The comparison of numerical models of a sandwich panel in the context of the core deformations at the supports

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Abstract

The paper presents the problem of static structural behavior of sandwich panels at the supports. The panels have a soft core and correspond to typical structures applied in civil engineering. To analyze the problem, five different 3-D numerical models were created. The results were compared in the context of core compression and stress redistribution**.** The numerical solutions verify methods of evaluating the capacity of the sandwich panel that are known from the literature.

Keywords: sandwich panels, finite element method, numerical models, structural behavior, indentation

1. Introduction

In the paper, sandwich panels are considered, which consist of two thin external steel facings and a thick and soft core. Such elements are commonly used in the building industry because of high load-bearing capacity at low self-weight and excellent thermal insulation. Undoubted advantages of sandwich panels arise from their structure. Unfortunately, the more complex structure is characterized by more complex behavior than in the case of homogeneous elements. Different failure modes can be distinguished: face yielding, global and local instability, debonding, shear and indentation of the core. The detailed list of possible defects is presented in [1]. From a practical point of view, the most important phenomenon is the local instability of facings, but the local core crushing seems the most difficult for a correct description. The difficulty arises, among others, from the heterogeneity of the core, its anisotropy, and non-linear behavior during compression and tension.

The most popular cores of sandwich panels are made of polyurethane foam. This type of material has been repeatedly tested and described in the literature [2, 3]. When a piece of foam is compressed, the stress-strain curve shows three regions [4]. At low strains, the foam deforms in a linear-elastic way; then there is a plateau region with a nearly constant stress; and finally, there is a densification. The walls of cellular foam can collapse by different mechanisms: elastic buckling, plastic yielding or brittle crushing. Laboratory tests are carried out in order to recognize the behavior of the material. Polyurethane foam test results aimed at multi-axial yield behavior are presented in [5, 6].

Using the results of experimental tests and advanced software packages, the behavior of sandwich panels can be simulated numerically. The ABAQUS system offers at least two well-established foam models: the hyperfoam model and the crushable foam model. The first one is based on the hyperelastic theory. The second one is based on the plasticity theory. The hyperelastic model was used to analyze the viscoelastic behavior of open-cell polyurethane foam [7]. The crushable foam model was applied in [8] to simulate the quasi-static indentation of the sandwich panel.

The aim of the paper is the application and comparison of different numerical models to the problem of core compression at sandwich panel supports. The advanced hyperelastic and crushable foam models of the core material will be applied. The results will be compared with more classical constitutive relations, such as isotropic, orthotropic elasticity combined with classical plasticity or Hill's condition of plasticity. The classical models were used in [9]. The numerical solutions should be compared with the full-scale, real experiments.

2. Description of the problem

To analyze the problem of core compression and degradation at the supports, two systems presented in Fig. 1 are studied. In the case of the one-span system, the narrow support of a width $L_S = 0.04$ m is located on the right-hand side. In the case of the two-span system, the support interactions are observed at the intermediate support which has the width $L_S = 0.08$ m. The numerical models are 3-D and the supports are located at the bottom of the sandwich panel. Between the considered supports and the facing of the panel, surface-to-surface contact was introduced. The width of the panel is $B = 1.0$ m. The basic results were obtained for the panel having the total depth $D = 0.100$ m (the thickness of both facings $t_F = 0.0005$ m and the core thickness $d_C = 0.099$ m). The assumed geometry ensures the significance of phenomena observed at the supports. Both structures are subjected to a uniform transverse loading q.

The main aim of the study is the assessment of phenomena occurring at the support. For this purpose, deformations of the core, the appearance of zones of plastic deformations and the changes with increasing load are observed. To date, the existing approach to the problem of core crushing in large part was based on the measurement of the relative displacement of panel facings. Our observations show that this approach is too simplistic. To simulate the described phenomena, advanced numerical models prepared in Abaqus were used.

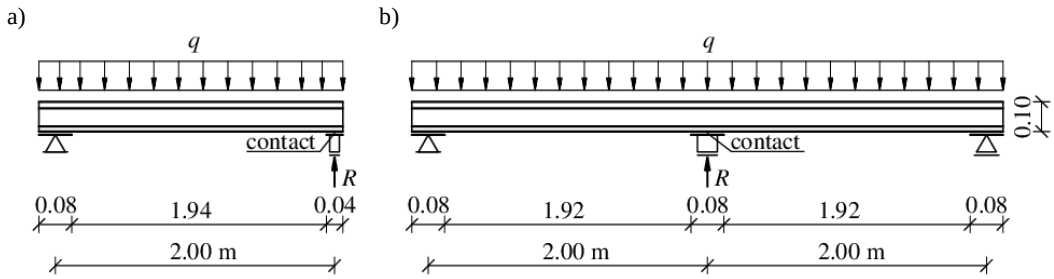

Figure 1: The static system of analyzed sandwich structures: (a) the one-span system; (b) the two-span system

3. Numerical models

The parameters of the model correspond to the parameters determined in the laboratory tests. Steel facings were assumed as isotropic, elastic-plastic material with the modulus of elasticity $E_F = 210$ GPa and the Poisson ratio $\nu_F = 0.3$. The actual relationship between stress and strain was introduced. The yield strength was 360 MPa and the ultimate strength reached 436 MPa. Facings were modeled using shell finite membrane strain elements S4. The core of the panel was modeled using eight node, linear brick elements C3D8.

The key issue is the constitutive relation for the core material. The first and simplest model was elasto-plastic and isotropic. In the elastic range, according to the results of laboratory tests, the following parameters were assumed: $E_C = 3650$ kPa, $G_C = 3000$ kPa. Above the yield stress (90 kPa) the actual, nonlinear relationship between stress and plastic strain was introduced. The second model was similar, but orthotropic ($E_1 = 13450$ kPa, $E_2 = 4410$ kPa, $E_3 = 3650$ kPa, $\nu_{12} = 0.55$, $\nu_{13} = 0.995$, $\nu_{23} = 0.20$, $G_{12} = 2510$ kPa, $G_{13} = 3000$ kPa, $G_{23} = 2300$ kPa). The third model was similar to the second one, but Hill's condition of plasticity was applied. The fourth model was hyperelastic. To define the material behavior, Ogden's energy potential and available planar test and uniaxial test data were used. The fifth model was assumed as the crushable foam with strength ratios $k = 0.5$ and $k_t = 0.1$ and the elastic parameters were taken from the first model.

4. Discussion of the results

The models were compared to each other in terms of relative displacement of the facings (expressing the core crushing), extreme normal and shear stresses, the distribution of stresses and plastic deformation areas. Exemplary results for the five models are shown in Fig. 2.

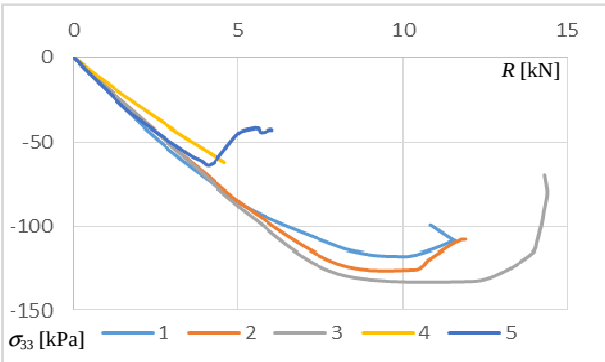

Figure 2: The core compression stress σ_{33} at the edge of the support as a function of the support reaction R

The results obtained for the classical models (1, 2 and 3) are consistent. In the case of the hyperelastic core, there were problems with the convergence of the numerical solution. The results for the crushable foam model are interesting. For a small load (and stress), the results are close to the classical models. Along with the increase of loading, the core is locally degraded, and the stresses are transferred through the adjacent elements.

5. Conclusions

The results of numerical analyzes show a high level of problem complexity. There are also several difficulties in the modeling. Advanced models require knowledge of many parameters, some of which are difficult to determine experimentally. The presented models provide ample opportunities, but require precise calibration. This calibration should be done on the basis of laboratory experiments performed on whole layered structures corresponding to the considered problem.

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