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Technical Note

# Prediction of sound reduction index of double sandwich panel

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ABSTRACT

This study deals with the prediction model for *SRI* of double sandwich panels widely used in living quarters of ships and offshore installations. The proposed prediction model is obtained from the modification of the conventional models based on empirical measurements. The prediction model is divided into six frequency bands and the boundary of each band is determined from the physically meaningful frequencies including the mass-air-mass frequency, the limiting frequency, the critical frequency and their combination. The key factors including the critical frequency of a single sandwich panel, the sound absorption coefficient of the air cavity and the damping loss factor required to the prediction model and obtained from the empirical measurements and the physical features. Feasibility of the proposed model was verified from acoustical measurements using the double sandwich panels with varying of the width of the air cavity, the thickness and density of absorption material and the thickness of steel. Comparison with the conventional models shows that the proposed model produces more accurate prediction than the conventional models for the double sandwich panels.



## 1. Introduction

Sound transmission loss or sound reduction index (*SRI*) is a measure of the effectiveness of building elements such as wall, floor and door in restricting the passage of sound through the element. Rules and regulations define specific requirements of sound insulation through panel partitions for habitability of crew and passenger in ships and offshore installations. In living quarters of ships and offshore installations sandwich panel composed of multiple layered structures is commonly applied to enhance not only fire resistance but also sound insulation. And double sandwich panel composed of two sandwich panels separated by the air cavity is widely utilized due to sound absorption inside the air cavity when lightweight structure with high noise insulation performance is required.

Many literatures deal with theoretical or experimental models to predict *SRI* [1–14,19–23] of single or double walls. Most theoretical models are focused on prediction of *SRI* through single or double-leaf walls. Some studies deal with prediction models applicable to single sandwich panel, which is a structure made of multiple layers: low density and thick core inserted in between two relatively high density and thin skin layers. However, it is hard to find prediction models applicable to double sandwich panel widely utilized in living quarters of ships and offshore installations. Although conventional models focused on double-leaf walls can be extended to double sandwich panel, high accurate prediction of *SRI* does not be achieved.

The objective of this study was to develop a prediction model applicable to double sandwich panel from the modification of conventional models proposed by Sharp [7] and Davy [12,13] based on empirical measurements. Verification of feasibility of the developed model and comparison with the conventional models are carried out based on the acoustic measurement results.

## 2. Conventional models

### 2.1. Sharp's model [7]

Sharp developed a model to predict *SRI* of single-leaf panel as

$$SRI = \begin{cases} 20\log(mf) - 48 & f < 0.5f_c \\ 20\log\left(\frac{\pi m}{Z_0}\right) + 10\log\left(\frac{2\eta f}{\pi f_{cr}}\right) & f > f_c \end{cases}, \qquad (1)$$

where $m$ is the surface mass (kg/m$^2$) and $Z_0$ is the characteristic impedance of the air, i.e. the product of the air density ($\rho$) and the speed of sound in the air ($c$). $\eta$ is the damping loss factor for the leaf panel and $f_c$ is the critical frequency. The coincidence effect is exhibited where the propagation speed of the bending wave in the panel equals the speed of sound in the air, and this effect results in the resonance dip of *SRI*. $f_c$ is the lowest frequency at which the coincidence effect occurs and it is given by

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$$f_c = \frac{c^2}{2\pi}\sqrt{\frac{m}{B}}, \tag{2}$$

where $B$ is the bending stiffness of the panel.

Sharp's model for double-leaf panel without stud is presented as

$$SRI = \begin{cases} SRI_M & f < f_0 \\ SRI_{m1} + SRI_{m2} + 20\log(fd) - 29 & f_0 < f < f_l, \\ SRI_{m1} + SRI_{m2} + 6 & f_l < f \end{cases} \tag{3}$$

where $SRI_M$, $SRI_{m1}$ and $SRI_{m2}$ are the values calculated from Eq. (1) for the double-leaf panel ($M = m_1 + m_2$) and two single-leaf panels ($m_1$ and $m_2$), respectively. $f_0$ represents at which the fundamental mass-air-mass resonance of the single-leaf panel masses and the stiffness of the air cavity occurs. At this frequency, both the single-leaf panels vibrate like two masses coupled by an air-spring. $f_0$ is given by

$$f_0 = \frac{1}{2\pi}\sqrt{\frac{1.8\rho_0 c^2(m_1+m_2)}{dm_1m_2}} \cong \frac{113}{\sqrt{dm_e}}, \tag{4}$$

where $d$ is the width of the air cavity and $m_e$ is equal to $2m_1m_2/(m_1 + m_2)$. $f_l$, the limiting frequency, is related to $d$ and given by

$$f_l = \frac{c}{2\pi d} \cong \frac{55}{d}. \tag{5}$$

Sharp's model assumes that the two single-leaf panels vibrate like a single-leaf panel with the total surface mass of $M$ in the frequency region below $f_0$ whereas they vibrate independently each other in the frequency region above $f_0$.

### 2.2. Davy's model [12,13]

Davy's model for double-leaf panel assumes that the total sound transmission coefficient is the sum of air-borne and structure-borne paths as

$$\tau = \tau_a + \tau_s, \tag{6}$$

where $\tau_a$ and $\tau_s$ are the air-borne and structure-borne sound transmission coefficient, respectively.

Below 2/3 of the normal incidence mass-air-mass resonance frequency, $f_0$, the air-borne sound transmission coefficient is given by

$$\tau_a = \frac{1}{a^2}\ln\left(\frac{1+a^2}{1+a^2\cos^2\theta_l}\right), \tag{7}$$

where

$$a = \frac{2\pi f(m_1+m_2)}{2\rho_0 c}. \tag{8}$$

The normal incidence mass-air-mass resonance frequency, $f_0$, is given by

$$f_0 = \frac{1}{2\pi}\sqrt{\frac{\rho_0 c^2(m_1+m_2)}{dm_1m_2}}, \tag{9}$$

and note that $f_0$ is slightly different from the one of Sharp's model in Eq. (4).

In the frequency region above $f_0$ and below 0.9 times the lower of the two critical frequencies ($f_{c1}$ and $f_{c2}$), the air-borne sound transmission coefficient is calculated as

$$\tau_a = \frac{1-\cos^2\theta_l}{(q+p\cos^2\theta_l)(q+p)}, \tag{10}$$

where

$$q = \frac{1}{2}\left(\frac{a_2}{a_1}+\frac{a_1}{a_2}\right), \tag{11}$$

$$p = a_1a_2\alpha, \tag{12}$$

and

$$a_i = \frac{\pi f m_i}{\rho_0 c} \quad (i = 1, 2). \tag{13}$$

$\theta_l$ is the limit incidence angle introduced to make Eq. (10) agree better with experimental results and it is less than or equal to 61°. In the frequency range between 2/3 of $f_0$ and $f_0$, $SRI$ is obtained from interpolation in the logarithmic frequency domain using $SRI$s calculated using Eq. (7) at 2/3 of $f_0$ and Eq. (10) at $f_0$. $\alpha$ is the sound absorption coefficient inside the air cavity and the value between 0.10 and 0.15 is recommended for cavities without absorbing material.

In the frequency region above 0.9 times the lower of the two critical frequencies, the air-borne sound transmission coefficient is calculated as

$$\tau_a = \frac{\pi(\xi_1+\xi_2)n}{4B_1^2B_2^2\eta_1\eta_2\xi_1\xi_2(n^2+v^2)\alpha^2}, \tag{14}$$

where

$$B_i = \frac{\pi f m_i}{\rho_0 c}, \tag{15}$$

$$\xi_i = \sqrt{\frac{f}{f_{ci}}}, \tag{16}$$

$$n = \eta_1\xi_2 + \eta_2\xi_1, \tag{17}$$

$$v = 4(\xi_1 - \xi_2), \tag{18}$$

and $\eta_i$ is the damping loss factor for the $i$th leaf panel.

The structure-borne sound transmission is also considered separately in the frequency range above $f_0$ and it is calculated as

$$\tau_s = \frac{64\rho_0^2c^3D}{\left[g^2 + (4\omega^{3/2}m_1m_2cC_M - g)^2\right]b\omega^2}, \tag{19}$$

where

$$g = m_1\sqrt{2\pi f_{c1}} + m_2\sqrt{2\pi f_{c2}}, \tag{20}$$

and $\omega$ is the angular frequency and equal to $2\pi f$. $b$ is the spacing between the studs and $C_M$ is the stud compliance. $D$ is a factor to account for the effects of resonant vibration and it is set to empirically constant value of 2.

## 3. Prediction model

### 3.1. General

The conventional models proposed by Sharp and Davy are modified based on empirical measurements in order to enhance $SRI$ estimation accuracy for double sandwich panel separated by the air cavity. Typical double sandwich panels used for ships and offshore installations can be categorized as shown in Fig. 3.1. In general there is no stud connecting two sandwich panels and mineral wool is covered by facing material such as Glass Cloth Fabric (GCF). Thus, the structure-borne sound transmission is out of scope of this study. Type A, which is the most widely used structure, is mainly focused on in this study.

The conventional models including Sharp' and Davy's models show considerable error to calculate $SRI$ of double sandwich panels used for ships and offshore installations in Fig. 3.1. Thus, this study tries to hybrid and to modify the conventional models based on empirical measurements. $SRI$ of several double sandwich panels