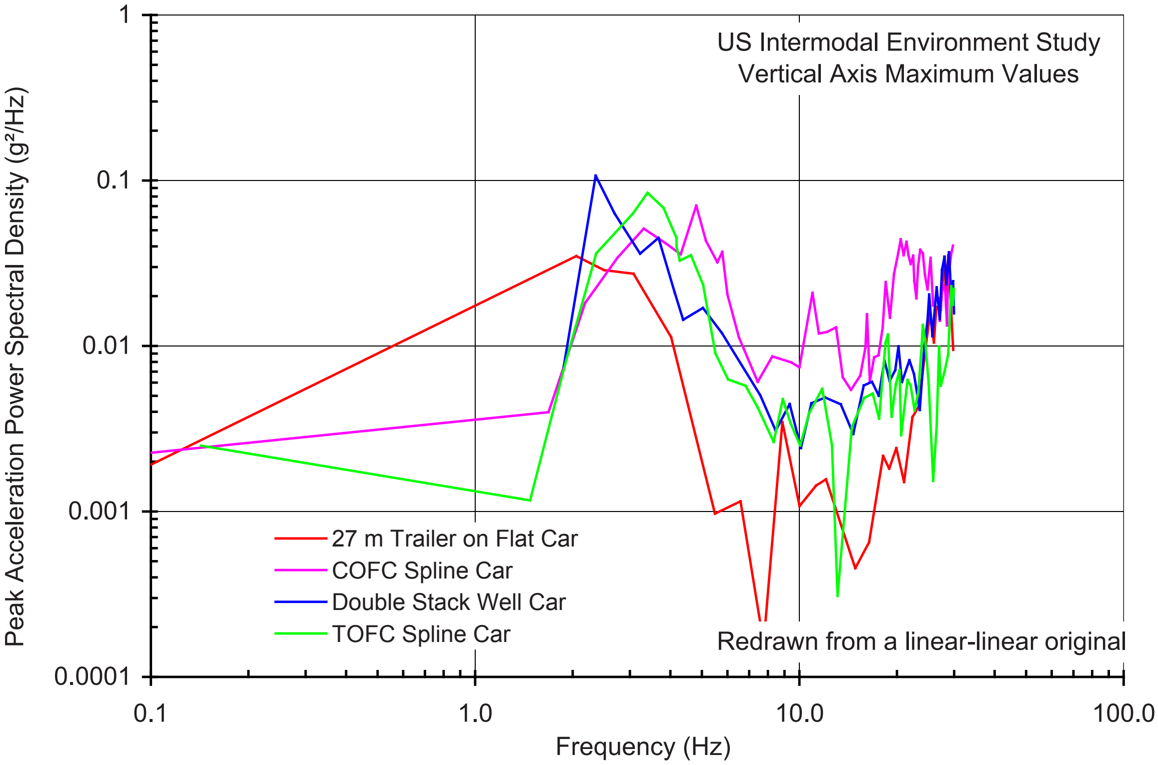

Figure 14 – Association of American Railroads – Intermodal study – Vertical axis spectral values

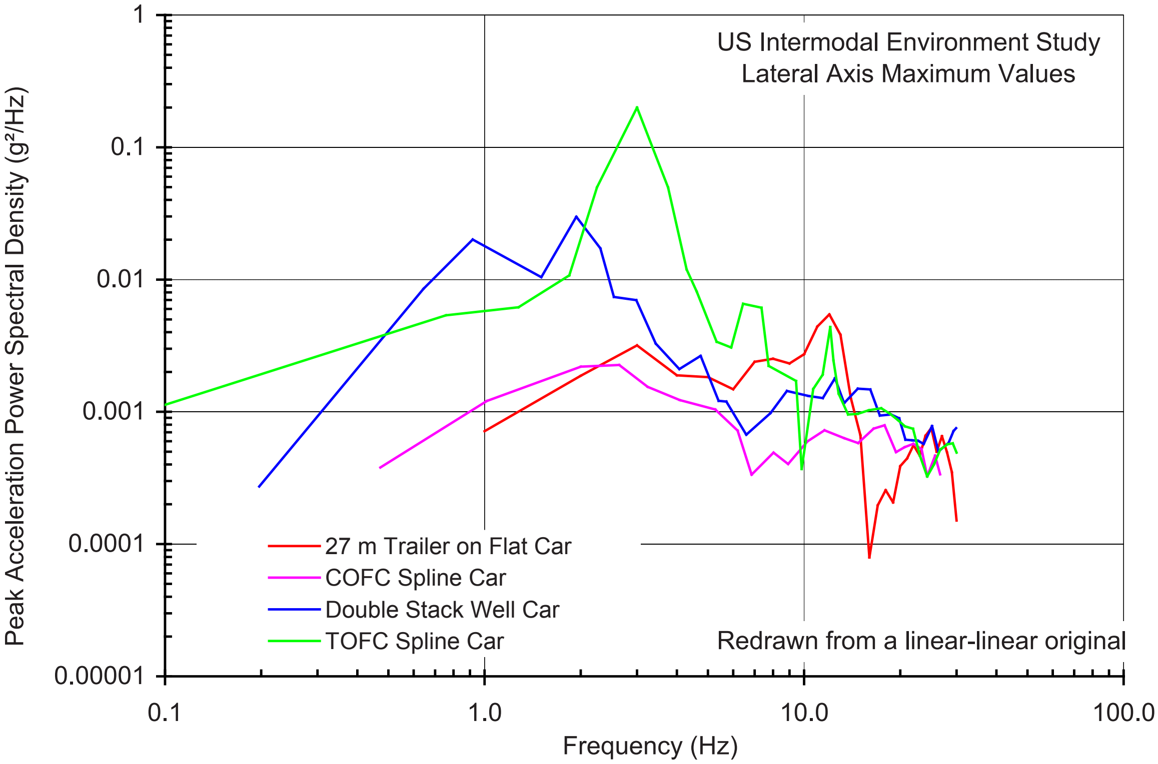

Figure 15 – Association of American Railroads – Intermodal study – Lateral axis spectral values

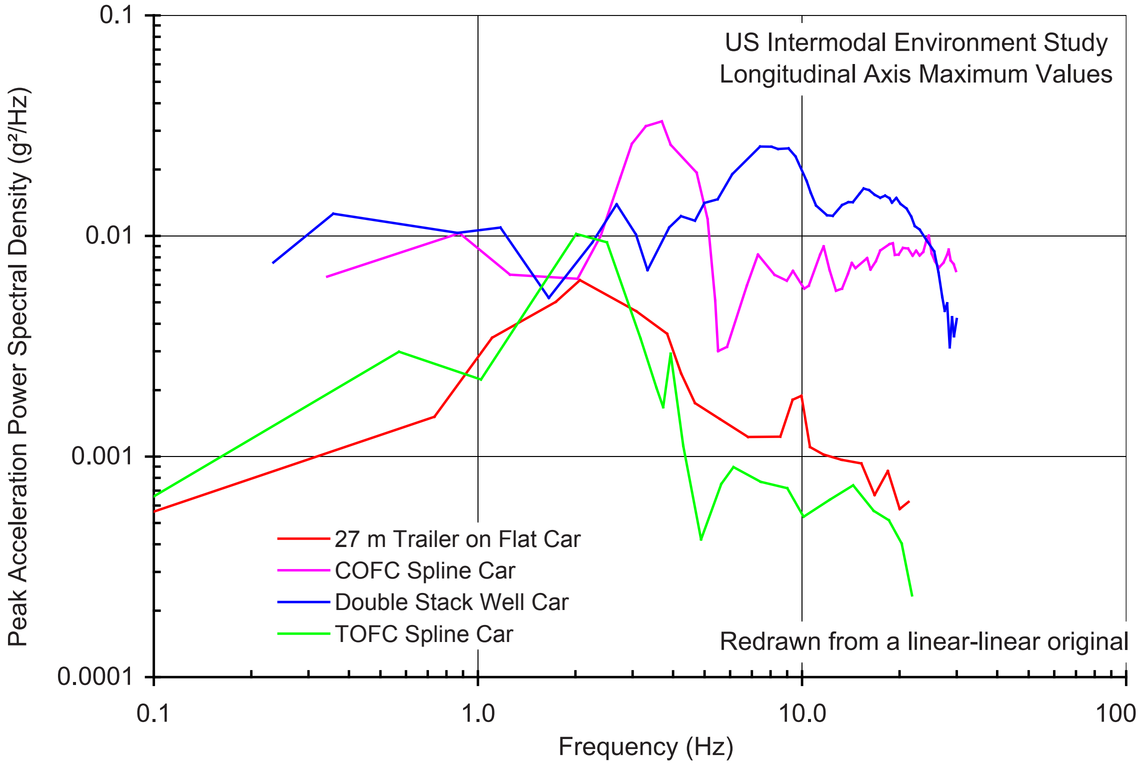

Figure 16 – Association of American Railroads – Intermodal study – Longitudinal axis spectral values

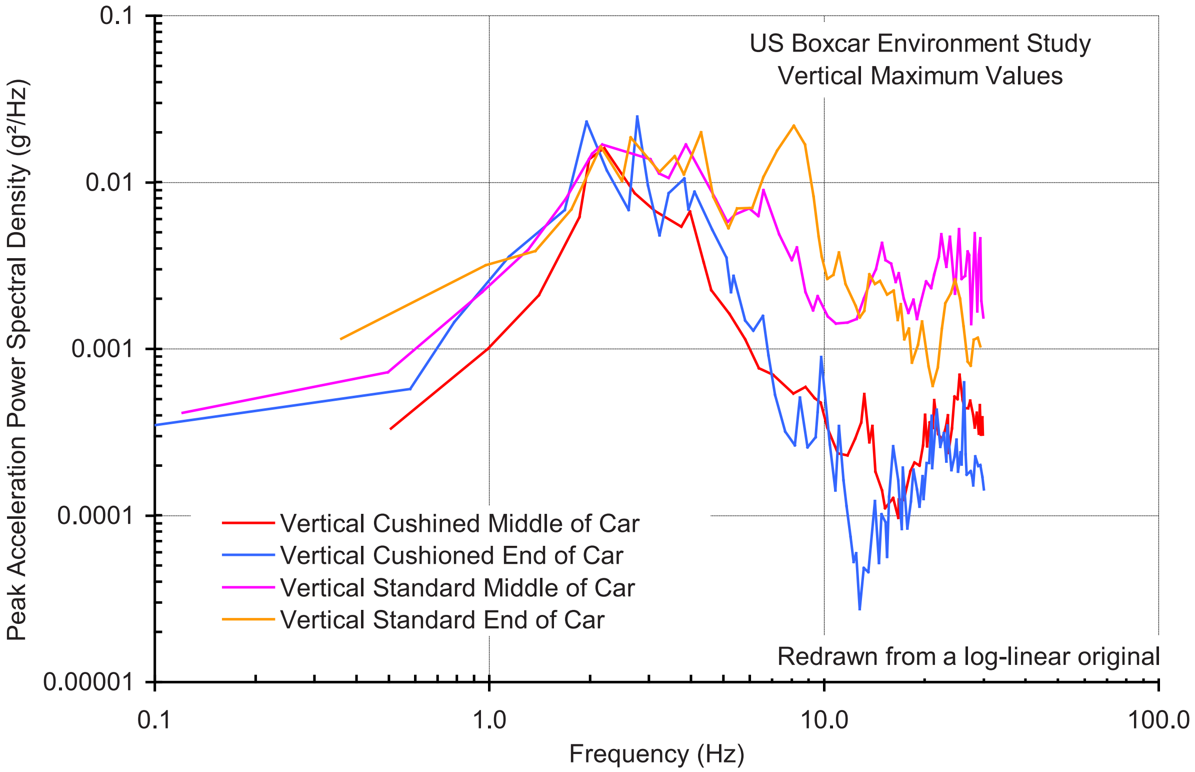

Figure 17 – Association of American Railroads – Boxcar measurements – Vertical axis spectral values

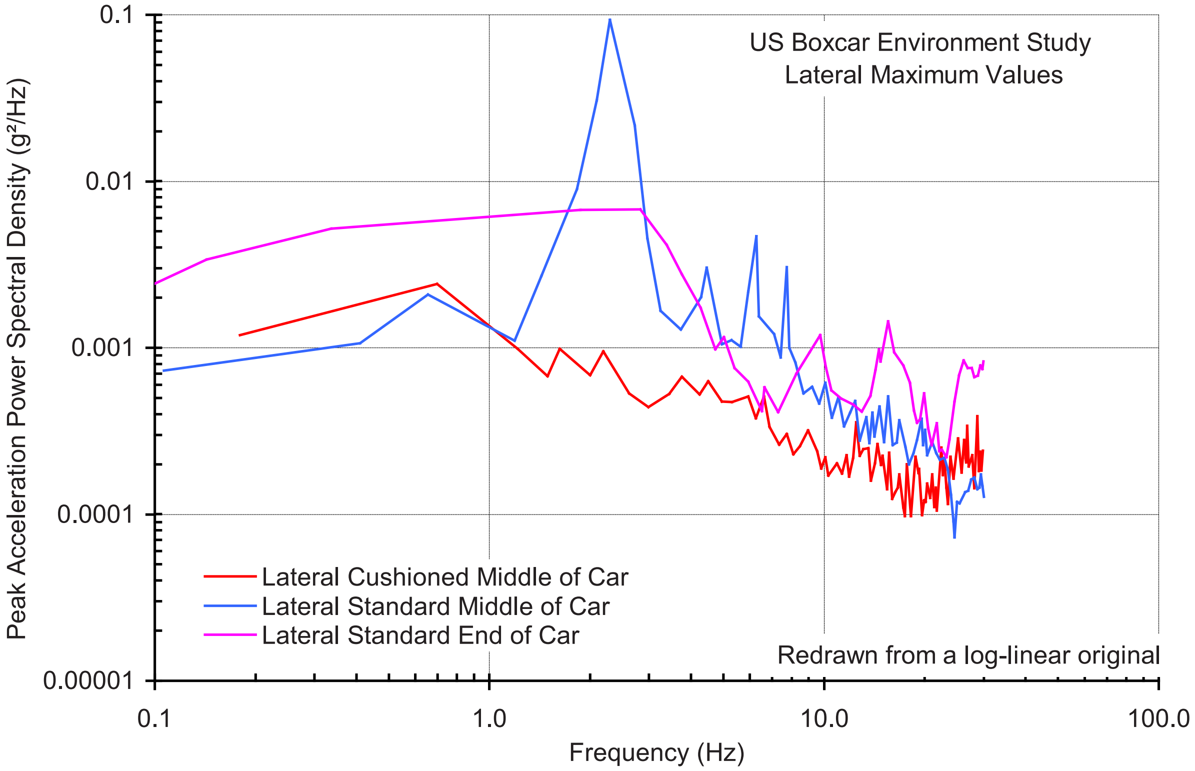

Figure 18 – Association of American Railroads – Boxcar measurements – Lateral axis spectral values

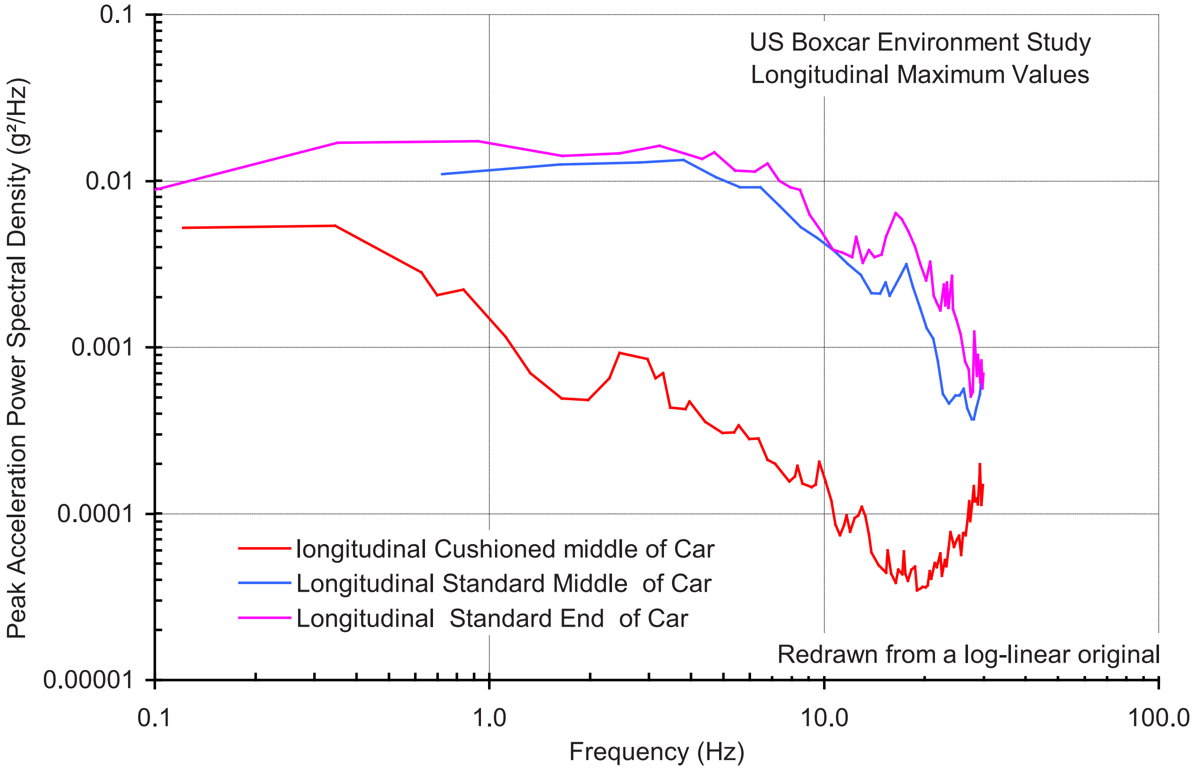

Figure 19 – Association of American Railroads – Boxcar measurements – Longitudinal axis spectral values

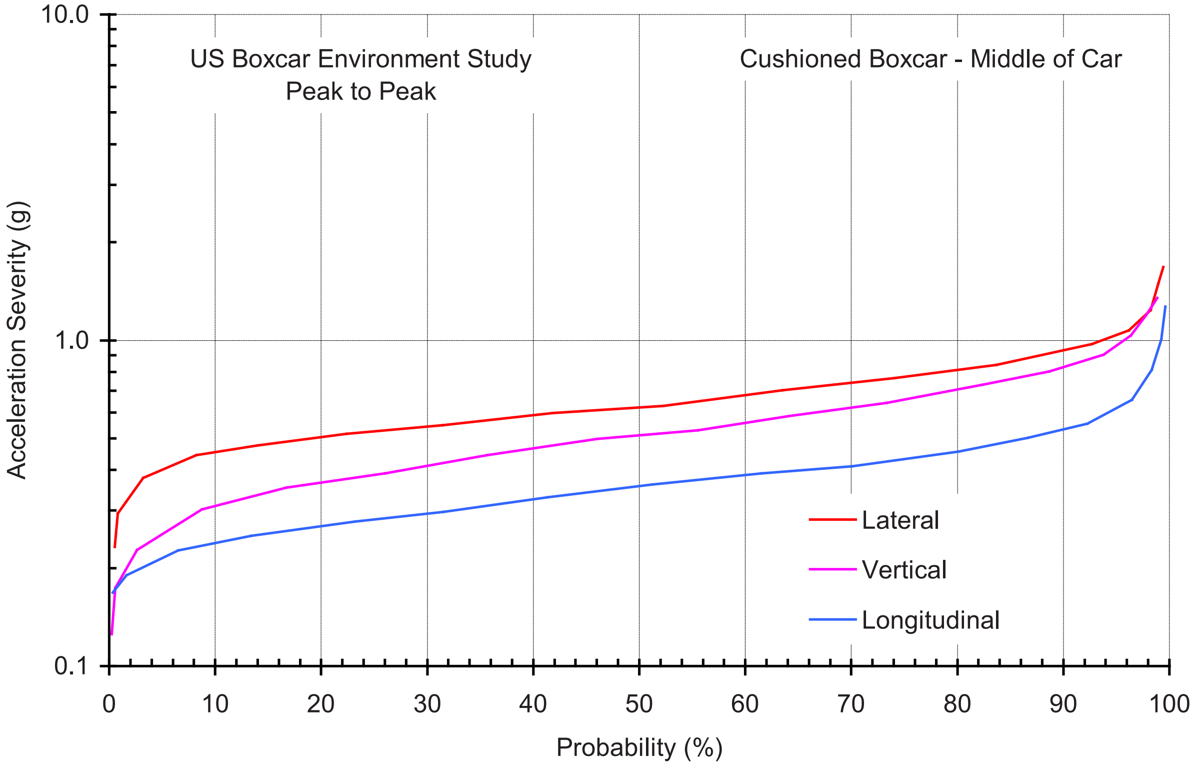

Figure 20 – Association of American Railroads – Cushioned boxcar measurements – Middle of car

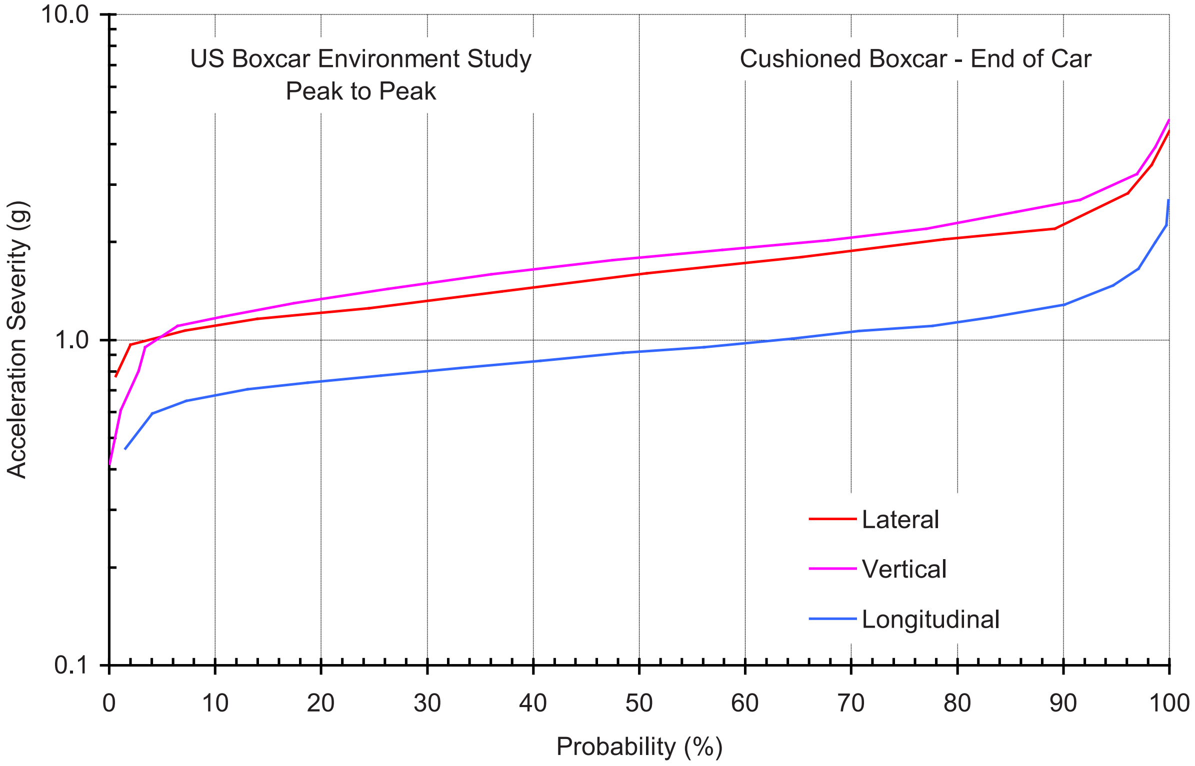

Figure 21 – Association of American Railroads – Cushioned boxcar measurements – End of car

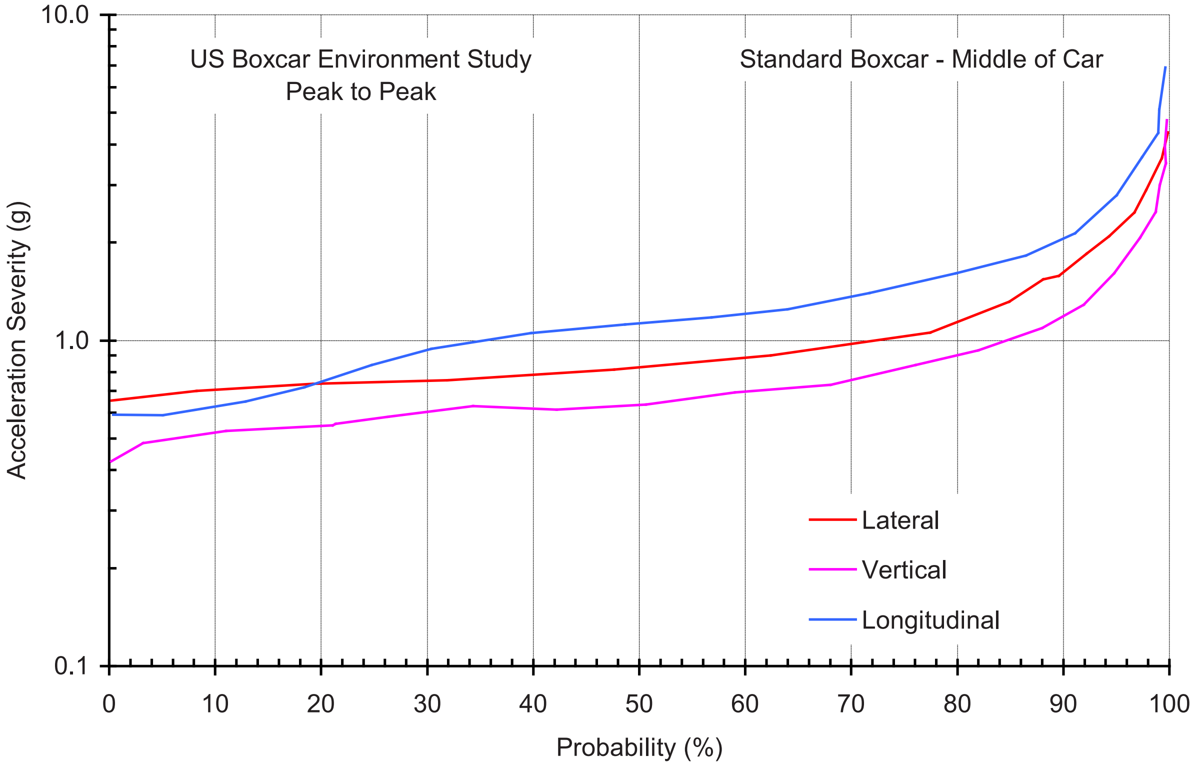

Figure 22 – Association of American Railroads – Standard boxcar measurements – Middle of car

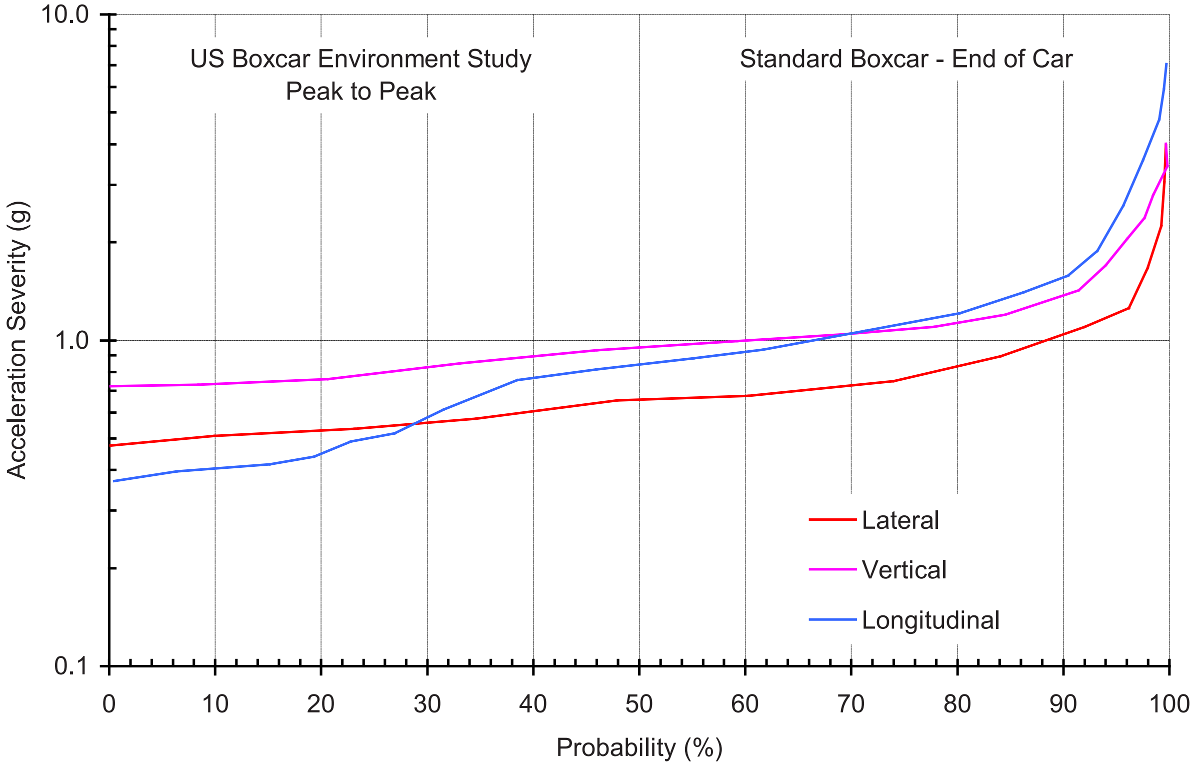

Figure 23 – Association of American Railroads – Standard boxcar measurements – End of car

Table 7 – Association of American Railroads – Boxcar measurements – Distribution of shocks

Distribution of shocks					
Type of car and axis		Percentage of shocks			Extreme value measured g
		< 0,3 g	< 0,5 g	< 1,0 g	
Vertical	Cushioned boxcar – Middle of car	10,0	50,0	96,0	1,6
	Cushioned boxcar – End of car	0,5	4,8	66,0	4,7
	Standard boxcar - Middle of car	11,2	85,0	98,2	5,0
	Standard boxcar – End of car	0,0	64,8	97,6	4,2
Lateral	Cushioned boxcar – Middle of car	2,0	22,0	94,0	1,5
	Cushioned boxcar – End of car	0,0	3,0	79,3	4,5
	Standard boxcar – Middle of car	0,0	72,0	97,1	4,1
	Standard boxcar – End of car	3,6	88,0	98,1	3,9
Longitudinal	Cushioned boxcar – Middle of car	35,0	90,0	99,0	1,3
	Cushioned boxcar – End of car	3,1	58,3	98,9	2,6
	Standard boxcar – Middle of car	0,0	37,8	93,4	7,0
	Standard boxcar – End of car	23,1	67,3	98,1	7,0

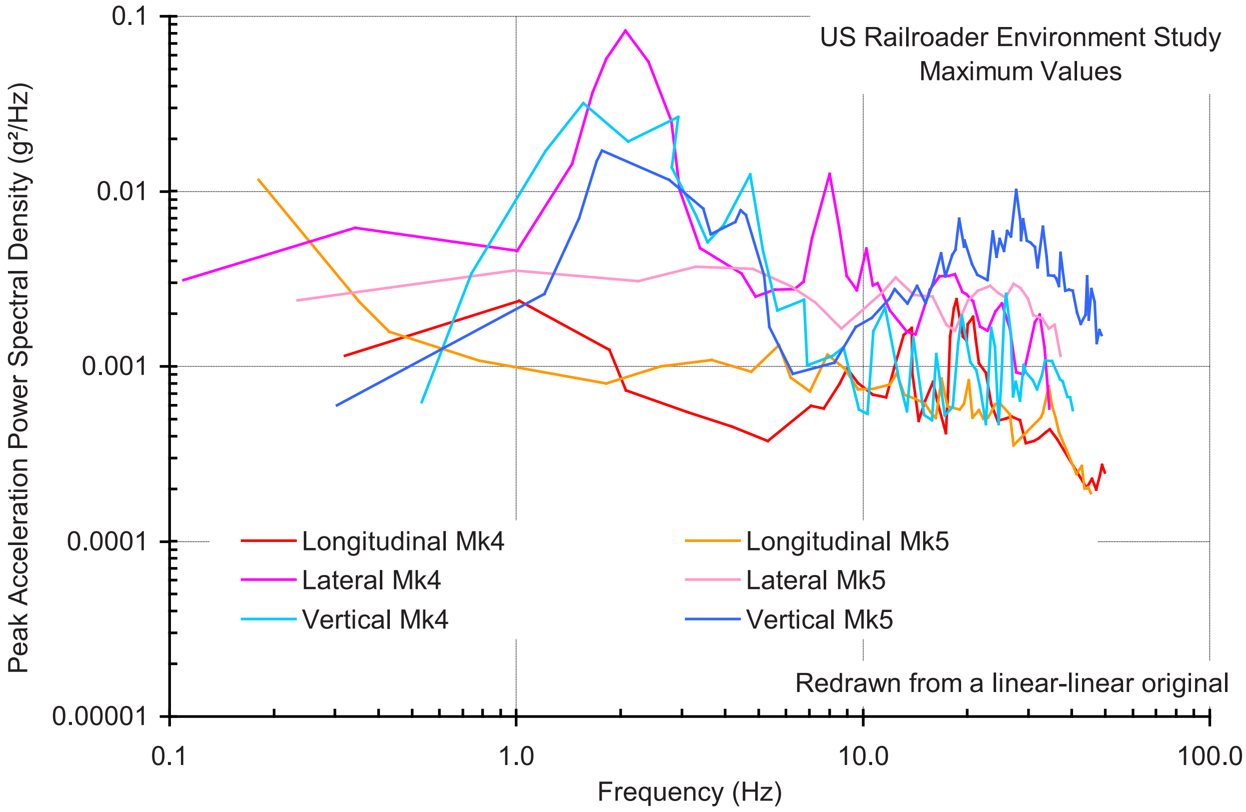

Figure 24 – Association of American Railroads – Railroader measurements – Peak spectral value

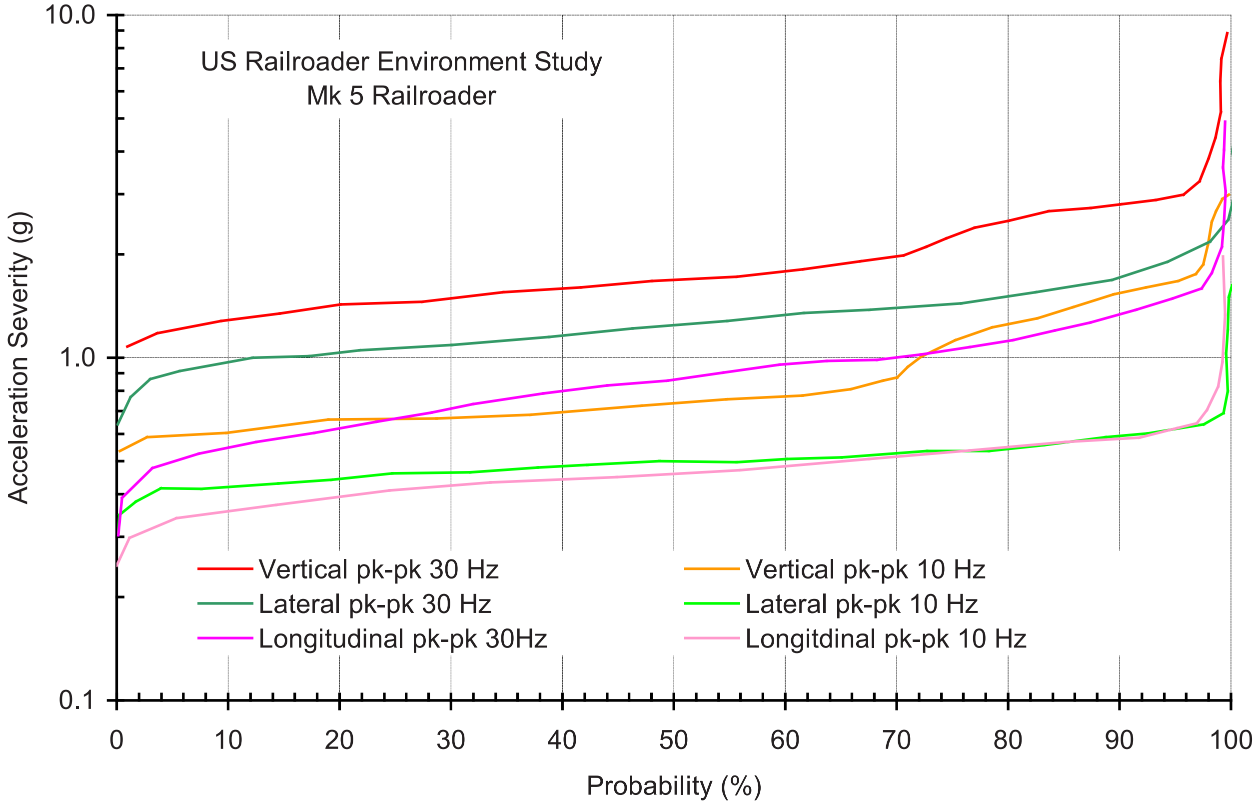

Figure 25 – Association of American Railroads – Railroader measurements – Amplitude probabilities

Table 8 – Association of American Railroads – Railroader measurements as they relate to Figure 25

Average extreme amplitude (g) /Levels at 10 Hz and 30 Hz			
0 – 10 Hz	Longitudinal	Lateral	Vertical
Mark IV	1,32	1,58	4,2
Mark V	1,9	1,59	3,0
0 – 30 Hz	Longitudinal	Lateral	Vertical
Mark IV	3,08	3,28	4,3
Mark V	4,91	4,64	8,78

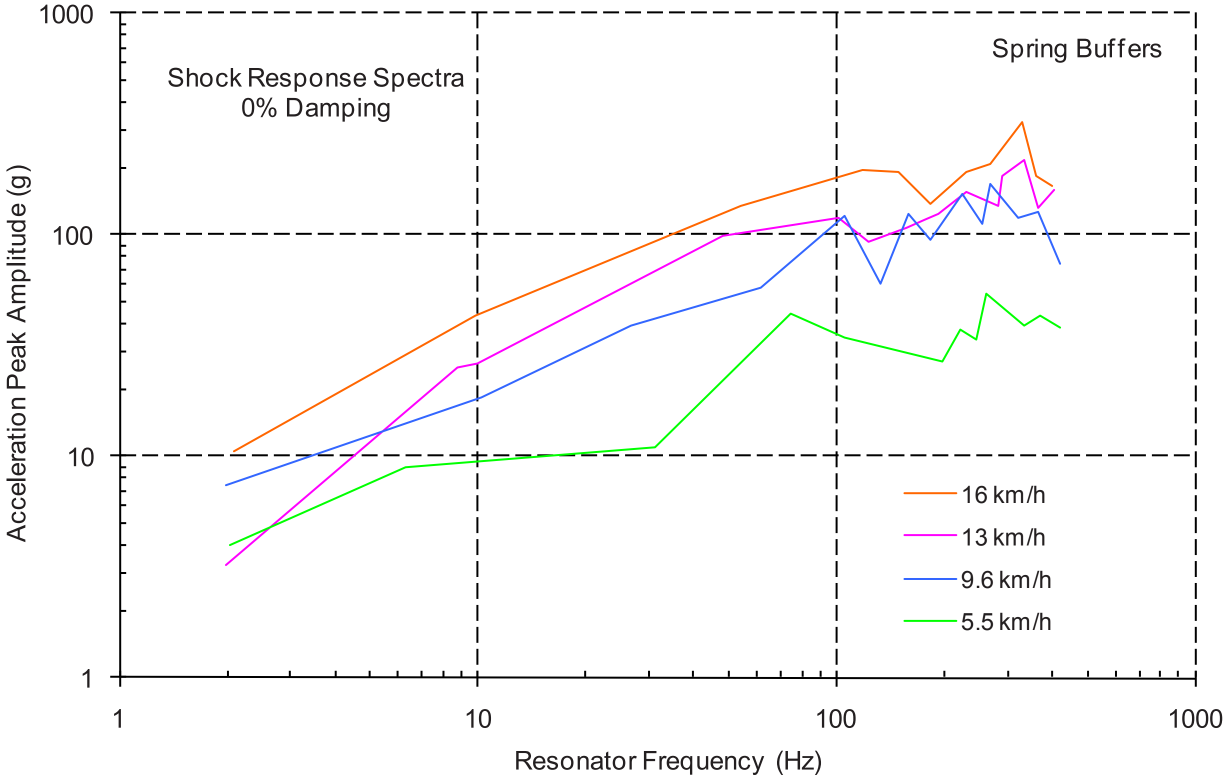

Figure 26 – Johnson – Reported measurements – Spring buffers

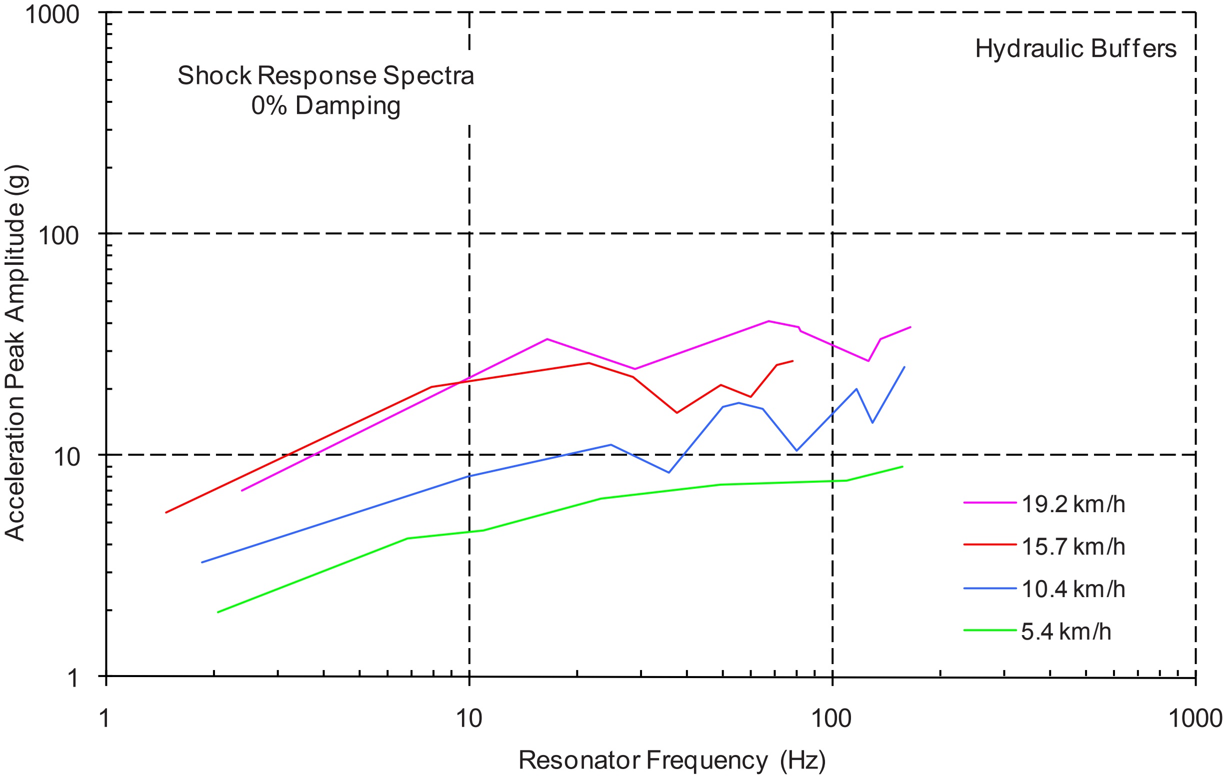

Figure 27 – Johnson – Reported measurements hydraulic buffers

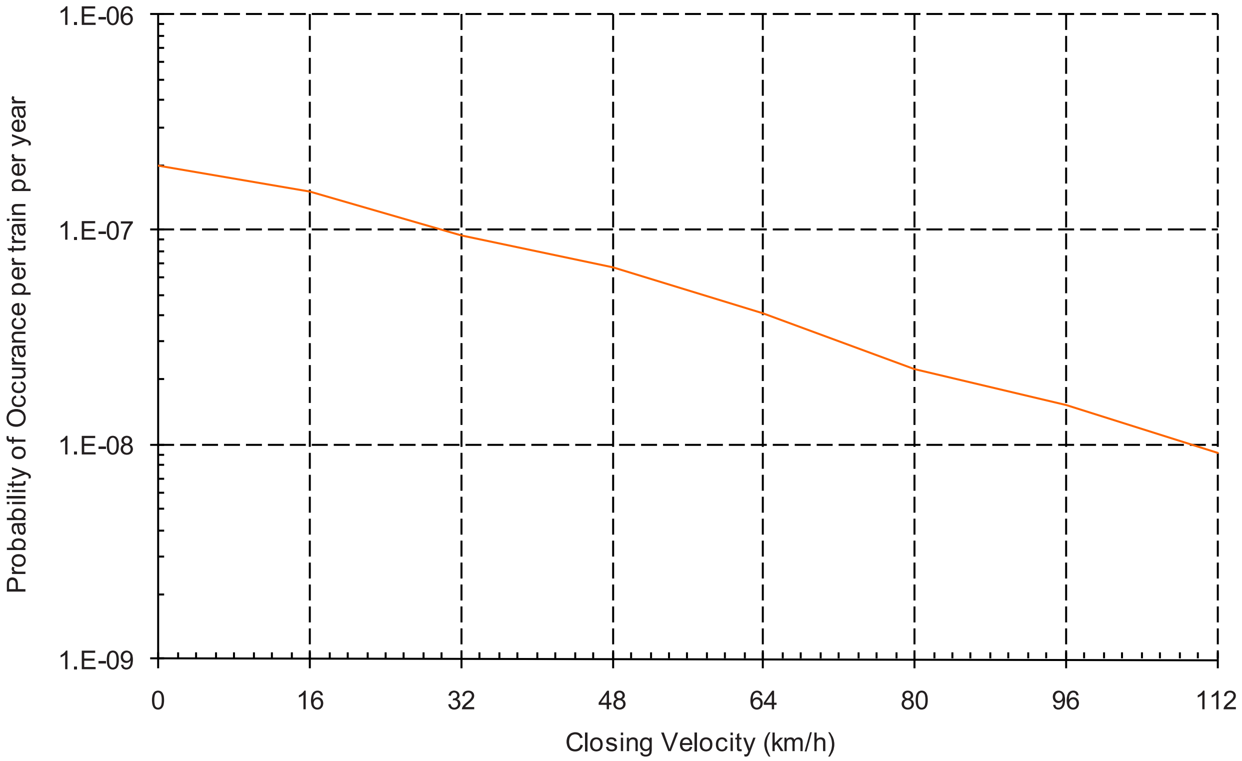

Figure 28 – Johnson – Reported measurements – Probability of occurrence

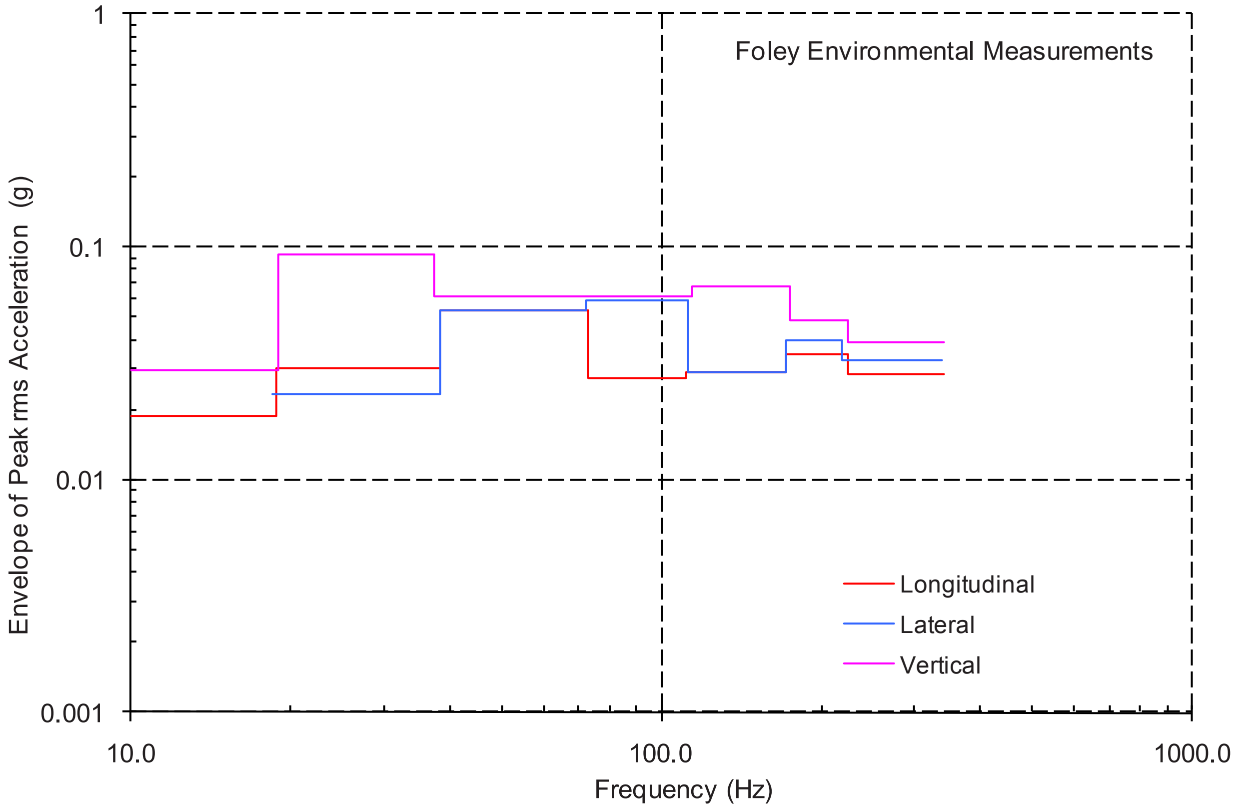

Figure 29 – Foley – Reported measurements – Frequency distribution

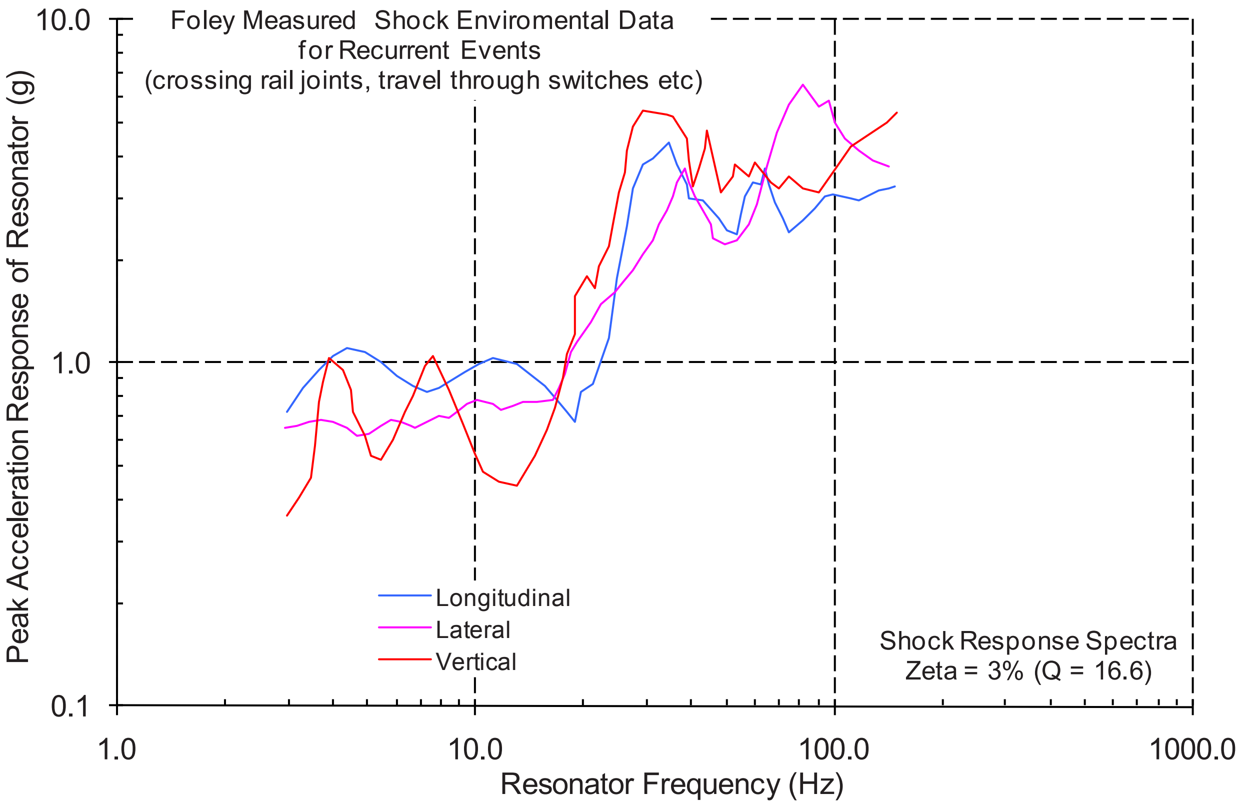

Figure 30 – Foley – Reported measurements – Recurrent events

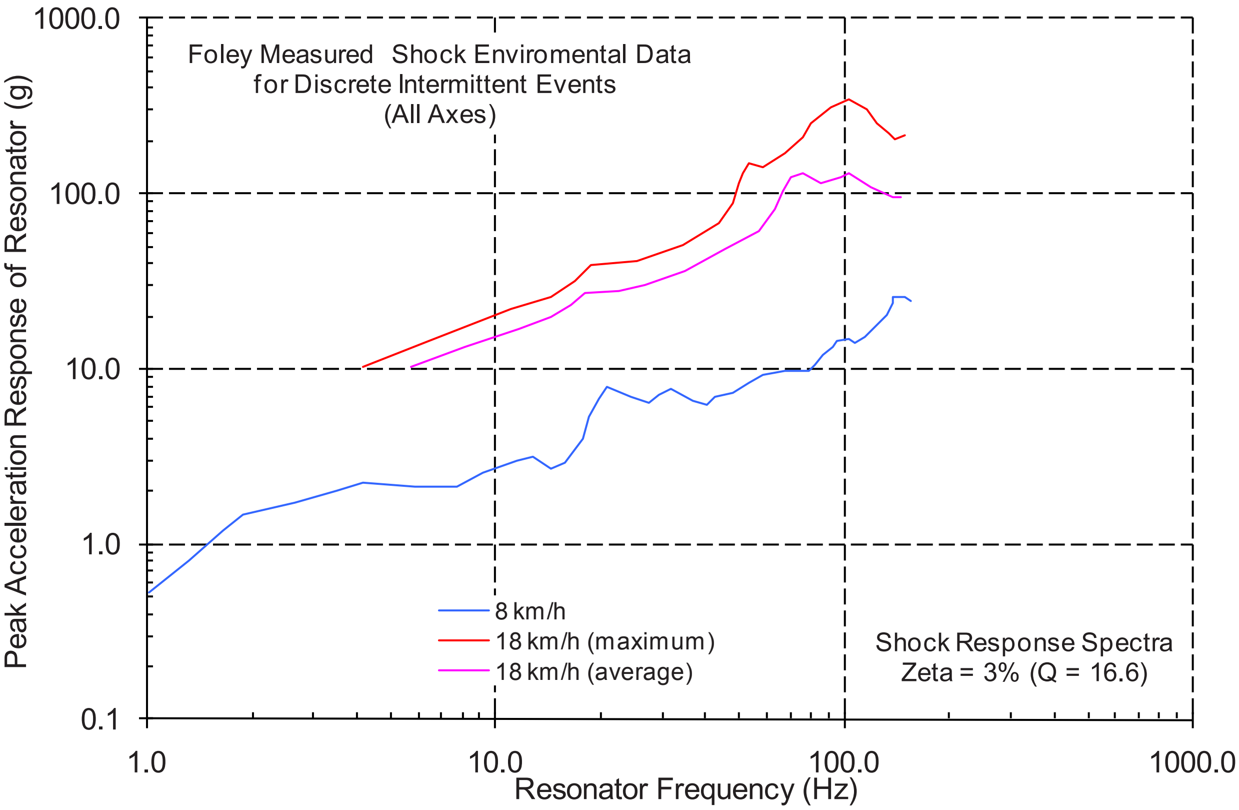

Figure 31 – Foley – Reported measurements – Intermittent events

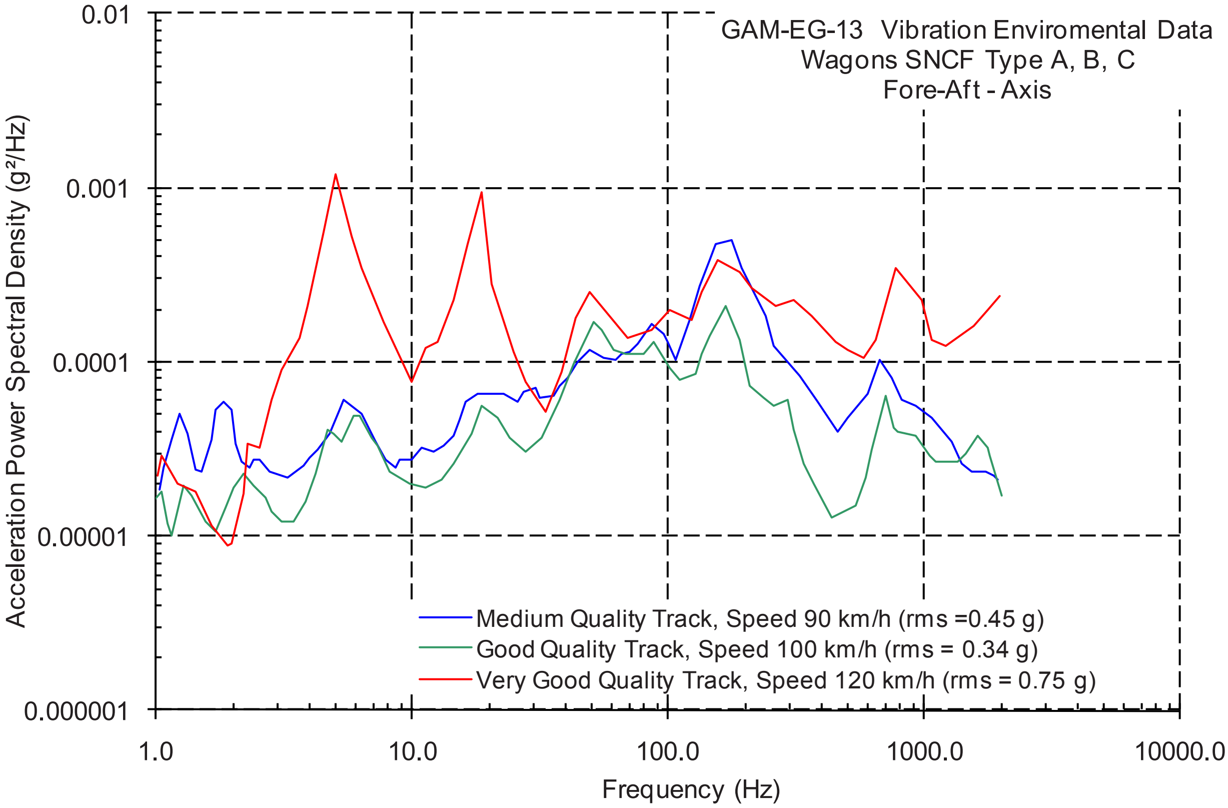

Figure 32 – GAM-EG-13 – Reported measurements – Longitudinal axis

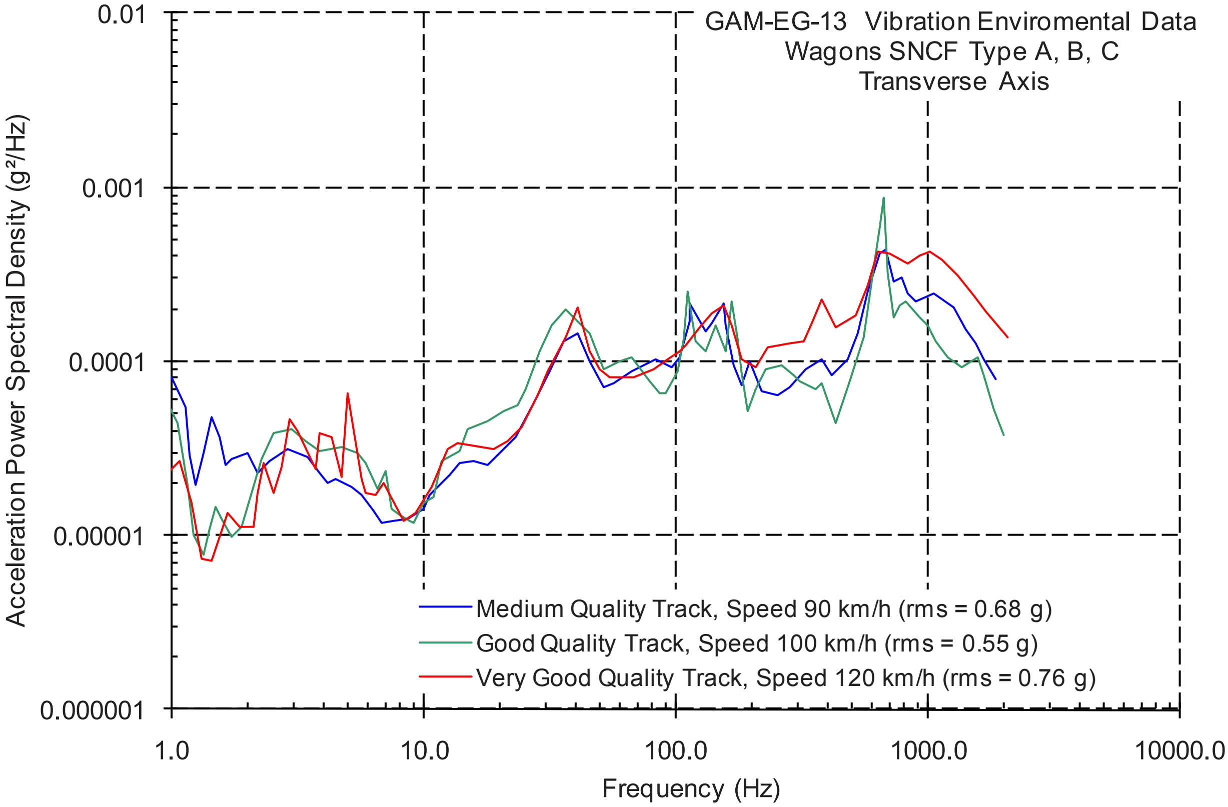

Figure 33 – GAM-EG-13 – Reported measurements – Lateral axis

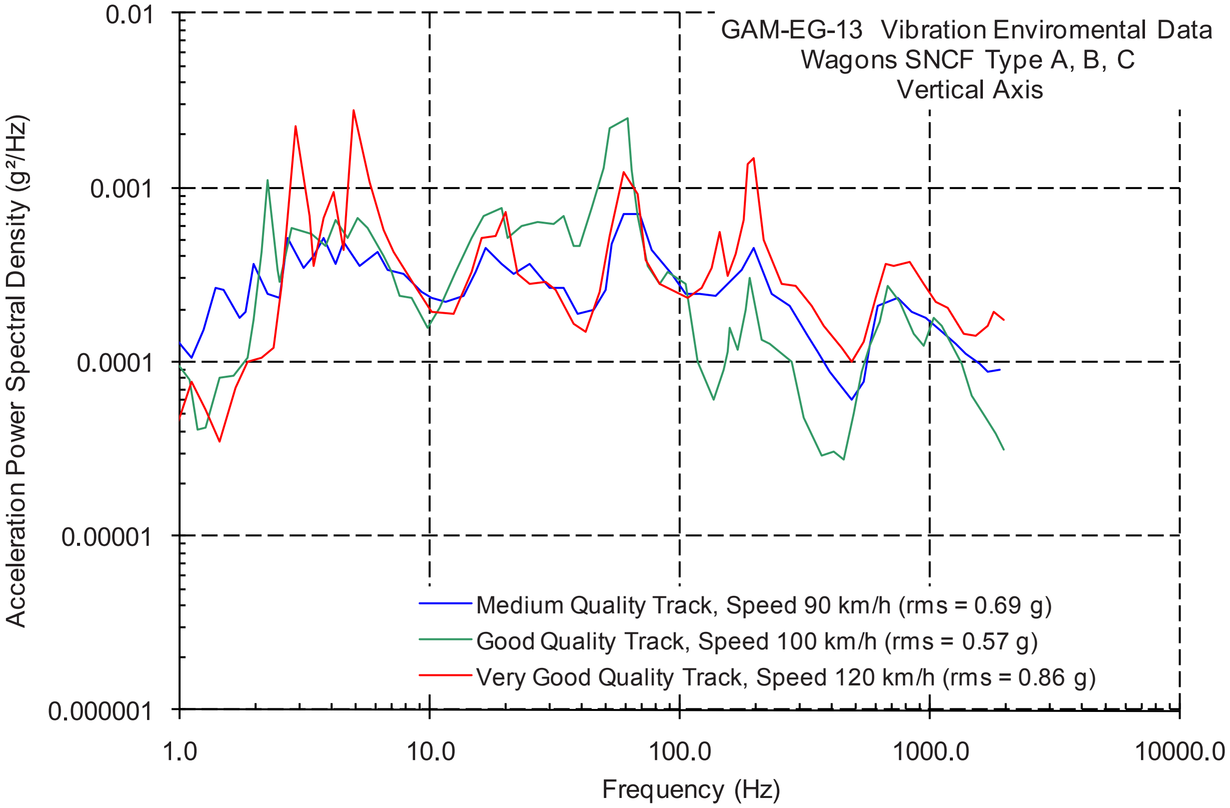

Figure 34 – GAM-EG-13 – Reported measurements – Vertical axis

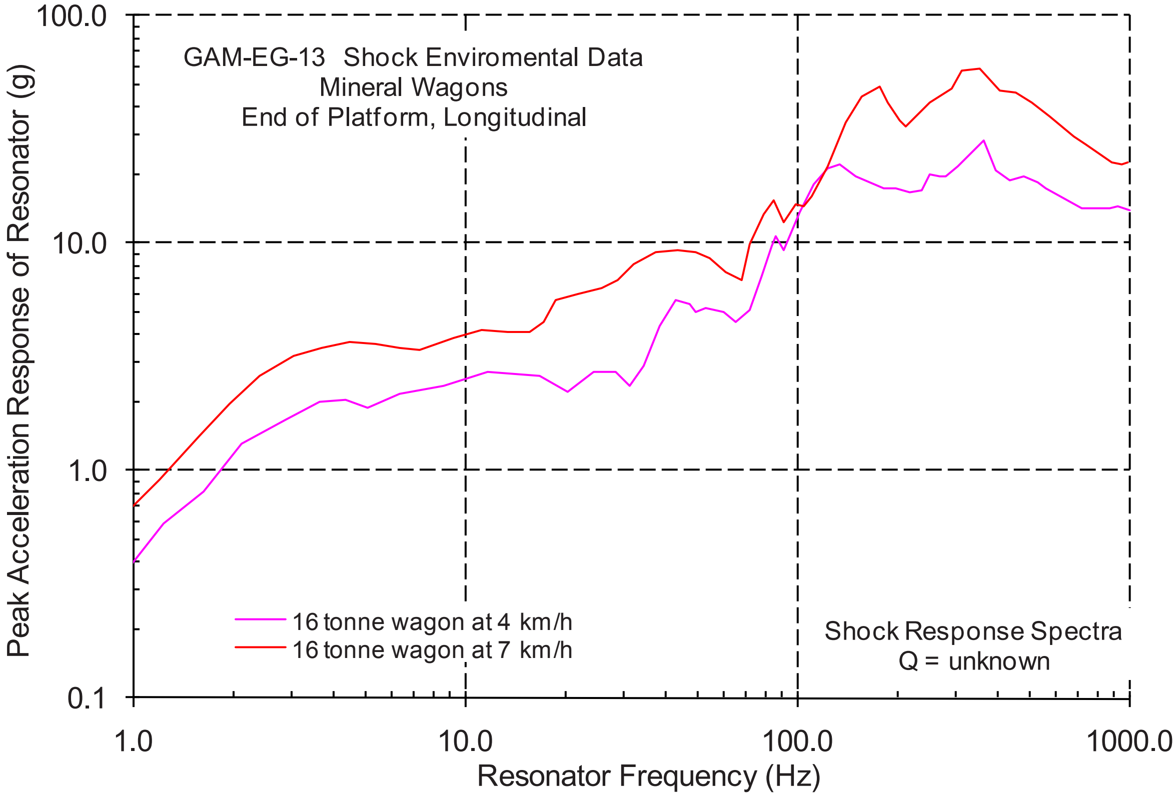

Figure 35 – GAM-EG-13 – Reported measurements – Longitudinal shocks

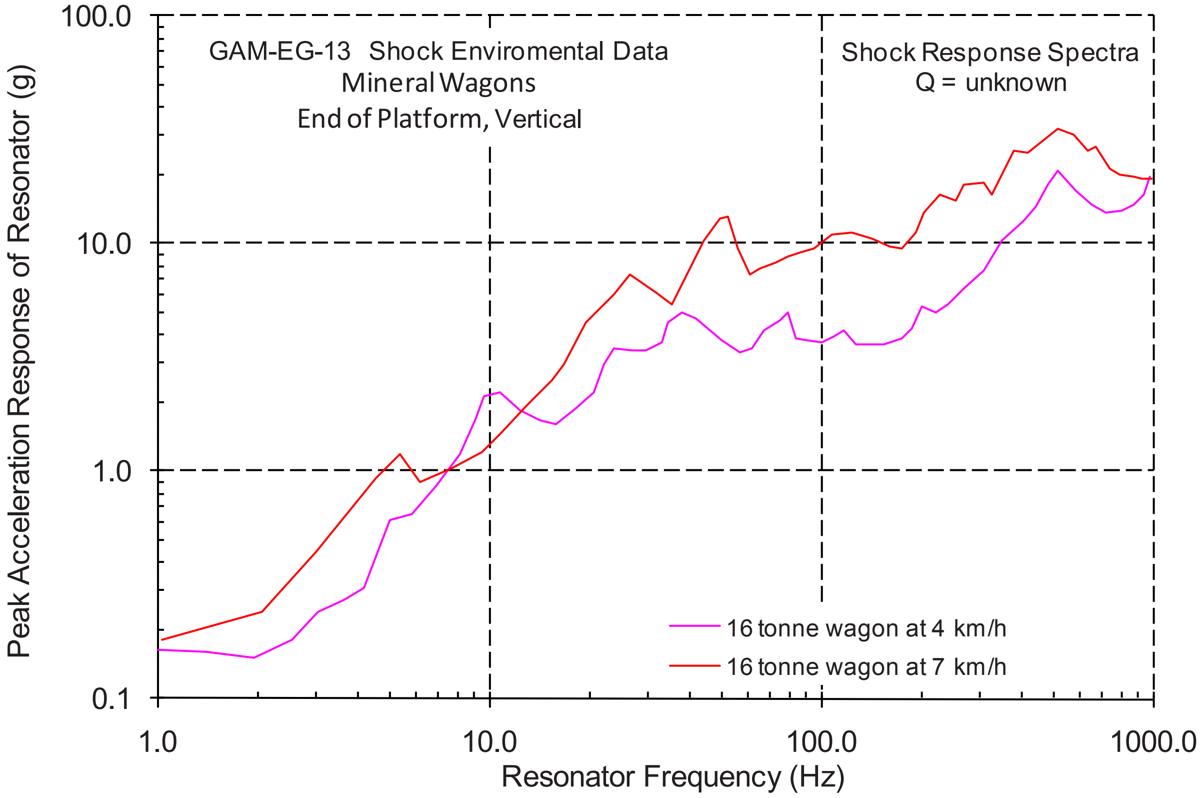

Figure 36 – GAM-EG-13 – Reported measurements – Vertical shocks

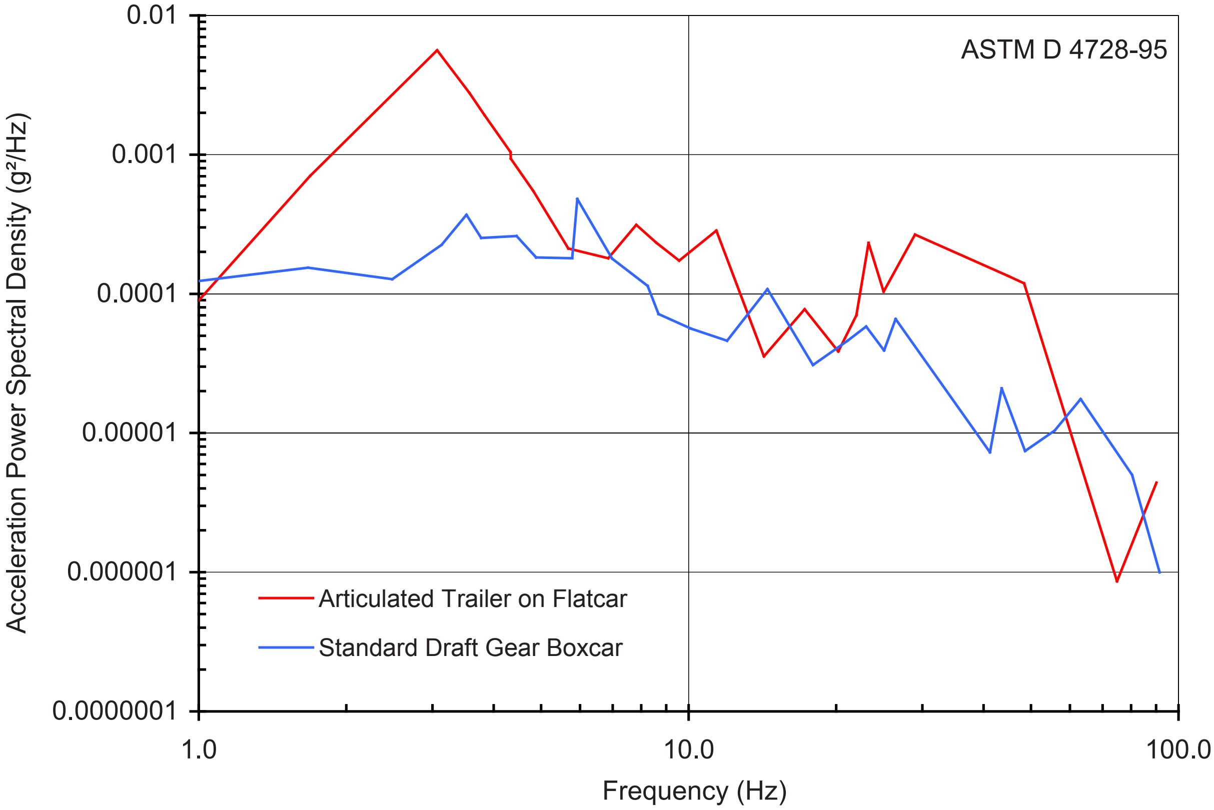

Figure 37 – ASTM D4728-95 – Reported measurements

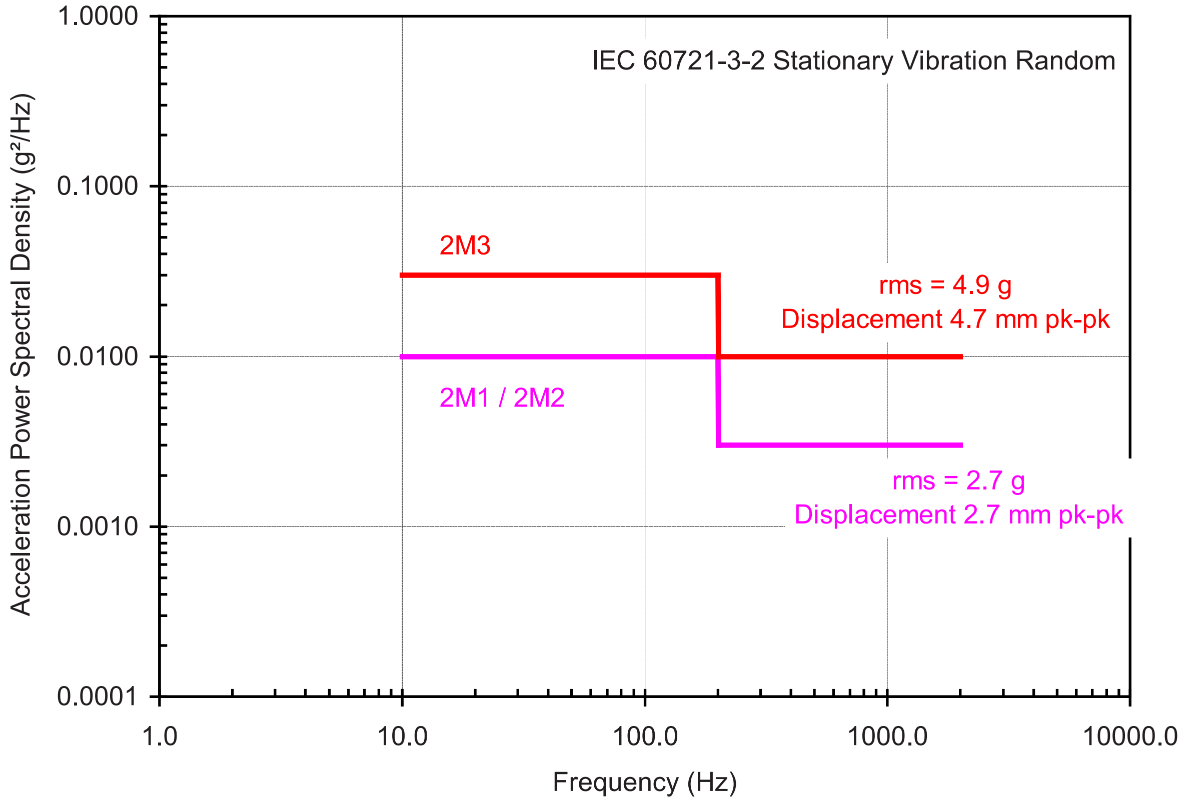

Figure 38 – IEC 60721-3-2:1997 – Random vibration severity

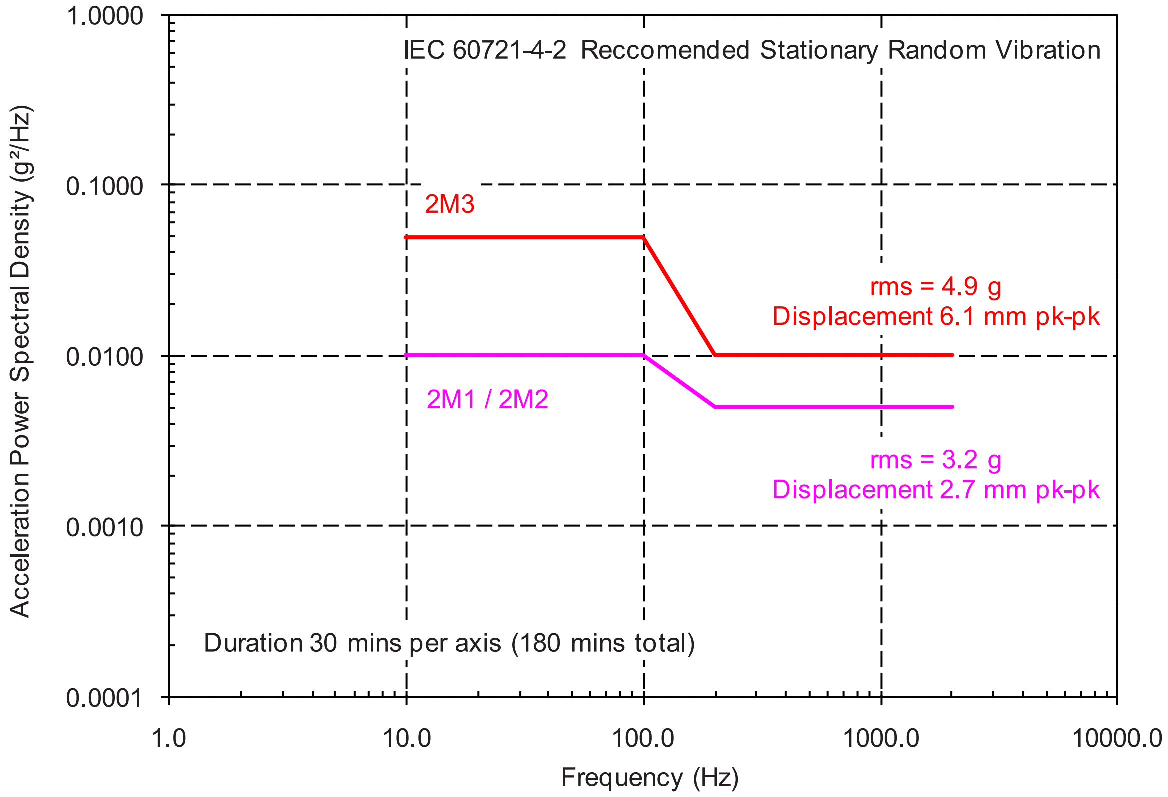

Figure 39 – IEC 60721-4-2:1997 – Random vibration severity

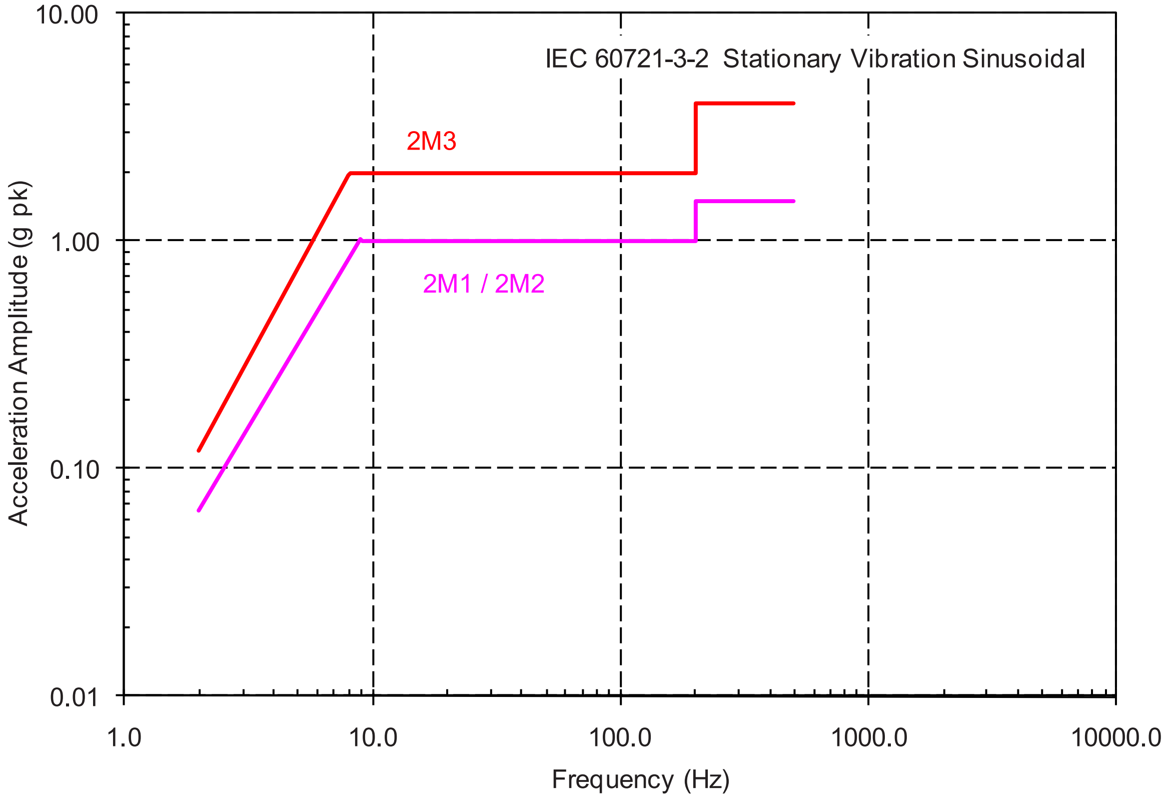

Figure 40 – IEC 60721-3-2:1997 – Sinusoidal vibration severity

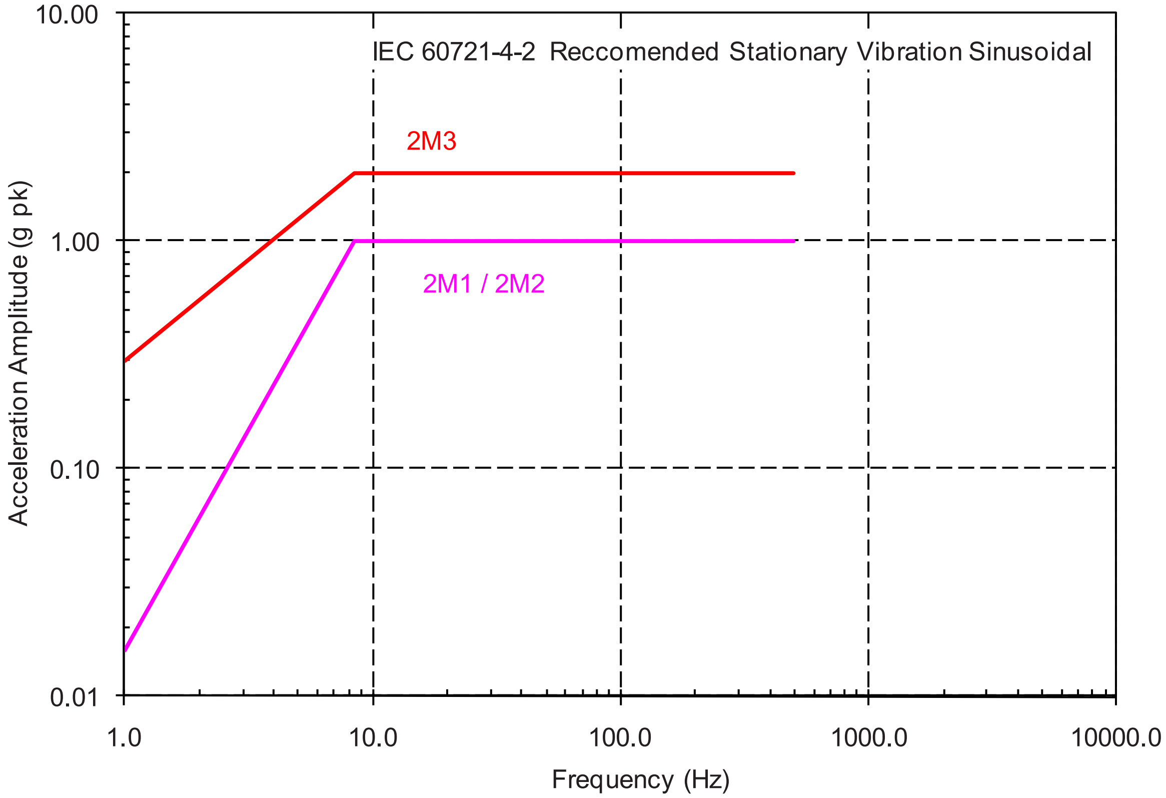

Figure 41 – IEC 60721-4-2:1997 – Sinusoidal vibration severity

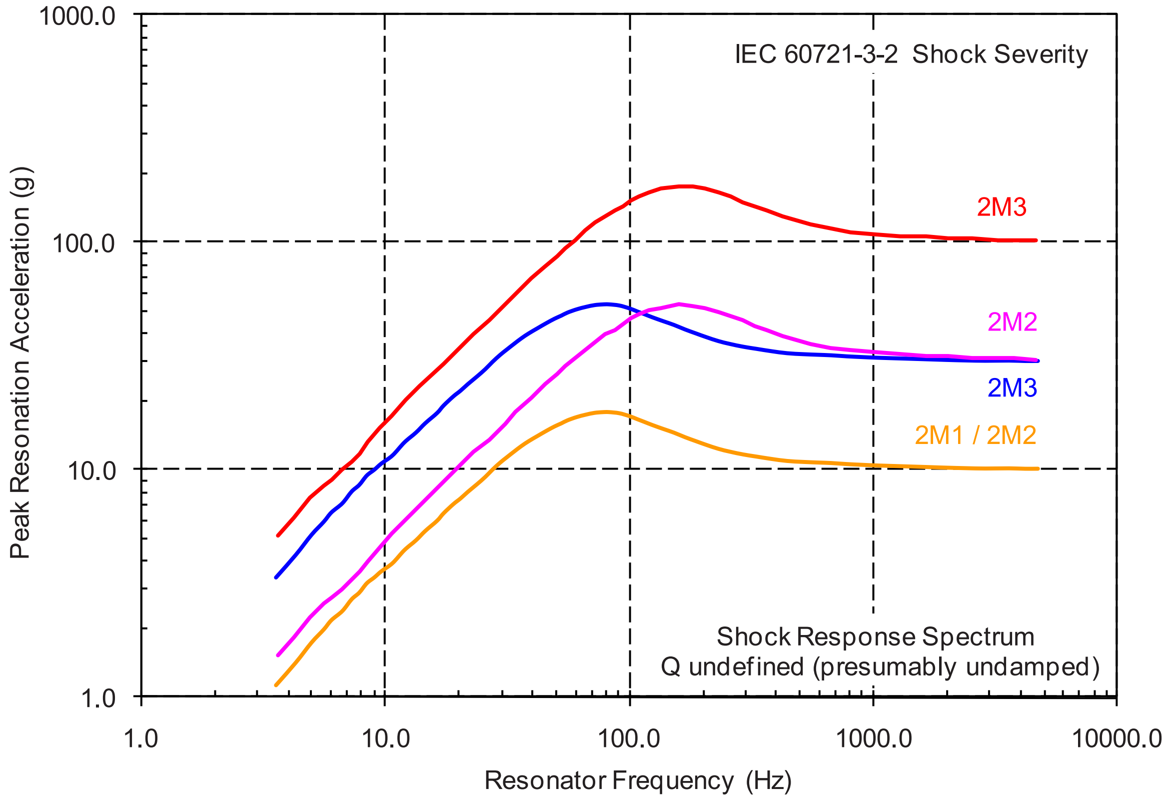

Figure 42 – IEC 60721-3-2:1997 – Shock severity

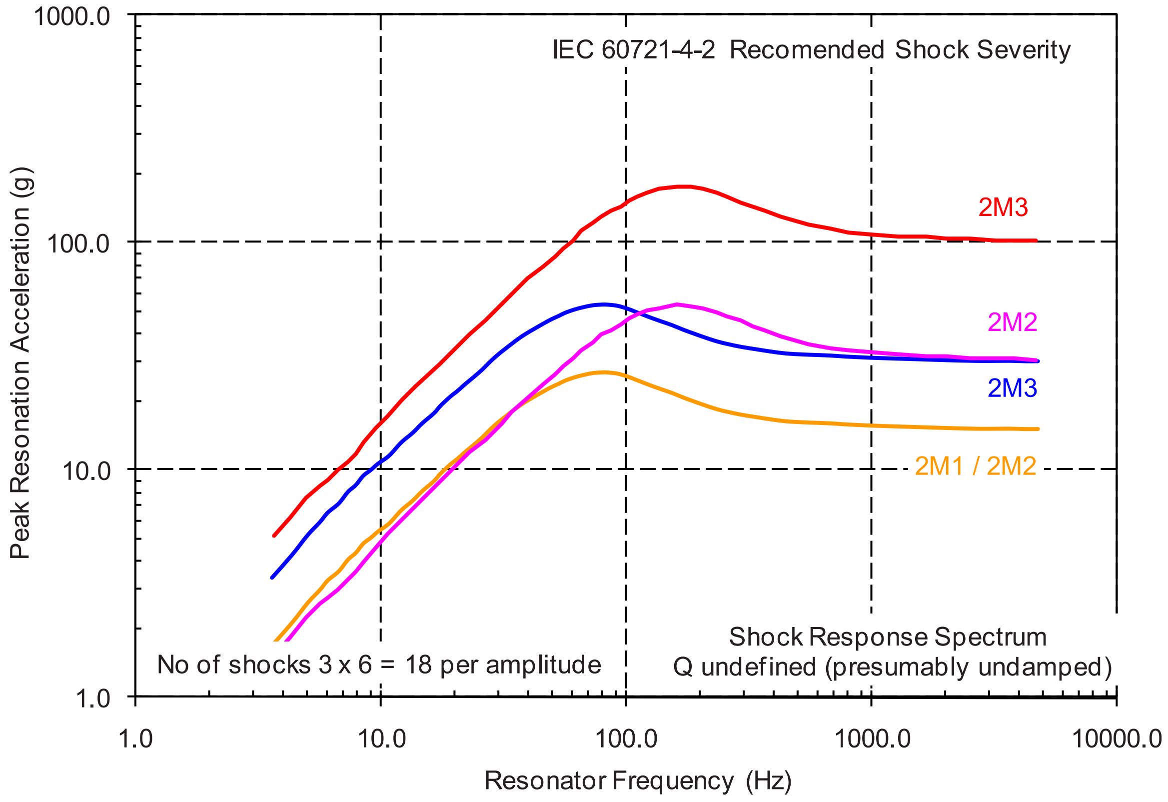

Figure 43 – IEC 60721-4-2:1997 – Shock severity

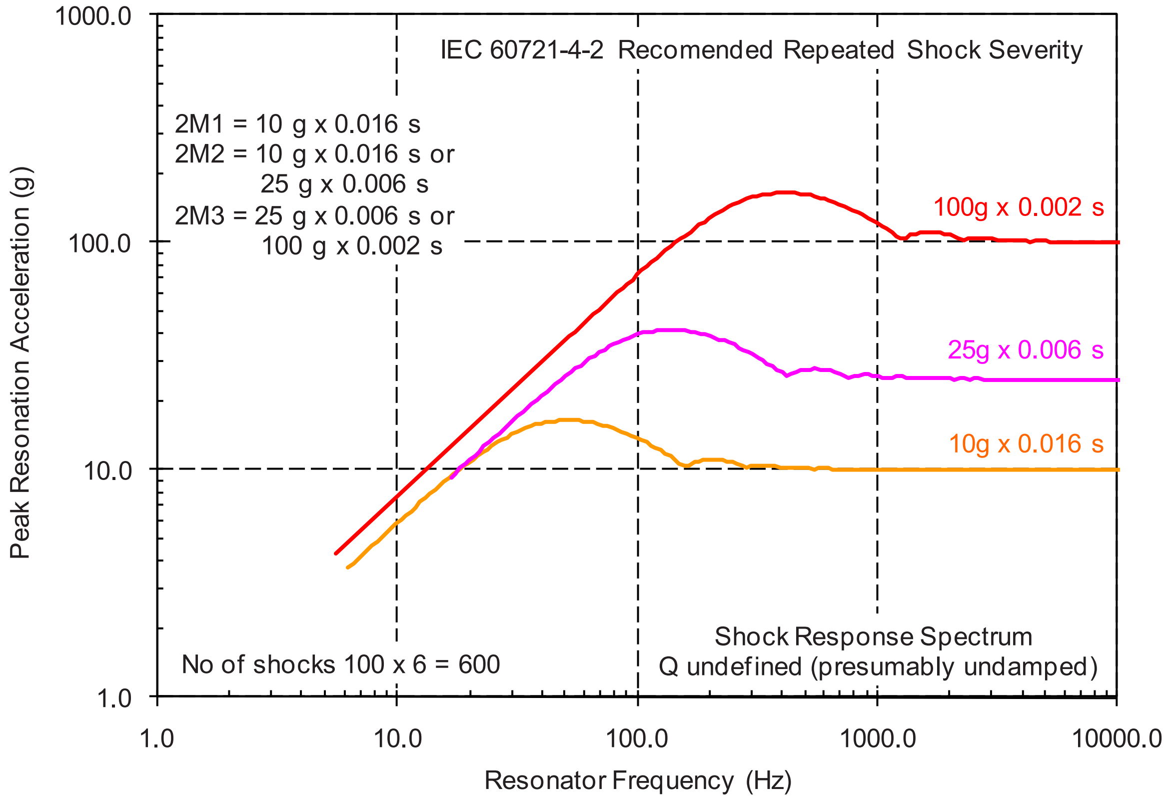

Figure 44 – IEC 60721-4:1997 – Recommended repeated shock severity

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