Influence of the purlin shape on the load-bearing capacity of sandwich panels

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Abstract. This study aimed to develop knowledge about the behavior of bent, multi-span sandwich panels. The analyzed panels have a soft polyisocyanurate foam core and rigid metal facings. The paper presents the results of experimental studies. The influence of support width, the span of the panel and purlin shape on the load-bearing capacity of the panel are analyzed. The tests carried out by the author have shown that not always the load capacity determined according to the standard is on the safe side. Therefore, the actual support conditions of the designed structure should always be taken into account.

Introduction

In this paper, sandwich panels composed of thin metal sheets and a thick, polyisocyanurate foam core (PIR) are considered. These kinds of structures are widely used in various areas of engineering. As a core material the different kinds of foams, usually made from polymers, metals, ceramics, glass, etc. are widely used in various branches of civil engineering since the 80s. In the literature, it is possible to find many papers focused on sandwich structures, their applications, designing [1-3] and testing procedures which take into account the influence of the soft core on the behavior of the layered structure [4, 5]. Nevertheless, because of the variety of factors affecting the structural response, e.g. variety of the core material, shape of the metal sheets, geometry and others, the development of design and testing methods is still a current challenge undertaken by scientists.

When analyzing this type of sandwich panels, despite the rather complex foam structure [6], it is usually assumed that the core material is homogeneous and isotropic or sometimes orthotropic. It is possible to use effective material parameters, which quite well reflect the global behavior of the panels [7]. Difficulties arise when local effects play a significant role, such as in the case of wrinkling of metal facing, where the stiffness of the core directly adjacent to the facing is decisive [8].

In this work, the main attention is focused on the analysis of the influence of the purlin shape and the deformation of the core material under the purlin on the load-bearing capacity of sandwich panels. All conclusions are drawn based on experimental tests.

Problem formulation

This paper deals with the problem of the behavior of bent, multi-span sandwich panels. At the intermediate support, an interaction of facing compression, core shear and compression of the core as a result of interaction with the support is observed.

In accordance with the EN 14509 standard [9], which is used in the design of sandwich panels, the experimental determination of the load capacity of multi-span panels above the intermediate support is simplified to a single-span scheme loaded with a linear load in the middle of the span (Fig.1). Such a static scheme, though simple, is very common in practice. It is more important, however, that the phenomena observed in a simple static scheme are easier to carry out, assess and interpret. In fact, in case of analyzed sandwich panels with soft core, the load transfer is more complicated due to the variety of the material of the core, the thickness of the panel and the shape of purlin sections used. Simplifications of calculation schemes or assumptions are often used, however, they must give results on the safe side - the obtained limit loads should be close or lower than those in the actual structure.

The aim of the paper is to determine the influence of the core deformation on the load-bearing capacity of a sandwich panel depending on the length of the panel and the shape of the purlin. For this purpose, a 3-line bending test of the panel is performed, in which the load will be transferred by a steel beam (according to standard) in one case, and by the real shape of the purlin in the second case (the cold-formed thin-walled Z section).

a)

b)

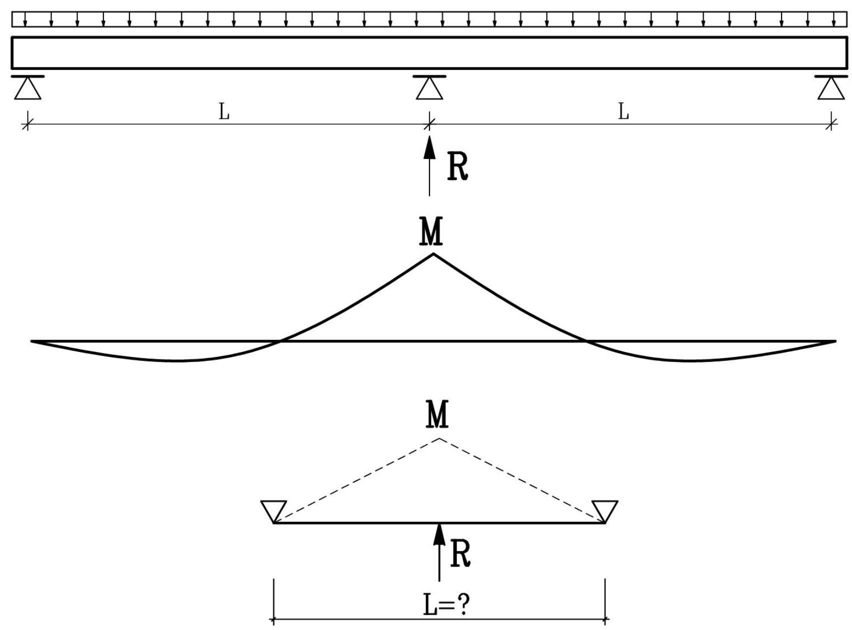

Fig.1 a) actual static scheme of a multi-span beam, b) simplified static scheme - simulation of the intermediate support

Experimental approach

Sandwich panels with soft core are very sensitive to concentrated loads. Their deformation is more complicated and various phenomena such a bending, compression, delamination and shear is occurred what is shown in Fig.2.

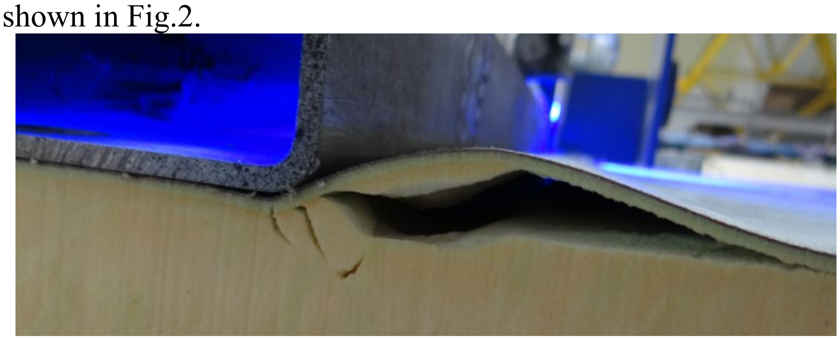

Fig.2 Forms of panel failure under concentrated load

The intensity of individual local failure mechanisms and their impact on the global behavior is closely related to the span of the panel, its bending stiffness (thickness of the core and their material parameters) and the way the load is applied. In order to accurately identify the behavior of the panel and the deformation of the foam core under the applied load, a series of full-scale tests are carried out.

In this work, sandwich panels with a PIR foam core with a density of 38 kg/m^3 are tested. The first group of tests is planned with the aim to check the influence of the panel's span L_0 and the width of the applied load L_S on the local deformation of the core and load-bearing capacity of the whole panel. Therefore, three types of tests were carried out and analyzed, as shown in Fig.3. Schemes 1 and 2 will allow us to observe the effect of the width of the applied load. Schemes 1, 2 and 3 will be used to analyze of the impact of the span of the tested panel on its load-bearing capacity.

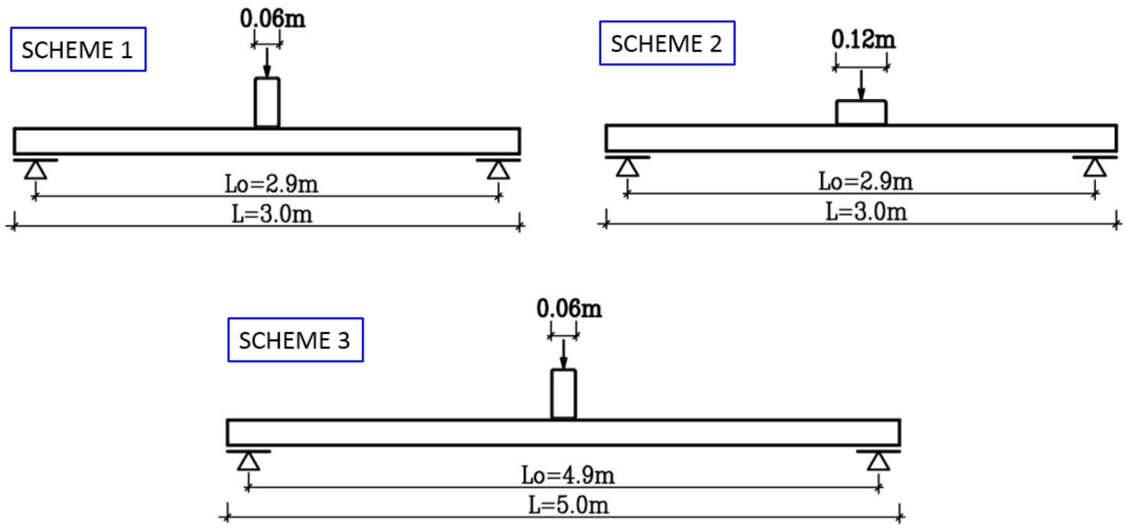

Fig.3 Interaction between bending moment and support reaction – types of experimental schemes

In this study, samples had following dimensions: the thickness of the core d_C = 99.24 mm, distance between the centroid of faces e = 99.67 mm, the total length L = 3.0 m and 5.0 m, the length of span L_0 = 2.9 m and 4.9 m, width B = 1.0 m, and the thickness of steel facings t = 0.43 mm. In each case, during the experiment, the applied force F and displacement u in the middle of the panel's span were continuously measured. Obtained results from all tests are summarized in Table 1.

Table 1: Experimental results of wrinkling stresses for Scheme 1 - 3

		Scheme 1	Scheme 2	Scheme 3
L_0	[m]	2.90	2.90	4.90
F_{max}	[N]	6352.60	7265.70	4243.30
$M(F_{max})$	[kNm]	4.61	5.27	5.20
σ_w	[MPa]	107.56	123.02	121.40

For maximum force F_{max} theoretical values of the wrinkling stress σ_w are calculated according to equation (1)

$$\sigma_w = \frac{M}{e \cdot t \cdot B}\ , \tag{1}$$

where: $M = \frac{F_{max} \cdot L_0}{4}$.

Obtained results show, that for shorter plates, the width of the applied load plays a significant role. In the case of Scheme 1, the failure of the panel occurred surprisingly early, resulting in a very low value of the wrinkling stresses. If we use a wider support, changing the width L_S from

0.06 m to 0.12 m as in scheme 2, then the load-bearing capacity of the panel increases significantly (15 %) and is close to that obtained in Scheme 3.

For a more detailed analysis, the paths between bending moment and displacement measured in the middle of the span for each of the tests are presented in Fig.4.

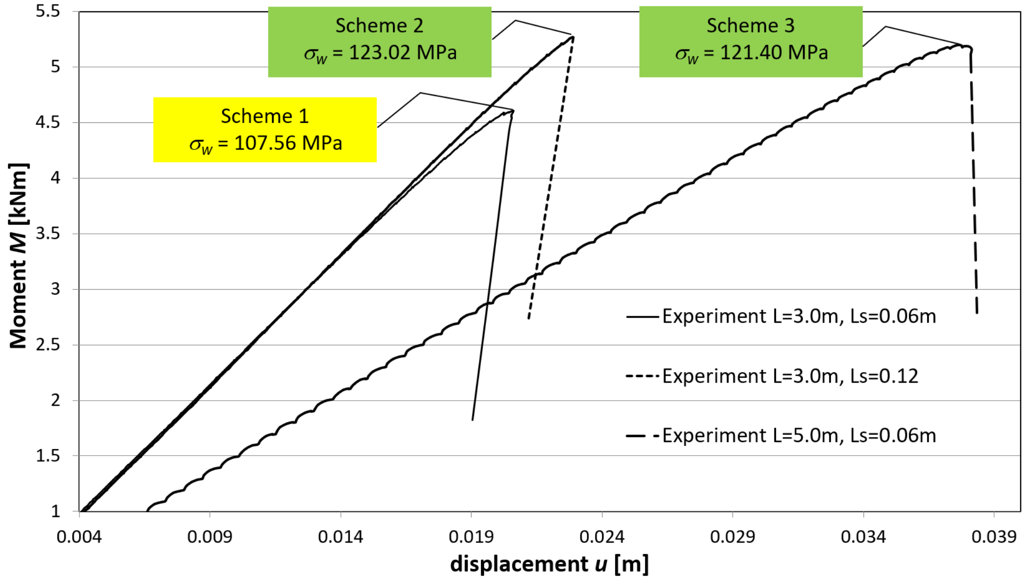

Fig. 4 Experimental paths obtained from three-point bending test

For higher load levels the plot for Scheme 1 reveals the non-linear response of the structure. The non-linear behavior is not manifested in the case of Scheme 2 or 3 because of lower stresses in the foam core directly under the applied load, consequently we observe smaller deformations of the core.

The second group of tests concerned the analysis of the influence of the purlin shape on the load-bearing capacity of sandwich panels. Therefore, two types of tests were carried out and analyzed, as shown in Fig.5. In this case, it was ensured that the width of the applied load was the same in both cases and equal to the minimum required standard value: $L_S = 0.06$ m.

In this study, samples had following dimensions: the thickness of the core d_C = 99.01 mm, distance between the centroid of faces e = 99.47 mm, the total length L = 6.2 m, the length of span L_0 = 6.0 m, width B = 1.15 m, and the thickness of steel facings t = 0.46 mm. In both cases, during the experiment, the applied force F and displacement u in the middle of the panel's span were continuously measured. Obtained results from both tests are summarized in Table 2.

Table 2: Experimental results of wrinkling stresses for Scheme 4 and 5

	Scheme 4	Scheme 5
L_0 [m]	6.00	6.00
F_{max} [N]	5480	4725
M [kNm]	8.22	7.09
σ_w [MPa]	156.22	134.69

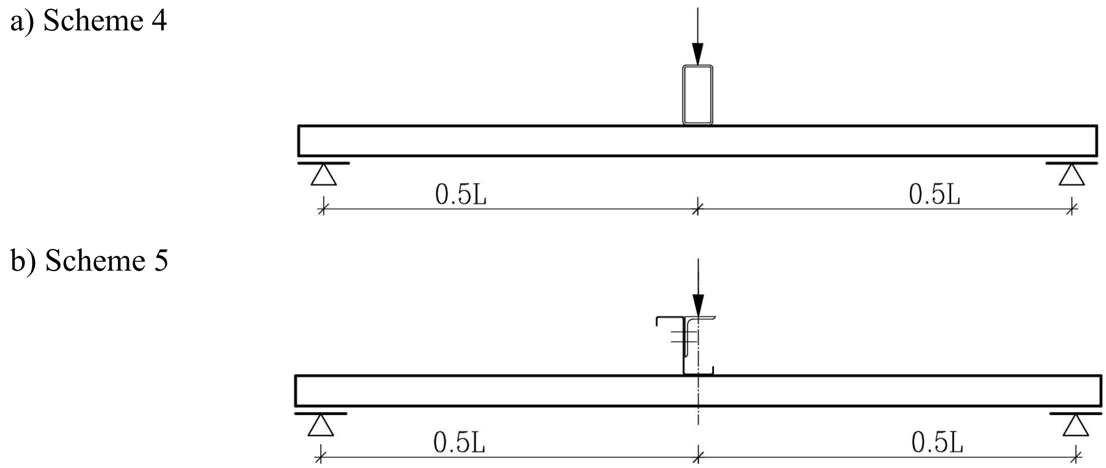

Fig.5 Purlin shape with L_S = 0.06 m: a) the box-section, b) the cold-formed Z-section

To analyze the obtained results we can say that the failure of both panels were occurred directly in the vicinity of the applied load, as shown in Fig.6. Additionally, the force-displacement paths, shown in Fig. 7, show a similar, linear behavior of both samples during the whole test until the failure. However, the load-bearing capacity of the panel loaded by box-section purlin is much higher (15 %) than in case of cold-formed Z section purlin. During the experiment, a slight rotation of the Z-section purlin was observed. Most likely, this caused uneven pressure of the purlin flange on the panel and thus accelerated the global damage to the whole sandwich panel.

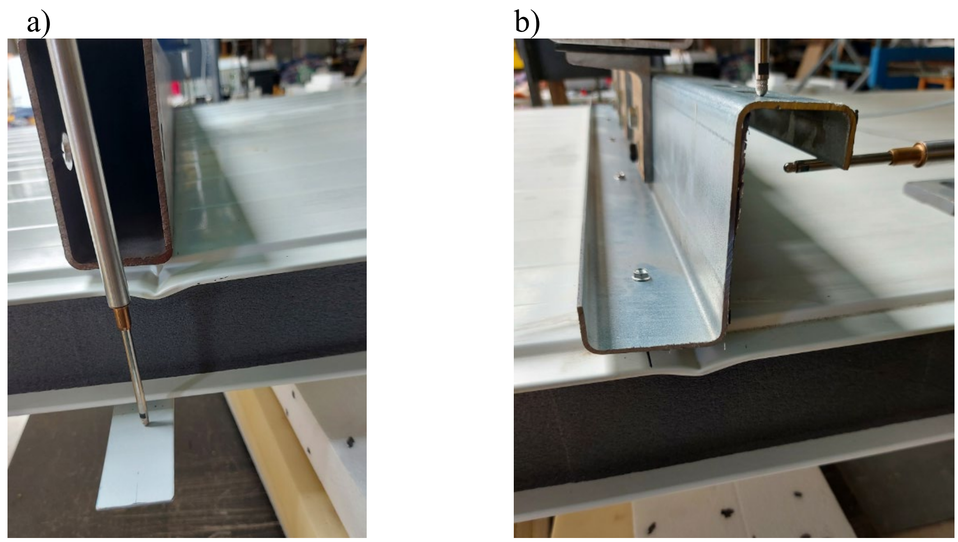

Fig. 6 Local deformation under the purlin: a) box section, b) cold formed Z section

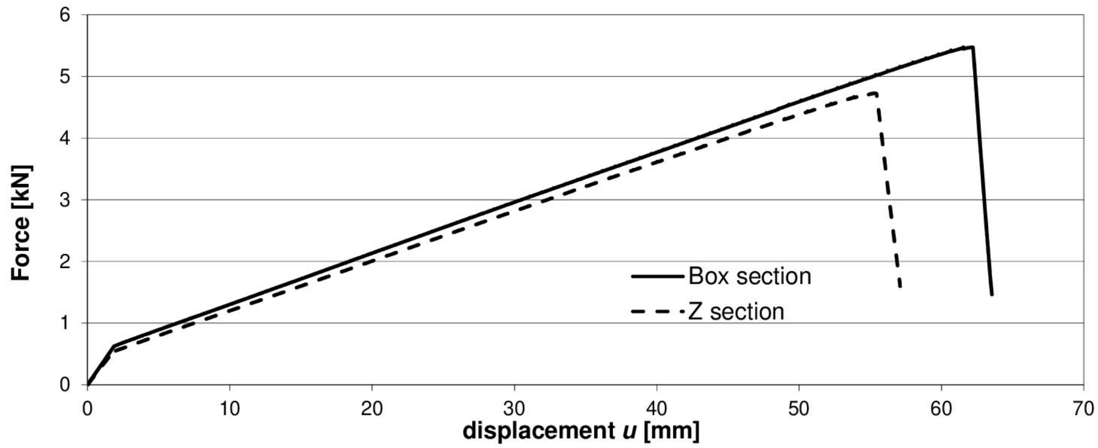

Fig. 7 Experimental paths F-u obtained for the box-section and the cold formed Z-section of the purlin

Summary
Different effects have an influence on the behavior and load-bearing capacity of sandwich panels with soft core. In this work, the main attention has been focused on the study of the structural sensitivity to the influence of the local deformation of the foam core, as well as the influence of the purlin shape. Sandwich plates loaded by concentrated loads exhibits a complex behavior. Their deformation are more complicated and various phenomena such a bending, delamination and shear occur. The obtained results clearly show that the higher stresses under the loading beam lead to faster failure of the panel. The load-bearing capacity of panels with a small span is strictly dependent on the width of the applied load. In this case, local deformations of the core can significantly reduce the load capacity of the panel. The load-bearing capacity of the panel on the central support given in the manufacturer's tables is determined for rigid purlins such as a box section. The tests carried out by the author have shown that not always the load capacity determined according to the standard [9] is on the safe side. The actual support conditions of the designed structure should always be taken into account.

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