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AIRBORNE AND IMPACT SOUND INSULATION OF JOIST FLOOR SYSTEMS: A COLLECTION OF DATA

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ABSTRACT

About 190 lightweight joist floors with different joist types, sub-floors, ceiling types, ceiling support systems and type and thickness of sound absorber were constructed and tested at the National Research Council Canada. Three types of sound absorbing material were used and the disposition of resilient metal channels was varied. For floors incorporating resilient metal channels and sound absorbing material, the sound transmission class and impact insulation class could be predicted with sufficient accuracy by simple regression analysis using variables such as the mass of the layers, joist depth and spacing, insulation thickness and density and resilient metal channel spacing.

1 - INTRODUCTION

The IRC Acoustics Laboratory recently completed the measurement phase of a study of airborne and impact sound transmission through typical floor constructions used in Canadian housing [1,2]. Airborne and impact sound transmission were measured for about 190 specimens in the floor test facility [3] according to ASTM standards [4,5,6,7] but with a frequency range extended down to 50 Hz. Most of the 190 floors in the project incorporated wood joists or trusses. Joist type, spacing, and depth were varied. There were only 14 steel joist systems and 4 concrete slab floors. The joist types comprised solid wood, wood trusses, I-joists, and steel joists. Three types of sound absorbing material were used: glass, rock and cellulose fibre. The measurements provide an extensive, consistent set for analysis and testing of computer models.

2 - REPEATABILITY AND REPRODUCIBILITY

To establish rebuild repeatability for the project, a reference floor was constructed and tested eight times over a period of about 1 year using new materials each time. The floor construction consisted of a 15 mm thick OSB (oriented strand board) subfloor, 38 x 235 mm wood joists, 406 mm apart, a layer of 152 mm thick glass fibre batts in the joist cavities, 13 mm deep resilient metal channels screwed 610 mm apart perpendicular to the joists, and one layer of fire-rated gypsum board, 15.9 mm thick, applied to the resilient metal channels. Figure 1 shows the repeatability values for airborne and impact sound transmission measurements. The laboratory also has two concrete slabs that can be re-installed in the test frame for use under different floor toppings. The repeatability for eight re-installations of our 150-mm thick slab is also shown in the figure. The installation and sealing procedures were nominally identical in each case. The anomalous value at 80 Hz for the transmission loss (TL) repeatability has not been explained. The charts also present the reproducibility values (R) from ISO 140-2. Note that the reproducibility given in ISO140-2 for the tapping machine test is smaller at several frequencies than the repeatability for rebuilding the wood joist floor. According to ISO 140-2, the values for impact tests are based on measurements made by different teams on the *same* specimen in a *single* laboratory. Thus there were no variations in specimen materials or mounting.

3 - SINGLE LAYER RESULTS

At various times in the project sound insulation was measured for some single layer ceilings or floors to provide data for modeling. Results for single layers of gypsum board comprising two sheets showed

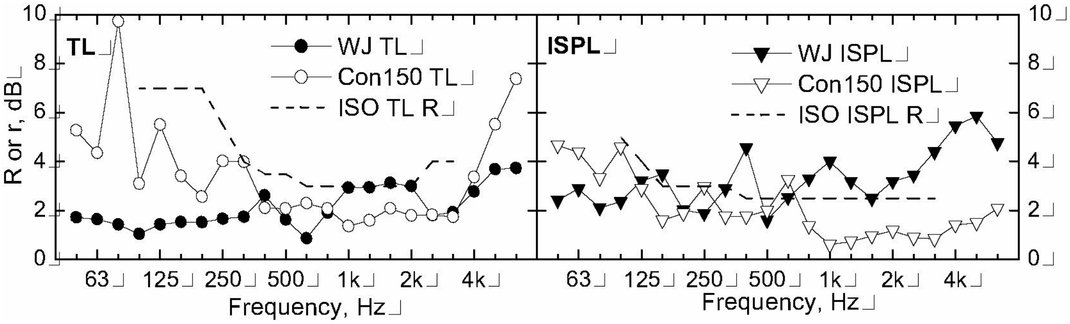

Figure 1: Rebuild repeatability values for TL and ISPL measurements for the reference floor; the figure also shows re-install repeatability estimates for the 150 mm concrete reference slab.

reduced transmission loss around 1 kHz. The two sheets of material are not perfectly in contact and air confined between them enables a mass-air-mass resonance to occur and reduce the TL. The *differences* between the single sheet and the double sheet results are plotted in Fig. 2 for three types of gypsum board. The calculated thickness of the trapped air is about 1 mm in each case. Similar effects were seen for double sheets of plywood. In complete floors with the subfloor or ceiling layer comprising more than one sheet of material, the effects of this resonance are still evident.

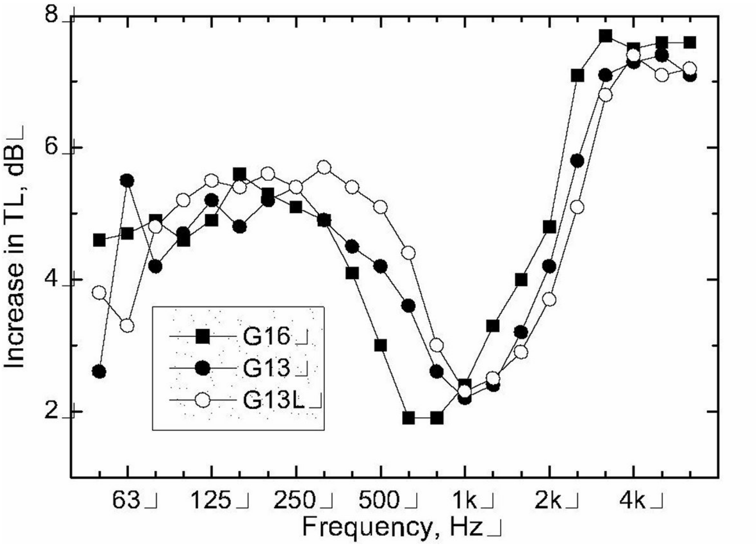

Figure 2: Differences between single sheet and the double sheet transmission losses for the three types of gypsum board used in the project.

Fig. 3 shows measured variations in sound transmission loss for 15-mm OSB on four joist types. The variations in joist spacing and depth produce large variations in sound insulation. The I-joists and the solid wood joists give results that are quite similar when spacing and depth are the same. Evidently parameters such as joist depth and spacing are important parameters when predicting sound insulation even for single layer floors.

4 - RESILIENT CHANNEL EFFECTS

The arrangement of resilient metal channels is an important issue for fire resistance and for sound insulation. If gypsum board edges are not properly supported, fire resistance ratings will be low. Measurements on the reference floor with resilient metal channels spaced uniformly at separations ranging from 203 to 610 mm showed a dependence of STC and IIC on channel separation or, the total length of channels in the floor [1]; as the spacing between channels increased, the STC increased from 47 to 52 and the IIC from 40 to 46.

Fig. 4 shows how transmission loss decreases for some frequencies as the total length of resilient metal channels supporting the ceiling layer increases. The four frequencies shown are those where the effect is

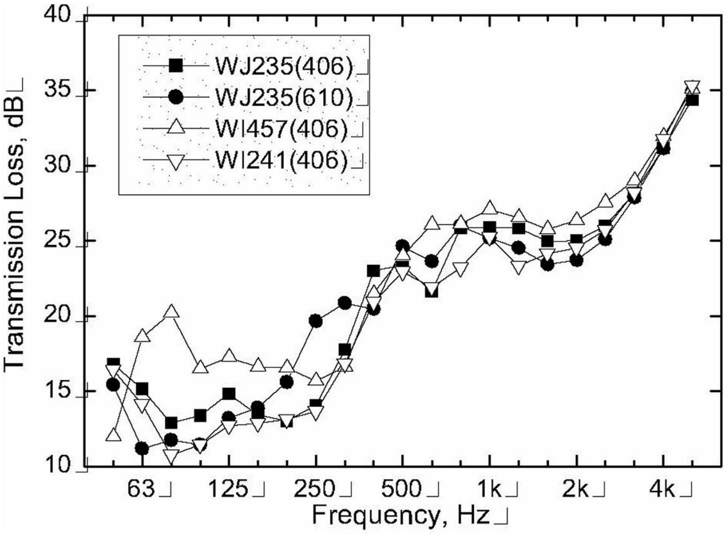

Figure 3: Airborne sound transmission loss for 15 mm OSB on four joist types: 235 mm deep wood joists (WJ235), 406 and 610 mm apart and wood I-joists, 241 and 457 mm deep (WI241, WI457), 406 mm apart.

most prominent. At other frequencies there is still an effect due to increasing the length of the channels, but it is about 1/3 of that shown in the figure.

It was established during the project that to ensure good fire resistance, single layers of gypsum board needed additional pieces of channel to support the untapered, short edges. These additional supports reduced sound insulation. The data points for these cases are for total channel lengths around 57 m in Fig. 4. These additional pieces of channel were not found necessary for good fire resistance when the ceiling layer comprised two sheets of gypsum board.

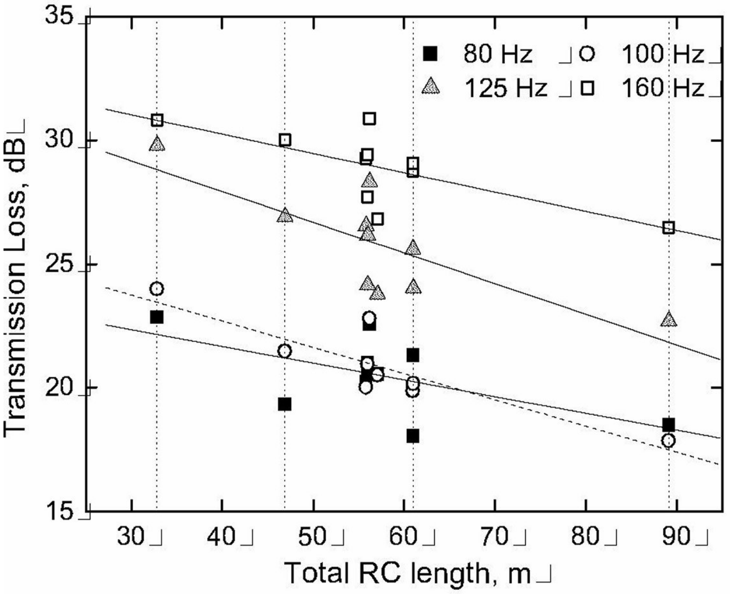

Figure 4: TL versus the total length of resilient metal channels supporting the 16-mm gypsum board ceiling; the solid lines are best fits to the data; the vertical dotted lines correspond to uniformly spaced cases with separations of 203, 305, 406, and 610 mm.

5 - THICKNESS AND TYPE OF SOUND ABSORBING MATERIAL

The effects of different thicknesses and types of sound absorbing material were examined in a 250-mm deep wood joist floor, a 470-mm deep wood I-joist floor, and a 215-mm steel joist floor (The depth includes 13 mm for the thickness of the resilient metal channels). In each case the joist spacing was 406 mm. Apart from the different joist types, the construction elements were the same as used in the reference floor. The dependence of STC on percentage thickness is shown in Fig. 5.

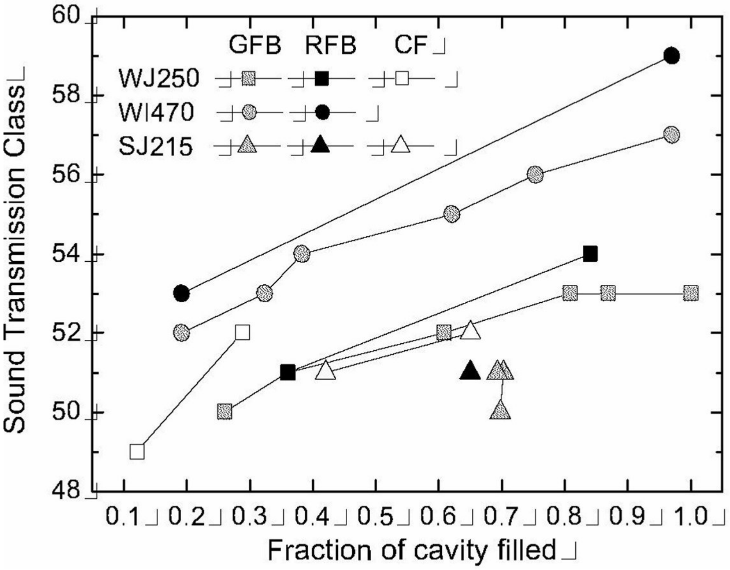

Figure 5: Dependence of STC on thickness of layer of sound absorbing material in a 235 mm wood joist floor (WJ250), a 457 mm deep wood Ijoist floor (WI470), and a 205 mm deep steel joist floor (SJ215); GFB = glass fibre batts, RFB = rock fibre batts, CF = cellulose fibre.

Sound transmission class and impact insulation class increased fairly linearly with the amount of sound absorbing material in the cavity. In the 250-mm deep cavity there is an apparent maximum reached in the STC when the cavity is about 80% full. This is not the case, however, in the 470-mm deep cavity. The trends for IIC are less clear and are not shown here. Note that the more dense rock fibre batts give small but definite improvements in sound insulation relative to the glass fibre batts.

Cellulose fibre was installed in two ways: as a layer wet-sprayed on to the underside of the wood joist floor and as loose material blown in from the top of the steel joist cavity. From the limited data available, it is not possible to say whether the wet-sprayed cellulose fibre gives sound insulation much different from the glass and rock fibre. Only two thicknesses were tested with the larger thickness being about 70 mm. There is a suggestion that the loose material gives slightly higher sound insulation than glass fibre of the same thickness.

6 - FACTORS DETERMINING RATINGS

The most important variables determining the sound insulation for all joist floor types are the masses of the floor and ceiling layers, the use of resilient metal channels, and the use of sound-absorbing material. For a restricted set of floors with the same joist type and spacing, Fig. 6 shows clearly the benefits of these physical factors. (The floors with masses around 100 kg/m^2 had a 35-mm concrete layer on top of the oriented strand board sub-floor.) If resilient metal channels are not used, the STC rating was always below 50 and sound-absorbing material did not significantly improve the rating. Once resilient metal channels are used, the addition of sound-absorbing material increases STC by about eight points. A corresponding plot for IIC shows similar effect except that the addition of a concrete topping greatly reduces the IIC and the data points are far from the regression line.

In building regulations, single number ratings determine whether a construction is acceptable or not. Since this work was largely in support of the National Building Code of Canada, the dependence of STC and IIC on physical factors was determined using simple regression analysis. This permitted interpolation and extrapolation of the results to cases that were not actually measured. Developing an analytical model would be more satisfactory but is a long-term goal.

For all the analyses, the physical variables found to be significant were the mass per unit area of the subfloor and the ceiling layers, joist depth and spacing, resilient metal channel spacing, and the thickness and density of the sound absorbing material. Other parameters did not correlate with sound insulation. In particular, adding the mass of the floor framing as an independent variable or in combination with other variables decreased the square of the correlation coefficient.

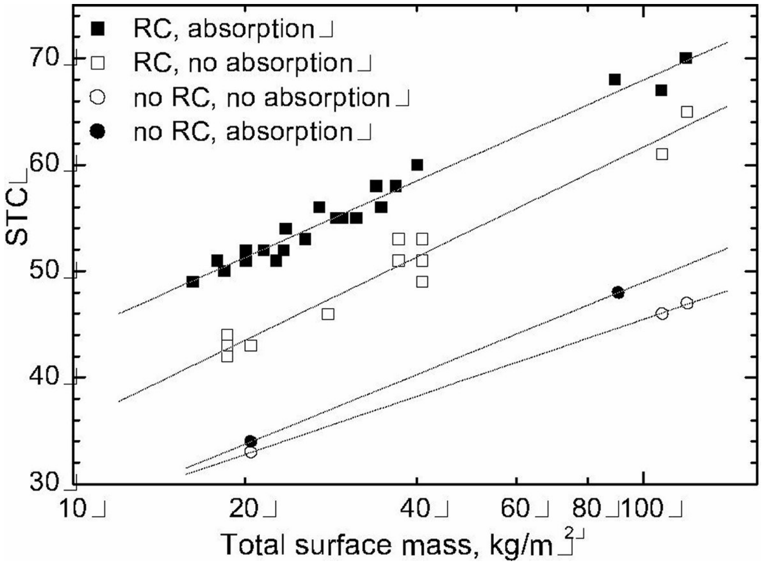

Figure 6: Dependence of STC on total surface mass for floors with 240 mm deep joists spaced 406 mm apart; resilient metal channels are spaced 610 mm apart.

For floors incorporating resilient metal channels and sound-absorbing material, the regression equations are:

$STC = 7.1 + 23.9 \log_{10}(MassOfLayers) + 0.0086\ JoistDepth + 0.0066\ JoistSpace + 0.017\ InsThick + 0.0085\ RCSpace + 0.030\ InsDensity$, $r^2 = 0.92$, 110 cases

$IIC = 10.6 + 22.2 \log_{10}(MassOfLayers) - 0.010\ JoistSpace + 0.016\ InsThick + 0.012\ RCSpace$, $r^2 = 0.68$, 102 cases

In these equations dimensions are in mm, insulation density is in kg/m ^{3}, and the mass of the layers is in kg/m^2. For STC, 90% of all the predictions fell within ± 1 dB of the measured values, 96% within ± 2 dB, and 94% of the predictions were no more than 1 dB below the measured values. For IIC the corresponding values are 75%, 92% and 89%. Because of the strong influence of the floor surface, floors incorporating concrete or resilient toppings were excluded from the analysis, thus the regression equation for IIC is of limited value.

It is surprising that the IIC rating shows a negative dependence on joist spacing whereas the STC increases with joist spacing. No explanation has been found for this. More detailed study using one-third octave band data may provide insight.

7 - WOOD I-JOIST TYPE

While the regression equations above were adequate for building code purposes, there were significant outliers in the data. I-joist floors proved to be particularly variable. Eight floors, nominally identical except for the brand of I-joist, were tested to determine whether using I-joists from different manufacturers had an effect on sound insulation. All floors in this sub-set had the same construction as the reference floor except 241 mm deep I-joists were used instead of solid wood joists. Flange materials and dimensions varied and the material in the web was either OSB or plywood. The STC ranged from 48 to 53, the IIC from 42 to 46, ranges that are significant and perplexing. The standard deviation and range for the transmission loss and impact sound level measurements are shown in Fig. 7 and Fig. 8, which also show the standard deviation for rebuilds of the reference floor.

No reason has been found for these disparate ratings. The differences in IIC and STC can not be attributed to the small variations in weight of the floor constituents. Differences in I-joist dimensions, weight and calculated dynamic properties were also minor. Future work may determine the reason for the differences.

8 - SUMMARY

More details on this project can be found in the two internal reports cited earlier [1,2]. A paper of this length can only mention some of the more obvious issues. The data presented here show that rebuild repeatability for some floor constructions can be quite small. For others, this is not the case and the factors responsible for the variability have yet to be determined. A second phase of this project is beginning and some of the issues may be addressed in that.

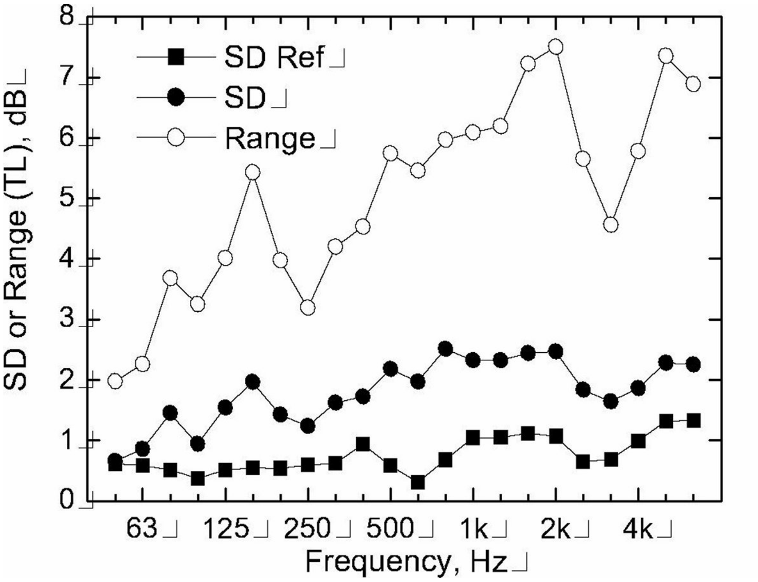

Figure 7: Standard deviation and range of transmission loss values for floors differing only in the type of I-joist used; SD Ref is the standard deviation for the reference floor described earlier.

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7. **ASTM E989**, *Standard Classification for Determination of Impact Insulation Class*

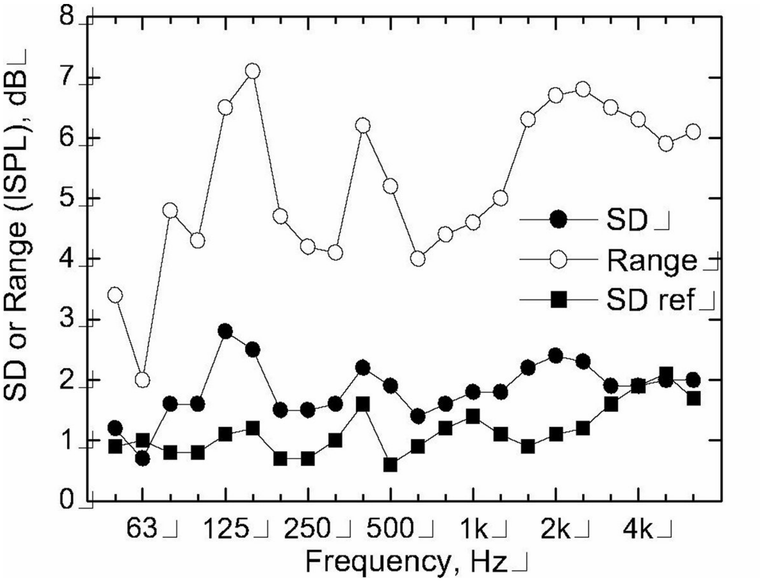

Figure 8: Standard deviation and range of impact sound levels for floors differing only in the type of I-joist used; SD Ref is the standard deviation for the reference floor described earlier.