Sound Transmission Loss of Movable Double-leaf Partition Wall

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Abstract: In this paper, the laboratory tests of Sound Transmission Loss (STL) of movable double-leaf partition walls are present. Three sets of sample partition walls, with different configuration, are employed; and all tests were carried out under the guidance of ISO140-1 and 3 standards. The results shown that bigger air gap, increase frame’s damping and reducing frame’s stiffness are benefit to the improvement in walls’ acoustic performance. It was also demonstrated that if movable partition walls are mounted in similar manors to the actual construction in laboratory tests, their STL are much worse than that of the counterpart drywalls.

Keywords: sound transmission loss, movable partition wall, laboratory test.

1 Introduction

Movable partition walls are broadly used in construction industry for room’s subdivision. This kind of partitions enjoys the merit of flexible setting for its lightweight characteristic. They share the similiar double-leaf configuration to fixed partition drywalls. Like all lightweight walls, the sound insulation level of movable partition walls is an important factor that needs to be taken into account during their application. The existing research has studied the sound performance of double-leaf configuration and Sound Transmission Loss (STL) of drywalls.

Sharp [1] developed an empirical method for predicting the STL of double panel by analyzing the power radiated from a point-or line-loaded panel. Mead and Pujara [2] proposed to use space-harmonic expansions to study periodic partitions; they set up a two-dimensional model in which the panel is represented as a beam supported by regularly spaced elastic supports. The experimental sound insulation data for different partition configuration has been showed in J.Q.Wang’s work [3]. The carefully planned experimental parametric study present by Hongisto et al. [4] also strengthens the understanding of double panel’s acoustic performance. Wang

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et al. [5] studied the smeared and periodic model for sound transmission across the partition walls, and the predictions of the two models are compared on the basis of practical testing results. Most of the research is based on fixed partition walls' experiments. In this paper, the laboratory sound transmission tests on three sets of movable partition walls were conducted. Owning to the differences in configuration, the experiment results proved that air gap and frame's stiffness and damping influence the moveable partition walls' STL. Meanwhile, compared to previous research on fixed partition walls, it was also concluded that the moveable partition walls' acoustic performance is confined by the installation ways adopted in the tests.

2 Prediction of sound transmission loss

The theories present here are only for purpose of estimating the various in moveable partition wall's STL than the absolutes values. Previous work [5] has put forwards a periodic model of the sound transmission loss through double-leaf lightweight partitions stiffened with periodically placed studs. In this model, the panels on two sides are assumed infinitive large and stiffened in one direction by studs which is simplified as translational and rotational springs with two pieces of lumped mass attached to the two panels respectively. The STL of double-leaf partition can be predicted by the following route.

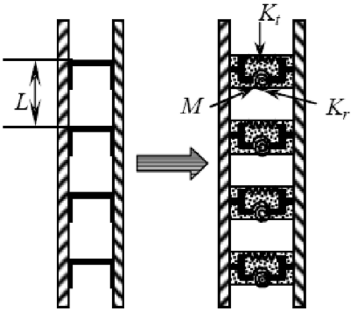

Figure 1. Side view of double-leaf partition wall with studs

The panel transverse displacement *Wi (x, t)* and the velocity potential (*Φ1, Φ2, Φ3*) in the incident, cavity and transmitted areas (Fig. 1) can be presented as

$$W_1(x,t) = \sum_{n=-\infty}^{+\infty} \alpha_{1,n} e^{-j[k_x+(2n\pi/L)]x} e^{j\omega t} \tag{1a}$$

$$W_2(x,t) = \sum_{n=-\infty}^{+\infty} \alpha_{2,n} e^{-j[k_x+(2n\pi/L)]x} e^{j\omega t} \tag{1b}$$

$$\Phi_1(x,y,t) = I e^{-j[(\mu/L)x+k_{y0}y-\omega t]} + \sum_{-\infty}^{+\infty} \beta_n e^{-j[((\mu+2n\pi)/L)x-k_{yn}y-\omega t]} \tag{2a}$$

$$\Phi_2(x,y,t)=\sum_{n=-\infty}^{+\infty}\varepsilon_n e^{-j\left[((\mu+2n\pi)/L)x+k_{yn}y-\omega t\right]}+\sum_{n=-\infty}^{+\infty}\zeta_n e^{-j\left[((\mu+2n\pi)/L)x-k_{yn}y-\omega t\right]} \tag{2b}$$

$$\Phi_3(x,y,t)=\sum_{n=-\infty}^{+\infty}\xi_n e^{-j\left[((\mu+2n\pi)/L)x+k_{yn}y-\omega t\right]} \tag{2c}$$

where $W_i(x,t)$ is the panel transverse displacement, the coefficient $\alpha_{i,n}$ can be considered as the travelling wave amplitude of the structure, L is the spacing between studs, ω is the angular frequency, k_x is the component of the wave number in the x direction (Fig. 1). With reference to Fig. 2, one has:

$$k_x(\omega)=k\sin\theta \tag{3}$$

$$k_y(\omega)=k\cos\theta \tag{4}$$

where $k=\omega/c$ is the wave number of the incident plane wave.

k_{yn} is the wave number in the y direction, which can be calculated from the following formula [6,7] :

$$k_{yn}=\sqrt{(\omega/c)^2-(k_x+2n\pi/L)^2} \tag{5}$$

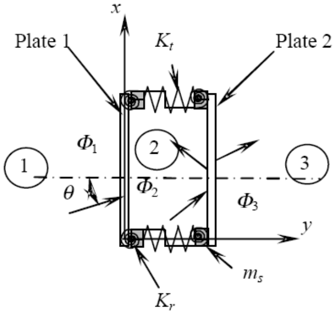

Figure 2. One periodic element and notation

When $(\omega/c)<|k_x+2n\pi/L|$ the corresponding pressure waves become evanescent, and the appropriate sign convention is to then replace $jk_{yn}y$ in the exponent of equation (2a) by $+\gamma_{yn}y$, where $\gamma_{yn}=\sqrt{(k_x+2n\pi/L)^2-(\omega/c)^2}$

Corresponding changes are made to equation (2b) and (2c). Φ_1, Φ_2 and Φ_3 represent the velocity potentials in incident, cavity and transmitted areas respectively. The coefficients β_n, ε_n, ζ_n and ξ_n may be considered as the travelling waves amplitudes of the incident (to the bottom panel), reflected and transmitted waves, which are coupled with the motions of the two panels.

The coefficients $\alpha_{i,n}$ can be found by solving the linear equation system derived using the principle of virtual work for one bay of the partition (Fig. 1) [6,7] shown below:

$$D_1\left(\partial^4 W_1/\partial x^4\right)+m_{p1}\left(\partial^2 W_1/\partial t^2\right)-j\omega\rho_0\left(\Phi_1-\Phi_2\right)=0 \tag{6}$$

$$D_2\left(\partial^4 W_2/\partial x^4\right)+m_{p2}\left(\partial^2 W_2/\partial t^2\right)-j\omega\rho_0\left(\Phi_2-\Phi_3\right)=0 \tag{7}$$

where Di is the flexural stiffness of the panel and mpi is the mass per unit area of panels.

Following the procedures proposed in[5], the power transmission coefficient is:

$$I_i=\left(\omega\rho_0 k_{y0}/2\right)|I|^2 \tag{8}$$

where I_i and I_t are the incident and transmitted normal intensities, respectively, given by [6,7]:

$$I_i=\left(\omega\rho_0 k_{y0}/2\right)|I|^2 \tag{9a}$$

$$I_t=\left(\omega\rho_0/2\right)\sum_{n=-\infty}^{+\infty}\left|\xi_n\right|^2 \mathrm{Re}\left[k_{yn}\right] \tag{9b}$$

Substitution of (8) and (9) into the following equation (10) and (11) completes the calculation of the STL, RL, across a double-leaf partition.

The transmission coefficient averaged over all angles of incidence is:

$$\tau=\int_0^{\theta_{\lim}}\tau(\theta)\sin\theta\cos\theta\,d\theta\bigg/\int_0^{\pi/2}\sin\theta\cos\theta\,d\theta$$

(10)

from which the transmission loss is calculated as:

$$RL=-10\log_{10}\tau \tag{11}$$

3 Experimental arrangement and measurements

Three sets of movable partition walls were tested. Each sample consists of three panels and there are two categories in the panel's thickness: 110mm and 150mm. One of the 110mm samples and the 150mm sample are composed of three standard panels; for simplicity, we will called them 110 standard and 150 standard respectively in the following sections. Another 110mm sample is composed of two standard panels and one final panel with a telescoping panel mounted inside, and this sample will be named as 110 plus in the following sections. All panels are supported by aluminium frames in flank, which play the same function as aforementioned partition walls' studs. Specially, the aluminum frames of 150 standard panels are divided in the place of central line and riveted again via a connecting aluminium strip, and the rubbers are set at the connection points; this design leads to less configuration stiffness coefficient and better damping characteristic(see Fig 3).

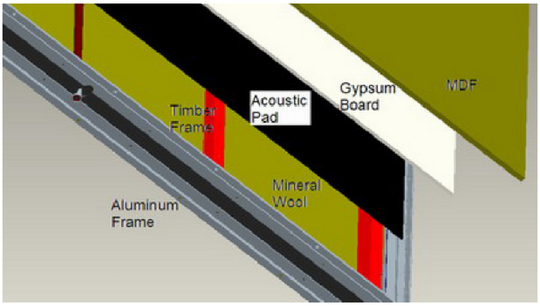

Figure 3. the configuration of 150 standard panels

For the standard panels, there is a layer of 15mm MDF boards as the outside facing on both sides of the panels, and the boards are screwed with aluminium frame in flank. A layer of 9.5mm gypsum boards are screwed on each inside of the MDF boards. Inside faces of both sides of gypsum boards are covered by a layer of 2.5mm polymeric acoustic pad. A jack is located in the centre of the panels to allow the extension of the sealing blocks top and bottom. Five wooden beams are periodically screwed on one side combined board (MDF + gypsum board + acoustic pad) to support the mechanical extending rods and, to some extend, horizontally strengthen the aluminium frames in spite of just a touch between them. Two layers of 25mm mineral wool are filled into the cavity of 150mm thick panels (see Fig. 3); but for 110mm thick panel, only one layer of 50mm mineral wool is packed inside. The differences in their configuration can also be seen in Fig. 3 to 5.

The area mass data of materials are list in table 1. The whole mass of 110 standard panels is 168kg and the surface density is 50 kg/m^2; for 150 standard panels, they are 189 kg and 56 kg/m^2 respectively.

Table 1. Surface density of materials

Material	**Kg/m^2**
15mm MDF Board	9.5
9.5mm Gypsum Board	6.3
2.5mm Acoustic Pad	5
50mm Mineral Wool	1.65
1.8mm sheet steel	14
1mm laminate	0.5

Because it needs a bigger space to place complicated mechanical system in the cavity of final panel, the gypsum boards are removed and only one side MDF is covered by a polymeric acoustic pad. Four pieces of wooden beam are vertically screwed on the combined board (MDF + acoustic pad) to support the mechanical system. The telescoping panel is mounted inside of the final panel, and 1.8mm steel sheet are used as the main material which is packed by 1mm laminate outside (area mass are shown in table1). The mass of final panel and telescoping panel is 135kg, and the surface density is 40kg/m^2.

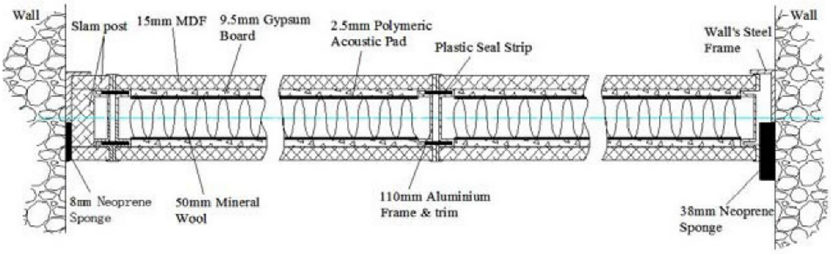

Figure 4. The installation way of 110 standard panels

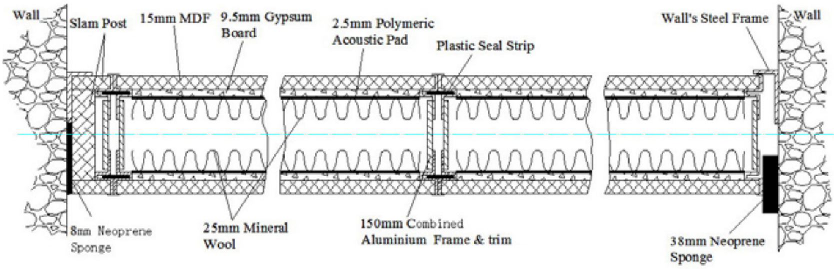

Figure 5. The installation way of 150 standard panels

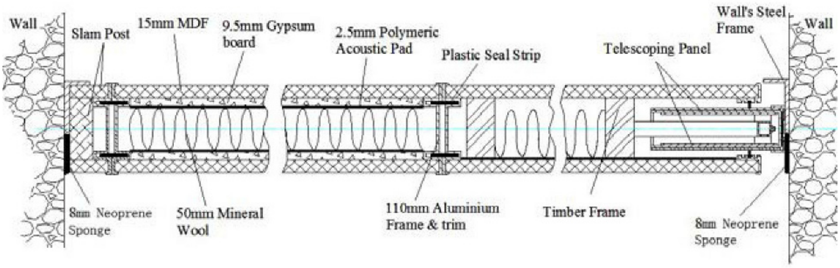

Figure 6. The installation way of 110 plus panels

The sound insulation of the movable partition walls were tested for under reverberant sound conditions in which sound is incident on one side of the specimen from all directions. All the mounting ways and tests are complied with

ISO 140-1 and 140-3 standards. The test samples were against a steel frame in the aperture of 10.58m^2 between two reverberant chambers, which have been constructed to suppress the transmission of sound by flanking paths. A slam post was fitted along the left hand side aperture for the panels to fit into, and the edges were lined with silicon. Sealing blocks were extended from the top and bottom of the panels to the top and bottom edges of the aperture. For the 110 standard (see Fig. 4) and 150 standard (see Fig. 5), the right hand side were packed with 38mm neoprene sponge, but for the 110 plus panels, the telescoping panel was extended out to squash into the 5 mm neoprene sponge, which is adhered to the right hand side aperture in advance (see Fig. 6). The edges of the sample were packed with close cell foam. Additionally, in order to mount the test partitions in a manner as similar as possible to the actual construction, special seal treatments in the joints like installation ways of drywall laboratory test were ignored in all three tests.

In each test process, a steady sound source with a continuous spectrum in the frequency bands of interest was used to drive an omni-directional loudspeaker, which was located sequentially in two positions in the source chamber. Measurements of the sound levels were made simultaneously in both chambers at the one-third octave intervals from 100 Hz to 5K Hz as prescribed in ISO 140-3. The measurements were made using a swept microphone scan in the receiving chamber and a swept microphone in the source chamber to obtain a good average of the sound pressure levels in each chamber.

The Sound Reduction Index (R) in decibels (dB) is calculated in each frequency band using the equation:

$$R = (L1 - L2 + 10\text{Log } S/A) \text{ dB}$$

Where:
L1 is the average sound pressure level in the source chamber (dB)
L2 is the average sound pressure level in the receiving chamber (dB)
S is the area of the test specimen (m^2)
A is the equivalent absorption area in the receiving chamber (m^2)

The equivalent absorption area in the receiving chamber was determined from twelve sets of reverberation time measurements using various microphone positions. The measurements were made in accordance with International Standard ISO 354.

The Weighted Sound Reduction (Rw) in decibels (dB) was calculated by comparing the eighteen values of Sound Reduction Index from 100 Hz to 5K Hz with a defined reference curve that was adjusted until the requirements of ISO 717-1 were met. The Rw rating system has two correction factors (C ; Ctr) which have been introduced to take into account different spectra of noise sources. C relates to higher frequency noise while Ctr relates to lower frequency noise. These correction factors are used to indicate the performance drop of the wall in corresponding frequency ranges. For example, an Rw (C ; Ctr) of 55 (-1 ; -4) would give a sound transmission loss of 55 - 4 = 51 decibels if the incident noise is predominantly low frequency.

4 Result and discussion

Fig. 7 shows the testing results of three sets of partition walls. The weighted sound reduction data for the 150 standard panels, 110 standard panels and 110 plus panels are 39dB, 36dB and 35dB respectively. It is obvious that 150 standard panels have better sound insulation level than other two kinds. The STL line of 150 standard panels shows that there are only small fluctuations responding to the frequency band from 100Hz to 2000Hz, approximately 1-2dB increase per octave; but after 2000Hz, the STL line increase strongly, about 7dB per octave. The 110 standard panels' STL line exhibits more apparent fluctuations; from 100HZ to 160Hz, there is a more than 10dB increase; but after that, the STL index go down against the frequency increase, reaching the rock bottom at 500Hz; then the STL line enters a smooth raise section at the rate of 3-5dB per octave. For the 110 plus panels, the increases in STL index are also obvious in the low frequency band; from 400Hz to 2000Hz, the fluctuation phenomena presents some small increases, accompanied by a couple of little drops; the increase rate from 2000Hz to 4000Hz is about 4dB per octave.

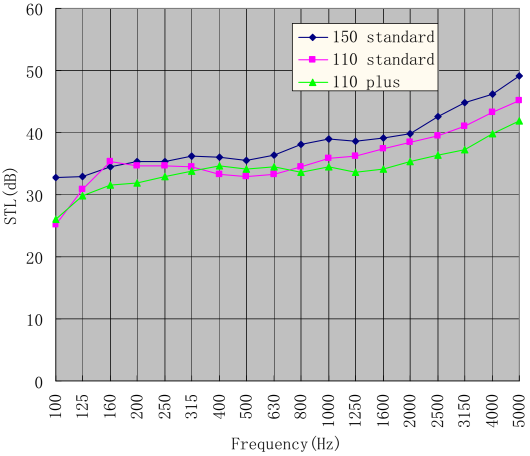

Figure 7. Test results

The complex aluminium frames of 150 standard panels enjoy lower structure stiffness and bigger damping coefficient. It is worth noting that the cavity of 150 standard panels is thicker than these of other two kinds. Therefore it is expectable that the 150 standard panels have best sound insulation level, which is in line with the acoustic performance rule of double-leaf partition. According to Sharp's conclusion[8], the slope of the STL with uncoupled double wall is 18dB/octave above the lowest mass-air-mass resonance frequency f_0; Hongisto et al. [4] experiment results also shown that there is approximately 10dB/octave increase above f_0 for the coupled double leaf wall. But this characteristic is not clear for all three testing samples. It is also expectative that sound-absorbing mineral wool in the cavity weakened all resonance and coincidence dips.

Because there is no special seal treatment in the joints like installation ways of drywall laboratory test, the testing results of these movable partition walls are worse than that of common drywall. It was proved that flanking sound leakages, to a large extend, influence the acoustic performance of movable partition wall, about 8dB loss compared to the results from Hongisto et al. [4]. Judging by the differences between 110 standard's STL line and 110 plus's STL line, the lighter surface density of final panel and the telescoping panel's application weakened the sound insulation level.

5 Conclusion

The results of this paper have revealed the STL differences of different movable partition walls. The stiffness and damping of frame affect the STL; and increasing the cavity thickness make sense to the improvement in the sound insulation level of movable partition walls. Telescoping panel and final panel used in practice are weak points in acoustic performance. Additionally, the installation ways also, to a large extent, influence the STL of movable partition walls, roughly 8dB loss in comparison with common drywalls.

6 Acknowledgments

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7 References

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