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COMPARING LABORATORY MEASURED IMPACT SOUND TO CALCULATED PREDICTION OF RESONANCE

Wilson Byrick

Pliteq Inc., VP Engineering Services, Toronto, Ontario, Canada
email: wbyrick@pliteq.com

Matthew Golden

Pliteq Inc., Director of Research and Development, Toronto, Ontario, Canada

Installation of a plasterboard ceiling is a common method of improving impact sound insulation. Different types of suspension are commonly used including resilient bars, furring bars, steel framing and wire suspended drop ceilings. Mass-air-mass resonance can dramatically limit the improvement provided by a ceiling assembly. The trapped air in the cavity created by the ceiling and upper surface acts as a spring and the effect on transmission loss is well documented. This paper aims to explore this effect with respect to impact sound. By using laboratory data collected on various floor samples with various ceilings types and comparing the results to predictive calculations, we hope to establish some guideline to understanding how cavity depth, use of insulation, use of resilient suspension mechanisms and other variables effect impact insulation in buildings.

Keywords: impact insulation, resonance, floor-ceilings.

1. Introduction

Transmission loss prediction, modelling and calculation has been shown to closely follow measured values in laboratory testing according to ISO 10140-5[1]. Sharp published a comprehensive guide to the principles of transmission loss in 1973[2]. In this analysis he shows calculation for critical frequency, and fundamental resonance frequency for various theoretical panels. The latter applies to double panel systems, and it is shown that measurement closely follows prediction. When dealing with floor-ceiling assemblies, often times single leaf partitions are used, such as a concrete slab, CLT or composite deck. In order to increase the weighted sound reduction index, Rw (ISO 717-1[3]) and weighted normalized sound pressure level, Ln,w (ISO 717-2[3]) often times a plasterboard ceiling is applied. The resonance frequency based on the new double panel construction details can be calculated based on either the air stiffness within the cavity, or the mass-air-mass resonance of the double panel system.

In this paper the resonance frequencies are calculated for various double panel floor-ceiling systems. The assemblies are then tested in a laboratory for impact sound attenuation. The results of the laboratory testing are compared to the calculated values to see if there is consistency and resonant increase in sound pressure level can be observed at the predicted one-third octave band level.

While the study of transmission loss is very well understood, the role of cavity resonance on impact sound in this type of double panel construction is less clear. Sound propagation and radiation at the underside of the structural element, coupling loss factor and presence and quantity of insulation all effect the cavity resonance characteristics. In this paper we plan to compare impact sound pressure level data to calculated cavity resonance frequencies using two methods, air stiffness and mass-air-mass resonance to see whether these are apparent in the laboratory measurements.

2. Calculation Methods

For the purpose of investigation, two different equations are used to determine resonance frequencies that could be affecting the impact sound insulation of the various floor-ceiling assemblies.

2.1 Air stiffness calculation

Sharp provided the air stiffness calculation in his 1973 paper[1] and earlier by London (1950)[4]. The resonant frequency due to air stiffness is dependant upon the cavity depth, speed of sound in air, density of air and effective mass per unit area (w) as seen in Eq. (2) below. This equation assumes that the cavity is filled with fiberglass insulation and the calculation is not used for uninsulated assemblies. For this reason uninsulated cavities are not applicable to the calculation in Table (1). Only wave motion normal to the surface is considered in the derivation of Eq. (2) which assumes diffuse sound field and that both panels can move. The calculated mass-air-mass resonances can be found in Table 1 as $F_{n1.}$

$$fo = \frac{1}{2\pi}\sqrt{\frac{g\rho\gamma}{dw}} \tag{1}$$

2.2 Mass-air-mass calculation

Fahy derived equations for mass-air-mass resonance calculation[5] where we use the ratio of specific heats, atmospheric pressure, gravitational acceleration and the distance between masses to determine mass-air-mass resonant frequency. The calculated mass-air-mass resonance values for the tested floor ceiling assemblies can be found in Table 1 under F_{n2}.

$$fo = \frac{1}{2\pi}\sqrt{\left(\frac{pc^2}{d}\right)\left(\frac{m1+m2}{m1m2}\right)}. \tag{2}$$

Table 1: Calculated resonance frequencies for various assemblies and ceilings

Structure	Ceiling Type	F_{n1} (Hz)	F_{n2} (Hz)
175mm CLT	0.04m Isolation clip w/ insulation	93	82
175mm CLT	0.305m Isolation wire suspended w/ insulation	34	30
150mm Concrete	0.04m Isolation clip w/ insulation	89	86
150mm Concrete	0.04m Isolation clip	N/A	101
150mm Concrete	0.152m Isolation bracket w/ insulation	46	44
150mm Concrete	0.305m Isolation bracket wire suspended w/ insulation	32	31
150mm Concrete	0.305m Isolation bracket wire suspended	N/A	37
100mm Composite deck	0.04m Isolation clip	N.A	97

3. Measured Results and Observations

3.1 Isolation clip ceiling on various structures

Impact sound pressure level data collected per ISO 10140 for three structures is shown in fig. (1). We can compare the peaks in each curve to the results in Table 1. The 175mm CLT with isolation clip ceiling has significant peaks at 63 and 80 Hz. This matches closely with the 82 Hz calculated resonance frequency for air stiffness. The lack of insulation present in the second concrete slab ceiling tested is causing some very significant changes in performance between 100-250 Hz. Calculated resonances were 86 Hz w/ insulation and 101 Hz without. Both assemblies exhibit very similar performance in the 80 Hz one-third octave band. The composite deck exhibits a resonant peak at 63 Hz with a calculated resonance of 37 Hz. We did not measure below 50 Hz in the laboratory.

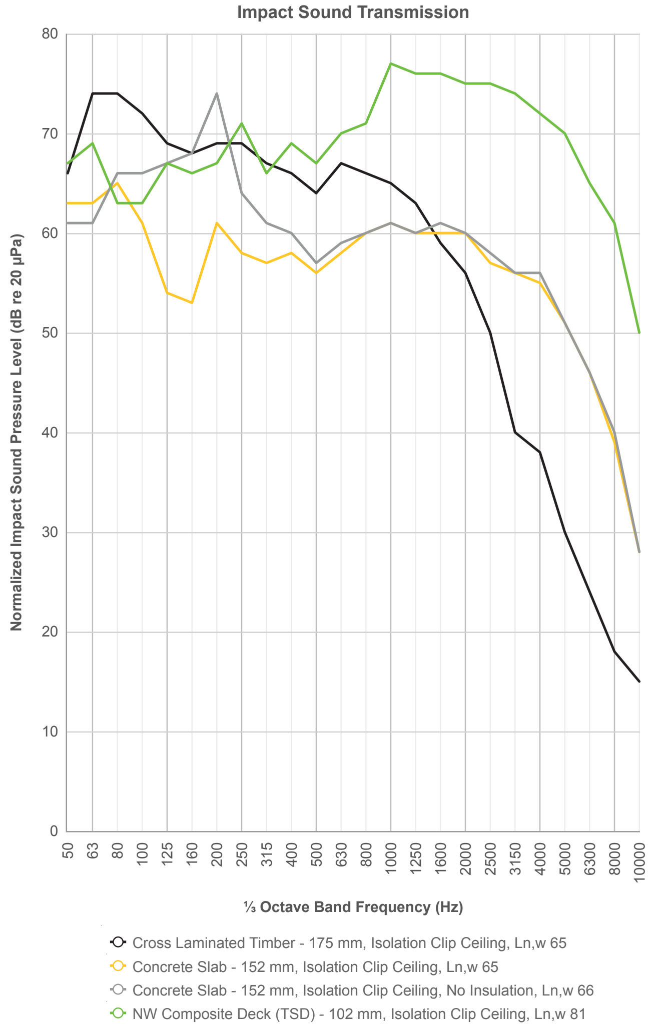


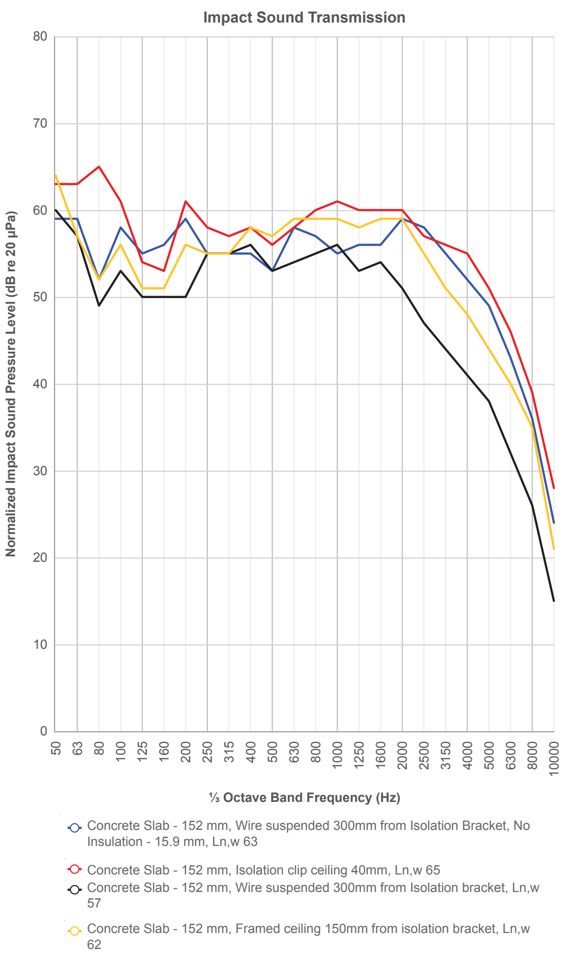
Figure 1: Impact sound pressure level of isolation clip ceiling assemblies.

3.2 Various ceiling constructions on 150mm concrete slab

Test data from 4 different ceiling types can be seen in fig. (2) below. The isolation clip was used to suspend an insulated cavity of 40mm. An isolation bracket was used to create a 150mm insulated plenum using steel framing. In the third ceiling type, the same isolation bracket is used to afix a wire suspended ceiling 300mm below the concrete deck. The wire suspended ceiling is partially filled with fiberglass insulation. The same wire suspended ceiling is tested with no insulation present.

The most prominent peak is at 80 Hz for the 0.04m isolation clip ceiling below the concrete slab. Both mass-air-mass and air stiffness resonance are calculated to occur in this one-third octave band. The lack of insulation in the 300mm wire suspended ceilings appears to have a profound affect not only between 80-200 Hz but above 1600 Hz. The calculated values of mass-air-mass resonance for the wire suspended ceilings occur at lower frequencies than measured. Resonant modes may be sustained in the airspace where insulation is not present, resulting in higher frequency deficiencies.

The 150mm and 300mm deep isolated ceiling data produce similar curve shapes. Where transmission loss is found to increase 6 dB with doubling of cavity distance (Long, 2006) we potentially see the same type of result here for impact sound pressure level. When the cavity depth is doubled the difference in sound pressure level is 3-6 dB at all one-third octave bands.



4. Discussion and Next Steps

The general shape and characteristic of the impact sound pressure level curves is likely driven primarily by coupling loss factor as well as mass, stiffness and natural frequency of the structural assembly. There are some interesting comparisons amongst the various ceiling types that can help predict impact sound pressure level performance.

4.1 Presence of insulation in 0.3m ceiling cavities

When analysing the effect of the various ceiling types, we can see that the presence of insulation in a cavity depth of 0.3m reduces impact sound pressure level by 5-6 dB between 100-200 Hz and has even larger positive influence between 2000-5000Hz. When there is no insulation we may be observing shear wave radiation at high frequencies that are otherwise absorbed by the insulated cavity[6]. The calculated cavity resonance is well below 50Hz so is not observable given the measurements made. A further analysis is required on the higher modal resonances.

4.2 0.04m Low profile ceiling cavity

80 Hz one-third octave band sound pressure level in the 0.04m ceiling cavity matches with the calculated mass-air-mass and air stiffness resonances of 89 and 86 Hz. This lowest profile, insulated ceiling was otherwise comparable to the deeper cavities, within a range of 2-3 dB and equivalent at some frequencies. It may be possible to use this lower profile ceiling to increase floor-to-ceiling height but the 80 Hz cavity resonance remains a significant issue. When the 0.04m ceiling cavity was not insulated there was no difference above 500 Hz. The uninsulated cavity had approximately the same sound pressure level at 80 Hz as the insulated cavity, once again closely matching the calculated

value. This indicates 80Hz sound pressure level is likely controlled largely by the cavity depth in this type of ceiling. The uninsulated ceiling was 10-12 dB louder between 125 and 200 Hz. The fiberglass insulation appears to be critical in providing an impact sound barrier ceiling at these frequencies.

4.3 Material of the structure and radiation efficiency

When we compare a 152mm concrete assembly (366.18 kg/m^2) to a 100mm trapezoidal composite deck (193.16 kg/m^2) in Fig. (1), with the same uninsulated 0.04m isolation clip ceiling, we can attempt to compare how the different material surfaces affect cavity resonance. The calculated air stiffness resonances are 101 and 97 Hz for the concrete and composite deck. Neither assembly seems to have a peak resonance at 100Hz due to air stiffness. The more flexible composite deck may have bending waves as part of the transmission mechanism resulting in increases around and below the resonant frequency[6]. This is observed with resonant peaks at 63 and 125 Hz. In future research we will use an impact hammer to compare the natural frequency of each structure tested in the laboratory for comparison purposes.

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