Design of Distance Profiles in Walls

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Abstract

Trapezoidal sheetings are connected via cold-formed Z-profiles to the substructure to provide space for intermediate thermal insulation. The design of these Z-profiles and their connections is for the transfer of the wind suction on the sheeting to the substructure. Finite Element analyses and experimental investigations showed that for the Z-profiles this design is governed by limitation of local deformations and not by their load carrying capacity. For the connections to the wall it has to be taken into account that contact forces which reduce the local stresses and deformations of the Z-profiles increase the axial forces of the fasteners compared to the forces which are calculated by multiplication of the proportionate loaded area with the wind load. A parametric investigation by Finite Element analyses gives the spacing of the fasteners required by the deflection limits and the load carrying capacity of the fasteners depending on the type of Z-profile and its arrangement, the size of the wind load and the dead weight (incl. insulation) of the sheeting.

1. Introduction

Cold formed Z-Profiles are used frequently as substructure of vertically spanned trapezoidal sheetings (Figure 1).
The connection of these distance profiles to the trapezoidal sheeting is in the bottom flange of the trapezoidal sheeting by means of commonly used mechanical fastener e.g. self-drilling screws [1]. The distance profiles are connected equidistantly to the building via anchors.

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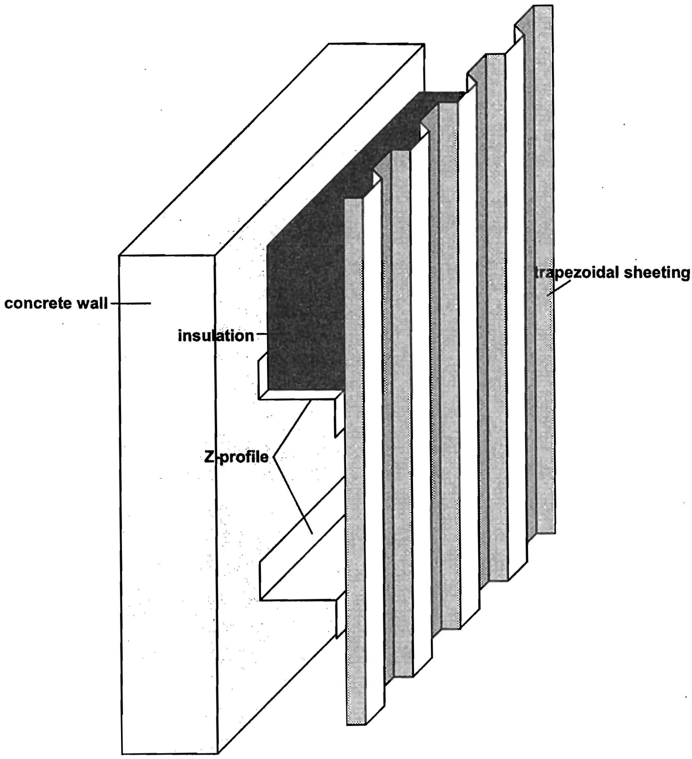

Figure 1: Assembly of wall with Z-profiles

With wind suction the anchors are subjected to tensile forces. The Z-profiles get beside their main structural task additional effects due to transverse bending. Their wall-sided flange is propped against the wall. This support decreases the effects of transverse bending and increases the tensile forces in the anchor. The allowable distances of the anchors are determined by the condition that under design loads the anchor as well as the distance profile should not exceed their load carrying capacities. In addition the deformations under working loads should remain in an acceptable range.

2. Numerical Analyses

The numerical analyses were performed with the Finite Element program ANSYS. The Finite Element model of the distance profile is shown in Figure 2.

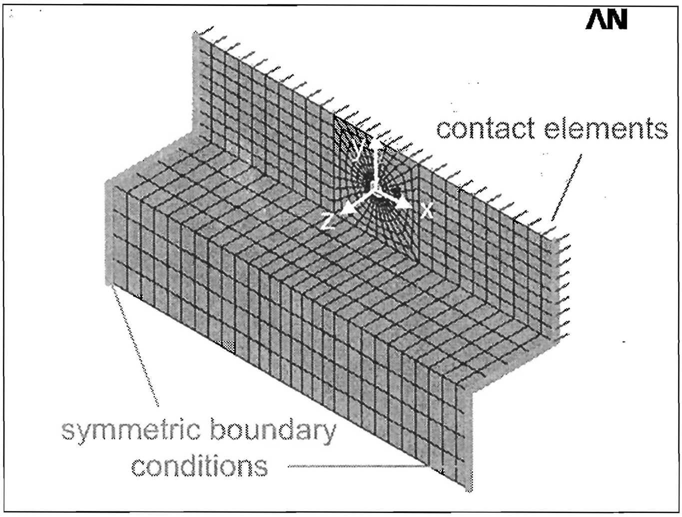

Figure 2: Finite Element model with contact elements

Only a part of the Z-profile including one anchor was simulated applying symmetry conditions. The support of the wall of the building to the flange of the Z-profile is taken into account in the Finite Element model by contact elements. Figure 3 depicts the distance profile in the anchor area.

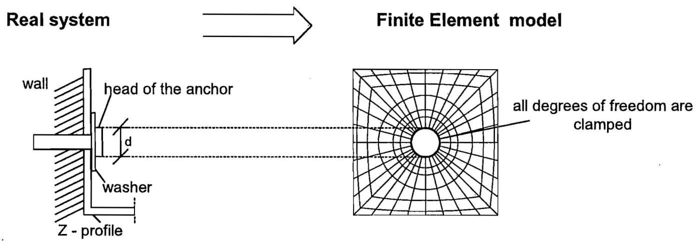

Figure 3: Modelling of the anchor area

The washer as well as parts of the anchor head which cover the distance profile were not considered in the Finite Element model.
Preliminary investigations showed that the continuous behaviour of the trapezoidal sheeting has no effect on the results. Thus, the load introduction into the trapezoidal sheeting was modelled according to Figure 4. The wind load was

applied as uniformly distributed load and the dead weight of the trapezoidal sheeting as line load.

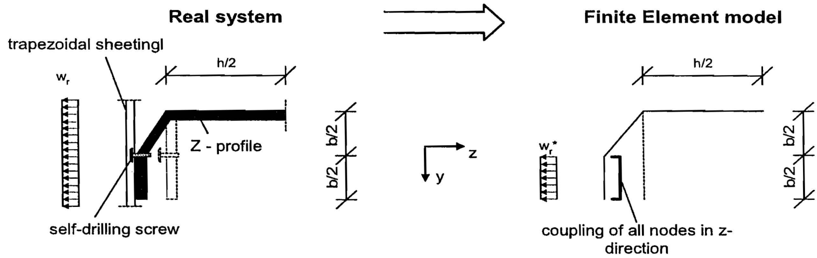

Figure 4: Modelling of the flange (trapezoidal sheeting-sided) of the Z-profile (arrangement 1)

The distance profile was modelled by using the element type SHELL 181, whereas the element type CONTAC 52 was used to consider contact between Z-profile and wall. A bilinear stress strain relation with a yield strength of 240 N/mm² and a tensile strength of 270 N/mm² was used as material law for the elements of the distance profile. Young's modulus was set to 210000 N/mm². Calculations with a yield strength of 320 N/mm² and a tensile strength of 390 N/mm² provided corresponding results.

3. Parameters of the investigation

The calculations with the above described model were performed varying the following parameters:

a. Arrangement of the Z-profiles. Figure 5 shows the investigated arrangements.

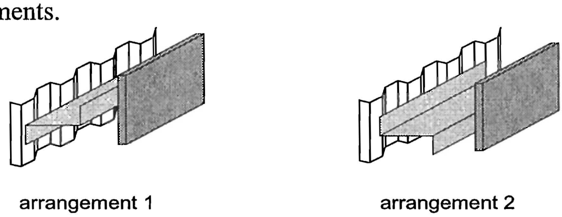

Figure 5: Alternative arrangements of Z - profiles

b. Dimensions of the Z-profiles. The dimensions as well as the designation of the investigated distance profiles are specified in Table 1. The two flanges of the profiles had the same dimensions.

Table 1: Dimensions of Z-profiles in mm

Designation	Length of flange [mm]	Length of web [mm]	Thickness of profile [mm]
40_60_1,5	40	60	1.5
40_120_1,5	40	120	1.5
60_60_1,5	60	60	1.5
60_120_1,5	60	120	1.5

c. Wind suction loads. According to DIN 1055-4 [2] the values of Table 2 have to be considered.

Table 2: Wind suction loads w_r in kN/m² [2]

Height over ground		< 8 m	< 20 m	< 100 m
h/a = 0.25*	$c_p = 0.5$**	0.25	0.40	0.55
h/a = 0.50*	$c_p = 0.7$**	0.35	0.56	0.77
Fringe area of building		1.00	1.60	2.20

* ratio height (h) of building / length (a) of building

** aerodynamic coefficient

d. Dead weight g_r of the trapezoidal sheeting (incl. insulation). The study covered light flat profiles 35/207 with $t = 0.75$ mm and $g_r = 0.073$ kN/m² as well as heavy high profiles 165/250 with $t = 1.25$ mm and $g_r = 0.201$ kN/m².

e. Distance between the anchors. The distance was varied from 250 mm to 2500 mm.

The arrangement of the fasteners between Z-profile and building and between Z-profile and trapezoidal sheeting was considered according to Figure 4 in the middle of the flanges.

4. Limit state of deformation and ultimate limit state of the anchors

Wall claddings have to fulfill static as well as aesthetic requirements. Thus, the displacements especially in the anchor area must be limited under working loads to satisfy the aesthetic requirements. Experimental investigations [3] showed

that horizontal displacements up to 4 mm in the anchor area decline completely after withdrawing the load. Furthermore tests with repeated loading [4] showed that an elastic shake-down occurs for the horizontal displacements. The local deformations do not exceed a maximum value. Significant plastic deformations could not be detected during these tests. Nevertheless, it should be mentioned that negligible local plastifications occur in the anchor area. As a result of the experimental investigations and with respect to aesthetic aspects a horizontal displacement of 4 mm under working load was considered as a limit state.
The ultimate limit state of the anchors is given by the design resistance of the anchors.

5. Results of the parametric study

5.1 Load factor for the anchor forces

The load factor is defined as

$$L_h = F_{z,anchor} / (w_d * R_A * D_A)$$

with $F_{z,anchor}$ = tensile force in the anchor
w_d = design value of the wind load
R_A = distance of the Z-profiles
D_A = distance of the anchors

Effects of the dead weight of the trapezoidal sheetings were considered in the determination of the load factor. According to Figure 6 the dead weight of the trapezoidal sheeting can reduce (arrangement 1) or increase (arrangement 2) the anchor forces. These effects are more significant for smaller wind loads.

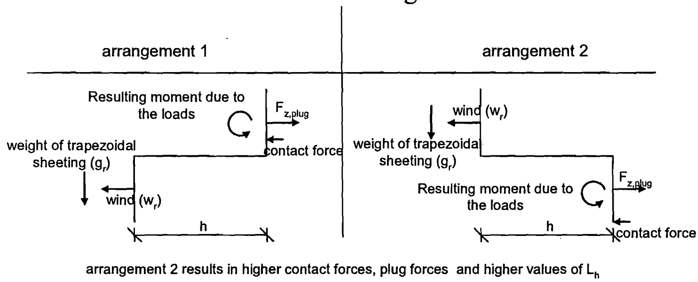

Figure 6: Influence of the Z –profile arrangement on the load factor L_h

For arrangement 2 an increase of the dead weight of the trapezoidal sheeting always increases the load factor. For arrangement 1 the effect of the trapezoidal sheeting on the load factor depends on the value of the dead weight of the trapezoidal sheeting. Low values result in a reduction of the load factor. The load factor reaches its minimum ($L_h = 1$), if the effect of the dead weight offsets the moment from the wind load. After passing this minimum an increase of the dead weight loads increases the load factor. This is due to the effect, that the contact area between the profile and the wall is shifting from the profile edge to the profile corner. Normally, for arrangement 1 the maximum load factors occur for the smallest dead weight of the trapezoidal sheeting.

5.2 Displacements

The horizontal displacements of the profile result from two effects. The first effect is the global deformation of the Z-profile. The second effect the local deformations in the anchor area. In the parametic study the horizontal displacement due to this second effect was limited to 4 mm in accordance with the above defined criterion (see section 4). The Finite Element analyses showed that the horizontal displacement increases almost linearly with the wind load as well as with the distance of the anchors (see Figure 7).

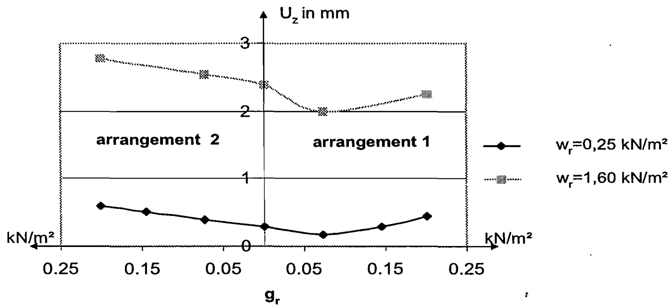

Figure 7: Displacements U_z of Z–profiles 60_120_1,5 with 2 m distance and 250 mm distance between the anchors

5.3 Stresses

The yield stress is attained in the anchor area of the profile even with small loads. Under these small loads horizontal displacements of $U_z \leq 2$ mm lead to plastification at the corner of the profile. However, this area does not significantly increase with an increase of the load. The limit state of deformation (U_z = 4 mm) is attained without appearance of a kinematic yield line pattern.

6. Design diagrams

Design diagrams were developed with the results of the parametric study (see Figure 8 to Figure 11). The following parameters are included in these diagrams:

- Z-profile type
- Arrangement of the profiles
- Magnitude of the wind load
- Magnitude of the dead weight of the trapezoidal sheeting (incl. insulation)

With the diagrams it is possible to determine two distances for the wall anchors. The first distance D_{A1} is based on the limit state of deformation ($U_z = 4$ mm). D_{A1} is read directly from the curves of the diagrams. The second distance D_{A2} is determined by the maximum allowable anchor force. For this purpose the load factor L_h from the diagrams is used in the equation:

$$D_{A2} = F_{ac,anchor} / (L_h * w_d * R_A)$$

in which:

$F_{ac,anchor}$ = maximum allowable anchor force [1]
L_h = load factor
w_d = design value of the wind load
R_A = distance of the Z-profiles

The load factors are given in the diagrams for the characteristic values of the wind loads w_r. However, they were determined with the design values w_d. Therefore, they have to be applied to these values. The design value w_d results from a multiplication of the characteristic wind load w_r with the load safety factor $\gamma_F = 1{,}5$. The curves of the diagrams as well as the load factors were determined with a distance of the Z-profiles of 2 m. If the distances $R_{A,exist}$ of the Z-profiles are different from $R_A = 2$ m, the existing wind load has to be multiplied with the factor $R_{A,exist}/2$. Furthermore, the load factor has to be determined for this modified wind load.

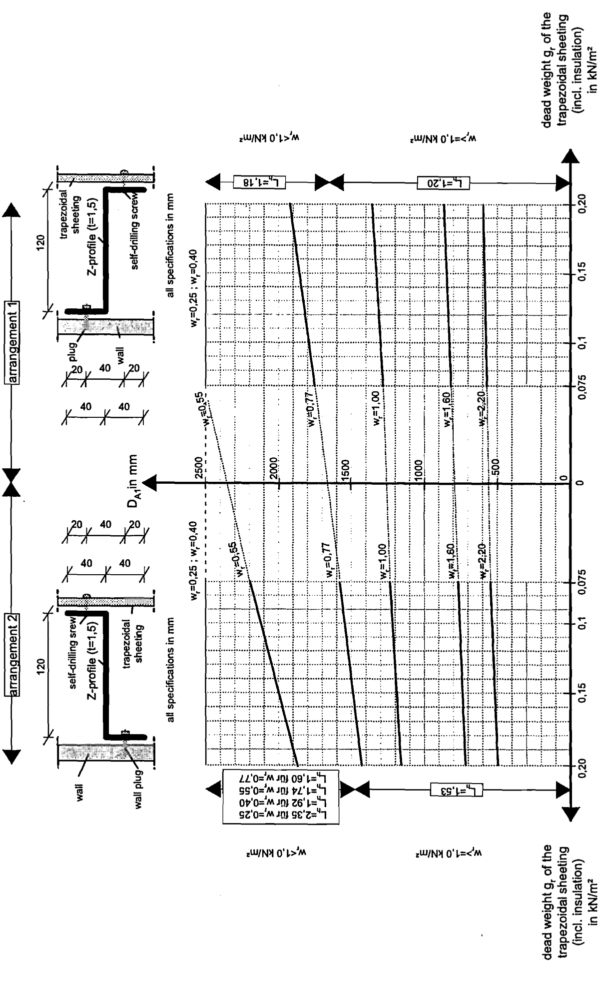

Figure 8: Diagram for determining the distances D_{A1} and D_{A2} for anchors with Z –profile 40_120_1,5

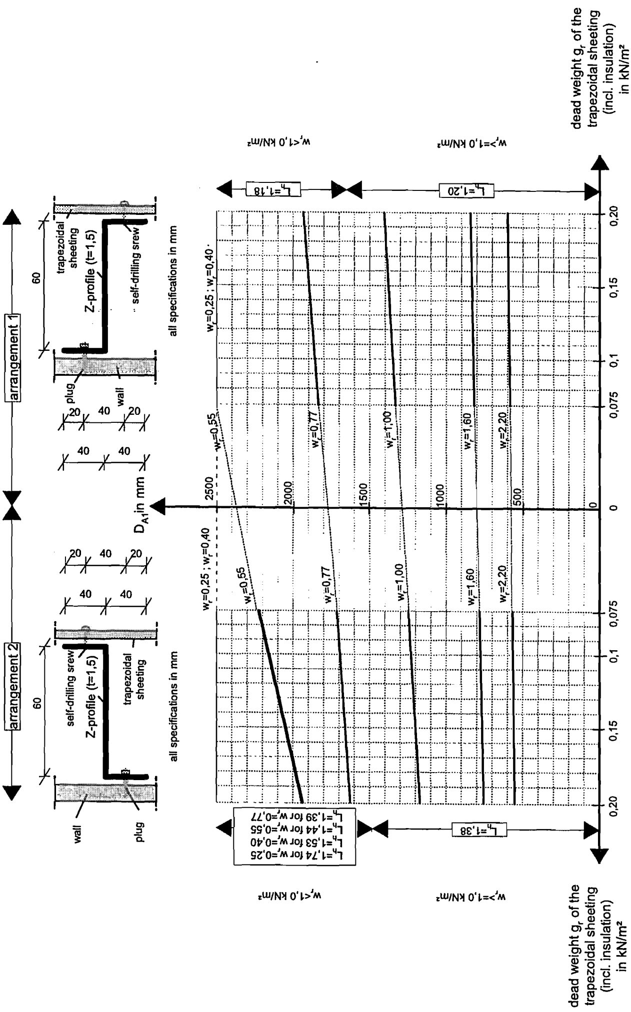

Figure 9: Diagram for determining the distances D_{A1} and D_{A2} for anchors with Z –profile 40_60_1,5

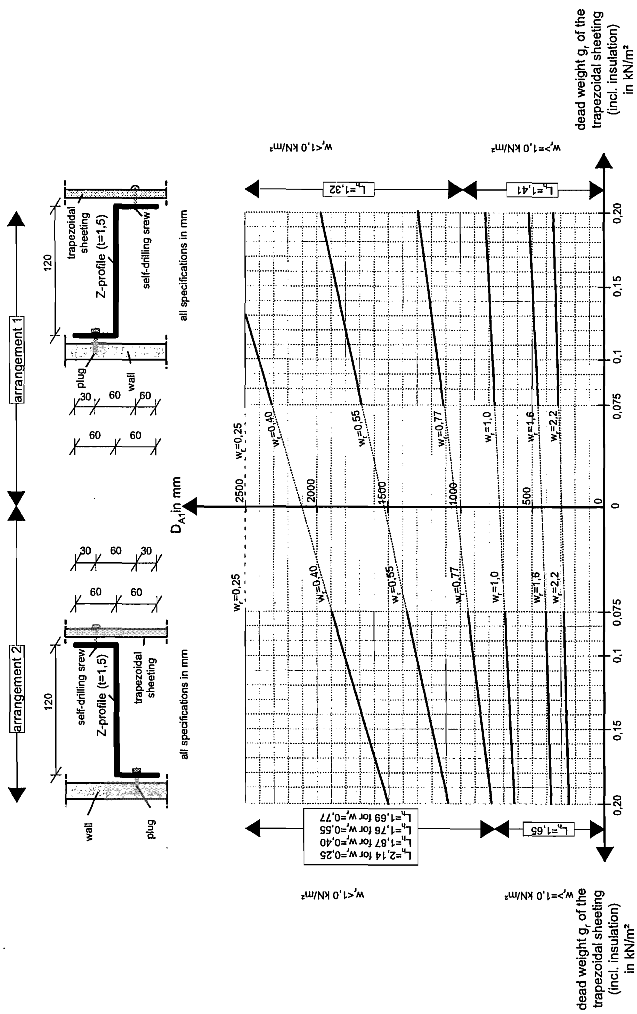

Figure 10: Diagram for determining the distances D_{A1} and D_{A2} for anchors with Z –profile 60_120_1,5

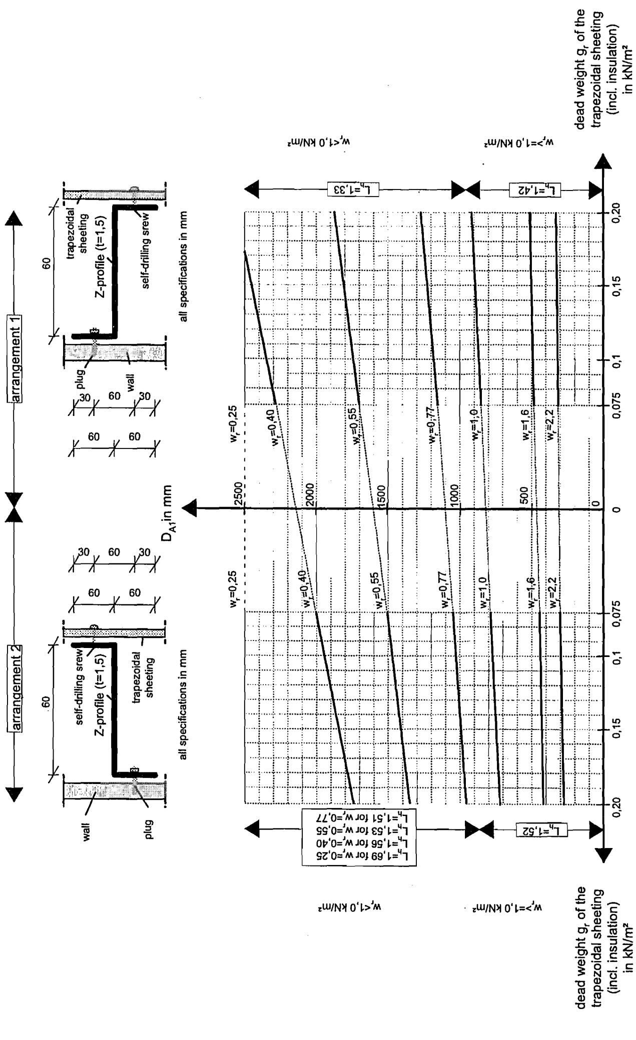

Figure 11: Diagram for determining the distances D_{A1} and D_{A2} for anchors with Z –profile 60_60_1,5

7. Conclusions

A parametric study was performed with a Finite Element model. With the results of this parametric study design diagrams were developed. These diagrams offer a simple and economic design of distance profiles and their connections in wall claddings. The design is governed by the local deformation of the profile and the allowable anchor force. The former criterion is reflected by D_{A1} and the latter by L_h and D_{A2} in Figures 8 to 11. This analytical investigation is based on and verified with results from experimental investigations.

8. References

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[3] Experimentelle und numerische Untersuchungen an Z-Profilen. Bericht Nr. 993708, Versuchsanstalt für Stahl, Holz und Steine, Universität Karlsruhe (TH), 2000.

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