doi: 10.18720/MCE.78.3

# Bearing capacity of facade systems fixing to sandwich panels

# Несущая способность крепления навесных фасадных систем к сэндвич-панелям

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**Key words:** facade system; sandwich panel; bracket; screw; facade

**Ключевые слова:** навесные фасадные системы; сэндвич-панель; кронштейн; самонарезающий винт; фасад

**Abstract.** The article presents results of the experimental and theoretical research of bearing capacity determination for fixings, used for bearing and supporting brackets in facade systems with the base from sandwich panel. The experiment included the consideration of several types of brackets fixing: using self-tapping screws and threaded rods, taking into account the variation in the thickness of the bearing steel plates. The required values of the research were critical longitudinal force for the pull-out from the base, deformations of the base, which lead to the disruption of sandwich-panel structural integrity. In addition, full-sized samples of the bearing bracket (the most loaded element of the facade system), installed on sandwich panel, were tested for the longitudinal (wind) and shearing (self-weight of cladding and system) load with different types of fixing. As a result, the article gives recommendations for the joints design of facade system brackets fixing to the base from sandwich panel, developed on the results of tests and theoretical studies.

**Аннотация.** В статье изложены результаты проведенных экспериментальных и теоретических исследований по определению несущей способности креплений несущих и опорных кронштейнов навесных фасадных систем (НФС) к основанию из стеновой сэндвич-панели. В процессе испытаний по определению несущей способности крепления НФС к стеновой сэндвич-панели ставились задачи по определению критического продольного усилия необходимого для вырывания элемента крепления или деформации основания, приводящей к нарушению целостности конструкции; испытывались полноразмерные образцы несущего (наиболее нагруженного элемента системы) кронштейна расчетной продольной (ветровой) и вертикальной (весовой) нагрузкой; измерялись величины поперечной деформации сэндвич-панели от сосредоточенной силы, вызываемой действием весовой и ветровой нагрузок, действующей на систему НФС. По результатам проведенных испытаний и теоретических исследований даются рекомендации по проектированию соединений крепежных элементов креплений навесных фасадных систем к основанию из стеновой сэндвич-панели.

## *1. Introduction*

Nowadays, rapid progress in the field of application of energy-efficient outdoor facade systems and increased amount of work, associated with using of various fastenings combinations for these systems, lead to the need of deciding large number of questions, which appear at engineers about requirements for reliability and durability of facade connections. Insufficient volume of the conducted researches in this sphere essentially complicates qualitative designing and the subsequent normal exploitation of facade systems designs.

While researching this area, it is necessary to make a review of some works made on this theme. Questions of strength and anchor deformation from static and dynamic load, considered in the D.A. Kiselev dissertation work [1]. Author developed and proposed the practical application of the test procedure, performed a comparative assessment of existing test methods, established criteria for the value of calculation load, which can act on the anchor and recommended some types of anchors for using in buildings and structures, constructed in areas with seismicity range: 7 - 9 points.

I.V. Katranov in his work [2] developed a method for testing the shear and stretching of joints with rivets or self-tapping screws, identified and classified the failures of light steel structures connections and also made practical recommendations for conducting certification tests of rivet and screw connections for shear and tension.

Articles [3, 4] show the experimental studies of the self-tapping screws work in seismic areas, in conditions of the dynamic loading effect; also authors give recommendations in the field of fastening for sandwich-panels in building areas with seismicity of 7÷9 points. A.V. Granovsky [5] developed and approved the testing method for breakout anchors from various base materials, compared the test methods that are conducted abroad and in our country and noted the advantages of testing anchors method, developed at the Kucherenko Central Scientific Institute.

M.Yu. Ananyin and Yu.S. Vedischeva [6] revealed the nature of the deformation of the fastening system on the basis of a series of preliminary numerical experiments performed with the application of a uniformly distributed static load to the system, as well as loads arising from the difference in temperatures outside and inside the building. Calculated results obtained by authors and compared with theoretical calculations, however, during the experiment, the joint operation of the sandwich panel system with the building frame was not taken into account.

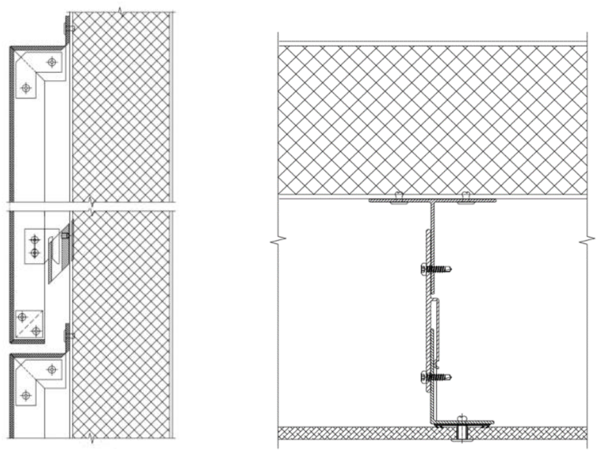
Articles of O.A. Tusnina [7–9] considered fastening thin-walled Z-purlins supported by sandwich panels. In this paper she considered questions of numerical analysis of purlins in sandwich panel coverings. Numerical analysis was based on laboratory experiments and modeling of the situation in the program. The results of the theoretical study were compared with the results of the experiments. A finite-element model proposed for constructing the connection of cold-bent purlins and sandwich panels.

Paper [10] is devoted to the development of a complex geometrically nonlinear theory of three-layered shells, which also includes the influence of initial geometric imperfections. It assumed that the sandwich panel is an anisotropic material. Taking into account all features, authors developed a structural model that provides checking load bearing capacity of the three-layer panels and, in addition, ways of increasing the load capacity of the three-layer shells and plates.

In articles [11, 12], authors presented a technique of bearing capacity calculation for multilayer structures, determining stresses and deformations in sandwich panels, based on numerical simulation with taking into account design features and comparing the results of calculations with experimental data for the maximum permissible load.

Currently, there are many newly constructed and reconstructed objects with enclosing structures made from sandwich panels. To impart for these buildings new aesthetic and architectural features, it is necessary to use non-standart technologies and materials to make cladding on the surface of sandwich panel. In this regard, the constructive solution is to fix the facing materials to the body of the sandwich panel.

There are several types of these fastening (see Figs. 1, 2).



**Figures 1, 2. Existing methods of fixing systems to sandwich panels (Fig. 1 (left, section) – “Hand-made” system of fixing, Fig. 2 (right, top view) – system with uniformly fixed T-profile to sandwich panel)**

Galyamichev A.V., Kirikova V.A., Gerasimova E.A., Sprince A. Bearing capacity of facade systems fixing to sandwich panels. *Magazine of Civil Engineering*. 2018. No. 2. Pp. 30–46. doi: 10.18720/MCE.78.3.

These two types of fixing have obvious disadvantages, due to the dependence from the cohesive joint bearing capacity between the zinc-coated steel sheet and insulation material, which will deteriorate over time due to temperature fluctuations and condensation. An example of such object with a similar fixing see on Figure 3.

**Figure 3. Western speed diameter office (St. Petersburg)[1]**

Researched type of fastening (Figs. 4–9) have known thermal and aesthetic disadvantages, due to the presence of "cold bridges" in the insulating structure and visible self-tapping screws at internal structure. However, theme of the study was obtaining of necessary and sufficient bearing capacity of connection. Negative factors solved by the thickness of insulation and internal finishing by gypsum plasterboard sheets [13].

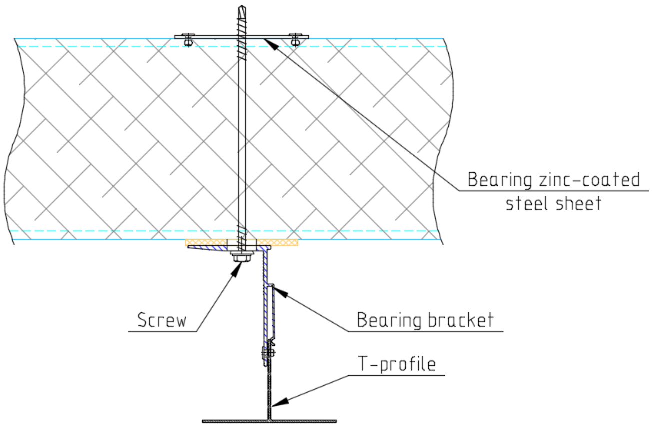



**Figure 4. One of the researched types of fastening to sandwich-panel**

The main aim of this article, based on the experimental and theoretical studies, is to develop:

- Method of static testing connection between the facade system elements and sandwich panels on the action of wind (longitudinal) and self-weight (shear) forces;
- Method of testing for the action of a cyclic (breakout) load;
- Investigation of strength and deformation of fastening under the action of calculation loads;
- Recommendations for different types of fastening application.

The task of the study is to determine the bearing capacity for combinations of different facade systems fastening types to sandwich panels

## 2. Materials and Methods

The object of a study – is connection between the bearing and supporting brackets of facade systems with sandwich panels with external and internal zinc-coated steel sheets, at least 0.5 mm thick and mineral wool insulation (total panel thickness in experimental tests was 150 mm).

[1] Photo link: https://yandex.ru/maps/-/C6aqM-6f

Research for defining the bearing capacity included several types of fastening to sandwich panels:

1. Fixing system by self-tapping screw [14] to the structure from the following composition: zinc-coated steel sheet with thickness 1 mm; sandwich panel t = 150 mm (0.5 / 0.5); steel zinc-coated sheet with thickness 1 mm. Type 1, abbreviated name “1+1” (Fig. 5).

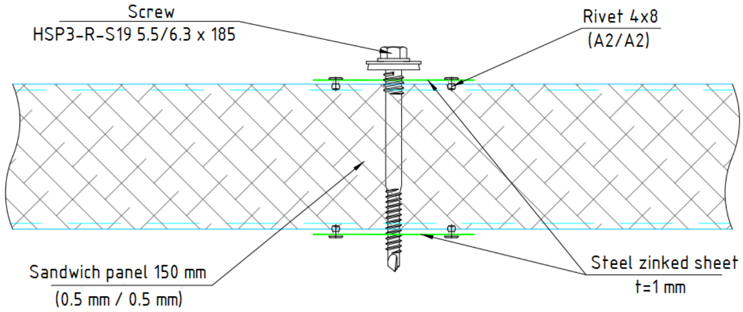



**Figure 5. Experimental type of fixing (Type 1 – “1+1”)**

2. Fixing system by self-tapping screw to the structure from the following composition: sandwich panel t = 150 mm (0.5 / 0.5); zinc-coated steel sheet with thickness 1 mm from the inside. Type 2, abbreviated name “0+1” (Fig. 6).

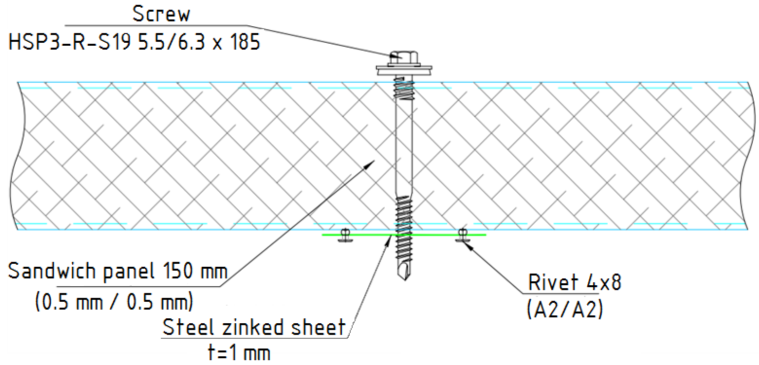



**Figure 6. Experimental type of fixing (Type 2 – “0+1”)**

3. Fixing system by self-tapping screw to the structure from the following composition: sandwich panel t = 150 mm (0.5 / 0.5); zinc-coated steel sheet with thickness 2 mm from the inside. Type 3, abbreviated name "0+2" (Fig. 7).

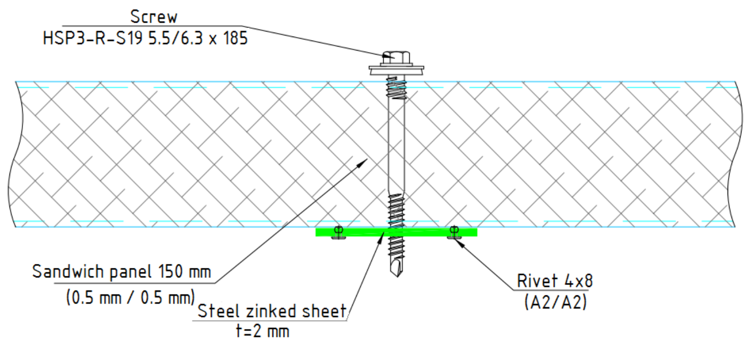
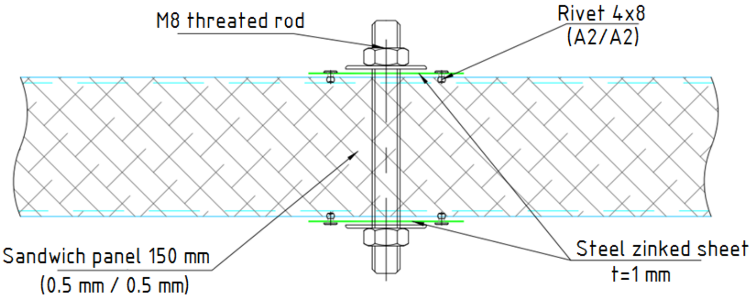



**Figure 7. Experimental type of fixing (Type 3 – “0+2”)**

4. Fixing system by threaded rod with M8 diameter to the structure from the following composition: zinc-coated steel sheet with thickness 1 mm; sandwich panel t = 150 mm (0.5 / 0.5); steel zinc-coated sheet with thickness 1 mm. Type 4, abbreviated name “TR 1+1” (Fig. 8). If this connection applied on construction objects, it is necessary to use the methods of locking the threaded connection provided by the existing normative documentation




1.

**Figure 8. Experimental type of fixing (Type 4 – «Threated rod 1 + 1»)**

5. Fixing system by self-tapping screw to the structure from the following composition: zinc-coated steel sheet with thickness 1 mm; sandwich panel t = 150 mm (0.5 / 0.5); steel plate with thickness 8 mm. Type 5, abbreviated name “1+8” (Fig. 9). This type of structure is considered to show, how system work in conditions of fixing to existing steel substructure and to restrict the limit values of thickness for supporting plates.

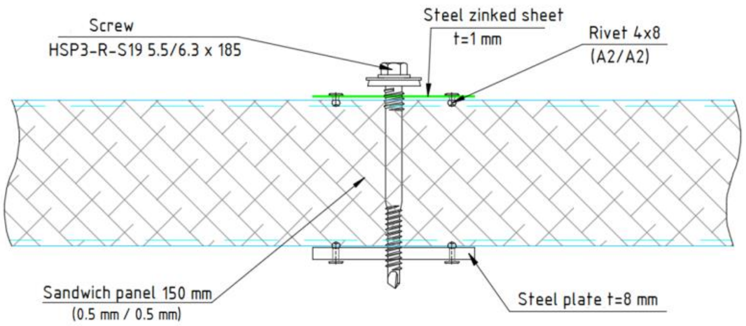



**Figure 9. Experimental type of fixing (Type 5 – “1+8”)**

Determination of the fastening bearing capacity of facade system brackets to the sandwich panels was performed in three stages:

I. Determination of the longitudinal force, necessary for the breakout of fixing element from the base material, or deformation, which leads to defects in the structure integrity.

II. Testing the full-sized sample of the bearing (the most loaded element of the system) bracket with the calculated wind (longitudinal) and self-weight (shear) load.

III. Determination of the sandwich panel deformation from the forces caused by the action of the weight and wind load acting on the facade system.

The essence of the first method is in test the fastening elements by the tensile load, applied to the connection element along its axis, determination the strength resistance and base deformation, setting of values for limit states. Stretching bearing capacity of the fixing elements calculated by processing the test results, must ensuring the work of the fixing element in the elastic conditions. In addition, rivet joints, installed near to the anchor, increases the bearing capacity of the joint and test must provide the most disadvantageous position of rivets.

The second method involves checking the calculated values on a full-size model in conditions of a complex stress state corresponding to the actual operation of the system and help to evaluate the accepted reliability coefficients for the design work. The principle of the test is to apply a constant vertical (weight) load to the fragment of a façade system and sequential increase of the horizontal (wind) load to determine the critical value of the applied force group. Experimental sample loaded by stages with subsequent unloading to determine the value of inelastic deformations. After evaluation of residual effects, the sample loading until the appearance of the first limit state signs on the fixing element or on the supporting base.

The third method is designed to determine the maximum possible displacements of the building base under the action of a concentrated load, evaluate the rigidity of the sandwich panel and perform a comparative analysis for compliance with the second limit state.

For the first test was applied method, given in [15].

Measuring instrument: Hydrajaws 2000, EMC 91/130364526/100613273 (Fig. 10) – hydraulic jack "hydrajaws limited".

**Figure 10. Measuring instrument (tensile machine)**

On the Figure 11, shown sample of a panel, in which was installed fixing elements for test.

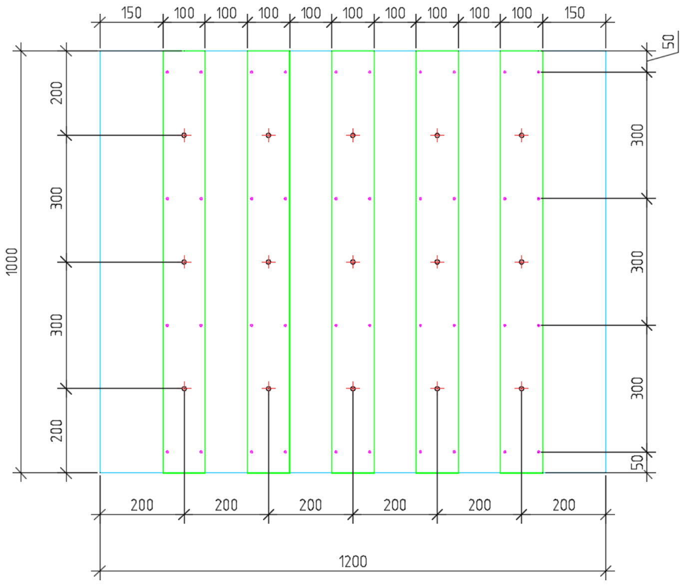
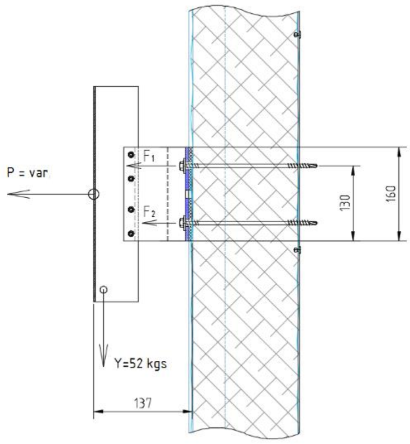


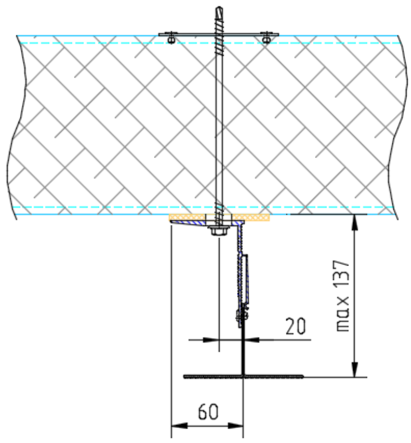

**Figure 11. Sandwich panel test sample with a marking for the installation of fixings**

Self-tapping screws fixed in the basis in the most disadvantageous position, implying no effect of the rivet connections on the bearing capacity required for plate mounting.

The basis for the analysis of the second testing is a comparison of the obtained values of the tearing force in full-sized modeling with the results obtained by pulling along the longitudinal axis of the fixing element during the first testing. The difference in the values lies in the fact that under operational loads, not only the longitudinal force comes to the bracket, but also the shearing loads in combination with the bending moment, caused by the effect of the weight of the liner and the subsystem. Conditions for the most disadvantageous position of system were determined during the test and include the maximum span of the system adopted on basis of [14] of 137 mm and the height of the bracket of 130 mm (Figs. 12 and 13). At this case, the specimen is the most loaded upper fixing element, as it connects with the action of bending moment. In addition, it is necessary to take into account in the calculation the eccentricity of the load application in the plan, shown in Figure 12.

To calculate the value of $F_1$ with taking into account action of the moment in two planes, the standards of the manufacturer of anchor technics for this type of impact should be considered.




**Figures 12 and 13. Scheme for testing the fixing element in the second stage**

# 3. Results and Discussion

## 3.1. The first stage of the study

Process of experimental determination of the longitudinal force, necessary for the breakout of fixing element from the base material, is shown on Figures 14 and 15.

As a result, the following parameters were found for each type of structure:

***Table 1. The results of the pull out tests of structure Type 1 (“1+1”)***

| № | Name | Applied longitudinal load (kN) | The mean square deviation of unit load values (kN) | Type of failure |
|---|---|---|---|---|
| 1 | 1+1 | 2.17 | 0.000 | Pull out a screw |
| 2 | 1+1 | 2.18 | 0.001 | Pull out a screw |
| 3 | 1+1 | 2.59 | 0.192 | Pull out a screw |
| 4 | 1+1 | 2.09 | 0.004 | Pull out a screw |
| 5 | 1+1 | 2 | 0.023 | Pull out a screw |
| 6 | 1+1 | 1.88 | 0.074 | Pull out a screw |
| | | $N = 2.15\ kN$ | $S = 0.242\ kN$ | |

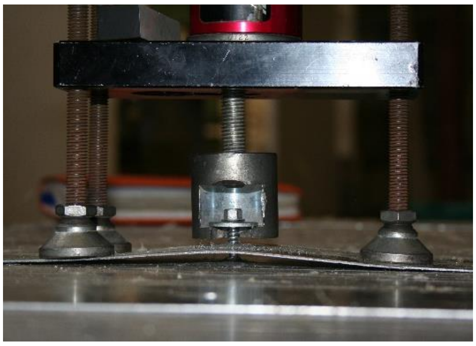


**Figure 14 and 15. Process of pulling out a screw (left), hole in the plate after the pull out (right)**

Average value of load [15]:

$$N = \frac{\sum_{i=1}^{n} N_i}{n} = \frac{12.91}{6} = 2.15\ kN \qquad (1)$$

The mean square deviation of unit load values:

$$S = \sqrt{\frac{\sum_{i=1}^{n}(N_i - N)^2}{n-1}} = 0.242\ kN \qquad (2)$$

Variation coefficient:

$$\nu = \frac{S}{N} = 0.11 \quad (3)$$

Design value of resistance for calculations:

$$R = \frac{N(1 - t\nu)}{m} \quad (4)$$

where $m$ – Reliability coefficient of the material ($m = 1.3$ according to [14]);

$t$ – Coefficient corresponded to the lower limit of the bearing capacity of the anchor with security 0.95 at veracity of 90 % (For 6 tests t = 3.091 according to [15] Table 1).

$$R = \frac{2.15 \cdot (1 - 3.091 \cdot 0.11)}{1.3} = 1.08\ kN \quad (5)$$

As fixing elements were set in laboratory, it is necessary to reduce the results by coefficient of the working conditions

$$R_c = \frac{\mathrm{R}}{\gamma_n} = \frac{1.08}{1.1} = 0.98\ kN \quad (6)$$

***Table 2. The results of the pull out tests of structure Type 2 (“0+1”)***

| № | Name | Applied longitudinal load (kN) | The mean square deviation of unit load values (kN) | Type of failure |
|---|---|---|---|---|
| 1 | 0+1 | 2.68 | 0.375156 | Pull out a screw |
| 2 | 0+1 | 1.63 | 0.191406 | Pull out a screw |
| 3 | 0+1 | 1.72 | 0.120756 | Pull out a screw |
| 4 | 0+1 | 2.13 | 0.003906 | Pull out a screw |
| 5 | 0+1 | 2.32 | 0.063756 | Pull out a screw |
| 6 | 0+1 | 1.82 | 0.061256 | Pull out a screw |
| 7 | 0+1 | 2.71 | 0.412806 | Pull out a screw |
| 8 | 0+1 | 1.53 | 0.288906 | Pull out a screw |
| | | $N = 2.07\ kN$ | $S = 0.47\ kN$ | |

Design value of resistance for calculations [15]:

$$R = \frac{2.07 \cdot (1 - 2.755 \cdot 0.22)}{1.3} = 0.6\ kN \quad (7)$$

$$R_c = \frac{\mathrm{R}}{\gamma_n} = \frac{0.6}{1.1} = 0.55\ kN \quad (8)$$

***Table 3. The results of the pull out tests of structure Type 3 (“0+2”)***

| № | Name | Applied longitudinal load (kN) | The mean square deviation of unit load values (kN) | Type of failure |
|---|---|---|---|---|
| 1 | 0+2 | 3.67 | 0.001344 | Pull out a screw |
| 2 | 0+2 | 3.88 | 0.030044 | Pull out a screw |
| 3 | 0+2 | 3.58 | 0.016044 | Pull out a screw |
| 4 | 0+2 | 3.76 | 0.002844 | Pull out a screw |
| 5 | 0+2 | 3.68 | 0.000711 | Pull out a screw |
| 6 | 0+2 | 3.69 | 0.000278 | Pull out a screw |
| 7 | 0+2 | 3.79 | 0.006944 | Pull out a screw |
| 8 | 0+2 | 3.56 | 0.021511 | Pull out a screw |
| 9 | 0+2 | 3.75 | 0.001878 | Pull out a screw |
| | | $N = 3.71\ kN$ | $S = 0.1\ kN$ | |

Design value of resistance for calculations [15]:

$$R = \frac{3.71 \cdot (1 - 2.645 \cdot 0.1)}{1.3} = 2.65\ kN \quad (9)$$

$$R_c = \frac{R}{\gamma_n} = \frac{2.65}{1.1} = 2.4\ kN \tag{10}$$

It was revealed in the course of experiment that the loss of the bearing capacity of joining type 4 – “Threated rod 1 + 1” and joining type 5 – “1 + 8” does not occur. The failure was caused by delamination of sandwich panel at $4.1\ kN$ (Figs. 16 and 17).

$$R_c = \frac{R}{\gamma_n \cdot \gamma_m} = \frac{4.1}{1.1 \cdot 1.3} = 2.87\ kN \tag{11}$$

**Figures 16 and 17. Delamination of sandwich panel**

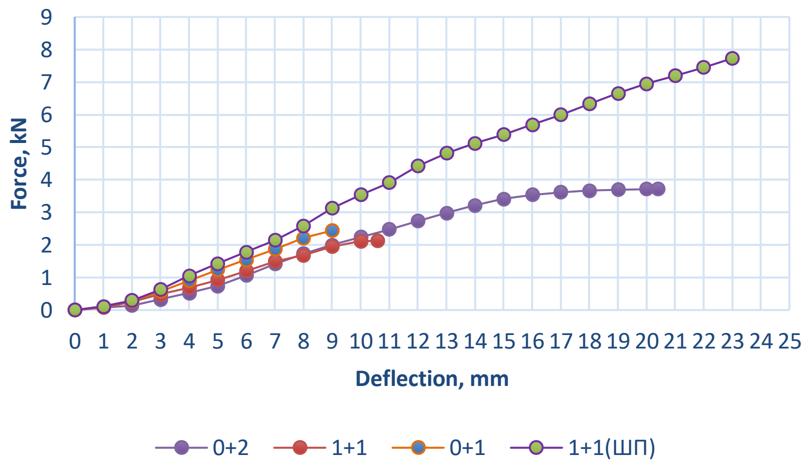



**Figure 18. Dependence of deformations on the tensile force**

### *3.2. The second stage of the study*

The experimental construction is shown in Figure 19.

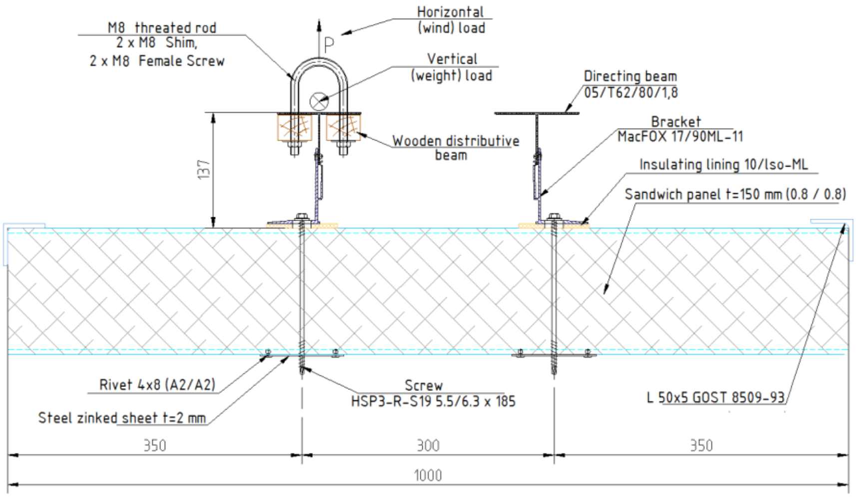



**Figure 19. Scheme of the experimental structure with fixing to the plate t = 2 mm**

Measuring instrument: strain gauge [18], accuracy class III according to [19].

Samples of joining Type 3 (“0 + 2”), Type 4 (“1 + 1”) and Type 5 (“1 + 8”) were not destroyed, but at a load of 595 kg the zinced sheathing began to flake off at the inner surface of the sandwich panel. This process developed most actively in the samples with fixing of the facade system by threated rod: the large diameter of shim M8 created a local zone of stress concentration and local areas of crumpling that contributed to the flaking of the sheathing.

***Table 4. The results of the tests of structures Type 1, Type 2 and Type 3***

| № | Number of samples | Fixing elements | | Load, kg | | | | **Type of failure** |
|---|---|---|---|---|---|---|---|---|
| | | Plates | Fixing tool | Weight | Stage 1 | Stage 2 | Max | |
| 1 | 1 | 1+1 | Screw | 52 | 257 | 314 | 437 | Pull out |
| 2 | 1 | 1+1 | Screw | 52 | 222 | 314 | 418 | Pull out |
| 3 | 1 | 1+1 | Screw | 52 | 222 | 314 | 418 | Pull out |
| 4 | 1 | 0+1.2 | Screw | 52 | 222 | - | 493 | Pull out |
| 5 | 1 | 0+1.2 | Screw | 52 | 222 | - | 456 | Pull out |
| 6 | 1 | 0+1.2 | Screw | 52 | 222 | - | 447 | Pull out |
| 7 | 1 | 0+1 | Screw | 52 | 222 | - | 428 | Pull out |

The breaking of bracket attachment to the sandwich panel occurred by pulling out the self-tapping screws from the sandwich with the simultaneous deformation of the shim of head of the self-tapping screw to the bracket.

The maximum load on stages 4, 5, 6 was higher than for 1, 2, 3 due to a small (0.2 mm) increasing of the thickness of the plate (from 1.03 to 1.22 mm).

The results of values of tensile forces in the top $(F_1)$ and bottom $(F_2)$ bracket fastenings, obtained during the second stage, are summarized in Table 5.

***Table 5. The value of tensile force based on the calculation results***

| № | Type of fixing | | Critical load, kN | | Longitude force, kN | | **Type of failure** |
|---|---|---|---|---|---|---|---|
| | Plates | Anchors | Weight (Y) | Wind (P) | $F_1$,kN | $F_2$,kN | |
| 1 | 1+1 | Screw | 0.516 | 4.29 | 3.470 | 3.104 | Pull out |
| 2 | 1+1 | Screw | 0.516 | 4.1 | 3.325 | 2.959 | Pull out |
| 3 | 1+1 | Screw | 0.516 | 4.1 | 3.325 | 2.959 | Pull out |
| 4 | 0+1.2 | Screw | 0.516 | 4.84 | 3.889 | 3.525 | Pull out |
| 5 | 0+1.2 | Screw | 0.516 | 4.47 | 3.607 | 3.242 | Pull out |
| 6 | 0+1.2 | Screw | 0.516 | 4.39 | 3.546 | 3.181 | Pull out |
| 7 | 0+1 | Screw | 0.516 | 4.2 | 3.401 | 3.035 | Pull out |
| 8 | 1+1 | Threated rod | 0.516 | 5.84 | 4.651 | 4.289 | Delamination |
| 9 | 1+8 | Screw | 0.516 | 5.84 | 4.651 | 4.289 | Delamination |
| 10 | 0+2 | Screw | 0.516 | 5.84 | 4.651 | 4.289 | Delamination |

Results of numerical determination of forces $F_1$ and $F_2$ obtained in calculation comlex Hilti Profis Anchor (Fig. 20).

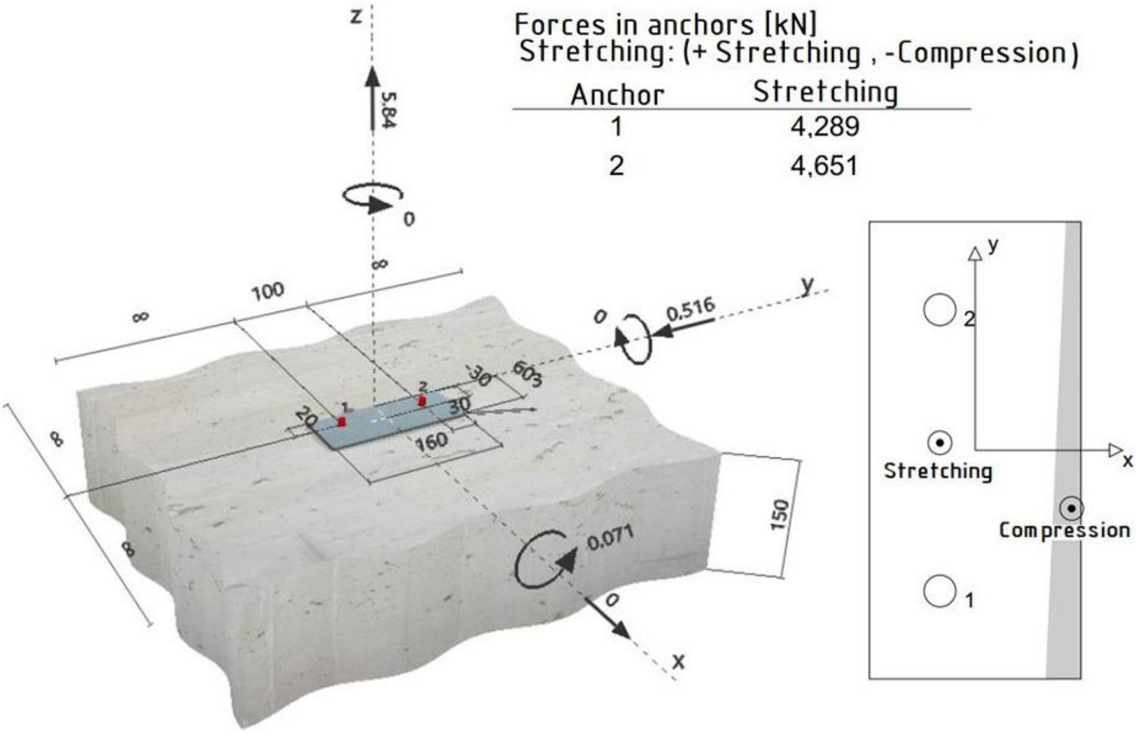



**Figure 20. Design scheme, stress distribution along the base of bracket and the results of calculation (according to [21])**

### *3.3. The third stage of the study*

Experiments that are carried out to determine deformations of a wall sandwich panel impacted by load from an facade system make possible to conclude about occured stress-strain state of structures. The experimental construction is on Figure 21.

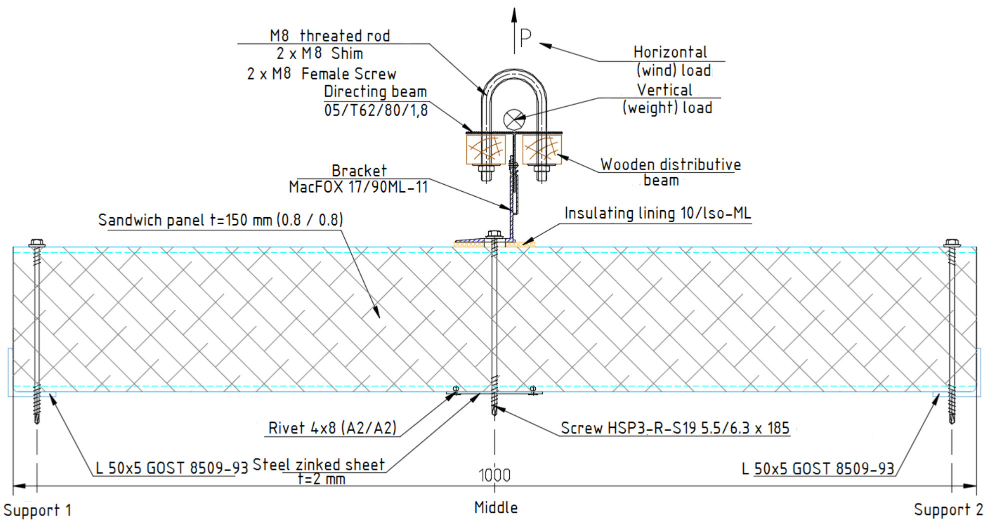



**Figure 21. Scheme of the experimental structure for determination of deflections**

Measuring instruments: deflectometer [20] for determining the values of displacement of considered points of structures under static loading; strain gauge [18], accuracy class **III** according to [19].

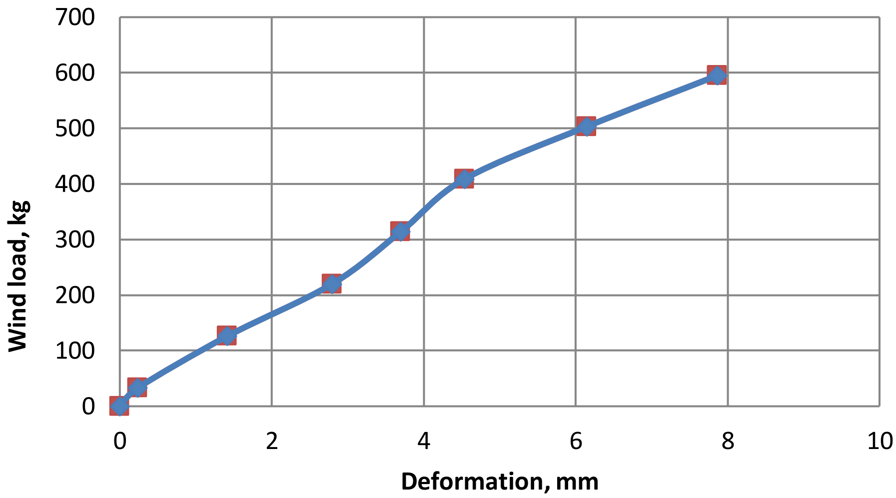



**Figure 22. Averaged displacement chart**

Thus, it is possible to draw a generalized conclusion about the operation of the structure for various types of fixing elements used. Table 6 gives the values of the longitudinal force of the fixing element necessary for the pulling out or deformation of the base, which causes structural integrity violation.

***Table 6. Summary of the pull out tests***

| № | Name | Average calculative critical longitude force (kN) | Type of failure |
|---|---|---|---|
| 1 | 0+1 | 0.55 | Pull out |
| 2 | 1+1 | 0.98 | Pull out |
| 3 | 0+2 | 2.4 | Pull out |
| 4 | Threated rod 1 + 1 | 2.87 | Delamination |
| 5 | 1+8 | 2.87 | Delamination |

On the basis of the obtained results, it can be concluded that self-tapping screws can be used as fixing elements of facade system to a bearing base by wall sandwich panel. In this case, the value of the bearing capacity of the joint is sufficient to resist the combined effect of peak wind loads and weight loads of the sheathing and the system within the design resistance to the breaking of the fixing element.

It is recommended to use sandwich panels with additional amplification by steel zinced plates with a thickness of at least 2 mm.

Usage of amplifying plates with a thickness of 1 mm in combination with self-tapping screw for fixing the brackets is not allowed due to considerable variation in the values of the tearing force (up to ± 0.58 kN) while testing in laboratory conditions. It is caused by small thickness of the thread of the self-tapping screw in the zinced plate and the random distribution of the thread turns while screw installation.

This conclusion is confirmed, in particular, by the limitations established in [14]: the minimum thickness of the plates in which it is allowed to install self-tapping screws HSP3 is 2 mm. The values of the tearing force obtained in experiment are close to the values of the critical force given in [14] for plates with 2 mm thick:

$$R_c^{STO} = \gamma_c \cdot \frac{F_{tn}}{\gamma_m} = 0.9 \cdot \frac{3.315}{1.3} = 2.3\,kN \qquad (12)$$

$$R_c = \frac{\mathrm{R}}{\gamma_n} = \frac{2.65}{1.1} = 2.4\,kN \qquad (13)$$

The difference in the value of 0.1 kN is explained by the presence of additional steel sheets (2 x 0.5 mm) in the sandwich panel structure, for which fixing is also carried out, but due to results they have no significant effect.

As an alternative method of fixing, it is allowed to use threaded rods with a diameter of 8 mm in combination with a washer and a nut. To prevent unscrewing of the joint, it is necessary to use the methods of locking the threaded connection.

In addition, on the basis of the tests, it can be stated that the fixing of the facade system by a self-tapping screw to the bearing steel structures (on the example of a plate 8 mm thick) is permissible and reliable.

On the basis of the test, it can be concluded that it is necessary to take into account the value of the edge distance from free edge of the sandwich panel to the axis of the fixing element installed by the panel manufacturers together with the producers of self-tapping screws. This requirement is set due to the need to prevent detachment of the inner sheathing of steel zinced sheet and mineral wool insulation. It is permissible not to take into account the value of the edge distance during installing the bracket in the immediate vicinity of the sandwich panel locks, and also during fixing of system elements directly to the frame of the building.

The design value of the tearing force for the object must be taken on the basis of full-scale tests of the sample with considering possible features of sandwich panels, self-tapping screws and amplifying zinced plates. The test can be performed according to the methodological instructions described in [15].

Analysis, based on the results of pull-out tests, is confirmed by the study of static operation of full-size models. Samples fixed with self-tapping screws in the sandwich panel with amplifying zinced steel plate 2 mm thick, and samples with a threaded rod and fixing in a steel plate 8 mm thick have sufficient bearing capacity for perception of loads from façade system. The first (ultimate) limit state was obtained due to detachment of sandwich panel near free edge of panel. At the same time, the connection remains bearing capable.

Samples, which are fixed to zinced plate 1 mm thick, were destroyed during tests: first (ultimate) limit state occurred as a result of pulling the self-tapping screw out of the steel zinced plate. As in the case of pull-out testing, there was a significant variation in the values of the critical load, what confirms the thesis of the small thickness of gearing of the thread of self-tapping screw in the zinced plate and the random distribution of the thread turns while screw installation.

Analysis of cyclic loading (loading-unloading-loading) revealed no significant residual deformations and decreasing of bearing capacity of the connection in the samples, taking into account the work within the design resistance of the fixing element.

Tests indicated necessity of replacement the standard sealing EPDM shim of self-tapping screws by two shims M6 DIN 9021 due to significant deformations caused by the compression of the sealing rubber under loading (Fig. 23).

**Figure 23. Difference between using of rubber and steel plates**

It led to heeling of the screw, which causes additional deformations of the sample. When using double shims, such deformations were eliminated. In the design of facade systems, it is necessary to precise this requirement in working documentation.

The difference in the results in the first and second test groups is explained by the effect of the weight (shear) load on the bearing capacity of the threaded connection in fixing to the sandwich panel. This effect contributes a better gearing of the thread of the self-tapping screw to the zinced amplifying plate.

At the same time, the physical modelling demonstrated a greater bearing capacity of the joint than results of the longitudinal tearing of self-tapping screws.

In this way, when designing structures of façade system, it is recommended to adhere to calculated resistance to the tearing of the fixing elements obtained from the first test group (pulling out due to [15]), because coverings used at the construction sites have different weight characteristics and amplifying impact on the connections. The additional bearing capacity, acquired due to the weight of covering, is taken into the safety margin of the system.

The obtained values of deformation for facade system fixed to sandwich panel by self-tapping screw and a zinced plate 2 mm thick must be correlated with the requirement [22] for second (serviceability) limit state (the value of permissible deformations).

In accordance with paragraph E.2.4.3 [22], "The horizontal limit deflections of the racks and girders, as well as of wall hinged panels, from wind load, must be taken as l / 200, where l is the design span of the racks or panels".

Thus, for panels with a height between clutch locks 1200 mm:

$$f_{per} = \frac{1200}{200} = 6\ mm \tag{14}$$

Maximum permissible load for the "0 + 2" system:

$$R_c = 2.4\ kN \tag{15}$$

Therefore, on the basis of the deformation diagram given in Figure 22, the value of deflection under the given load will be:

$$f_{(2,4\ kN)} = 3\ mm < f_{per} = 6\ mm \tag{16}$$

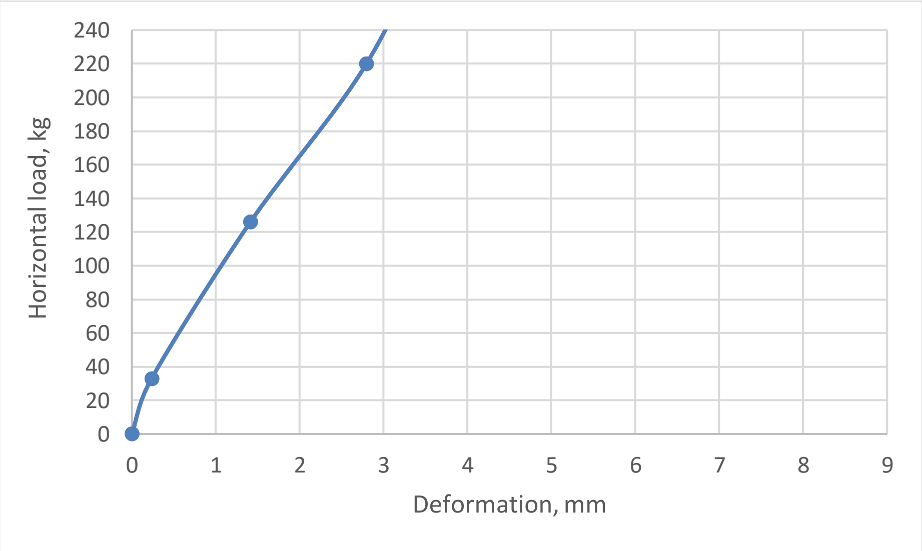



**Figure 24. Enlarged graph of the averaged displacement, shown on Figure 22**

In this way, it can be concluded that the fixing of facade system to the sandwich panel 150 mm thick using a self-tapping screw and a zinced plate t=2 mm satisfies the requirement of the second (serviceability) limit state.

## *4. Conclusions*

According to the results of the study, it can be concluded that use of self-tapping screws as element, which provides fixing of facade system [13] to a wall sandwich panel jointly with an amplifying plate with a thickness of at least 2 mm. An alternative method of fixing is the use of self-tapping screws as fixing element with fastening to the bearing metal frame of the structure with thickness of at least 2 mm. It is also possible to replace the self-tapping screw with a M8 threaded rod fixed on both sides with a shim M8 and female screw M8, in this case, it is permissible to use amplifying plates with a thickness of at least 1 mm. Thread locking means on construction objects must be provided by the existing normative documentation.

While designing a façade system structure, it is recommended to adhere the following conditions:

- To act in accordance with the calculated value of the resistance of the fixing elements to the tearing force, obtained by the method [15].
- To replace the standard EPDM shim of self-tapping screw with double shim in the working documentation to eliminate deformations and heels associated with the compression of the rubber seal.
- To note that the application of self-tapping screws must be carried out taking into account the aggressiveness of the environment in accordance with technical certificate, and the steel and zinced elements must be protected against corrosion in accordance with [23, 24].
- To take into account the values of the edge distance between free trimmed edge of the sandwich panel and axis of the fixing element, which is set by manufacturers of panels jointly with the manufacturers of self-tapping screws.

## *5. Acknowledgment*

The group of researchers thanks the company NordFOX and Teplant for the provided elements of facade systems and sandwich panels.

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Галямичев А.В., Кирикова В.А., Герасимова Е.А., Спринце А. Несущая способность крепления навесных фасадных систем к сэндвич-панелям // Инженерно-строительный журнал. 2018. № 2(78). С. 30–46.