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Measurements on Timber-Framed Floors with a Granular Material in the Floor Topping

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ABSTRACT

Over the years timber-framed floor system designs have sometimes included some sort of granular material infill in order to reduce sound transmission between tenancies. Historically this has been in the form of some readily-available, low-cost material (e.g. ash, scoria, and sand). Recent research has been conducted into timber-framed floor toppings which contain a granular material infill in the form of a sand and sawdust mixture. The sand and sawdust mixture increases the mass of the floor, which improves the low-frequency impact insulation performance. This sand and sawdust infill also greatly increases the vibration damping in the upper part of the floor, improving the mid to high-frequency sound insulation performance, while also making the system robust to construction defects. This paper presents results of isolated element impact insulation and flanking transmission measurements of timber-framed floors which have a sand and sawdust mixture in the floor topping.

INTRODUCTION

This paper is an analysis of some recent measurements conducted on timber-framed floor toppings (Emms et al, 2006; Emms & Walther, 2010). The focus of this paper is the use of granular materials in floor topping system. The form of the granular materials considered is sand and sawdust mixtures. The granular material infill increases the mass of the floor, which improves the low-frequency impact insulation performance. The granular material infill also greatly increases the vibration damping in the upper part of the floor, improving the mid to high-frequency sound insulation performance, while also making the system robust to construction defects.

GRANULAR MATERIALS IN FLOORS

Granular or particle-type materials have been used quite frequently in the past as an infill in timber structures. It was not uncommon to have sand or fly ash in timber floors in parts of the United Kingdom many years ago – the fill would be either placed on shelves between the joists or on the ceiling (which was made of material which could support the weight). The primary function of this fill was for sound insulation purposes. Another example of this is found in some old multi-storey timber buildings in New Zealand (e.g. the old parliament buildings in Wellington), where volcanic scoria was used in the floors. More modern references to this are found in Switzerland, where sand has been used as a layer in both retrofit and new buildings (Lappert & Geinoz, 1998). Incidentally, Lappert and Geinoz do note that the sand should be heated to ensure no living things are introduced.

Walk and Keller (2001) did recent work to develop a floor using a massive amount of ‘granular’ material on which a walking surface was floating. They do not say what exactly this granular material was and further communication with the authors did not reveal it, although they did say that it was being installed in a block of apartments. However, they said that the main reason for using this granular material was to take advantage of the high damping afforded by the granular material due to the friction between particles, because a lightweight floor, in their opinion, could never have enough mass to provide excellent sound insulation. Figure 1 illustrates this floor and shows how much granular filling there was in the floor (i.e. lots).

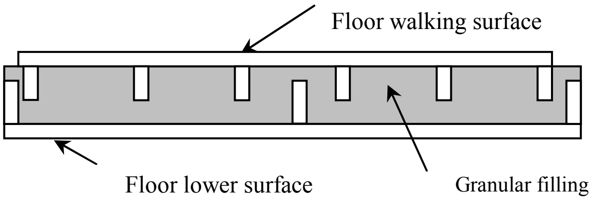

Figure 1. Swiss trial timber floor with upper floor surface floating on granular material (Walk and Keller, 2001).

Granular material vibration damping

Since granular materials, particularly sand, have been used with some success in buildings as a way of improving vibration damping, it is worth overviewing some of the literature which exists about this. It is clear from the literature that the damping processes which occur in granular materials are complicated and not very well understood apart form some specific instances.

A good account of the use of sand with other mixtures of materials has been provided by Kuhl and Kaiser (1962) for use with concrete structures. They tested various sands and mixtures (fine sand, course sand, brick rubble, and mixtures of sand and sawdust), and found that hard granular materials with sharp edges or with a soft material (e.g. sawdust or rubber dust) gave better damping at lower frequencies. They thought that this was due to the sharp edges giving more friction with vibrational strains and the lower wavespeed of vibrations in the sand sawdust or rubber dust mixtures. The sand/sawdust mixture tested was 80/20 sand/sawdust. They also note that the impedance of the granular fill should try to match the impedance of the surrounding, structural material to enable maximum coupling of energy into the granular fill. They determined that the maximum damping was attained at cavity resonances in the granular fill. The damping was also found to be non-linear in the sense that it depended on amplitude of the vibrations: higher amplitudes result in more movement of the granules and hence more friction.

Richards and Lenzi (1984) did measurements on the vibration damping due to sand and found that below a strain of 10^{-6} the particle movement is small and the damping in the sand is small and is probably not due to the friction of the particles; above that point damping becomes increasingly significant. They also noted that loose sand in cavities is useful because there is the added damping benefit of having the granules move around from regions of high density to regions of lower density. This movement is a maximum in resonances in the cavities which contain the granular fill.

Xu et al. (2005) note that shear friction is the major contributing factor to the damping due to granular fills. Since our concern in low-frequency floor vibrations is the bending waves in the floor which would cause a lot of shearing of any infill, this is an important point to note.

Sun et al. (1986) observed from experiment that, when looking at sand laid on a vibrating metal plate, the vibrational damping in the plate is a maximum at frequencies above when the thickness of the sand is about equal to $0.05\lambda_c$, where λ_c is the longitudinal wavelength of the vibrations in the sand ($\lambda_c = c/f$, where c is the propagation speed of the vibrations (100 to 200 m/s for sand) and f is the frequency). Below this point there is a sharp drop in damping, and above this point there is a gradual decrease (due to the increasing weight of the sand packing down the sand below and stopping movement of the sand granules). Interestingly, sawdust is often mixed with sand when used for anechoic terminations for experiments with vibrations in beams. The sawdust is included to keep the sand from packing down, thereby improving its absorption characteristics.

Other vibration damping sources

If vibration damping is important, another way to include this is to add a constrained viscous damping material, for example like a viscoelastic polymer glued between plywood layers. This can be expensive, and the polymer's damping performance can be dependent on frequency and temperature, but it is usually not dependent on vibration amplitude.

Yet another way to achieve more damping is to have layers of material and to rely on the interaction between these layers to provide more damping, whether by friction between the layers, air pumping, or fretting (where the surfaces become damaged due to rubbing, forming fragments, and thus contributing to frictional effects).

IMPACT INSULATION MEASUREMENTS ON FLOORS WITH GRANULAR MATERIAL INFILLS

In this section we describe measurements that were done on a number of floor system elements which have a granular infill in the floor topping. The granular infill used was either paving sand, or a mixture of paving sand and sawdust.

The floor elements were tested in the same facility, with suppressed flanking sound transmission, and in accordance with standard ISO 140-6.

The following floors were tested:-

- Basic Floor (Figure 13): A timber floor with plywood upper, solid timber floor joists, a fire-rated ceiling disconnected from the joists using rubber isolation clips, and filled with dense fibreglass.
- 40mm Sand Floor (Figure 14): The Basic Floor as a subfloor with a floor topping consisting of 40mm deep layer of sand between 45mm wooden battens, and another layer of plywood on the battens.The sand density is 1250 kg/m^3.
- 40mm Sand/Sawdust Floor (Figure 15): The Basic Floor with a floor topping consisting of 40mm deep layer of sand and sawdust between 45mm wooden battens, and another layer of plywood on the battens. The sand-sawdust mix is 60% sand and 40% sawdust by loose volume (density 1170 kg/m^3).
- 85mm Sand/Sawdust Floor (Figure 16): The Basic Floor with a floor topping consisting of 85mm deep layer of sand and sawdust between 90mm wooden battens, and another layer of plywood on the battens. The sand-sawdust mix is 80% sand and 20% sawdust by loose volume (density 1210 kg/m^3).

Measurement Results

In Figure 2 we can compare the results of the Basic Floor and the 40mm Sand Floor. The greater mass and damping of the floor upper has resulted in significant improvements to the impact insulation performance.

It was noted before that the addition of sawdust with sand does tend to improve the damping characteristics of sand alone. In Figure 3 we can compare the results of the 40mm Sand Floor and the 40mm Sand/Sawdust Floor. We note that although the mass has been slightly reduced by displacing sand with sawdust, the extra damping has resulted in an improvement of performance, particularly at the higher frequencies.

It was also noted that increasing the thickness of the sand/sawdust infill may improve vibration absorption at low frequencies. In addition, increasing the sand/sawdust layer will increase the mass, which will also improve the low-frequency impact insulation performance. In Figure 4 we compare the results of the 40mm Sand/Sawdust Floor and the 85mm Sand/Sawdust Floor. We see that the extra damping and greater mass has resulted in an improvement of performance for the mid to low frequencies.

It should be noted that the floor uppers with the granular infill are not floating on the subfloor in any way. The separation of the additional layer of plywood is achieved through battens which are directly fixed to the subfloor surface. And the top layer of plywood is directly fixed to the battens. There is no resilient isolation between layers. All the isolation is achieved through vibration absorption in the granular material. It is an inherently robust system.

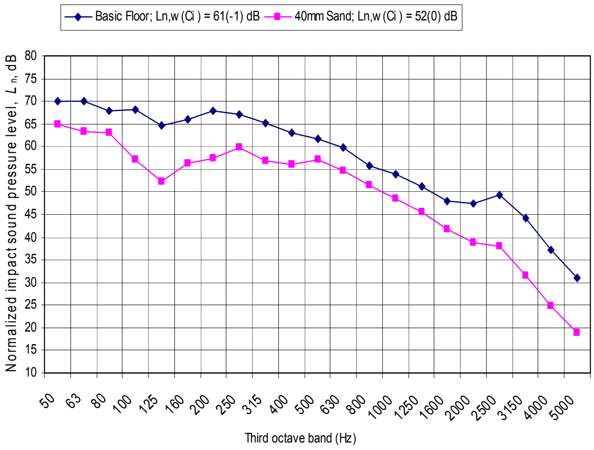

Figure 2. Comparison of the impact insulation performance of the ‘Basic Floor’ and the ‘40mm Sand Floor’. Both floors are 3.2m by 7m (joist length).

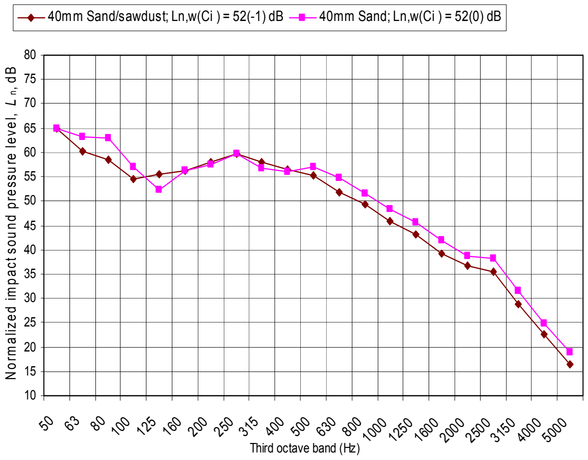

Figure 3. Comparison of the impact insulation performance of the ‘40mm Sand/Sawdust Floor’ and the ‘40mm Sand Floor’. Both floors are 3.2m by 7m (joist length).

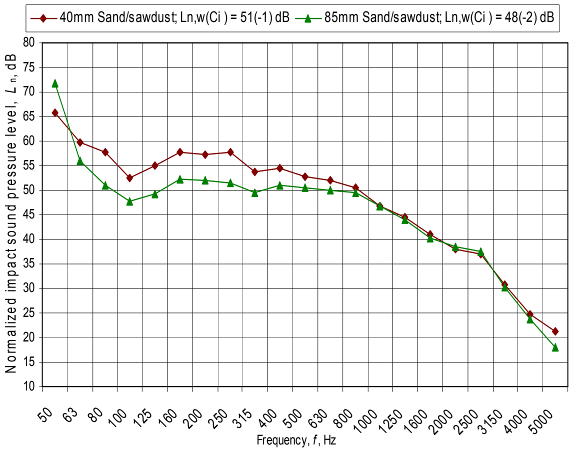

Figure 4. Comparison of the impact insulation performance of the ‘40mm Sand/Sawdust Floor’ and the ‘85mm Sand/Sawdust Floor’. Both floors are 3.2m by 5.5m (joist length).

FORCED VIBRATION MEASUREMENTS

In the previous section it was stated that the granular infills are able to absorb the vibrations generated in the floor (presumably by impacts). This can be shown experimentally from surface vibration measurements.

On the floor an electrodynamic shaker was used to provide a vertical force on the floor upper surface. The shaker was connected to the floor through a wire stinger and a reference force transducer. A scanning laser vibrometer (Polytec PSV 300) was used to measure the velocity of the floor and ceiling normal to the surface. A grid with a spatial resolution of 10-14cm was used to obtain a map of the surface velocity of the floor and ceiling relative to the input force; both amplitude and phase information was recorded at each frequency.

Figure 5 shows the results of the vibration measurements on the ‘85mm Sand/Sawdust Floor’. We can see how the vibration is quickly damped by the granular infill.

In comparison, Figure 6 shows the results of the vibration measurements on a floor with a floating gypsum concrete screed (Figure 17). We can how the vibration is not damped, and spreads over the whole floor. Carefull edge detailing is therefore required to avoid severly reducing the floors sound insulation performance.

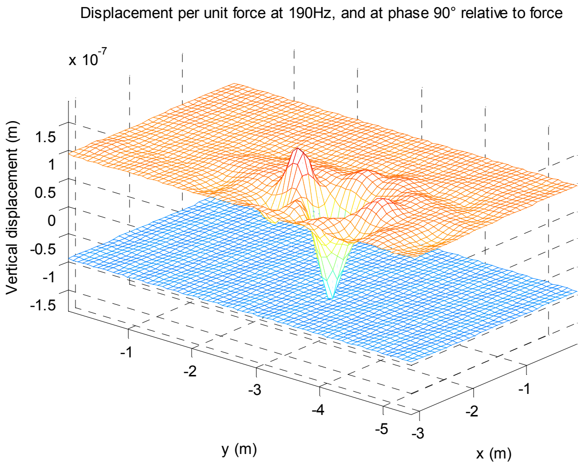

Figure 5. Measured vibration (displacment) of the 85mm Sand/ Sawdust floor upper surface and ceiling from 1N of forced vibration on the upper surface.

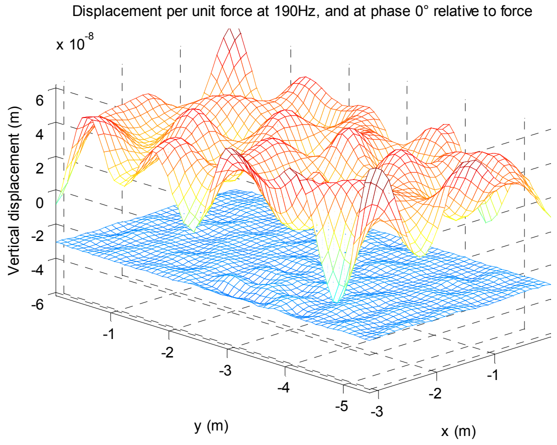

Figure 6. Measured vibration (displacment) of a Floating Gypsum Concrete floor upper surface and ceiling from 1N of forced vibration on the upper surface.

FLOOR/WALL SYSTEM MEASUREMENTS

The performance of a floor/wall system with a granular material-infilled floor topping was measured in the BRANZ four-room flanking test facility. The flanking facility was designed to test the sound insulation of a horizontal cruciform wall/floor system (Figure 7). All other sound paths were suppressed by the test facility (Emms & Walther, 2010). The measurements were done in accordance with standard ISO 140.

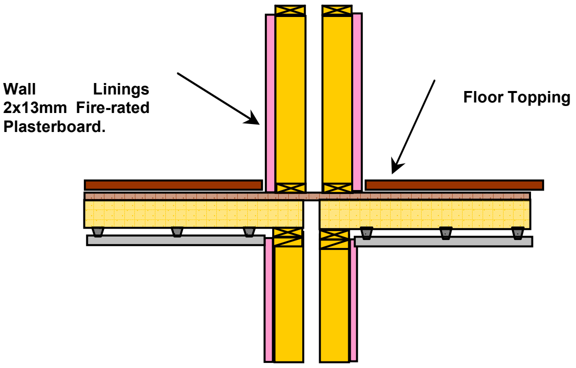

Figure 7. The form of the specimen tested for flanking transmission.

The system under test used the floor's 17mm plywood as a structural floor diaphragm. Hence there was significant acoustic bridging for horizontal sound transmission. The wall consisted of a double-stud construction, with two layers of 13mm fire-rated plasterboard on each side (Figure 7). The subfloor construction is shown in Figure 8. On the subfloor a number of floor topping systems were trialled. The measurement results of two floor toppings are examined:-

- 20mm particleboard screwed to the subfloor.
- 45mm deep battens screwed to subfloor, 40mm of sand/sawdust (80% / 20% by loose volume) infill between battens, and 20mm particleboard screwed to top of battens. Edges are constructed by butting battens against walls –no foam separation was used.

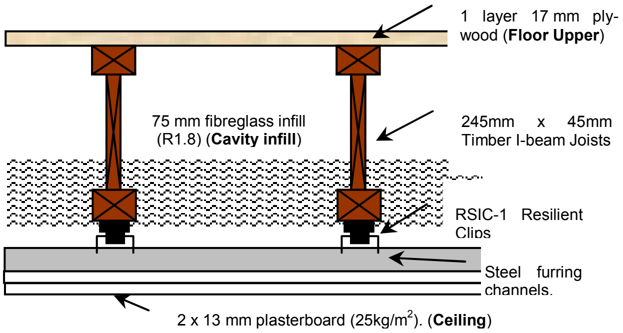

Figure 8. The basic subfloor used for the flanking transmission measurements.

Measurement results

In the following figures we compare the sound insulation measurement results of the two floor toppings (i.e. 40mm sand/sawdust and 20mm particleboard).

We can see that the sand/sawdust mixture markedly improves the horizontal insulation performance (Figure 9 and Figure 11). Presumably this is due to a significant reduction in vibration energy being transmitted to the subfloor and across the continuous floor diaphragm. The horizontal airborne insulation performance of the system (Figure 11) with the 40mm sand/sawdust topping system is limited by the wall performance; whereas the sound transmitted via the floor flanking path limits performance in the 20mm particleboard system.

The sand/sawdust mixture also improves the vertical insulation performance (Figure 10 and Figure 12). This improvement is due to a combination of increased mass and damping in the floor topping reducing energy being transmitted to the ceiling and to the frame and wall.

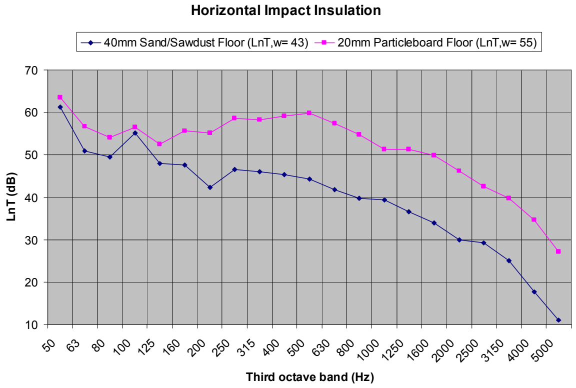

Figure 9. Horizontal impact sound insulation measurements.

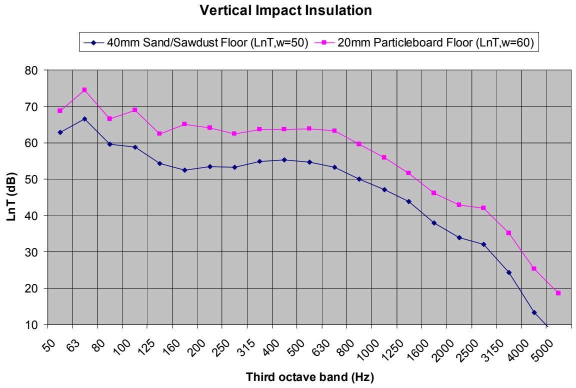

Figure 10. Vertical impact sound insulation measurements.

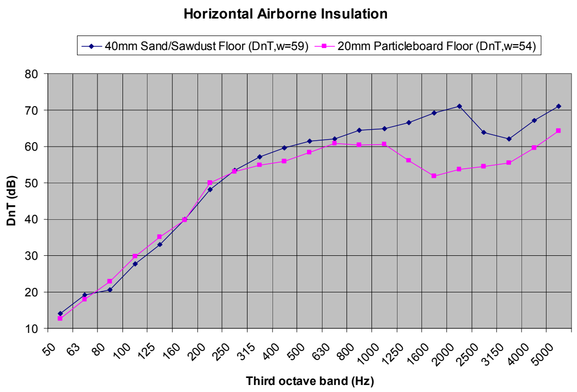

Figure 11. Horizontal airborne sound insulation measurements.

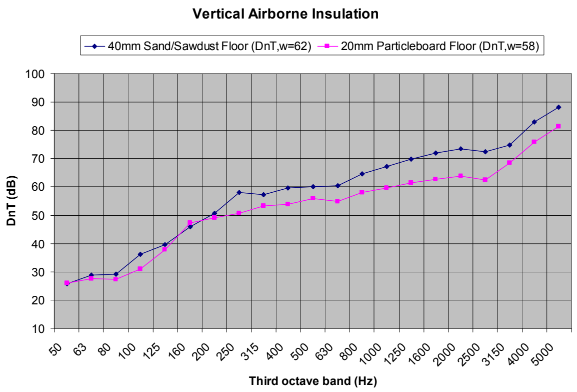

Figure 12. Vertical airborne sound insulation measurements.

CONCLUSION

In this paper the use of granular materials (specifically sand and sand/sawdust mixes) in floor topping systems have been considered. Recent measurement results were compiled and examined to show that these sorts of systems can significantly improve the sound insulation performance of the floor. The improved performance is due to increased vibration damping and due to increased mass. As a result of these two factors, performance is improved across the whole frequency range.

It was also shown that the vibration damping effect localises impact vibrations, thereby reducing flanking transmission issues.

Another advantage such floor topping systems with granular infill is that they are not floating on the subfloor in any way. The topping is directly fixed to the subfloor, and there is no resilient isolation between layers. Edges are simply constructed by butting battens against walls – again no foam separation is used. All the isolation is achieved through vibration absorption in the granular material. It would appear, therefore, that it is an inherently robust system.

ACKNOWLEDGEMENTS

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Thanks to Tony Walther and Graeme Beattie for the opportunity to make the flanking transmission measurements at BRANZ, Judgeford, New Zealand.

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APPENDIX: FLOOR DIAGRAMS

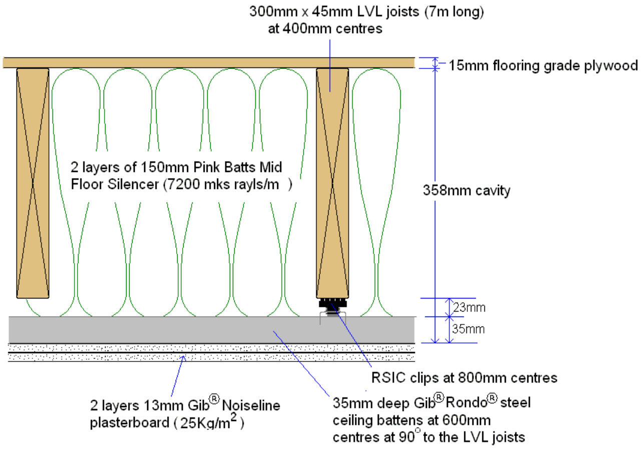

Figure 13. The 'Basic Floor' on which toppings were added.

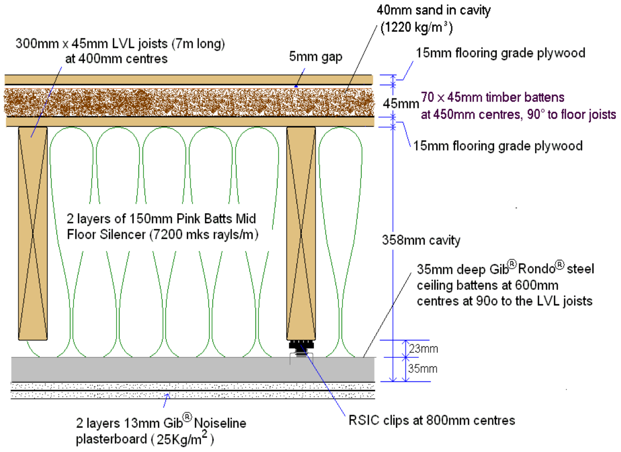

Figure 14. The '40mm Sand Floor'.

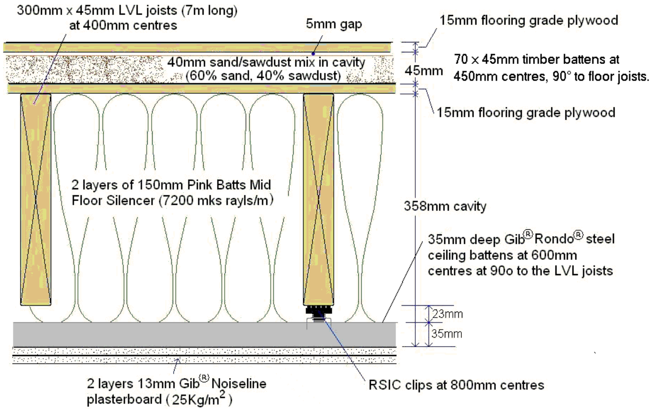

Figure 15. The '40mm Sand/Sawdust Floor'.

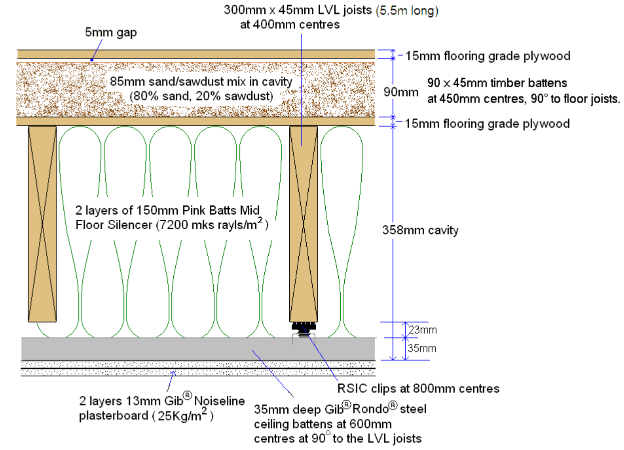

Figure 16. The '85mm Sand/Sawdust Floor'.

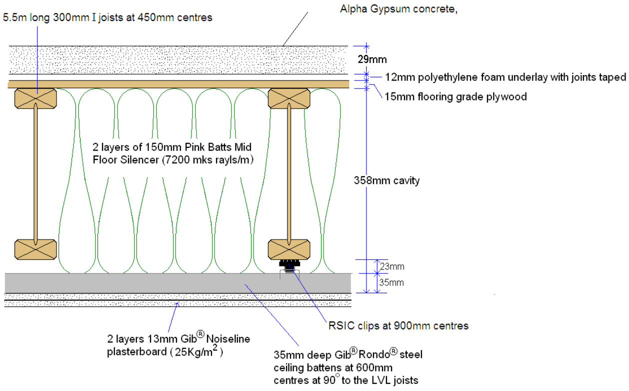

Figure 17. Floating Gypsum Concrete Floor.