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Bending Analysis of Sandwich Panel with Soft Core

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***Abstract:** A sandwich panel is a lightweight structure, economical and having low thermal conductivity. It is made up of three layers in which the middle layer is called core which is bounded with thin layers at top and bottom called faces. Generally, the core has relatively low-density which makes it lightweight. The bending behavior of the sandwich panel with soft core is studied using the finite element (FE) based software ABAQUS. Shell elements in the three-layer arrangement has been considered to model the sandwich panel. The present model is validated with suitable published results. Then it is extended to analyze bending of sandwich panel with soft core. An FE model has been developed to generate many new results for different thickness, boundary conditions, aspect ratio, etc.*

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

I. INTRODUCTION

In the last few decades, sandwich panels [Fig. 1 and Fig. 2] have produced rapid growth in construction due to its lightweight and structural stiffness. Sandwich panels are composite structural elements that consist of two thin skin layers that are bonded to each side of the lightweight core. The lightweight core offers shear resistance and maintains the position of skin layers, whereas two faces offer resistance to in-plane forces of tension and compression. Sandwich panels are preferred due to its lightweight, ease, and speed of installation, structural rigidity, thermal, fire and sound insulation, durability, airtightness, weather resistance, and dimensional stability.

These panels are subjected to transverse load are used in various engineering applications like structural, marine, mechanical and others. These panels are used in large column-free space, external cladding for buildings, partition, insulation, etc in the construction field. Sandwich roofs/walls having different conditions of end supports are used in practice.

Construction of the building is a big challenge to civil engineers and the government especially in developing countries throughout the world. This problem is due to the dense concentration of the population in urban areas. It is a very difficult task to meet the challenges in the construction practices; however, it is a big challenge to the civil engineers to meet the housing demand in a short span without compromising on the quality. Traditional building construction is inadequacy so a new building system was developed at the beginning of the 20th century. So we have to use different alternative materials to decrease the concrete portion and to save the environment [1]. A Sandwich is a new construction technology which was used by William Fairbairn in the year 1849.

The sandwich panel system is used around the world for low rise and high rise commercial structures. According to the architecture and structural point of view, the precast concrete sandwich panels are widely used [2]. Oskoei and Hasen [3] studied the behavior of sandwich panels using higher-order finite elements. Their model facilitates calculating the shear, transverse and normal stresses of sandwich panel with different load combinations, boundary conditions, material properties. Hazem et al. [4] presented a finite element model of a sandwich panel in ABAQUS to investigate deflection. They compared their results with different plate theories (Classical; First-Order Shear Deformation and the Higher-Order Shear Deformation). Taczała and Banasiak [5] investigated the buckling of I-core panels which are subject to compressive loading with local buckling modes. Elasticity solution for buckling of wide sandwich panels subjected to axially compressive loading was studied by Kardomateas [6]. He derived pre-buckling solution for the orthotropic phases for face and core. Kolsters and Zenkert [7] studied buckling of laser-welded sandwich panels using a finite element (FE) software ABAQUS. Indentation of aluminum foam core sandwich panel was investigated using the finite element model developed in ABAQUS by Xu et al [8]. They compared their simulation results and experimental results with various thicknesses of foam and bottom face constrained. Chakrabarti et al. [9] presented a buckling analysis of soft-core sandwich beam by the co-efficient FE model and calculated critical loads for the multi-layered soft-core sandwich beam. The behavior of sandwich structures [10-11] and recent FE studies [12-25] have been studies by many researchers.

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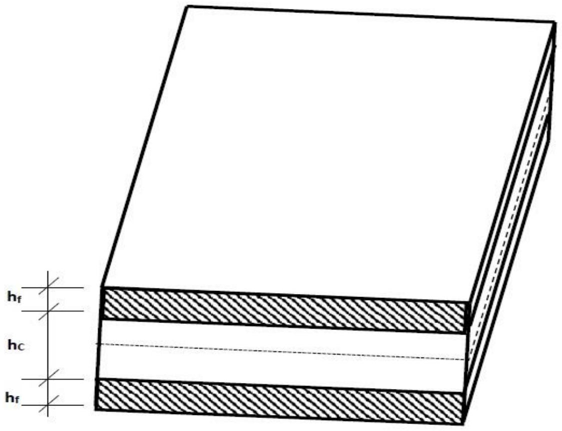

Fig. 1: Sandwich panel

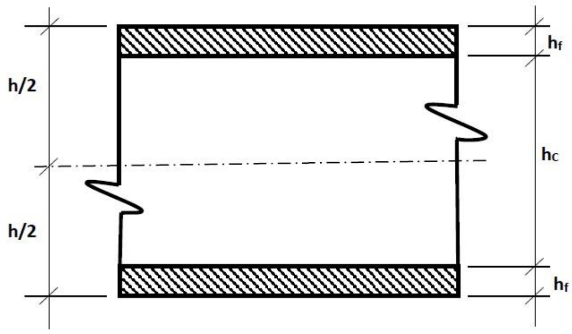

Fig. 2 Cross-section of sandwich panel

II. RESEARCH SIGNIFICANCE

Sandwich panel with the soft core is lightweight, stiff and has good thermal properties. The sandwich panel absorbs heat and it also acts as an insulation material. Sandwich panel is having similar properties as compared to precast wall panels in terms of cost, durability, fire resistance and it can also be used as a shear wall, retaining wall and bearings walls. It can be used in the building expansion if needed. It is light in weight and easy to construct and it reduces the usage of concrete. Thus, for the safe design of the sandwich structure, an FE model is required to solve different bending problems with good accuracy and with a less computational cost. And also the effect of boundary conditions, aspect ratio and thickness on bending behavior are beneficial for researchers and for designers.

III. METHODOLOGY

The mathematical model in ABAQUS is based on the first-order shear deformation theory (FSDT) as follows:

$$\{A\}=\{B\}+z\{C\}$$

where $\{A\}=\begin{Bmatrix}u\\v\\w\end{Bmatrix}$; $\{B\}=\begin{Bmatrix}u_0\\v_0\\w_0\end{Bmatrix}$ and $\{C\}=\begin{Bmatrix}\theta_x\\\theta_y\\\theta_z\end{Bmatrix}$

$\{A\}$ is displacement, $\{B\}$ is mid-plane displacement along with the (x, y, z) coordinates and $\{C\}$ 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

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

The governing equation for bending analysis:

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

where $\{\delta\}$ is the nodal displacement vector, $[K]$ is the linear stiffness matrices, F is the load matrix.

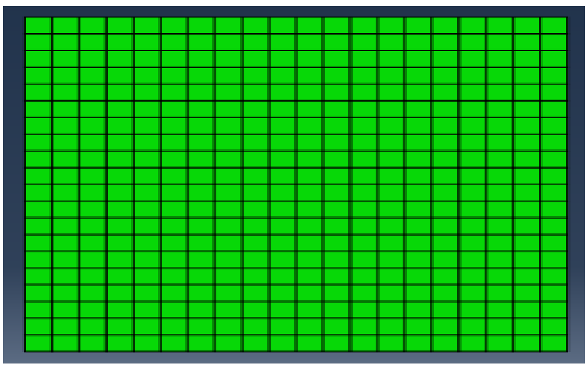

Fig. 3. The meshing of sandwich panel

IV. RESULTS AND DISCUSSION

Comparison Study:

The accuracy of the present FE model developed using ABAQUS has been validated with Chakrabarti and Sheikh [26] and Pagano [27] [Table 1]. For comparison study, a simply supported sandwich panel has been considered. The sandwich panel has been divided into 20 x 20 elements [Figure 3].

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The material property and nondimensional formula have been taken from Chakrabarti and Sheikh [26].

Table 1: Validation study

	$\bar{w}$	$\bar{\sigma}_x$	$\bar{\tau}_{xy}$
Present Results	1.680	1.658	-0.0850
Chakrabarti and Sheikh [26]	1.7118	1.6021	−0.0865
Pagano [27]	1.7116	1.5931	−0.0834

Present Study:

After validation effect of boundary condition, aspect ratio and thickness have been studied using the present finite element model.
The material properties used for the analysis is

For face:
$E_1 = 25E$, $E_2 = E$, $\mu_{12} = 0.25$, $G_{12} = 0.5$, $G_{13} = 0.5$, $G_{23} = 0.2$
For core:
$E_1 = E_2 = 0.04E$, $\mu = 0.25$, $G_{12} = 0.016$, $G_{13} = 0.06$, $G_{23} = 0.06$
The non-dimensional deflection and stresses formulas have been taken from Chakrabarti and Sheikh [26].
where 'a' is length and 'h' is thickness of the sandwich panel.

Effect of boundary condition:

In this subsection, the effect of boundary conditions on non-dimensional deflection and stresses has been studied on the sandwich panel (0/90/C/90/0). The effect of six practically possible boundary conditions has been presented in Table 2. It can be seen that the clamped sandwich panel has the lowest non-dimensional deflection and stresses compared to others for the sandwich panel. CFCF sandwich panel has the highest non-dimensional deflection.

Table 2. Effect of boundary conditions on non-dimensional deflection and stresses of sandwich panels (a/b = 1 and h/a =0.05).[S – Simply supported; C – Clamped; F – Free]

Boundary Conditions	SSSS	CCCC	CSCS	CCSS	CFCF	CCFF
$\bar{w}$	1.680	0.568	0.922	0.820	16.550	0.878
$\bar{\sigma}_x$	1.658	0.564	0.883	0.847	-0.536	0.914
$\bar{\sigma}_y$	0.083	0.029	0.045	0.039	-0.023	0.009
$\bar{\tau}_{xy}$	-0.085	0.000	0.000	-0.010	0.000	-0.003

Effect of aspect ratio:

In this subsection, the effect of aspect ratio (a/b) has been studied on simply-supported sandwich panels (0/90/C/90/0). Here, a/b values have been varied from 1 to 5. It can be seen from Table 3 that with an increase in aspect ratio (a/b values) the value of the non-dimensional deflection and stresses values decreases.

Table 3. Effect of aspect ratio on non-dimensional deflection and stresses of sandwich panels (h/a = 0.05).

Aspect ratio	a/b = 1	a/b = 2	a/b = 3
$\bar{w}$	1.68	0.30	0.09
$\bar{\sigma}_x$	1.66	0.25	0.06
$\bar{\sigma}_y$	0.08	0.04	0.02
$\bar{\tau}_{xy}$	-0.09	-0.03	-0.02

Effect of thickness:

In this subsection, the effect of thickness has been studied on a sandwich panel (0/90/C/90/0). Here h/a has been varied from 0.01 to 0.05. It can be seen from Table 5 that with a decrease in h/a ratio, the value of non-dimensional deflection and stresses of sandwich panel with soft core decreases.

Table 4. Effect of a/h ratio on non-dimensional deflection and stresses of sandwich panels.

Thickness	h = 0.05	h = 0.025	h = 0.0166	h = 0.0125	h = 0.01
$\bar{w}$	1.68	1.47	1.43	1.41	1.38
$\bar{\sigma}_x$	1.66	3.506	5.23	6.96	8.43
$\bar{\sigma}_y$	0.08	0.171	0.25	0.34	0.41
$\bar{\tau}_{xy}$	-0.09	-0.192	-0.29	-0.39	-0.49

V. CONCLUSIONS

In this present work, an FE model is being developed in ABAQUS its validation has been done. In this work, ABAQUS was used to analyze deflection and stresses for the sandwich panel having soft core with different boundary conditions, aspect ratios and thickness ratios. The validation is clearly showing that the present FE model is capable to solve various bending problems with good accuracy and with a less computational cost. The following general conclusions are:

- Clamped sandwich panel with soft core has the lowest nondimensional deflection and stresses.
- With an increase in an aspect ratio of sandwich panel with soft core the value of nondimensional deflection and stresses decreases.

- With a decrease in h/a ratio, the value of non-dimensional deflection and stresses of sandwich panel with soft core decreases.

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