Direct and flanking sound transmission of solid gypsum walls - practical experience and numerical prediction

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In modern multi storey buildings gypsum blocks are often used for solid inner walls without static requirements. However, these relatively light walls with a mass per unit area of about 90 kg/m² are not connected rigidly to the adjacent building elements. They are decoupled with elastic interlayers made of bitumen, cork or polyethylene foam. These elastic interlayers have a significant influence on the direct and the flanking sound transmission of the gypsum walls. For this reason the decoupled walls have to be considered different to rigidly connected walls. Within a recent research project there was an extensive investigation into the direct and the flanking sound transmission of gypsum walls in different test facilities in the laboratory. For several kinds of elastic interlayers the sound reduction index of gypsum walls was measured in the test stand for direct sound transmission. The vibration reduction index was investigated in a test facility for flanking transmission as well as in different building situations. The measured values are used as input data for the prediction model according EN 12354-1. The overall sound reduction index calculated with this prediction model is compared with the results measured in the buildings.

1 Introduction

In Germany, in France and in the Netherlands light solid internal walls without static requirements are often constructed with gypsum blocks. In Germany the thickness of these gypsum walls is 60, 80 or 100 mm, however, the walls with 100 mm are the most used. In France the gypsum walls are usually 50 or 70 mm thick. The density of the gypsum blocks is about 900 kg/m³ that means a wall with a thickness of 100 mm has a relatively small mass per unit area of about 90 kg/m². Due to this material characteristic one would expect a low direct sound insulation combined with decreased flanking insulation. However, the light gypsum walls are not connected rigidly to the adjacent construction components but decoupled using flexible elastic interlayers, for instance, made of cork, bitumen or polyethylene foam. These elastic interlayers with a thickness of 3 to 5 mm were fitted on all edges of the gypsum walls. The primary reason for the decoupling is to avoid the crack formation between the different building elements. As another result there is the possibility of a much higher insulation for flanking transmission of the gypsum walls compared to a rigid connection. Figure 1 shows the construction of a gypsum wall in a building.

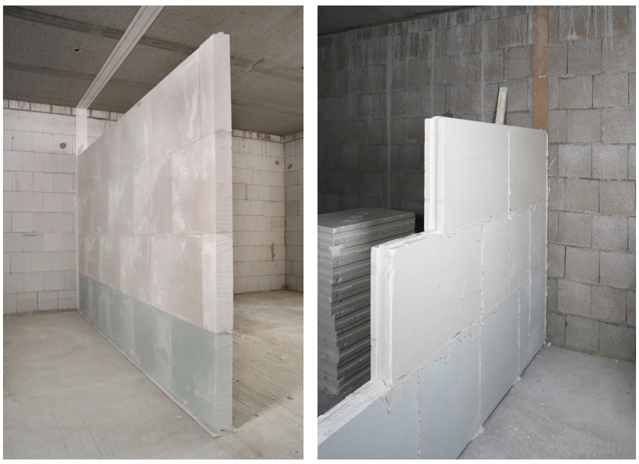


Fig. 1 - construction of gypsum walls in buildings

As a part of a current research project [1] at the Stuttgart University of Applied Sciences different acoustic measurements have been performed in order to investigate the direct and the flanking insulation of gypsum walls in the laboratory. The sound reduction index of gypsum walls depending on the various elastic interlayers was measured in a test stand for direct sound transmission. The flanking insulation of gypsum walls was investigated in two different test facilities for flanking transmission, the first one for the horizontal and the second one for the vertical sound transmission. The construction of the gypsum walls in the test facilities was carried out as in real buildings. In addition to the investigations in the laboratory, extended measurements were also performed in real buildings. These field measurements were conducted in vertical and horizontal direction like in the laboratory.

Part of the measurements in the laboratory and in real buildings was the determination of the sound insulation between two adjacent rooms with the flanking transmission by the gypsum walls. In addition the vibration reduction index K_{ij} was investigated for the different transmission directions according to the standard DIN EN ISO 10848-1 [2]. One part of the vibration reduction index measurement is to determine the loss factor of the building elements by measuring their structural reverberation time. The other part is the measurement of the velocity level difference between two connected building elements by excitation of one of these building elements with a small tapping machine shown in figure 2.

Fig. 2 - small tapping machine for the excitation of the building elements to measure the vibration reduction index

An important ambition of the research project is to verify the application of the calculation model according to the standard DIN EN 12354-1 [3] for different transmission situations with flanking gypsum walls. The extensive measurement data from the field and laboratory measurements are used as input data for the calculation model. For the vertical transmission situations in the various buildings with gypsum walls there was done a calculation according DIN EN 12354-1 and a comparison with the measured results. The paper presents some results of the laboratory and building measurements as well as the first calculated results of the different investigated building transmission situations.

2 Measurements in the laboratory

2.1 Flanking transmission - horizontal

For the investigation of the horizontal transmission a wall, made of calcium silicate, was installed in the flanking transmission test facility of the Stuttgart University of Applied Sciences. This wall with 240 mm thickness and a mass per unit area of 470 kg/m² is a typical partition wall in multi-storey-houses. On both sides of this heavy wall gypsum walls (m′ = 90 kg/m²) decoupled with 5 mm thick cork interlayers were connected. Figure 3 illustrates the construction in the flanking test stand.

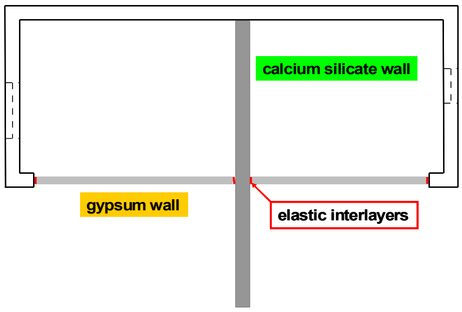
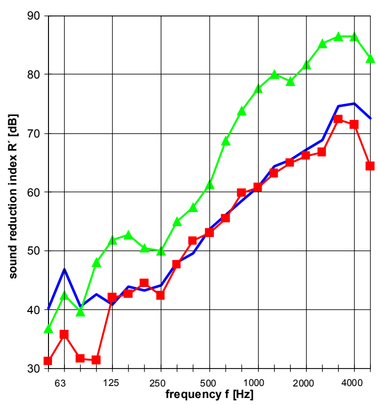


Fig. 3 - test facility for the investigation of the horizontal flanking transmission

This cross connection was investigated for two different cases. In the first case there was an excellent elastic disconnection between the gypsum walls and the calcium silicate wall. In the second case there was a thin gypsum plaster layer over the cork interlayers. The elastic interlayers were over-primed to form a kind of a rigid connection between the walls. The same measurements were done for polyethylene foam interlayers instead of cork interlayers.

The sound reduction index of the separating wall was measured using air borne sound and structure borne sound measurement methods. The result from the sound reduction index measurement of the calcium silicate separating wall with the decoupled gypsum walls is shown in Figure 4.



air borne sound measurement → R'_w = 57 dB

structure borne sound measurements

calcium silicate wall

gypsum wall

Fig. 4 - sound reduction index of a calcium silicate wall with flanking transmission by a decoupled gypsum wall

Figure 4 shows clearly the higher flanking reduction index of the decoupled gypsum wall, especially at higher frequencies, so it can be stated that there is no significant influence of the flanking transmission. The sound reduction index of the calcium silicate wall is only determined by the direct sound transmission for the case with the decoupled gypsum walls. When the cork interlayers are over-primed, the single value of the flanking reduction index decreases by 7 dB. However in this case, the total sound reduction index of the calcium silicate wall will only decrease by 1 or 2 dB.

Figure 5 shows the vibration reduction index K_{ij} in the flanking test facility in horizontal direction, measured from gypsum wall to gypsum wall with the calcium silicate wall between (transmission path Ff). The vibration reduction index K_{ij} of the decoupled cross connection, measured by excitation with the small tapping machine (shown in Figure 2), were significantly higher than the calculated value by DIN EN 12354-1 [3] for a rigid connection. The vibration reduction index of the wall decoupled by cork and polyethylene foam is quite similar. With the over-primed elastic interlayers, the vibration reduction index is clearly lower.

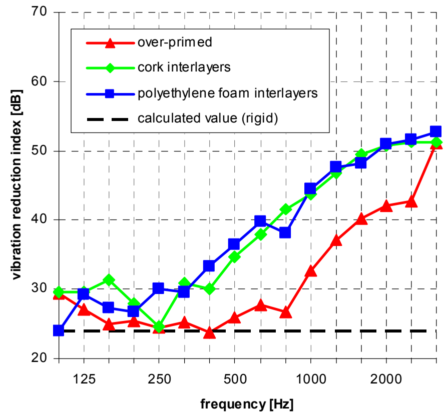


Fig. 5 - vibration reduction index K_{ij} from gypsum wall to gypsum wall (path Ff) - horizontal transmission

2.2 Flanking transmission - vertical

A vertical transmission situation was realized in the two-storeyed combination test facility at the Stuttgart University of Applied Sciences, the construction is shown in figure 6.

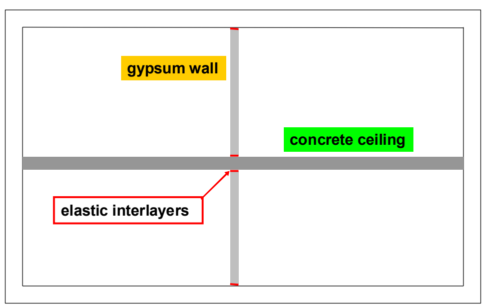


Fig. 6 - two-storeyed combination test facility for the investigation of the vertical flanking transmission

The concrete ceiling of this test facility is 180 mm thick, the gypsum walls on and below the ceiling were 100 mm thick. Investigating the vertical transmission, four different cases were measured:

1. The gypsum walls were decoupled with cork interlayers.
2. The gypsum walls were connected to the test facility with a thin gypsum plaster layer on the cork interlayers (over-primed).
3. The gypsum walls were set up again with a rigid connection to the test facility (without any elastic interlayers).
4. The gypsum walls were decoupled with polyethylene foam interlayers.

With the decoupling of the gypsum walls the sound reduction index of the concrete ceiling was 56 dB, the flanking transmission by the gypsum walls had no significant influence. But with the rigid connection and the over-primed cork interlayers the sound reduction index of the concrete ceiling decreased by 3 dB.

In the next step the vibration reduction index K_{ij} of the four variants were compared with one another as well as the calculated value according to DIN EN 12354-1 [3] for a rigid connection. Figure 7 shows the vibration reduction index K_{ij} for the transmission from the gypsum wall to the concrete ceiling (transmission path Df respectively Fd).

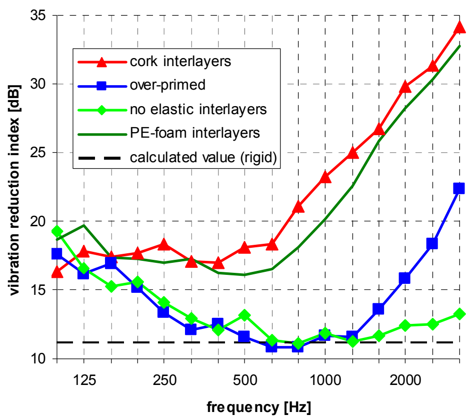


Fig. 7 - vibration reduction index K_{ij} between gypsum wall and concrete ceiling (transmission path Df respectively Fd) - vertical transmission

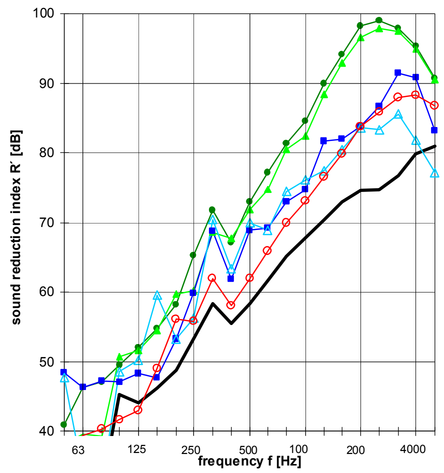
In case of correctly implemented decoupling by the cork and polyethylene foam interlayers much higher vibration reduction indexes are attainable compared to a rigid connection. The only thin over-primed cork interlayers reduce the vibration reduction index significantly. The K_{ij} measurement without any elastic interlayers is in the mid frequency range in the same order of magnitude as the calculated value for a rigid junction. Only at lower frequencies there are higher measured results than the calculated value which is not depending on the frequency.

3 Measurements in buildings

In buildings with internal walls made of gypsum blocks a lot of air borne sound and structure borne sound measurements were done in vertical and horizontal transmission direction. The measurements included the determination of the sound reduction index between two adjacent rooms with flanking gypsum walls and also the investigation of the vibration reduction index for T- and cross-junctions with decoupled gypsum walls.

The current problem of the German sound insulation standard DIN 4109 [4] for the prediction of the sound reduction index between two adjoining rooms is the missing possibility to consider decoupled flanking walls exactly. Therefore a comparison between the calculated sound reduction index according the national DIN 4109 [4] and the actually in the building measured value is done by an example.

The following building situation was investigated: A 200 mm thick concrete ceiling with a floating floor. For the mass per unit area of 460 kg/m² the DIN 4109 [4] considers a sound reduction index $R'_{w,R,300}$ = 58 dB for the case that the flanking walls have an average mass per unit area of about 300 kg/m². The flanking building elements in the investigated case are three decoupled gypsum walls with 90 kg/m² and one calcium silicate wall with 360 kg/m². For this average mass per unit area of 158 kg/m² the DIN 4109 [4] instructs a correction of -3 dB for the sound reduction index of the separating ceiling. That means, the prediction for the resulting sound reduction index of this ceiling is $R'_{w,R}$ = 55 dB according to DIN 4109 [4]. But the actually measured sound reduction index of the ceiling was R'_{w} = 63 dB. The measured sound reduction index of the ceiling and the associated flanking reduction indexes are shown in Figure 8.



air borne sound measurement → R'_{w} = 63 dB

structure borne sound measurements

concrete ceiling	$R_{v,d,w}$ = 65,9 dB
calcium silicate wall	$R_{v,f,w}$ = 70,6 dB
gypsum wall 1	$R_{v,f,w}$ = 73,9 dB
gypsum wall 2	$R_{v,f,w}$ = 73,3 dB
gypsum wall 3	$R_{v,f,w}$ = 69,1 dB

Fig. 8 - sound reduction index of a typical concrete ceiling with the associated flanking reduction indexes

All measured flanking reduction indexes are significantly higher than the sound reduction index of the concrete ceiling. For this reason the flanking transmission has no significant influence for the resulting sound reduction index of the ceiling. This is obvious for two of the gypsum walls, especially at higher frequencies. That means these two gypsum walls were quite good decoupled. The third gypsum wall has a flanking reduction index in the same order of magnitude as the calcium silicate wall which mass per unit area is about four times higher. So this investigation of the flanking transmission shows that light gypsum walls (90 kg/m²) can accomplish better flanking transmission reduction than solid heavier walls (360 kg/m²). The measured sound reduction index is much higher than the calculated value according to the German standard DIN 4109 [4]. This is due to the fact that the calculation according to the German standard so far doesn't take into account the effect of decoupling elastic interlayers regarding the flanking sound transmission.

For a better calculation of the sound reduction index in buildings with decoupled gypsum walls the vibration reduction indexes K_{ij} of the junctions between the flanking walls and the separating building elements are needed as input data for the calculation. These vibration reduction indexes were determined in different buildings. Figure 9 shows some building measurement results of K_{ij} in vertical direction for the transmission path Ff compared with the result measured in the laboratory at a similar situation as well as the calculated value according to DIN EN 12354-1 [3] for a rigid junction.

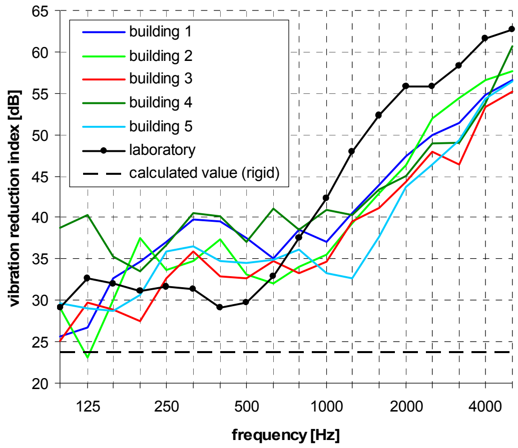


Fig. 9 - vibration reduction index K_{ij} from gypsum wall to gypsum wall (path Ff) in different buildings and in the laboratory - vertical transmission

Figure 9 shows clearly that the vibration reduction index which is attainable in buildings is similar to the vibration reduction index measured in the laboratory. The measurement value of the laboratory is probably in excess of the measurement results in the buildings at higher frequencies than 1000 Hz because of the better conditions in the laboratory. In buildings there is, for example, often the necessity of electrical cables in the range of the junction between gypsum wall und ceiling. This aspect may result in minor structural connections which can decrease the vibration reduction index K_{ij} of the junction.

The vibration reduction index K_{ij} for the transmission path Df (between ceiling and gypsum wall) respectively Fd (between gypsum wall and ceiling) was also determined in all investigated buildings. The measured results have a similar frequency response characteristic like for the transmission path Ff but they are about 15 dB lower. This is due to the fact that there is only one elastic interlayer in the transmission direction Df or rather Fd.

4 Calculation model EN 12354-1

According DIN EN 12354-1 [3], the calculation of the sound reduction index between two adjoining rooms can be carried out by using the "detailed model" or the "simplified model". The detailed model calculates with frequency-dependent values. However, the calculation of the simplified model is done with singular values (not frequency-dependent).

All results shown in this paper are calculated by using the simplified model. The investigated building situations were only with vertical sound transmission.

The direct sound reduction index of the separating building element (R_{Dd}) and all flanking reduction indexes (R_{Ff} - R_{Fd} - R_{Df}) have to be considered for the calculation of the apparent sound reduction index. That means that in a room with four walls there are altogether thirteen transmission paths. The calculation of the apparent sound reduction index R'_w can be carried out by the following equation:

$$R'_w = -10\lg\left[10^{-R_{Dd,w}/10} + \sum_{F=f=1}^{n} 10^{-R_{Ff,w}/10} + \sum_{f=1}^{n} 10^{-R_{Df,w}/10} + \sum_{F=1}^{n} 10^{-R_{Fd,w}/10}\right]$$

<u>Symbol meaning:</u>

$R_{Dd,w}$ direct sound reduction index
$R_{Ff,w}$ flanking reduction index, transmission path Ff
$R_{Df,w}$ flanking reduction index, transmission path Df
$R_{Fd,w}$ flanking reduction index, transmission path Fd

The several flanking reduction indexes (R_{Ff} - R_{Fd} - R_{Df}) are calculated as follows:

$$R_{ij} = \frac{R_i}{2} + \Delta R_i + \frac{R_j}{2} + \Delta R_j + K_{ij} + 10\lg\frac{S_S}{l_0 \cdot l_{ij}}$$

<u>Symbol meaning:</u>

R_i / R_j sound reduction index of the building element i or rather j in [dB]
ΔR consideration of facing formwork in [dB]
K_{ij} vibration reduction index in [dB]
S_S area of the separating building element in [m²]
l_0 reference-coupling-length in [m]; $l_0 = 1$m
l_{ij} coupling-length of the building element ij in [m]

In a first step the calculated singular value of the vibration reduction index according annex A of DIN EN ISO 10848-1 [2] was used as input data for the calculation model. The determination of the K_{ij} singular value is carried out by an arithmetic averaging of the values from 200 Hz to 1250 Hz.

The apparent sound reduction index R'_w of each building situation was calculated with the vibration reduction index $K_{ij,building}$ which was measured in the respective building. On the other hand the calculation was done with the average of all vibration reduction indexes $K_{ij,average}$ measured in vertical transmission direction. Some results of the calculated sound reduction index compared with the actually measured apparent sound reduction index are shown in figure 10.

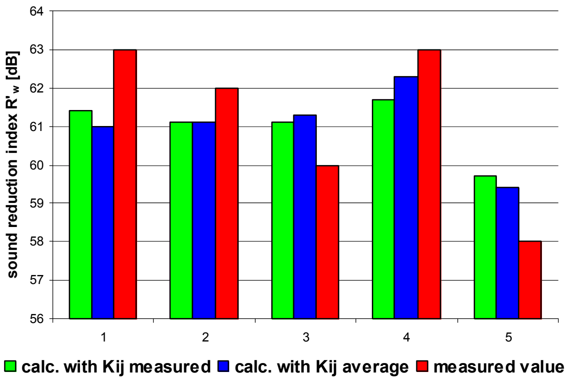


Fig. 10 - sound reduction index - calculated with the simplified model according EN 12354-1 and measured in five different buildings

The difference between the two calculated variants was typically not more than 0,6 dB. That means a good average of the vibration reduction index K_{ij} can be composed of an adequate number of representative K_{ij} measurements. Between the calculated value and the effectively measured sound reduction index is a discrepancy of not more than 2 dB. The correlation should be improved in the near future. Perhaps, a possibility to improve the correlation is to use another frequency range to generate the singular value of the vibration reduction index as input data for the calculation model.

5 Conclusion

The use of decoupled gypsum walls as non-supporting internal walls has a couple of advantages in buildings. The vibration reduction index K_{ij} and hence the flanking reduction index of gypsum walls decoupled by elastic interlayers, made of cork or polyethylene foam is much higher than the values which were calculated and measured for rigid junctions. However, the condition for this fact is a good accomplishment of the elastic connection. If this is ensured, a quite good apparent sound reduction index of a separating building element, for example a ceiling, is attainable. The extensive measurements in different buildings and in the laboratory have approved high sound reduction indexes between adjoining rooms with gypsum walls as flanking elements. In fact with consistent decoupled gypsum walls the flanking reduction index can be at least just as good as with heavy walls with a mass per unit area of about 300 kg/m².

For the acoustic planning of a building it is necessary to calculate the sound reduction index between adjacent rooms in the building. It is difficult to consider decoupled flanking gypsum walls exactly because of the missing input data. The calculation with singular values according the simplified model of the EN 12354-1 and the measured vibration reduction indexes of the gypsum walls as input data has shown a comparative good correlation to the actually measured sound reduction index. This beginning should be tracked in principle. Maybe for decoupled gypsum walls the generation of the singular value of the vibration reduction index K_{ij} should be adjusted for a better accuracy of the calculation model. In addition the frequency-dependent calculation in compliance with the detailed model of the EN 12354-1 will be carried out.

References

[1] „Umsetzung der europäischen Normen des baulichen Schallschutzes für das Bauen mit Gips-Wandbauplatten“ - a current research project at the Stuttgart University of Applied Sciences: „Conversion of the European standards of the structural sound insulation for building with gypsum walls”

[2] DIN EN ISO 10848-1: Akustik - Messung der Flankenübertragung von Luftschall und Trittschall zwischen benachbarten Räumen in Prüfständen; 2006-08 - the German version of ISO 10848: Acoustics - Laboratory measurement of the flanking transmission of airborne and impact sound between adjoining rooms

[3] DIN EN 12354-1: Bauakustik - Berechnung der akustischen Eigenschaften von Gebäuden aus den Bauteileigenschaften - Teil 1: Luftschalldämmung zwischen Räumen; 2000-12 - the German version of EN 12354-1: Building acoustics - Estimation of acoustic performance of buildings from the performace of elements - Part 1: Airborne sound insulation between rooms

[4] DIN 4109, Beiblatt 1: Schallschutz im Hochbau - Ausführungsbeispiele und Rechenverfahren; 1989-11 - the German standard regarding sound insulation