Design of a standalone, modular test facility for measuring sound transmitted through a common ceiling plenum

Edward A. BARCLAY[1]; Robin R. WAREING[2]; John R. PEARSE[3]

[1, 2, 3] University of Canterbury, New Zealand

ABSTRACT

The design of a modular ceiling test facility is described. The University of Canterbury's acoustic test facilities are undergoing substantial renovation and in some cases replacement. A number of new test facilities are being constructed. These test facilities must be relatively low cost, and be able to be easily stored. A facility for testing suspended ceilings to ASTM E1414 and ISO 10848 has been developed. The reverberation time within the facility was modelled utilising measured absorption data to ensure the design was within acceptable levels. The direct and indirect sound transmission paths were assessed.

Keywords: Sound Transmission, Ceiling Acoustic Class, Sound Insulation, Facility Design

I-INCE Classification of Subjects Number(s): 23.9, 32.3, 33, 72.9

1. INTRODUCTION

The widespread use of open plan workspaces has increased the importance of the acoustic environment in such spaces. If open plan spaces are not appropriately treated then work performance can be negatively affected (1).

Studies have shown that the installation of suspended ceilings in place of exposed structure designs can improve the acoustic performance of open plan workspaces (2). Suspended ceilings have several acoustic roles including increasing the absorption within the room, reducing the noise from building services (HVAC etc.) and reducing the transmission of noise between rooms that share a common plenum. To understand and improve the acoustic performance of suspended ceilings, laboratory testing can be performed. Absorption tests can be easily performed in a reverberation room in accordance with ISO 354 (3). Testing the performance of the suspended ceiling for transmission of noise between rooms sharing a common plenum requires the construction of a specific facility. Two current test standards for evaluating transmission through common plenum ceilings are ASTM 1414 (4) and ISO 10848 (5). This paper describes the design of a test facility for evaluating the performance of suspended ceilings in accordance with ASTM E141 and ISO 10848 test standards.

2. TEST FACILITY REQUIREMENTS

ASTM 1414 requires two adjoining rectangular rooms which are structurally isolated from each other (Figure 1). The separating wall between the two rooms is required to be 760 ± 25 mm lower than the roof, the suspended ceiling is then constructed on the top of this separating wall to create a common plenum between the two rooms. The separating wall must have a high transmission loss to ensure that the direct transmission path is at least 10 dB lower than the path through the test installation. The rooms must be sufficiently reflective to ensure an acceptably diffuse sound field within the rooms.

1 edward.barclay@pg.canterbury.ac.nz
2 robin.wareing@pg.canterbury.ac.nz
3 john.pearse@canterbury.ac.nz

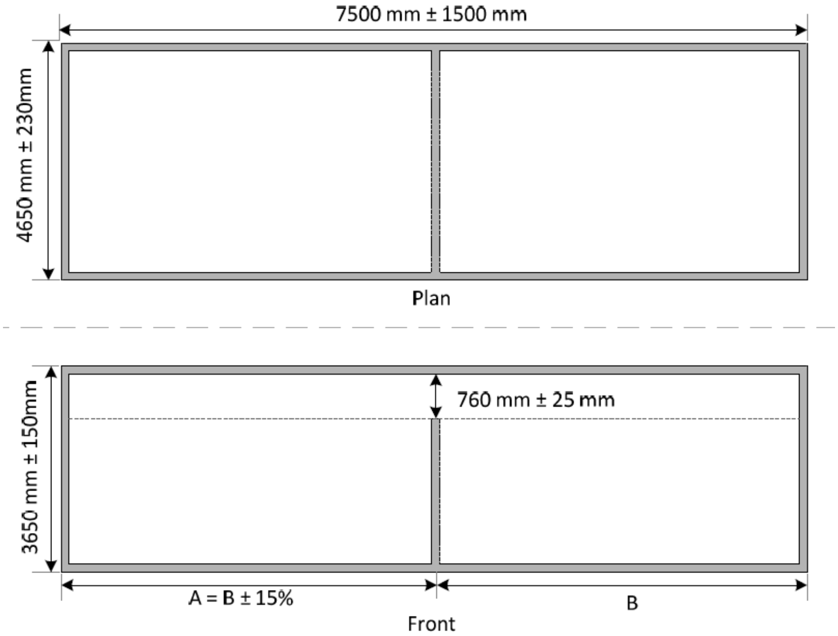


Figure 1 - Dimensions of test facility required by ASTM E1414

ASTM E1414 specifies that a test signal of continuously distributed noise in one-third octave bands between 125 Hz and 4000Hz is generated in one room (the source room). The sound pressure is measured in both the source and receiving rooms, sufficient microphones must be used to adequately sample the sound pressure in each room. From the measured sound pressure levels, the ceiling attenuation class (CAC) can be found using:

$$D_c = \bar{L}_1 - \bar{L}_2 \tag{1}$$

and

$$D_{n,c} = D_c - 10\log(\frac{A_0}{A}) \tag{2}$$

where D_c is the ceiling attenuation, $\bar{L}_1$ and $\bar{L}_2$ the average one-third octave band sound pressure levels in the source and receiving room respectively, $D_{n,c}$ the normalized ceiling attenuation, A_0 = 129 Sabin (12 m^2) and A the sound absorption of the receiving room in Sabin measured by the decay method. The single number CAC rating can then be determined using the normalized ceiling attenuation ($D_{n,c}$ and ASTM E414 (6)).

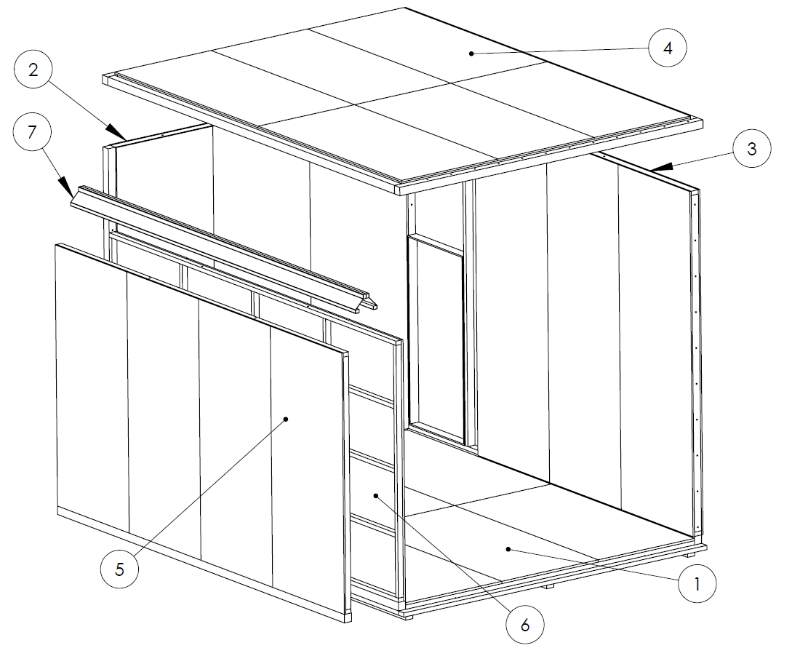
ISO 10848 has similar specifications to those found in ASTM E1414. The room dimensions require 4.5 ± 0.5 m wide rooms, a separating wall which is at least 2.3 m high and 750 ± 50 mm below the roof, and the volume of each room must be at least 50 m^3. If the stricter dimensional tolerances set by ASTM E141 are achieved then ISO 10848 requirements will also be met. Unlike ASTM E1414, ISO 10848 specifies the required number of microphone positions, five, and sound source positions, two.

Additionally, the test facility must be easy to deconstruct for transport and storage. This is due to the University of Canterbury's current test facilities undergoing significant renovation which requires the facility to be relatively portable.

3. TEST FACILITY DESIGN

3.1 General Design of Test Facility

The assembly of one of the two identical rooms is shown in Figure 2. The internal dimensions of each room are 4.8 x 3.6 x 3.6 m and the overall dimensions of the test facility are 5.1 x 7.8 x 3.9 m.



Item #	Assembly
1	Floor
2	Side Wall
3	Back Wall
4	Roof
5	Separating Wall 25mm
6	Separating Wall 18mm
7	Separating Wall Cap

Figure 2 - Exploded view of one of the two identical rooms to be constructed for the CAC test facility.

Note: One of the side walls is removed for clarity

The side, back wall and roof are a double leaf construction. The framing uses 45 x 90 mm studs, the outer leaves are 18 mm medium density fibre board (MDF), and the cavity is filled with absorption material. The decision to use MDF over the better performing gypsum plaster board (higher STL and lower absorption) was due to its increased durability, which was very important for the collapsible design of this facility. There was concern that MDF would not create a diffuse enough sound field within the rooms. To ensure that this was not the case, an ODEON model was developed to compare the reverberation times between gypsum and MDF constructed rooms using measured absorption data.

3.2 ODEON Model of Test Facility

ODEON requires absorption values for all materials present within the room of interest. The absorption coefficients were calculated using Equation 3 and 4 which are given in ISO 354.

$$\alpha_s = A_T/S \tag{3}$$

where α_s is the sound absorption coefficient, S is the area covered by the test specimen and A_T is given by:

$$A_T = 55.3V\left(\frac{1}{c_2T_2} - \frac{1}{c_1T_1}\right) - 4V(m_2 - m_1) \tag{4}$$

where V is the room volume, c is the propagation speed of sound in air, T_1 and T_2 are the reverberation times of the empty and treated rooms respectively, m is the power attenuation coefficient.

The absorption coefficients for MDF, gypsum and two commercially available ceiling tiles are summarized in Table 1.

Table 1 - Absorption coefficients, α_s, used within ODEON model

Octave Band Centre Frequency (Hz)	125	250	500	1000	2000	4000
MDF	0.03	0.05	0.09	0.09	0.08	0.02
Gypsum	0.01	0.02	0.06	0.07	0.06	0.03
25 mm Ceiling Tile	0.05	0.30	0.75	0.95	0.95	0.90
40 mm Ceiling Tile	0.10	0.55	1.00	1.00	0.95	0.90

One of the rooms was modelled in ODEON, with the reverberation times calculated for four different arrangements. MDF was used as the floor material for all arrangements, MDF or gypsum was used for the walls while the ceiling was modelled using either 25 mm or 40 mm ceiling tiles, the results are shown in Figure 3.

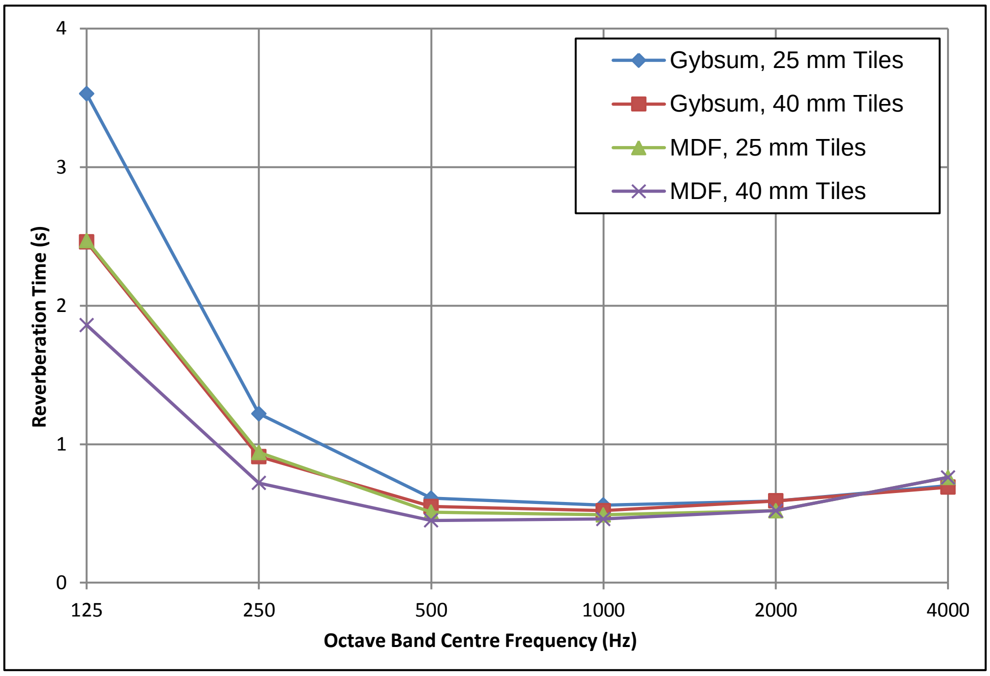


Figure 3 – Predicted reverberation times, gypsum vs. MDF, with the two ceiling tiles modelled

The results from the ODEON model show that the reverberation times are not greatly influence by using MDF in place of gypsum across most of the frequencies of interest. Low frequency behaviour and room diffusivity will be enhanced with the installation of steel diffusers, with a combined area of 8 m^2 as recommended in ASTM E14141.

3.3 Separating Wall

There are several acoustic transmission paths present in the test facility. Of particular interest is the transmission directly through the separating wall. This wall requires a sound transmission loss at least 10 dB higher than the transmission path through the common ceiling plenum, the two primary transmission paths are shown in Figure 4. The sound transmission loss of two commercially available, high performance ceiling tiles were measured at the University of Canterbury. As a first approximation, the transmission loss of the path through the ceiling plenum was assumed to be twice the transmission loss of a single panel plus an additional 5 dB across the frequency range.

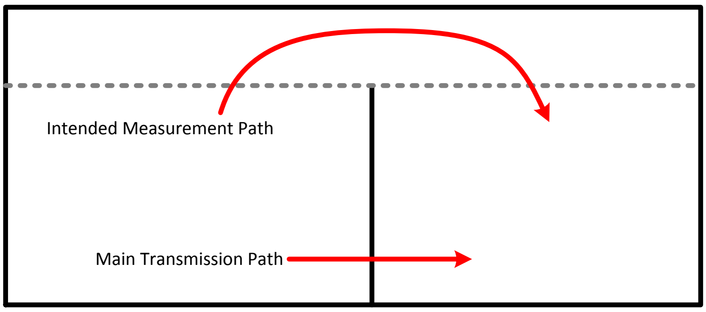


Figure 4 – Main sound transmission paths present in the test facility.

The initial separating wall design was a double leaf wall with MDF of different thicknesses for each leaf. These leaves were structurally isolated from each other (Figure 5). The performance of this construction was evaluated using the prediction methods described by Bies and Hansen (7).

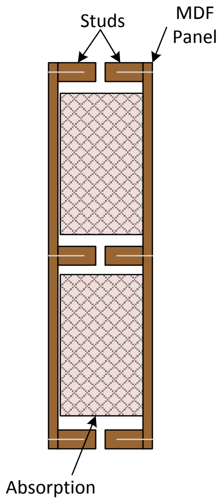


Figure 5 – Initial separating wall design.

This construction was found to have inadequate sound transmission loss, as shown in Figure 6. To improve the acoustic performance an alternative wall construction was developed. This wall system was a double leaf, structurally separated, MDF wall with 8 kg/m^2 mass loaded vinyl barriers on either side (Figure 7). This wall is expected to have a sound transmission loss similar to a double leaf 8 kg/m^2 mass loaded vinyl barrier. This design achieves the required sound transmission loss throughout the frequency range of interest.

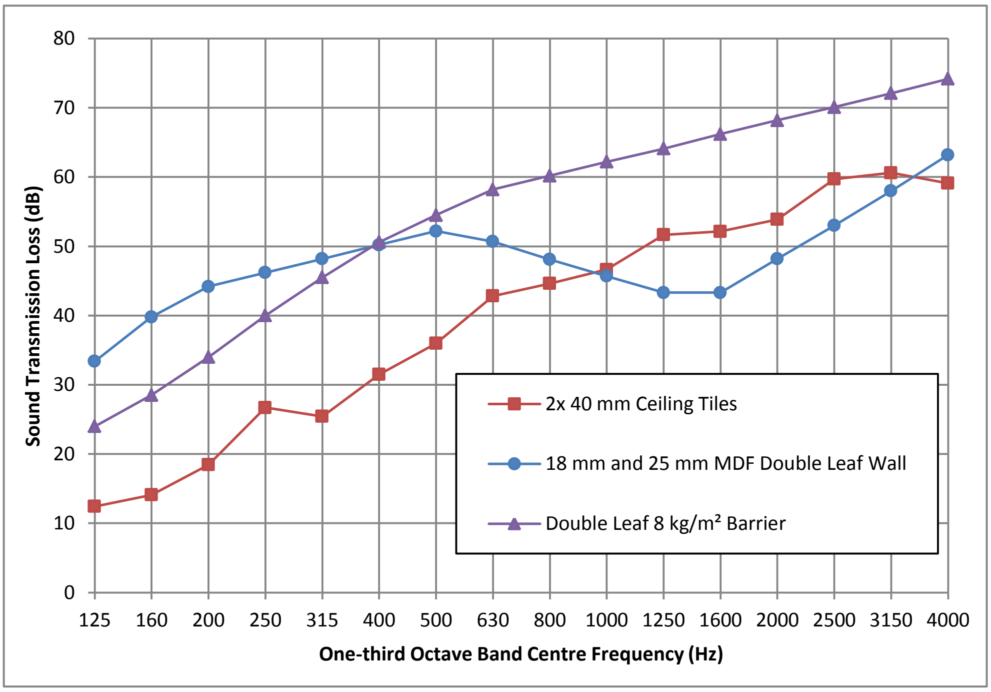


Figure 6 – Estimated sound transmission loss of two walls compared to estimated sound transmission loss of ceiling system.

The proposed wall design combines the sound insulation properties of the mass loaded barrier and the low absorption of the MDF panels. The design uses resilient mounts to space the MDF panel off the studs, allowing the mass loaded barrier to be installed between the MDF and the studs.

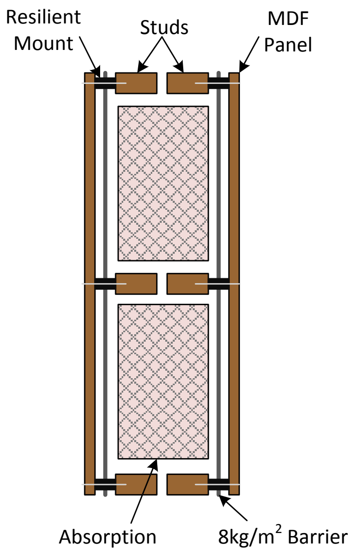


Figure 7 – Proposed separating wall design.

3.4 Assembly Design

The floor, walls and roof are clamped together using a bolt and T-nut arrangement shown in Figure 8. T-nuts are used in place of normal nuts as access to the inside of the frame is difficult due to the double leaf construction. An outer frame surrounds most of the wall elements and is used to clamp the elements together.

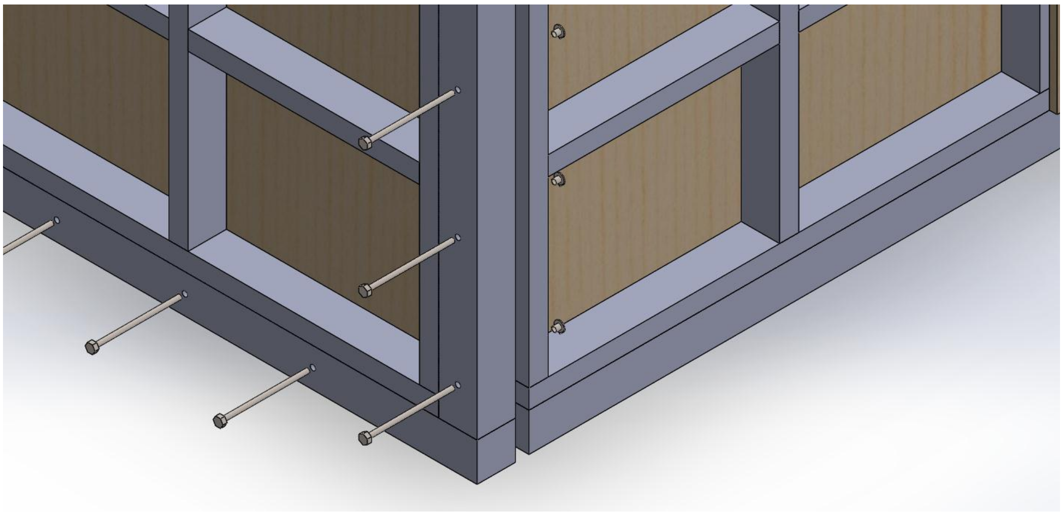
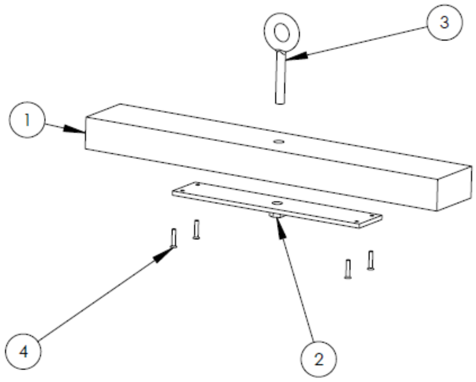


Figure 8 - The test facility bolt and T-nut construction method. Note: The outer leaves of the wall are hidden so the T-nut locations are visible

Each of the building elements have lifting points integrated within the frame to ensure that the rooms can be easily be constructed and deconstructed with the aid of an overhead crane. The typical construction of the lifting points is shown in Figure 9; the lifting assembly is screwed to the frame. The eye bolt can be removed easily, allowing the elements to be stacked flat for storage.



Item #	Part
1	45 × 90 × 565 mm
2	Lifting Plate
3	Threaded Eye Bolt
4	Lifting Plate Screws

Figure 9 - Typical construction of lifting points

The two rooms are not structurally connected in any way and the weight of the structures will hold the rooms at their desired locations. A rubber seal is installed between the two rooms, to ensure there are no air gaps between the rooms.

4. DISCUSSION

The design of the test facility for testing sound transmitted through a common ceiling plenum has been evaluated using ODEON and analytical calculations. ODEON was used to investigate the influence of different facing materials on the reverberation time of the rooms. The two materials studied were MDF and gypsum; commonly used building materials. The results showed that the gypsum produced longer reverberation time than the MDF walls but the difference was minimal. It was expected that gypsum would meet the room requirements so the knowledge that the MDF did not significantly reduce the room performance helped support the selection of the more durable MDF.

The ODEON model does not explicitly ensure that the facility will provide the required acoustic performance. If the diffusivity and reverberation times do not meet the specified performance criteria then a range of different treatments can be applied. Such treatments include painting the MDF surface to reduce the surface porosities, installing steel sheet facing or the addition of extra diffusers.

The sound transmission paths were investigated to aid in the development of a separating wall that is expected to meet performance requirements. The modelled separating wall used a double leaf wall arrangement with 8 kg/m^2 vinyl barrier material which was attached via resilient studs. The final design has fully isolated structural studs and external MDF facing sheets. The difference between the modelled wall and the final design suggests the constructed wall will perform better than the modelled wall.

The noise transmitted through the suspended ceiling and common plenum was derived from the measured sound transmission loss of single ceiling tile. The ceiling system will have a lower performance than the measured single tile due to leakage around individual tiles. In the constructed system the expected lower performance of the ceiling system and the increased performance of the separating wall should result in a greater signal to noise ratio than predicted.

5. FUTURE WORK

Following construction of the test facility, the prediction methods presented will be evaluated so that this development procedure can be confidently used in the design of facilities with similar acoustic requirements. The facility will be used for testing and development of different ceiling tile compositions and the overall construction of the suspended ceiling system. The rooms will also be used to investigate the use of treatments within the plenum to reduce sound transmission through a common plenum.

6. CONCLUSIONS

The design of a facility for testing suspended ceilings to ASTM E141 and ISO 10848 standards was described. The acoustic design was assessed using modelling software with support from analytical calculations and measured data to ensure that the facility meets the required specifications.

REFERENCES

1. Valtteri Hongisto AH, Esko Keskinen, Mila Haka. Effects of office noise on work performance and acoustic comfort - Laboratory experiment simulating three different office types. Internoise 2010; Lisbon, Portugal2010. p. 1-7.
2. K. P Roy ALS. Acoustics and sustainable design in exposed structures. Euronoise; Paris, France2008. p. 525 - 30
3. ISO 354:2003; Acoustics - Measurement of sound absorption in a reverberation room
4. ASTM E1414/E1414M - 11a; Standard Test Method for Airbourn Sound Attenuation Between Rooms Sharing a Common Ceiling Plenum
5. ISO 10848-1:2006; Acoustics - Laboratory measurement of hte flanking transmission of airborne and impact sound between adjoining rooms
6. ASTM E413; Classification for Rating Sound Insulation
7. Hansen CH, Bies DA. Engineering Noise Control: Spon; 1995.