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## Effective design solutions for ventilated facades

**Abstract.** The article investigates a cold-formed steel subsystem for ventilated facades, considering the composite action of studs, brackets, and fastening elements. An analytical calculation is combined with numerical modeling to evaluate the structural behavior under service loads and to determine rational variants of its geometric configuration. It is shown that the load-bearing capacity and deformability of the system significantly depend on the profile thickness, support scheme, and the nature of force transfer within the joints. The obtained results confirm the feasibility of a comprehensive design approach to the facade subsystem, in which not individual elements are assessed, but the entire structural system as a whole.

**Keywords:** ventilated facade, cold-formed steel, thin-walled profile, brackets, structural analysis, numerical modeling

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### Introduction.

Ventilated facades are widely used in modern construction due to their combination of operational reliability, manufacturability, and adaptability to various structural conditions. The load-bearing subsystem is particularly important, as it ensures the fixation of the cladding and the transfer of the main loads acting on the facade. In this regard, there is a need to substantiate the rational parameters of the subsystem elements that ensure its performance and economic efficiency.

### Review of the research sources and publications.

The design of ventilated facades and cold-formed steel elements is an important area of modern construction science, as these structures combine manufacturability, relatively low weight, and high efficiency within building envelope systems. In scientific sources, ventilated facades are considered multi-component systems in which operational characteristics depend not only on the cladding and insulation, but also on the load-bearing subsystem that transfers loads to the building's main structure [1]. A separate area of research is devoted to cold-formed steel profiles, which are widely used in frame and facade systems due to the ability to manufacture thin-walled, complex-shaped elements with high geometric accuracy. Such studies emphasise that the design of thin-walled elements requires consideration of effective geometric characteristics of cross-sections, local and global buckling, and connection behaviour [2,

3]. Publications devoted to cold-formed steel structures highlight that, for open-section profiles, decisive factors include the ratio of element width to thickness, the presence of edge and intermediate stiffeners, and the nature of element fixation in joints. These factors determine the applicability limits of the profile in real structural schemes and form the requirements for verifying the load-bearing capacity of both cross-sections and elements as a whole [2, 4]. For ventilated facades, particular importance is given to the coordination of the behaviour of vertical studs, load-bearing and support brackets, and fastening elements. Scientific studies show that even with sufficient strength of individual components, the structure may lose serviceability due to local deformations in connection zones, uneven force distribution, or an improper choice of support scheme. Therefore, modern approaches to the design of such systems are based on a comprehensive analysis of all subsystem elements rather than solely on verifying an individual profile [1, 3, 5]. An important component of scientific research is also the issue of steel efficiency in thin-walled elements. It has been shown that cold forming alters the material's mechanical properties in bending zones. Therefore, both nominal and effective cross-sectional characteristics must be considered in design. This is of direct importance for studs and brackets of facade systems, where the structure operates under wind loads, local compression, tension, and combined action of forces [2, 4, 6].

### Definition of unsolved aspects of the problem.

Despite the availability of a regulatory framework and numerous studies, the problem of rational design of the vertical subsystem of a ventilated facade remains relevant. First of all, this is because, in real conditions, the system elements operate within a complex spatial scheme, where loads are distributed unevenly depending on the building height, the position of the facade section, and the nature of wind effects [1, 2]. One unresolved aspect is substantiating the optimal number of supports for the stud and the arrangement of brackets along its length. For thin-walled C-shaped profiles, the support scheme can significantly alter the diagrams of bending moments and shear forces, and thus affect the ultimate uniformly distributed load. This means that for identical geometric dimensions of the profile, it is necessary to separately determine rational operating configurations for the windward and leeward sides of the facade [2, 4]. The second problematic issue is determining the limits of applicability of specific steel thicknesses for studs and brackets. As the thickness decreases, the risk of local buckling increases, stiffness decreases, and excessive deformations may occur in the connection zones. At the same time, increasing the thickness leads to higher material consumption and a higher structure cost.

Therefore, a technically justified balance between load-bearing capacity, stiffness, and economic efficiency of subsystem elements is required [3, 5]. The third unresolved aspect is the combined behaviour of the stud, load-bearing bracket, support bracket, and self-tapping screws as a single system. In design practice, the main profile and fasteners are often verified separately; however, in facade systems, the critical point may be their interaction. Local stresses in the hole zones, reduction of cross-sectional area, and the specifics of force transfer through fastening elements require separate evaluation [3, 6].

Thus, the problem lies not only in determining the load-bearing capacity of individual elements, but also in developing a consistent calculation model of the entire vertical facade subsystem. Therefore, for further analysis, it is necessary to perform a comprehensive calculation of studs, brackets, and fasteners, taking into account the actual support scheme, the geometric parameters of the cross-sections, and the operating conditions of the structure [1–6].

### Basic materia and results.

The calculation part is devoted to the selection of rational parameters of the vertical subsystem of a ventilated facade made of cold-formed steel elements. As a basis, C-shaped studs, load-bearing brackets KH, and support brackets KO made of galvanised steel DX51D with Zn140 coating are adopted. The calculation is performed for elastic behaviour, taking into account the requirements of [4]. The designed subsystem is vertical and operates according to a structural scheme in which the upper part of the stud is hinged and fixed to the first load-bearing bracket, while the intermediate supports are assumed to be hinged and movable. The stud is subjected to a uniformly

distributed wind load from the windward and leeward sides. For corner zones of the building, the leeward scheme is considered more unfavourable due to increased pressure. For the calculation, three stud lengths are specified (Figure 1) - 3.0, 3.3, 3.6 m - and five variants of metal thickness - 0.7, 0.8, 0.9, 1.0, and 1.2 mm - from a strip of width 178.5 mm (1/7 of a standard coil of width 1250 mm). The stud width is 60 mm, and the depth is 40 mm, which ensures convenient fastening of the facade clamp and compensation of base irregularities.

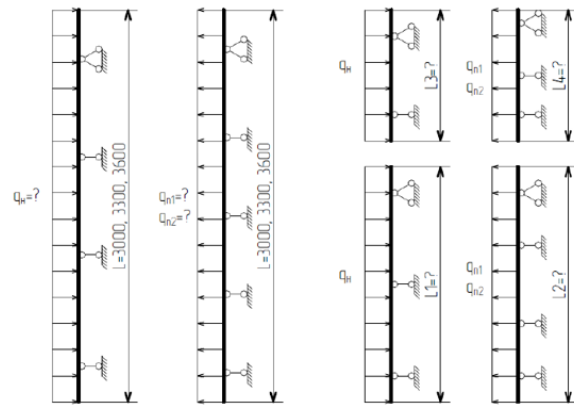


Figure 1 – Design schemes of C-shaped studs

The stud width is 60 mm, allowing a clamp to be fastened to its front surface for hanging the finishing panels. The stud depth is set to 40 mm, allowing it to be fastened to the brackets with a 25 mm clearance to compensate for the curvature of the walls being clad (Figure 2). The edge bends are designed in such a way that a 19 mm self-tapping screw can be used (Figure 2). The studs are positioned with the edge bends facing the wall.

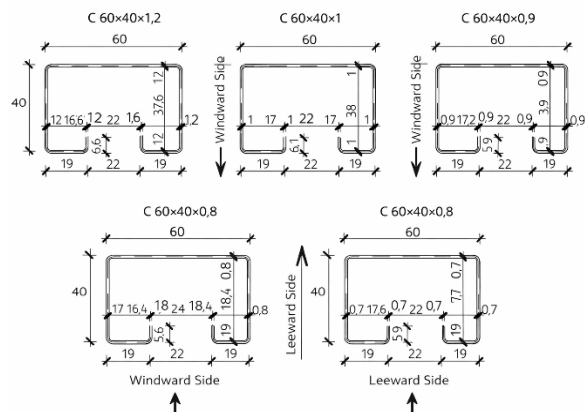


Figure 2 – Transverse sections of C-studs

Load-bearing brackets carry compressive forces from the stud and additional loads from the cladding, while support brackets operate, taking into account the weight of the cladding material. For both types of elements, a set of lengths of 300, 250, 200, and 150 mm and several sheet thickness options are adopted. The fastening of the stud to the brackets is carried out using self-tapping screws with a hex head; 2–4 fastening points are предусмотрены for load-bearing elements



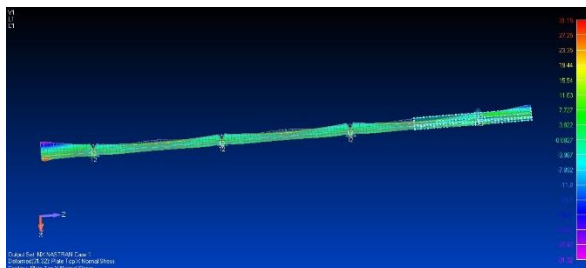


Figure 8 – Distribution of normal stresses in the upper flange of the C-stud

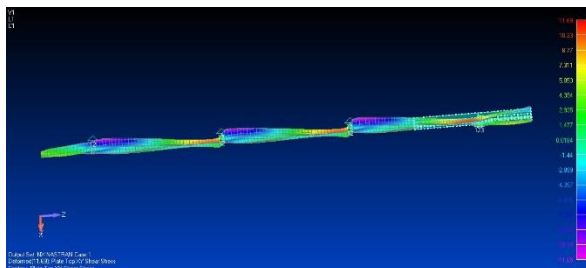


Figure 9 – Distribution of shear stresses in the C-stud

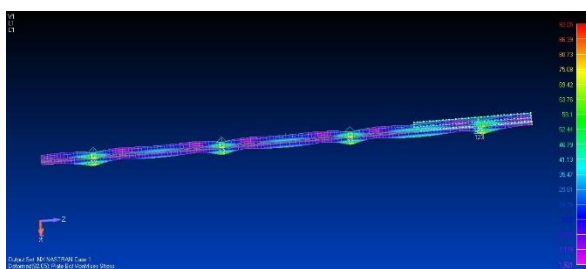


Figure 10 – Distribution of shear stresses in the C-stud

For further comparison of analytical and numerical results, the obtained effective geometric characteristics are summarized in Table 1. It shows that with an increase in profile thickness, the load-bearing capacity of the stud increases. Based on these values, Table 2 is formed with allowable stresses and parameters of the design performance of C-studs.

Table 1 – Allowable stresses of C-studs

Designation of quantities according to [4–7]	Units	Value				
$f_{yb}$	MPa	140	140	140	140	140
$\lambda_w$	MPa	0,51	0,45	0,40	0,36	0,30
$f_{bv}$	MPa	81,2	81,2	81,2	81,2	81,2

According to Table 1, for a C-stud with a 60×40 mm web, the following calculated values were obtained and entered in Table 2.

Table 2 – Allowable loads on the C-stud

Designation of quantities according to [4–7]	Units	Value				
Thickness	mm	0,7	0,8	0,9	1,0	1,2
$q_M$	κH/m	2,54	2,91	3,28	3,65	4,37
$q_{M+Fw}$	κH/m	1,20	1,47	1,76	2,07	2,70
$q_{M+N}$	κH/m	2,20	2,58	2,96	3,34	4,08
$q_{M+N+Fw}$	κH/m	1,07	1,34	1,63	1,93	2,55
$q_v$	κH/m	10,35	11,83	13,31	14,79	17,75
$q_{M+N+V}$	κH/m	1,81	2,22	2,54	2,85	3,37
$q_{M+N+V}$	κH/m	1,07	1,34	1,63	1,93	2,55
$q_{min}$	κH/m	1,07	1,34	1,63	1,93	2,55

In the presented form, the material allows combining analytical calculation, numerical modeling, and interpretation of results within a single logical framework, which corresponds to the objective of substantiating rational parameters of the vertical subsystem of a ventilated facade.

### Conclusions.

The study established that the load-bearing capacity of the vertical subsystem of a ventilated facade is determined not by an individual element, but by the combined action of studs, load-bearing and support brackets, and fasteners. The greatest influence on the performance of the system is exerted by the thickness of the cold-formed profile, the support scheme, and the level of wind load. The conducted analysis showed that with an increase in the stud thickness, the overall stiffness and load-bearing capacity of the subsystem increase. This confirms the feasibility of selecting the parameters of the facade structure based on the calculation of effective geometric characteristics and verification of element behavior in the elastic stage.

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## Ефективні проєктні рішення для вентилязованих фасадів

**Анотація.** Вентилювані фасадні системи з металевою несучою підсистемою посідають важливе місце в сучасному будівництві, оскільки дозволяють поєднати конструктивну легкість, технологічність монтажу та можливість застосування в будівлях різного призначення. Їхня ефективність залежить не лише від властивостей облицювання, а насамперед від раціонального вибору несучих елементів, які забезпечують сприйняття та передавання навантажень на основну конструкцію. У зв'язку з цим особливого значення набуває оцінювання роботи стійок, кронштейнів і кріплень як єдиного конструктивного комплексу. У роботі досліджено поведінку фасадної підсистеми з холодноформованих сталевих елементів за різних варіантів геометричного виконання та схем опирання. Розглянуто вплив товщини профілю, довжини елементів і конструкції вузлів на зміну несучої здатності та жорсткості системи. Для аналізу застосовано поєднання розрахункових залежностей і чисельного моделювання, що дало змогу простежити особливості напружено-деформованого стану, встановити характер переміщень елементів та виявити зони, де виникають найбільші зусилля. Отримані результати показують, що підвищення надійності фасадної підсистеми досягається не окремим посиленням одного елемента, а збалансованою роботою всієї системи, включно з місцями з'єднань та передавання навантажень. Запропонований підхід може бути використаний під час проєктування легких сталевих фасадних конструкцій для вибору раціональних параметрів їх елементів і підвищення загальної ефективності системи.

Ключові слова: вентиляований фасад, холодноформована сталь, тонкостінний профіль, кронштейни, розрахунок конструкцій, чисельне моделювання.

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