Prefabricated steel structures with a corrugated web (Part 1. Beam)

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Abstract. This paper considers prefabricated steel structures with a corrugated wall. Their relevance of development, new improvements of existing beam structures and their application are substantiated. Composite beams are known and widespread, a significant drawback of which is the inseparability and the need for their production in the factory, even despite the enlargement as assembly unit. Beams of a composite I-beam are offered, but of a detachable section of individual elements (flanges - rolled steel: corner, channel, box section; web - profiled sheet). Particular attention is paid to be prefabricated - demountable and the possibility of their delivery to the installation site in a "detailed" form, assembly and installation in a building site, dismantling (if necessary), and reuse. Between themselves, fastening is carried out on self-tapping screws or bolts, which allows assembly at the installation site. For increase the rigidity of the corrugated wall without a significant change in geometric parameters, including web thickness, additional layers of the profiled sheet will be sufficient amplification. In addition, this configuration allows you to increase the bearing capacity. The advantages of the design of I-beams with corrugated web are revealed: accessibility of materials, repeated use of the beam, low laboriousness, cutting of elements and assembly can be carried out at the construction site, waste-free production, reduced transportation costs, the possibility of selecting a section depending on the load.

1. Introduction
The trend of widespread use of prefabricated buildings and structures is determined by the following factors:

- High competition and focus on the downsizing of enterprises. The creation from large production structures more smaller or medium, with more specific specialization and the possibility of short forecasting [1];
- Lack of developed infrastructure in the regions of Siberia and the Far East;
- The need for modern temporary buildings against the backdrop of natural disasters and emergencies, when high-speed construction of structures is required right at the scene [2].

The need for prefabricated, easily transported, mobile structures is relevant in the current situation. Modern constructive and progressive technological solutions are needed.

New construction systems will allow resolving the issue of restructuring, which will strengthen the economy, since the basis of market relations is the sector of small and medium enterprises, and the largest industrial enterprises in Russia are represented on the market as groups of small companies.
Mobile structures with low resource consumption and ease of assembly can be effectively used in the extreme north, and also if necessary temporary settlements in emergency situations or martial law [3].

One way to solve this problem is to use prefabricated steel structures with a corrugated web, the main advantage of which is the high bearing capacity at a relatively low cost and universal availability of materials, as well as simplicity and speed of assembly.

There is a number of scientific studies on the topic of steel structures with corrugated web, indicating the cost-effectiveness and manufacturability of such structural solutions [4-9]. The study [10] addresses the issue of fatigue resistance of such structures. There are also proposals for the use of steel beams with a corrugated wall as part of steel-concrete floors [11].

Consider a hinged-supported single-span beam with a span $l$ under a uniformly distributed load $q$ (Figure 1). In the beam, the moment $M_{\text{max}}$ (1) and the transverse force $Q_{\text{max}}$ (2), as well as normal stresses $\sigma$ (3) and tangential stresses $\tau$ (4), arise.

$$M_{\text{max}} = \frac{ql^2}{2}, \quad Q_{\text{max}} = \frac{ql}{2}, \quad \sigma = \frac{M}{W}, \quad \tau = \frac{QS}{Ib},$$

where $S$ – the static moment of the movable part of the section located between the level of the point under consideration and the edge of the section, $I$ – the axial moment of inertia of the entire section, $b$ – the width of the section at the level of the point under consideration.

The selection of the geometric parameters of the cross section with a constant span and constant load is to determine the moment of resistance - $W$ and the moment of inertia - $I$.

The distribution of normal $\sigma$ and shear stresses $\tau$ in an I-beam is shown in Figure 2.

The moment is a product of force - $F$ on the shoulder - $h$ (5):

$$M_{\text{max}} = Fh,$$

From the point of view of material consumption and perception of loads, an I-beam is optimal [12]. That is, the material of the cross section is located in the zones of greatest effort - the flange, and the web of the I-beam perceives tangential stress $\tau$ (Figure 2).

However, it is necessary to note the low efficiency of the beams made of rolled profiles, associated with the irrational distribution of material between the flanges and the web, which, remaining approximately 70% underloaded, accounts for half the cross-sectional area, and also disadvantageous, in terms of metal consumption, the ratio of the height of the beams to the span they overlap.
In order to reduce the effort in the flanges, the flanges must be spaced along the height of the section, that is, to increase the height of the web of section. One way is to use a beam with a perforated web. This raises the question of ensuring the stability of the web, which is solved by stiffening ribs. However, sections are not detachable, that is, they are used once.

2. Materials and Methods
In ordinary beams, the web thickness required by the shear strength conditions is approximately 2-4 times less than under the conditions of ensuring local stability [13]. The transverse stiffeners providing local web stability are simultaneously diaphragms that increase torsional the stiffness of the beams. The desire to meet these requirements while reducing metal consumption led to the idea of corrugating the webs (Figure 3), and the corrugations can be normal and inclined to the flanges. The stability of the webs increases, there is no need for transverse stiffeners, with the exception of supporting ones; as in thin-walled beams with a flat web, metal consumption is reduced in comparison with traditional beams [14].

Studies have revealed a number of positive properties that provide a high degree of flexibility, rigidity, the ability to withstand concentrated loads and the loads applied to the compressed flange with an eccentricity within the height of the corrugation, suitability for automated making on the production line or in the conditions of a construction site for manual assembly on the striker.

Analysis of studies of beams with vertically corrugated webs showed that in such structures the work of flanges and webs is definitely differentiated. The web does not perceive stresses directed perpendicular to the corrugation, and is in a pure shear, while the bending moment is completely
perceived by the flanges. The presence of vertical corrugations makes it possible to develop a beam cross section in height and to obtain a rigid structure with the least material costs [15].

In this work, propose a beam of construction manufacturing (prefabricated) of individual elements of the flanges and the web of the corrugated sheet, which is designed to ensure the stability of the wall. The whole structure is assembled on galvanized self-tapping screws (Figure 4).

![Figure 4. Schema of a prefabricated beam with a corrugated web: 1 - elements of the upper flange, 2 - elements of the lower flange, 3 - corrugated web, 4 - strap.](image)

It is proposed to use rolled steel as beam flanges (1, 2 - Figure 4) (corners, channels, I-beams, Tauri, box section, etc.). The corrugated sheet (3 - Figure 4) serves as a web for future construction. The planes (4 - Figure 4), installed with a certain calculation step, are attached to the rolled elements by galvanized self-tapping screws and allow for the joint work of the flange elements. The moment of resistance $W$ - can also be increased by enlarging the area of the flanges; accordingly, the stresses perceived by the flanges will decrease [16]. Varieties of beams depending on the flanges are shown in Figure 5.

![Figure 5. Types of prefabricated beams with a corrugated wall: 1 - the flange from a rolling corner, 2 - the flange from a rolling channel, 3 - the flange of a box-section.](image)
If we talk about the geometric dimensions of this construction, then when choosing the height of the web and the power of the flanges, you should focus on the sheet gauge of steel I-beams. The thickness of the connecting strap (plane) must be not less than the thickness of the corner shelf. When choosing a perforated wall, attention should be paid to Appendix A of the organization’s standard “Profiled steel flooring for coatings of buildings and structures. Design, manufacture, installation Organization Standard 0043-2005”, which takes into account the calculated values of the ultimate loads on the profiled flooring with transverse bending [17].

The plates, which are mounted on the flanges, are placed at the points of support of the overlying structures. In addition, connecting gaskets of the upper and lower flanges of the beam are also provided, which also ensure the joint work of the corners and the corrugated sheet. The installation step of the gaskets depends on their location. The upper flange is compressed, therefore the plates are placed at a distance of 40i from each other, where i is the radius of inertia of one corner relative to the axis parallel to the gasket; at the same time, at least two gaskets should be installed within the calculated length of the compressed element lef. The lower belt is stretched, the step of the plates is 80i, respectively.

The beam can be with parallel or inclined belts, single-slope or double-sloping - repeating the diagram of moments (Figure 6) [18]. In the case of a gable beam, on the central, most loaded part, pads are installed that are attached to the upper flange with self-tapping screws (Figure 7).

**Figure 6.** Types of beams: a - with parallel flanges, b - single-inclined, c - double-inclined, d - sprengel type.

**Figure 7.** Assembly of ridged knot: 1 - upper flange, 2 - corrugated web, 3 - steel plate, 4 - self-tapping screws.
3. Results and discussion

All possible variations of prefabricated beam structures are supposed to be tested on the installation (Figure 8), where

I stage - elastic work.
II stage - elastoplastic work.
III stage - plastic deformations, loss of bearing capacity (loss of local stability of the upper zone).

Figure 8. Shema of experimental setup: 1 - jack, 2 - cross-arm, 3 - a dynamometer, 4 - secondary cross-arm, 5 - a beam with a corrugated web, 6 - deflection meter.

The alleged results of experimental studies of thin-walled beams:
1. The two-web layout of the beam section is more technologically advanced than the one-web.
2. The insufficient bearing capacity of a thin web from a profiled sheet according to the criterion of local stability in two-web beams can be compensated by installing additional layers of the sheet.
3. The bearing capacity of the developed beams depends on the type of joints used.

An analysis of the foregoing allows us to conclude that there is a real possibility of creating effective collapsible beam structures of construction manufacturing.

The advantages of such corrugated steel beams:
- availability of materials;
- reuse (collapsible) beams;
- lack of need for highly qualified personnel at the construction site, due to the simplicity of cutting steel elements and their assembly into a single design;
- cutting and assembly can be carried out in a building site;
- virtually non-waste production due to the correct cutting of rolled steel and profiled sheet;
- the ability to deliver structural elements to the assembly site in packages, which will reduce transportation costs, especially for remote and hard to reach areas.
- increased corrosion resistance and durability due to high-quality and technological zinc coating.
- the ability to select size of section for a specific load or load range;
- implementation of the stress fragmentation principle and viscosity of the compounds.

4. Conclusions

The optimal distribution of the material over the cross-sectional area in accordance with the stress-strain state of the elements is a way to reduce the material consumption of building structures. The use of a beam with a web in the form of a corrugated sheet, which also has other important features, corresponds to this direction.

The use of rolled steel and profiled sheet is an ideal combination for creating structures from them.
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