Effects of length-thickness ratio on the dynamic calculation accuracy of the honeycomb panel equivalent models

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Abstract. In order to improve the numerical calculation accuracy of the hexagonal aluminum honeycomb panel, the influence of the length-thickness ratio on the dynamic calculation accuracy of the equivalent models is studied. The modal frequencies of the equivalent models and the entity model are compared to analyse the influence of the length-thickness ratio on the dynamic calculation accuracy of the equivalent models. The results show that the first 10 order errors of sandwich panel theory model and honeycomb panel theory model are less than 20% for medium thickness panel with length-thickness ratio less than 10.3, so the equivalent effect is ideal. When the ratio of length to thickness of Reissner theory model and honeycomb panel theory model is about 10.3 and 13.7 respectively, the calculation accuracy is low and the error peak appears. The sandwich panel theory model has lower accuracy than other equivalent models for thick panel.

1. Introduction

Honeycomb sandwich panel is a kind of multipurpose structural material which is widely used at present. Based on their good mechanical properties and ease of weight reduction, some of the major stress structures of satellites consist almost entirely of honeycomb sandwich panels. In general, the quality of the honeycomb structure can account for 80-90% of the entire satellite panel structure [1-3]. Current engineering software such as ABAQUS, NASTRAN do not have a honeycomb structure unit, so only a three-dimensional entity model or an equivalent model can be used for numerical analysis of a honeycomb sandwich panel structure [4-5]. The three-dimensional entity model has high calculation accuracy but with a large amount of calculation. The equivalent models have less computational complexity and is more widely used. The equivalent theories of current honeycomb sandwich panels are sandwich panel theory, Reissner theory, honeycomb panel theory, etc. Xu Sheng-jin [6] used numerical analysis methods to study the effect of the thickness-to-span ratio on the calculation accuracy. In engineering, the ratio of the minimum size to the maximum thickness is generally

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referred to as the length-thickness ratio, and greater than 5 is referred to as a thin panel, otherwise it is referred to as a thick panel. The length-thickness ratio can be expressed as \( \lambda = \frac{b}{H} \). The above studies did not consider the influence of the length-thickness ratio of the honeycomb sandwich panel on the calculation accuracy of equivalent models. The influence of the ratio of length to thickness is of great significance to the selection of equivalent models for dynamic calculation.

Firstly, the equivalent models of uniform hexagonal aluminum honeycomb sandwich panel with uniform wall thickness is summarized. Then the modal analysis results of equivalent models are compared with the honeycomb sandwich panel model, and the influence of length-thickness ratio on the modal frequency calculation accuracy is analyzed. Finally, the influence law of length-thickness ratio on the dynamic calculation accuracy of the equivalent models is summarized, which provides a reference for the dynamic calculation of honeycomb sandwich panel members [7-10].

2. Equivalent models of hexagonal aluminum honeycomb sandwich panels

Honeycomb sandwich panels typically consist of upper and lower skin layers and an intermediate honeycomb core layer. The hexagonal honeycomb is widely used because of its simple manufacture, low cost, and high structural efficiency. A simplified model of a honeycomb sandwich panel with a uniform core thickness is shown in Fig. 1.

![Figure 1 Structure and dimension of honeycomb sandwich panel](image)

As figure 1 shows, \( a \) is the board length; \( b \) is the board width; the thickness of the upper and lower boards is \( h_1 \); the core thickness is \( h_2 \); \( t \) is the wall thickness of the core; \( L \) is the length of the side.

2.1. Sandwich panel theory

Sandwich panel theory is an equivalent method only for the honeycomb core layer. The equivalent material parameters of the core layer are as follow formula 1 [11].

\[
\begin{align*}
E_x &= \frac{4}{\sqrt{3}} \left( 1 + \frac{t}{P} \right) E_t, \quad E_y = \frac{4}{\sqrt{3}} \left( 1 + \frac{t}{P} \right) E_t \\
E_z &= \frac{2}{\sqrt{3}} E_t, \quad G_{xy} = \frac{\sqrt{2}}{3} E_t \left( \frac{1}{r} \right) \\
G_{yx} &= \frac{\sqrt{2}}{3} \left( \frac{1}{r} \right) G, \quad G_{yz} = \frac{\sqrt{2}}{3} \left( \frac{1}{r} \right) G \\
\rho_s &= \frac{2t}{3\pi} \rho_t, \quad \mu_{xy} = \frac{1.155}{t} \rho_t, \quad \gamma_{xy} = \frac{1}{3}
\end{align*}
\]  

(1)

In the formula, \( E, P, \rho, \mu \) are the elastic modulus, shear modulus, density, Poisson ratio of the core material respectively.

2.2. Reissner theory

Reissner theory is a kind of equivalent theory, which equates the whole honeycomb sandwich panel with isotropic material of different thickness. And then the equivalent elastic modulus and thickness of the equivalent panel are derived based on the same stiffness. Equivalent panel density can be derived based on equal mass. The equivalent elastic parameters are calculated as shown in formula 2.
In addition, the equivalent density of the equivalent panel can be calculated based on the equal mass as shown in formula 3.

$$\rho_{eq} = \frac{2\rho_f h_f + \rho_c (H - 2h_f)}{t_{eq}} \quad (3)$$

### 2.3. Honeycomb panel theory

The honeycomb panel theory is based on the dynamic equation and Hamiltonian principle, the whole honeycomb sandwich panel is equivalent to an orthotropic panel with equal stiffness and size.

Assuming that the thickness of the surface layer is $d$, the height of core layer is $2h$. The structure before and after equivalence is shown in the Fig. 2, the black dotted line draws the honeycomb panel structure, while the red solid line draws the equivalent structure.

![Figure 2 Structure equivalence of honeycomb sandwich panel](image)

The equivalent elastic parameters are calculated as shown in formula 4.

$$
\begin{cases}
E_x = \frac{(e_{11}e_{22} - e_{12}^2)/e_{22}}{e_{11}}, \\
E_y = \frac{(e_{11}e_{22} - e_{12}^2)/e_{11}}{e_{22}}, \\
G_{xy} = e_{44} \\
G_{xz} = e_{55}, \\
G_{yz} = e_{66}, \\
\mu_{yz} = e_{12}/e_{22}
\end{cases} \quad (4)
$$

And the density expression is shown in formula 5.

$$\rho = \frac{d \rho_f + h \rho_c}{d + h} \quad (5)$$

$e_i (i, j = 1, 2,...6)$ is an expression related to the cell size of the honeycomb panel. The subscript $c$ denotes the honeycomb core layer, the subscript $f$ denotes the panel.

### 3. Influence analysis of length - thickness ratio on equivalent models

The material parameters of the core layer are obtained from the equivalent formulas of the above-mentioned equivalent theories. The honeycomb sandwich panels with $a = 454mm$ in length and $b = 462mm$ in width were studied with different core thicknesses (50, 40, 30, 22, 10 mm, respectively). The geometric parameters and material parameters of the sandwich structure are shown in the Table 1.
Table 1 Geometric and material parameters of honeycomb sandwich panels

| Position  | Geometric parameters (m) | Material parameters |
|-----------|--------------------------|---------------------|
| Core layer| $h_c = 2.2 \times 10^{-2}$ | $E = 6.8 \times 10^4 \text{MPa}$ |
|           | $t=2e^{-5}$ $l=6e^{-5}$   | $G = 2.4 \times 10^4 \text{MPa}$ |
|           |                          | $\mu = 0.3$         |
|           |                          | $\rho = 2.8 \times 10^{-9} \text{t / mm}^3$ |
| Panel     | $h_f = 2 \times 10^{-4}$  | $E_{fy} = 3.0 \times 10^4 \text{MPa}$ |
|           |                          | $G_{fy} = 400 \text{MPa}$, $\mu = 0.05$ |
|           |                          | $\rho = 4.2 \times 10^{-10} \text{t / mm}^3$ |

3.1. Comparison of modal analysis of equivalent models with different length-thickness ratios

According to sandwich panel theory, the formula (1) and the parameters listed in Table 1 can be used to calculate the equivalent geometric parameters and material parameters, as shown in the following Table 2.

Table 2 Equivalent parameters of sandwich panel theory

| Parameters | Thickness | Elastic modulus | Shear modulus | Poisson ratio | Density |
|------------|-----------|-----------------|---------------|---------------|---------|
| Value      | 22mm      | $E_{xx} = E_{yy} = 5.8e^3 \text{MPa}$ | $G_{xy} = 8.7e^3 \text{MPa}$ | 0.33 | $1.6e^{11} \text{t / mm}^3$ |

The equivalent models with different core thicknesses and corresponding to entity models were established. Under the same four-point fixed boundary conditions as the entity model, the first 10 modal frequencies of the three models with different core thicknesses are shown in Fig.3 [12].

Figure 3 The first ten modal frequencies of different length-thickness ratio models

For the core thickness $h_c = 10 \text{mm}$, the first modes of honeycomb sandwich panel and the equivalent models are shown in Fig. 4.

(a) Honeycomb structure
(b) Sandwich panel theory
(c) Reissner theory
(d) Honeycomb panel theory

Figure 4 The first modes of honeycomb sandwich panel and the equivalent models

3.2. Error analysis

Comparing the modal frequency calculation results of the equivalent models with the refinement model, the absolute values of the modal frequency calculation errors of different length-thickness ratios are obtained. The results are shown in Fig. 5.
It can be seen that the effect of length-thickness ratio on the modal calculation of each equivalent model is obvious. The calculation error of the first 10 modal frequencies of sandwich panel theory model when the length-thickness ratio is between 8-20 increases with the increase of the length-thickness ratio. The effect of the length-thickness ratio on the calculation error is small when the length-thickness ratio is greater than 20, and the calculation error of each mode tends to be stable.

The modal frequency errors of the Reissner theory model are less than 30%. There will be a peak in the error when the length-to-thickness ratio is 10.3, and then the calculation errors will decrease as the length-thickness ratio increases or decreases. The modal frequency errors of the honeycomb panel theory model are within 37%. When the length-to-thickness ratio is 13.7, the error appears to peak, and then the calculation error will decrease as the ratio of length-thickness increases or decreases. When the ratio of length to thickness is less than 10.3, the sandwich panel theory model and the honeycomb panel theory model are all within 20% of the error of the first 10 orders.

4. Conclusion
Based on the analysis of the calculation results of the above equivalent models at different length-thickness ratios, the following conclusions can be obtained.

(1) The research results provide an important reference for calculating the dynamic response of honeycomb sandwich panels by selecting the appropriate equivalent theory.
(2) The change of calculation accuracy can provide an important reference for the correction and development of each equivalent theory.
(3) The effect of different length-thickness ratio on equivalent accuracy can provide important suggestions for the application and design of honeycomb structure.

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