Hanger bolts and solar fasteners in sandwich panels

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Abstract

For the energetic use of sunlit roofs, photovoltaic and solar thermal elements are mounted using different fastening systems on existing roof surfaces. For the installation on trapezoidal profiles or sandwich panels, hanger bolts and solar fasteners belong to the most prevalent fastening systems. For the structural analysis of these systems, however, only insufficient design approaches are available until up to date. Especially for the application on roofs covered with sandwich panels no design criteria is available at the present. The introduction of roof parallel loads from roof shear, wind and snow into the substructure can be specified as pressing problem. Within the scope of a research project sponsored by the DIBt (German Institute for Building Technology) design criteria for hanger bolts and solar fasteners in sandwich panels with a plastic foam core were developed. When roof parallel forces are applied to the fastener the fastener is supported by the sandwich panels' surface sheet. For that reason the load bearing capacity of thin steel sheets with a thickness from 0.38 mm to 0.56 mm for different diameters of hanger bolts or solar fasteners is determined. Beside the local hole load bearing capacity of the sandwich panel the load bearing capacity of the whole upper flange is from major interest. Performed tests show that an overloading of the upper flange results in cracks in the core material combined with a separation of the core material and the surface sheet. Because of the various designs and materials of sandwich panels the definition of a universal load bearing capacity is not possible. But when respecting some boundary condition relating to the material properties and the shape of the sandwich panel a conservative value of 0.70 kN can be used. Beside the already developed design approaches there are still open questions for further investigations. Among others this includes the mentioned load bearing capacity of the upper flange and the load bearing capacity for cyclic stresses.

Keywords: sandwich panel, hanger bolt, solar fastener

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1. Introduction

Worldwide national governments, companies but also private households get involved in pushing forward the global need for sustainable and regenerative energy production. Therefore hydro-electric power plants, onshore and offshore wind power parks and solar collectors are installed everywhere the boundary conditions are matching. Because of the rapid progress of the development of new systems, sometimes the performance of single components is only analysed insufficiently. Especially the fastening of photovoltaic systems on industrial buildings is rarely investigated up to date. These industrial buildings, often covered with trapezoidal profiles or sandwich panels, provide huge sunlit areas. For the mounting of photovoltaic components hanger bolts and solar fasteners belong to the most prevalent fastening systems. But neither for the use in trapezoidal profiles nor for the use in sandwich panels sufficient design rules are available. Although for trapezoidal profiles some approaches are developed, for sandwich panels no design criteria is available up to now. Especially the introduction of transverse forces into the substructure resulting from roof shear forces, wind and snow can be regarded as a pressing problem. For this purpose the paper at hand deals with newly developed design approaches for determining the load bearing capacity of hanger bolts and solar fasteners in sandwich panels.

Hanger bolts are dowel type fasteners with a metric thread at one end and a threat for metal screws or wood screws at the other end. Usually they are made of stainless steel with a total length from 100 mm up to 400 mm. The diameter varies between 8.0 mm and 12.0 mm. A common hanger bolt with a plain centre is shown in figure 1.

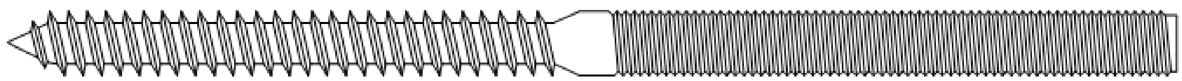

Figure 1: Hanger bolt

Solar fasteners are a further development of hanger bolts especially designed for the application on trapezoidal profiles or sandwich panels. They differ only in an additional hexagon located in between of both threats. This hexagon is, in contrast to a nut, immovable and improves the assembly of the fastener. A common solar fastener is shown in figure 2.

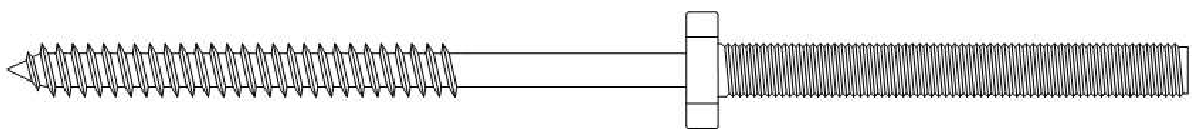

Figure 2: Solar fastener

For installing the fastener on trapezoidal profiles or sandwich panels the surface sheet and the substructure are predrilled first. Subsequently the fastener combined with a sealing is screwed into the substructure. For fixing any kind of installation normally an additional predrilled metal sheet is mounted in the area of the metric thread. A typical situation of installation of a solar fastener in a sandwich panel is shown in figure 3.

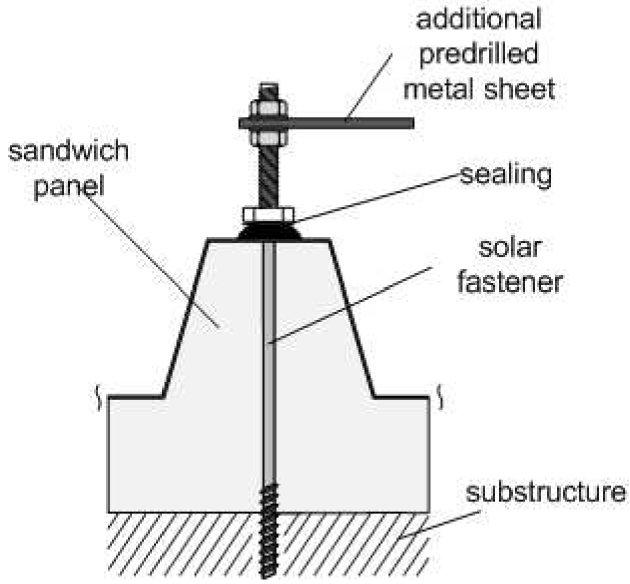

Figure 3: Typical installation situation of a solar fastener in sandwich panels

Beside the load bearing capacity of the fastener itself, the resistance of the sandwich panel is of major interest, because roof parallel forces may cause a crack in the core material or a separation of the surface sheet and core material. That is why the verification procedure for hanger bolts and solar fastener in sandwich panels has to be separated into two sub steps:

- The verification of sufficient load bearing capacity of the fastener. This includes the local hole bearing capacity of the surface sheet of the sandwich panel.
- The verification of sufficient transverse load bearing capacity of the sandwich panel

2. Local load bearing capacity of the fastener

2.1 Mechanical model

For determining the load bearing capacity of hanger bolts and solar fasteners in sandwich panels first a practical simplified mechanical model is required. This model has to include the partially clamping of the fastener inside the substructure and the resilience resistance of the local hole in the sandwich elements' surface sheet. These boundary conditions and the external loads F_E and V_E lead to the mechanical model a shown in figure 4. The external load F_E, representing the dead load of the solar installation and snow load, is normally applied eccentrically. This is taken into account by an additional bending moment M_E. For calculating the resulting support reactions F_b, $F_{a,h}$ and M_a the mechanical properties of the fastener and the spring stiffness C_a and F_b are required. In many situations, especially when using slender shaped fasteners, the influence of the spring C_a is neglect able. This leads to the simplified model b also shown in figure 4. The only unknown component for determining the load bearing capacity, assuming the material properties and the shape of the fastener are known, is the local resistance of the outer surface sheet of the sandwich panel $F_{b,R}$.

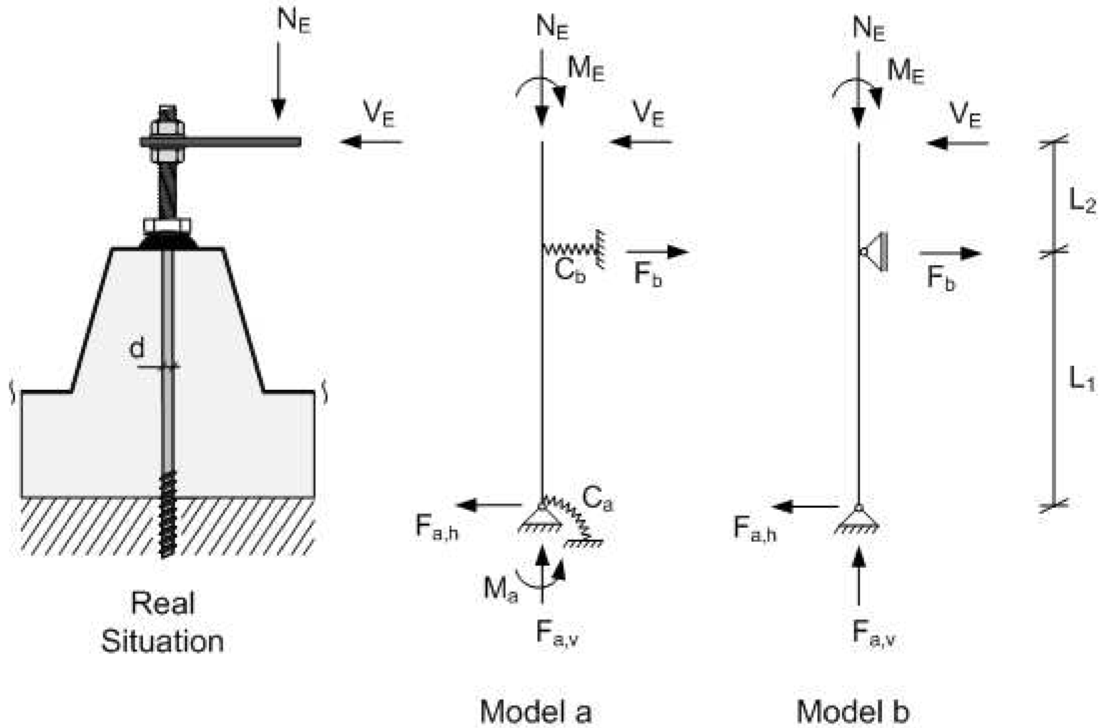

Figure 4: Mechanical model

2.2 Local hole resistance of the sandwich panels' surface sheet

When using model b according to figure 4, the major value for determining the load bearing capacity of the fastener is the local hole resistance $F_{R,b}$ of the sandwich panels' surface sheet. Because this value cannot be calculated, it is determined on the basis of tests performed. The chosen test set up is shown in figure 5. Metal sheets with a size of 120 mm x 120 mm x t were clamped into a circular shaped metal frame with an inner radius of 40 mm. The solar fasteners were screwed into a predrilled hole in the middle of the sheets. The diameter of the hole was similar to the diameter d of the solar fastener (see Fig. 4). The thicknesses of the sheets amounted to 0.38 mm, 0.49 mm or 0.60 mm. The diameter of the solar fastener was determined to 7.0 mm or 9.0 mm. The chosen sizes represent the most common designs for sandwich panels and solar fasteners. During the test, the solar fastener was continuously pushed through the hole until the metal sheet was destroyed. A representative force – deformation – diagram is added to figure 5. During the test, the linear elastic load bearing capacity is normally achieved at a deformation of $w \leq 1.0$ mm. The maximum value of the local hole resistance is normally achieved at $2.5 \text{ mm} \leq w \leq 4.0$ mm. Seven test series with a total of 85 single tests were performed. All holes were predrilled in realistic, not laboratory, conditions. That means they were predrilled using a regular hand drilling machine. This is important, because the local hole resistance is strongly depended on the quality of the predrilled holes.

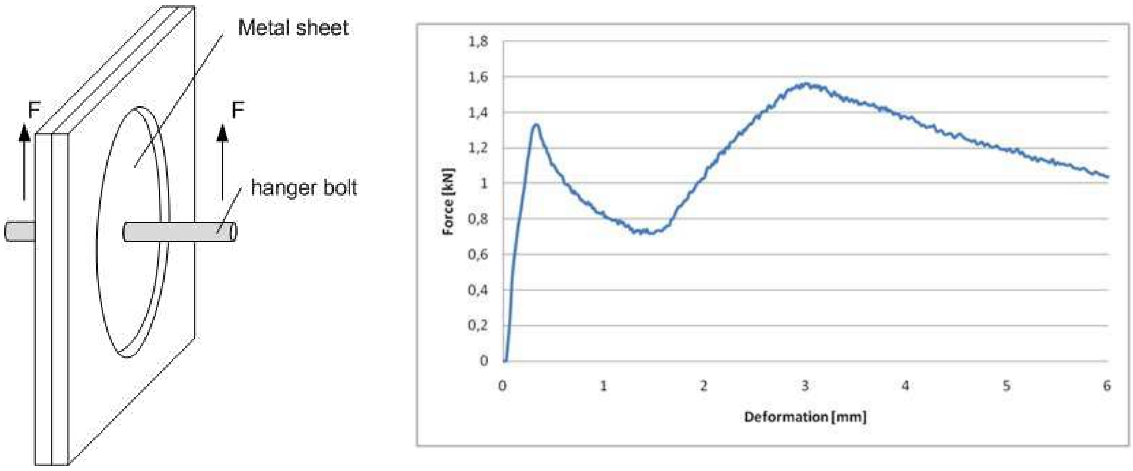

Figure 5: Test set up and characteristic force – deformation diagram

The measured mean values of the local hole resistance (maximum values) F_{mean}, the measured mean values of the deformation at maximum force W_{Fmean} , the mean values of the sheet thickness t, the mean values of the tensile strength of the surface sheets σ_s and the determined variance of the maximum forces for each test series V_x are shown in table 1.

Table 1: Test results

Series	1	2	3	4	5	6	7
Diameter of the fastener [mm]	7.0	7.0	7.0	9.0	9.0	9.0	11.0
Thickness of the sheet [mm]	0.38	0.49	0.56	0.38	0.49	0.56	0.38
F_{mean} [kN]	1,18	1,80	2,28	1,27	1,78	2,51	1,47
V_x [-]	0,051	0,050	0,044	0,070	0,078	0,063	0,110
W_{Fmean} [mm]	3,28	3,79	4,15	3,86	4,10	5,07	4,40
σ_S [MPa]	390	405	375	390	405	375	390

A statistical analysis of each test series leads to characteristic $F_{R,b,k}$ values for the local hole resistance. To ensure the comparability of the measured test results the values are normalised to a tensile strength of the surface sheet of 360 MPa. The 5% percentile value with a confidence level of 75% using Gauss distribution is calculated to

$$F_{R,b,k} = (F_{mean} - F_{mean} * V_x * 1,64) * 360 \text{ MPa} / \sigma_s$$

The characteristic values $F_{R,b,k}$ are shown in table 2. These values do not include any kind of safety factor, neither for the resistance nor for the applied forces. A minimum tensile strength of the surface sheet of 360 MPa is required.

Table 2: Characteristic values

Diameter of the fastener [mm]	7.0	7.0	7.0	9.0	9.0	9.0	11.0
Thickness of the sheet [mm]	0.38	0.49	0.56	0.38	0.49	0.56	0.38
$F_{R,b,k}$ [kN]	1,09	1,67	2,12	1,14	1,57	2,26	1,23

2.3 Tension resistance of the fastener

The tension resistance $F_{R,a,v}$ is depended on the substructure the fastener is screwed into. For wooden substructures the load bearing capacity can be calculated, for example according to DIN EN 1995-1-1. There are some restrictions regarding the thread, but usually they do not affect hanger bolts and solar fasteners. For steel structures a development method is described in "Statistische Auszugtragfähigkeit gewindeformender Schrauben in Metallonstruktionen" by Roderich Hettmann (2006).

2.4 Stability of the fastener

The pressure resistance of the connection to the substructure is identical to its tension resistance. Additionally the stability of the fastener has to be taken into account. For that reason a calculation using second order theory is required. The factor α can be determined by

$$\alpha = 1 / (1 - N_E/N_{ki})$$

with

$N_{ki} = (\pi\text{^}3 * E * d\text{^}4) / (64 * (\beta_1 * L_1)\text{^}2)$

N_E value of the applied pressure load
d Minimum diameter of the fastener
E elastic modulus of the fastener (normally 170000 MPa for non corrosive steal)
β_1 buckling coefficient
= 0.7 + 1.85 * L_2 / L_1 for wooden substructures or thick steel structures
= 1.0 + 1.87 * L_2 / L_1 for thin steel structures

The factor α considers the shape of the fastener and the clamping of the connection to the substructure. But in addition the misalignment of the fastener has to be taken into account by applying and additional bending moment $M_{E,add}$

$$M_{E,add} = N_E * L_1 * \arctan (W_{F,mean} / L_1)$$

2.5 Temperature indicated imposed deformation

The thermal movement, especially when using deflection resistant fasteners, is partly blocked by the fasteners. This results in local hole forces that are significantly higher than the determined hole resistances $F_{R,b,k}$. For that reason it has to be ensured, that the thermal movements do not exceed the maximal values $W_{F,k}$.

3. Load bearing capacity of sandwich panels

Beside the local hole bearing capacity of the surface sheet, also the load bearing capacity of the panels' upper flange is of major interest. Roof parallel forces being applied in direction of the span of the panel are not critical and therefore not further investigated. Roof parallel forces that are applied transverse to the panels' direction of span lead to stresses the panel is not constructed for. As illustrated in figure 6 they may cause cracks in the core material or a separation of the surface sheet from the core material.

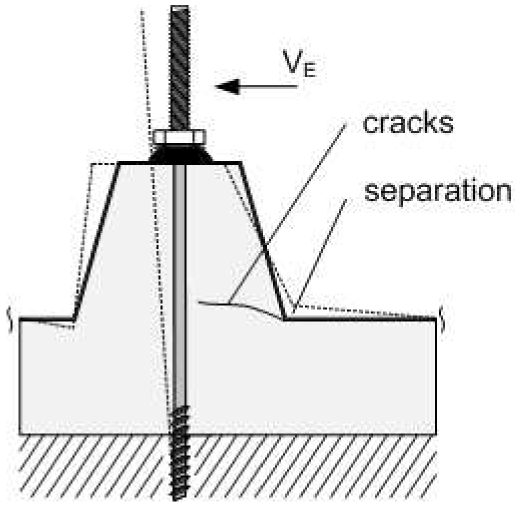

Figure 6: Damage to the sandwich panel caused by roof parallel forces

To analyse the behaviour of the sandwich panel large component tests with 1 m x 2 m sized sandwich panels as well as tests with cut outs were performed. For the tests sandwich panels with plastic foam core and layer sheets made of steel were used. The tests revealed, that the mentioned failure modes are not just theoretically and have to be investigated in detail. The major problems for determining a universal load bearing capacity are the anisotropic material properties and different production methods for sandwich panels. Nevertheless a statement on the basis of the performed tests for a specified group of panels is possible. When the tensile strength of the connection between core material and surface sheet is at least 0.06 N/mm^2, the shear strength of the core material is at least 0.10 N/mm^2 and a minimum thickness of the surface sheet of 0.45 mm a value of 0.70 kN for the load bearing capacity $V_{R,panel}$ can be used. This value requires that the hanger bolts or solar fasteners are not mounted at the edge areas of the panel. The maximum height of the upper flange is limited to a value of 45 mm with a minimum width of the upper flange of 23 mm.

4. Conclusion and Outlook

The presented approaches and values can be used for determining the load bearing capacity of hanger bolts and solar fasteners in sandwich panels. The local hole resistance is given for the most common thicknesses of surface sheets and diameters of hanger bolts or solar fasteners. For the load bearing capacity of the sandwich panel a value of 0.70 kN is presented. As this is just a conservatively determined value that matches many panels this value can probably increased with the help of further investigations. Also surface sheets with a thickness of more than 0.60 mm have to be part of further studies to exploit the full capacity of modern industrial fabricated sandwich panels. One futher aspect, that is still not known in detail, is the long term performance of the local hole resistance. Because of thermal movements the holes are stressed continuously and small, slowly growing cracks, may occur a reduction in load bearing capacity.

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