Optimization of the assembly of cross-truss structures

Aleksandr Marutyan¹, Avetik Abovyan²* and Arkadiy Kravchenko²

¹Federal state autonomous educational institution of higher education "Pyatigorsk Institute (branch) of North Caucasus Federal University", 56, 40 years of October avenue, Pyatigorsk, 357538, Russia
²Moscow State University of Civil Engineering, Yaroslavskoe shosse, 26, Moscow, 129337, Russia

Abstract. As a result of a review and analytical search based on patent research and development, a new method of assembling cross-truss structures in relation to modules of the Pyatigorsk type has been optimized. The scope of its rational application is outlined, including the construction of new facilities and the reconstruction of existing buildings. The efficiency of assembling such structures in earthquake-resistant construction, including flexible upper floors capable of dampening mechanical vibrations, is noted. The continuation of flexible manufacturing technology in this method of assembly has been revealed, when the entire set of cross-truss structures of full factory readiness is mounted on the construction site in the project position. At the same time, all assembly and welding, transport, installation operations in shop and building conditions are performed by the same personnel due to their high qualifications, which ensures the necessary and sufficient competitiveness under the most difficult conditions of the economic conjuncture.

Keywords: cross trusses, profile pipes, bent-welded profiles, manufacturing, assembly, installation, light metal structures, earthquake-resistant construction, flexible upper floor.

1 Introduction

The accumulated experience of designing and constructing facilities using cross-structures confirms the rationality, efficiency and versatility of their basic technical solutions, providing increased resources of force resistance and resistance to progressive (avalanche-like) destruction [1], which turned out to be very popular after the earthquake in Spitak [2]. The use of closed bent-welded profiles (profile pipes) contributes to the growth of these resources, providing a certain relief of load-bearing structures, reducing their labor intensity and reducing the consumption of structural material [3, 4]. In the general range of cross systems, light metal structures of complete delivery, representing blocks (modules) of coatings and overlappings from cross trusses of the Pyatigorsk type, occupied their field of
rational application. Despite the instability of the market, they continue to be in demand, attracting the attention of investors and customers with their technical and economic characteristics "figure 1".

Relatively small, but the most popular sizes (usually ranging from 6×6 to 12×12 meters) allow them to be conditionally classified as "pocket" modules and manufactured all-welded [5]. Such constructions are especially rational in earthquake-resistant construction with flexible upper floors "figure 2", capable of dampening mechanical vibrations [6, 7].

Fig. 1. Images of the frame with mounting windows at the beginning of construction (a), the overlap (b) and the coating (c) of the Pyatigorsk type cross trusses during finishing works.

Fig. 2. Images of buildings with flexible upper floors in Kislovodsk (a, b), Pyatigorsk (c) and Vanadzor (d).

The real relevance of the development and research of cross systems, their applied significance and the prospect of further development were reflected in the All-Russian scientific and practical conference "45 years of the light metal structures industry: from the Kislovodsk module to the Pyatigorsk module", held on April 3-5, 2017 on the basis of the Kislovodsk experimental plant of metal structures "Module-Stroy" and the "Pyatigorsk Institute (branch) "North Caucasus Federal University" [8]. The source of maintaining and further growth of their competitiveness are new layout, design and technical solutions, as well as new manufacturing and installation technologies. Such technologies include the proposed technical solution designed for the construction of spatial coverings (ceilings) of buildings and structures from cross trusses.
2 Methods

A well-known spatial load-bearing structure of coatings of buildings and structures includes a system of cross trusses, with the upper and lower belts of trusses of one direction located above the homonymous belts of trusses of another direction. The trusses of one direction can serve as support structures during installation, and the trusses of the other direction can be installed on such supports at the points of intersection of the braces, where special support tiles-tables are provided, and at the same points the cross trusses interact with the operational load. In order to implement such an installation, removable inserts in the belts are provided at the intersection of the trusses: the upper belts – at the support trusses and the lower belts – in the removable inserts installed on belts. After installing the overlying trusses, the support tiles are fastened, the belt breaks are closed and the intersecting belts are connected to each other for their mutual decoupling from the plane of the trusses "figure 3" [9].

The main disadvantage of the known solution is the interruption of compressed and stretched belts by mounting windows. At the same time, the mounting joints are placed in the most stressed places of the structure, because of what special inserts and overlays must fill in the sections of the belt elements, which leads to overspending of material and an increase in the number of connecting bolts and welding.

![Cross trusses from paired corners with mounting gaps (windows) of belts (a) and their closure after assembly (b).](image)

Another well-known solution is a spatial load-bearing structure covering buildings and structures, including a system of cross trusses, in which the upper and lower belts of trusses of one direction are located above the homonymous belts of trusses of another direction. The nodes of the cross trusses are aligned vertically, and the grid braces of the overlying truss at the nodes are offset from the axis by the width of the upper belt of the underlying truss. Moreover, the lower belts of the overlying trusses are removable, and the trusses are connected through the upper belts. Here, the core elements of the grids are connected to removable belts by means of nodal plugs "figure 4" [10].
Modified truss structures with removable belts, but without plugs for the lattice elements, were made possible by a shapeless slanted knot "figure 5, a" [11]. In such a node, the brace is directly adjacent to the truss belt, so the minimum size of its cross-section is 0.6 of the belt width. The lattice stand is directly adjacent to the brace, so the minimum size of its cross-section is 0.6 of the brace width or 0.36 of the belt width, which reduces the consumption of structural material. The reduction of material consumption is also facilitated by the shortening of the lattice stands, which cannot be directly adjacent to the truss belts. In addition, the stretched brace turns out to be clamped between the lattice stand and the truss belt, which reduces the pulling force and ensures a more uniform distribution of stresses in the shapeless node, and this also has a positive effect on the material consumption of the structure. The successful approbation of the node during the tests of the suspended crane for static and dynamic impacts accelerated the application in practice of construction and design of lattice structures using bent welded profiles in the form of modules of coatings (overlaps) from cross trusses of the Pyatigorsk type "figure 5, b, c, d".

The disadvantage of such a well-known solution, as well as its modifications with diagonal nodes, is the difficulty of passing all removable belts of trusses of one direction.
through all trusses of the other direction, followed by welding not only the nodes of the intersection of the trusses, but also the nodes of attaching the core elements of the grids to removable belts, which increases the complexity of installation. At the same time, there are much more attachment points in the core system of the supporting structure than there are intersection points, which also negatively affects the complexity of installation. The cross trusses of one direction differ from the same trusses of the other direction by both removable belts and lattices, whose braces at the intersection points are shifted by the width of the belts, which leads to a decrease in the degree of unification of load-bearing structures and is accompanied by an increase in the complexity of their manufacture.

The closest to the proposed (adopted as a prototype) is a technical solution, which is a method of assembling a coating from cross trusses, including the installation of trusses of the first direction with a parallelogram grid and passing through their inter-belt gap of trusses of the second direction with an external cross-section height greater than this gap. Through such a gap, the trusses are passed in an inclined form and unfolded to the design position with the strut of the belts of the trusses of the first direction, thereby causing the elongation of the diagonal of the parallelogram lattice and the construction lifting of the coating trusses "figure 6" [12].

![Cross trusses made of wood (a) and their adjustment to the design position after assembly (b).](image)

The disadvantage of the prototype is manifested in the fact that the passage of cross trusses of one direction in an inclined form through cross trusses of another direction is no less difficult and time-consuming than the passage of removable belts. Additional difficulties are associated with the reversal of the mounted trusses from the inclined position to the design position, in which it is necessary to apply a certain amount of force to rasp the belts of the trusses in another direction. In addition, the implementation of the described method of assembling the coating from cross trusses requires increased accuracy of their calculation, design, manufacture and installation.

### 3 Results

The technical result of the proposed solution is to simplify the assembly of the coating (overlap) from cross trusses and to reduce the complexity of their installation. The specified result is achieved by the fact that in the method of assembling the coating (overlap) from cross trusses, including the installation of identical trusses with additional lattice stands at the nodes of the intersection of the trusses (angular, contour and internal), as well as continuous runs dividing all the cells of the cross system in half, mounted trusses of one of
the directions with mounting windows in the upper (compressed) belts are suspended by means of an inverted traverse for the lower belts of the installed trusses of the other direction and deployed to the design position. A girder is used as a traverse, which, after assembling the next trusses, is installed in the middle of the cells of the cross system "figure 7" [13].

The proposed method of assembling a coating or overlap from cross trusses includes the installation of identical trusses (1) with additional lattice stands (2) in corner, contour and internal intersection nodes, as well as continuous runs (3) dividing all cells of the cross system in half. The upper and lower belts of the trusses (1) at the intersection points are located floor by floor, because of what the additional racks (2) are shorter than the ordinary racks of the grids by the height of the belt elements.

The continuous girders (3) are located in one direction and are supported on the upper belts of the trusses (1) in such a way that with the upper belts of the trusses (1) of the other direction to form a support plane (or surface) for the enclosing structures. After installing the supporting structures, which are corner columns, they are tied with trusses (1). With the number of cells of the 2×2 cross system, the trusses (1) are left single along the contour, and with the number of cells 3×3, they are doubled. Then internal trusses (1) of the same direction are installed on contour trusses. In the upper (compressed) belts of internal trusses (1) of the other direction, mounting windows (4) are made using double straight cuts, the dimensions of which are determined taking into account the width of the cross-section of the trusses (1) and minimizing the complexity of their assembly. For vertical transportation of the truss (1) with mounting windows (4), the nodes of its lower belt are connected to the girder (3) using rigging chains (5), as with the mounting traverse "figure 7". Rigging chains (5) make connections in the form of eights, the upper loops of which are tightly tightened around the girder (3), and the lower ones encircle the belt nodes with certain backlashes sufficient for linear and angular movements of the mounted truss when it is installed in the design position. With the help of a girder (3) and a crane with its slings (6), the mounted truss is brought into a vertical position and in an inverted position is raised to the bottom of the lower belts of the installed trusses in another direction "figure 8". Using another set of rigging chains, the girder (3) is suspended by the lower belts of the installed trusses so that the turn of the mounted truss (1) from the inverted position leads it to the design position "figure 9". For this turn, the crane slings (6) are fixed to the upper belt, the mounting windows of which are passed through the lower belts and grilles of the installed trusses of the other direction "figure 10". After turning the truss (1) and bringing it to the design position, the inserts of the mounting windows are welded, the additional racks of the gratings (2) are installed and the connecting nodes of the trusses are welded "figure 11". The girder (3) used as an assembly traverse is dismantled and placed according to the project on the upper belts of the installed trusses of another direction "figure 12".

![Fig. 7. Assembly of a covering (overlap) from cross trusses with a mounted truss equipped with mounting windows and prepared for vertical transportation using a girder as a traverse.](image-url)
Fig. 8. Lifting of the mounted truss in an inverted form.

Fig. 9. Suspension of the mounted truss in an inverted form through the traverse for the lower belts of the installed trusses of another direction.

Fig. 10. Reversal of the mounted truss from the inverted position to the design position.

Fig. 11. Fixing the mounted truss to the design position.
4 Discussion

The proposed method of assembling cross trusses has a fairly universal technical solution for the installation of load-bearing structures, both coatings and ceilings. At the same time, by analogy with the prototype, cross trusses can be wooden with nodal connections on metal toothed plates. With no less efficiency, it can be used in modules (blocks) of coatings and overlappings from cross trusses of the Pyatigorsk type with the use of rectangular pipes (closed bent-welded profiles) "figure 13".

The positive effect of the proposed solution can be recognized not only as simplifying the assembly of the coating (overlap) from cross-trusses, reducing the complexity of their installation, but also the flexibility that is quite noticeable when it is used in conjunction with a new method of manufacturing mounted structures. This approach provides a significant reduction in material and labor costs due to the fact that its implementation is largely based on modern compact equipment (primarily welding) and the appropriate qualifications of those who work on it both in shop and building conditions. The ongoing modernization of the structures themselves and the methods of their manufacture, as well as assembly (installation), provides them with a certain demand in the unstable conditions of the current conjuncture.

5 Conclusions

Thus, if we sum up the main results, we can draw a number of conclusions and generalizations.

As a result of a review and analytical search based on patent research and development, a new method of assembling cross-truss structures has been optimized, the originality of which is confirmed by the patent for the invention.
The optimized assembly method is essentially a continuation of the flexible manufacturing technology, when the entire set of cross-truss structures of full factory readiness is mounted on the construction site in the project position. At the same time, all assembly and welding, transport, installation operations in shop and building conditions are performed by the same personnel due to their high qualifications, which ensures the necessary and sufficient competitiveness under the most difficult conditions of the economic conjuncture.

The field of rational application of the optimized method of assembling cross-truss structures covers not only the construction of new facilities, but also the reconstruction of existing buildings. Especially effective is the assembly of such structures in earthquake-resistant construction, including flexible upper floors capable of dampening mechanical vibrations.

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References

9. Bespalov S.M., Dolginov E.S., Fuchs O.M. Spatial design of covering buildings and structures // Copyright certificate 608897, Bul. 20 (1978)