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FRAME STRUCTURES MADE OF COMPOSITE STEEL-TIMBER I-BEAMS WITH CORRUGATED STEEL WEBS

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Abstract. Frame structures made of composite steel–timber I-beams with transversely corrugated steel webs represent an innovative composite solution in the construction industry, combining the strength of steel with the environmental benefits of timber. These structures offer significant advantages, including a high strength-to-weight ratio, improved thermal and acoustic performance, enhanced seismic resistance, and high corrosion resistance. From an economic perspective, their use reduces overall construction costs due to lower self-weight, high manufacturability, and ease of installation. The combination of a thin profiled steel web and massive timber flanges ensures optimal utilization of the physical and mechanical properties of both materials, increasing the load-bearing capacity and stiffness of the elements while reducing their weight by a factor of 2–3 compared to traditional steel or solid timber beams The technological aspects of manufacturing elements of constant and variable cross-section are revealed, including the mechanical pressing of the corrugated wall into the wood and glue joints based on two-component epoxy mixtures. The ability to adjust the height of frame cross-sections allows for the optimization of material consumption depending on the bending moment diagram, which increases the efficiency of structures. The advantages of such structures in thermal insulation and prevention of thermal bridges, improved acoustic comfort, long-term durability, and corrosion resistance due to the use of galvanized steel are highlighted.

For Ukraine, the implementation of frame structures made of composite steel–timber I-beams is of strategic importance. They will contribute to increasing the competitiveness of domestic production, reducing dependence on imported materials and technologies, and supporting the development of the country's scientific and engineering potential. Further development and standardization of these structures open broad prospects for creating energy-efficient, reliable, and economically viable buildings, which is critically important in the context of infrastructure reconstruction and modernization.

Keywords: frame structures; steel-timber beam; composite beam; HTS beam.

INTRODUCTION

Definition and concept of steel-timber composite structures

Frame structures made of steel-timber I-beams represent an advanced type of composite profile construction that integrates the properties of two different materials – steel and timber [11, 12].

Steel-timber I-beams are also known as "composite beams" or "HTS beams," indicating their belonging to the category of high-tech hybrid structures.

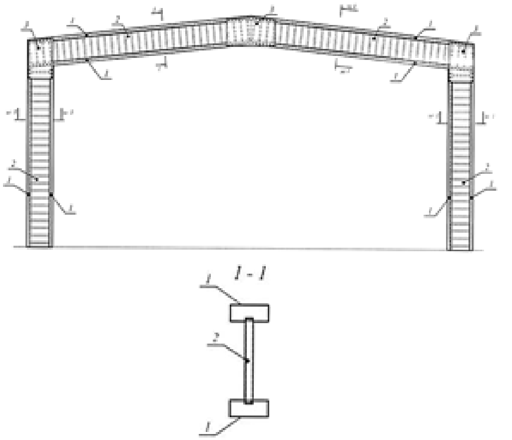

Fig. 1 Frame made of composite steel-timber I-beams with a transversely corrugated steel web:
1 – timber beam flange;
2 – web made of steel profiled sheet with a trapezoidal corrugation shape;
3 – reinforcing plywood plates

Рис. 1 Рама композитного металодерев'яного двотаврового перерізу з поперечно гофрованою стінкою:
1 – пояс з клеєної деревини;
2 – стінка з поперечно-гофрованим трапецевидним перерізом;
3 – підсилюючі дерев'яні накладки

The fundamental idea underlying these hybrid solutions is to use the strengths of each material to compensate for their individual weaknesses.

The principle of material optimization is central to the concept of steel-timber I-beams. Steel, especially in a thin corrugated form, is extremely effective in resisting shear forces, making it ideal for the beam web. Timber, in turn, in the form of solid or glued flanges, perfectly withstands significant normal stresses along the fibers and, due to its massiveness, provides the flexural-torsional stability of the beams [1, 2, 6, 13, 17, 23, 24, 25].

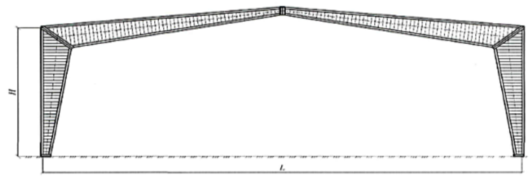

Fig. 2 Variable cross-section frame made of composite steel-timber I-beams with a transversely corrugated steel web

Рис. 2 Рама змінного перерізу, виготовлена з композитних метало-дерев'яних дво-таврових балок із поперечно гофрованою сталевою стінкою

Thus, each material is placed in the part of the cross-section where it functions with maximum efficiency under typical loads (bending moments and shear forces). This approach leads to the creation of a significantly more efficient overall cross-section compared to using either of these materials separately for the same structural function [5, 10]. This is a direct application of construction mechanics principles to achieve higher performance.

Relevance and prospects for development in Ukraine

The current state of the construction market in Ukraine, amidst infrastructure damage and destruction, necessitates the development of new effective structural forms. These forms must have less dependence on production bases, allow for the use of local renewable materials, and ensure speed and ease of building erection [7, 8, 9]. Timber is one of the most accessible materials in this context. The Ukrainian market for metal structures is saturated with proposals from foreign enterprises, leading to capital outflow from the country and a gradual decline in scientific and engineering personnel. An urgent scientific and practical task is to increase the efficiency of metal structures so that domestic factories can compete with foreign manufacturers without fundamental re-equipment. This will allow the country to preserve production capacities, eliminate capital outflow, and maintain a high level of scientific potential in the industry.

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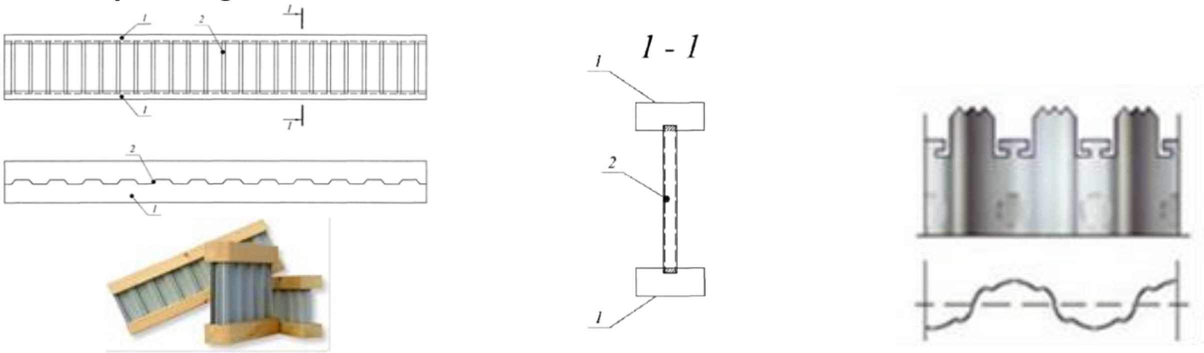
MATERIALS AND METHODS

Components: transversely corrugated steel web and timber flanges

The design of frame elements from composite steel-timber I-beams with a transversely corrugated steel web involves milling a longitudinal groove in the timber flanges of the I-beams (element 1 in Fig. 3), into which a steel profiled sheet is glued or pressed (element 2 in Fig. 3). The width of this groove precisely matches the height of the steel profile's corrugation.



a *b* *c*

Fig. 3: Construction of metal-and-timber I-beam: a – general appearance; b – cross-section; c – shape of the corrugated wall teeth for pressing into the wood belt.

Рис. 3: Конструкція металодерев'яної двотаврової балки: a – загальний вигляд; b – поперечний переріз; c – форма зубців гофрованої стінки для запресовування в дерев'яний пояс.

Galvanized metal sheet is used as the web, most often made of S550 GD + Z steel according to DIN EN 10147. The thickness of the steel sheet is usually 0,5-0,8 mm. The performance of these beams largely depends on advanced manufacturing technologies and careful material selection. The thinness of the steel web (0,5-0,8 mm) is key to reducing weight, but it is the corrugated profile that provides its stability, and the specific steel grade ensures the necessary strength.

Connection methods: mechanical pressing and adhesive bonding

To ensure a reliable connection between the steel profiled sheet and the timber flanges, two main methods are proposed: mechanical pressing of the rigid corrugated steel web into the timber flanges or connection using a two-component epoxy adhesive that demonstrates good adhesion to both metal and timber surfaces [18, 19].

Assembly, pressing, or gluing processes are carried out on specialized technological lines, the length of which can vary depending on the required length of the elements (Fig. 4). The reliability of the composite structure's performance critically depends on the quality of the connection between steel and timber. Mechanical pressing relies on friction and form-fitting, while adhesive bonding is based on chemical adhesion. The use of specialized technological lines indicates industrial, high-precision manufacturing that can be adapted to various element lengths.

Fig. 4: The technological line for connecting steel joints with timber belts. Photo by *WST Tragwerke GmbH*

Рис. 4: Технологічна лінія для з'єднання сталевих елементів із дерев'яними поясами. Фото виконано *WST Tragwerke GmbH*

Features of designing variable cross-section elements

Steel-timber I-beams can be manufactured as elements of constant cross-section or as structures with variable web height. The web thickness, the height of the steel sheet corrugation, and the dimensions of the timber flanges are determined by calculation.

The ability to vary the cross-section height (and, consequently, stiffness and strength) along the length of the I-beam allows for precise structural optimization (Fig. 5).

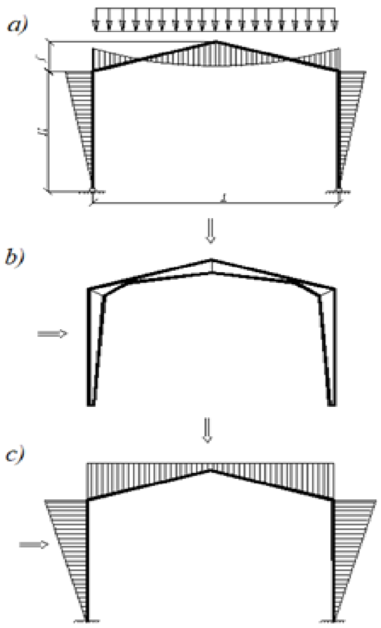


Fig. 5 Design scheme (a) , construction (b) , and material diagram (c) of a variable cross-section frame.

Рис. 5: Розрахункова схема (a), конструкція (b) епюра матеріалу (c) рами змінного перерізу

This means that material can be strategically placed in areas with the highest stresses (e.g., at supports or in the middle of the span for bending moments), leading to significant material savings compared to constant cross-section beams designed for peak loads. This principle of material distribution according to the bending moment diagram is directly applicable here, maximizing efficiency and minimizing waste [14, 15, 16, 20, 21, 22]

RESULTS AND DISCUSSION

The use of a metal profiled web in timber I-beams leads to an increase in the load-bearing capacity and stiffness of the profile, as well as a reduction in the required cross-section height. From a purely static point of view, the use of steel-timber beams is expedient for spans from 7 to 24 meters, where a solid timber cross-section typically cannot be used.

Reduction of self-weight and its consequences

Due to the lower density of timber and the use of a thin corrugated web, the self-weight of composite I-beams is 2-3 times less than analogous metal and solid rectangular timber elements. This significantly reduces building construction costs. For example, a steel-timber beam measuring 510/80/140 has a weight of 0,117 kN/m, which corresponds to a self-weight load of 0,25 kN/m². For comparison, a glued laminated timber beam with a cross-section of 140x420 mm weighs 0,28 kN/m, which corresponds to a distributed load of 0,70 kN/m². This significant reduction in self-weight has a cascading effect on the entire construction project. It directly leads to reduced loads on foundations, allowing for the design of smaller, simpler, and cheaper foundation systems. Lighter elements also simplify and accelerate transportation and installation processes, potentially reducing crane usage time, labor costs, and overall project timelines. This provides systemic cost savings that go beyond just the cost of the beam material itself, making the overall construction project more economical and efficient.

Thermal characteristics and insulation properties

The very thin steel web (0,5 mm) gives steel-timber I-beams excellent properties for manufacturing thermal insulation building elements. Their insulating properties are significantly better than when using solid or laminated timber beams, especially if the formation of thermal bridges needs to be avoided. With proper insulation installation, condensation will not form in the web area.

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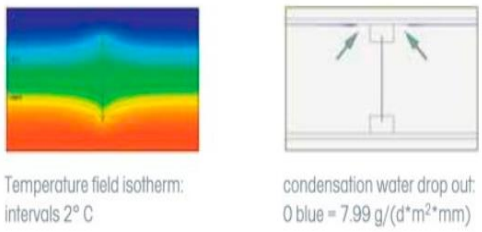

Fig. 6: Thermal insulation of panels with metal-and-timber beams
Рис. 6: Теплоізоляція панелей з металево-дерев'яними балками

Steel typically creates thermal bridges in composite structures. However, the thinness and corrugated shape of the steel web in this design, combined with the insulating properties of timber, effectively minimize this problem. The corrugated shape increases the heat transfer path through the web and allows for better integration of insulation into the web cavity, thereby enhancing the overall thermal performance of the composite element [3, 4]. This is a thoughtful design solution to overcome a common problem in hybrid structures.

Acoustic properties: vibration and noise absorption

The light steel web in these load-bearing systems reduces the transmission of vibrational oscillations, which positively affects sound absorption. In addition to structural efficiency, this design contributes to human comfort. The combination of materials and specific geometry (thin web, timber flanges) creates a damping effect on vibrations, reducing noise transmission. This means that the beams not only bear loads but also contribute to the overall acoustic performance of the building, making them suitable for applications where noise control is important (e.g., industrial, office, or residential buildings).

Durability and corrosion resistance

High corrosion resistance is ensured by the use of galvanized metal webs made of S550 GD + Z steel according to DIN EN 10147, with a zinc layer of at least 275 g/m² (approximately 40 µm). Under operating conditions with high humidity and a medium degree of air aggressiveness (e.g., industrial or urban atmosphere, or coastal climate with low chloride content), the expected service life of the protective zinc coating is 20-30 years. When used indoors, durability can reach 50 to 100 years. Hot-dip galvanizing has significantly better resistance to mechanical impacts compared to painted coatings due to the cathodic protection effect, even with minor surface damage. Additional reliability can be ensured by corrosion protection at the intersection of the flanges with the steel web when used in aggressive operating conditions.

Seismic resistance

The reduction of the frame's self-weight and the use of a flexible corrugated web in combination with the characteristics of timber provide building frame structures made of steel-timber profiles with increased seismic resistance. Seismic forces are directly proportional to the mass of the structure. A lighter structure inherently experiences smaller inertial forces during an earthquake, making it more stable. The flexible corrugated web and timber flanges in composite I-beams contribute to energy dissipation and ductility, allowing the structure to deform without brittle failure. This combination enhances the overall dynamic performance and safety of buildings in seismically active zones, making these structures a desirable choice for such applications.

Aesthetic qualities

The reduction of the frame's self-weight and the use of a flexible corrugated web in combination with the characteristics of timber provide building frame structures made of steel-timber profiles with increased seismic resistance. Seismic forces are directly proportional to the mass of the structure. A lighter structure inherently experiences smaller inertial forces during an earthquake, making it more stable. The flexible corrugated web and timber flanges in composite I-beams contribute to energy dissipation and ductility, allowing the structure to deform without brittle failure. This combination enhances the overall dynamic performance and safety of buildings in seismically active zones, making these structures a desirable choice for such applications.

Economic and production aspects

The assembly, pressing, or gluing of steel-timber beams takes place on specialized technological lines, allowing for the manufacture of both constant and variable height elements. A significant advantage is the manufacturability of these beams: traditional hand building tools are sufficient for their processing. Timber itself is easily processed, and the steel used in the web has a thickness of 0,5-0,8 mm and can be processed with hand circular saws. As noted earlier, the self-weight of composite I-beams is 2-3 times less than analogous metal and solid timber elements, which reduces building construction costs. For comparison, let's consider a frame with a span of 14,0 m at a design load of 3,0 kN/sq.m. The required cross-section of a steel-timber beam with a 510 mm steel web and 80x140 mm flanges will have a weight of 12,30 kg/lin.m. and a current retail price of approximately 28,0 euros/m. In contrast, for the same loads and overall dimensions, the required cross-section of a glued laminated timber beam will be 140x420 mm, with a cost of about 26,0 euros/m. Thus, despite a slight difference in material cost, the significantly lower weight of the steel-timber beam frame leads to substantial savings on foundations and installation costs. This comparison clearly demonstrates that while the initial cost per linear meter may be comparable or slightly higher for steel-timber beams, a compre-hensive economic analysis reveals a significant advantage. The reduction in self-weight directly leads to a cascade of savings: smaller foundations, less need for heavy lifting equipment, faster installation, and potentially reduced labor costs. This provides systemic cost savings that go beyond just the cost of the beam material itself, making the overall construction project more economical and efficient.

Table 1 Comparative characteristics of metal-timber I-beams and traditional materials.
Табл.1 Порівняльні характеристики металево-дерев'яних двотаврових балок і традиційних матеріалів

Characteristic	*Metal-timber I-beam*	*Traditional metal/solid timber beams*
Self-weight (relative to analogous)	2-3 times lighter	Base (1x)
Load-bearing capacity	Increased	Lower (relative to composite)
Stiffness	Increased	Lower (relative to composite)
Optimal span range	7-24 m	Solid timber typically limited for such spans
Thermal conductivity	Significantly better insulation, prevents thermal bridges	Less insulating, potential for thermal bridges
Sound absorption	Reduces vibrational oscillations, positive impact	Varies, often requires additional measures
Seismic resistance	Increased due to reduced self-weight and material characteristics	Varies, heavier structures bear higher seismic loads
Corrosion resistance (steel component)	High (galvanized S550 GD+Z steel, service life 20-100 years)	Unprotected steel prone to corrosion without special treatment

CONCLUSIONS AND RECOMMENDATIONS

Frame structures made of composite steel-timber I-beams with transversely corrugated steel webs represent a highly promising direction in modern construction, demonstrating numerous advantages. They provide increased stiffness, significant self-weight reduction, improved thermal and sound insulation properties, high seismic and corrosion resistance, and the aesthetic appeal of natural material. From an economic perspective, these structures allow for significant savings on foundations and installation work, despite the comparable material cost per unit length with traditional counterparts. The simplicity of their processing and the possibility of waste-free production further emphasize their technological and environmental efficiency.

For Ukraine, the implementation of frame structures made of composite steel-timber I-beams is of strategic importance. They will contribute to increasing the competitiveness of domestic production, reducing dependence on imported materials and technologies, and supporting the development of the country's scientific and engineering potential. Further development and standardization of these structures open up broad prospects for creating energy-efficient, reliable, and economically sound buildings, which is critically important in the context of infrastructure reconstruction and modernization.

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РАМНІ КАРКАСИ З КОМПОЗИТНИХ МЕТАЛОДЕРЕВ'ЯНИХ ДВОТАВРІВ З ГОФРОВАНОЮ СТАЛЕВОЮ СТІНКОЮ

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Анотація. Рамні конструкції з композитних сталево-дерев'яних двотаврових балок з поперечно гофрованими сталевими стінками є інноваційним композитним рішенням у будівельній галузі, що поєднує міцність сталі та екологічність деревини. Ці конструкції мають значні переваги, зокрема високе співвідношення міцності до ваги, поліпшені теплові та акустичні властивості, підвищену сейсмостійкість та корозійну стійкість. З економічної точки зору, їх використання призводить до зниження загальних витрат на будівництво завдяки меншій власній вазі, високій технологічності та простоті монтажу.

Поєднання тонкої профільованої сталевої стінки та масивних дерев'яних поясів забезпечує оптимальне використання фізико-механічних властивостей обох матеріалів, підвищуючи несучу здатність і жорсткість елементів за одночасного зменшення їхньої маси у 2–3 рази порівняно з традиційними металевими або суцільними дерев'яними балками. Розкрито технологічні аспекти виготовлення елементів постійного та змінного перерізу, включаючи механічне пресування гофрованої стінки в деревину та клеєві з'єднання на основі двокомпонентних епоксидних сумішей. Можливість варіювати висоту перерізу рамних каркасів дає змогу оптимізувати витрати матеріалу залежно від епюри згинальних моментів, що збільшує ефективність конструкцій. Показано переваги таких конструкцій у теплоізоляції та запобіганні утворенню теплових містків, у підвищенні акустичного комфорту, довговічності та корозійній стійкості завдяки використанню оцинкованої сталі.

Для України впровадження рамних конструкцій із композитних метало-дерев'яних двотаврових балок має стратегічне значення. Вони сприятимуть підвищенню конкурентоспроможності вітчизняного виробництва, зменшенню залежності від імпортних матеріалів і технологій, а також підтримці розвитку науково-технічного потенціалу країни. Подальший розвиток і стандартизація цих конструкцій відкривають широкі перспективи для створення енергоефективних, надійних і економічно вигідних будівель, що має вирішальне значення в контексті реконструкції та модернізації інфраструктури

Ключові слова: рамні конструкції, метало-дерев'яні балки, композитні балки, HTS-балки.

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