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Load Bearing Strength of Sandwich Panel Walls with Window Openings

Résistance ultime des panneaux sandwich de façade comportant des ouvertures

Tragfähigkeit von Wänden aus Sandwichelementen mit Fensteröffnungen

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SUMMARY

Sandwich panel elements used as walls of buildings are often weakened by holes for windows. In this paper is discussed the design of vertically and horizontally placed sandwich elements with openings for windows in different positions.

RÉSUMÉ

Les panneaux sandwich utilisés comme éléments de façade de bâtiment sont souvent affaiblis par les ouvertures nécessitées par les fenêtres. Cet article traite du dimensionnement des panneaux sandwich disposés verticalement ou horizontalement et comportant des ouvertures pour fenêtres en différents emplacements.

ZUSAMMENFASSUNG

Sandwichkonstruktionen, die als Wandelemente benutzt werden, weisen häufig Schwächungen infolge der Anordnungen von Fenstern auf. In diesem Beitrag wird der Entwurf und die Berechnung senkrecht und waagrecht eingebauter Sandwichelemente mit Fensteröffnungen in verschiedenen Positionen behandelt.

1. INTRODUCTION

Sandwich panel elements with foam-in-place cores and light-gauge cold-formed metal skins are becoming more and more popular as external walls of buildings both in Sweden and in many other countries. As often as not it is necessary to fit windows, vents and doors into the panel wall. Door and larger openings normally need to be strengthened by using, for example, a steel frame. It is, however, not necessary to strengthen openings for windows if the sandwich element is designed so that it may cope with the extra forces, especially those at the corners of the window.

Numerous alternative solutions are possible for the fitting of sandwich elements and the positioning of windows. The sandwich elements may be horizontal or vertical, simply supported or continuous. The windows may occasionally be symmetrically placed in the element, but are normally placed independently of the element joints. Fig. 1 shows some typical window positions in industrial building walls.

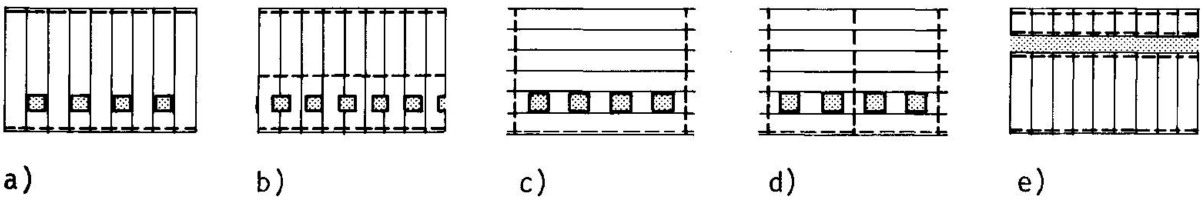


Fig. 1 Example of window positions in sandwich element walls

In many cases the windows are so close to each other, e.g. case b) and e) in Fig. 1, that the sandwich elements and windows must be supported by special beams.

In the following it is assumed that the window frames are fastened in the corners only and that no composite action with the sandwich elements exists.

2. SIMPLY SUPPORTED VERTICAL ELEMENTS

2.1 Windows in every second element

The element between two windows in Fig. 1 a) will be acted upon by symmetrical forces, wind load on the element itself, shear forces from the adjacent elements above and below the windows and shear forces from the adjacent windows. If the bending stiffness in the transverse direction is slightly less than that in the longitudinal direction (for example sandwich elements with flat or linear skins as in Fig. 2) and if the element length is large compared to the element width, the element can simply be designed for the maximum bending moment in a section through the upper corners of the window opening and the shear force in a section through the lower corners. Furthermore the shear force in the element joints close to the corners must be checked, se below.

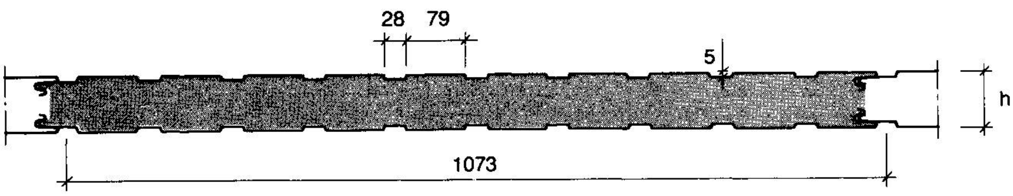


Fig. 2 Sandwich element with linear skins

2.2 Torsional rigidity

When there is more than one element between the windows, the elements between the windows will be acted upon by asymmetrical forces. The distribution of the loads from the windows and from the elements above and below the windows depend on the bending, shearing and torsional rigidity of the elements. According to Timoshenko [1] all values of torsional rigidity D_{xy} based on purely theoretical considerations should be regarded as a first approximation, and a direct test must be recommended in order to obtain more reliable value. Therefore, two simple torsional tests according to Fig. 3 and two bending-torsional tests according to Fig. 4 were made. The torsional tests gave

$$GK_v = 84 \text{ kNm}^2 \text{ and } 147 \text{ kNm}^2$$

for 55 and 85 mm thick elements with the cross section shown in Fig. 2 and skins of 0.42 mm steel sheet.

These values may be compared with values according to a modified Bredt's formula, compare Fig. 5,

$$GK_v = \frac{4\ (2b_s/3)^2\ h^2}{2\ (2b_s/3G_f t + 3h/G_c b_s)}$$

which, for G_f = 81000 N/mm^2 for the sheet, G_c = 8 N/mm^2 for the core, t = 0.42 mm and b_s = 1083 mm, gives

$$GK_v = 78 \text{ kNm}^2 \text{ and } 148 \text{ kNm}^2 \qquad (1)$$

for h = 55 and 85 mm respectively.

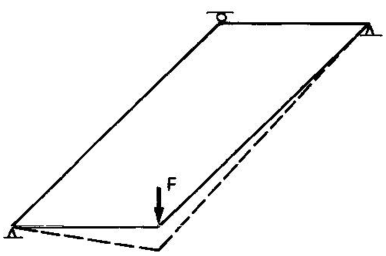


Fig. 3 Sandwich element in torsion

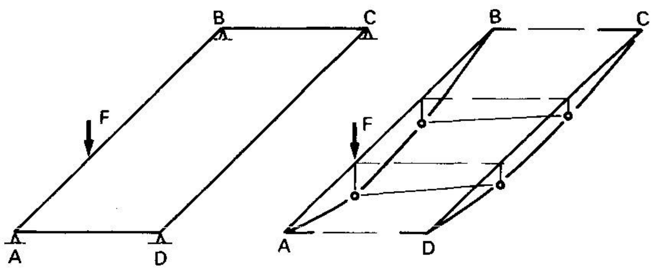


Fig. 4 Sandwich element in bending and torsion

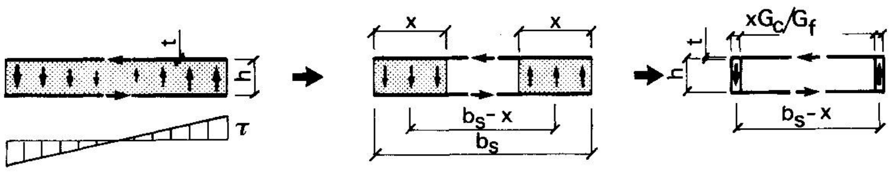


Fig. 5 Model for calculating the torsional rigidity GK_v. $x = b_s/3$.

The deflection of the torsional-bending test elements of Fig. 4 were compared with a finite element calculation based on 24 elements in the longitudinal direction and 2 elements in the transverse direction. Isoparametric, orthotropic plate elements taking into account shear deformation (Mindlin-theory) with four nodes were used. The torsional rigidity was supposed to be $D_{xy} = GK_v/2b$ = 37 kNm.

It can be seen in Fig. 4 that the agreement between tests and calculations was good.

2.3 Windows in every third element

A finite element calculation was carried out for the example in Fig. 6 a) where, by using geometrical symmetry, one whole element and half of the element above and below the window were studied. The window was assumed to have the same width as the sandwich elements.

Calculated deflection, bending moments and shear forces in the element joint are shown in Fig. 6 c), d) and e) respectively.

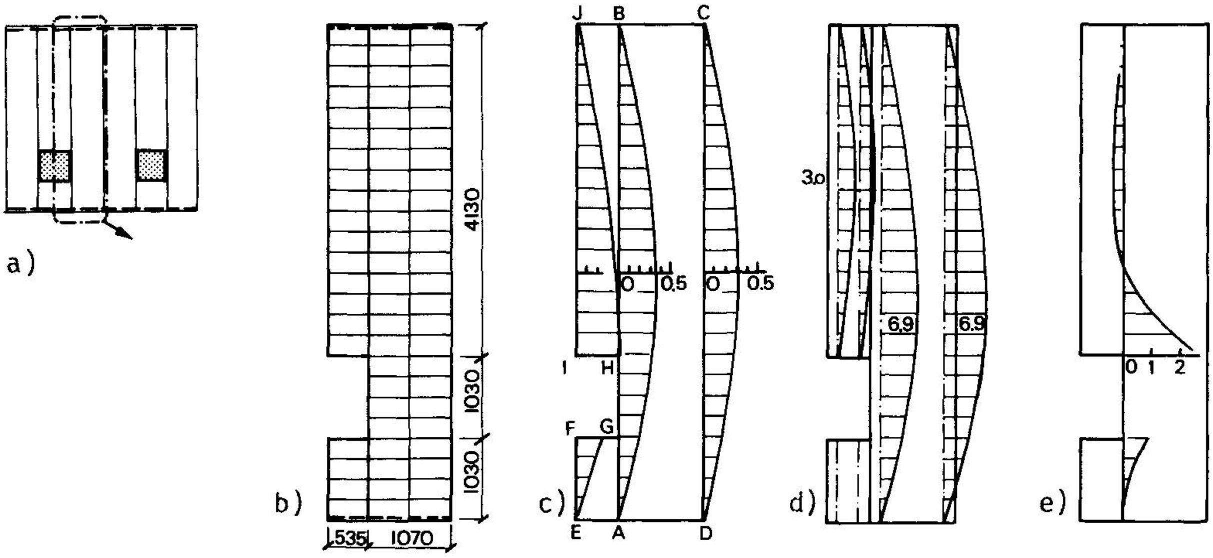


Fig. 6 a) Window in every third element
b) Finite element mesh
c) Deflection
d) Bending moment
e) Shear force in element joint

Fig. 6 c) shows that torsion in the element ABCD is small. Therefore, the bending moment on both sides of the element is almost the same. The bending moment in the element above the window is about 1.5 times that of an element which was supposed to be simply supported on the window. The maximum bending moment is only slightly larger than 1.5 M_0 where M_0 is the moment at a section through the upper corner of the window for one isolated element. This result was used when the approximate formulae in 2.6 were derived.

The shear force in the joints between the elements has a marked peak at the upper corner of the window opening. A very rough estimate for the peak value is

$$V = 2.5\ q\ b_w. \qquad (2)$$

2.4 Test on joints between elements

The shear capacity of the joints depends, of course, on the shape of the joints. Tests on joints shown in Fig. 7 gave shear strengths which were 55 to 70 % of the shear capacity of the element in the longitudinal direction. During testing crack 1 in Fig. 6 a) appeared at 60 to 80 % of the collapse load (which occurred when crack 2 arose). In the rules in Fig. 8 the shear strength of the joints were, on the safe side, supposed to be half of the shear strength of the element.

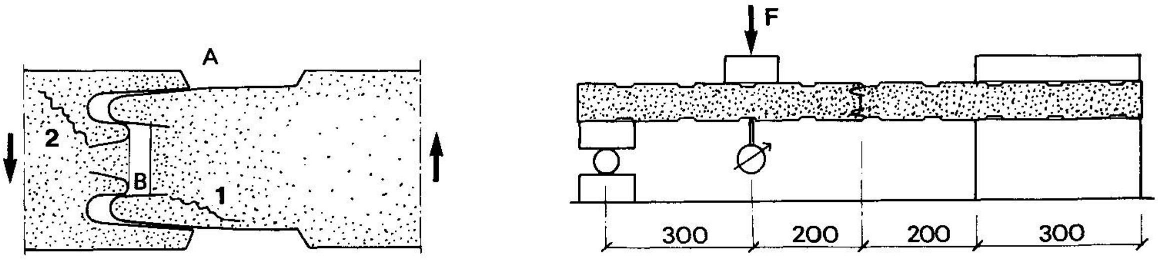


Fig. 7 Testing of the joints between sandwich elements

2.5 Two or more elements between windows

When there are two or more elements between the windows the bending moment in the element next to the window will decrease. The reduction depends on the relation between the bending, torsional and shear rigidity of the element.

For the type of element shown in Fig. 2 the following reduction factor for the bending moment can be used

$$\kappa = 0.6 + 1.6/n^2 \tag{3}$$

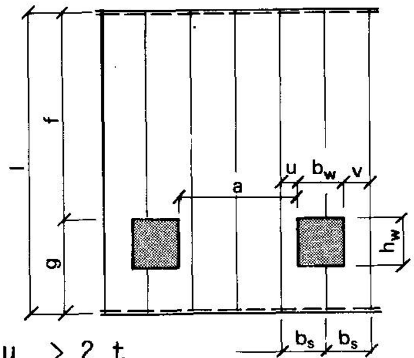
where n is the number of elements between the windows.

The shear forces will not decrease to the same extent, which is why no reduction is recommended.

2.6 Design formulae

Proposed design formulae for the type of elements shown in Fig. 2 are given in Fig. 8. As was pointed out in the introduction the formulae are valid for the case where the window frames have been fastened in the corners only. The formulae are conservative if there is composite action between the window frames and the sandwich panels.

Simply supported vertical elements



$u > 2\ t_s$

$v > 2\ t_x$

$b_w < 1.2\ b_s$

Bending moments and shear forces according to the following formulae shall be less than allowable values for the actual sandwich panel:

$$M = M_o\left(1 + \frac{0.58\ b_f}{b_s + t_s}\right)\cdot\left(0.6 + \frac{1.6}{n^2}\right) \quad \text{for } n \geq 2$$

$$M = 2\ M_o \quad \text{for } n = 1$$

$$M_o = \frac{q\ell g}{2}\left(1 - \frac{g}{\ell}\right)$$

Furthermore $M \geq q\ell^2/8$ kNm/m

$$V = 5\ qb_w \geq q\ell^2/2 \text{ and}$$

$$\geq q\ (\ell/2 - g + h_w)(1 + 1.2\ b_w/a)\ \text{kN/m}$$

where

q = wind load (kN/m^2) $\quad b_s$ = element width
t_s = element thickness (m)
n = number of whole elements between windows

Fig. 8 Proposed design rules for vertical sandwich elements with flat or creased skins

3. SIMPLY SUPPORTED HORIZONTAL ELEMENTS

It is assumed that the windows are so close to each other that the wind load on the windows will be almost evenly distributed along the adjoining sandwich elements, see Fig. 9.

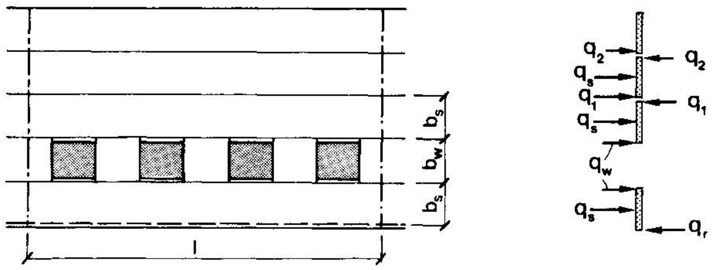


Fig. 9 Windows in horizontal elements

3.1 Sandwich element supported on three edges

The deflection v of the element below the windows is the sum of v_b due to bending moments, v_s due to shear forces and v_t due to torsional moments.

$$v_b = B\ (q_w + q_s - q_r) \quad \text{where} \quad B = 5\ \ell^4/(384\ EI) \tag{4}$$

$$v_s = S\ (q_w + q_s - q_r) \qquad S = \ell^2/(8\ GA_w) \tag{5}$$

$$v_t = T\ (q_w + q_r) \qquad T = \ell^2 b_w/(16\ GK_v) \tag{6}$$

At the lower edge of the element below the window the deflection $v = v_b + v_s - v_t = 0$ which gives

$$q_r = q_w\ (1 - 2\beta) + q_s\ (1 - \beta) \quad \text{where} \tag{7}$$

$$\beta = T/(B + S + T) \tag{8}$$

The above is strictly correct only if the distribution of the bending deflection is affined to the shear and the torsional deflection. The maximum deflection, bending moment, shear forces and torsional moment is then

$$v_{max} = (2\ q_w + q_s)(B + S)\ 2\beta \tag{9}$$

$$M_{max} = (2\ q_w + q_s)\ \beta\ \ell^2/8 \tag{10}$$

$$V_{max} = (2\ q_w + q_s)\ \beta\ \ell/2 \tag{11}$$

$$T_{max} = (2\ q_w + q_s)(1 - \beta)\ b_s\ \ell/4 \tag{12}$$

The torsional moment gives shear stresses which shall be added to the stresses due to the shear forces. The shear stresses due to the torsional moment are derived according to the model in Fig. 5.

$$\tau_c = \frac{T \cdot 1.5}{2\ (2b_s/3)h\ (b_s/3)} = \frac{T}{0.30\ h\ b_s^2} \tag{13}$$

where the factor 1.5 accounts for the peak value of the shear stress in Fig. 5 a).

A fictitious shear force can be derived

$$T_{eq} = \tau \, h_{bs} = \left[\frac{V_{max}}{hb_s} + \frac{T_{max}}{0.30 \, hb_s}\right] hb_s \qquad (14)$$

which, with V_{max} and T_{max} according to (11) and (12) and $q_w = Q \, b_w/2$ and $q_s = Q \, b_s$ gives

$$T_{eq} = qb_s \, \ell \, (1 + b_w/b_s)(0.833 - 0.33 \, \beta)$$

where q is the wind load.

3.2 Sandwich elements elastically supported along one longitudinal edge

The element above the windows in Fig. 9 is supported by the other elements above the windows. If the upper edge of the top element is simply supported, then the direct wind load on the elements gives no torsional moments. The shear stresses are then less than in the element below the windows while the bending moment is larger.

The deflection of the elements caused by the load on the window can be written

$$v_1 = (q_w - q_1)(B + S) - (q_w + q_1) \, T = (q_1 - q_2)(B + S) + (q_1 + q_2) \, T \qquad (15)$$

which with regard to eqn (8) gives

$$q_1 = (q_w + q_2)(1/2 - \beta) \qquad (16)$$

and similarly

$$q_2 = (q_1 + q_3)(1/2 - \beta) \qquad (17)$$

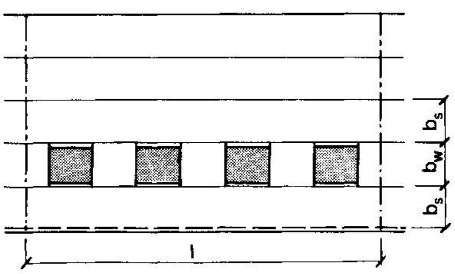
If there are only two elements, then $q_2 = 0$ and the total load on the element above the window will be

$$\Sigma q = q_s + q_w - q_1 = q_s + q_w \, (1 + \beta)/2$$

If there are three elements $q_r = 0$, $q_2 = (0.5 - \beta) \, q_1$ and from eqn (16)

$$q_1 = q_w \, (1/2 - \beta)/(1 - (1/2 - \beta)^2) \qquad (18)$$

β is often close to 1/2 which is why the denominator for practical design can be put equal to unity. The design formulae can then be summarized as in Fig. 10.



$$M = q \left(1 + \frac{h_w}{b_s} (1 + \beta)\right) \cdot \frac{\ell^2}{8} \qquad \text{kNm/m}$$

$$V = q\ell \left(1 + \frac{h_w}{b_s}\right)(0.83 - 0.33 \, \beta) \qquad \text{kN/m}$$

$\beta = T/(B + S + T)$ where

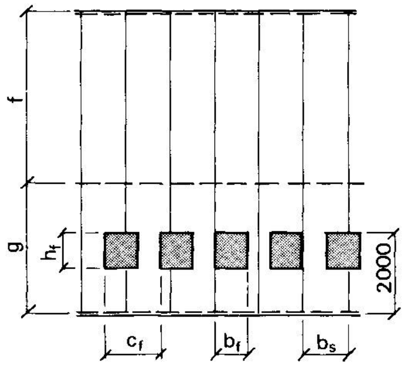
$$B = \frac{5 \, \ell^4}{384 \, EI}; \quad S = \frac{\ell^2}{8 \, GA_w}; \quad T = \frac{\ell^2 \, b_s}{16 \, GK_v}$$

Fig. 10 Proposed design rules for horisontal sandwich elements with flat or lined facing

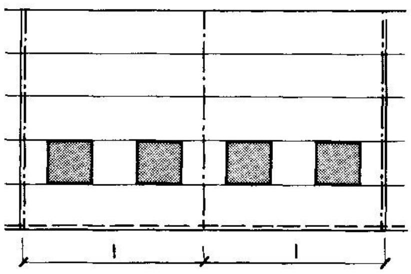
4. CONTINUOUS ELEMENTS

The temperature difference between the inside and outside of the sandwich elements can be considerable. If the elements are continuous, then restraining forces must be considered in design. Even if higher permissible stresses are used for the combination of forces due to temperature differences and wind load, this load combination is governing. Testing of two continuous elements subjected to a combination of distributed load and temperature difference has shown that elastical behaviour can be supposed.

Despite the simplification of design methods the calculation involved for the design of continuous elements with window openings is considerable. The design tables for permissible loads have therefore been constructed for a number of spans, window positions and window sizes, compare Fig. 11 a) and b). As these tables are applicable for specific products only, they are not included here.



a)



b)

Fig. 11 Continuous sandwich elements with windows

ACKNOWLEDGEMENT

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REFERENCES

1. TIMOSHENKO S. & WOINOWSKY-KRIEGER S., Theory of Plates and Shells. Mc Graw-Hill, 1959.
2. PLANTEMA F.J., Sandwich Construction. John Wiley & Sons, 1966.