기술보고

Sound Transmission Loss through Double Walls

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1. Introduction

Regulations and standards define specific requirements of sound transmission loss through panel partitions for habitability of crew and passenger in ships and offshore facilities. Double walls are widely used when lightweight structure with high noise insulation performance is required. The sound insulation characteristics of double walls are complex and many literatures deal with theoretical or experimental models to predict sound transmission loss (London, 1950; Sharp, 1978; Davy, 2009, 2010). However, it was shown that none of the prediction models are capable of predicting the whole spread of commercial wall types (Hongisto, 2006). So, acoustical measurements in accordance with international standard (ISO 140-3) using a well-equipped facility have been widely adopted to investigate sound insulation performance through double wall.

Sound transmission loss through double wall is closely related with vibrations of each walls separatedby air gap. When the flanking path of sound can be ignored, vibration of wall structure is the main factor to determine sound insulation performance of a double wall. Measurement of sound transmission loss, however, is focused on measurement of sound pressure or intensity and there is no literature in which sound transmission loss is theoretically represented as a closed form function dependent only on vibrations of wall.

The purpose of this study is to theoretically formulate sound transmission loss as a function of vibrations of wall. Chapter 2 covers the derivation of the theoretical formulation. The verification results based on sound insulation experiment is dealt with in Chapter 3.

2. Theoretical Formulation

Theoretical formulation of sound transmission loss is well described in several literatures (Fahy, 1985; Bies and Hansen, 2003). Thus, in this paper we focus on the theoretical relationship between the vibration ratio of the double limp wall and sound transmission loss.

Fig. 1 shows the idealized sound transmission model for normal incidence. Two single limp walls of mass per unit area m_1, m_2 are assumed to be separated by distance d, and are mounted on viscously damped and elastic suspensions. The damping and stiffness coefficients per unit area of walls are r_1, r_2 and s_1, s_2, respectively. The cavity pressures P_2 and P_3 are related to the wall displacements ξ_1, ξ_2 and the pressure A, B as below

$$P_2 = A + B, \tag{1}$$

$$P_3 = A\exp(-jkd) + B\exp(-jkd), \tag{2}$$

$$v_1 = j\omega\xi_1 = (A - B)/(\rho_0 c), \tag{3}$$

$$\begin{aligned} v_2 &= j\omega\xi_2 \\ &= \{A\exp(-jkd) - B\exp(-jkd)\}/(\rho_0 c). \end{aligned} \tag{4}$$

v_1 and v_2 are the wall velocity and k is the wave number. c is the speed of sound in air and ρ_0 is the air density. The equation of motion of the incident -side wall is derived as below

$$\begin{aligned} P_1 - P_2 &= m\xi'' + r_1\xi' + s_1\xi \\ &= (j\omega)^2 + j\omega r_1 + s_1\xi_1 \end{aligned} \tag{5}$$

From eqs. (9) and (10) the pressure P_1 takes the form

$$j\omega\xi_1 z_1 = P_1 - P_2, \tag{6}$$

$$j\omega\xi_2 z_2 = P_3 - P_t, \tag{7}$$

$$z_i = j\omega m_i + r_i + s_i/(j\omega) \quad (i=1,2). \tag{8}$$

z_1 and z_2 are the wall impedances.

The wall displacement ξ_1 and the pressure P_1 are related to the incident and reflected pressures P_i, P_r as below

$$P_i - P_r = j\omega\rho_0 c\xi_1, \tag{9}$$

$$P_1 = P_i + P_r. \tag{10}$$

From eqs. (9) and (10) the pressure P_1 takes the form

$$P_1 = 2P_i - j\omega\rho_0 c\xi_1. \tag{11}$$

The transmitted pressure P_t takes the form

$$P_t = j\omega\rho_0 c\xi_2. \tag{12}$$

With an assumption of very short cavity width compared with the wavelength, i.e. $kd \ll 1$, eq. (2) can be rewritten as

$$P_3 \cong A + B = P_2. \tag{13}$$

In other word, the cavity pressure can be assumed to be uniform. In this case, eqs. (3) and (4) can be combined to give

$$(\rho_0 c/d)(\xi_1 - \xi_2) = P_2 \cong P_3, \tag{14}$$

which indicates that the air inside the cavity acts as a spring of stiffness $\rho_0 c/d$.

The wall vibration ratio σ_v can be given by combination of eqs. (6) - (14) as

$$\sigma_v = \frac{\xi_2}{\xi_1} = \frac{\rho_0 c^2/d}{j\omega(z_2 + \rho_0 c) + \rho_0 c^2/d}, \tag{15}$$

which represents how much the vibration of the transmitted-side wall is reduced compared with the vibration of the incident-side wall. Note that σ_v is controlled by the transmitted-side wall impedance z_2 and the cavity width d.

The ratio of incident and transmitted pressures σ_p can be easily derived from eqs. (6), (11), (12), (14) and (15) as below

$$\begin{aligned}\sigma_p &= \frac{P_t}{P_i} \\ &= -\frac{2j(\rho_0 c)^2/(kd)}{\{z_1 + \rho_0 c - j\rho_0 c/(kd)\}\{z_2 + \rho_0 c - j\rho_0 c/(kd)\} + \{\rho_0 c/(kd)\}^2}\end{aligned}, \tag{16}$$

and sound transmission loss through double limp wall is defined as

$$TL = 20\log_{10}\left|\frac{1}{\sigma_p}\right|. \tag{17}$$

Note that σ_p in eq. (16) is controlled by not only the transmitted-side wall impedance and the cavity width but also the incident-side wall impedance z_1. The difference between σ_v and σ_p is that σ_p includes the physical relation between ξ_1 and P_i whereas σ_v does not. σ_p can be represented as a series of three terms as

$$\sigma_p = \frac{\xi_1}{P_t} \times \frac{\xi_2}{\xi_1} \times \frac{P_t}{\xi_2}. \tag{18}$$

The 2nd term is the transfer function between ξ_1 and ξ_2 represented in eq. (15). The 3rd term is the transfer function between P_2 and ξ_2 and it can be represented from eq. (12). The 2nd and 3rd terms are independent on the incident-side wall impedance, thus it can be found that the term including z_1 in the denominator of eq. (16) is only related with the transfer function between ξ_1 and P_i. This also can be inferred from eq. (11) although it is difficult to obtain a closed-form expression of the transfer function between ξ_1 and P_i.

In case that the two single limp walls are identical, i.e.

$Z_1=Z_2$, the term including Z_1 in the denominator of eq. (16) can be rewritten by using σ_v. After a few mathematical manipulations, σ_p can be rewritten as

$$\sigma_p = \frac{2jkd}{1/\sigma_v^2 - 1}, \tag{19}$$

and sound transmission loss through double limp wall is represented as

$$TL = 20\log_{10}\left|\frac{1/\sigma_v^2 - 1}{2jkd}\right|. \tag{20}$$

For convenience of further discussion, we similarlydefine vibration transmission loss of double limp walls as

$$TL_v = 20\log_{10}\left|\frac{1}{\sigma_v}\right|. \tag{21}$$

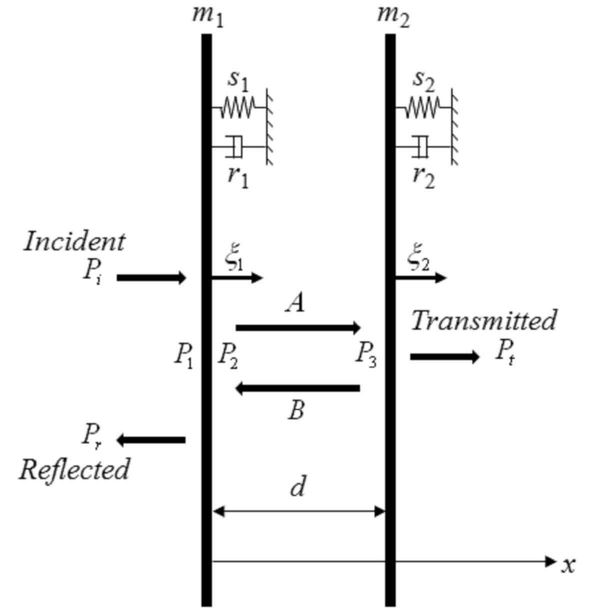

Fig. 1 Normal incidence sound transmission of a double limp wall

3. Experiment

To verify the relationship between σ_p and σ_v, an experiment using a double sandwich panel widely used as partition walls in ships and offshore facilities was carried out. Table 1 shows specification of the test panel. Test panel is composed of two identical sandwich panels separated by air gap of 50 mm. Each sandwich panel is composed of seven small panels connected by widely used joints. The width and height of each small panel are 520 mm and 2,730 mm, respectively.

Sound insulation test in accordance with international standard(6)was carried out using the facility in the Korea Marine Equipment Research Institute. Sound transmission loss in eq. (17) (or sound reduction index) was obtained by measurement of averaged sound pressure levels and reverberant time in the test rooms. Vibration levels of some selected positions were also measured using the B&K type 4371 accelerometer. Fig. 2 shows the vibration measurement positions on the incident-side wall. Vibration levels at the same positions on the transmitted-side wall were also measured simultaneously. Thus, the vibration ratios defined in eq. (15) were obtained at five positions and the averaged vibration ratioacross all positions was used to calculated sound transmission loss in eq. (20).

Fig. 3 shows the experimental results. TL_v represents the measured vibration transmission loss defined in eq. (21). TL_1 is the calculated sound transmission loss from measured σ_v and eq. (20). TL_2 is the measured sound transmission loss at 1/3 octave band center frequency. TL_1 is well coincident with TL_2 whereas TL_vshows significant difference to $TL_2$and the difference is resulted from the 2nd and 3rd terms in eq. (18).

Table 1 Specification of test panel

Structure	0.6T S - 15T M/W (180K) - 50T A/G - 15T M/W (180K) - 0.6T S
Size	3,640 mm × 2,740 mm

T : thickness in mm, S : Steel sheet, M/W : Mineral wool, K : density in kg/m^3, A/G : Air gap

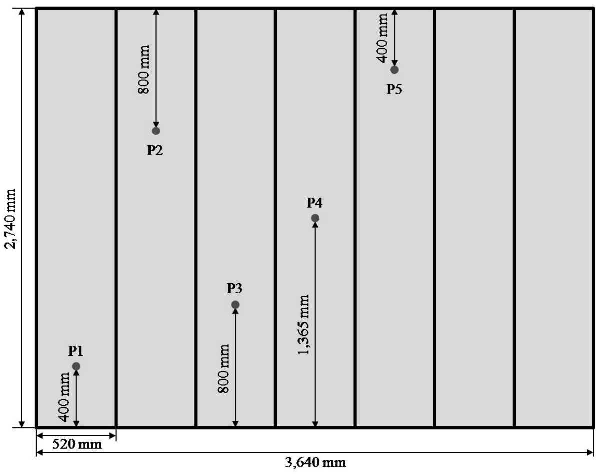

Fig. 2 Vibration measurement positions

Horizontal location of each measurement position is the center of each small panel.

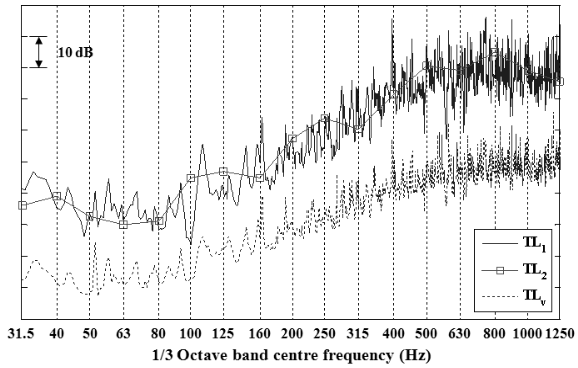

Fig. 3 Experimental results

TL_1 : STL from measured σ_v and eq. (20)
TL_2 : measured STL according to ISO 140-3
TL_v : vibration transmission loss defined in eq. (21)

4. Conclusion

Sound transmission loss through double limp wall composed of two identical single limp walls separated by air gap was theoretically formulated as a functionof vibrations of wall. Sound insulation test was carried out using a double sandwich panel widely used in ships and offshore facilities. In the results, it was found that sound transmission loss estimated by measured vibrations on wall is well agree with the one obtained by acoustical measurement in accordance with international standard. Therefore, it is concluded that sound transmission loss through double wall can be accurately estimated by measurement of vibrations without any acoustical measurements.

Acknowledgements

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