Features of the Power Work of Light Metal Structures

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Abstract. Took into account experience of light metal constructions using in building. Paid attention to possible metal beams weight reduction ways. Interest to metal beams weight reduction appears, because they are widely used in modern building. Beams weight reduction is considered as an effective way of building spending reduction. The ways of reducing the material consumption of I-beams are formulated as manufacturing corrugated and perforated walls. Stress-strain state of corrugated beams numerical research results are shown. The results of solving the optimization task of finding the circular perforation geometry in the I-beam wall are presented. I-beam stress-strain state during bending under constrained torsion conditions research are presented. Made a conclusion about the efficiency of corrugated and perforated beams in comparison with traditional rolled beams. Concluded that it is necessary to take into account the stresses caused by the I-beam constrained torsion when the load adding eccentricity exceeds 15% of the flange width.

1. Introduction
It is used to consider steel constructions, which have a significantly reduced material consumption, compared to traditional constructions [1], due to any constructive activities, as light metal constructions.

Low material consumption for supporting structures leads to lower economic costs. It is especially important to reduce the consumption of not renewable materials. Reduced material consumption leads to significant energy savings. According to some data, the share of energy consumption in a unit of production manufactured in the Russian Federation is up to 20% of its total cost [2].

The most commonly used building structures are beams. A significant economic effect on construction industry can be expected as a result of reduction in material consumption for beams manufacturing. Many researchers had been working on reducing metal beams weight [3-5]. These are main directions of reducing material consumption for beams manufacturing:

1) manufacturing beams with a thin corrugated wall;
2) manufacturing beams with a perforated wall;
3) decrease in wall thickness by calculating justification of the beam operation permissibility after the wall has lost local stability.

In last option, the possibilities are limited by the fact that limited reserves of bearing capacity are used. Two first options are more interesting. Further we will focus on the practice of improving beams with a corrugated [6-8] and perforated wall [9].

A corrugated beams weight reduction, compared to usual beams is achieved by using a much thinner steel sheet in the wall. It is possible due to increasing the wall rigidity. The wall rigidity is
increased by giving it a template geometry. This allows to increase the thin wall local stability without increasing its thickness and without reinforcing it with additional ribs. The beam torsional rigidity is increased [10]. In usual beams, the wall thickness required by the strength of shear conditions is approximately 2-4 times less than that required by local stability conditions. The use of thin-walled corrugated beams requires less materials. Savings of 30-50% compared to hot rolled I-beams [11, 12].

Nowadays there are many examples of successful corrugated beams using. At the same time, there is a lack of research in corrugated beams stress-strain state (SSS) features. Especially few studies on the corrugated beams resistance to bending moment simultaneous action and transverse and longitudinal directions forces. Corrugated beams, as a rule, are designed with a simplified understanding of their work. A simplification is the assumption that bending moment and longitudinal force are perceived by flanges, and the transverse force is perceived by the wall [6]. This division is conditional. It does not correspond to the real state of the beam. This leads to a significant tolerance in determining the beam stress-strain state under complex deformation conditions [8, 10].

2. Materials and methods

Authors made a research on corrugated beams in complex SSS conditions. The research was carried out using theoretical and experimental method. Numerical experiments were carried out simulating various variants of complex SSS. Simulation was made in several program complexes: Lira, SCAD, STAAD, Cosmos, DisignSpace, Ansys. The researched models were made close to physical prototypes (fig. 1). Some of results of these researches were published earlier [6-9, 13].

![Figure 1. Model of corrugated beam in Cosmos program.](image)

In building laboratory conditions, beams with sinusoidal corrugated wall tests were carried out (fig. 2). Beams with length 6, 9, 12 m were tested.
Experiments in laboratory and numerical research allowed to establish features of load distribution in corrugated beam elements. One of important results, obtained by authors is a more accurate scheme of load distribution in wall of corrugated beam (fig. 3). It has been established, that in contrast to flat-beams, normal stresses are distributed nonlinearly [12, 14, 15]. It was established that middle part of the wall is not involved in perception of normal stresses. Graphical representation of normal stresses distribution in a corrugated wall is more consistent with a perforated wall than a traditional flat wall (fig. 3). In places far from flange, attenuation of normal stresses is observed. The noted attenuation of normal stresses is characterized by a change in the sign of stresses in a small section of the wall (fig. 3). The height of the wall sections, involved in perception of normal stresses under complex stress-strain state depends on the rigidity of the wall (on the thickness of the sheet and the geometry of corrugation). Another significant difference between corrugated and traditional flat one is the almost equal shear stresses in the corrugated wall along its entire height. The revealed stress distribution scheme clearly demonstrates the unreliability of simplified calculations.

Beams with corrugated wall have less weight than traditional beams. The use of perforated beams in the floors of multi-storey buildings can reduce height of the floor. This is achieved through the rational use of space within the beam height. Very often engineering communications are laid through holes in the walls of the beams.

The shape of holes in beam wall can be round, sinusoidal, multifaceted, and others. The SSS of the wall depends on the perforation shape. For example, it is known that for holes in the form of a
polyhedron, stress concentration at the corners is characteristic. Circular perforations have no specified stress concentrations. At the same time, perforation in the form of a polyhedron can be obtained using a much simpler technology than round perforation. Obtaining a beam with the best perforation in the wall according to strength and economic criteria is an optimization task. To solve this problem, the authors performed several numerical researches.

The task of finding the optimal step and diameter of a circular perforation in I-beam of variable cross-section was solved. The task was solved by the method of iterative calculation. Experimental researches of the beam stress-strain state were carried out at each iteration. Numerical experiments were made in program complex Lira. The optimality criterion was the beam weight. For each version of the beam, the level of normal, shear and equivalent stresses in the wall was controlled. As a result of consistent searches of various perforation options, the beam with the smallest mass was found. The proposed beam is 12.5% lighter than a similar beam without perforations. The final results of numerical experiments are partially presented in the figures 4, 5.

**Figure 4.** Image of stress distribution in a perforated wall (MPa)

a – normal stresses $\sigma_x$; b – equivalent stresses $\sigma_{ef}$.

**Figure 5.** Graphics of normal stresses $\sigma_x$ along sections by FE method.
Interesting results were obtained in I-beam numerical researches, taking into account constrained torsion.

Constrained torsion is always present to one degree or another in real beam structures. Perfect transverse bending does not exist in practice. The loads application on a real structure occurs in presence of some deviations. This means tolerances for installation and manufacturing of structures. The practice of examining existing constructions of buildings and structures shows that there are often cases of exceeding the acceptable deviations in the geometry of real building constructions.

The degree of non-axial load application influence on beam performance was estimated during numerical experiment. A number of researches related to an I-beam work loaded with a vertical transverse load, displaced from its axis was carried out (fig. 6). Researches were made in program complex Lira. A series of SSS calculations were performed for an I-beam loaded with a uniformly distributed load. Each calculation differed only in the place of load application. Load was applied to finite elements of beam upper flange model nodes. For the first calculation, the load position was taken to the nodes, located on the vertical axis of beam section symmetry. For each following calculation, the load application was shifted one row away from the axis of symmetry (fig. 6, 7). The load value was the same in all calculations. The load value was determined from the calculation of a beam loaded with a load without displacement. The load value was taken from the condition of first finite elements with equivalent stresses equal to the yield strength of the material appearance in the beam.

Load displacement causes torque to appear in the beam. The presence of a torque simulated the effect of constrained torsion of an I-beam. Torque increases the level of stresses in the beam compared to symmetrical loading. As a performed calculations analysis result, the following was established:

- at eccentricities not exceeding 15% of the flange width, local zones of limited plastic deformations appear. These zones are located in the middle third of the beam length (fig. 7). The appearance of these zones nearly does not change the picture of the structure general deformed state, which means, the beam sections deflections and rotation angles the remain the same as in the elastic work of the beam;

- at eccentricities exceeding 15% of the flange width, the deformation of the beam and the stresses in its sections differ significantly from the state of its elastic work [9].

Figure 6. Beam scheme with non-axial load application.
Figure 7. Equivalent stresses distribution in a beam under constrained torsion.

3. Conclusions
1. Using beams with corrugated and perforated walls allows to save about 10-50%.
2. It is necessary to take into account the effect of constrained torsion on beam SSS for improving reliability and safety of buildings and constructions.
3. It is acceptable to make simplified calculation, which means not taking into account the effect of constrained torsion, for l-beams with load application eccentricity less than 15% of the flange width.

4. References
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