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Analysis of Sandwich Structure under the Action of Dynamic Evenly Distributed and Concentrated Loads

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Abstract: Sandwich structures have an increased bending stiffness with low weight which makes it possible to achieve a significant saving in weight for the structures taking the compressive forces. Besides, in many cases, the multiple sandwiches have high thermal insulating and radiotechnical properties which is an important factor in operation of a number of state of the art products of different purpose. Experience in operating and testing of facilities with the use of three-layer sandwiches has shown a high efficiency of sandwich structures and their irreplaceability sometimes. The analytical dependences for analysis of sandwich structure which is subjected of a load uniformly distributed over the surface in combination with a compressive force acting in the plane of a structure middle surface and a concentrated impulse force have been derived in the study.

Key words: Sandwich structure, base layer, dynamic load, fibrous material, impulse force

INTRODUCATION

The requirements placed on modern structures are continuously rising which leads to the need for solving a variety of problems regarding determination of sandwich structure parameters (Arshad *et al*., 2011; Singh and Nanda, 2013; Van Dung and Hoa, 2013; Pentaras and Elishakoff, 2010; Li *et al*., 2012; Avades and Sharma, 2013). The above-mentioned structures should be light-weight and sturdy, take static and dynamic loads as well as perform a number of other functions. Multilayered structures, including sandwich structures, meet these requirements more fully from the viewpoint of multi-functionality (Fig. 1).

MATERIALS AND METHODS

The problem of the analysis of sandwich structure which is simultaneously under the load uniformly distributed over the surface combined with a compressive force acting in the plane of the structure middle surface and a concentrated impulse force is considered by research. The sandwich panel which design model is shown in Fig. 2. is considered as an example. The sandwich structure itself consists of the base layers and a discrete aggregate filled with a fibrous material. Analysis of the structure for action of a uniformly distributed load can be performed by means of dependencies stated in the dependences previously proposed in papers (Goldsmith, 1965; Ustarkhanov *et al*., 2013, 2014 and 2016; Kerimov *et al*., 2015) shall be used for determination of reduced characteristics. Maximum normal stresses acting in the base layers are as follows:

$$\sigma_{max} = -E_{1,2}\left\{\frac{qb^2(h+t)m_2}{\frac{E_{1,2}t}{1-\gamma_{1,2}^2}\left[\frac{t^2}{6}+2\left(h+\frac{t}{2}\right)^2\right]}+\frac{N}{2\frac{E_{1,2}t}{1-\gamma_{1,2}^2}}\right\}$$

Where:

- N = Intensity per unit length of contour of compressive forces
- q = Intensity per unit area of a uniformly distributed load
- m_2 = Coefficient depending on the nature of edge restraint

Shearing stresses in the aggregate shall be defined as:

$$\tau_{shear} = \frac{qb(h+\frac{1}{2})m_2}{4\left[\frac{t^2}{2}+2\left(h+\frac{t}{2}\right)^2\right]}$$

Sandwich structure (plate) buckling failure critical strain in case of a loading scheme under consideration is equal to:

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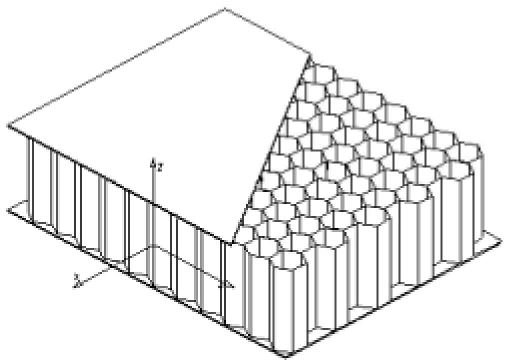

Fig. 1: Sandwich structure general view

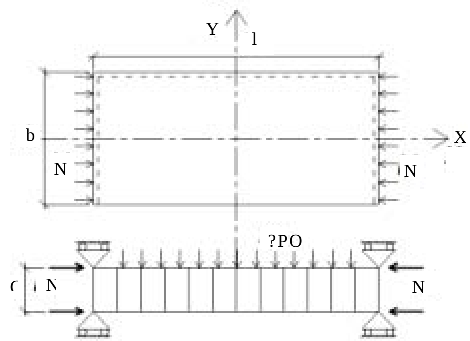

Fig. 2: Sandwich panel design model

$$\sigma_{crticial} = \frac{\pi^2 \frac{E_{1,2}t}{1-\gamma_{1,2}^2}\left[\frac{t^2}{6}+2\left(h+\frac{t}{2}\right)^2\right]}{b^2 t\left[1+\frac{\pi^2 E_{1,2}th}{(1-\gamma_{1,2}^2\ )2G_{xz_3}b^2}\right]}$$

Varying t, $E_{1,2}$, h, G_{xz3}, $\gamma_{1,2}$ values at the given q, N, b, it is possible to obtain sandwich structure parameters close to the optimal ones during the action of a uniformly distributed load q and compressive forces N, on the basis of the following dependences:

$$\sigma_{max} \approx \sigma_{critical}, \tau_{shear} < \tau_{xz_3}$$

Sandwich structure weight is equal to:

$$M_{design} = ab\left(t_1\rho_1 + 2h\rho_3 + t_2\rho_2\right)$$

Where:

a, b = Sandwich structure dimensions in plan view

ρ_i = Density of sandwich structure layers material (i = 1, 2, 3)

The sandwich structure reduced weight efficiency is equal to:

$$\bar{\rho}_{design} = \frac{M_{design}}{ab(t_1 + 2h + t_2)}$$

The requirement imposed on a sandwich structure exposed to the action of impulsive concentrated load lies in the fact that under the action of the hammer weighing $m_{specific}$, having an initial velocity ν_0, the structure should:

- Dump the velocity to the value ν_1 which is caused by the action of hammer limit after-penetration effect, in this case, the structure becomes untightened
- Dump the velocity to the value $\nu_1 = 0$ which corresponds to the demand of structure tightness preservation

From the abovementioned, it is possible to record the distribution condition of velocity values that are dumped in each sandwich structure layer:

$$\nu_0 = \Delta_1 + \Delta_2 + \Delta_3 + \Delta_1$$

Where:

Δ_1 = Velocity loss on the first base layer

Δ_2 = Velocity loss on the fibrous material

Δ_3 = Velocity loss on the second base layer

After-penetration velocity ν_1 is equal to:

$$\nu_1 = \nu_0 - (\Delta_1 + \Delta_2 + \Delta_1)$$

RESULTS AND DISCUSSION

Proceeding from the position that the energy of base layer penetration by means of a cone-shaped hummer is equal to (Singhand Nanda, 2013):

$$W = \pi t_{1,2}R^2\left[\rho\left(\frac{\nu_0 R}{L}\right)^2 + \frac{1}{2}\sigma_T\right]$$

We shall obtain:

$$\frac{m_{specific}\Delta_{1,2}^2}{2} = \pi t_{1,2}R^2\left[\rho\left(\frac{\nu_0 R}{L}\right)^2 + \frac{1}{2}\sigma_T\right]$$

Where:

σ_T = Tensile strength of a material, layer being penetrated

T = Thickness of a layer being penetrated

R = Hammer radius

L = Hammer head length

$\Delta_{1,2}$ = Velocity loss on the base layer being penetrated

Then:

$$\nu_1 = \nu_0 \left\{ \left[\frac{\pi t_1 R^2 \left[\rho \left(\frac{\nu_0 R}{L} \right)^2 + \frac{1}{2}\sigma_T \right]}{m_{specific}} \right]^{\frac{1}{2}} \left[\frac{\pi t_2 R^2 \left[\left(\rho \frac{\nu_0 R}{L} \right)^2 + \frac{1}{2}\sigma_T \right]}{m_{specific}} \right]^{\frac{1}{2}} + \Delta_3 \right\}$$

If we assume that the after-penetration velocity $\upsilon_1 = 2$ and free-reinforced filler is absent then we shall obtain:

$$\nu_0 = \left[\frac{\pi t_1 R^2 \left[\rho \left(\frac{\nu_0 R}{L} \right)^2 + \frac{1}{2}\sigma_T \right]}{m_{specific}} \right]^{\frac{1}{2}}$$

$$\left[\frac{\pi t_2 R^2 \left[\left(\rho \frac{\nu_0 R}{L} \right)^2 + \frac{1}{2}\sigma_T \right]}{m_{specific}} \right]^{\frac{1}{2}}$$

In case of equal base layer thicknesses and materials we shall obtain:

$$\nu_0^2 = 4 \frac{\pi t_1 R^2 \left[\rho \left(\frac{\nu_0 R}{L} \right)^2 + \frac{1}{2}\sigma_T \right]}{m_{specific}}$$

Thus the energy of base layer penetration is equal to hummer energy (provided that $\upsilon_1 = 20$) which shall be calculated as:

$$W_{specific} = \frac{m^2_{specific0}}{2} = W_{baselayer}$$

Where from:

$$\nu_0^2 = \frac{4\pi t_{1,2} R^2 \sigma_T}{m_{specific} - 8\pi t_{1,2} \frac{\rho}{L}}$$

The thickness of a base layer being penetrated:

$$t_{1,2\ penter} = \frac{\nu_0^2\ m_{specific}}{8\pi t_{1,2} R^2 \left[\rho \left(\frac{\nu_0 R}{L} \right)^2 + \frac{1}{2}\sigma_T \right]}$$

The thickness of the obtained base layer $t_{1,2penetr}$ should not be less than $t_{1,2}$ obtained with taking into account a bearing capacity from the distributed load, i.e.:

$$t_{1,2\ penter} \geq t_{1,2}$$

Then the sandwich structure weight will be equal to:

$$M_{sandwich\ structure} = ab(t_{1,2\ penter}\ \rho_{baselayer} + 2h\rho_3)$$

and the relative weight effectiveness:

$$\overline{M}_{sandwich\ structure} = \frac{t_{1,2\ penter}\ \rho_{base\ layer} + 2h\rho_3}{t_{1,2\ penter}\ \rho_{base\ layer} + 2h\rho_3}$$

Will be equal to or less than one. The reinforcement is not required if :

$$\overline{M}_{sandwich\ structure} = 1$$

If we assume that the fibrous material is used for increasing the sandwich structure resistance to the action of a concentrated impulse load then it is necessary to calculate the hammer speed lost for penetration of the base layers having the thickness $t_{1,2}$. The velocity shall be determined based on the condition of resistance to the action of distributed and longitudinal compressive load as follows:

$$\nu_{1,2} = \frac{\pi t_{1,2} R^2 \left[\rho (\frac{\nu_0 R}{L})^2 + \frac{1}{2}\sigma_T \right]}{m_{specific}}$$

The velocity value which should be dumped on a fibrous material shall be determined from the condition of equality of after-penetration velocity to zero $\upsilon_1 = 0$ as follows:

$$\Delta_3 = \nu_0 - \nu_{1,2}$$

It is possible to determine the required density of a fibrous material providing hammer speed loss equal to Δ_3 with a specified weight and geometry from the graph plotted based on the experimental data and shown in Fig. 3. Having determined ρ_3 Fiber material we will find a sandwich structure weight:

$$M_{sandwich\ structure} = ab\left[t_{1,2}\rho_{base}\,layer + 2h(\rho_3 + \rho_{3fiber\ material)}) \right]$$

Relative weight efficiency of a sandwich structure will be equal to:

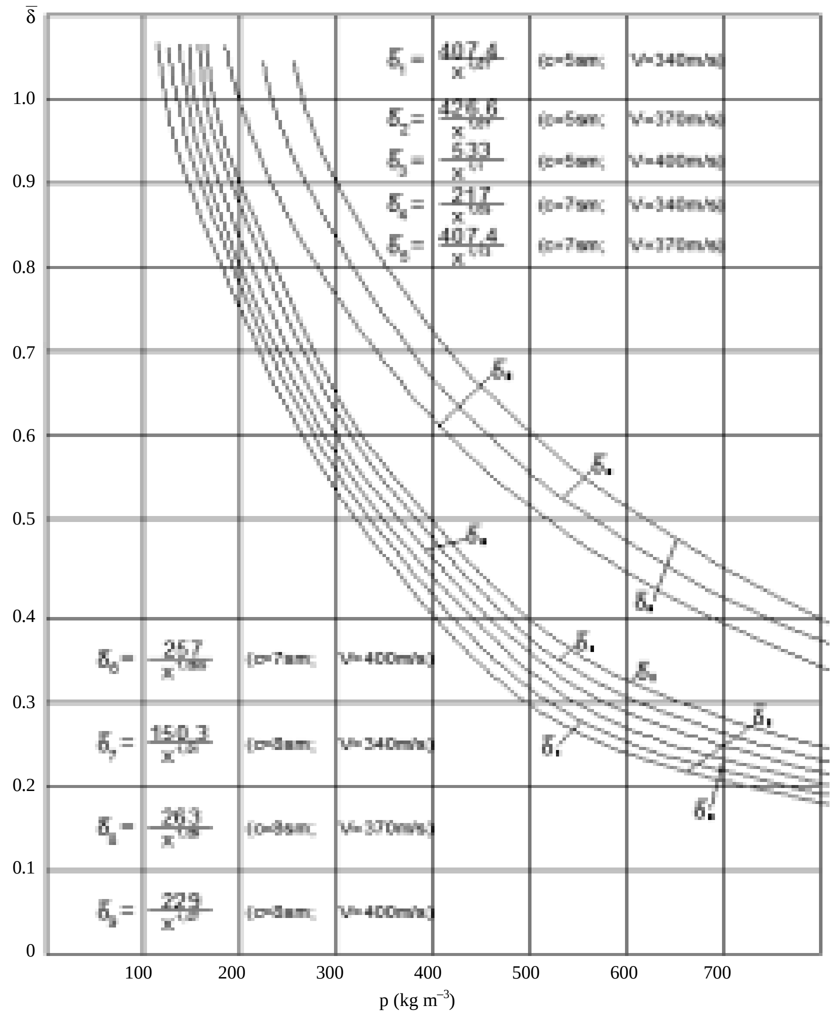

Fig. 3: Dependence of the penetration relative thickness via hammer on the density of fibrous material

$$\overline{M}_{\text{sandwich structure}} = \frac{t_{1,2}\rho_{\text{base layer}} + 2h\rho_3}{t_{1,2}\rho_{\text{base layer}} + 2h(\rho_3 + \rho_{3\text{fiber material}})}$$

The reinforcement is not required when. The effectiveness of a particular method of providing sandwich structure resistance to the action of an impulse concentrated force can be determined from the relationship:

$$\partial = \frac{\overline{M}_{\text{Sandwich structure}}\ 1}{\overline{M}_{\text{Sandwich structure}}\ 2}$$

Where:

$\partial L > 1$ = The reinforcement is more effectively by means of increasing the thickness of the base layers

$\partial L > 1$ = The application of a fiber material is more efficiently

The reinforcement is not required when $\partial L = 1$, $\rho_{3\text{fiber material}} = 0$, $t_{1,2}$ $t_{1,2\text{penter}}$.

CONCLUSION

Thus, the proposed method of calculating the resistance and bearing capacity of a sandwich structure under the action of a dynamic uniformly distributed load and impulse load provides an opportunity to make the choice of parameters quite reliably and reasonably. The developed analytical apparatus and the dependence of the fibrous material penetration thickness on its density make it possible to calculate the sandwich structure characteristics under the influence of specified external effects.

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