Ensuring Advancement in Sandwich Construction through Innovation and Exploitation (EASIE)

Work package 4 (WP4)
Cladding of sandwich panels

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1. Introduction

1.1 Subject and purpose of the guidelines

Facades and roofs like many other components of the buildings need retrofitting time to time. Facades made of light-weight components and of sandwich panels are not exceptions. Repairing actions may mean cleaning or painting of the surfaces, fixing of the joints and sealants or repairing of the structural parts of the façade and roof. The goal of the repairing actions is to improve the technical and visual properties, the functional behaviour and safety and to extend the service life of the structure.

Reasons to the repairing actions are normally the ageing of the materials or the faults and damages caused by the environmental effects or by human activities. Reasons to repairing may also be the need to improve the thermal insulation properties, the air and water tightness or the mechanical resistance or further, the need to update the architectural appearance of the façade to correspond the style of the new time and place.

Retrofitting is a subject in EASIE project. The project opens questions, which arise in the design and execution phases of the renewal of a façade and roof made of light-weight metal-sheet faced sandwich panels. The project looks for the practical means and methods to repair local damages of the faces and core caused by the internal effects like blistering and imperfections and by different sort of external effects. The project studies also typical systems to cover the panel in full with a new light-weight structures made typically of metal sheets, cassettes and purlins. Other possible solutions to cover a façade made of sandwich panels are the different boards, panes, composite laminates and even brick walls. The application of the additional cladding does not need to be limited to old walls and roofs but can be applied to new facades and roofs as well. Cladding means normally the covering of the external face of the sandwich panels. However, if needed, the same principles can be used to improve and update the properties of the internal faces.

The list of questions concerning the design and use of the new composite facade and roof panel may include following items;

- distributions of the external mechanical load such as a wind pressure and suction load between the additional cladding and the face of the ordinary panel
- distribution and effects of the temperature on the components of the cladding systems and on those of the ordinary sandwich panel
- local stresses and effects caused by the self-weight of the additional cladding
- static interaction between the ordinary sandwich panel and the additional cladding components
- effects of the local imperfections and damages
- long-term effects caused by ageing and repeated loads
- influence of the cladding on the thermal insulation power and other physical properties of the system

Repairing of sandwich walls and roofs is made today using case by case tailored systems. The systems of retrofitting depend very much on the local needs and the local practice and the way of the building. Because of the increasing interest to improve the functional properties and to extend
the service life of facades and roofs, more industrial methods and systems are needed, however, keeping in the mind the requirements to the technical and visual flexibility of the system. New guidelines shall allow a continuous development of the cladding systems.

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Figure 1. Cladding systems based on thin-walled components

1.2 Subject area and limitations

The report introduces two cladding systems in more details. The precondition for the additional cladding of the old walls and roofs is a functioning force-fit bonding between core and face and a solid core layer. The bond or the core shall not have been destroyed through mechanical loads, ageing or detach. The application area of the cladding systems introduced in the document are the wall panels loaded by short-term loads, only.

1.3 Definitions

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<th>Term</th>
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<tr>
<td>Cladding</td>
<td>Additional covering structure or surface fixed in the external or internal face of the ordinary sandwich panel</td>
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<td>Monopanel</td>
<td>Two-layer plate made of an external face and of a core</td>
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<tr>
<td>Rail</td>
<td>Thin-walled hat- or z-profile fixed in longitudinal or in transverse direction to a face or the ordinary sandwich panel</td>
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2. Cladding systems

2.1 General

The document introduces cladding systems based on thin-walled metal sheet components and mechanical fastenings, only. The components may be made of steel or of stainless steel sheets, which have been cold-formed in shapes of purlins and corrugated sheetings. Also covering elements made of composite structures such as thin sandwich panels are possible components of the cladding systems. Design and testing of these components can be based on the European standards [1, 2, 3].

Self-drilling and self-tapping screws and rivets are well-known fasteners with a large variation of materials, diameters and shapes. The screws and rivets of the thin-walled components are not standardized products like the screws of ordinary steel structures. However, there are guidelines available for the testing and design of the mechanical fastening of the thin-walled structures [8].

Adhesive fastening of the components provides a fluent flow of stresses between the parts without local stress concentrations. When using adhesive jointing, there will not be any holes penetrating the external face of the sandwich panel nor visible fastenings in the cladding.

The challenges of the adhesive jointing in practice are the strict requirements for the cleaning and primary coating of the surfaces the methods and materials being dependent of the earlier coatings. The adhesive joints need possibly a prestressing during the hardening of the adhesives. The work on the site may lay further limitations to the adhesive jointing concerning the humidity and temperature.

2.2 Thin-walled purlins and sheetings

The cladding systems considered in this context consist usually of rails which are mounted on the external face of the sandwich panels. The cladding itself are in turn fixed on the rails. The rails are normally made of Z-profiles or of hat-profiles. The cladding profiles are typically sidings, cassettes or corrugated or trapezoidal sheeting. Due to the own stiffness and strength of the additional components, due to the static interactions and due to the local effects, the additional cladding normally increases the stiffness of the ordinary sandwich panel but may improve or reduce the load-bearing capacity of the system compared to that of the ordinary sandwich panel.

Two basic system layouts can be distinguished. The rails may be mounted in the transverse direction or parallel to the span of the ordinary sandwich panels. The cladding profile itself spans normally in the transverse direction to the rails. Examples of these are:

- vertical sandwich panels with vertical rails and sidings (Fig. 2),
- vertical sandwich panels with vertical rails and horizontally installed corrugated sheeting (Fig. 3) and
- vertical sandwich panels with horizontal rails and vertical trapezoidal sheeting (Fig. 4).

The same solutions are applied to sandwich panels, which are mounted in horizontal direction.
Figure 2. Cladding of vertical panels consists of vertical rails and horizontal cassette profiles.

Figure 3. Cladding of vertical panels consists of vertical rails and horizontal sinusoidal sheets.

Figure 4. Cladding of vertical panels consists of horizontal rails and vertical trapezoidal sheets.
Fastening of the cladding system to the sandwich panels is typically made using mechanical fasteners, such as the self-drilling and self-tapping screws and rivets. The cladding profiles can be fixed to the rails also using mechanical fasteners. The siding panes may be suspended to the rails without any mechanical fastenings.

In EASIE project, a test series was performed to study the behaviour and resistance of some basic cladding systems made of thin-walled hat- and Z-sections and of sinusoidal cladding sheets fixed together with screw fastenings. The essential experimental observations and results are summarized in Table 1.

Table 1. Essential results of the experimental study of traditional cladding systems.

- Cladding increases the stiffness of the ordinary sandwich panels independently on the cladding system itself.
- Cladding sheets fixed directly in the face in the direction of the span of the ordinary sandwich panel increase the resistance of the panel noticeably if the wrinkling failure mode dominates the resistance of the system.
- Rail profiles installed in the longitudinal direction to the span of the sandwich panel increase also the resistance noticeably if the wrinkling failure mode dominates.
- Rail profiles installed in the transverse direction reduce the resistance because of the local line loads exposed to the compressed face of the sandwich panel. This is especially true if the profiles are Z-shaped profiles in which case the pressure load is transferred through a web only.
- Shear load is carried by the core of the ordinary sandwich panel. Usual cladding systems do not provide additional shear resistance.

2.3 Additional panels and monopanels

Cladding of sandwich panels may consists also of additional sandwich panels or of monopanels fixed to a face of the ordinary sandwich panel (Fig. 5). The monopanels are two-layer composite plates consisting of a core layer and of an external face. The additional panels may have similar faces and core but may also consist of different material compositions with different depths of the layers. The additional sandwich panels are mounted to the direction of the span of the ordinary sandwich panels but may also be placed in the transverse direction to the ordinary panels.

Composite actions between the additional sandwich panels and the ordinary sandwich panels depend on the type and number of fastening between the panels. The composite action between the monopanel and the ordinary panel plays normally a minor role because of a low shear stiffness between the external face of the monopanel and that of the ordinary sandwich panel.

In EASIE project, a test series was performed to study the behaviour and resistance of cladding systems based on additional elements and mechanical rivet and screw fastenings. The essential experimental observations and results are summarized in Table 2.
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Table 2. Results of the full-scale tests of cladding systems based on additional elements.

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<td>- Additional thin sandwich panels increase the resistance of the ordinary sandwich panels. The increase of the number of the fastenings increases the resistance, also.</td>
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<td>- The mono panels do practically not increase the resistance of the ordinary sandwich panels, if the mono panels are fixed to the ordinary sandwich panels with screws and rivets fastened through the mono panels to the external face of the ordinary panels. This is because of the low shear stiffness of the mechanical connections. However, the monopanels are light additional components to improve the thermal insulation and the outside appearance of the facade.</td>
</tr>
<tr>
<td>- The reduced resistance due to the defects in the compressed face layer, can not be improved by cladding the ordinary sandwich panels with mono panels.</td>
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<tr>
<td>- Wrinkling failure modes are brittle-type failure modes without remaining resistance. The cladding does not change the character of the wrinkling failure of the ordinary sandwich panel.</td>
</tr>
<tr>
<td>- Discontinuities in the core such as the joints in the core have influence in the location of the failure mode and in the ultimate load.</td>
</tr>
<tr>
<td>- Specimens made of glass-fibre laminate faced sandwich panels failed through a wrinkling failure mode, also. Wrinkling stress of the glass-fibre laminate faced panels was clearly less than the wrinkling stress of the steel sheet faces panels.</td>
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<td>- Cladding caused a light non-linearity in the beginning of the load-deflection curve, which might be caused by the friction between the internal face of the cladding elements and the external face of the ordinary sandwich panels.</td>
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<td>- Repeated loading history consisting of 5000 cycles with an intensity of 0.42-times the mean ultimate resistance of the ordinary panels did not have noticeable effect in the resistance of the specimens.</td>
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3. Design of cladding systems

3.1 Loads of the sandwich panels and cladding systems

In typical cases, the ordinary sandwich panels are fixed with direct or invisible screw fastenings to the purlins being the secondary structures or to the load-bearing frame of the building. The ordinary sandwich-panels are usually self-supporting structures used to resist the wind pressure and snow load and to isolate spaces having different temperatures and climates such as the difference between the internal and external atmosphere.

Self-weight of the cladding causes additional stresses and imperfections in the face of the vertically assembled wall panels because of the eccentricity of the mass center of the cladding.

Wind pressure and suction loads cause air pressure differences between the external and internal surface of the cladding and between the external and internal surfaces of the sandwich panel. The distribution of the air pressure to the cladding sheet and on the other hand, to the sandwich panel depends on the air tightness of the cladding sheet. If the cladding sheet is perforated or if the space between the cladding and the panel is well ventilated, the air pressure loads in majority the sandwich panel. If the space between the cladding and the panel is completely closed, the air pressure loads the cladding sheet. The usual cases are between these two extreme solutions. It means, that a part of the pressure loads the cladding sheet and a part directly the sandwich panel. The load against to the cladding sheet is further transferred to the sandwich panel through the contact surfaces, lines or points between the cladding and the external face of the sandwich panel.

Information about the evaluation of the wind pressure distribution to the cladding and the sandwich panel is given in EN 1991-1-4 Section 7.2.10.

Temperatures of the external and internal faces to be used in the design of sandwich panels are given in EN 14509 for the summer and winter seasons. Caused by a shadowing of the cladding profile, a summer temperature of 40°C can be applied to the external face behind the cladding independently on the color group. The temperature of 40°C may be applied also to the rails in the shadow. A temperature of 55°C, 65°C or 80°C has to be applied to the external cladding sheets, depending on the color group. For winter, a temperature of -20°C is assumed in Central Europe and the temperature of -30°C (min) in Scandinavia for the external face sheet, the rails and the cladding profiles. Special care is needed in the design of the roof claddings if the space between the cladding and the external face is open to temperature variations.

The estimated temperature of the internal face sheet is 25°C in summer and 20°C in winter. However, if needed, the temperatures have to be adapted on the operating temperature (cooling houses etc).

3.2 Static systems and design calculations

The shear flexibility between the components of the cladding and the directions of the cladding components have a high influence on the mechanical behaviour and resistance of the system. The calculation model is different to conventional systems based on rails in the parallel or in the transverse direction to the span of the ordinary sandwich panel (Fig 3, 4). Naturally, the static model of the cladding based on additional sandwich panels is different compared to the model of the conventional cladding system.

Design of the cladding system may be based on analytical or on numerical models. Analytical models describing the distribution of the stresses in simply supported one-span systems based on the traditional cladding system are given in Annex A. The system is loaded with an uniformly distributed load, however, similar systems of solutions can be derived to other load cases, also. The
expressions base on the theory of elastic bonds between the cladding members and they have been derived in [5] and [6]. The expressions result in the normal stresses in the faces of the ordinary sandwich panel and in the rail or sheeting depending on whether the rail or the cladding sheet locates in the longitudinal or in transverse direction to the sandwich panel. The expressions result in further the shear forced in the fastenings between the sandwich panel and the axial member of the cladding. The expressions can be used in the preliminary analysis of a traditional cladding system.

It is recommended to base the ordinary design calculations on numerical models, in which the shear stiffness caused by the distortion and warping of the rail profiles and by the deformations in the fastenings are modelled on the basis of experimental data. The numerical model shall produce the deflection of the system, the axial stresses of the faces and cladding elements, the line or points loads in the contact points, the shear stresses in the core and finally, the shear and tensile forces in the fastenings of the system. In Annex B and C examples are given to show the flow of the design calculations of the traditional cladding systems in practice.

Analysis of the cladding system based on additional sandwich elements using the analytical or numerical models. The models shall result in the deflection of the system, the axial stresses in the faces of the ordinary and additional sandwich panels and elements, the shear stresses in the core and the shear and tensile forces in the fastenings between the ordinary and cladding elements.

3.3 Verification of the resistance

The load-bearing capacity of the ordinary sandwich panels can be evaluated by applying the rules given in EN 14509. The strength and modulus of the elasticity of the core and the wrinkling stress of the faces are given in the CE-declaration of the manufacturers. The reduced values of the wrinkling stress at the intermediate support may be applied to the line load introduction of the wind pressure load and snow load and to the point load introduction of the wind suction load in the verification of the resistance of the external face.

When cladding an old facade, the evaluation of the strength and resistance of the old panels shall be based on initial test data or on necessary testing of the specimens removed from the old sandwich panels, if this data is not available. The testing shall cover the mechanical properties of the faces and the core and the composite action between the layers. Inspection on site should be made to discover possible defects and faults in the faces and in the core and bond. It is important to investigate the condition and resistance of the old fastenings and in needed, to improve the resistance by adding fasteners or by replacing the old fasteners with new ones.

Strength and resistance of the additional sandwich elements used in cladding shall be made by applying the guidelines given in EN 14509.

The verification of the resistance of the additional thin-walled steel sheet components of the cladding shall be made by applying if rules given in EN 1993-1-3 and on the data in the CE-declaration of the manufacturer.

Verification of the shear and tensile resistance of the fastenings shall be based on experimental information produced using the standards and directions [3, 8].

In verifications, the additional effects caused by the composite actions between the cladding system and the ordinary sandwich panel shall be taken into account. The analysis of the composite action requires the proper, usually experimental information about the shear flexibility of the rails and fastenings.
3.4 Experimental information

Cladding systems are normally fixed in one face of the sandwich panel, only. Experimental information is needed about the shear and tensile resistance of the fastenings used in the fixings. The effects of the repeated loads caused by the various actions shall be known, also.

Shear flexibility of the profiles and fastenings between the cladding and the sandwich panel plays an important role in the static behaviour, in the distribution of the stress resultants and in the load-bearing resistance of the cladding systems. The shear flexibility shall be determined experimentally. Advanced methods of analysis may provide useful information about the shear flexibility also.

4. Practical guidelines and remarks

In the choice of the materials of the cladding elements and fasteners special care shall be paid to the compatibility of the materials to avoid the risks of the corrosion.

Arrangement of the suitable ventilation of the air space between the components is an important task because of the air pressure distribution and the remove the risks of condensation.

Verification of the condition of the old wall and roof panels and of the fastenings has to be done carefully before the design and installation of the cladding to an old facade or roof.

The static system of the new cladding should follow the system of the ordinary sandwich panels. For instance, an installation of one-span cladding elements on continuous multi-span ordinary sandwich panels may cause additional unexpected stresses at the intermediate supports in the ordinary sandwich panels.

Shear flexibility between the structural members plays an important role in the stress distribution and resistance of the cladding systems. The flexibility may be changed by additional single components at joints, corners and openings. The effect of the additional single elements shall be included in the design calculations or their use shall be avoided.

Tolerances in cutting, mounting and tightening of the components and fasteners shall be taken care in the design and use of the cladding systems. The correct tightening is important also because of the tensile and shear resistance of the self-drilling screws. The rivet fastenings may be more safe in this respect.

Special care has to be paid to the handling the additional components during the transport and mounting. The light and long components can be easily damaged locally, after which the use of the additional components does not result in the required improvement in the appearance.

5. Conclusions

The report introduces typical cladding systems for old and new facades and roofs made of sandwich panels. A cladding provides new architectural and visual appearance and technical benefits to old facades but enlarges also the area of utilization of the new walls and roofs made of sandwich panels. The subject area is limited to principal cladding systems based on thin-walled metal sheet components, only. The report presents a list of questions which may arose in the design and use and which should be solved in practice. The report gives directions for the selection, design and mounting of the cladding systems. The careful inspection of the old facades and roofs and an evenly careful static analysis covering the mechanical behaviour and resistance of the new structures consisting of the ordinary sandwich panels and cladding components to all existing loading cases is highly emphasized.

The report provides ideas and tools for further development and testing of new cladding solutions.
References

Annex A

Analysis of the cladding system consisting of thin-walled purlins and sheetings

A.1 Determination of the stress resultants, rails in longitudinal direction

The procedure is based on a series expansion that was truncated after the first term. In a simplified form, the method is already used in the design of sandwich panels. The reference line of the calculation of the cross-sectional value follows the centroidal axis of the cross-section. For a structure with rails spanning parallel to the span of the sandwich panel, the centroidal axis locates in most cases in the core close to the external face (Fig A1). Due to the discretely distributed bending stiffness of the rails, a cross-section of a tee-shaped beam is used to describe the face and the rail. One segment of a width of \( b' \leq e_L \) of the sandwich panel carries the corresponding load \( q \) uniformly distributed on the width \( e_L \). In the expression \( e_L \) is the distance of the rails. The effective areas of the face sheets \( A_{F1} \) and \( A_{F2} \) can be calculated as

\[
A_{F1} = b' \cdot t_{F1}
\]

Figure A1. Distribution of stress resultants in the cladding system, in which the rail profiles have been placed in the longitudinal direction to the span of the sandwich panel

In the further calculations, the modulus of elasticity of the faces, which are usually made of steel sheets, is taken as a reference value. If the rail profiles are made of another material, for ex. of an aluminium alloy, the cross-sectional values \( A_L \) and \( I_L \) are to be reduced with the ratio of the moduli of the elasticity. The spring stiffnesses \( K_S \) used to describe the mechanical connections can be taken for example from [7]. The value of \( K_S = 2.5 \text{ kN/mm} \) may be used for the self-tapping and self-drilling screws and \( K_S = 4.0 \text{ kN/mm} \) for the rivet fastenings. The effective bending stiffness

\[
I_{ef} = I_L + \vartheta_{L,F1} \cdot h_{L0} + \vartheta_{F1,F2} \cdot e
\]

can be evaluated on the basis of the parameters
The values of the stress resultants $N_L$ and $M_L$ exposed to the rails are

$$N_L = \frac{4 \cdot q \cdot l^2}{\pi^3} \cdot \frac{\partial_{LF_1}}{l_{ef}}$$

$$M_L = \frac{4 \cdot q \cdot l^2}{\pi^3} \cdot \frac{I_L}{l_{ef}}$$

The design of the rails can be made on the basis of the standard EN 1993-1-3.

The stresses of the face layers of the ordinary sandwich panel are

$$\sigma_{F_1} = \frac{N_{F_1}}{A_{F_1}} = \frac{4 \cdot q \cdot l^2}{\pi^3} \cdot \frac{\partial_{F_1F_2} - \partial_{F_1F_3}}{l_{ef}}$$

$$\sigma_{F_2} = \frac{N_{F_2}}{A_{F_2}} = \frac{4 \cdot q \cdot l^2}{\pi^3} \cdot \frac{\partial_{F_1F_2}}{l_{ef}}$$

The load-bearing capacity of the faces of the sandwich panel can be taken from the CE-declarations of the manufacturers of the sandwich panels.

A.2 Determination of the stress resultants, rails in transverse direction

If the rails are mounted in the transverse direction to the span of the sandwich panels (Fig. A2, the determination of an effective width $b'$ is not necessary. For sake of simplicity, the reference width of a unit width of 1 m can be used in calculations. The shear flexibility of the rails in the longitudinal direction caused by the distortion of the cross-section is modeled through spring stiffnesses. The spring stiffness of a hat-section can be calculated using (Fig. A3a)

$$\frac{1}{K_L} = \frac{2 \cdot (1 - v^2) \cdot h_L^3}{E \cdot b_2^5 \cdot t^3} \left[ \frac{b_0^3}{2} + \frac{(b_S - b_0)^2}{2} + h_L \cdot b_0^2 + h_L \cdot (b_S - b_0)^2 - h_L \cdot b_0 \cdot (b_S - b_0) \right]$$
and the stiffness of a Z-profile with (Fig. A3b)

\[
\frac{1}{K_L} = \frac{(1 - \nu^2) \cdot k_L^2}{E \cdot t^3} \cdot \left[ b_S + h_L \right]
\]

Figure A2. Distribution of stress resultants and a failure mode of the cladding system, in which the hat-shaped rails have been placed in the transverse direction to the span of the sandwich panel.

Figure A3. A) Determination of the spring stiffness of a hat section and b) of a Z-section describing the shear stiffness of the connection.
Connecting the springs in series results in the expression

\[ K = \frac{1}{\frac{e_s}{K_s} + \frac{1}{K_I} + \frac{e_s}{K_s}} \]

The values of the parameters are

\[ K_{p,F_1} = 1 + \frac{\pi^2 \cdot E \cdot A_P \cdot A_{F_1} \cdot e_L}{\pi^2 \cdot K \cdot (A_P + A_{F_1})} \]
\[ K_{F_1,F_2} = 1 + \frac{\pi^2 \cdot E \cdot A_{F_1} \cdot A_{F_2}}{\pi^2 \cdot G_C \cdot (A_{F_1} + A_{F_2})} \]
\[ \Phi = K_{p,F_1} \cdot K_{F_1,F_2} - \frac{A_P \cdot A_{F_2}}{(A_P + A_{F_1}) \cdot (A_{F_1} + A_{F_2})} \]
\[ \vartheta_{p,F_1} = \frac{A_P \cdot A_{F_1}}{(A_P + A_{F_1})} \left( (h_L + h_{P_0}) \cdot K_{F_1,F_2} + e \cdot \frac{A_{F_2}}{(A_{F_1} + A_{F_2})} \right) \]
\[ \vartheta_{F_1,F_2} = \frac{A_{F_1} \cdot A_{F_2}}{(A_{F_1} + A_{F_2})} \left( e \cdot K_{p,F_1} + (h_L + h_{P_0}) \cdot \frac{A_P}{(A_P + A_{F_1})} \right) \]

Expression for the effective bending stiffness can be written as

\[ I_{ef} = I_p + \vartheta_{p,F_1} \cdot (h_L + h_{P_0}) + \vartheta_{F_1,F_2} \cdot e \]

For the design of the cladding profiles, the stress resultants \( N_p \) and \( M_p \) are required:

\[ N_p = \frac{4 \cdot q \cdot l^2}{\pi^3} \cdot \frac{1}{l_{ef}} \cdot \vartheta_{p,F_1} \]
\[ M_p = \frac{4 \cdot q \cdot l^2}{\pi^3} \cdot \frac{1}{l_{ef}} \]

The cladding profiles can be designed for example following the guidelines given in EN 1993-1-3. In many cases, the resistance of the cross sections are available in tabulated form. The stresses in the faces can be written as

\[ \sigma_{F_1} = \frac{N_{F_1}}{A_{F_1}} = \frac{4 \cdot q \cdot l^2}{\pi^3} \cdot \frac{\vartheta_{F_1,F_2}}{l_{ef}} - \frac{\vartheta_{p,F_1}}{l_{ef}} \]
\[ \sigma_{F_2} = \frac{N_{F_2}}{A_{F_2}} = \frac{4 \cdot q \cdot l^2}{\pi^3} \cdot \frac{\vartheta_{F_1,F_2}}{l_{ef}} \]

The load-bearing capacity of the faces of the sandwich panels can be also taken from the CE-declaration of the manufacturers. The reduced values of the wrinkling stresses given for the design at the intermediate supports may be used to verify the effect of the line load introduction (wind...
pressure) and the point load introduction (wind suction) into the external face. For this application it must be additionally checked, whether a composite action between the cladding system and the sandwich panel develops at all, i.e. whether the flexibility of the rails and the rail’s distances do not completely uncouple both systems.

A.3 Shear Stress resultants of fastenings and shear stress of the core

If the rail profiles are installed parallel to the direction of span of the sandwich panels, the resistance of the connections between rails and the sandwich panel shall be verified. In addition to the tensile forces caused by the wind suction and the shear forces caused by the self-weight, also shear forces resulted in from the composite actions have to be taken into account. The shear force caused by the composite action can be evaluated using

\[ V_S = V_{LF1} = \frac{4 \cdot q \cdot l}{\pi^2 \cdot \alpha_{LF1} \cdot \frac{\varepsilon}{\varepsilon_S}} \]

If the rail profiles are running rectangular to the direction of span of the sandwich panels, an expression for the shear force can be written as

\[ V_S = V_{PF1} = \frac{4 \cdot q \cdot l}{\pi^2 \cdot \alpha_{PF1} \cdot \frac{\varepsilon}{\varepsilon_S}} \]

In the expressions, \( \varepsilon_S \) and \( \varepsilon_S \) can be different for the connections between the cladding sheet and rail profile and between the rail profile and the sandwich panel. The proof of the mechanical fastenings for the shear and tensile forces can be done on the basis of the experimental data and on the relevant ETA guidelines. The tensile forces introduced into the external face sheet of the sandwich panel has to be transferred via the tensile strength of the bond and core.

The shear stress of the core layer of the ordinary sandwich panel may be evaluated using the expression

\[ \tau_c = \tau_{F1,F2} = \frac{4 \cdot q \cdot l}{\pi^2 \cdot \alpha_{F1,F2} \cdot \frac{1}{\varepsilon}} \]
Annex B

**Design example of a cladding system consisting of thin-walled purlins and sheetings, analytical model**

The preliminary stress distribution of the simply supported one-span cladding systems can be evaluated using analytical expressions without numerical computations [5, 6].

**B.1 Determination of the shear stiffness of the connection**

For the calculation of the stresses in face layers and in the sinusoidal cladding sheet the stiffness of the connection between external face layer and cladding sheet has to be determined. In the case in the example, the connection is made of a transversal hat-shaped profile and of self drilling screws. The stiffness of a screw was measured to be 2.5 kN/mm. The stiffness of the hat profile can be determined by calculating the deflection caused by a horizontal load.

**B.1.1 Shear stiffness of the hat-shaped profile**

The static system for the calculation of the deflection is a two-hinged frame having the dimensions of the real hat shaped profile.

![Static system of the hat shaped profile](image)

Figure B1: Static system of the hat shaped profile

To determine the stiffness of the profile the displacement of the of the top chord caused by the load of 1 kN is measured. The relation between the deflection and the load is the inverse of the shear stiffness. The bending moment distribution and the application of the force method results in the required deflection of the top chord.
The method gives the displacement of

\[ \frac{1}{K_L} = \frac{2(1-\nu^2)h_L^2}{E\cdot b_S^3 t^3} \left[ \frac{b_0^4}{2} + \frac{(b_S-b_0)^2}{2} + h_L \cdot b_0^2 + h_L \cdot (b_S-b_0)^2 - h_L \cdot b_0 \cdot (b_S-b_0) \right] = 0.27 \text{ mm} \]

The values of the parameters in the expression are

- \( \nu = 0.3 \) Poissons ratio of steel
- \( E = 210000 \text{ N/mm}^2 \) modulus of elasticity of the steel
- \( t = 0.75 \text{ mm} \) thickness of the steel
- \( h_L = 30 \text{ mm} \) height of the hat-shaped profile
- \( b_0 = 30 \text{ mm} \) width of the top chord
- \( b_S = 55 \text{ mm} \) distance of the screws the profile is fixed on the upper face layer with

The deflection of 0.27 mm results in a stiffness of the profile of

\[ K_L = \frac{1000N}{0.27 \text{ mm}} = 3703.7 \text{ N/mm} \]
B.1.2 Evaluation of the stiffness with R-Stab software

To compare the results, the same system was analyzed using the R-Stab software.
The displacement of 0.25 mm given by the computation corresponds to the previously calculated displacement. None calculations take into account the deformations taking place in the screw connections.
B.1.3 Stiffness of hat shaped profile and screws

The shear stiffness of 2.5 kN/mm is used for each screw connection. A hat-shaped profile of a length of 1000 mm is fixed through the both flanges to upper face layer, thus altogether with six screws. The sinusoidal sheet is fixed to the hat profile in three points, altogether with three screws. The whole profile is a combination of springs arranged parallel and in series.

![Figure B2: Calculation of the spring stiffness.](image)

The spring stiffness of the system is calculated using the expression

\[
\frac{1}{K} = \frac{1}{6K_S} + \frac{1}{K_L} + \frac{1}{3K_S} = 0.47 \text{ mm/kN}.
\]

which gives the stiffness of \( K = \frac{1000}{0.47} = 2127.66 \text{ N/mm} \).

The stiffness of the connection was also measured in tests during the project. The measured value of 810 N/mm is considerably lower than the calculated one. The reason for the difference comes from the fact, that the influences of all deformations are not taken into account in the expression above.

Because of the horizontal load a couple of forces arises between the tensioned screws and the and the compressed web of the hat-shaped profile. This leads to a lifting effect of the face layer at a small area and the compressed part of the web of the profile presses into the layer. These additional deformations are not taken into account in this calculation. Further, the static system of the calculation model obtains only the deformations close to the screws. In the other parts of the hat section, i.e., between the connection points, the section deforms because of the torsion moment due to the eccentric supports to the face layer. Visible warping could be seen in those areas in the tests.

Because of those two additional effects, the real deformation of the hat-shaped profile is larger than the calculated one. Those effects which can’t be calculated could be taken into account by using in the calculation an ideal effective width of the beam next to the screws.

B.2 Distribution of stresses in the cross section
B.2.1 Initial values

A distance of 1000 mm between the hat-shaped profiles is used in the calculations. The value of the shear modulus of the core is 4.75 N/mm$^2$.

Figure B3: Elements of the cross section of the sandwich panel and cladding

Initial values for the calculation:

\[ E = 210000 \text{ N/mm}^2 \quad \text{modulus of elasticity} \]
\[ A_P = 775 \text{ mm}^2 \quad \text{cross-sectional area of the sinusoidal sheet} \]
\[ I_P = 28900 \text{ mm}^4 \quad \text{second moment of area of the sinusoidal sheet} \]
\[ A_{F1} = 510 \text{ mm}^2 \quad \text{area of the external face layer} \]
\[ G_C = 4.75 \text{ N/mm}^2 \quad \text{shear modulus of the core material} \]
\[ A_{F2} = 460 \text{ mm}^2 \quad \text{area of the internal face layer} \]
\[ e = 99.5 \text{ mm} \quad \text{distance between the centroids of the face layers} \]
\[ L = 4000 \text{ mm} \quad \text{span length} \]
Numerical values of the parameters

\[ K_{P,F1} = 1 + \frac{\pi^2 \cdot E \cdot A_P \cdot A_{F1} \cdot e_k}{l^2 \cdot K \cdot (A_P + A_{F1})} = 19,73 \]

\[ K_{F1,F2} = 1 + \frac{\pi^2 \cdot E \cdot A_{F1} \cdot A_{F2}}{l^2 \cdot G_c \cdot (A_{F1} + A_{F2})} = 7,60 \]

\[ \phi = K_{P,F1} \cdot K_{F1,F2} - \frac{A_p \cdot A_{F2}}{(A_p + A_{F1}) \cdot (A_{F1} + A_{F2})} = 150,66 \]

\[ \vartheta_{P,F1} = \frac{A_p \cdot A_{F1}}{(A_{F1} + A_{F2})} \cdot \left( (h_L + h_{P0}) \cdot K_{F1,F2} + e \cdot \frac{A_{F2}}{(A_{F1} + A_{F2})} \right) = 105682,64 \text{ mm}^3 \]

\[ \vartheta_{F1,F2} = \frac{A_{F1} \cdot A_{F2}}{(A_p + A_{F1})} \cdot \left( (e \cdot K_{P,F1} + (h_L + h_{P0}) \frac{A_p}{(A_p + A_{F1})} \right) = 480484,12 \text{ mm}^3 \]

\[ I_{ef} = I_p + \vartheta_{P,F1} \cdot (h_L + h_{P0}) + \vartheta_{F1,F2} \cdot e = 5,196 \cdot 10^7 \text{ mm}^4 \]

B.2.2 Axial load and bending moment of the sinusoidal sheet

\[ N_p = \frac{4 \cdot q \cdot l^2}{\pi^3} \cdot \frac{\vartheta_{P,F1}}{I_{ef}} = 4198,52 \cdot q \]

\[ M_p = \frac{4 \cdot q \cdot l^2}{\pi^3} \cdot \frac{I_p}{I_{ef}} = 1148,08 \cdot q \]

The value of the wind pressure load of 0,52 kN/m² is used in the calculation.

\[ N_p = 7976,77 \cdot 0,52/1000 = 2,18 \text{ kN} \]

\[ M_p = 1594,13 \cdot \frac{0,52}{1000} = 0,6 \text{ kNm} \]
B.2.3 Axial stresses in the sinusoidal cladding sheet and in the faces of the sandwich panel

The stress in the sinusoidal sheet is \( \sigma_p = \frac{N_p}{A_p} = 2.81 \, \text{N/mm}^2 \).

The stress in the upper face is \( \sigma_{F1} = \frac{N_{F1}}{A_{F1}} = \frac{4qL^2}{\pi^3} \cdot \frac{\varphi_{F1F2} - \varphi_{pF1}}{l_{ef}} \cdot \frac{1}{A_{F1}} = 15.18 \, \text{N/mm}^2 \).

The stress in the lower face is \( \sigma_{F2} = \frac{N_{F2}}{A_{F2}} = \frac{4qL^2}{\pi^3} \cdot \frac{\varphi_{F1F2}}{l_{ef}} \cdot \frac{1}{A_{F2}} = 21.58 \, \text{N/mm}^2 \).

B.3 Conclusions

This analytical method can be used in the evaluation of the stresses of the face layers and of the sinusoidal cladding sheet of simply supported one-span beams. Because of some simplifying assumptions concerning the static system, this procedure is applicable only for a first approximation of the stresses. For more specific and detailed results the use of a numerical software such as R-Stab is necessary.

Some of the effects having not taken into account in this calculation procedure are explained in chapter B.1.3. The exact displacement of the hat profile between the screws can’t be described with the model used in this calculation. Also the local deformations of the external face layer have not been considered.

The properties of the hat profile and the fastenings are taken into account in the calculation by estimating them as a continuous flexible support of the sinusoidal sheet which is an approximation that might lead to imprecise results.
Annex C

Design example of a cladding system consisting of thin-walled purlins and sheetings, numerical model

C.1 Static system
The static system of the vertically mounted two-span wall panel is modeled using the R-Stab software. The equal spans of the panels are 4000 mm each. In order to stabilize the panel and to increase the load bearing capacity, a traditional cladding is added on the external face layer of the panel (Fig. C1).

Figure C1: Static system of the vertically mounted two span wall panel
C.2 Sandwich panel and cladding system

The thickness and width of the wall panel are 100 mm and 1000 mm, respectively. The wall panel consists of flat steel sheet faces and a core layer made of PU-foam. The density of the core is 40 kg/m³. The thicknesses of the internal and external face layers are 0,46 mm and 0,51 mm. The cladding mounted on the external face layer is in this example a sinusoidal steel sheet which has a total depth of 18 mm and the thickness of the steel of 0,7 mm.

The connection between the sinusoidal sheet and the external face consists of hat shaped steel profiles. The hat profiles have a total depth of 30 mm and the thickness of the steel of 0,75 mm (Fig. C2).

The profiles are mounted at intervals of 1000 mm perpendicular to the direction of the span of the sandwich panel and the sinusoidal sheet. The hat profiles are screwed onto the external face of the panel and the cladding is mounted on the hat profiles. The distance between the screws in the transverse direction is 300 mm. Thus, the sinusoidal sheet is fixed at three points on each hat-shaped profile.

Figure C2: A cladding system consisting of a sinusoidal sheet and of hat profiles fixed with screws to the external face of the wall panel.

C.3 Elements of the R-Stab model

C.3.1 Wall panel

The wall panel is modeled as a plane trussed beam (Fig. C3). The horizontal beams of the truss model the face layers of the wall panel. The vertical distance between the beams corresponds the height of the truss which is equal to the distance between the centroids of the external and internal face.

The faces are modeled as beams with the real dimensions of the steel faces. Thus, the axial deformation of the beams results in the deformation of the panel caused by the bending moments. Each face layer consists of several beams whose lengths are the distances between the vertical rods. To prevent the beams from buckling the second moment of area of the compressed face must be increased.

The vertical and diagonal rods of the truss model the core material. The vertical rods are rigid, they do not deform. The diagonal struts in contrast can extend and by their elongation they
model the shear deformation of the core material. The area of the strut can be determined on the basis of the shear modulus of the real wall panel. The shear angle caused by a shear force in the model shall be the same as the shear angle of the wall panel.

C.3.2 Cladding
The sinusoidal sheet runs in the longitudinal direction of the panel. In the R-Stab program the sheet is modeled by several beam elements in the similar way as it was done to the face layers. The length of the beams corresponds to the distance of the hat profiles between the sinusoidal sheet and the external face of the wall panel. The area and the second moment of area for the R-Stab model can be taken from the data sheet of the manufacturer.

C.3.3 Hat profiles
The connection between the face and the sinusoidal sheet on the panel is made of hat shaped steel profiles, which run in the transverse to the direction of panel and the sinusoidal sheet. The profiles are fixed with screws on the external face layer and the sinusoidal sheet. In the R-Stab model the hat profile and the screws are modeled with two beam elements. A rigid beam element is placed in vertical direction between face and sinusoidal sheet. It keeps the distance of 39 mm between those two structural elements, which is the distance between the external face and the centroid of the sinusoidal sheet. The second strut can extend and it runs in a diagonal direction. Its flexibility simulates the shear stiffness of the hat profile and the stiffness of the connections between the face and hat profile and between the hat profile and the sinusoidal sheet in the horizontal direction.

![Figure C3: Elements of the R-Stab-model](image)

1 upper/external face layer  
2 lower/inner face layer  
3 rod (depth of the core, rigid)  
4 strut (shear deformation of the core)  
5 rod (hat profile, rigid)
C.4 Determination of the stiffness of the hat profile and fastenings

The spring stiffness of the connection is determined in a small scale shear test (Fig. C4). A part of the panel with the cladding is placed in vertical direction and a load is introduced into the cross-section of the sinusoidal sheet. From the load-deflection curve of the test the spring stiffness of the combination of hat profile and fastenings can be determined and later, converted to correspond the shear stiffness of the whole width of the panel.

For the cladding consisting of the hat profiles running in the transverse direction a spring stiffness of 810 N/mm corresponding the whole width of the panel was measured. This value is calculated for a hat profile with a length of 1000 mm and for altogether six screws to fix the profile on the external face layer and three screws for fixing the sinusoidal sheet on the profile.

Figure C2: Small scale test to determine the spring stiffness given by the hat profile and fastenings
C.5 Generating the R-Stab-Model

C.5.1 Face layer

Both face layers are modeled with rectangular cross sections using the real dimensions. The thickness of the external face is 0.51 mm and the thickness of the internal face 0.46 mm. The second moment of area must be enlarged, in order to take into account the supporting effect of the core material. For a realistic consideration of the wrinkling stress of the compressed face the second moment of the area of the face can be calculated to be conform to the wrinkling stress of the face of the panel. In this way the real wrinkling failure can be found also in the R-Stab-model.

C.5.2 Core layer

The vertical rods of the truss are modeled as rigid elements to correspond the distance of the centroid of the external and internal face.

The axial rigidity EA of the diagonal struts can be determined from the load deflection curve of the six-point-bending test of the single span sandwich beam without the cladding. To evaluate the axial stiffness EA a load and the corresponding deflection are taken from the linear part of the load deflection curve. For the panel in the example the load is 8 kN with a corresponding deflection of 22.04 mm. The span length between the supports was 4000 mm. To determine the parameters of the diagonal struts the test with the contemplated single loads of 4 times 2 kN must be modeled in the R-Stab software. According to the section A5.6 of the standard EN 14509, the loads are placed in the 1/8, 3/8, 5/8 and 7/8 points of the span of the panel (Fig. C5).

If the face layer is modeled with its correct EA value, the EA value of the diagonal strut describing the shear flexibility of the core can be varied, until the deflection of 22.04 mm is found. For the sandwich panel in the example, the axial rigidity of 1350 kN results in the expected deflection measured in the test. By calculating the parts of the deflection caused by bending moments \( w_b \) and the shear force \( w_s \), separately, the R-Stab-model can be verified.

If the struts are modeled as rigid elements, the deflection calculated with R-Stab software should be equal to the deflection caused by bending moment in the test. Accordingly only the shear deflection should take place if the chords of the truss are axially rigid elements.

![Figure C5: Loading of the wall panel in a full scale test](image_url)

As an alternative to the determination of the value of EA explained above, the axial stiffness can also be calculated on the basis of the shear modulus of the core material. The area of the strut is
$A_Q = \frac{G \cdot B \cdot d^3}{E \cdot a \cdot m}$ In the expression $B$ is the width of the panel, $d$ the length of the strut, $a$ the height of the truss and $m$ is the distance between the posts. The calculation of $EA_Q$ using this expression gives a value of 1348.6 kN, which is close to the value determined on the basis of the results of the bending test.

The parameters determined in the test can be used also in the model of a two-span sandwich beam.

C.5.3 Cladding

The sinusoidal sheet is modeled with several beam elements with rigid connections to each others. The material and geometric parameters such as the modulus of the elasticity, the area and the second moment of the area are taken from the data sheet of the manufacturer.

The connection between the sandwich panel and the sinusoidal sheet is made of a hat shaped profile and screws, which in this example are modeled with two truss members. The vertical post is rigid and has a length of 39 mm which is the distance between centroid of the external face and centroid of the sinusoidal sheet. The strut is adjusted to the stiffness of the connection. To determine the rigidity of the strut a small R-Stab model is made in which the axial stiffness $EA$ of the strut is varied until the horizontal deflection corresponds to the spring stiffness of the connection (Fig. C6).

![Figure C6: Determination of the spring stiffness in the R-Stab-model given by the hat profile and the connections](image)

The spring stiffness of the connection consisting of the hat profile and the screws is 810 N/mm. There are six screws connecting the hat profile to the face layer and three screws between the hat profile and the sinusoidal sheet at each hat profile corresponding the whole width of the panel. In the model the rigidity of 810 N/mm is reached with $EA=100$ kN, so at a load of 810 N the horizontal deflection of 1 mm is measured.
C.6 Loads in the model
C.6.1 Dead load

The self-weight of the steel faces is taken into account by using the real dimensions and material properties in the model. The self-weight of the core material is calculated on basis of the density and it will be introduced in the posts of the truss in the R-Stab model.

The density of 40 kg/m$^3$ of the core results in a load of 0.4 kN/m$^3$. At a distance between the posts of 100 mm and a width of the panel of 1000 mm, the self-weight of the core corresponds to an uniform load of 0.04 kN/m on each post. The self weight of the sinusoidal sheet is given by the manufacturer and can be assumed to be a line load along the width of 1000 mm.

As the element is a vertically mounted wall panel, the self weight has to be applied in the longitudinal direction onto the panel.

C.6.2 Wind load

For a building having a height less than 10 m and locating in a wind zone 2, the basic wind pressure load can be assumed to be $q = 0.65$ kN/m$^2$.

For $h/d \neq 1$, in the area D the following values of the wind loads can be calculated:

- wind pressure load: $c_{pe,10} = 0.80 \Rightarrow w_D = 0.52$ kN/m$^2$
- wind suction load: $c_{pe,10} = -0.50 \Rightarrow w_S = -0.33$ kN/m$^2$

The calculated loads are introduced as line loads on the beam elements modeling the sinusoidal cladding sheet in the R-Stab model.

C.6.3 Temperature of the faces in Summer:

- Cladding: $T = 65$ °C (colour group II)
- external face layer: $T = 40$ °C (shadowed by the cladding)
- internal face layer: $T = 25$ °C (inside temperature in Summer acc. to EN 14509)

$\Delta T = 40$ °C between the cladding and the internal face

C.7 Calculated results

The results of the calculation made using the R-Stab model are given in Table C1 for each load case. The values correspond the characteristic stress values without load factors. The Tables contain comparisons between the results of the R-Stab models with and without the cladding. Thus, the results show the influence of cladding on the stress distribution in the cross section of the sandwich panel.
For the two span beam the stresses from load cases the wind suction and the temperature in Summer are given for the cross section at the mid support. Additionally to the model of the two-span wall panel, also a single span wall panel having a span of 4000 mm was modeled. Using the model of the single span wall panel, the stresses caused by the wind pressure load were calculated in the mid-span. The Table C2 shows the calculated axial stresses in the two face layers and in the sinusoidal cladding sheet.

The maximum shear force in the hat profile in the one-span system is 0,21 kN which leads to a displacement of 0,26 mm between external face and sinusoidal sheet.

The maximum shear force in the hat profile in the two-span system equals to the normal force in the exterior diagonal truss. It is 1,11 kN which results in a displacement of 

$$ w = \frac{1110 \text{ N}}{810 \text{ N/mm}} = 1,37 \text{ mm} $$

between the external face and the sinusoidal cladding sheet.

Because there are a minimum of three fasteners in a row, the maximum shear force in one screw is 0,37 kN.

The maximum tensile force in one screw caused by the wind suction load is $0,42/3 = 0,14 \text{ kN}$.

<table>
<thead>
<tr>
<th>Wind suction temperature</th>
<th>without Cladding</th>
<th>with Cladding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cladding</td>
<td>0,08</td>
<td>-3,64</td>
</tr>
<tr>
<td>σ1 (external face)</td>
<td>-10,86</td>
<td>-63,33</td>
</tr>
<tr>
<td>σ2 (inner face)</td>
<td>10,35</td>
<td>68,48</td>
</tr>
<tr>
<td>Cladding</td>
<td>0,08</td>
<td>-3,64</td>
</tr>
<tr>
<td>σ1 (external face)</td>
<td>-9,78</td>
<td>-22,61</td>
</tr>
<tr>
<td>σ2 (inner face)</td>
<td>9,46</td>
<td>30,37</td>
</tr>
</tbody>
</table>

Table C1. Two span beam, stresses in N/mm² at the mid support
<table>
<thead>
<tr>
<th></th>
<th></th>
<th>Wind pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>without Cladding</strong></td>
<td>( \sigma_1 ) (external face)</td>
<td>-20.49</td>
</tr>
<tr>
<td></td>
<td>( \sigma_2 ) (inner face)</td>
<td>22.72</td>
</tr>
<tr>
<td><strong>with Cladding</strong></td>
<td>Cladding</td>
<td>-0.40</td>
</tr>
<tr>
<td></td>
<td>( \sigma_1 ) (external face)</td>
<td>-20.04</td>
</tr>
<tr>
<td></td>
<td>( \sigma_2 ) (inner face)</td>
<td>22.89</td>
</tr>
</tbody>
</table>

Table C2. Single span beam, stresses in N/mm\(^2\) at the mid span
Annex D Design of cladding made of additional elements

D.1 Static system

The static system of the single span sandwich-panel is described using the FEM-modelling system in the Matlab environment. The same computations can be made also using general purpose finite element codes in which beam and plane elements are available. The span length and the total length of the ordinary sandwich panel are 3800 mm and 4000 mm, respectively. The support widths are 200 mm each (Fig D.1).

![Figure D.1. Static system and load of the single span sandwich-panel a) ordinary sandwich panel and b) sandwich panel with an additional cladding panel.](image)

D.2 Cladding system

The total length and depth of the ordinary sandwich-panel are 4000 mm and 100 mm. The total length of the additional sandwich-panel is also 4000 mm but the total depth is 40 mm, only. The width of the both sandwich-panels is 1000 mm. The design thickness of the internal and external face layers made of steel sheets of the both sandwich-panels is 0.52 mm. Shear modulus of the core of the ordinary and additional sandwich panels is in the calculations 2.73 N/mm².

The cladding panel is mounted to the external face of the ordinary sandwich panel using self-drilling IR2 screws and washers (Fig D.2.). The length of the IR2 screw is 60 mm.
Figure D.2. Self-drilling IR2 screw with a detailed picture about the head and washer.

The screws are fastened in a three rows in the width direction and in four points in the longitudinal direction of the system. The distance of the first fastener from the end of the sandwich-panel is 500 mm and centre-to-centre distances of the next fastener in a row is 1000 mm.

D.3 Calculated results

The table D.1 and D.2 show the normal force and normal stress in the faces of the ordinary sandwich panel and the additional panel exposed to the uniformly distributed load. The load case is computed without and with the additional cladding panels. The figure D.3 shows the distribution of the normal forces in the faces in one half of the system. The stepwise changes of the normal force in the external face of the additional panel and in the internal face of the additional panel present the shear forces of the fastenings in the points. In this case, the fastenings are placed in two points in the longitudinal direction of the half length, i.e., in 1/8 and 3/8 points of the total length.

Table D.1 Normal forces and normal stresses of the face layers at mid-span without cladding.

<table>
<thead>
<tr>
<th>Ordinary sandwich-panel</th>
<th>F [kN]</th>
<th>σ [N/mm²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>External face</td>
<td>-9,35</td>
<td>-17,98</td>
</tr>
<tr>
<td>Internal face</td>
<td>9,36</td>
<td>18,00</td>
</tr>
</tbody>
</table>
Table D.2 Normal forces and normal stresses of the face layers at mid-span with cladding.

<table>
<thead>
<tr>
<th></th>
<th>Additional sandwich-panel</th>
<th>Ordinary sandwich-panel</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F [kN]</td>
<td>σ [N/mm²]</td>
</tr>
<tr>
<td>External face</td>
<td>-4,95</td>
<td>-9,52</td>
</tr>
<tr>
<td>Internal face</td>
<td>1,97</td>
<td>3,79</td>
</tr>
</tbody>
</table>

Table D.3 Shear force of the fastenings. \( Q_{\text{row}} \) represents the value of the shear force in a point in the longitudinal direction of the system and \( Q_1 \) the value of the shear force of a single fastener.

<table>
<thead>
<tr>
<th></th>
<th>( Q_{\text{row}} ) [kN]</th>
<th>( Q_1 ) [kN]</th>
</tr>
</thead>
<tbody>
<tr>
<td>First point</td>
<td>2,12</td>
<td>0,71</td>
</tr>
<tr>
<td>Second point</td>
<td>0,87</td>
<td>0,29</td>
</tr>
</tbody>
</table>

Figure D.3 Normal forces in the faces of the sandwich panel system without and with the cladding element.
Figure D.4 Normal stresses in x-direction in the core layers without and with the cladding element, in kN/m$^2$.

Figure D.5 Normal stresses in y-direction in the core without and with the cladding element, in kN/m$^2$.

Figure D.6 Shear stresses in the core layers without and with the cladding elements, in kN/m$^2$. 