Optimization of sandwich panels with a deep-profiled facing

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Abstract

The paper deals with an optimization problem concerning sandwich panels with a deep-profiled facing. The panels have a soft core and correspond to typical structures applied on building roofs. The design variables describe the geometry of the deep-profiled steel facing. The objective function expresses the maximum allowable loading of the panel. The problem is solved for the fixed length of the metal sheet. Additionally, technology limitations are imposed on the design variables. Further constraints follow from requirements of the ultimate and serviceability limit states.

Keywords: sandwich panels, deep-profiled facing, optimization, design, engineering applications

1. Introduction

The sandwich panels considered in the paper consist of two thin external steel facings and a thick and soft core. Such elements are used in civil engineering as a building envelope (roof and external walls). Sandwich structures are very interesting because of their high load-bearing capacity and complex mechanical behavior. Particularly interesting is the analysis of multi-span systems of panels with deep-profiled facings. This is also due to the interaction of environmental loads (snow, wind) and thermal (different temperatures on the cladding) and the need to consider the creep of the core.

Optimal design of sandwich panels has been widely discussed in literature. In most cases, the optimization concerns the core of the structure, such as in [1 Lewiński], where the optimal design of the core layer was presented to make the plate compliance minimal. Bozhevolnaya and Lyckegaard [2] analysed the problem of optimal design of the core junctions which minimize local disturbances between two different core materials. It is also worth mentioning the article [3] presenting optimal designs of multi-span sandwich panels with slightly profiled steel facings and a polyurethane foam core (PUR) that satisfy conflicting demands of the market, i.e. minimal variance in types of panels, maximal range of application and minimum cost. A large part of the papers deals with lattice type cores. Several core topologies, including square-section truss members in pyramidal and tetrahedral configurations, square honeycombs, and corrugated sheets, were considered in [4]. The objective of the optimization was to find the geometric parameters that minimize weight, for a prescribed load. Tan and Soh [5] optimized a new type of sandwich panel to have minimum weight and maximum heat transfer performance. An interesting and practical example of the optimization of the layered structure has been presented in [6]. This paper describes the application of an Ant Colony Optimization algorithm to the multiple objective optimization of a rail vehicle floor sandwich panel.

In spite of the many works devoted to the optimization of sandwich panels, it is surprising to note that roof panels used in engineering practice do not appear to be optimal. Therefore, the aim of this paper is the optimization of the geometry of deep-profiled facing. We would like to indicate possible solutions that increase the load capacity of the panel with unchanged production costs.

2. Formulation of the problem

The paper discusses single-span and multi-span sandwich panels. The distances between supports are equal to L. Both facings are made of steel and the core is made of polyurethane foam. The lower facing with thickness t_{F2} is flat, but the upper facing with thickness t_{F1} is deep-profiled (Fig. 1). The width of the panel is constant and equal to B. The structure is subjected to the dead weight, the uniform transverse loading q representing variable action (snow), and the extreme curvatures θ induced by the difference in temperature between the facings. Two extreme temperature differences were considered: $\Delta T = 40°C$ (winter) and $\Delta T = -30°C$ (summer). The long-term nature of the loading requires taking into account creep effects.

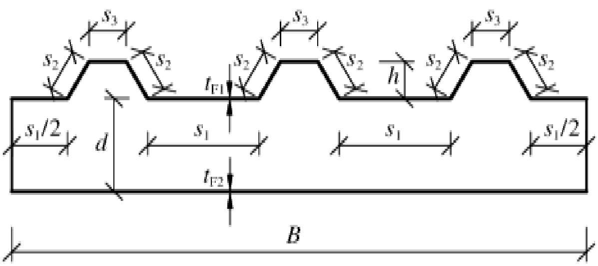

Figure 1: The geometry of the deep-profiled sandwich panel

The geometry of the profiled facing is presented in Fig. 1. Due to technological requirements, it is assumed that the width of the (unfolded) steel sheet C will not change

$$C = N(s_1 + 2s_2 + s_3) = \text{const.} \quad (1)$$

This also significantly reduces the differences of production costs of panels with different geometry. The variable can be a number of webs N ($N = 3$ in Fig. 1). Because of the geometric dependencies, with fixed B and C, the vector of design variables $\mathbf{x}$ has the form

$$\mathbf{x} = [N, h, s_1]. \tag{2}$$

Our task is to find optimal design vector $\mathbf{x}$, satisfying the constraints and providing maximum of the objective function $G(\mathbf{x})$:

$$\max_{\mathbf{x}\in X_0} G(\mathbf{x}), \qquad G(\mathbf{x}) = q_a, \tag{3}$$

where q_a is the maximum allowable transverse load and X_0 is the allowable domain of design vector $\mathbf{x}$ specified by constraints $g_i(\mathbf{x}) \le 0$. The constraints follow from requirements of the ultimate and serviceability limit states (up to 30 conditions) and from the technological conditions on the components of $\mathbf{x}$. The optimization problem was solved by searching the solution space. Verification of the design limit states has been carried out in accordance with [7].

3. Results of the optimization

Profiled facing of the single and three-span sandwich panel was optimized. The procedure was applied to systems with a span of 1.5 to 7.2 m. The exemplary solution, namely the maximum permissible load q_a expressed as a function of the deep-profile height h and the number of webs N, for the span $L = 6.0$ m and the panel depth measured in the valley $d = 0.10$ m (cf. Fig. 1), is shown in Figs. 2-3.

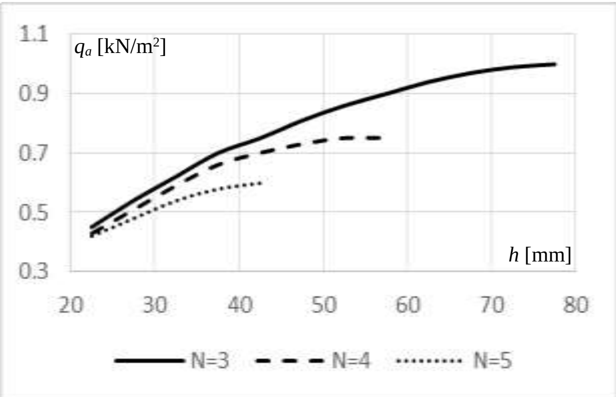

Figure 2: The extreme permissible pressure q_a in the case of the one-span panel (L = 6 m, d = 0.10) as the function of N and h.

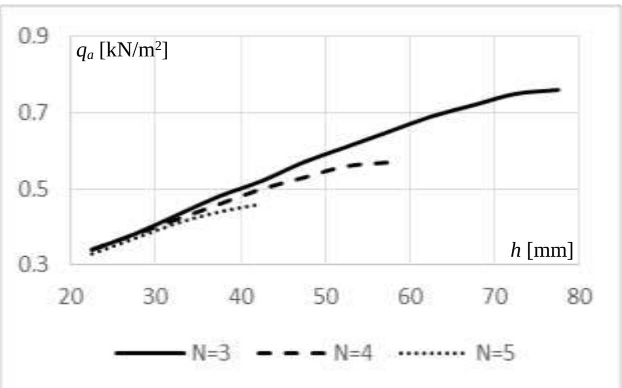

Figure 3: The extreme permissible pressure q_a in the case of the three-span panel (L = 6 m, d = 0.10) as the function of N and h.

The obtained results show that in both analyzed cases, the increase in web height h is an effective way to increase the load capacity of the sandwich panel. The increase of the number of webs does not lead to an increase of the permissible loading since it is assumed that we have the same width of the steel sheet C. Thus, the increase in the number of webs is associated with a corresponding decrease in their height. It should also be remembered that any particular value of h is accompanied by the optimal width of the valley s_1. In general, it can be concluded that the smaller the s_1, the better.

4. Conclusions

In the paper, the problem of optimal shaping of profiled facing of sandwich panels was presented. The fixed width of the steel sheet from which the facing is profiled was assumed. The aim of the optimization was to maximize the permissible uniformly distributed load acting on the panel. Constraints imposed by the technology of production, as well as implicit constraints that follow from requirements of the ultimate and serviceability limit states were taken into account.

The obtained results clearly indicate that to increase the load capacity of the structure, the height of the web h and its width s_3 should be increased (the width of the valley s_1 should be decreased). It should be emphasized that the optimum solutions tend to increase the capacity (and by the way the stiffness) of the structure by increasing the distance between the centers of gravity of the top and bottom facings. This solution seems obvious for long panels, but in the case of multi-span systems with short spans and high thermal excitations, the solution is not so obvious. We hope that this work will be an impulse for further efforts to implement new, optimal solutions of the sandwich panels on the industrial scale.

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