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# Design of Sandwich Panels against Thermal Loads

## Dimensionnement de panneaux sandwich sous charges thermiques

## Bemessung von Sandwichtragwerken auf Temperaturbeanspruchungen

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**SUMMARY**

Lightweight structural sandwich panels possess a high stiffness and strength and good insulating properties. In the panels the thin outer face is exposed to rapid changes of the outside temperature, which cause deflections and stresses in the panel. These thermal stresses are much influenced by the flexibility of the panel, which consists of bending and shear deformations of the face and core layers. In addition, the shear creep of the core and the deformations of connections are of great consequence in reducing the termal stresses especially in thick and short multispan panels. In this paper the design of panels against thermal stresses is discussed with the aid of examples.

**RÉSUMÉ**

Les panneaux sandwich des structures légères présentent une rigidité et une résistance élevées ainsi qu'un bon pouvoir d'isolation thermique. La couche extérieure mince des panneaux est exposée aux variations rapides de la température externe, provoquant des déformations et des contraintes dans les éléments sandwich. Ces sollicitations thermiques sont fonction de la rigidité du panneau, impliquant des déformations à la flexion et au cisaillement des couches constitutives de l'élément sandwich. En outre, le fluage au cisaillement de la couche centrale et les déformations dans les joints jouent un rôle important dans la réduction des contraintes thermiques, tout particulièrement dans les panneaux sandwich épais et courts à portées multiples. Le dimensionnement des panneaux soumis à des sollicitations thermiques est illustré par des calculs effectués sur certains exemples pratiques.

**ZUSAMMENFASSUNG**

Leichte Sandwichtragwerke haben eine hohe Steifigkeit und Tragfähigkeit und gute Wärmedämmeeigenschaften. Die äussere Deckschicht des Elementes ist der schnellen äusseren Temperaturschwankung ausgesetzt. Dies verursacht im Tragwerk Durchbiegungen und Spannungen, deren Höhe von der Biege- und Schubsteifigkeit des Tragwerkes abhängig ist. Schubkriechen und Deformationen in den Fugen spielen eine wichtige Rolle in der Verminderung der Temperaturspannungen, insbesondere bei dicken und kurzen mehrfeldrigen Sandwichelementen. Das Bemessen von Sandwichtragwerken auf die Temperaturbeanspruchungen wird anhand numerischer Beispiele diskutiert.

## 1. INTRODUCTION

Strutural sandwich panels composed of a foam or a mineral wool core and of thin metal faces are widely used in wall and roof structures in cold storages and industrial buildings. The temperature difference between the faces of the panel in a cold storage can in summer time reach the value $\Delta T = T_{outside} - T_{inside} = +80-(-20) = 100\ ^oC$ and in an industrial building in the arctic climate in winter time $\Delta T = T_{outside} - T_{inside} = -60-(+20) = -80\ ^oC$.

Insulation material between the face layers escapes the temperatures in faces to become even. Thus, the temperature differences cause large curvatures and large deflections and stresses to a panel. Temperature differences between the different structural layers in multilayer panels produce also high local shear stresses to the joints of the layers. In the most cases the shear stress level in the core caused by thermal curvatures is low and the most critical components in the panels are the face layers. Alone or together with the other loads the thermal stresses can easily lead the thin compressed face layer to the buckling failure.

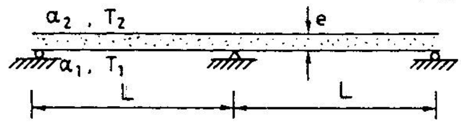
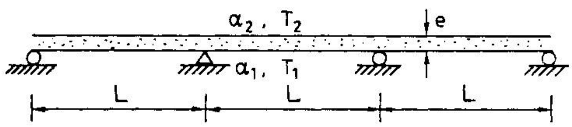
## 2. THERMAL LOADS IN SANDWICH PANELS

Evaluation of thermal stresses of an elastic sandwich panel is usually based on the well known fourth order differential equations for sandwich beams with thick or profiled faces and second order differential equations for beams with thin flat or slightly profiled faces /1, 2/. The problem can be formulated also using finite elements

$$\{F\} = [K]\ \{d\} \qquad (1)$$

In the numerical analysis it is also possible to take into account the flexibilities of the other structures having joints with the panels like the supports and connections. Numerical results of the thermal stresses depend strongly on the bending and shear stiffnesses (table 1). The theory of elasticity yields often too high thermal stresses, because it does not take into account the time dependent deformations in the core or the local flexibilities in the joints of the panel.

Table 1. Support reactions and bending moments on the intermediate support of two and three span thin faced sandwich beams. B means the bending stiffness and S the shear stiffness of the panel. $\vartheta = (\alpha_2 T_2 - \alpha_1 T_1)/e$ and $k = 3B/L^2S$.

| Static system | R | M |
|---|---|---|
|  | $\frac{3\ \vartheta\ B}{e\ L}\ \frac{1}{1+k}$ | $-\frac{3\ \vartheta\ B}{2\ e}\ \frac{1}{1+k}$ |
|  | $\frac{6\ \vartheta\ B}{e\ L}\ \frac{1}{5+2k}$ | $-\frac{6\ \vartheta\ B}{e}\ \frac{1}{5+2k}$ |

## 3. SHEAR CREEP IN CORE LAYER

The behaviour of the structural core materials is usually desribed by elastic material models. Their behaviour actually depends on the stress level, the temperature and the time. The foams particularly are so called thermo-viscoelastic materials. In the engineering calculation models the shear creep is desribed by the time dependent shear modulus /1/

$$G_t = \frac{G_o}{1 + \varphi(t)} \qquad (2)$$

The more accurate method to take the shear creeping into account is to use a linear visoelastic material model for the core.

$$G(t) = \frac{\tau(t)}{\gamma_o}, \; J(t) = \frac{\gamma(t)}{\tau_o} \qquad (3)$$

With the relaxation modulus G(t) and the creep function J(t) the shear stress carried by the core can be integrated in time using the equation.

$$\tau = \int_0^t G(t - t') \left(\frac{d\gamma}{dt'}\right) dt' \qquad (4)$$

The equation (1) to the viscoelastic sandwich beam can now be written in an iterative form

$$[K]_1 \{d\}_2^{n+1} = \{F\} - ([K]_2^n - [K]_1) \{d\}_2^n \qquad (5)$$

where {F} is the loadvector. The subscripts 1 and 2 refer to times $t_1$ and $t_2$ and the superscripts to the iteration cycles.

The linear viscoelastic models used in the above equations are still not able to model the structural foams completely, because in the loading and unloading phases some plastic deformations remain in the foams /3/. Some special methods are needed to take them in consideration in the calculations. The shear creep phenomenon of the core means that the stresses caused by a constant temperature difference between the face layers are reduced gradually due to the relaxation of the core layer. The level of the thermal stresses, ie. compressive and tensile stresses in the faces and shear stresses in the core, is dependent on the rate and the duration of the action of the temperature.

## 4. FLEXIBILITY OF THE SUPPORTS

Tensile stiffnesses of connections with common through going screws are mainly determined by the thickness and the profiles of the outer face and the compressive stiffness of the core layer. For the calculation models the constant tensile stiffness can be evaluated from the linear part of the force-displacement curve

$$k = F/(u_1 - u_2) \qquad (6)$$

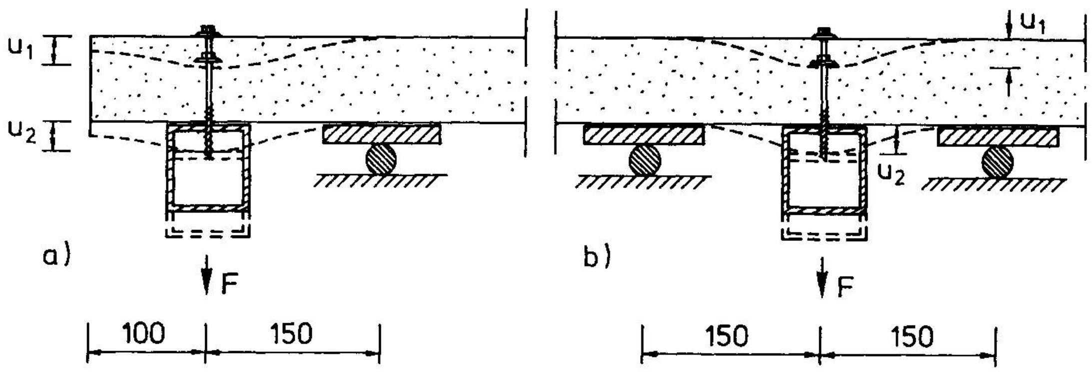



Fig.1. Test arrangements to determinate the tensile stiffness and the strength of a through going screw connection for a sandwich panel with steel faces and a polyurethane core.

Table 2. Tensile stiffness and strength of a screw connection used in sandwich wall panels (see Fig. 1). Diameter of the screw and of the washer were 6.3 mm and 19 mm. Thickness outer steel face was 0.58 mm and the yield and tensile strength of the steel sheet 363 N/mm$^2$ and 451 N/mm$^2$. Density of the polyurethane core was 39 kg/m$^3$ and its compressive modulus of elasticity 2.0 N/mm$^2$ (e = 75 mm) and 3.7 N/mm$^2$ (e = 150 mm).

| Specimen | e(mm) | $F_{exp}$(kN) | k(N/mm) | Specimen | e(mm) | $F_{exp}$(kN) | k(N/mm) |
|---|---|---|---|---|---|---|---|
| F1 | 75 | 4.3 | 200 | F8 | 150 | 4.6 | 280 |
| F2 | 75 | 3.5 | 220 | F9 | 150 | 4.6 | 260 |
| mean value | | 3.9 | 210 | mean value | | 4.6 | 270 |
| F3 | 75 | 3.8 | 270 | F10 | 150 | 4.8 | 360 |
| F4 | 75 | 4.3 | 260 | F11 | 150 | 4.6 | 350 |
| F5 | 75 | 4.0 | 300 | F12 | 150 | 4.5 | 380 |
| F6 | 75 | 4.6 | 330 | F13 | 150 | 4.2 | 350 |
| F7 | 75 | 4.3 | 310 | F14 | 150 | 4.7 | 340 |
| mean value | | 4.2 | 290 | mean value | | 4.6 | 350 |

## 5. EXPERIMENTAL RESULTS

A test series in a cold chamber was performed in the Laboratory of Structural Engineering at VTT to study thermal stresses in sandwich panels. The tests were also analyzed with the finite element method. In the tests two span panels with nearly flat faces were subjected to cyclic temperature loading. The test arrangement is given in Fig. 2 and the loading in Fig. 4a. Figures 3 show the displacements on the supports and were used to evaluate the flexibilities of the connections. During the tests the end supports were connected against both upward and downward movements using 'rigid' continuous support beams.

The approximate temperature history in fig. 4a was used in the numerical analysis. In Figures 4b and 4c the experimental results for the central support reaction and the midspan deflection are compared with the corresponding calculated values. Three numerical analyses have been done, purely elastic, elastic with flexible supports and viscoelastic with flexible supports.

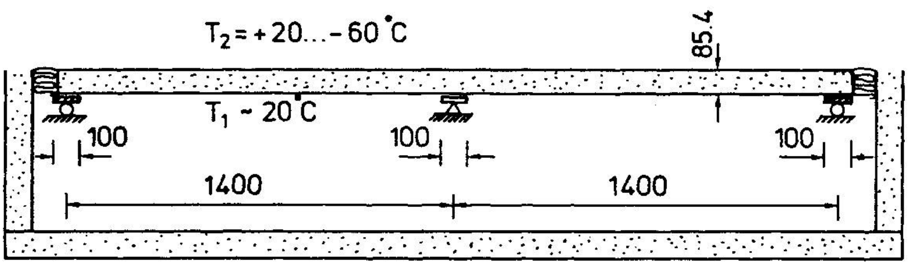



Fig.2. Figurative loading arrangements. Thickness of the steel faces was 0.46 mm, width of the panel 600 mm and the initial shear modulus of the core at T = +20 °C 4.08 N/mm$^2$.

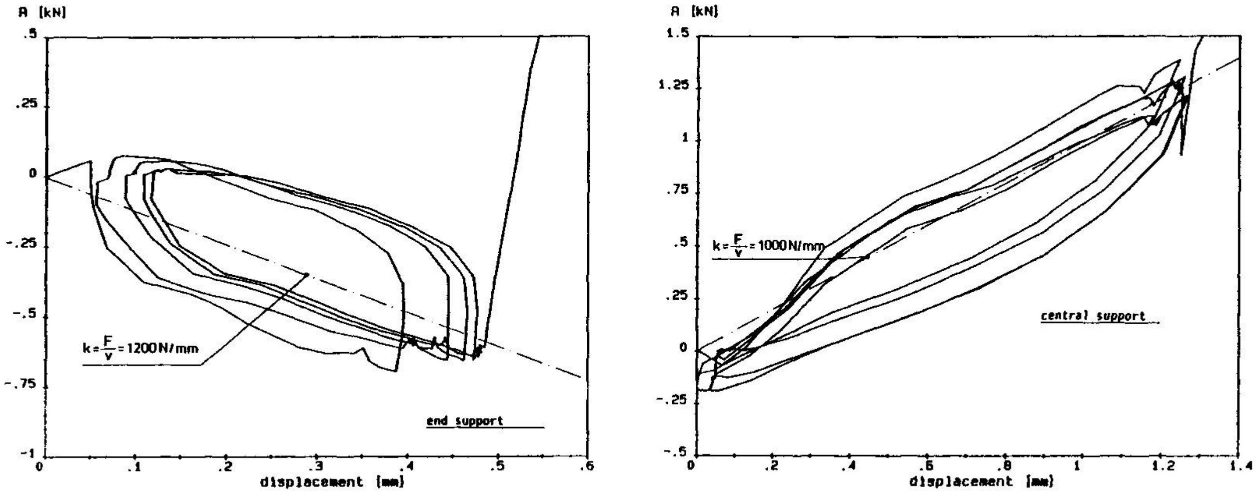



Fig.3. Displacements from(-, upward) and to(+, downward) the support plate on the end and central supports during the temperature cycles.

## 6. CONCLUSION

In practical design light weight sandwich panels are treated elastic for short term loads and viscoelastic for long term loads. The test results confirm that in short 'daily' temperature cycles the influence of the timedependent behaviour of foams is negligible. On the other hand the results emphasize the importance of the flexibility of the connections and suggest that they should be considered in design. On the other hand the connectors with the support beams restrain rotation of the panel and increase both the stiffness of the structure and thus also thermal stress and this should be studied too.

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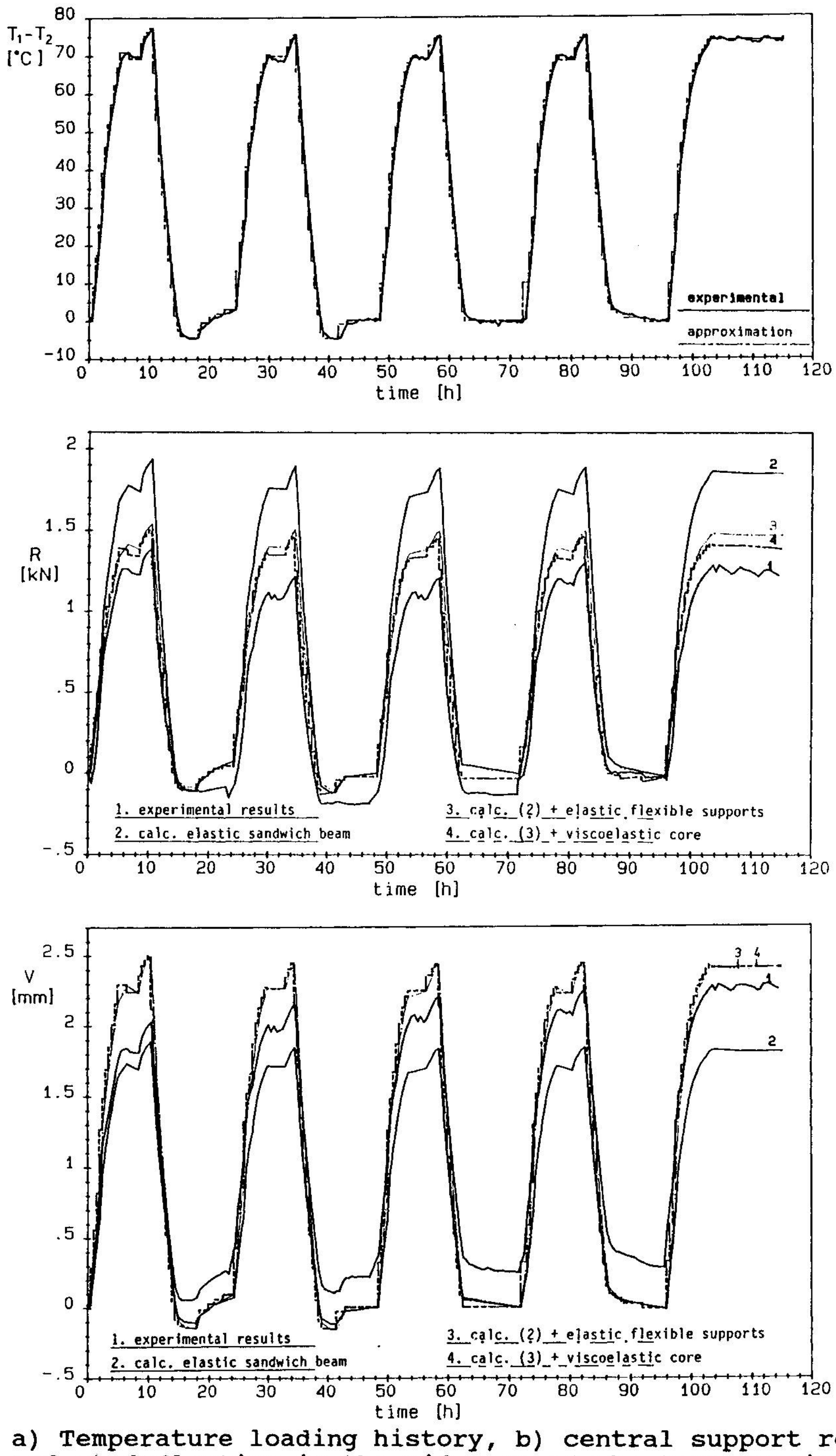


Fig.4. a) Temperature loading history, b) central support reaction and c) deflection in the mid span of the test specimen given in the fig. 2. In the calculations Findley's model was used $J(t) = 0.2452 + 0.03\ t^{0.37}$ ($mm^2/N$, the time in hours).