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Design of Continuous Lightweight Structural Sandwich Panels

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Summary

Lightweight sandwich panels are composite structures made of two strong, stiff face layers, which are separated by a soft, thick and well-insulating core. In addition to the mechanical properties and dimensions, the static behaviour and load-bearing capacity of sandwich panels is influenced also by the flexibility of the fastening system and the support structure. The paper studies the response and strength of sandwich panels loaded by temperature difference between the face layers. It is proposed to model the flexibility of the fastenings by a simple spring model.

1. Introduction

Lightweight sandwich panels with metal-sheet faces and a plastic foam or mineral wool core are used to cover walls and roofs of industrial buildings, stores and cold stores, but also walls of office and even residential buildings. Design principles and calculation models of single-span sandwich panels are known and they have been applied without problems for years. Design of multi-span sandwich panels is a more complicated task, because continuous panels are loaded by transverse support reactions and high bending moments simultaneously at intermediate supports. Lightweight sandwich panels have high stiffness and resistance against bending moments and axial forces but they do not stand very well local transverse loads like support reactions.

Two different design cases can be distinguished at the intermediate supports. Positive support reaction is defined as resulting in compressive contact stresses in the joint between the support structure and the panel, and it is caused by wind pressure and snow load and by winter temperature difference between the faces of the panel. Positive support reaction results in local damages in the face which is placed against the support structure and which most often is the visible internal face. The second design case, negative support reaction, is defined as causing tensile forces in fasteners which fix the panel to the support structure. Negative support reaction is caused by wind suction load and summer temperature difference between the faces, and it results in local damage at the points of fasteners in the external face of the panel leading finally to the collapse of the cross-section at the support and giving rise to risks for the air- and water-tightness of the panel. After the local failures at intermediate supports, multi-span panels are in most cases able to carry significantly more load until the ultimate limit state failure of the panel.

Temperatures of dark-coloured external faces may reach a value of 80 °C in summer. In winter temperatures of -20 °C in Central Europe and -40 °C in the Nordic countries are not unusual. Thus, even the daily temperature difference between the internal and external faces may be 60 °C. In wall panels of cold stores the temperature difference in summer is even higher. Stresses caused by the temperature difference depend essentially on the shear rigidity of the core and on the flexibility of the fasteners and supports. In plastic foam core sandwich panels the shear creep of the core layer also affects the stresses and displacements caused by long-term temperature loads.

Rock-wool is a relatively new core material of sandwich panels. In addition to the usual sandwich panel applications, rock-wool core panels are applied to buildings with high requirements for fire safety. To understand the real behaviour of the rock-wool core sandwich structures, loading tests with temperature differences and mechanical loads with full-scale multi-span sandwich panels were carried through in a research project at Helsinki University of Technology. Results of the tests and analyses can also be utilized in the design of plastic foam core sandwich panels.

2. Theoretical background

Metal-sheet faces of rock-wool core sandwich panels are typically flat including only small cold-formed stiffeners for architectural aspects, in which case the theory of thin-faced sandwich beams can be applied in the analysis of the global bending moments, shear forces and deflections. The small flexural rigidity of the flat faces has effects on the local stresses and deformations close to the supports and fasteners. For the evaluation of the global stress resultants and deflections, analytical solutions have been published in several textbooks / *Stamm & Witte 1974*/. The more complicated continuous multi-span sandwich beams with flexible fastenings and supports can most conveniently be analysed using numerical methods like the finite element method.

Static behaviour of a sandwich beam fixed with flexible fastenings can be described by a finite element model consisting of a beam element, the nodal point i of which is supported against the uplift forces by a spring with a constant spring coefficient (k). The equation for the shear-flexible beam element with two nodal points (i,j) describing the beam-type sandwich structure can be written as

$$\frac{2B_s}{L^3(1+4\beta)}\begin{bmatrix} 6+k & 3L & -6 & 3L \\ 3L & 2L^2(1+\beta) & -3L & L^2(1-2\beta) \\ -6 & -3L & 6 & -3L \\ 3L & L^2(1-2\beta) & -3L & 2L^2(1+\beta) \end{bmatrix}\begin{bmatrix} w_i \\ w_i' - \gamma_i \\ w_j \\ w_j' - \gamma_j \end{bmatrix} = \frac{qL}{12}\begin{bmatrix} 6 \\ L \\ 6 \\ -L \end{bmatrix} + B_s\theta\begin{bmatrix} 0 \\ 1 \\ 0 \\ -1 \end{bmatrix} \qquad (1)$$

where B_s is flexural rigidity and S shear rigidity of the cross-section of sandwich panel, L length of beam element between the nodal points, $\beta = 3B_s/SL^2$, k spring coefficient describing the tensile stiffness of fastening, q uniform load, $\theta = \alpha_T (T_2 - T_1)/e$, α_T coefficient for thermal expansion of face material, e distance between the centroids of the face layers and T_1 and T_2 temperatures of the external and internal faces. w and γ are deflection and shear strain. $w'_i = dw_i/dx$.

Tensile stiffness of the fastening against the uplift loads has to be determined by testing. If the core material properties do not change with the outside temperature, the analysis can be based on the modulus and strength values determined in tests at room temperature. Modulae of elasticity of plastic foams decrease at high temperatures. However, the reduction at 50...80 °C is small and so the analysis with temperature-independent parameters gives acceptable approximate results.

3. Experimental and calculated results

In the project, loading tests were made with positive and negative support reactions caused by the temperature difference between the faces of test panels. In positive support reaction tests, a relatively large support width of 200 mm was used. Test panels in negative support reaction tests were fixed with two different kinds of fastenings: screws drilled through the panel to the support and special roof panel fixtures placed in the longitudinal joints between two panels (Fig. 1) / *Martikainen & Hassinen 1996*/. In this paper some test results are shown to characterize the stress resultants and deflections caused by the positive and negative support reactions and the different fastening systems (Figs. 2 and 3). Two-span test panels had equal spans of L + L = 2450 + 2450 mm. In the project, tests with other two-span panels and tests with three-span panels were also made, the results of which indicated the same conclusions as reported in this paper.

The external face of the full-scale test panels was heated by infra-red heaters, while the temperature of the internal face was kept at a room temperature of 20 °C. The core of the test panels consisted of structural rock-wool, in which the fibres run normal to the faces of the panel. The flat faces were made of steel sheet with steel thicknesses of 0.48 and 0.46 mm in the exterior and interior faces, respectively. Total depth and width of the panels were 100 mm and 1200 mm, respectively.

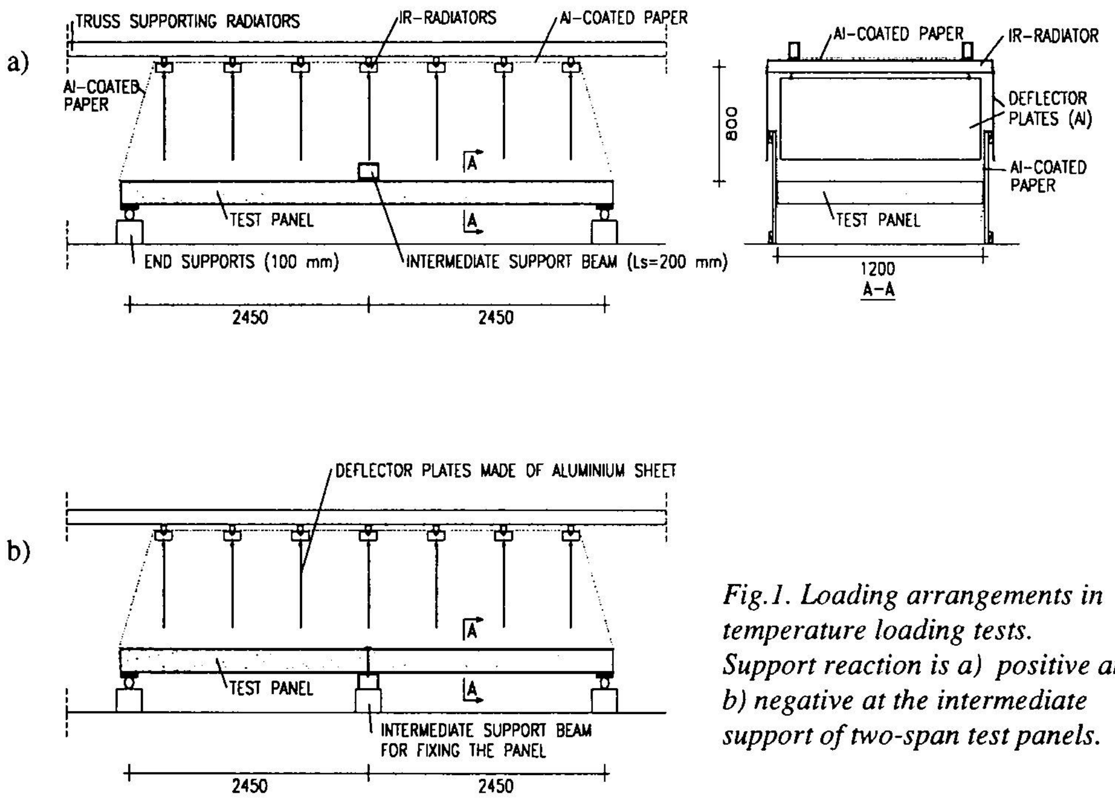

Fig.1. Loading arrangements in temperature loading tests. Support reaction is a) positive and b) negative at the intermediate support of two-span test panels.

Experimental results have been compared with calculated results using the linear theory of elasticity and by taking into account the shear deformations of the core layer and the tensile flexibility of the fastening (1). Shear deformations of the core result in app. 20% of the total deflection of the test panel and, therefore, are of high importance in the analysis of test results.

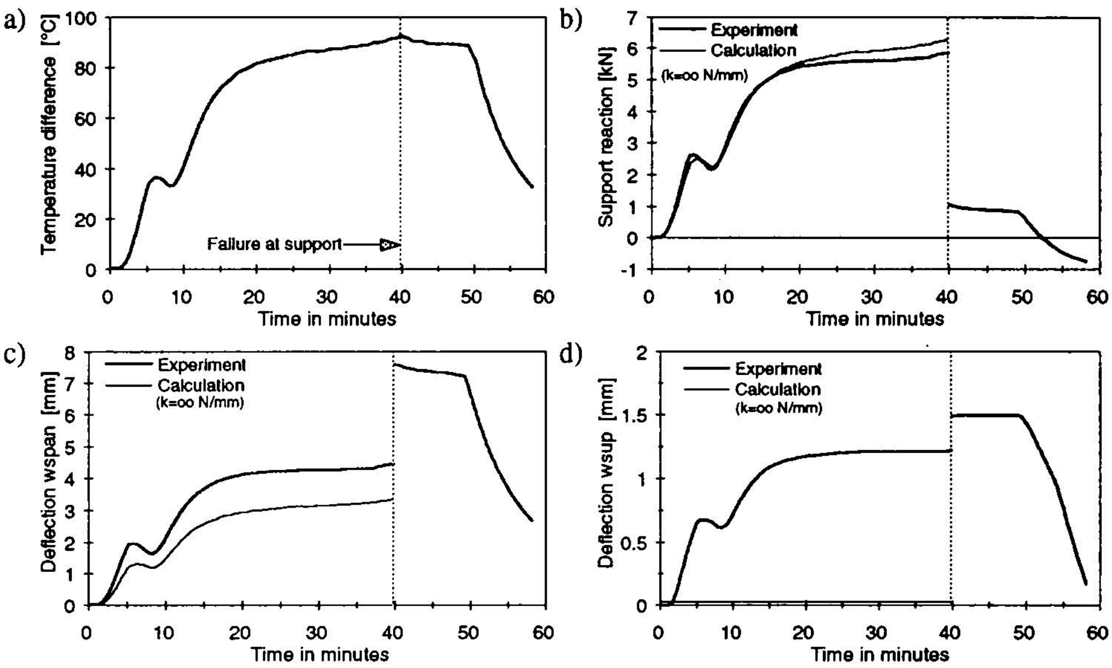

Fig. 2. Experimental and calculated (k = ∞) results of two-span test panel loaded by temperature difference in positive support reaction test. a) Temperature difference between the exterior and interior face, b) central support reaction, c) mid-span deflection and d) vertical displacement between the panel and the support structure at the central support. Dotted line shows the time point of local failure in the compressed external face at the central support.

In positive support reaction tests, the test panel is pressed against the support beam. The transverse flexibility at the intermediate support is caused only by the local compressive and shear deformations in the core close to the intermediate support. Calculated support reaction is slightly higher and the mid-span deflection smaller than the corresponding experimental values, if the spring constant k describing the stiffness of the support in the calculations is assumed to be infinite $k = \infty$ (Fig. 2). In current design calculations the supports are modeled to be completely rigid, which seems to be a valid assumption in the loading case of positive support reaction / *CIB 1993*/.

If the central support reaction is negative, the transverse flexibility is caused by the deformations of the fasteners and the local deformations in the core and exterior face close to the fasteners. Additional flexibility in sandwich panels fixed with roof panel fixtures is caused by the transverse curvature of the panel between the longitudinal joints. The transverse curvature results in a transverse tensile stress field in the exterior face, which further stiffens the compressed exterior face against the local buckling failure. The test panel fastened with roof panel fixtures did not fail in the test, which is due to the high flexibility of fastening and the transverse curvature of the compressed exterior face. The compressed face of the test panel fixed to the support structure with four screws failed locally at a temperature difference of app. 61°C (Fig. 3).

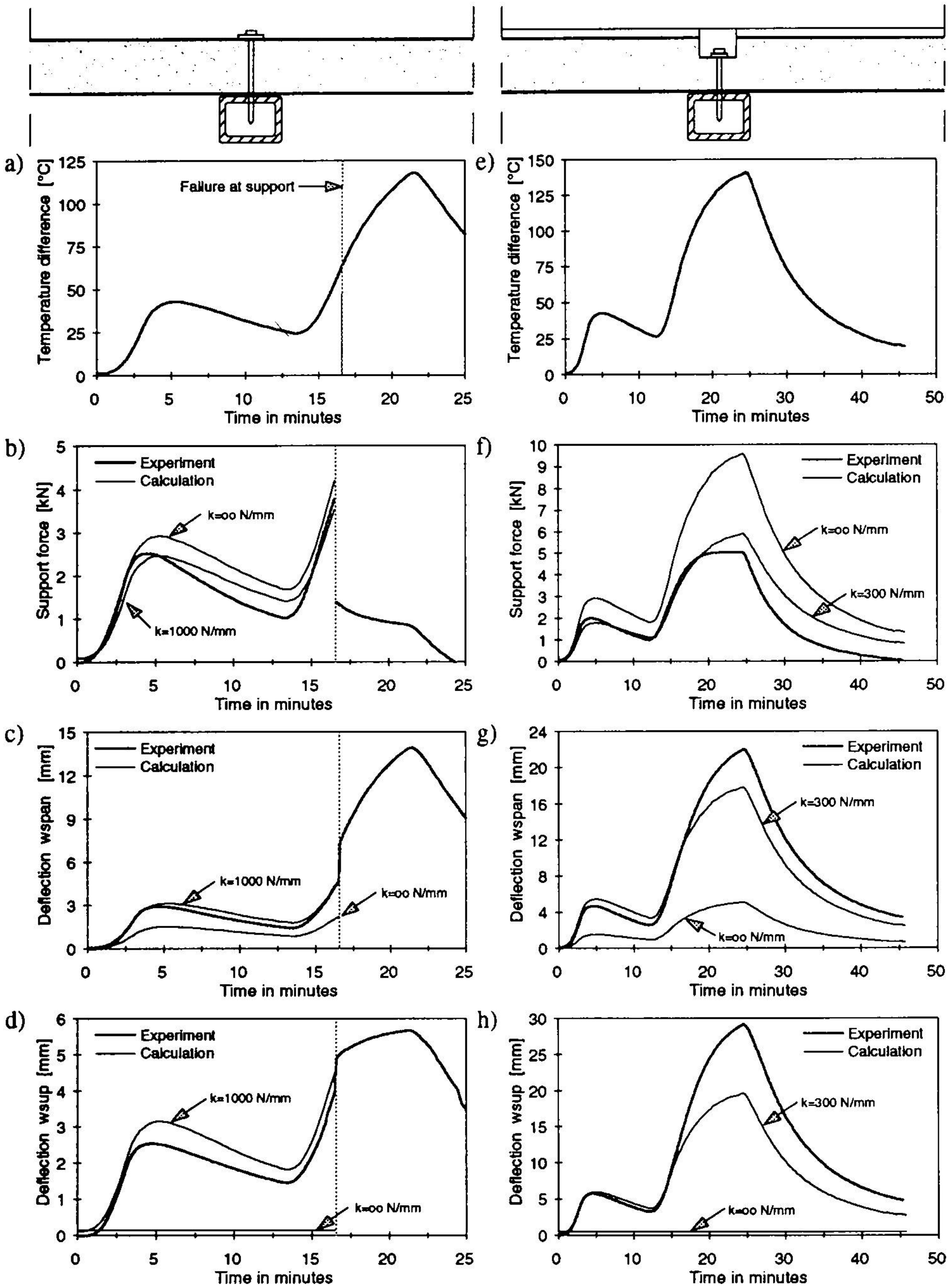

Fig. 3. Experimental and calculated results of two-span test panel loaded by temperature difference in negative support reaction tests. At the central support the test panels are fixed with four screws drilled through the panel (a...d) or with two roof panel fixtures (e...h).
a & e) Temperature difference between the exterior and interior face, b & f) central support reaction, c & g) mid-span deflection and d & h) vertical displacement between the panel and the support structure on central support. Dotted line shows the time of local failure.

The calculation model based on rigid supports, $k = \infty$, overestimates the support reactions in negative support reaction tests and thus, also the stresses caused by the temperature difference. The model underestimates strongly the mid-span deflections and, naturally, does not show the vertical displacements between the panel and the intermediate support (Fig. 3). If the finite spring coefficients, k = 1000 N/mm and k = 300 N/mm, describing the tensile stiffness of the screw fastening and the roof panel fixture are added to the calculation model, the calculated results are in reasonable agreement with the experimental results.

4. Summary and Conclusions

Temperature differences result in large bending moments at intermediate supports of continuous multi-span sandwich panels. At intermediate supports the bending resistance is reduced because of the transverse support reaction. The reduction depends on the direction of the support reaction, i.e., support reaction is positive or negative, and further, on the support width and the type and number of fasteners. Unfortunately, the space in this paper does not allow further details concerning the resistances of sandwich panels. In practical design work, bending resistance of the cross-sections at intermediate supports is assumed to be 80-90 % of the bending resistance in the spans. An accurate evaluation of stresses caused by the temperature differences but also a careful analysis of the bending resistances and support reaction resistances are important in order to achieve economical design and use of lightweight sandwich panels. Both sides, i.e., the stress and resistance sides, of the design equation are of equal consequence in design.

In the current design calculations, the supports are assumed to be completely rigid. The model is valid, if the panel is pressed against the support structure and the support structure is relatively rigid against the transverse loads. But if the panel is loaded by wind suction loads or summer temperature differences causing tensile forces in fasteners, the finite flexibility of the fastenings should be taken into account. In most loading cases, the support can be modelled by a simple spring having a constant spring coefficient. A bilinear spring is needed for the loading cases in which the direction of the support reaction may change from positive to negative and vice versa.

Acknowledgements

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