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Prediction methods and evaluation of high sound insulations (I)

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ABSTRACT

When consulting pop venues or cinema's with critical spaces like dwellings nearby, high sound insulations will have to be realized. In an early stage of the design the related structural consequences will have to be known very stringently and reliable, because adaptations afterwards are usually not possible. In a recent situation with dwellings lying diagonal directly above a pop venue a high sound reduction for the roof of the pop venue of $R_{A,house}$≥75 dB had to be realized to limit exterior noise transmission towards the facade of the dwellings. The interior noise transmission towards the dwellings had to full fill at least $D_{nT,A,house}$≥90 dB. Question was what structural principles would be necessary to reach these values? Based on a practical prediction method for the sound insulation value in the key octave band (63 Hz) for a heavy double roof structure, a heavy separated double concrete roof (f_0<3 Hz) was designed and implemented, combined with fully vibration isolated bearings (<10 Hz) under the pop hall as well as under the dwellings. The latter demanded specific high pressure vibration insulated mountings to be designed and implemented. In order to evaluate the prediction method used for the double roof and to see whether the high sound insulations that were predicted have actually been realized, measurements after delivery have been performed, using a special measurement setup with 18 subwoofers producing noise levels of 125 dB(A) house spectrum inside the pop venue. Measured values of $R_{A,house}$=76-79 dB and $D_{nT,A,house}$=99 dB show that the prediction method used proved its value and that the goals set have been met, whereas further investigation is recommended for subsequently fine tuning the prediction model for instance for the influence (absence or presence) of mineral wool as damping material in the void between the double concrete roof.

Keywords: Sound, Insulation, Transmission

1. INTRODUCTION

The brief for the new popvenue Doornroosje in Nijmegen for the contractor Klokbouw-Zublin was to combine three buildings on a small footprint: a pop centre with two pop halls (1100 and 400 seats) and a cafe, a bicycle parking (4000 bicycles) and hundred 4-room dwellings for students. According to the brief both pop halls should be suitable for pop concerts with an equivalent sound level of 105 dB(A) house spectrum at the mixing desk and the cafe should be suitable for 100 dB(A) popspectrum.

The maximum allowable music levels in surrounding spaces were set as 40 dB(A) in the foyers and 30 dB(A) in the adjacent pop hall. Legal limits were a maximum equivalent music level of L_{Aeq}=30 dB(A) on the façade of dwellings and L_{Aeq}=15 dB(A) inside the dwellings. Based on these demands the following sound insulations should be met:

- $R'_{A,house}$≥75 dB for the roof of the pop hall;
- $D'_{n,T,A,house}$≥90 dB between pop hall and dwellings.
- $D'_{n,T,A,house}$≥65 dB between pop hall and foyers;
- $D'_{n,T,A,house}$≥75 dB between pop halls;

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2. DESIGN ASPECTS OF THE SOUND INSULATION

2.1 Prediction of the sound reduction of the roof

The demands for pop concerts have primarily determined the design of the sound insulation. Based on earlier experience with a double concrete roof (f_0<5 Hz) where a practical sound reduction of $R'_{A,house}\geq 70$ dB was required, a similar practical prediction method was used for the design for the underlying roof of the pop venue that should full fill $R'_{A,house}\geq 75$ dB. Based on this value a corresponding sound reduction value R' for the predominant 63 Hz octave band of at least R(63 Hz)=62 dB was determined.

As a practical prediction method an estimation of the sound insulation of large, heavy double structures for the predominant 63 Hz octave band is made based on extrapolation from the resonance frequency with an increase of 14 to 15 dB for each octave up to the 63 Hz octave band, assuming a zero insulation at the resonance frequency itself. Above the 63 Hz octave band the estimated increase of the sound insulation is limited to 9 dB/octave up to the 500 Hz band, and above the 500 Hz octave band the predicted increase is limited to 5 dB/octave.

Based on these assumptions a maximum value for the resonance frequency of f_0=3 Hz could be deduced for the double concrete roof. Based on this value for the resonance frequency the roof build for the large pop hall was designed as follows from inside to outside:

- an interior roof/ceiling of 900 – 1000 kg/m2 concrete, forming the inner roof of the concrete box of the pop hall that should be completely separated from the outer roof structure;
- an air void of at least 1,3 – 1,5 m with a layer of mineral wool (if necessary), with sufficient height for the bearing structure of the large span of the outer roof. For the small hall, due to its lower height, a higher void (>3,5 m) resulted between the inner and outer roof, which was used for technical space.
- an exterior roof of at least 500 kg/m2 concrete.

The estimated octave band spectra for the sound reduction values R' for the roof of the large pop hall is given as a red line in figure 1, resulting in an estimated prediction value of $R'_{A,house}$=75-78 dB for the large hall. The measured values indicated in the graph will be treated later.

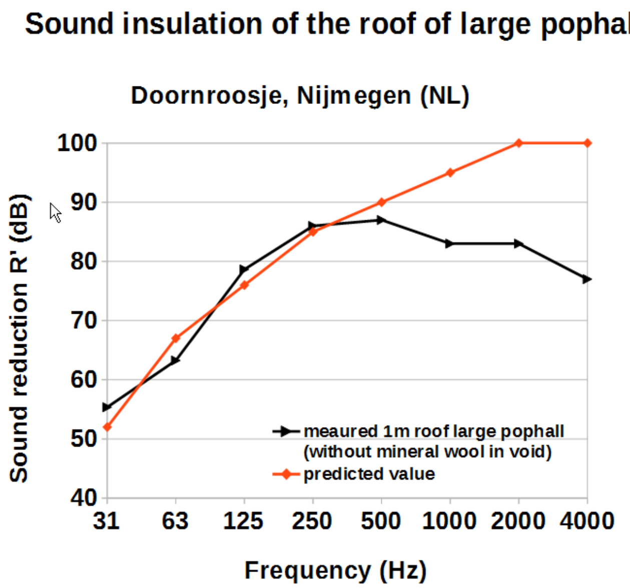

Figure 1 – Sound reduction R' of roof of the large pophall.

The estimated octave band spectra for the sound reduction values R' for the roof of the small pop hall is given as a red line in figure 2, resulting in an estimated prediction value of $R'_{A,house}$=82-85 dB for the small hall.

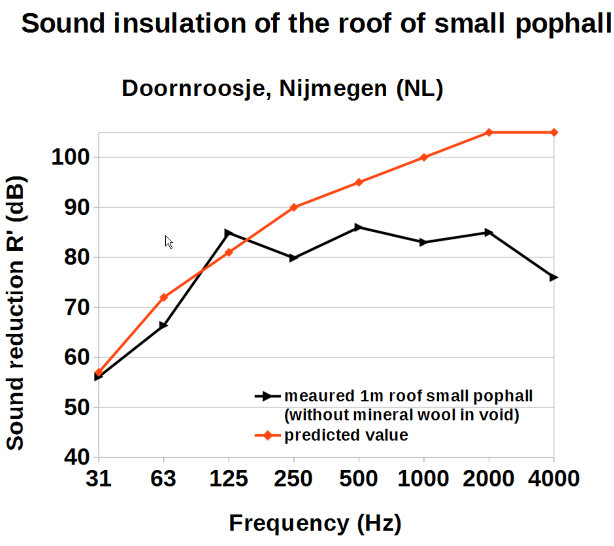

Figure 2 – Sound reduction R' of roof of the small pophall

2.2 Final build up of the roof of the pop halls

The final build up of the double roof of the large pop hall can be clearly seen in figure 3, in which the final height of the air void of 1,25 m is indicated as well as the complete structural separation (dilatation) between both roofs which is necessary to reach the required direct sound reduction of $R'_{A,house} \geq 75$ dB for the double roof. Because the outer roof had an additional function as a garden for the dwellings its total mass became around 800 kg/m2 (500 kg/m2 concrete and 300 kg/m2 soil-layers of the garden). Figure 3 also shows the transition of the roof at the connecting side towards the dwellings, where a dilatation with a vibration isolated mounting of the dwellings has been designed and implemented.

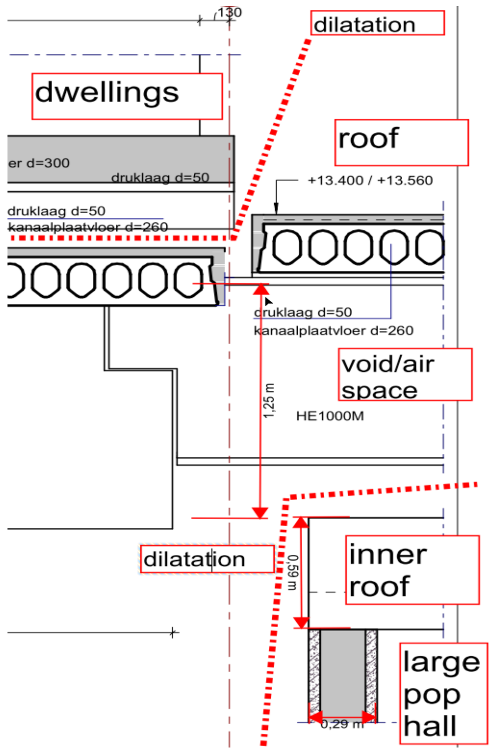

Figure 3 – Detail of structural cross-section (side large pophall towards dwellings)

Because of the high weight requirements for the inner roof of the pop halls as well as the demand for a free span to reach sufficient interior height inside the halls, the interior roof was finally build up using large, concrete T-beams with a height of 350 mm (small hall) and 500 mm (large hall). These T-shaped beams were placed upside down and subsequently attached with steel reinforcement and finished with a flat upper side using poured concrete. This resulted in a structural thickness of this interior roof of 450 mm for the small hall and 570 mm for the large hall. This build up can be seen in figure 3 and 4 where a detail of the interior roof/ceiling structure is given.

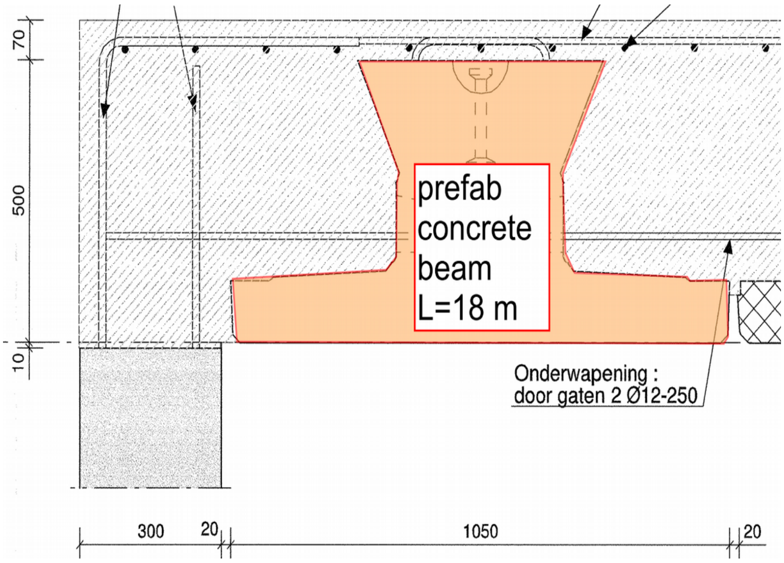

Figure 4 – Detail inner roof large pop hall (18 x 30 m).

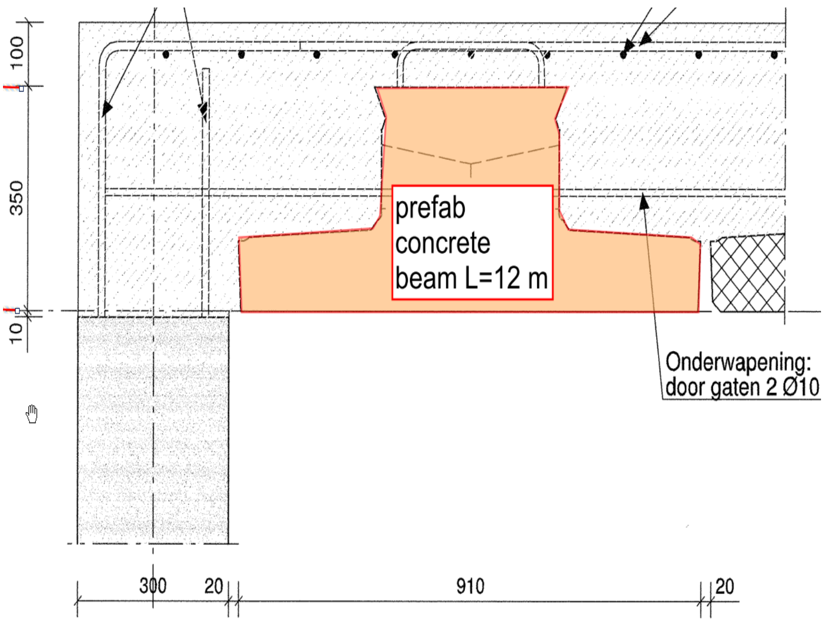

Figure 5 – Detail inner roof small pop hall (12,5 x 24 m)

2.3 General lay-out of pop halls within the pop venue and dwellings on top

Both pop halls have been built as a fully separated heavy boxes of concrete on elastic bearings (<10 Hz) placed on columns in the basement. All around the concrete boxes of the halls a full separation is applied, see next figure 6 and 7. Figure 6 shows a ground floor plan of the 3-storey pop centre with besides both pop halls also a café, foyers and a loading dock with a unique truck-rotation lift.

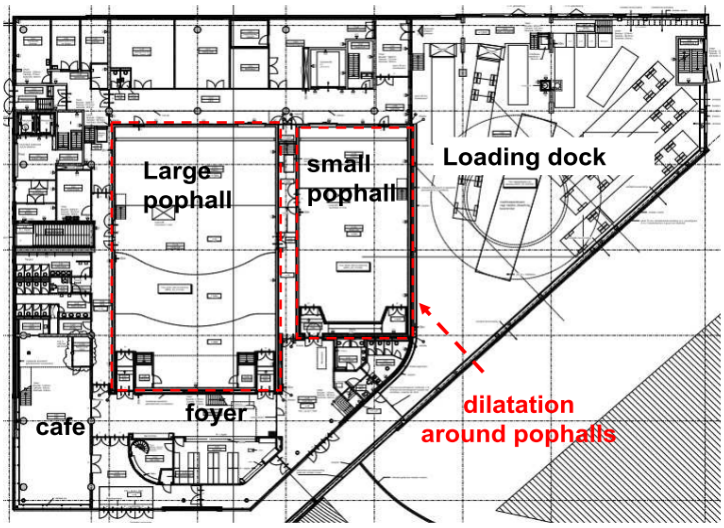

Figure 6 – Ground floor plan of popvenue Doornroosje in Nijmegen (NL)

The walls of the boxes of the pop halls are of 300 mm concrete with a mass of 720 kg/m2, the floors are 900 kg/m2 concrete and the ceiling/interior roof is at least 1,050 kg/m2. In between both halls is a corridor of 2m width. Towards the foyers deep door locks are applied and a free standing dry-lining wall of 40 kg/m2 gypsum boards on 0.35 m air cavity filled with 0.15 mm mineral wool. Under the floor a flexibly resilient suspended ceiling of 30 kg/m2 fibre board has been applied on 0.3m air cavity filled with 0,15 mm mineral wool.

In order to realize 100 4-chamber dwellings on the same footprint, these dwellings were projected in a ten storey high building above the three storey pop centre, as shown in figure 7 in a cross-section.

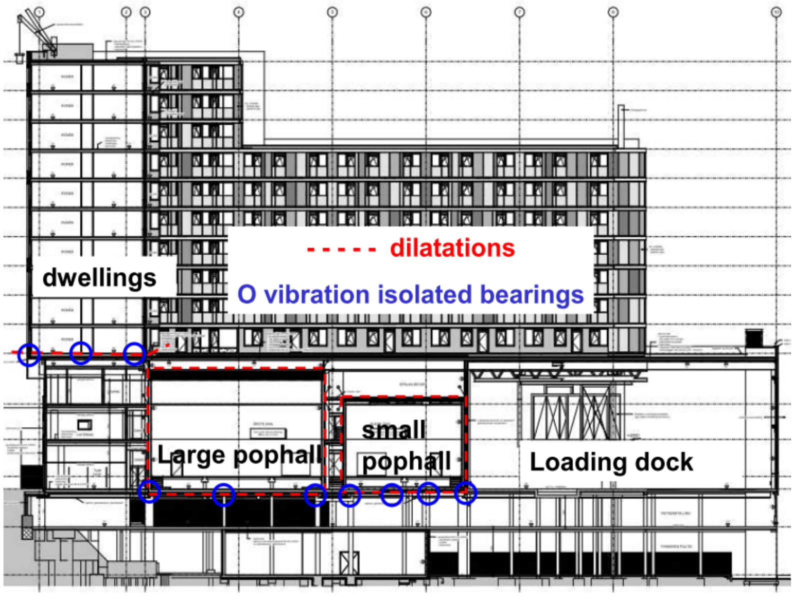

Figure 7 – Cross-section through building of Doornroosje, with dwellings above the pop centre

2.4 Vibration isolated mountings

To realize a sufficient sound insulation from the cafe and the pophalls towards the dwellings and simultaneously reducing railway vibrations an additional measure was taken by placing the total building of the dwellings on elastic bearings on the pop centre with a full dilatation in between, and by placing the dwellings aside from the pop halls as can be seen in figure 7. This isolated mounting of a complete 10 storey building required specific high pressure vibration insulated mountings to be designed and implemented. Figure 8 shows a photo of the elastic bearings designed by CDM under the dwellings. The elastic bearings applied have a resonance frequency below <10Hz and a 16 MPa vertical loading capacity and consist of 4 layers of 20 mm rubber with 5 mm steel plates (size 125x125x95 mm).

Figure 8 – Elastic bearings in position under dwellings on the pop centre during the construction phase

One of the requirements from the principal for using these elastic bearings under the dwellings was that the pads could be interchanged at all times during the life of the building. For this reason a sufficiently high void space (0.9 m height) was designed between the lowest floor of the living building and the concrete roof of the pop centre, such that the supports were reachable after completion. Also a specific procedure for eventual replacement was designed by the supplier: In the design of the elastic bearings additional layers of high density fibre board were applied under the steel-rubber bearings, so that these could be demolished by drilling through. Subsequently these could be replaced by new rubber-steel pads that have been frozen under pre-stressed conditions.

3. MEASURING RESULTING SOUND INSULATIONS

3.1 Set up of equipment

Delivery measurements of the sound insulations had to be performed before the PA-system of the pop hall itself was present. Therefore a special set was hired, shown in figure 9.

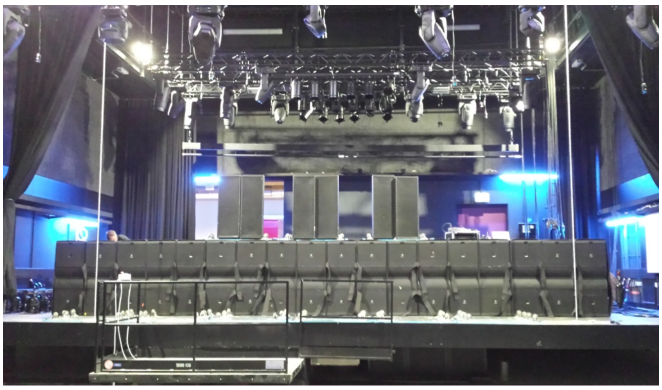

Figure 9 – Measurement set up on the stage of the large pop hall with 18 subwoofers and 6 arrays

This measuring set consisted of 18 subwoofers and 6 array-speakers, that were being fed with pink noise for each separate octave band from 31 Hz to 4 kHz. The equivalent noise levels for each separately measured octave band are given in figure 10 and result in a equivalent pink noise level of L_{Aeq}=125 dB(A) at the mixing desk.

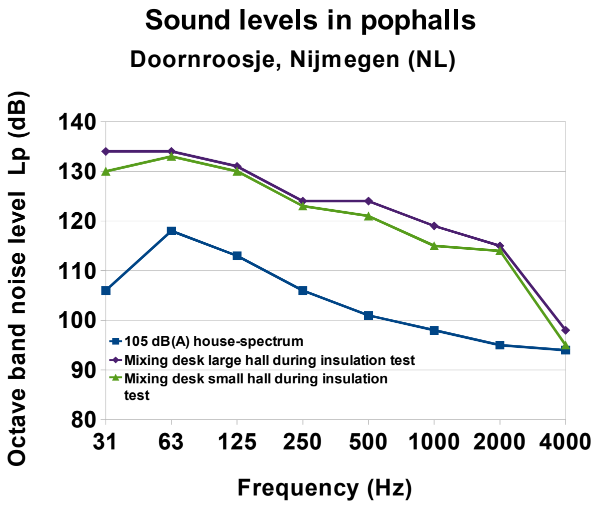

Figure 10 – 105 dB(A) house spectrum compared with 125 dB(A) noise level with measuring set

Using the measuring setup mentioned above provided a sufficient signal-noise ratio inside the dwellings (>10 dB) up to 500 Hz octave band, and gave sufficiently reliable values for the main predominant octave bands of the external sound insulation of the roof up to the 125 Hz octave band.

3.2 Resulting sound insulation of double roof and comparison with prediction

The resulting sound level differences D' of the double roofs (@1m) of both pop halls are spectrally given in figure 11. Using a standard substraction of 3 dB the resulting sound reduction values measured become $R'_{A,house}$=76 dB for the large hall and $R'_{A,house}$=79 dB for the small hall. Both full fill the requirement of $R'_{A,house} \geq 75$ dB.

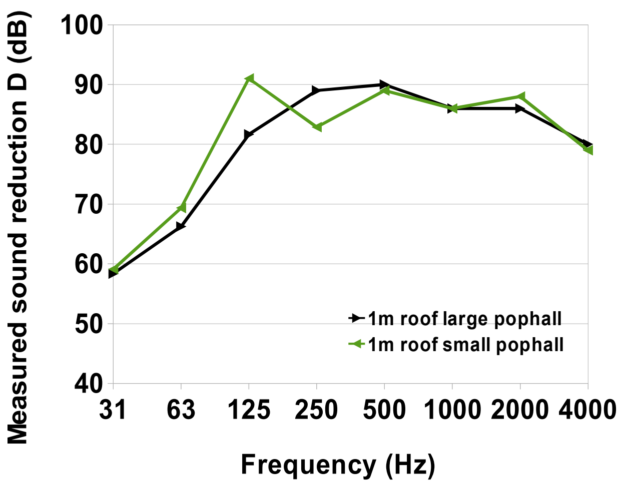

Figure 11 – Measured D'(@1m) of pop hall roofs.

These measured octave band values for the sound reduction R' of the double roofs can be graphically combined and compared with the predicted spectral values, which is done in figure 1 and 2 shown in the first chapter of this article.

From figure 1 showing the comparison for the large pop hall, it can be concluded that at the predominant octave band of 63 Hz the value measured is about 3-4 dB below the predicted value (based on 15 dB/2f). This may partially be caused by the absence of damping (layers of mineral wool) within this void, due to a practical consideration of the contracter only to implement mineral wool if proven necessary to meet the demands set. For the 31 Hz and 125 Hz band however the values measured are 3 dB higher than predicted. The differences between measured and predicted values above 250 Hz are mainly due to insufficient signal-noise ratio but are not predominant for the differences in the overall single digit value for the house music spectrum realized of $R'_{A,house}$=76 dB for the large hall, that full fills the requirement of $R'_{A,house}\geq$75 dB.

From figure 2, showing the comparison for the small pop hall, it can be concluded that at the predominant octave band of 63 Hz the value measured is about 6 dB below the predicted value (based on 15 dB/2f). This may partially be caused by the similar absence of damping (layers of mineral wool) within this void due to considerations mentioned above, but possibly also by the use of the void as a technical space (with several penetrations through the inner roof) and as a storage with connecting light-weight walls etc. The differences between measured and predicted values above 500 Hz are mainly due to insufficient signal-noise ratio but are not predominant for the differences in the overall single digit value for the house music spectrum realized of $R'_{A,house}$=79 dB for the small hall, that full fills the requirement of $R'_{A,house}\geq$75 dB but remains 4 dB(A) below the predictad values of $R'_{A,house}$=83 dB.

3.3 Resulting interior sound level difference towards dwellings

Regarding the the interior noise transmission from the pop halls towards the dwellings the sound level differences measured are spectrally given in figure 12 and are at least $D_{nT,A,house}$=99 dB and all full fill the requirement of $D_{nT,A,house}\geq$90 dB.

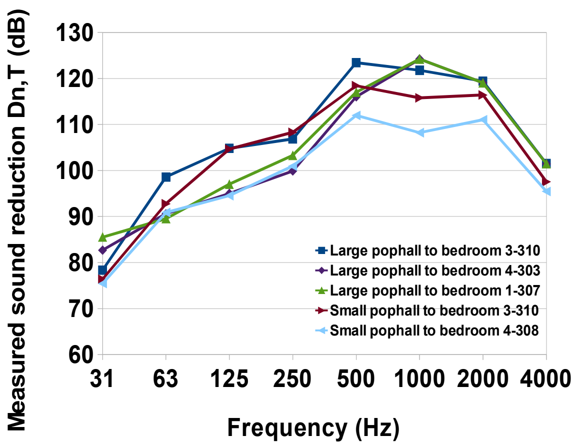

Figure 12 – Measured D'n,T between pop halls and sleeping rooms of adjacent dwellings

4. CONCLUSIONS

Measured values of $R'_{A,house}$=76-79 dB and $D'_{nT,A,house}$=99 dB show that the prediction method used to predict the sound reduction of double roofs proved its value and that the goals set for high sound insulations have been met in the pop Venue project of Doornroosje in Nijmegen (NL). However, further investigation is recommended for subsequently fine tuning the prediction model for instance for the influence (absence or presence) of mineral wool as damping material in the void between double concrete roofs.

A solid acoustic design proved to be of major importance to realize the sound insulation values aimed for, as well as accurate construction, execution and surveillance during the building phase. Having realized the sound insulations aimed for in these new venue plays an important factor in its success. Doornroosje in Nijmegen is the first building in the Netherlands that shows that dwellings can be build above pop halls, and the first where it showed possible to realize and prove a sound insulation of $D'_{nT,A,house}\geq$99dB to the dwellings by using a special setup with 125 dB(A) noise level.

REFERENCES

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