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THE SOUND INSULATION OF WOOD JOIST FLOORS

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INTRODUCTION

The objective of this work was to develop a lightweight construction, based on timber joists and plasterboard ceilings, which would with some degree of certainty satisfy the Building Research Station party floor standards for Grade 1 sound insulation. The secondary objective was to make a complete study of the sound insulating properties of typical timber joist systems and accurately compare their performance and cost. This study is, as yet, incomplete.

Between 1948 and 1958 the Building Research Station have carried out extensive field measurements of the sound insulation properties of various floor structures and have related these studies to the subjective impressions of noise transmission between dwellings.[1] Grade 1 insulation is supposed to refer to the case where more than 70% of the occupiers would be satisfied with the general level of sound being transmitted through the party floor under normal conditions. These studies have indicated that the only sure way to meet the proposed standard is by the use of 150 mm thick reinforced concrete with a floating screed or wood raft or a suitable soft floor covering. The grade curves then, are based upon the average measured sound insulation of this type of floor under field conditions.

The Building Research Station have categorised a few types of wood joist floors which satisfy Grade 1 conditions for both airborne and impact conditions if used with "thick" walls. The "thick wall" term being usually applied to double thickness masonry weighing more than 400 kg/m^2. These floors have a floating raft, 50 mm of sand pugging, plaster on wood or metal lath ceilings, and weigh about 150 kg/m^2. The draw-back here, however, is that plaster and lath ceilings are rarely used nowadays and dry sand is difficult to keep dry on building sites. Plasterboard will not normally support the weight of sand pugging without special precautions.

This paper, therefore, describes how, starting with a standard wood joist floor and plasterboard ceiling it was possible to carry out a systematic examination of the effects of successive modifications, keeping all other parameters constant, and hence gain an understanding as to what is required for further developments.

METHOD OF MEASUREMENT

All the floor specimens were built into an aperture 3.1 m square. The aperture was contained in a floor slab 450 mm thick. This slab is vibration isolated from both the upper and lower 108 cu m reverberation rooms.

Measurements were carried out in accordance with I.S.O. R 140 using $^1/_3$ octave white noise and a B & K tapping machine as appropriate.

CONSTRUCTION OF FLOORS

The constructions, for a variety of reasons, were divided up into two basic categories depending upon the main structural element.

A) Floors based upon 175 mm x 50 mm joists located at 400 mm centres.

B) Floor to a special Timber Research and Development Association design based on 200 mm x 38 mm joists at 300 mm centres. The 50 mm deep dry sand pugging is contained in a semi floating plywood sub floor. Joists are fire protected with mineral wool matts sandwiched between ceiling membrane and resilient fixing.

The summarised results of the measurements on the floors are shown in Table 1, where R is the average sound reduction index, and R_E is the empirical mass law [2] sound insulation, and I_i is the impact insulation index according to I.S.O. R 717. (There being no other convenient single figure method of rating impact sound insulation in common use in the U.K. as yet).

Where the table refers to a floating floor, this implies that the floor membrane is screwed to battens which rest on a 25 mm thick paper backed mineral wool quilt draped over the joists. MW pugging, implies granular mineral wool pellets laid about 100 mm deep. Gravel pugging, implies dry gravel 50 mm deep. Resiliently mounted ceilings refer to ceiling boards screwed to Z shaped metal channels (24 s.w.g. steel) fixed across the underside of the joists. These resilient furring strips are usually spaced at 600 mm centres and effectively vibration isolate the ceiling from the floor structure.

All floor specimens were constructed by building site tradesmen and measured without floor coverings.

RESULTS AND CONCLUSIONS

The investigation was much more extensive than table 1 indicates, and also included field measurements. For the

But Z cosec θ_0 = slant range D (figure 1), and another inversion of equation (7) thus gives

$$D = \bar{C}t[1 + \tfrac{1}{2}\overline{y^2}\ (\bar{C}^2t^2/z^2 - 3)] \qquad (8)$$

Equation (8) expresses D directly in terms of travel time, depth of water and the mean and standard deviation of the velocity/depth profile. It constitutes the solution to the problem.

Accuracy

Equation (8) is an approximation in which terms in $\overline{y^3}$ and higher moments have been ignored, and it is clearly necessary to determine the errors so introduced (and indeed even to decide if the series is convergent).

The problem may be expressed as follows. Given only the mean and standard deviation of the velocity profile, which profiles will give the maximum deviations from the true slant range when using the expression in equation (8)? This problem has been solved by expressing the various integrals in the basic equations as equivalent sums over a number of discrete points (e.g. $nX = Z \sum_{r=1}^{n} \cot \theta r$), and then using the method of Lagrangian multipliers to determine the values of Cr which give X a stationary value.

The analysis shows that stationary values will occur when the Cr have only two discrete values (i.e., a two layered medium). This condition by itself is not sufficient, however, since, in the absence of further constraint, X (for a given t) can be as large as desired. The further constraint may be imposed by limiting the extreme values of Cr to the extreme values shown on the known velocity profile. If this is done it can then be shown that the extreme values are obtained when one of the two values of Cr is made equal to the maximum or to the minimum values of C on the profile (figure 2). It will be easily seen that either of these conditions, together with the given values of $\bar{C}$ and $\overline{y^2}$, determine the two-layer profile completely.

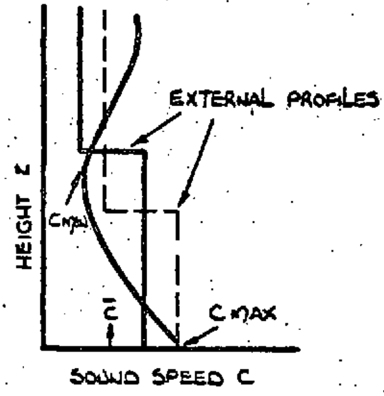

Figure 2. Extremal Velocity Profiles

From these extreme profiles it can be shown that the series expansion is convergent, and that the value of D is given by

$$D = \bar{C}t\left[1 + \tfrac{1}{2}\overline{y^2}\,(\bar{C}^2t^2/Z^2 - 3)(1 + \varepsilon)\right] \qquad (9)$$

where ε, the error factor, is limited by

$$\cot^2\theta_0\,(\overline{y^2} - b^2)/b \leq \varepsilon \leq \cot^2\theta_0\,(a^2 - \overline{y^2})/a \qquad (10)$$

$$C_{max} = \bar{C}(1 + a)$$

$$C_{min} = \bar{C}(1 - b)$$

For most real profiles $a - b \ll a + b$, and in these conditions it can be shown that the extreme values of ε are given, to a good approximation, by

$$\varepsilon = \pm\tfrac{1}{2}X^2/X^2_{max} \qquad (11)$$

where Xmax is the maximum range for which a direct water path is available. It follows that the maximum uncertainty occurs at this limiting range, and is there equal to ½ the magnitude of the second order correction term; for shorter ranges the actual error in range decreases as the fourth power of range, and thus soon becomes negligible.

Numerical Values

To obtain a feel for the magnitudes involved, consider the profile shown in figure 3, which is typical of a deep-water oceanic profile.

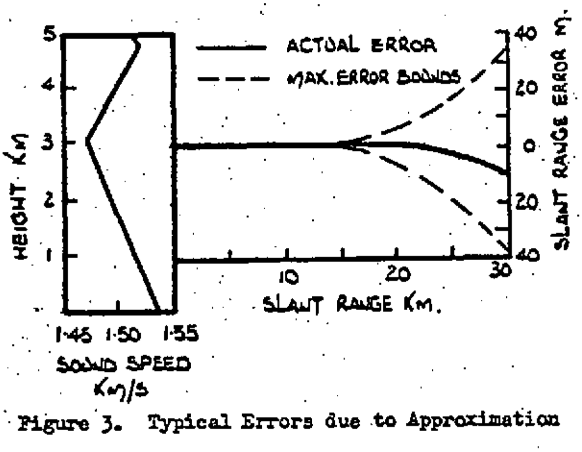

Figure 3. Typical Errors due to Approximation

The total variation of Sound Speed in this profile is 4.4%, $\overline{y^2}$ is 1.42×10^{-4}, and the limiting range is 29.3 Km for a depth of 5 Km. Slant ranges as a function of travel time have been computed by exact ray-tracing and by using equation (8). The

APPENDIX TO PAPER 70/70: "THE SOUND INSULATION OF WOOD JOIST FLOORS" by C.WALKER.

TABLE 1

CONSTRUCTION NO.	TYPE	THICKNESS mm	WEIGHT kg/m^2	FLOOR SYSTEM	PLASTERBOARD CEILING	R dB 100-3200 Hz	R_{x} dB MASS LAW	I_i	REMARKS
1	A	210	35	22 mm floor boards	1 layer 12.7 mm	31	32	88	
2	A	270	38	As above but floating	1 layer 12.7 mm	44	33	77	
3	A	260	50	22 mm floor boards	1 layer 12.7 mm but pugged MW	40	34	82	
4	A	270	52	22 mm floor boards floating	1 layer 12.7 mm pugged MW	48	35	72	
5	A	283	62	22 mm floor boards, floating	2 layers 12.7 mm pugged MW	49	36	71	
6	A	226	37	22 mm floor boards	1 layer 12.7 mm resil. mounted	38	33	80	
7	A	226	39	22 mm floor boards	1 layer 12.7 mm resil. mounted 25 mm MW in cavity	43	33	72	
8	A	290	65	Floating floor as above	2 layer 12.7 mm resil. mounted and pugged MW	51	36	70	
9	A	300	72	Floating floor as above	2 layer 12.7 mm 1 layer 9.5 mm resil. pugged MW	49	37	66	Laboratory Grade 1
10	A	299	73	Floating floor 22 mm boards + ¾" plasterboard	1 layer ¾", pugged with MW	49	37	66	Laboratory Grade 1
11	A	215	108	Floating floor 22 mm Chipboard	2 layers, 12.7 mm pugged with gravel	55	38	57	Laboratory Grade 1
12	B	305	122	Semi floating ⅞" T & G sand filled sub-floor	2 layers, 12.7 mm resil. + MW mattress	54	40	60	Laboratory Grade 1

Note: ⅞" = 22 mm ¾" = 19 mm 12.7 mm = ½" 9.5 mm = ⅜" sake of brevity, only the most important results are shown. As a result of this work, however, we were able to draw the following broad conclusions.

1) The simpler forms of floors, types 1 and 3 as used in two storey domestic houses behave acoustically in an analogous manner to simple timber stud partitions. The depth of joist is of little significance and the main factor controlling the insulation is the mass of the floor and the air leaks in the floor boards.

2) Improvements of about 8 dB average insulation to the standard house floor can be brought about by the use of either mineral wool pugging or resilient ceiling fixings.

3) The use of either a floating raft floor or a resiliently mounted ceiling with mineral wool, can increase the sound insulation of a standard house floor by as much as 12 dB average. Both systems are acoustically equivalent.

4) Either a floating floor with a rigid ceiling or rigid floor with a resilient ceiling behave acoustically rather like a double leaf partition and give about 10 dB greater than mass law.

5) A floating floor with a normal plasterboard ceiling suitably pugged with mineral wool will not meet the standard required by the Scottish Building Regulations for party floors.

6) Combining a floating floor with a resilient ceiling and mineral wool pugging gives a construction which has a high value of acoustic insulation at all frequencies above 200 Hz. These constructions exceed mass law by 17 dB and generally give an average insulation of about 50 dB.

7) Mass loading the ceiling of an otherwise floating floor system with a suitable dry granular pugging can result in insulation values as high as 55 dB. These floors will meet the necessary grading standards when constructed so as not to be too rigidly linked to the flanking structure.

8) If the heavy granular pugging is included in the sub floor i.e. not resting on the ceiling boards, it does not behave so usefully in dampening ceiling resonances but gives a more satisfactory structure in terms of fire resistance, liklihood of ceiling sag or collapse, and ease of prefabrication.

9) If a suitably heavy and rigid plasterboard ceiling is used in conjunction with a floating

floor dampened with one or more layers of plasterboard under the walking surface (total weight = 73 kg/m^2) heavy pugging is not necessary for the floor to meet the grading standard (Scottish).

10) The most difficult criterion proved to be the low frequency impact sound requirement for flats. Subjective measurements have shown that this criterion is in fact fairly important in practice especially when dealing with floor weights of only 60 kg/m^2. It is thought that 65 - 70 kg/m^2 is about the minimum weight of floor which will, within the capabilities of modern building technology, with any degree of certainty and within reasonable cost limits, meet the present British and International Acoustic Standards for floors in flats.

REFERENCES

1) National Building Studies, Research Paper 33, P. H. Parkin, H. J. Purkis, W. E. Scholes, H.M.S.O. 1960

2) British Standard Code of Practice CP3. Chapter III (1960) Sound Insulation and Noise Reduction P.105.