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Flexural Behaviour of Skew Sandwich plate with Soft Core

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Abstract:

A sandwich panel is a composite lightweight structure used for roofing, partition in civil engineering. Sandwich panels can reduce the weight of the structure and offers thermal, acoustic and strength properties. Sandwich panel consists of three layers in which the skin layer called faces bounded to the lightweight layer called core. The bonding between these layers is maintained with adhesive joints such as epoxy resins, phenolics, polyutheranes, etc to transfer the load between the layers. The skin layers are thin resisting the shear force and core material is light density material resist the movement of the faces. Flexural behavior of the sandwich panel is analyzed using a finite element model in ABAQUS software. The finite element sandwich model is created using shell elements in an arrangement of three layers (two faces and a core layer in the middle). The present FE model is validated with published results. The sandwich panel with various skew angles is analyzed for an extension with different boundary conditions, aspect ratio and thickness.

***Keywords:** flexural behavior, skew sandwich panel, ABAQUS.*

I. INTRODUCTION

From the past few decades, the sandwich panel (Fig. 1 & Fig. 2) has tremendous growth in the field of civil engineering, due to its lightweight and structural rigidity. Sandwich panel comprises of composite layers of high stiffness skin layers are bonded with adhesive joints to the light density core. The advantage of the core is lightweight, maintains the location of faces, and resists the shear forces. The material used for the core layer is balsa wood, polyvinyl chloride (PVC), polyethylene terephthalate (PET) and styrene-acrylonitrile resin (SAN). The skin layers resist the in-plane forces compression and tension. The material used for skin layers is metallic (mild steel, stainless steel, aluminum, titanium etc) and non-metallic (glass fibers, carbon fibers and aramid fibers). Sandwich panels are not only used in civil engineering, but there are also various applications in the field of aeronautical, marine, automobile etc. The advantages with the Sandwich panels are to maintain the structure lightweight, ease, and speed of installation, good thermal, fire and sound insulation, structural stiffness, durability, weather resistance, and dimensional stability, airtightness.

. These sandwich panels are widely used in industrial, commercial, cold storages which are large column-free space and also recommended for residential due to its advantages. In high population urban areas, there are so many challenges in the construction field. The flexural behavior of the sandwich panel has been studied by various researchers by developing a finite element model which gives the accurate result with a less computational cost. In 1849, the concept was

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introduced in construction technology by William Fairbiam.

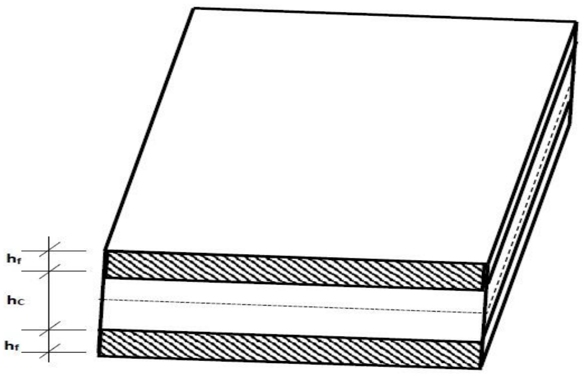

Fig.1: Sandwich panel

Qin et al. [1] has studied the bending and dynamic behavior of sandwich panels with softcore with a variety of sizes and different type of sandwich core. Their model facilitates foam core, truss core, honeycomb and corrugated cores analyzed numerically and calculated the response with size effect. Ansari and Kumar [2] studied the bending response of CNT (carbon nanotube) rhombic cone with a skew varied from 0 to 60 with 15 degrees interval. T. sadowski and J. Bec (2009) studied static and Eigen vibrational properties for sandwich panels with polymer foam filling and aluminum honey comb core. The model created in ABAQUS which clamped in all four directions and sandwich core is filled with foam. Shear behaviour of sandwich panel with poly vinyl chloride as core and glass fiber reinforced polymer as faces studied the delamination of plate under shear loading by Mostafa et al [4]. Rahim et al [5] were studied on buckling analysis of skew sandwich panel with various skew angle and h\t ratio subjected to compressive loading with simply supported boundary conditions. They concluded that there is increase in buckling force of skew plate having simply supported condition with an increase in skew angle. The response of flexible sandwich panels with polystyrene and aluminum honeycomb cores subjected to blast loading studied by Kaeagiozova [6]. They conducted experimental tests and compared them with numerical solutions and suggested that honeycomb core gives better performance than polystyrene core.

Vyacheslav N. Burlayenkov and Tomaz Sadowski [7] carried out analysis on sandwich panel with aluminum hexagonal honey foam filled core with bottom face fixed which subjected to the buckling and free vibration and calculated the displacement. S. Kapuria and S. D. Kulkarni [8] studied on finite element model of sandwich square panel clamped on all four directions in ABAQUS for static analysis and made comparison with the Kirchhoff quad element based on third order zig-zag theory. A finite element model for post-buckling and pre buckling investigations of curved composite stiffened panels is presented by Jeevan [9]. The modes of failures and critical load are obtained for the composite stiff panel under the post-buckling analysis. The stiffener was derived by changing the parameters with different composite materials and ply- orientation. The behavior of the FE sandwich model [10-18] having different material properties, dimensions, loads and conditions has been studied by many researchers

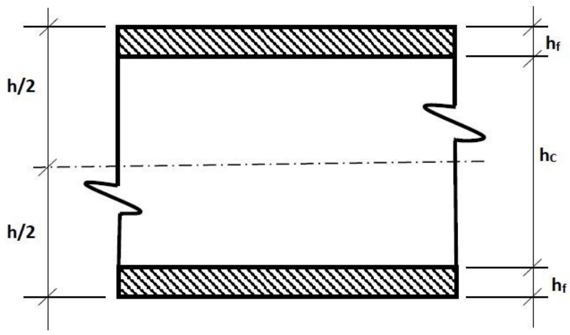

Fig. 2: Cross-section of the sandwich panel

RESEARCH SIGNIFICANCE

Sandwich panel is composite layers of less weight and high structural rigidity and good thermal and acoustic properties. Sandwich panels widely are used as an external cladding for single and multi-story buildings, roofing, ceiling panels, partitions and for fire-resisting, architectural appearance, shear walls and retaining walls. The sandwich panel plays a good role in insulation and heat absorption. Sandwich panels are easy to install, durability, fire resistance, reuse if shifting is done and having properties similar to precast wall panels. Using of sandwich panel, we can decrease the dead weight of the structure and also can go for story expansion if needed. Thus, analysis of the sandwich panel is required for better design and safety measures. ABAQUS is one of the FE based software that gives an adequate design of sandwich panel for different loading and boundary conditions with less experimental cost and material cost. The effect of different boundary conditions, skew angles, thickness, the aspect ratio on the skew sandwich panel is advantageous to designers and researchers.

II. METHODOLOGY

In ABAQUS, the mathematical is based on the FSDT is as follows:

$$\{\alpha\}=\{\beta\}+z\{\chi\}$$

where $\{\alpha\}=\begin{Bmatrix} u \\ v \\ w \end{Bmatrix}$; $\{\beta\}=\begin{Bmatrix} u_0 \\ v_0 \\ w_0 \end{Bmatrix}$ and $\{\chi\}=\begin{Bmatrix} \theta_x \\ \theta_y \\ \theta_z \end{Bmatrix}$

$\{\alpha\}$ is displacement, $\{\beta\}$ is mid-plane displacement along with the (x, y, z) coordinates and $\{\chi\}$ is rotation.

The strain vector:

$$\{\varepsilon\}=\{\varepsilon_0\}+z\{K\}$$

where $\{\varepsilon\}=\begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \varepsilon_z \\ \gamma_{xy} \\ \gamma_{yz} \\ \gamma_{zx} \end{Bmatrix}$; $\{\varepsilon_0\}=\begin{Bmatrix} \varepsilon_{x0} \\ \varepsilon_{y0} \\ \varepsilon_{z0} \\ \gamma_{xy0} \\ \gamma_{yz0} \\ \gamma_{zx0} \end{Bmatrix}=\begin{Bmatrix} \frac{\delta u_0}{\delta x} \\ \frac{\delta v_0}{\delta y} \\ 0 \\ \frac{\delta u_0}{\delta y}+\frac{\delta v_0}{\delta x} \\ \frac{\delta w_0}{\delta y}+\theta_y \\ \frac{\delta w_0}{\delta x}+\theta_x \end{Bmatrix}$ and

$$\{K\}=\begin{Bmatrix} K_x \\ K_y \\ K_z \\ K_{xy} \\ K_{yz} \\ K_{zx} \end{Bmatrix}=\begin{Bmatrix} \frac{\delta\theta_x}{\delta x} \\ \frac{\delta\theta_y}{\delta y} \\ 0 \\ \frac{\delta\theta_x}{\delta y}+\frac{\delta\theta_y}{\delta x} \\ \frac{\delta\theta_x}{\delta y} \\ \frac{\delta\theta_y}{\delta x} \end{Bmatrix}$$

For bending analysis, the governing differential equation is as follows:

$$[K]\{\delta\}=\{F\}$$

where δ, K and F is the displacement , linear stiffness and the load respectively.

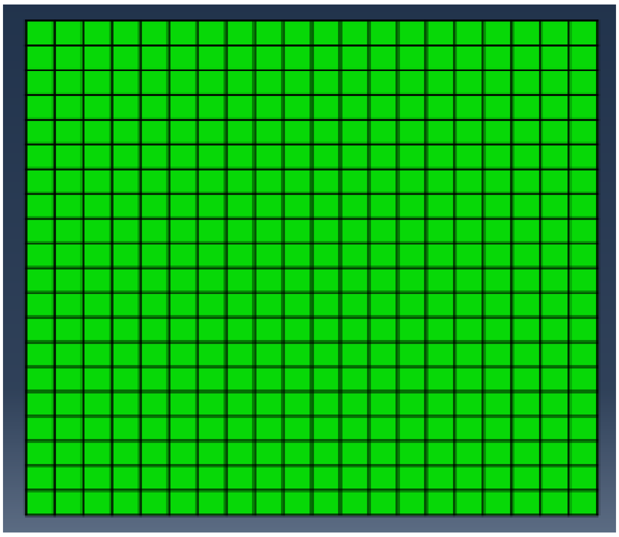

Fig. 3. Meshing of the softcore sandwich plate

III. RESULTS AND DISCUSSION

COMPARISON STUDY:

The present FE model developed using ABAQUS gives accurate results and has been tested [see Table 1] with Pagano [11] and Chakrabarti and Sheikh [10]. For validation and comparison study, a sandwich plate with softcore having simply supported conditions on four sides has been considered. Sandwich panel model has been meshed into 20 x 20 elements [Figure 3]. From Chakrabarti and sheikh[10], the non-dimensional formula and material properties have been taken.

Table 1: A validation study

Non-dimensional deflection and stresses	Present Result	Chakrabarthi and Sheikh [10]	Pagano [11]
$\overline{w}$	1.680	1.7118	1.7116
$\overline{\sigma_x}$	1.658	1.6201	1.5931
$\overline{\tau_{xy}}$	-0.085	-0.0865	-0.0834

PRESENT STUDY:

After the validation study, bending behavior of skew sandwich of composite layer 0/90/C/90/0 with the effect of skew angle 0, 10, 20 degrees and having different boundary conditions, aspect ratio thickness has been studied with developed finite element model in ABAQUS.

Table 2: Material properties used in present study for sandwich plate.

	E_1	E_2	μ	G_{12}	G_{13}	G_{23}

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Face	25E	E	0.25	0.5	0.5	0.2
Core	0.04E	0.04E	0.25	0.016	0.06	0.06

For the present study, material properties are shown in Table 2. The non-dimensional formulas for deflection and stress is given below.

Deflection $\overline{w} = 100WEh^3/q_0a^4$

Normal stress $\overline{\sigma_x} = \sigma_x h^2/q_0 a^2$

Tangential stress $\overline{\tau_{xy}} = \tau_{xy} h^2/q_0 a^2$

Where ‘a’ and ‘h’ is the length and the thickness of the sandwich panel respectively.

***Effect of end supports*:**

In this part, the effect of end supports on the bending behavior of skew sandwich plate (0/90/C/90/0) has been studied by varying skew angles [0, 10 and 20 degrees]. The obtained results with the six possible practical end conditions have been presented [Table 3] in the non–dimensional form. It can be observed that the four sides clamped condition sandwich panel has the least non-dimensional deflection and stresses compared to other boundary conditions. Sandwich plate with CFCF boundary condition has the highest deflection. It can be also seen that with an increase in skew angle deflection decreases (except CFCF and CCFF end supports)

Table 3: Effect of end supports and skew angle on sandwich panels in non-dimensional form (a/b=1 & h/a = 0.050). [C – Clamped; S – Simply supported; F – Free]

Skew angle		S-S-S-S	C-C-C-C	C-S-C-S	C-C-S-S	C-F-C-F	C-C-F-F
0	$\overline{w}$	1.68	0.568	0.922	0.820	16.550	0.878
10		1.591	0.549	0.884	0.795	19.198	0.885
20		1.343	0.494	0.779	0.722	21.125	0.897
0	$\overline{\sigma_x}$	1.658	0.564	0.883	0.847	-0.536	0.914
10		1.575	0.5451	0.846	0.822	-0.970	0.901
20		1.346	0.492	0.750	0.750	-1.382	0.858
0	$\overline{\sigma_y}$	0.083	0.029	0.045	0.039	-0.023	0.009
10		0.080	0.028	0.043	0.038	-0.015	0.009
20		0.072	0.027	0.041	0.038	-0.007	0.011
0	$\overline{\tau_{xy}}$	-0.085	0.000	0.000	-0.010	0.000	-0.003
10		-0.021	-0.001	-0.001	-0.001	-0.001	0.010
20		-0.005	-0.0006	-0.0007	0.001	-0.001	0.012

***Effect of aspect ratio*:**

In this part, the skew sandwich panel (0/90/C/90/0) with four sides simply supported conditions that have been studied to see the effect of aspect ratio (a/b) with skew angle 0, 10, 20 degrees. Here, the a/b value varies from 1 to 3 can be seen in Table 4. With an increase in a/b value and skew angle, there is a decrease in the non-dimensional value of deflection and normal stresses.

Table 4: Effect of aspect ratio and skew angle on sandwich panels in non-dimensional form (h/a=0.05).

Skew angle	Aspect ratio	a/b=1	a/b=2	a/b=3
0	$\overline{w}$	1.68	0.30	0.09
10		1.59	0.289	0.089
20		1.343	0.249	0.078
0	$\overline{\sigma_x}$	1.66	0.25	0.06
10		1.575	0.236	0.053
20		1.346	0.203	0.045
0	$\overline{\sigma_y}$	0.08	0.04	0.02
10		0.08	0.037	0.017
20		0.072	0.033	0.016
0	$\overline{\tau_{xy}}$	-0.09	-0.03	-0.02
10		-0.022	-0.011	-0.008
20		-0.005	-0.003	-0.003

***Effect of thickness*:**

In this part, the skew sandwich panel (0/90/C/90/0) with four sides simply supported conditions has been studied to find the effect of thickness on bending behavior. Here, the thickness of the plate varies from 0.05 to 0.1 can be seen in Table 5. With the decrease in thickness and increase in skew angle, there is a decrease in non-dimensional deflection. Whereas, the non-dimensional value of stresses increases with a decrease in thickness.

Table 5: Effect of a/h ratio and skew angle on sandwich panels in non-dimensional form.

Skew angle		h = 0.0500	h = 0.0250	h = 0.01667	h = 0.01250	h = 0.010
0	$\overline{w}$	1.68	1.47	1.43	1.41	1.38
10		1.591	1.377	1.337	1.309	1.287
20		1.343	1.132	1.091	1.074	1.053
0	$\overline{\sigma_x}$	1.66	3.506	5.23	6.96	8.43
10		1.575	3.326	5.012	6.563	8.046
20		1.346	2.839	4.277	5.648	6.882
0	$\overline{\sigma_y}$	0.08	0.171	0.25	0.34	0.41
10		0.080	0.164	0.246	0.322	0.397
20		0.072	0.146	0.217	0.286	0.348
0	$\overline{\tau_{xy}}$	-0.09	-0.192	-0.29	-0.39	-0.49
10		-0.021	-0.120	-0.271	-0.462	-0.690
20		-0.005	-0.059	-0.165	-0.318	-0.514

I. CONCLUSIONS

In this present work, a developed FE model using the ABAQUS software has been tasted with the published results. Using ABAQUS, the bending behavior of skew sandwich shell of layers 0/90/C/90/0 is studied with the varying boundary conditions, thickness ratios, aspect ratios and skew angle. There is good accuracy in the validation of the present FE model and recommended to solve various problems on bending with a less computational cost. The following are the general conclusions of the present study:

- Sandwich panel with softcore having four sides clamped condition has the least non-dimensional deflection and stresses compared with other boundary conditions.
- Increase in skew angle in different boundary conditions there is a decrease in non-dimensional deflection and stresses.
- For CFCF boundary condition, there is the lowest value of non-dimensional deflection and stresses and the values increases with an increase in skew angle
- The non-dimensional value of deflection and stresses are decreased with an increase in an aspect ratio and skew angle of a sandwich panel with softcore.
- With an increase of skew angle and a decrease of h/a ratio from 0.05 to 0.01, the sandwich panel with softcore shows a decrease in the value of non-dimensional deflection.

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