Sensitivity analysis of sandwich panels with rectangular openings

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Abstract

Sandwich panels, composed of thin metal sheets and a thick, anisotropic foam core, are considered in the paper. These lightweight structures are frequently weakened by cut-outs and various openings, what is the subject of the present analysis. Due to a complex behaviour of such structures, there are no universal, acceptable design rules, that take into account factors related to the kind of modifications that made the panel weaker. In this paper, the problem of the influence of two factors on the mechanical response of sandwich panel is considered, namely: the influence of opening location and type of the load. Additionally, the influence of stiffener, in the form of window frame, is considered. Finally, selected results obtained from FE analyses will be compared with the experimental results carried out by the authors and some conclusions are drawn.

Keywords: sandwich panels, openings, orthotropic model, numerical analyses, numerical investigation

1. Introduction

Self-supporting sandwich panels made up of two external thin and metal facings separated by a thick, lightweight core are considered in the paper. This kind of panel is widely used to cover the facades and roofs of industrial buildings. Due to inevitable openings in building envelope, like windows, doors or technical inlets, it is necessary to cut out holes in sandwich panels. Those openings generally have different size, geometry and locations [1] what can significantly reduce their load-bearing capacity. The European standard EN 14509 [2] specifies requirements for the production, testing and designing of complete factory-made sandwich panels, but not include any information about openings. Now, this problem is simply solved in such a way that all applied loads on the openings are transferred to the spaced frame of building structure by additional longitudinal and cross beams. According to [3-4], additional supports are not always necessary. Therefore, further research aimed at the development of a consistent and appropriate design and testing methods shall be considered. Nevertheless, because of the variety of factors affecting the structural response, e.g. variety of the core material, shape of the metal sheets, geometry, size and position of the openings and other, it is a big challenge. Although, new recommendation [5] completes the direction given in EN 14509 and introduces possibility to design sandwich panels with openings without unnecessary additional supports, there is a lack of a consistent design method, especially in case of openings with significant size.

In the most popular approach it is assumed that all layers of sandwich panels are made from homogeneous and isotropic materials. Here, more advanced, orthotropic material model with nine independent constants is used. Testing methods for reliable identification of material parameters for porous material such a polyurethane foam are described in [6]. The sensitivity of structural response to variations of material parameters is studied and discussed in [7].

2. Problem formulation

The aim of this work is to demonstrate the sensitivity of bearing capacity of sandwich panels to different location of rectangular openings, that are stiffened, or not, with window frame. Analyses are carried out for two types of loads: concentrated force and equally distributed pressure.

3. Numerical analysis

Structural behaviour of sandwich panels is investigated using ABAQUS software package [8]. The geometrically nonlinear static analysis is used. Geometric imperfections are introduced as a combination of five buckling modes with the multiplier equal to 0.001 m. The problem is solved using Newton-Raphson and Riks procedures. Numerical instability is used as a failure criterion.

The influence of frame mounted inside the opening is modelled in two different ways. Firstly, the frame stiffness is neglected and only the vertical distance between corresponding nodes of lower and upper sheets is maintained. Secondly, the stiffness of frame is introduced by inserting frame which is made of additional beam elements. Frame is then meshed in such a way, to correspond to the sheets' mesh, so appropriate degrees of freedom of nodes of sheets can be constrained to degrees of freedom of frame's nodes, accordingly. Thus, from mechanical point of view, two cases are simulated as follows: first, neglecting the frame stiffness; second, with certain mechanical parameters of frame corresponding to actual example of frame mounted inside the opening.

The static scheme of the system and geometrical parameters are presented in Fig.1. It is assumed that the steel facings are flat and covered by zinc, what results in Young's modulus $E_F = 195$ GPa and Poisson's ratio $\nu_F = 0.3$. The material properties of the foam core, based on experimental data and used for numerical analysis, are summarised in Tab.1.

Openings with only one size are analysed in this paper. The hole has dimensions 0.3 x 0.5 m and it is placed 0.5 m from the left edge of the plate.

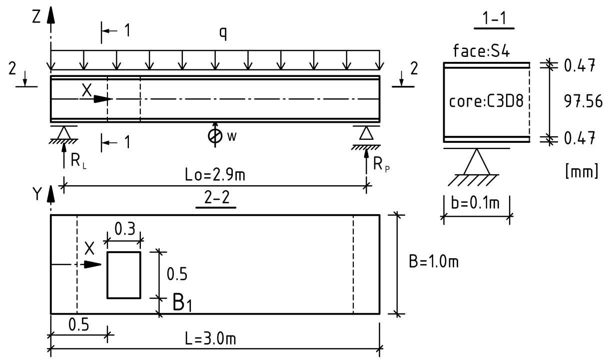

Figure 1: Geometry and the scheme of the analysed plate

Table 1: Material parameters of analysed foam core

E_X	E_Y	$\mathbf{E_Z}$	G_{XY}	$\mathbf{G_{ZX}}$	G_{YZ}	ν_{XY}	$\boldsymbol{\nu_{ZX}}$	ν_{YZ}
[MPa]						[-]		
20.04	4.71	**5.26**	2.51	**3.00**	2.30	0.53	**0.24**	0.17

The authors analyse the influence of location the hole along the width B of the panel. So, the parameter B_1 is taken into account as variable (Fig.1).

The first analysed panel is loaded by uniform pressure q. Four different positions of the hole: B_1 = 10 cm, 15 cm 20 cm and 25 cm, are analysed. The last case means that the hole is placed symmetrically with respect to the X – axis. Obtained relations between applied force F and deflection w measured in the middle of the span are presented in Fig.2 and summarised in Tab. 2.

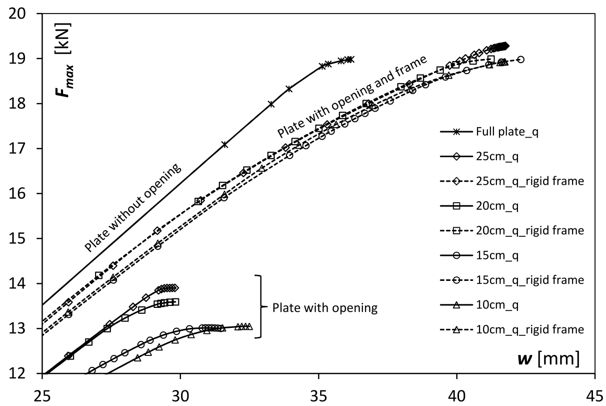

Figure 2: Numerical paths for plate loaded by q

Table 2: Numerical results – panels loaded by q

		B_1 [cm]			
		10	15	20	25
1	2	3	4	5	6
Plate with opening	F_{max},[kN] (R_L+R_R)	13.0	13.0	13.6	13.9
Plate with opening and rigid frame		18.9	19.0	19.0	19.3
	δ [%]	45.4	46.2	39.7	38.8

The comparison of obtained results shows that the influence of location of the hole along the width B on the global behaviour of the plate is negligibly small. On the other hand significant impact of the mounted frame on the load-bearing capacity of the plate is observed.

The next study is focused on the sandwich panels loaded by concentrated load. A load is applied through a rigid 100 mm x 100 mm block on the longitudinal edge at mid-span. The distribution of the displacements field in example with B_1 = 15 cm is presented in Fig. 3.

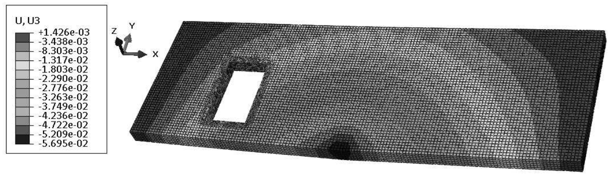

Figure 3: Distribution of the vertical displacement in plate loaded by concentrate load

4. Conclusions

Different effects have influence on the behaviour and bearing capacity of sandwich panels with openings. In this work, the main attention has been focused on the study of the structural sensitivity to the location of the hole for panel with different load schemes, as well as the influence of frame which stiffen the opening. For panels loaded by uniformly distributed load, we can draw the general conclusion that the plate with an opening placed closer to the middle of the plate exhibits slightly higher load-bearing capacity. In analysed case the crucial role in the response of the system plays the stiffness of the frame.

The numerical results and experimental validation for panels loaded by concentrated load will be presented during the conference.

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