ACOUSTICS 2017 PERTH
SOUND, SCIENCE AND SOCIETY

Drop towers and fitness flooring assemblies

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ABSTRACT
Typical practice for quantifying acoustic performance in fitness flooring solutions involves dropping a weight onto a sample and recording the sound pressure level in the receiving room. This causes issues when trying to obtain an apples-to-apples comparison of the different flooring solutions as the 1/3 octave band data is controlled by slab natural frequencies. By instrumenting, with an accelerometer, a known mass dropped from a known height onto a fitness flooring specimen, a force impulse is recorded. This force impulse provides unbiased insight into specimen properties, such as damping, contact time and max acceleration. By using a fast Fourier transform, the impulse can also be examined in the frequency domain, which provides further insight into the acoustical properties. Additionally, repeating this process on the same specimen gives an understanding of how the material fatigues acoustically, which determines the duration of its lifetime.

1 INTRODUCTION
Often in the field of fitness acoustics, the performance of resilient flooring is assessed by measuring only the noise or vibration levels in the receiver room. This only gives insight into the energy out of the assembly and provides no information of the energy into the assembly. This means structures must be tested for a wide range of weight drops of varying masses and heights, conducive to the activities performed in the gym, to get an idea of how the structure will behave. This paper will attempt to assess and develop an alternative approach that looks at how the output energy is affected by the input force which is measured in a controlled laboratory setting.

2 PROCEDURES AND APPARATUS
Two different experiments were conducted. One where the only the output response was measured and one where the input force response was measured. Both experiments used the same make and model specimens.

2.1 Test specimen
Table 1 lists the 3 test specimens used in all experiments.

Table 1: Test specimens displaying material thickness and specimen type

Specimen number	Product name	Material/Specimen thickness	Material/specimen type
1	GenieMat® FIT08	8 mm	Recycled, rebonded rubber sheet
2	GenieMat FIT30	30 mm	Recycled, rebonded rubber tile
3	GenieMat FIT70	70 mm	Recycled, rebonded rubber tile

2.2 Input energy
The input force pulse was assessed using a custom-built drop tower (Figure 3) located in the Pliteq Material Testing Laboratory outside of Toronto ON, Canada. The drop tower is installed on a concrete block that is 2 m long x 2 m wide x 1.2 m deep for a total approximate mass of 11,500 kg. This makes the mass of the base of the drop tower at least two orders of magnitude greater than the falling mass. Therefore, it can be shown that almost all the energy is directed into the material under test and not dissipated by the floor. The base of the drop tower is also covered in a steel plate to further increase the input impedance. Low friction rails are mounted to two massive support columns that are filled with sand to reduce vibration. Two carriages are mounted on low friction bearings. The upper carriage is attached to a lifting mechanism that raises the lower carriage to a predefined height. The upper carriage can then remotely release the lower carriage. The lower carriage is equipped with an impact foot that approximates the radius of curvature of a standard Olympic- style lifting plate. This was designed in this fashion as this is the most common weight design that is dropped in the most repeatable way (dumbbells are manufactured in many different ways and can be dropped at many different angles). A load cell is located

above the impact foot but below the majority of the mass of the lower carriage. Ideally the load cell would be located below the entire mass of the lower carriage for inertial reasons, however the mass of the carriage is over 10 times the mass of the foot. Therefore, the resultant measurement error can be assumed negligible. The load cell is connected to a data acquisition device. The carriage is released from a known height and impacts a test specimen. As the carriage has a mass of approximately 22.5 kg, tests from the experiment in section 2.2 were not able to be replicated exactly. Instead, the carriage was released from a calculated height that obtained an equivalent input energy. Throughout the rest of this paper, drop heights are referred to by their input energy.

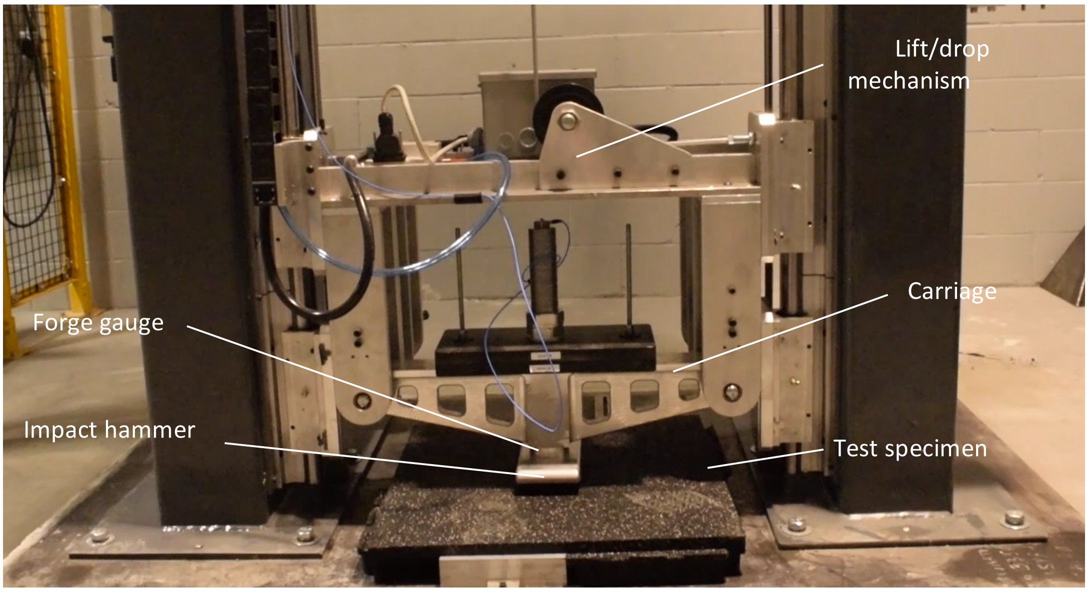

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Figure 1: Image of drop tower gauge

Table 2: Summary of Tests Conducted on the Pliteq Drop Tower

Test number	Weight	Input Energy	Drop Height
1	22.7 kg	12.7 kJ	57 mm
2	22.7 kg	64.6 kJ	289 mm
3	22.7 kg	84.7 kJ	380 mm
4	22.7 kg	169.4 kJ	760 mm

2.3 Output energy

The output levels were measured in-situ at an acoustical laboratory qualified to run ASTM E90 and ASTM E492. A 5.5" metal pan (shown in Figure 2), corrugated deck was installed in the vertical acoustical chamber located at Intertek in York, PA. and instrumented with an accelerometer on the underside directly below the impact location.

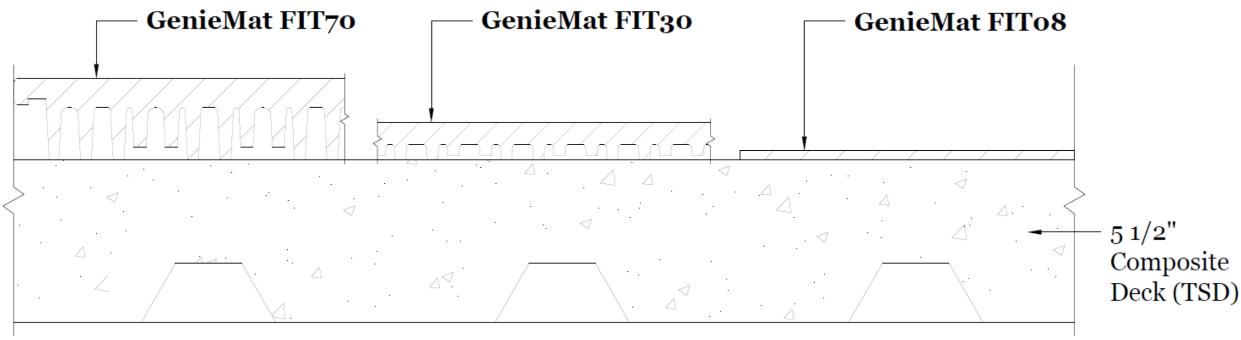

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Figure 2: Drawing of test assembly with three test specimens

A sound pressure level meter was installed in the receiving room and fast max sound pressure levels ($L_{i,Fmax}$) were recorded as weights were dropped on the test assembly. Figure 3 shows a diagram of the weight drop setup.

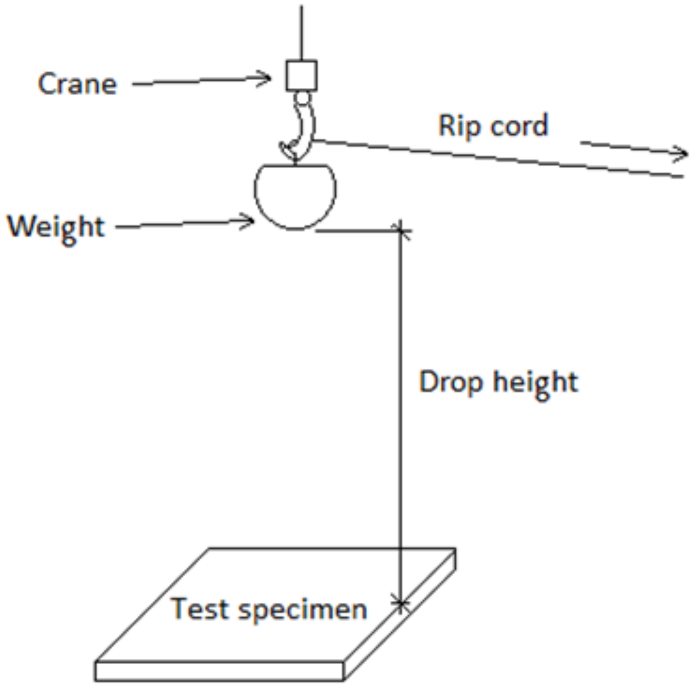

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Figure 3: Diagram of the setup used to drop the weight

As shown by (LoVerde, 2015), spherical contact surfaces create repeatable impacts, compared to the non-uniform surface of a typical dumbbell. To create the spherical contact surface, handles were ground off kettle bells and a hook attached to the other side. Images of the unmodified and modified kettle bell are shown in Figure 4.

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Figure 4: Original kettle bell (left) and modified version (right)

The weights and heights of each drop are listed in Table 3. GenieMat FIT08 was only tested at the lowest drop height because the laboratory staff were worried about chipping the concrete surface. Given that the input energies could be accurately repeated by the drop tower (discussed in Section 2.3), no attempt was made to control the exact mass of the kettlebells.

Table 3: Drop heights and weight as well as the corresponding energy

Test number	Weight	Drop Height	Input Energy	Specimens Tested
1	13.2 kg	100 mm	12.7 kJ	1, 2, 3
2	23.6 kg	100 mm	64.6 kJ	1, 2, 3
3	17.3 kg	500 mm	84.7 kJ	Only evaluated in input energy
4	17.3 kg	1000 mm	169.4 kJ	2, 3

Note, as both the drop tower and the acoustical test chamber have physical limitations of weights and drop heights (the drop tower has a minimum weight of 22.7 kg and minimum drop height and the test chamber has a maximum drop height on GenieMat FIT08 of 100 mm), equivalent input energies were used and the associated heights and weights were determined by solving for height or weight in the potential energy equation, E=mgh.

3 RESULTS

3.1 Input Energy

After the drop tower, as described in section 2.2, was constructed, a series of force pulse measurements were conducted. For this series of impacts, GenieMat FIT70 was impacted several times. An input energy of 129 kJ was chosen. The time history of each of those impacts were plotted against each other as shown in Figure 5. A Fast Fourier Transform (FFT) was performed on each impact. Those resulting frequency responses were plotted against each other.

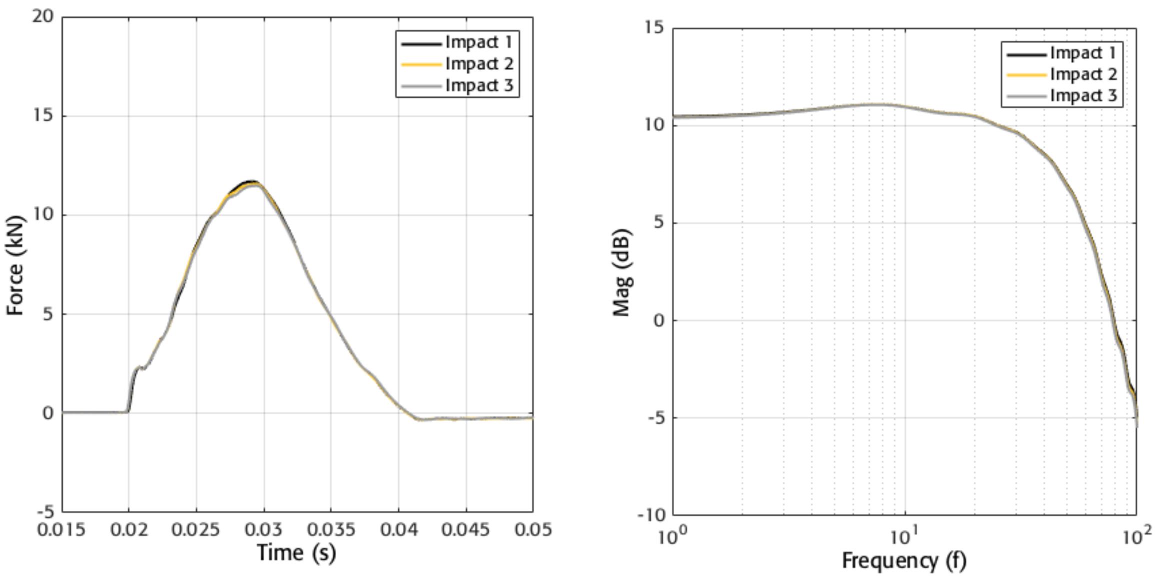

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Figure 5: Time History (Left) and Frequency Response (Right) of Three Impacts on GenieMat FIT70 at 129 kJ Input Energy to Measure Repeatability

Different energy levels, as described in Table 3, were input into the same GenieMat FIT70. Figure 6 shows a comparison of time histories and frequency responses at each of these energy levels.

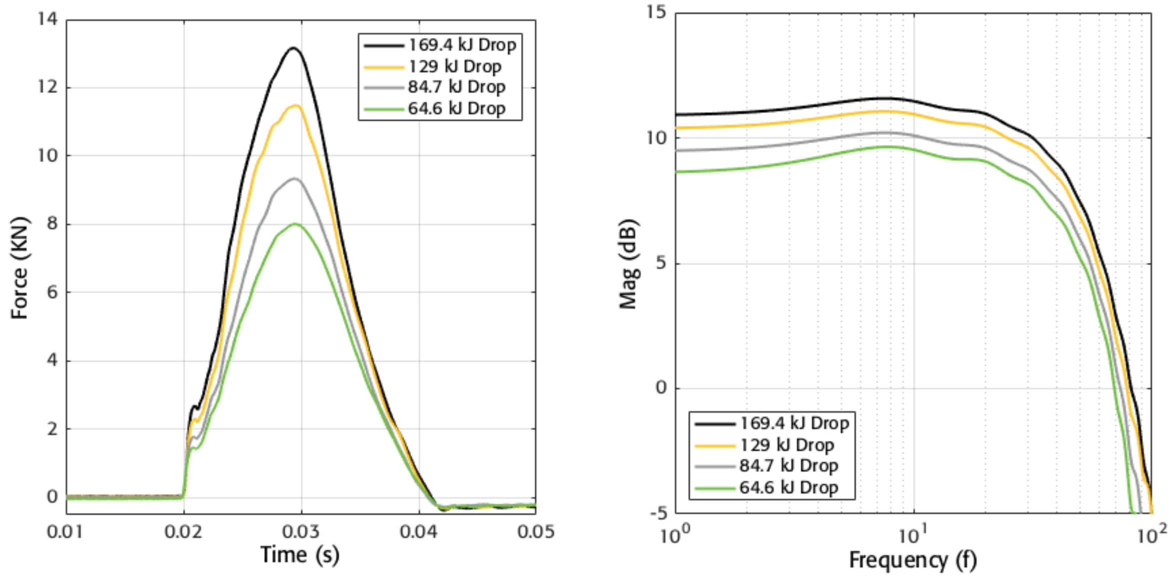

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Figure 6: Time History (Left) and Frequency Response (Right) of the Force Pulses at Different Energy Levels Input into GenieMat FIT70

The drop tower was then used to input the same energy, 84.7 kJ, into three different models of GenieMat FIT. Figure 7 shows the time history and frequency response of the resulting force pulse.

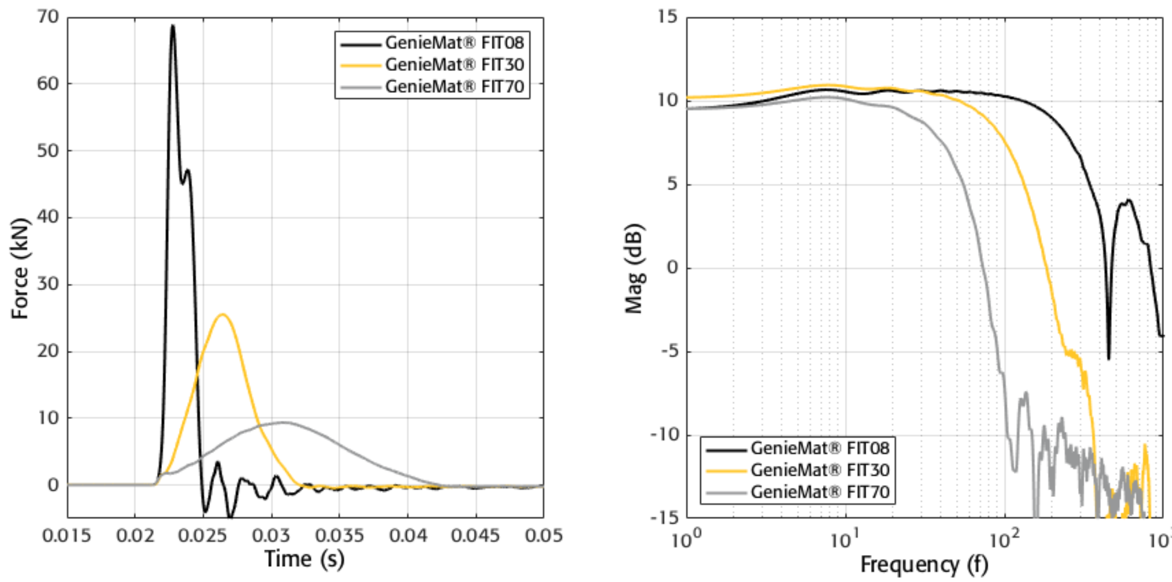

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Figure 7: Time History (Left) and Frequency Response (Right) of the Resulting Force Pulse with Three Different GenieMat FIT tiles at the Same Input Energy 84.7 kJ

3.2 Output Energy

As described in section 2.3, the fast max impact acceleration level ($L_{i,Fmax}$) on the bottom side of the assembly and the fast max impact sound pressure level ($L_{v,Fmax}$) in the lower receiver room was obtained.

Three different models of GenieMat were impacted with a modified kettlebell which resulted in an impact energy of 12.7 kJ, 64.6 kJ and 169.4 kJ. The $L_{v,Fmax}$ and the $L_{i,Fmax}$ from each impact are shown in Figure 8 and Figure 9 and respectively.

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Figure 8: Time $L_{v,Fmax}$ (left) and $L_{i,Fmax}$ (right) resulting from 12.7 kJ impacts on three different GenieMat FIT models.

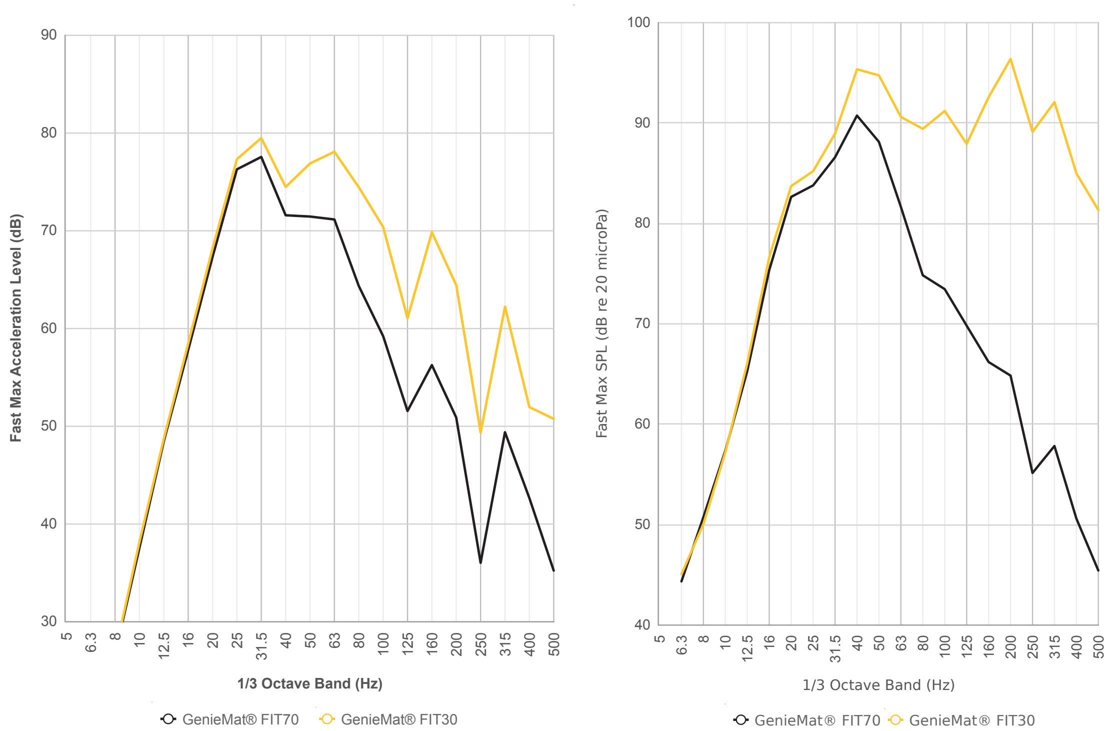

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Figure 9: Time $L_{v,Fmax}$ (left) and $L_{i,Fmax}$ (right) resulting from 64.6 kJ impacts on three different GenieMat FIT models.

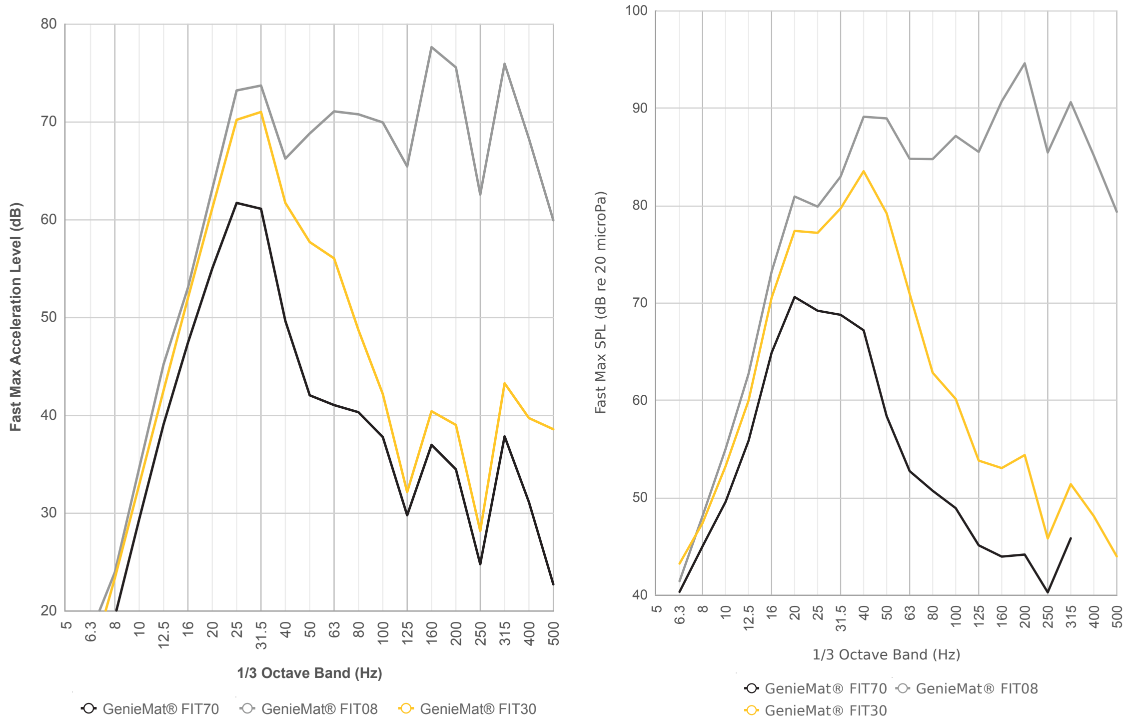

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Figure 10: Time $L_{v,Fmax}$ (left) and $L_{i,Fmax}$ (right) resulting from 169.4 kJ impacts on three different GenieMat FIT models.

4 DISCUSSION

4.1 Input Energy

The repeatability of the drop tower has been shown to be excellent. Since, the time histories and frequency responses, Figure 5, are highly correlated amongst the three impacts, the authors proceeded with the rest of the data collection. Further research will attempt to quantify the level of repeatability.

When the same GenieMat FIT tile was impacted with increasing levels of input energy, Figure 6, two important observations were made. First, as the input energy increased, the contact time remains constant at roughly 0.02 seconds but the magnitude increases. The shape of each signal is only stretched vertically and not horizontally. Second as one would expect, there is no difference in the shape of the signal in the frequency domain, there is just a difference in the magnitude of each impulse.

Next, the three different GenieMat FIT models were impacted with the same input energy, shown in Figure 7. The first observation that was made was that the time domain signal is not perfectly smooth. The author's pervious research showed that the time domain force pulse should approximate a half sine wave (Gartenburg, 2016). The authors believe this is due to the components of the lower carriage vibrating at various frequencies which are then recorded by the force gauge. This could also be due to the effect of the mass of the impact foot below the force gauge. Further experimentation is needed. This effect is especially evident in the GenieMat FIT08 curve in Figure 7. This is expected, as the forces are larger, therefore more resonances are excited.

As opposed to the various impact energies on the same GenieMat FIT tile, when the different GenieMat FIT tiles were impacted with the same input energy, an opposite effect was observed.

The contact time was non-constant and maximum magnitude increased (e.g. the stretching of the force pulse in both the vertical and horizontal directions), however the magnitude at low frequencies for each of the three GenieMat FIT samples were relatively constant. As the frequency increased, the magnitude rolled off at drastically different frequencies. The thicker the GenieMat FIT sample the lower the frequency of roll off. This roll off looks exactly like the frequency response of low pass filters (Wikipedia) with different 3 dB down points.

4.2 Output Energy

At first look, the output energy appears to have no correlation with the input energy, but upon further review, where each signal separates from the rest is correlated to the results from Figure 7. In Figure 8, the GenieMat FIT08 and GenieMat FIT30 $L_{v,Fmax}$ begin to separate significantly from each other at around 40 Hz. The same occurs in Figure 7. Analyzing this for GenieMat FIT70 versus GenieMat FIT30 is slightly more difficult as the plots do not line up below 20 Hz as would be expected. This could be due to error in measurement, drop height etc. If this offset at those frequencies is ignored, the true separation occurs around 20 or 25 Hz. Separation in Figure 7 occurs between 10 and 20 Hz. The exact same trend is shown in Figure 9 and Figure 10 but with different input energy.

5 CONCLUSIONS & FUTURE RESEARCH

This paper has shown that there is a definite trend between input energy in the frequency domain and one-third octave band $L_{i,Fmax}$ and $L_{v,Fmax}$. This trend needs to be further studied by looking at more data points (more test specimens and more input energies) and more variables (structure type, field versus lab measurements, etc). If the trend continues throughout the further research, indication that a predictive model could exist would become more evident.

REFERENCES

John LoVerde, Rich H. Silva, Wayland Dong and Samantha Rawlings, "*Investigation into a Standardized Test Method for Measuring and Predicting Heavy Weight Impact Noise Transmission*". Internoise 2015, San Francisco, CA, US.

Paul Gartenburg and Tony Nash, "*Fitness Noise Control Products – Should we be Measuring System or Material Properties?"*, NoiseCon 2016, Providence, RI, US.

Low pass filter, < https://en.wikipedia.org/wiki/Low-pass_filter>

Standard Test Method for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions and Elements, American Society for Testing and Materials ASTM E90-09(2016).