Openings in sandwich panels

K. Berner, U. Pfaff

1. State of the art

Sandwich panels with flat or lightly profiled faces are frequently used as "load bearing" wall construction units. "Load bearing" here refers to the admission and transmission of wind loads and climatic effects. Sandwich wall panels are mostly used for industrial buildings, but also e.g. for office buildings and halls with special application (e.g. exhibition and sales halls).

It is obvious that in many buildings, walls necessarily also need to have "openings" like windows and doors. The "official" state of the art concerning openings within wall constructions with self-supporting sandwich panels is always a "replacement", i.e. an additional support of the wall panels in the range of openings. Thereby, all applied loads on window and door openings are transmitted to the spaced structural supports (e.g. framework) by longitudinal and cross beams (e.g. steel sections) (see fig. 1). This means however that a replacing, e.g. of a window opening, always is a substantial effort. Above all, concerning the use and the visual effect, this is not requested.

A replacing however is at present the only "official" solution for openings within sandwich panels because there are no accepted procedures in technical approvals or in the European standard prEN 14509, including openings in sandwich panels. If openings are designed without replacing, that would be an application of the panels beyond the approved rules, what is clearly not permissible.

This, in particular, also applies to the use of allowable spans, which were intended for panels without open-
ings. These spans naturally cannot be applied in any case, not even roughly, to panels with openings. In the following new possibilities for openings in sandwich panels shall be pointed out with the following purpose:

- No additional replacing
- Load bearing capacity (allowable spans) of the panels with openings as comparable as possible to not weakened panels
- Explicit compilation of the operational loads within the area of openings by comprehensible calculation methods regarding static-structural issues, in order to allow an extension of official documents, e.g. technical approvals, for panels with openings.

2. **Presentation of variants of openings in principle**

Depending on the use of the intended openings (e.g. as windows or doors) there is a set of conceivable variants of openings (with walls from sandwich panels), that can differ in principle by the following criteria:

- Size of the openings (fig. 2a)
- Location of the openings (fig. 2b)
- Variants concerning the span direction of the panels (fig. 2c and d)

On the basis of these criteria it is obvious that there must be a set of possibilities regarding the structural remarks, in order to plan openings in sandwich panels. In the following three possibilities and their feasibility are presented in principle.
3. Possibilities for the survey of loads within the openings in static-structural terms

3.1 Calculation of panels with openings with the remaining cross-sectional area

It is obvious that it can be tried at first, to ensure and to calculate the load capacity of a wall panel with an opening, with the remaining cross section (see fig. 3 and 4). The remaining cross section is then dedicated by the width of the panel less the width of the opening. The arising loads (also on the opening, e.g. on the window) must then be carried by the panel weakened thru the opening.

It must be pointed out that a simple calculation with the geometrically determined remaining cross section is on the unsafe side, since substantial stress peaks (fatigue strength) can arise in the corners of the openings. Thus, a realistic recording of the loads is in principle not possible by basic approach of the remaining cross section.

A direct survey by calculation of these stress peaks is only possible by FE-computations (or with improved “rod models”) in conjunction with appropriate tests. This however, is only feasible by a relatively high expenditure and not directly conceivable for individual calculations in practise.

The results of such computations however can be very important for practical experience, since simple procedures can be developed for practical use. A first attempt dealing with the stress peaks at the area of the openings was already submitted in 1998. For this a couple of sets of research work is achieved (e.g. at the Technical University of Darmstadt), whose results will be available in the near future.

In order to get an idea of the substantial reduction of the load capacity of panels with openings, rough computations with practical loads under approach of the remaining cross section and the stress peaks (according to the proposal of W. M. G. Courage und A. W. Thoma, TNO Building and Construction Research, Delft, Netherlands) were accomplished and presented exemplarily in fig. 5.

Due to these results it can be clearly recognized, that with realistic (wind -) loads on windows and doors permissible openings result that are outside of any reasonable application for practical use. Therefore, a solution by calculation with the remaining cross section only makes sense for small openings. For panels with realistic spans, loads and dimensions of windows and doors this is not an economic solution.
Panel type: Wallpanel with lightly profiled faces on both sides (see test No. V5)

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Panel thickness</td>
<td>100 mm</td>
</tr>
<tr>
<td>Sheet thickness</td>
<td>( t_{\text{ls}} = 0,45 ) mm, ( t_{\text{li}} = 0,52 ) mm</td>
</tr>
<tr>
<td>Area of the outer face</td>
<td>( A = 4,5 \text{ cm}^2/\text{m} )</td>
</tr>
<tr>
<td>Distance of the centroids</td>
<td>( h_D = 97,5 ) mm</td>
</tr>
</tbody>
</table>

According technical approval Z-10.4-233:

- Wrinkling stress: \( \sigma_K = 141 \text{ N/mm}^2 \)
- Reduction factor for ultimate limit state: 0.88
- Reduction factor for evaluated temperature: 0.81

Static system: One-span panel with span \( L \) and uniformly distributed load \( q = 0.50 \text{ kN/m}^2 \)

\[
\sigma = 1,85 \cdot \frac{M}{h_D \cdot A} \leq k_{\text{ultimate state}} \cdot k_{\text{temp.}} \cdot \sigma_K \\
\sigma = 1,85 \cdot \frac{8}{97,5 \cdot 4,5} \leq 0,88 \cdot 0,81 \cdot 141 \text{N/mm}^2 \\
\Rightarrow all L = 6,18 \text{m}
\]

Panel without opening:

Panel with opening:

Pre-values: see TNO-report

\[
\beta = \frac{b}{B} = 0,5 \\
\alpha_W = 2,49 - 0,62 \cdot \beta - 0,21 \cdot \beta^2 = 2,13 \\
K_T = \frac{2,27 + 4,35 \cdot \beta - 5,48 \cdot \beta^2}{1 - \beta} = 6,15 \\
\sigma_N = \frac{\alpha_W \cdot \sigma_K}{K_T} = 2,13 \cdot 6,15 \cdot 141 = 48,88 \text{ N/mm}^2 \\
\sigma = 1,85 \cdot \frac{M}{h_D \cdot A} \leq k_{\text{ultimate state}} \cdot k_{\text{Temp.}} \cdot \sigma_N \\
\sigma = 1,85 \cdot \frac{8}{97,5 \cdot 4,5} \leq k_{\text{ultimate state}} \cdot k_{\text{Temp.}} \cdot \sigma_N \\
\sigma = 1,85 \cdot \frac{8}{97,5 \cdot 4,5} \leq 0,88 \cdot 0,81 \cdot 48,88 \text{ N/mm}^2 \\
\Rightarrow all L = 3,63 \text{m}
\]

Abb. 5: Stützweitenvergleich bei Ansatz des Restquerschnittes

Fig. 5: comparison of allowable spans applying remaining cross section area
3.2 Activation of load-carrying effective areas of adjacent panels
Panels with openings with a remaining cross section have a smaller flexural rigidity within the range of the openings and thus altogether. If panels with openings (without reinforcing) shall be combined with panels without openings with a longitudinal joint within the wall, it can be assumed that the force-locked join due to a longitudinal tongue and groove joint forces the same deformation behaviour. The panel with an opening, and thus a smaller flexural rigidity, supports itself onto the panel without an opening with a larger flexural rigidity thru the longitudinal joints. Thus substantial loads in the longitudinal joints arise and the not weakened adjacent panels are additionally stressed (see fig. 4). This solution appears reasonable. Thereby however two substantial conditions must be present:
• Adjacent elements must not have openings
• The transmission of loads into the carrying not weakened elements must be ensured thru the longitudinal joints.

From these conditions the following effects on the bearing behaviour of the panels need to be considered necessarily:

a) The effective panels without openings are additionally stressed in either case. The load affects unfavourably as it arises on one side, more or less as line or single loads, within the range of the longitudinal joint. The size and the kind of the loads depend on the dimensions and the location of the openings respectively. A computational calculation appears difficult and is at the time perhaps only detectable with FE computation. A general valid calculation method for consideration of effective impact of adjacent not weakened panels is not available for practical application. Also in this respect research takes place at the University of Darmstadt. It is obvious that allowable spans of the not weakened panels with additional loads of the panels with openings are naturally smaller than with “normal” loads.

b) For activation of an effective impact of not weakened panels within the range of panels with openings a shear force transfer is necessary in either case at the longitudinal joints (see fig. 6). For a calculation of this shear force capacity permissible arithmetic values need to be specified which can only be specified by experimental testing. For a statistic evaluation and in consideration of the large number of variants of possible openings complex series of tests are presumably necessary. It is obvious that the shear force capacity of the longitudinal joints strongly depends on the kind of tongue and groove joint and might be very small for some existing longitudinal joints, e.g. in mineral wool panels.

3.3 Reinforcement within the range of openings with particularly conceived framework
In the following, principle possibilities for reinforcement within the range of openings shall be pointed out, with the following purpose:
• All openings, independently of size and location, are to be strengthened by structural measures which are not additional but within the window and door frame.
• Also with large openings (up to entire panel width) useful allowable spans shall be achieved by the reinforcement that approximately correspond to the spans of not weakened panels.
• The longitudinal joints and thus adjacent elements shall not be stressed additionally.
• The associated static calculations should be simply comprehensible, so that the reinforcement can be recorded into official documents by an appropriate calculation method also directly without complex series of tests.

For explanation of the stresses within the range of the openings at first the possibilities of a reasonable reinforcement for an opening with maximum width (extreme case), which correspond to the whole panel width, shall be presented in the following (see fig. 7):

The reinforcement in principle consists of a frame out of four (two at the lower and upper side respectively) cross beams in the range of the faces at the transverse edge of the openings and two special side beams at the longitudinal edge of the openings. In the presented example the frame shall transfer the...
loads by itself (without any remaining cross section of the panel).

By bending load due to external loads compressive stresses ($\sigma_d$) result in the upper face and tensile stresses ($\sigma_z$) result in the lower face of the panel which must be transmitted into the cross beams respectively. This can happen in principle by mechanical connections or by adhesion. The cross beams transmit the loads (in principle as horizontal support reaction of the respective crossbar) into the upper chord (D) and the lower chord (Z) respectively of the side members. In addition it must be ensured that the vertical shear forces (Q) will be transmitted from the corners of the framework into the longitudinal beams. Within the range of the opening the longitudinal beams of the reinforcing frame then transfer the bending moment and the shear force. The construction of the longitudinal beams as homogeneous cross section, e.g. as steel or aluminium full-profile, however is not possible because then cold bridges would exist between outside and inside. Therefore, the upper and lower chord of the side members must be thermally separated. At the same time they must be "shear-stiff" connected (composite section), in order to receive a sufficient bending and shear capacity. Thereby the load bearing capacity of the not weakened panel must be achieved essentially, if comparable spans shall be achieved.

In order to fulfil this demand the decisive philosophy was to conceive the use of special aluminium profiles with plastic webs, in the following named APK profiles, for the longitudinal beams (see fig. 8). APK profiles are used e.g. as load bearing profiles for winter garden constructions, whereby the profiles support the entire loads of self-weight, weight of glass roofing and snow loads with spans of approximately 3.0 m. All necessary characteristic values of these profiles are recorded for static calculations (which must be accomplished interestingly according to the sandwich theory!) in technical approvals. In particular the transmission of shear forces thru the plastic webs, made of fibre-glass reinforced plastics which are expanded into aluminium notches, was experimentally tested under short and long-term loads at different temperatures (up to +90 °C). The statistical evaluated calculation values are officially recorded with associated calculation methods in technical approvals, so that the static calculation of such profiles is easily possible.

In principle the upper and lower aluminium chord can be selected freely. Thus, also special edge profiles could be conceived, which correspond e.g. with the tongue and groove design of the adjacent sandwich panels.

The cross beams of the reinforcing frame, two at the ex- and interior respectively, can be separately intended right from the beginning, since they are only necessary for load transmission of the loads from the faces into the longitudinal beams.

Based on the considerations mentioned above first attempts were accomplished at the Institute for Sandwich Technology. For the investigation of the principle feasibility panels with openings at mid-span were examined. In terms of dimensions the extreme case, with an opening width that approximately corresponded with the panel width (1160 mm), was selected, so that none or only a small participating remaining cross section was available in the range of the openings.
Over all 5 tests were accomplished that are shown in table 1. The tests 1 to 4 were accomplished to investigate the bearing behaviour in principle of the bracing reinforcement. Test number 5 was accomplished as first approximation of a realistic construction of a reinforcing by a window framework in connection with a longitudinal beam with thermal separation and with a "shear-stiff" connection of the cross section parts (APK profiles).

Regarding the test results it must be mentioned that all parts of the framework necessary for reinforcing within the opening were technical manufactured, whereby significant improvement opportunities due to the test results certainly became recognizable afterwards. Thus the longitudinal beams were joined in principle by hand, whereby only the plastic web area was taken of APK profiles and these were bolted with suitable square tubes in that way that a symmetrical and concerning the panel thickness coherent cross section results.

Due to the test results the following substantial perceptions need to be noticed:

1. The load-carrying capacities of the APK profiles, in particular the shear bearing capacity of the plastic webs, were sufficient high. At no test the panel failed within the range of the side members.

2. The load transmission ($\sigma_D$) into the cross beams is difficult to realize with mechanical connecting device (see test 1 and 2, fig. 9 to 12) as many tapping screws would be necessary and the stress would not arise constantly in the range of the longitudinal beams, but concentrated (stress peaks).
<table>
<thead>
<tr>
<th>Test No.</th>
<th>Panel type and dimensions</th>
<th>Transmission of the forces (D, Z) into the longitudinal beams (D, Z)</th>
<th>Total failure load (kN)</th>
<th>Kind of failure</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Wall panel with lightly profiled faces on both sides: (d = 120, \text{mm}), (b = 1000, \text{mm}), (t_{c1} = t_{c2} = 0.56, \text{mm}), (\ell = 2940, \text{mm})</td>
<td>2 x M10, 8.8 per cross beam respectively</td>
<td>5.08</td>
<td>Failure at faces (load transmission into cross beams)</td>
</tr>
<tr>
<td>2</td>
<td>see test No. 1</td>
<td>screws EJOT-JZ 6.3, (e = 250, \text{mm})</td>
<td>5 x M10, 8.8 per cross beam respectively</td>
<td>9.26</td>
</tr>
<tr>
<td>3</td>
<td>see test No. 1</td>
<td>see test No. 1</td>
<td>see test No. 2, reinforcing of the welding seam in the corner of the frame</td>
<td>9.74</td>
</tr>
<tr>
<td>4</td>
<td>see test No. 1</td>
<td>see test No. 1</td>
<td>Bonding between the cross beams and the faces</td>
<td>see test No. 3</td>
</tr>
<tr>
<td>5</td>
<td>Wall panel with lightly profiled faces on both sides: (d = 100, \text{mm}), (b = 1160, \text{mm}), (t_{c1} = 0.52, \text{mm}), (t_{c2} = 0.46, \text{mm}), (\ell = 2935, \text{mm})</td>
<td>Bonding between aluminium angle section (cross beam) and the facings</td>
<td>A complete aluminium frame with welded corners, which was screwed to the side beams</td>
<td>13.20</td>
</tr>
</tbody>
</table>
3. A bonding between the cross beams and the faces appears as sufficient sustainable, as at test number 4 no failure could be determined within the range of the load transmission from the faces into the cross beams.

4. A substantial perception of the tests is the effect of the rigidity of the panel itself compared with the rigidity of the framework, and here in particular of the longitudinal beams which differed at the test specimens substantially. With very rigid longitudinal beams, that were manufactured by arbitrary joining of cross section parts, the risk is that regarding the deformation behaviour in the transfer area, from the panel to the longitudinal beams, a sharp bend arises within the elastic line. Thus, stresses result within the bonding between the face and cross beam flange that are perpendicular to the panel level, which initially leads to delamination of partitions of the bonding and therefore to a initial failure, see test 5 (fig. 13). With appropriate adjustment of the rigidities this problem can probably be optimized explicitly.

In summary it can be noticed due to the test results (especially at test 5) that there are absolutely possibilities to allow wide openings within panels and at the same time to receive a sufficient load-carrying capacity of the panels; as long as a reasonable introduction of loads from the faces into the cross beams (e.g. bonding) is assured within the transfer area of the opening and as long as the bending - and shear loads are transmitted by special beams with plastic webs in the direct range of the opening. Thereby the panel with openings transfers the loads by "itself" so that no additional loads arise for the adjacent elements and above all the longitudinal joints.

3.4 Calculations of the reinforcement and comparison to not weakened panels

In order to represent that the suggested reinforcements and their structural design can absolutely be comprehensible calculated, the stresses of test 4 and 5 shall be recorded arithmetically and compared with those of not weakened panels. With all that the suggested reinforcements can possibly be adapted for official documents (e.g. for static calculations on the basis of standards or technical approvals.

3.4.1. Test No. V4 (see fig. 14 and 15)

Panel (general)

Identification: wall panel with lightly profiled faces
panel thickness: \(d = 120\) mm
sheet thickness: \(t_{k1} = t_{l1} = 0.56\) mm
Panel with opening, see test 4

Exact calculation with a "rod model"
static system: see EDP (fig. 16)
determined shear force - and moment line: see EDP (fig. 17 and 18)

Size of opening: 1000 x 1000 mm

Failure load: applied load: 10.65 kN
    self-weight of the transverse loading beams: 0.53 kN
    self-weight of the panel: 0.97 kN
    total failure load $F_u$: 12.15 kN

Maximum shear stress in the plastic composite area:

$$\tau = \frac{F_u}{F_{\text{unit load}}} \cdot \frac{Q_{\text{unit load}}}{h_{\text{D}}} \cdot \frac{1}{n \cdot t}$$

$F_u$: Total failure load
$F_{\text{unit load}}$: Unit load
$Q_{\text{unit load}}$: shear force due to unit load
$h_{\text{D}}$: distance of centroids of aluminium profiles
$n$: number of composite webs (composite area)
t: web thickness of the composite area

$$\tau = \frac{12,15}{4} \cdot \frac{500 \cdot 1}{78,3 \cdot 2 \cdot 18} = 5.4 \text{ N/mm}^2$$

< 11.2 N/mm²
(shear strength of the composite area)

The design of stresses of the aluminium profiles, the sandwich panel as well as for the deflection are not decisive at this test.

Approximatively calculation by a simplified model:

System:
- span $L$
- moment of inertia of the sandwich panel $I_1$
- moment of inertia of the aluminium composite beams $I_2$

notes
- The shear rigity of the sandwich panel and of the composite range of the composite beams has to be considered at the determination of the internal forces and the stresses.
- The characteristic value of wrinkling stresses of the sandwich panels needs to be calibrated with the exact model and with controlling tests.

calculation
- stress proofs of the aluminium composite beams, including the composite range (according to DIN 4113 and the technical approvals of the composite range)
- stress calculations of the sandwich panel
- determination of deflection and fastenings

Panel without opening
Panel width: $B = 1000$ mm
static system: see panel with opening
Max. moment at mid-span: $M = F_u \times 36.7$ (kNcm)
Max. stress in the faces: \[ \sigma = \frac{M}{h_D \cdot B \cdot t_k} \]

with \( \sigma = 112 \text{ N/mm}^2 \) (extrapolated wrinkling stress according to the decisive technical approval)

\[ \Rightarrow \text{Total failure load} \]

\[ F_u = \frac{112 \cdot 118 \cdot 100 \cdot 0.056}{36.7} = 20.2 \text{ kN} \]

3.4.2 Test No. V5 (see fig. 19)

Panel (general)
Identification: wall panel with lightly profiled faces type L “Colorwall 1160”
panel thickness: \( d = 100 \text{ mm} \)
sheet thickness: \( t_{ia} = 0.45 \text{ mm}, t_{ia} = 0.52 \text{ mm} \)

Panel with opening, see test 5
static system: see EDP (fig. 20)

Determined shearforce and momentline: see EDP (fig. 21 and 22)

Size of opening: 805 x 805 mm
Failure load: applied load: \( 12.07 \text{ kN} \)

self-weight of the transverse loading beams: \( 0.53 \text{ kN} \)
self-weight of the panel: \( 0.60 \text{ kN} \)
total failure load \( F_u \): \( 13.20 \text{ kN} \)

Max. failure stress in the face (wrinkling):
\[ \sigma = \frac{82.71 \cdot 1000 \cdot 13.2}{97.5 \cdot 0.45 \cdot 201.7} = 123.4 \text{ N/mm}^2 \]
\[ \approx 0.9 \times 141 \text{ N/mm}^2 \] (declared value of the wrinkling-stress according to technical approval No. Z-10.4-233)

deflection at 1 kN total load

<table>
<thead>
<tr>
<th>test</th>
<th>calculation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.36 mm</td>
<td>1.39 mm</td>
</tr>
</tbody>
</table>

Panel without opening
Panel width: \( B = 1160 \text{ mm} \)
static system: see panel with opening
Max. moment at mid-span: \( M = F_u \times 36.7 \text{ (kNcm)} \)
Max. stress in the faces: \[ \sigma = \frac{M}{h'B't_k} \]
with \( \sigma = 141 \text{N/mm}^2 \) (wrinkling stress according to the technical approval No. Z-10.4-233)

⇒ Total failure load:
\[ F_u = \frac{14,1\cdot 9,75\cdot 116 \cdot 0,045}{36,7} = 19,6 \text{kN} \]

Comparison

Failure loads

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Panel with opening (achieved load at test)</th>
<th>Panel without opening</th>
</tr>
</thead>
<tbody>
<tr>
<td>V4</td>
<td>12,15 kN</td>
<td>20,2 kN</td>
</tr>
<tr>
<td>V5</td>
<td>13,20 kN</td>
<td>19,6 kN</td>
</tr>
</tbody>
</table>

Allowable spans \((q = 0,50 \text{ kN/m}^2)\) to test No. V5

<table>
<thead>
<tr>
<th>Panel with opening</th>
<th>Panel without opening</th>
</tr>
</thead>
<tbody>
<tr>
<td>without reinforcing</td>
<td></td>
</tr>
<tr>
<td>With reinforcing (APK-Profiles)</td>
<td>Panel without opening</td>
</tr>
<tr>
<td>all. ( l = 2,57 \text{ m} )</td>
<td>all. ( l = 6,18 \text{ m} )</td>
</tr>
<tr>
<td>all. ( l = 5,13 \text{ m} )</td>
<td>all. ( l = 5,13 \text{ m} )</td>
</tr>
</tbody>
</table>

4. Summary

Due to above-mentioned notes and first orienting preliminary tests it should be demonstrated that a sufficient load-carrying capacity (spans) can be achieved by reasonable reinforcing of sandwich panels with large openings (width of the openings up to the width of the panels). Thereby the application of special thermal separated aluminium profiles with plastic webs as longitudinal beams within the range of the openings was suggested.

The load-carrying capacity of the sandwich panels shall be ensured without participation of adjacent panels and therefore without an associated stress of the longitudinal joints between the panels.

The structural design can be comprehensible by calculation engineer-like due to structural analysis based on characteristic values of the special longitudinal beams, which are stated in technical approvals, so that in principle all possible variants of openings can be planned and prepared for official papers.

For a final practical application further investigations however are necessary, particularly for special product-related details of the reinforcing frameworks.

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