Predicting impulsive noise emission and compliance with the AAAC gymnasium guideline criteria

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Abstract - A prediction method has been developed to incorporate the AAAC Guideline for Acoustic Assessment of Gymnasiums and Exercise Facilities into gym flooring design. The impulsive noise emission is predicted using laboratory drop tower data and an in-situ standard drop on a calibrated reference sheet. This prediction method greatly reduces the time spent field testing and allows the prediction of $L_{AFmax(\Sigma Oct,31.5\text{-}250Hz)}$ at various drop weights and heights on different flooring buildups. This paper provides an overview of the prediction model methodology and presents two case studies based on field measurements. The first case study predicts $L_{AFmax(\Sigma Oct,31.5\text{-}250Hz)}$ midspan versus beside a column and compares the levels for three flooring types. The second case study analyses the change in predicted $L_{AFmax(\Sigma Oct,31.5\text{-}250Hz)}$ with increasing distance from the receiver. For both cases, the prediction method is compared with results from the simplified SEA method described by the ANC and IOA in the Gym Acoustics Guidance (GAG).

1 INTRODUCTION

The AAAC Guideline for Acoustic Assessment of Gymnasiums and Exercise Facilities ("AAAC Gym Guideline") published in 2022 provides clear framework for addressing noise and vibration emission from gyms to their sensitive adjacencies. To design a gym that meets the recommended sound levels, in-situ testing requires simulating the expected weight drops and measuring the $L_{AFmax(\Sigma Oct,31.5\text{-}250Hz)}$ in the sensitive adjacency. To avoid under-designing the flooring system while minimizing the time spent in-situ testing, a prediction model has been developed to predict the $L_{AFmax(\Sigma Oct,31.5\text{-}250Hz)}$ at any desired mass and height.

The predictive model uses a standardized drop of 7.26 kg from 50 cm to create a transfer function, relating the tested building to drop tower testing data. An automated drop tower measures the force-pulse response of different flooring materials in a repeatable way. Using this method, any mass/height/flooring combination that has been tested on the drop tower can be modelled, and the $L_{AFmax(\Sigma Oct,31.5\text{-}250Hz)}$ can be predicted.

This prediction model has been used to determine gym flooring requirements in Australia and across the world. Two buildings in Australia are used in this paper as case studies, highlighting the effects of drop position and floor frequency modes on $L_{AFmax(\Sigma Oct,31.5\text{-}250Hz)}$, as calculated in accordance with the AAAC Gym Guideline. For a floor with changing frequency modes, the effect of using one-third octave band frequency data versus single octave band frequency data is evaluated.

2 PREVIOUS WORK

The development of Pliteq's automated drop tower, shown in Figure 1, was completed in 2017. The intention of this device is to measure the response of single heavy/hard impacts on fitness flooring in the most repeatable fashion. The drop height is programmable, and the drop mass is customizable. As it is fitted with a load cell, a force-pulse measurement is outputted upon impact.

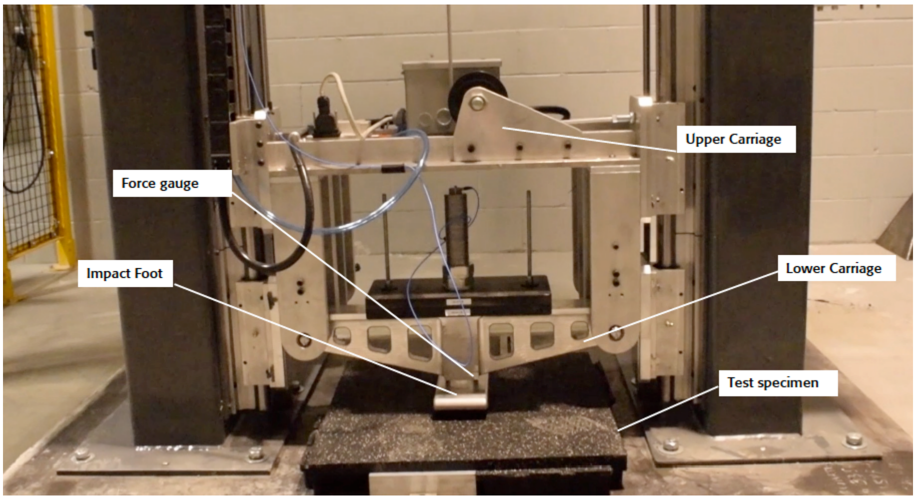

Figure 1. Pliteq's automated drop tower

Equation 1 has been developed to relate drop tower measurements to in-situ performance (Golden & Gartenburg, 2018).

$$L'_{I,F,max,DUT} = L'_{I,F,max,Ref} - (L_{lab,\ Ref} - L_{lab,\ DUT}) \quad (1)$$

Where $L'_{I,F,max,DUT}$ is the predicted in-situ measured fast-time-weighted maximum vibration level of the device under test, $L'_{I,F,max,Ref}$ is the measured in-situ fast-time-weighted maximum vibration level of the drop on the reference sheet, $L_{lab,\ Ref}$ is the overall impact force levels of the same reference sheet via Pliteq's drop tower, and $L_{lab,\ DUT}$ is the overall impact force levels of the device under test via Pliteq's drop tower.

The only in-situ measurement required for prediction is a 7.26 kg steel shot dropped from 50 cm on a calibrated reference sheet. This mass-height combination was determined to produce the best response for modelling based on a comparison of predicted and measured drops, as shown in Figure 2 (Golden & Patzke, 2022). Shown also is the accuracy of the prediction model, which was determined to slightly over-predict but be accurate to 250 Hz.

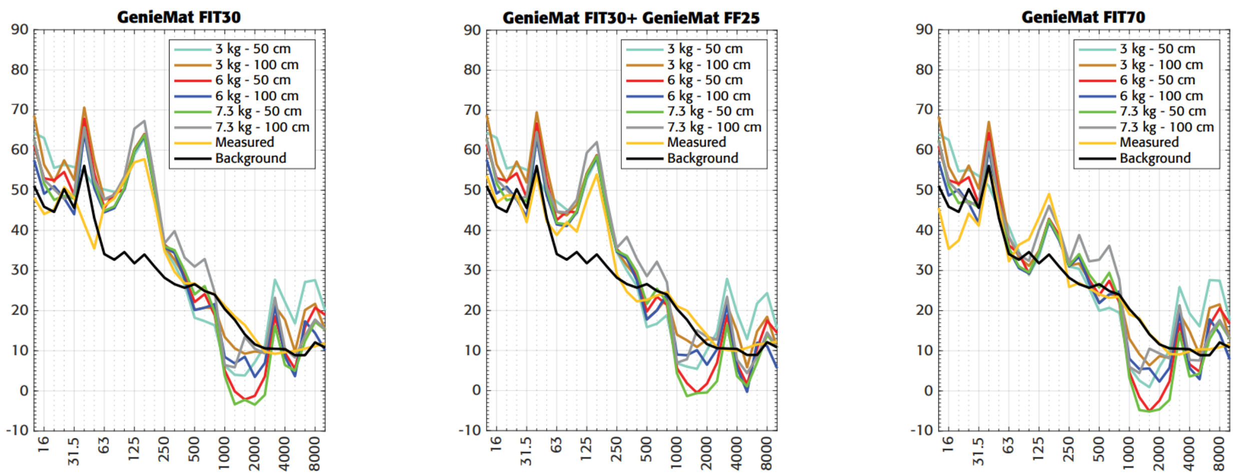

Figure 2. Predictions of sound pressure level due to a steel shot drop versus measured levels and maximum background noise levels (Golden & Patzke, 2022)

3 FIELD DATA

Two testing scenarios were chosen to analyse the changes in $L_{AFmax(\Sigma Oct,31.5\text{-}250Hz)}$ with a change in drop position. Building variables and drop test parameters are listed in Table 1. All drops were performed on a calibrated 8 mm reference sheet with a solid round shotput of 7.26 kg. At least four drops were performed at each location. The sound pressure levels at 1/3-octave band frequencies are plotted in Figure 3 along with the measured background noise in each building. These drops served as a baseline for modelling heavier drops on different floor types.

Table 1. Summary of testing parameters

Building	Concrete Slab Thickness	Acoustic Requirements	Receiver Location	Height of Reference Drop	Mass of Reference Drop	Drop Location Number	Drop Location Description
1	360 mm	$L_{AFmax(\Sigma Oct,31.5\text{-}250Hz)} \leq 35$ dB	Below	50 cm	7.26 kg	1	Midspan
				50 cm	7.26 kg	2	Near column
2	150 mm	$L_{AFmax(\Sigma Oct,31.5\text{-}250Hz)} \leq 45$ dB	Below	50 cm	7.26 kg	1	Directly above receiver
				50 cm	7.26 kg	2	9 m away from receiver
				50 cm	7.26 kg	3	17 m away from receiver
				50 cm	7.26 kg	4	26 m away from receiver

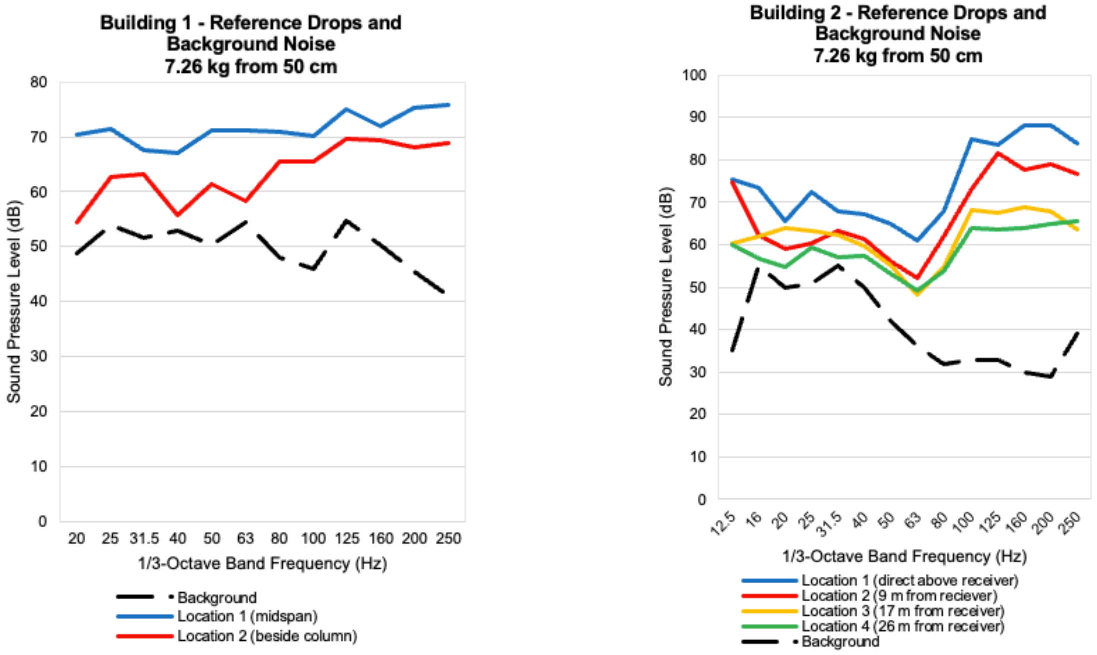

Figure 3. Reference drops for Building 1 (left) and Building 2 (right) with background noise measurements

The prediction model was used to predict heavier weight drops on different flooring types. Flooring types of various compositions were modelled, with thicknesses ranging from 70 mm to 120 mm, all available from Pliteq Inc. A predicted drop height and predicted drop mass was chosen based on the expected use of the gymnasium. To calculate the predicted $L_{AFmax(\Sigma Oct,31.5\text{-}250Hz)}$, Equation 1 was used for every drop at a given location. Then, the data was A-weighted, and the logarithmic sum was taken of the values at 1/3-octave band frequencies from 25 Hz to 315 Hz. Finally, the logarithmic average of the sums was taken to achieve a single $L_{AFmax(\Sigma Oct,31.5\text{-}250Hz)}$ value for each location. This was repeated for each flooring type, resulting in a different $L_{AFmax(\Sigma Oct,31.5\text{-}250Hz)}$ value at each location for three different flooring buildups. These results are summarised in Table 2.

Table 2. Prediction modelling inputs and results

Building	Drop Location	Drop Location Description	Predicted Drop Height	Predicted Drop Mass	Flooring Type	AAAC Rating $L_{AFmax(\Sigma Oct,31.5\text{-}250Hz)}$
1	1	Midspan	50 cm	25 kg	Type A	44.0
					Type B	42.4
					Type C	40.4
	2	Near column	50 cm	25 kg	Type A	36.7
					Type B	34.7
					Type C	33.2
2	1	Directly above receiver	50 cm	100 kg	Type D	68.5
					Type E	59.9
					Type F	54.5
	2	9 m away from receiver	50 cm	100 kg	Type D	60.7
					Type E	51.8
					Type F	47.1
	3	17 m away from receiver	50 cm	100 kg	Type D	53.6
					Type E	47.4
					Type F	43.3
	4	26 m away from receiver	50 cm	100 kg	Type D	49.9
					Type E	43.6
					Type F	39.1

4 DISCUSSION

For Building 1, the receiver location remained the same (one floor below) and the drop position moved from midspan to near a structural column. The below adjacency was considered a non-residential receiver with sensitive usage, so an $L_{AFmax(\Sigma Oct,31.5\text{-}250Hz)}$ of 35 dB was targeted in accordance with the AAAC Gym Guidelines. For a worst-case scenario, based on the management plan, a drop of 25 kg from 50 cm was modelled. These predictions are plotted in Figure 4, along with the baseline measurement drop of 7.26 kg from 50 cm.

Flooring type B did not meet the required $L_{AFmax(\Sigma Oct,31.5\text{-}250Hz)}$ for drops positioned midspan (42.5 dB) but met the requirements for drops positioned near the column (34.7 dB). For this building, the difference in sound transmission midspan versus near the column was an important variable for design.

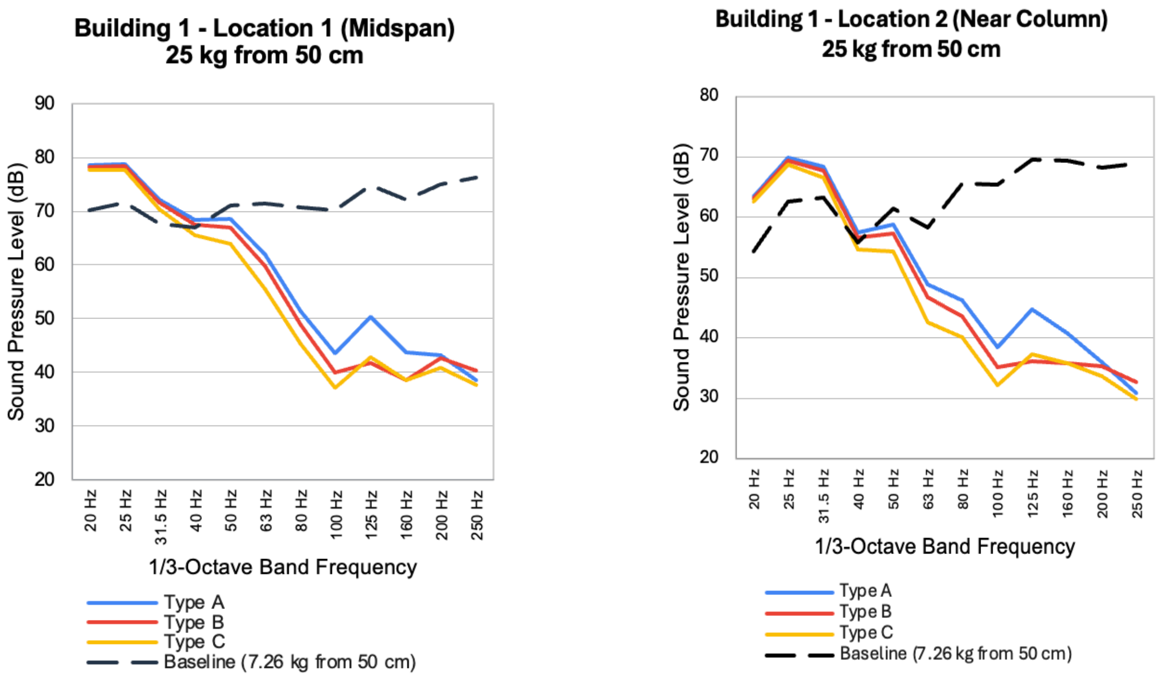

Figure 4. Building 1 Predicted SPL for a 25 kg drop from 50 cm on various flooring types

For Building 2, the receiver position was fixed, and the drop location was moved laterally in 9-metre increments away from the direct-above location. This was to determine the minimum distance from the sensitive adjacency that the weightlifting area can be positioned. The application of this building expects consistent 100 kg drops from 50 cm and the target $L_{AFmax(\Sigma Oct,31.5\text{-}250Hz)}$ in the receiver room was 45 dB.

Figure 3 shows each of the baseline drops in Building 2. The floor frequency modes shift slightly between the drop locations. Locations 1, 3, and 4 all have a floor frequency mode at 100 Hz, whereas the frequency mode of location 2 is shifted to 125 Hz. Similarly, locations 1 and 4 have another frequency mode at 25 Hz, but the frequency mode at location 2 is shifted up to 31.5 Hz. These distinctions are not apparent when evaluating only a single-number rating, like $L_{AFmax(\Sigma Oct,31.5\text{-}250Hz)}$, but might influence the perception of the impulsive noise. This is a benefit of graphical interpretation of sound pressure levels over 1/3-octave band frequencies, such as the use of the G-curve (ANC & IOA, 2023). The predicted sound pressure levels at each location for Building 2 are plotted in Figure 5.

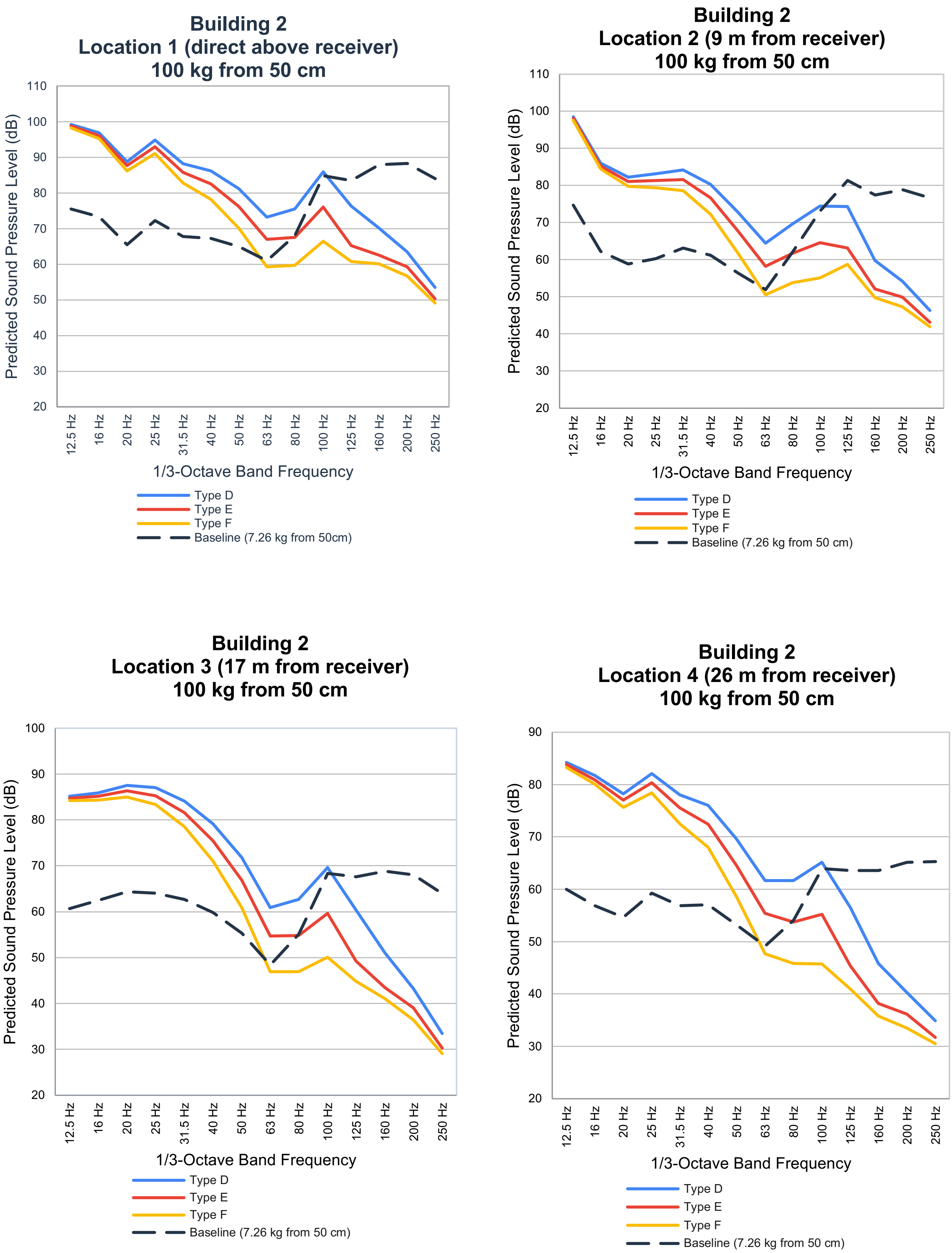

Figure 5. Building 2 predicted SPL for a 100 kg drop from 50 cm on various flooring types

The ANC and IOA have developed a prediction model using a simplified statistical energy analysis (SEA) to predict impulsive noise emission in proposed buildings and where in-situ testing is not possible. The methodology is detailed in the ProPG: Gym Acoustics Guidance (GAG) (ANC & IOA, 2023). The prediction method is specifically for gyms on a suspended slab with a below receiver. Using this prediction model requires the input of several variables, including room geometry, reverberation time, drop mass/height, radiation efficiency, and contact time.

In Figure 6, the predicted values for flooring Type B in Building 1 are compared with the GAG SEA model. Using the resulting plot, the $L_{AFmax(\Sigma Oct,31.5\text{-}250Hz)}$ is calculated for the three curves. The $L_{AFmax(\Sigma Oct,31.5\text{-}250Hz)}$ value calculated from the SEA model is comparable to the predicted drop midspan, but much higher than the predicted drop near the column. This may be due to the model not considering other structural elements, like columns in this case.

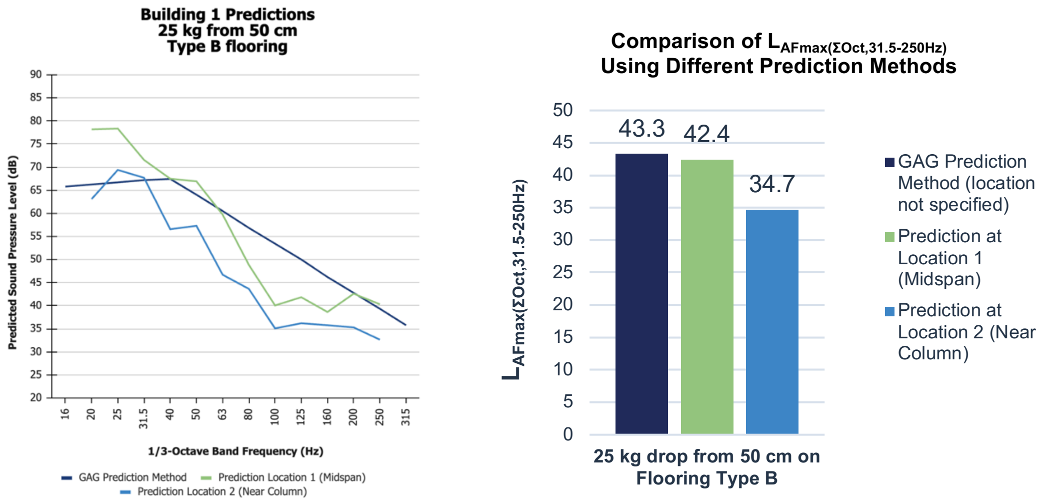

Figure 6. Comparison of Drop Tower Predictions and SEA predictions according to the GAG for Building 1

In Figure 7, the predicted values for flooring Type D in Building 2 are compared with the GAG SEA model. Only Location 1 is compared, as this was the only prediction for the direct-above adjacency. In this case, there is not a strong agreement between the SEA model and the drop tower prediction. There are several sources of uncertainty in the SEA model that may be factored in, especially considering that the reverberation time and the radiation efficiency are only estimates.

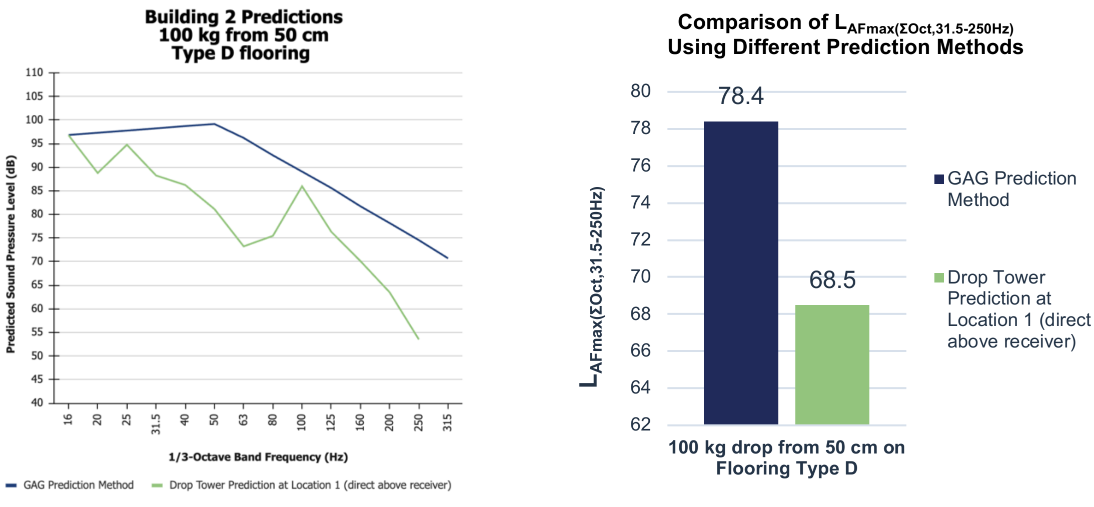

Figure 7. Comparison of Drop Tower Predictions and SEA predictions according to the GAG for Building 2

5 CONCLUSIONS

Using drop tower modelling to predict $L_{AFmax(\Sigma Oct,31.5\text{-}250Hz)}$ in accordance with the AAAC Gym Guidelines presents an opportunity to thoughtfully design gyms in an efficient manner. The data presented in this paper display the effects of drop location, and the importance of evaluating several drop locations while designing a gym. When comparing predicted drops to a simplified SEA model from the GAG using two case studies, there is some agreement but drops near structural elements are not as easily modelled with the SEA. There was better agreement with Building 1 than Building 2, so there are still some uncertainties or real-life factors that may be more difficult to model.

To further investigate these topics, in-situ testing will be completed once flooring is installed in Building 1 and Building 2. The inclusion of more types of gym flooring constructions are being tested on the drop tower to include on future predictions.

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