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EFFECT OF JOIST LENGTH ON SOUND TRANSMISSION THROUGH WOOD JOIST FLOORS

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The construction of a new floor facility at NRC [1] presented an opportunity to compare sound transmission data for similar floors measured in two rather different facilities. Two issues to be resolved were whether specimen size or room volume influences the results of standard tests from 100 Hz to 4000 Hz or the results of experimental impact sound measurements at frequencies down to 50 Hz or less. An earlier paper [2] presented some early comparisons of airborne and impact sound transmission for nominally identical floors measured in the two facilities. That paper also presented sound transmission results for a wood joist floor that had been sawn into two pieces along a line parallel to the joists and each piece tested separately. Other work [3] had suggested that there ought to be a strong relationship between sound transmission at low frequencies and joist dimensions. This paper presents some sound transmission results for a floor that was progressively made smaller by sawing through the joists. As well some further comparisons between results obtained in the two NRC floor testing suites are presented.

FLOOR TEST FACILITY AND MEASUREMENT TECHNIQUES

Both reverberation rooms in the new facility [1] have volumes of about 175 m^3. Standard measurements on the test floors include airborne sound reduction (50 to 6300 Hz) and impact sound insulation using the ISO standard tapping machine (25 to 6300 Hz). These data are used to calculate sound transmission class (STC), impact insulation class (IIC), and other single number ratings as needed. As well as the standard tapping machine tests, sound pressure levels from three other impactors are measured. These are: a male walker wearing leather shoes; a black rubber ball 180 mm in diameter, weighing 2.5 kg and dropped from

900 mm; and a version of the JIS 1418 tire machine modified to reduce the peak force.

Floor specimens are constructed in a concrete frame that can be inserted between the two rooms and withdrawn for modifications. The floor specimen opening in normal use measures 3.8 x 4.7 m. Specimens are slightly larger than this so they rest on the lip of the frame. To support floors with joists shorter than the long dimension of the frame, a special movable concrete support was constructed. This support is sketched in Fig. 1 and Fig. 2. The filler section shown in Fig. 2 held a 150 mm thick concrete slab, a 300 mm thick layer of sound absorbing material and a layer of 16 mm gypsum board so sound transmission through this section was negligible relative to that through the floor under test.

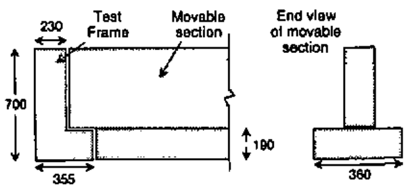

Fig. 1: The movable support used to change the floor size by supporting different joist lengths. (dimensions in mm)

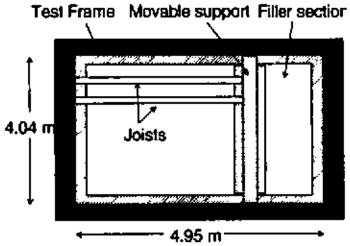

Fig. 2: Illustration of the use of the movable concrete support when testing floors with different joist lengths.

Floor Specimen

The construction tested consisted of a layer of 15.1 mm thick oriented strand board (OSB), (8.8 kg/m^2) attached to joists by screws spaced 150 mm apart around the perimeter and 300 mm apart elsewhere. The long axis of the OSB was perpendicular to the joists. The joists initially measured 38 x 235 x 4850 mm, were 400 mm apart and were end-nailed to the headers. Two sets of 19 x 64 mm cross bracing were installed between the joists 1615 mm from each short edge of the floor. 13 mm deep resilient metal channels were screwed 600 mm apart and perpendicular to the joists. Type X gypsum board, 15.9 mm thick (11.3 kg/m^2), was attached with the long axis perpendicular to the resilient metal channels with screws 300 mm apart A layer of glass fiber batts 150 mm thick was placed in the joist cavities.

The floor was first constructed to completely fill the test frame. Part of the OSB layer and the gypsum board were then removed at one end, the joists cut to a new length and a new header installed. The movable support was inserted, the floor repaired and the filler section constructed and sealed. This process was repeated for joist lengths of 4.34, 3.45 and 2.92 m. The cross-bracing was either left in place or removed completely as necessary during modifications. The results are shown in Fig. 3. The case where the joist length was 3.92 m is for a full-size floor with the joists perpendicular to the long axis of the specimen frame, the normal way of orienting joists, trusses, or I-beams in the laboratory.

The striking thing about these results is the close agreement between them. Apparently joist length and floor size do not influence the sound transmission through the floor even at low frequencies.

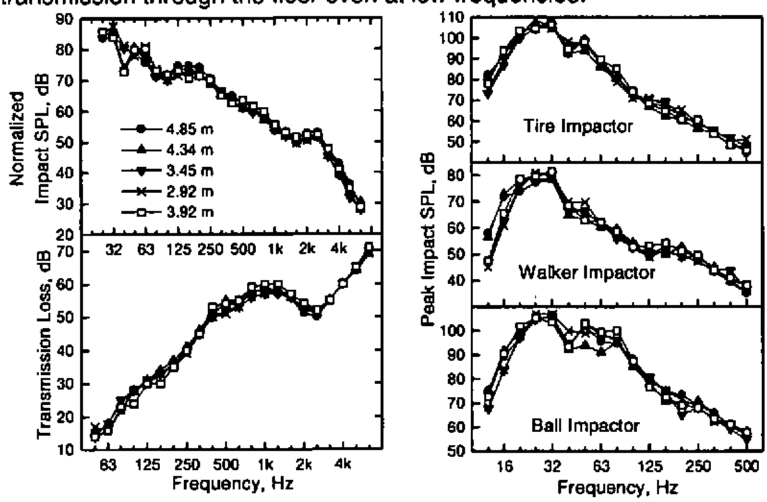

Fig. 3: Transmission loss, normalized impact sound pressure level from ISO tapping machine, and maximum impulse sound levels generated by the Tire, ball, and walker. All floors had STC 51 except for the 4.34 m case which gave STC 52. All had an IIC of 46 except for the 4.85 m case which had an IIC of 44.

VIBRATION MEASUREMENTS

To get further insight into what was happening with these floors, the vibrational response to an electrodynamic shaker was measured in nine places using an accelerometer. The measurements were made for other purposes but can be used to look at the response of the floor at low frequencies. In the previous paper it was suggested that the peak velocity in the floor would occur at the fundamental frequency, f_0. An approximate expression for f_0 is [4]

$$f_0 = \sqrt{\frac{E_j I_j (n-1)}{\rho_s h b + \rho_j c d (n-1)}}.$$

Here b is the floor width, h is the floor thickness, E_j is the joist modulus of elasticity, I_j is the joist moment of inertia, ρ_j is the joist density, ρ_s is the sheathing density (the OSB), c is the joist thickness, d is the joist depth and n is the number of joists, all in compatible SI units. This expression assumes no composite action between the sheathing and the joists. The calculated values of f_0 for the joist lengths used, in order of decreasing length, are 17, 21, 25, 34 and 47 Hz. Unfortunately, simple expressions can overpredict the resonance frequency, by as much as 40%. Shear deformation and rotatory inertia must be taken into account [5] to get closer to experimentally measured values. As well, edge conditions and the strength of the composite action have an influence on f_0.

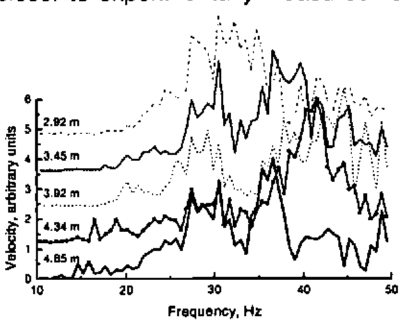

Fig. 4: Velocity measured on the five floors shown staggered for clarity.

The velocity response at one position on each floor is shown in Fig. 4. There are peaks at the low frequencies that might be identified as fundamental resonances, and low frequency peaks are less evident as the joist length decreases, nevertheless, the response is much greater at 30 Hz and above in all cases. These vibration measurements support the result from the acoustical tests, namely that the fundamental resonance is not so important when determining the radiated sound power.

COMPARISONS BETWEEN NRC FLOOR TEST FACILITIES

The previous paper on this topic [2] presented comparisons for floors measured in the old facility and the new facility. The test floor in the old facility measures 2.4 x 2.4 m and the receiving room has a volume of 65 m^3. At that time there seemed to be significant low frequency differences for closely similar wood joist floors. Since then, more floors have been measured in the new facility and other comparisons with the results from the old facility can now be made. Fig. 5 shows data for floors where the sub-floor in each case was 16 mm plywood, the joists were of solid wood (38 x 235 mm) spaced 400 mm apart, and the ceiling was 16 mm gypsum board. Differences in the way the joists were attached to the headers, the thickness of the glass fibre batts used, and in the spacing between the resilient metal channels are detailed in Table 1. The specimen identified as *new H* was presented in the previous work [2]. The transmission loss and the ISO impact levels show significantly greater sound transmission from 80 to 315 Hz. This result now seems to

Table 1: Differences in floor constructions in Fig. 5.

Case	Joist attachment	Channel spacing	Glass fibre
new H	hangers	400 mm	90 mm
old E	end-nailed	400 mm	90 mm
new E	end-nailed	600 mm	150 mm

be anomalous. Many floors of this general type have been tested using OSB and plywood. Increasing the thickness of the glass fibre batts and increasing the spacing between resilient metal channels increases the sound insulation but the general shape of the curves remains the same. It is tempting to attribute the increased transmission around 80 to 315 Hz to some influence of the joist hangers. These might allow the joists to rotate more freely about their long axis thus allowing the plywood to vibrate and radiate more. It will require further work to investigate this possibility.

The low frequency results from the walker and the tire machine

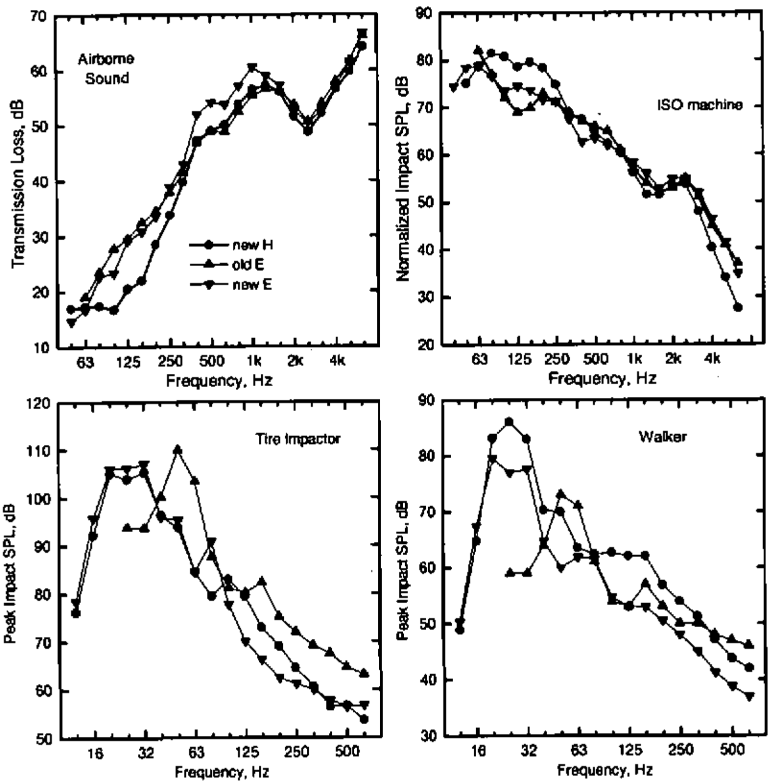

Fig. 5: Wood joist floors measured in two test facilities.

continue to be puzzling. The two receiving rooms show peaks at very different frequencies. It is tempting to suppose that the rooms are not responding in the low frequency bands where there are few modes. In the 65 m^3 room there are 3 modes in the 63 Hz band and 3 in all the bands below that. In the 175 m^3 room the corresponding numbers are 5 and 8. This hypothesis does not stand up well to close examination, however. Measurements of vibration response of the floor inside and outside the reverberation rooms showed no difference in relative response. If the room were limiting the response of the floor, there should have been a difference. McKell [6] presented levels from walkers on floors measuring 4 x 3 m with a receiving room volume of 150 m^3. For five wood joist floors and two hollow-core concrete slabs, the low frequency peak occurred around 32 Hz as it did in this work Blazier [3] found, however, that the maximum sound energy occurred around 20 Hz when a joist floor measuring 3×4 m with 4 m long joists was walked on. The room volume in his case was only 30 m^3.

CONCLUDING REMARKS

The conclusion from the current work is that floor joist length makes no significant difference to the measured sound transmission. The previous work [2] where the floor was cut in two pieces parallel to the joists, while producing an anomalous result, suggested that the floor breadth, perpendicular to the joists was not important.

The comparison between current results from the new facility and those from the old also suggest that floor size is not a significant factor in determining the airborne and tapping machine sound insulation down to about 50 Hz even in different laboratories. Most of the observed differences can be attributed to variations in construction techniques.

The major problem remaining seems to be the different location of the peak response when floors are walked on or struck with heavy impactors. While this remains unresolved, a new low frequency test could not be expected to give reproducible results at very low frequencies.

[1] R.E. Halliwell, J.D. Quirt, and A.C.C. Warnock, INCE 93, p995.
[2] A.C.C. Warnock, INCE94, p 1427.
[3] W.E. Blazier Jr. and R.B. Dupree, JASA, **96**, #3, p1521, 1994.
[4] I. Smith and Y.H. Chui, Canadian J. of Civil Eng., **15**, p 254, 1988
[5] I. Smith, L.J. Hu and A.B. Schriver, Canadian J. of Civil Eng., **20**, p885, 1993.
[6] B. McKell, "The Development of a Screening Test to Determine the Impact Sound Insulation of Floors", Thesis, Heriot-Watt University, Edinburgh, April 1991.