Prediction of Acoustic Performance of Composite Steel Floors

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ABSTRACT

One method of constructing lightweight concrete floors in residential dwellings is to use a trapezoidal profile steel pan as a permanent form for a relatively thin pour of concrete. The resulting structure has enhanced stiffness to weight ratio due to the composite action between the steel and concrete, and the inherent improved stiffness of the profiled cross section. However the floor is strongly orthogonal and the composite action makes the bending stiffness's difficult to calculate. Common models for predicting the sound insulation of panels are not accurate. Heckl has provided a solution for the sound transmission of an orthogonal panel, which requires a double numerical integration, however this is time consuming to solve especially if accuracy at high frequencies is required. The current work reports a successful use of ANSI C-2011 Standard for Composite Floors to calculate the bending stiffness's of the floor in orthogonal directions and implementation of a Gauss- Legendre method for carrying out the double integration.

Keywords: Sound insulation, sound transmission, concrete, composite steel floor, orthotropic

1. INTRODUCTION

Composite steel floors are a common method of constructing concrete floors (see fig 1.) They consist of a folded steel pan (typically a trapezoidal profile), onto which concrete is poured. The steel pan is not only used as a permanent form work, but also increases the stiffness of the floor, both by the increase in bending stiffness due to the profile, and also by the contribution of the steel due to composite action. The steel layer is thin (0.7 – 1.5mm), but it has a high elastic modulus (an order of magnitude greater than concrete) and is located on the plane of maximum bending. This composite effect relies on there being a good bond between the steel and the concrete, and this is often enhanced by texturing the steel pan and providing studs protruding into the concrete.

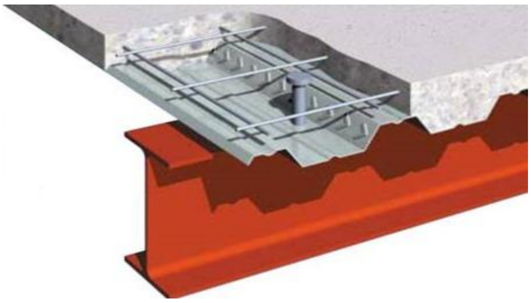

Figure. 1 – Typical composite steel floor

The composite action, and the profile give a high stiffness in the direction of the ribs, and such floors provide greater spanning capacity than an ordinary concrete slab. They permit a thinner concrete slab for the same spanning capacity, and this can be important both for economic reasons, and also for seismic reasons.

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However, composite steel floors have reduced sound insulation, partly because of their lower mass, but mainly because the profile of the finished slab makes the panels orthotropic, that is they have different properties in the x and y directions. The bending stiffness's in the x and y directions can be different by a factor of 5 or more. Because the stiffness's are different, in effect there are two critical frequencies, and the frequency region of reduced sound transmission due to coincidence is widened significantly. This can have the effect of reducing the weighted sound reduction (R_w or STC) by 6 or 7 dB compared to the equivalent mass of concrete.

2. PREDICTION METHODS

There are two key factors that complicate the prediction of the sound transmission loss of composite steel floors; the composite action of the steel pan, and more importantly the orthotropic nature of the construction.

The first factor can be accounted for by using methods developed for structural analysis. One such method is the American Standard ANSI/SDI C-011 *Standard for Composite Steel Floor Deck – Slabs* [1]. Note that concrete is a brittle material, and when used in a floor and subject to bending forces it is assumed that there will be cracking in the concrete where it is subject to significant tensile forces. This cracking must be taken into account when calculating the bending stiffness.

The ANSI Standard allows the calculation of the bending stiffness of simple composite slabs in the x and y directions (parallel to and perpendicular to the ribs) taking cracking into account. The required inputs include the profile of the steel sheet, the elastic moduli of concrete and steel and the thickness of concrete slab.

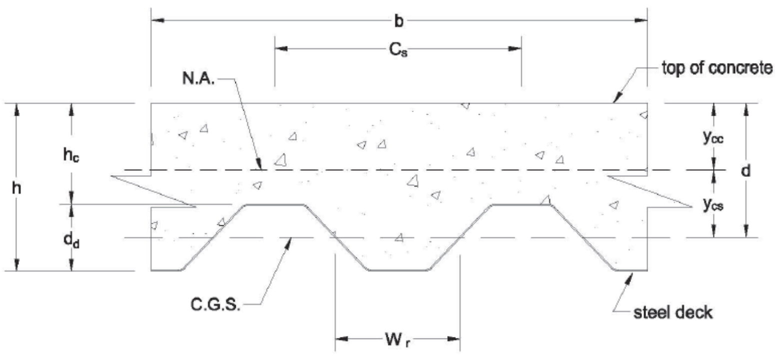

Figure 2 – Composite section showing location of neutral axis (from ANSI/SDI C-011)

The bending stiffness of the composite slab in the x and y directions can then be used to calculate the sound transmission loss of the construction. Heckl [2] has developed a method for predicting the sound transmission of orthotropic panels based on the bending stiffness of the panel in the x and y directions (Bx and By) which appear as the critical frequencies *fc1* and *fc2* in expression 2 below..

$$\tau = \frac{2}{\pi}\int_0^{\pi/2}\int_0^1 \frac{d(sin^2\vartheta)d\varphi}{\left|1+\frac{Z_r}{2\rho c}cos\vartheta\right|^2} \quad (1)$$

$$Z_r = i\omega m\left[1-\left(\frac{f}{f_{c1}}cos^2\varphi+\frac{f}{f_{c2}}sin^2\varphi\right)^2(1+j\eta)sin^4\vartheta\right] \quad (2)$$

Vigran [3] includes the effect of damping (η) in expression 2. The critical frequencies f_{c1}

and f_{c2} are calculated by the normal methods from the bending stiffness in the x and y directions.

However, there is no analytical solution for expression 1, and hence to solve this one must use numerical methods. While the numerical integration is relatively straightforward, it involves a double integration and requires a large number of computations, reducing its value as a design tool because of the time taken for the computation.

Heckl derived asymptotic solutions for high and low frequencies.

$$\tau \approx \frac{\rho c}{\pi \omega m} \frac{f_{c1}}{f} \left(ln \frac{4f}{f_{c1}} \right)^2 \qquad f_{c1} < f < f_{c2} \qquad (3)$$

$$\tau \approx \frac{\pi \rho c}{\omega m} \frac{\sqrt{f_{c1} f_{c2}}}{f} \qquad f > f_{c2} \qquad (4)$$

But note that neither expression includes the effect of damping which is a very important parameter at and above the critical frequency range. It is the frequency range around the critical frequency that is crucial for good prediction of the performance of concrete floors, especially composite floors that have an extended critical frequency region. In practice these expressions (3) and (4) do not provide a useful prediction of the sound reduction of composite steel floors.

3. NUMERICAL SOLUTION OF HECKL'S EXPRESSION

The solution of expression 1 can be carried out numerically as a double integral over the full frequency range. However, to obtain acceptable accuracy required computational times of the order of a few minutes on a typical consumer level personal computer. This was unacceptable for a design tool (in this instance INSUL software for predicting sound transmission loss) that required rapid evaluation of different constructions, such as increased thickness of concrete, addition of ceilings, etc.

A more efficient computation of expression 1 was obtained by using Gauss-Legendre quadrature. This uses a weighted sum of function values at specified points within the domain of integration, and so a significant reduction in the number of points that need to be evaluated can be achieved. Since expression 1 involves a double integral, this dramatically reduces the computational time. Adequate accuracy was achieved over the full frequency range up to 4 kHz with just 16 steps in each numerical integration compared to several hundred required for the straightforward numerical integration. Computational times were reduced to less than one second on a typical consumer level computer, thus making it practical for an engineering design tool.

4. RESULTS

The sound transmission loss of a composite steel floor 120mm thick has been measured at Auckland University's Acoustic Research Centre. This is a commercial system named Hibond, and the profile of the steel pan is shown in fig 3 and the transmission loss in fig. 4. The predicted transmission loss of a homogeneous slab of the same mass (91 mm thick) is also shown dotted for comparison.

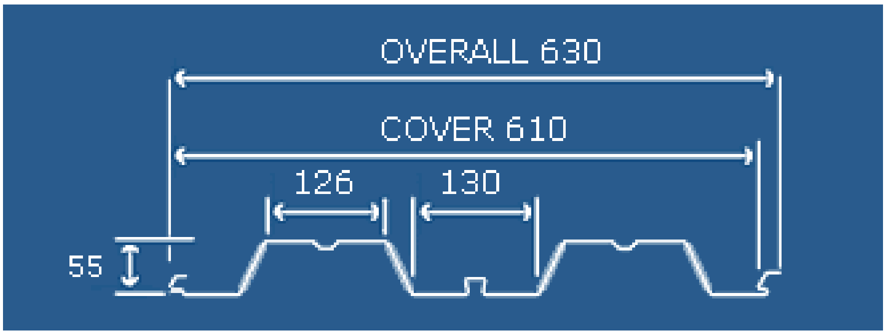

Figure 3 – Dimensions of Hibond steel decking

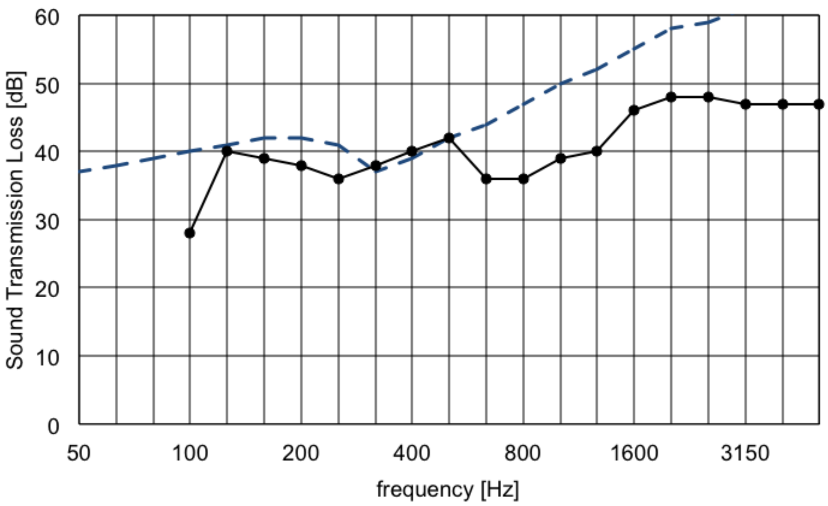

Figure 4 – Sound transmission loss of Hibond Slab (—measured, …predicted for equivalent mass of concrete)

The transmission loss (R_w 42dB) is considerably less than the equivalent mass of concrete in a homogeneous slab (91mm thick R_w 49dB). The transmission loss is much less in the important frequency region 500 to 1,000 Hz.

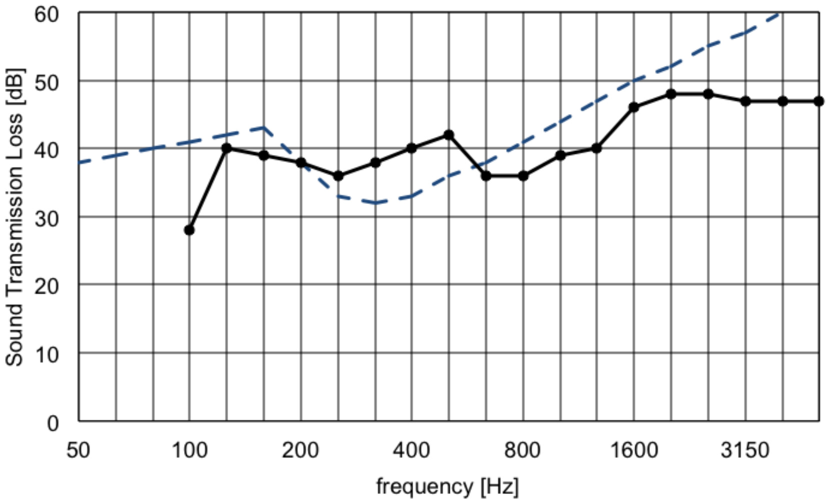

Figure 5 – Sound transmission loss of Hibond Slab (—measured, …predicted from Heckl's equation)

The calculated critical frequencies in the x and y directions are 205 Hz and 366 Hz and the transmission loss calculated from expression 1 is shown in fig 5 together with the experimental data. It can be seen that the prediction is closer than the simplified method based just on the equivalent mass of the slab. The predicted overall rating (Rw 42dB) is closer to the measured value. The agreement however is not perfect, and it could well be that there are some modes of vibration influencing the transmission loss that are not accounted for by the assumptions of a uniform orthogonal slab.

5. CONCLUSION

Composite steel floors are a widely used form of construction throughout the world. They provide high structural performance economically and with minimized mass. However, the sound transmission loss of such constructions can be significantly less than the mass law for homogeneous slabs of the same mass. This is due in part to the increased bending stiffness from composite action between steel and concrete, and partly due to the orthogonal behavior of the slab.

Standard structural engineering methods can be used to estimate the bending stiffness' of the floor in the x and y direction. Heckl's expression for the transmission of orthogonal panels can then be used to provide an improved prediction of the transmission loss. A Gauss-Legendre quadrate method can be used to do the numerical evaluation of the expression, and computational efficiency is greatly improved compared to a simple numerical integration.

Computational speeds sufficient for consumer level computers and simple engineering software can be achieved.

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