Parameter survey of a rib stiffened wooden floor using sinus modes model

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To improve calculation methods for lightweight building structures, more knowledge about the sound propagation in the lightweight systems is needed. The present study aims at gaining knowledge of rib stiffened plate by using Fourier series. From the model the vibration level of the floor is examined and evaluated by means of attenuation rate and vibration distribution. The attenuation is studied when changing dimensionless parameters. First a study with the statistical analysis of variances method was used with seven parameters at three levels. Then a detailed study of the stiffness and frequency parameters is shown. The analysis of variances study implies that several parameters do influence the attenuation. The detailed study shows that the frequency dominates over the stiffness as the parameters with most influence for the attenuation.

1 Introduction

When large wooden houses is built the sound insulation between apartments often have to be estimated before the actual building is built. For houses built with lightweight technique this is today mostly done by method of best practise. That method works rather well but have discrepancies when new circumstances appear. Details and sizes of buildings change during development of the buildings and this yield a bit of uncertainty for the sound insulation. A reliable tool for predicting the sound insulation would be valuable. When designing lightweight structures, as wood constructions with boards, such a tool cannot be found. The prediction models of lightweight structures are still under development.

The present model is built from the bending wave equation for a plate that is simply supported. Beams influence the vibrations on the plate by means of reaction forces and moments. These forces are a result from the bending and torsion equations for the beams. The plate is also excited by a harmonic point force. The pressure from the surrounding air is not included, which probably lead to less attenuation than if it were included. Reference [1] is not fully correct though, the bending wave equation with only the Fourier coeficients is

$$c_{p,q}\left[B\left(\Omega_p^2+\Omega_q^2\right)^2-\rho h\omega^2\right]= e_{p,q}-\sum_r\left(d_{p,q}+f_{p,q}\right) \quad (1)$$

where c,d,e and f are the Fourier coefficients for displacement, moment reaction force, excitation and vertical reaction force respectively. Then B, ρ, ω are the bending stiffness, density and radian frequency respectively. The two Ω reperesents the terms that evolves when differentiating the sine eigenfunctions, i.e. $\Omega_p = p\pi/L_x$ (Lx is the length of the plate). The final equation to solve should then be

$$c_{p,q}g_{p,q}-e_{p,q}=\frac{2}{L_x}\sum_{m=1}^{N_m}c_{m,q}\sum_r\Big[-\left(\Theta\omega^2\Omega_m-T\Omega_m\Omega_q^2\right)\left(\Omega_p\Upsilon_{m,p}(x_r)-\Omega_m\Phi_{m,p}(x_r)\right) -\left(B_f\Omega_q^4-m'\omega^2\right)\Phi_{m,p}(x_r)\Big] \quad (2)$$

The former study showed also that the attenuation was very directional and can be very strong. In figure 1 one can see the velocity distribution for a 1/3-octave band.

Studies on wooden floor with use of Fourier series have been made by Chung and Fox [2]. They model a structure with two plates, beams and a cavity in their studies,

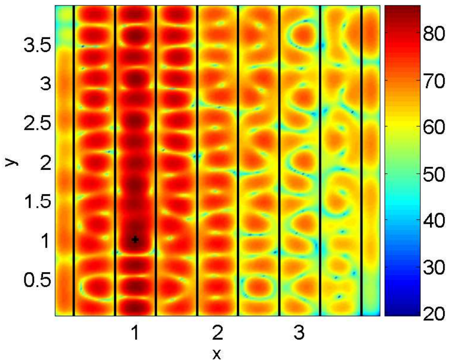

Figure 1: The plate seen from above. The position of the beams is marked with black lines, and the excitation point is marked with a '+' sign. The vibration level is displayed by colour, colder colour is less vibration; see the colour bar at the right hand side of the figure.

and the model shows good agrement with experiments made by Emms et al. [3]. Also Nightingale and Bosmans used a Fourier series expansion for a ribbed plate [4]. They used the expansion on smaller plates that were put together in order to have a system that simulates the beam enforced plate. The calculated input mobility showed that the distance between a beam and the driving point was what mostly effected the mobility.

The purpose of this paper is to demonstrate some aspects of the attenuation on a rib stiffened plate. It is made by making parameter study of a plate with a modal model.

2 Method

This paper present a parameter survey that is made theoretically. The calculation method have been presented before [1]. The aim of the study is to focus on what parameters are important for the attenuation the beam stiffened plate system. Two major studies will be presented one analysis of variance, ANOVA, study and one more detailed study for the bending stiffness and frequency parameters.

2.1 Numerical considerations

First one has to think about the implementation of the theory into a numerical model. The summations need to be finite, and some calculations are here presented to show how the length of the series was decided. It is

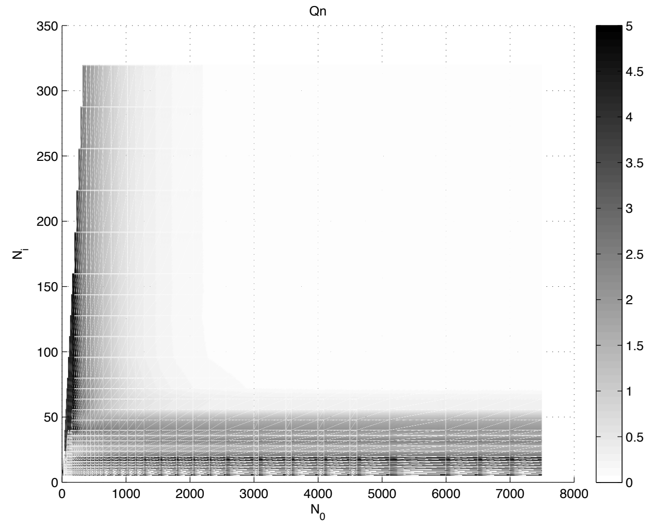

Figure 2: The norm Q_n for a calculation near 5000 Hz. At the horizontal axis the total series length and at the vertical axis the used series length are displayed. The reference value, v_{best}, was the value calculated with 7500 coefficient in total and 300 coefficients used.

Frequency	Total Series	Used Series
250 Hz	600 x 10	20 x 10
500 Hz	1150 x 16	32 x 16
2000 Hz	2000 x 60	50 x 60
5000 Hz	1500 x 55	80 x 55

Table 1: The series lengths to receive Qn $<$ 1 for a few frequencies

known that one cannot use all the calculated values for the series in the x-direction. One can see this by inspecting Eq. (2), where cp, q depends on the series containing $c_{m,q}$ summed over m. This has pointed out before by Nilsson [5], who told this in person to the author. One has to decide the needed number of Fourier coefficients to calculate and also how many of these coefficients that are useful.

Calculations with many alternative series lengths were evaluated in order to establish the needed number of Fourier coefficients. This was done for four different frequencies. The evaluation was done by inspecting the norm

$$Q = 10\log\left(\left\langle \frac{v_m^2}{v_{best}^2} - 1\right\rangle + 1\right),$$

where $\langle\cdot\rangle$ is the mean over the plate area, and v denotes the velocity. The result of such a calculation can be seen in figure 2. The figure shows how the error, Q, varies with the total and used length of series. One can see how the result closes into the result of the maximum used coefficients.

In table 1 the result is summarized for the four calculated frequencies. For the parameter study the values in this table was used as a guideline. Approximately 30 percent more coefficients were calculated for the parameter study, due to uncertainty what will happen when the frequency changes.

There exists also a size limit due to lack of internal memory on the used computer. For instance, at a certain point in the program 4 matrices of size M^2 were used. For $M = 10000$ one can expect a need of more than 6 GB internal memory. For the system used the limit was 1 GB. Using $M = 7000$ was therefore an upper size limit for this system.

Table 2: Input data to the ANOVA.

$k_p * l$	2.16	6.83	21.6
k_f/k_p	3e-5	4e-4	0.08
$B_f/(D*l)$	4.29	928	1.21e4
k_t/k_p	0.001	0.008	0.02
$T/(Dl)$	0.357	2.86	7.14
x_0/l	1.021	1.263	1.512
η	0.002	0.02	0.2

2.2 Parameter Survey

The vibrations for a plate that measures 4 times 4 meter and have beams with 0.5 m distance are calculated for both the ANOVA and the detailed parameter study. Damping is introduced by means of complex bending stiffness. The system also has the following properties:Dynamic force amplitude = 1 N, Plate density kg/m^2, Poissons number = 0.3, Bending stiffness of the plate = 2800(1+i0.02) Nm.

The input data to the ANOVA is displayed in table 2.2. The input paramters for the calculation program, ρ, A_b, E_b, T_b, was then calculated using expressions in Cremer[6].

For the detailed study the center values in table 2.2 were used, except for the parameters of the study, k_pl and $B_f/(Dl)$. The calculations were made with the mean attenuation from the source and 3 meters away in the y direction. Two kinds of calculations was performed. One that used the mean value of 10 randomly chosen frequencies within each 1/9-octave band. The other used no mean value, the frequencies was just randomized within smaller blocks to avoid using many frequencies that are exact multiples of each other.

3 Results

The results for the ANOVA study are shown in table 3. The table shows that probability for the hypothesis that a parameter has no influence on the attenuation. The attenuation was calculated as the mean attenuation for one, two and three meters respectively. The probability values are usually small except for the wavenumber parameter, k_f/k_p.

The result for the detailed parameter study is shown in figure 3 and 4.Both figures show the attenuation as a function of the stiffness parameter and the frequency parameter.

4 Discussion

A beam stiffened plate has been studied theoretically. Calculations were made with Fourier series to calculate

Table 3: Probability values from analysis of variances for selected parameters, F-test. The attenuation, A, for the first one, two and three meters were calculated.

	A 1m	A 2m	A 3m
$k_p l$	0	0	0
k_f/k_p	0.78	1	0.99
$B_f/(Dl)$	0	0	0
k_t/k_p	0.0097	0.00051	0.0017
$T/(Dl)$	0.15	1.34e-008	0
x_0/l	0	0	1.90e-014
η	0.0064	0.59	0.0011

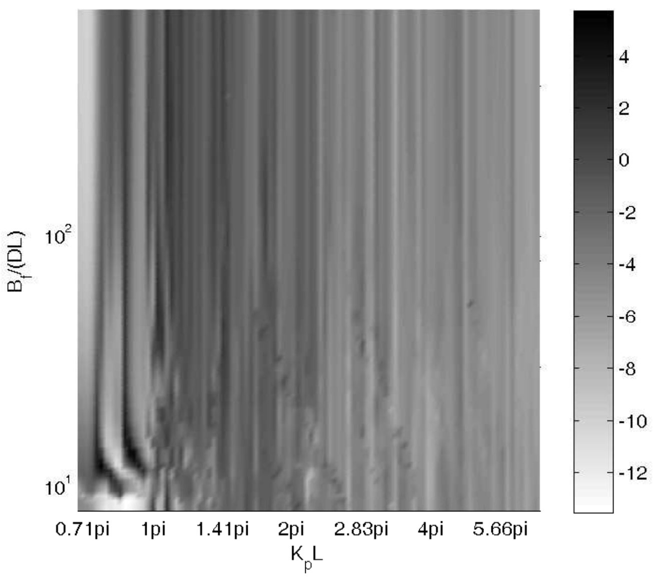

Figure 3: The mean attenuation for the first three meters away from the source in the direction across the beams.

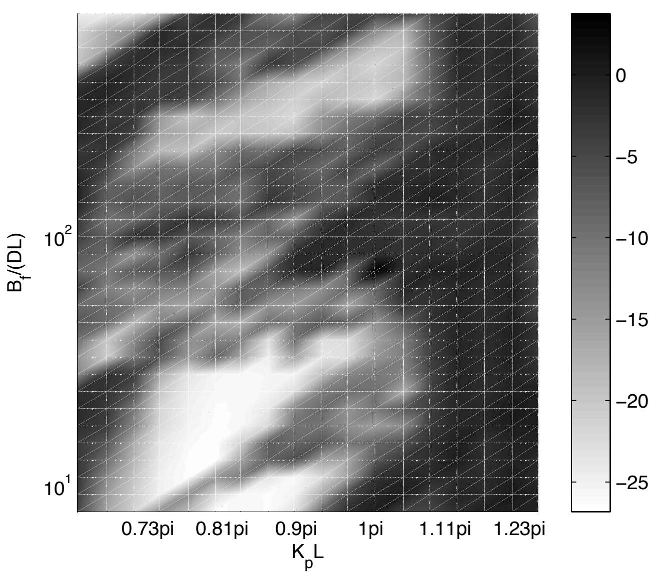

Figure 4: The mean attenuation for the first three meters away from the source in the direction across the beams. Each point is calculated as the mean of ten random frequencies within a 1/9-octave band.

the attenuation for several different situations. Dimensionless parameters were studied. First an ANOVA was performed to get a general view for seven parameters. After that a closer examination of the stiffness and frequency parameters was performed.

In table 3 the results from the ANOVA test are shown. It is shown that the attenuation varies much with all parameters except the wavenumber quota, k_b/k_p. The strongest variation were found here for $B_f/(Dl)$ and $k_p l$, the bending stiffness and frequency parameters. One should not pay too much attention to these slight differences, though. One can from the ANOVA tell that all parameters except the wavenumber quota do influence the attenuation for the rib stiffened plate. This result pinpoints that the attenuation have a rather complicated behavior since it depends on many parameters. This might also to some extent explain why the flanking transmission is so difficult to calculate for wooden houses. The flank at a wooden floor is made up of more parts that will contribute to the vibrational transmission, the stiffened plate is just a part of the total flank. One might therefore expect that it is at least as complicated to calculate the flanking transmission as it is to calculate the attenuation for the rib stiffened plate.

In figure 3 the attenuation is shown as a function of the parameters B_f/Dl and $k_p l$. When both the frequency and the stiffness are low the attenuation varies much with both parameters. In this region there exist therefore possibilities to adjust the material parameters in order to obtain an optimal attenuation. This can be an important aspect if for instance the house have very strong resonances between rooms. It would probably be wise to have strong attenuation in the floor at this resonance frequency. The strongest resonance frequencies for the whole floor are often very low. The possibility to adjust the attenuation by changing the stiffness of the beams is better at lower frequencies as well.

When the frequency or the stiffness parameter increases the influence from the stiffness parameter will decrease. The attenuation is then more controlled by the frequency parameter. The variations of the attenuation due to change of frequency is then rather regular. It might very well depend on the stopband and passband behavior that is so evident in stiffened beams. If one looks into figure 1 one can see that the behavior of the attenuation is rather one-dimensional. Therefore it is plausible that stopbands and passbands are significant for the attenuation of a rib stiffened plate as well.

The stiffness parameter has no influence once the beams have more than a certain stiffness. The reason for this can not be explained by these pictures. One might suspect that above a certain level the beam is so stiff that no more waves can pass with translational movements. Then only the rotational waves do actually pass the beams and the rotational stiffness of the beams are not changed during the parameter study.

One can of course do many more studies with this kind of model. One restraint is that each parameter study consumes a lot of calculation time. For the present study more than three years of processor time was used on 3 GHz processors.

5 Conclusions

A theoretical parameter survey have been carried out. The attenuation was calculated for combinations of dimensionless parameters.

The results show that the frequency parameter had high influence on the attenuation. This was probably due to a passband, stopband behavior.

The wavenumber parameter had no obvious influence on the attenuation in this study.

Acknowledgement

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