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Chapter

Light-Weight Structures: Proposals of Resource-Saving Supporting Structures

Chichulina Kseniia and Chichulin Viktor

Abstract

The article will present resource-saving constructions and nodes of steel beams with a double profiled trapezoidal wall with intermittent weld seams, welded t-zones, t-zones from rolling, roll-formed channels, filling between the walls with polystyrene foam with diagonal and cross-lattice, a lattice in the form arched elements and single arched element; steel beams with a single transversally profiled wall of sinusoidal and trapezoidal outline with channel belts; resource-saving combined steel structures of frames and arches; assembly units of steel frames with spatial elements of square and round pipes. It is determined that the corrugation provides a reduction in material consumption, and the use of profiled sheets allows you to vary the size of corrugations, leads to a significant loss of weight of the structure under the condition of strength and stability. The advantages of the proposed resource-saving combined structures, namely: saving construction height (at the same time performs the function of the enclosing structure), transport and installation costs, there is no need to install transverse ribs (except in support areas and areas of concentration of significant loads), the emergence of opportunities for the use of modern technological equipment, a wide variety of applications, esthetics and many other advantages.

Keywords: beams, profiled trapezoidal wall, truss, arch, closed profiles, light steel structures, composite structures

1. Introduction

In the conditions of modern construction, the reduction of material consumption with simultaneous increase in reliability and ensuring favorable indicators of economic efficiency is one of the priorities of designers. The main of the many ways to improve the efficiency of construction is the development and improvement of new progressive lightweight structural forms, which significantly improve the technical and economic performance. Recently, a large popularization received various combined systems, which include elements of different stress-strain state. Research of new constructive forms with application of progressive technologies and materials, new algorithms of calculation by numerical methods opened ways of wide distribution of the combined systems abroad. Robot welding line gave the possibility of making resource-saving structures with corrugated walls (beams, columns, arches) and complex light metal structures made of profile pipes an alternative to traditional

constructive solution. A comprehensive solution to this problem requires the development of new resource-efficient designs. With the aim of developing constructive solutions resource consuming structures presents a series resource consuming constructive solutions. The use of such solutions leads to a significant reduction in material consumption with sufficient performance indicators. The light beams can be used in truss structures of beam cages and other beam structures in the construction of residential and public buildings, attics, superstructures, hangars and extensions.

Theoretical and experimental studies of steel beams with corrugated walls are presented in scientific papers [1–3]. In [1] it is noted that in recent years light profiled steel beams (CWSBs) are gaining increasing popularity. The bearing capacity of such structures is lower than the beams with a flat wall and trusses. The existence of three types of failures, namely local, General and mixed, is determined on the basis of experimental studies. Let us consider in detail the results of nonlinear finite element analysis. It is revealed that the shear stress is at the maximum and the same throughout the wall until swelling. Also experimental beams had a margin of carrying capacity, about half of the limit. In the course of the analysis it is proved that the shear stress is the same throughout the low-profile wall and has a maximum value. The authors confirmed the feasibility of using 1993-1-5 for beams with corrugated wall. In [2] the authors consider the theory of stocky beams and propose a new method of nodal lines. This method applies to thin-walled or thick-walled stocky beams. The paper presents the results of solving the problem of delay shift box girder of different thickness. Also, the values of the normal stress of the box beam due to the restrained torsion are obtained. As a result of the research, the authors obtained the values of shear stresses of the box beam due to shear forces. The results of mathematical modeling of transverse shear effect for sandwich beams with sinusoidal corrugated cores are presented in [3]. The authors studied the bending and bending of two sandwich beams, identified trends and the main problem points, presented theoretical models. The possibilities of influence of transverse shear effect on deflections and critical loads of such structures are shown. The results were confirmed by numerical analysis. The main advantages of truss structures are presented. The author's approaches to the variability of use and layout of farms are presented in [4]. In [5] the authors investigate tabular structures. The article calculates the optimal size of the welded tubular truss, analyzes the structural constraints, especially on the strength, stress elements, and geometric parameters of the nodes of the trusses. This optimization makes it possible to notice that the optimal height is determined by a geometric restriction that prescribes the minimum angle of inclination of the diagonals. The authors have calculated the cost parameters of such structures. After comparing the costs of a reinforced pipe and a larger pipe, it was found that the cost of the first is much lower. In work [6] it is noted that in the conditions of modern construction the metal frame becomes gaining popularity and has an esthetic appearance, safe connections, an opportunity to reduce sections of elements, belongs to fast-built designs. The authors highlighted the advantages and disadvantages of aluminum and steel, the analysis of the cost of these materials. Patent developments closest on design features are presented in [7–9]. In [7] represented Beam I-section with a corrugated wall comprising a shelf and welded to them a wall of corrugated metal sheet with a transverse arrangement of corrugations of arbitrary shape, characterized in that the wall consists of two or more parallel connected corrugated sheets, and the shelves are made of steel-concrete, consisting of rigid reinforcement in the form of corrugated sheet metal and reinforcement cage, including longitudinal reinforcement and transverse reinforcement, which embraces the longitudinal reinforcement, connected to it, its ends with a bend inside are welded to a corrugated sheet of metal with a space from the beam wall. In [8] the authors developed a metal beam with a corrugated wall comprising a belt connected

to each other by a corrugated wall with a transverse arrangement of the corrugations by welding, characterized in that it is provided with angles arranged in pairs in the center of the belts parallel to their longitudinal axes, with the outer surfaces of the shelves of the corners are rotated to each other and welded straight weld with a gap between the shelves sufficient to install the corrugated wall, which is fixed by means of an adhesive composition. The beam with a corrugated asymmetric profile wall [9] contains a compressed and stretched belt and wall. The wall, at least in some areas, is traditionally or variably corrugated with transverse corrugations. The profile of the corrugations is asymmetric with respect to the plane passing through the top of the corrugation and normal to the longitudinal axis.

2. Proposals of resource-efficient beam structures of buildings

In General, this section is aimed at presenting improved structural forms of resource—economic beams, arches, trusses, the introduction of which will give a significant economic effect, high characteristics of bearing capacity and architectural expressiveness, minimize material and labor costs and provide the possibility of using modern technological equipment of the European level, a wide range of applications in construction, esthetics and many other advantages.

The proposed beams with cross-profiled wall of trapezoidal (sinusoidal) shape with belts of channels on self-tapping screws are shown in **Figure 1**. The structure of such structures includes a single profiled wall (1), trapezoidal (sinusoidal) shape, which is fixed by screws (4) belt (2) (bent or rolled channels). With the help of welding (3) support ribs (5) (welded brands) are adjacent to the belts, and the wall is attached by means of a lamella screws (4). The proposed design of a steel beam with a cross-profiled box-section wall with uneven pitch of corrugations is shown in **Figure 2**. The profiled wall (2) of the beam has a trapezoidal shape, consists of long (4) and short (3) horizontal sections of the profiled sheet, as well as an inclined section of the corrugation (5). The corrugations of the presented beam have uneven steps that can be adjusted, which is not possible for wavy walls.

The wall of the beam is two cold-formed profiled sheets (2), fixed to the belts and ribs (6) around the perimeter, or in this case using lamellas (8), by welding (7). The beam ends have support ribs (6) and the I-beam shelves (1) are made of sheets. The main feature of the work is that the action of the bending moment is perceived by the shelves, and the transverse force is the wall of the beam.

Represented a modified form suggested above I-beam, steel beam from a transversely profiled wall of the box section with unevenly-spaced corrugations and intermittent welds (**Figure 3**). The structure of such a beam includes a trapezoidal profiled wall (2), which is welded on both sides intermittently (6) only on horizontal sections (3, 4) parallel to the longitudinal axis of the beam. The wall of the beam consists of two profiled sheets, which are attached to the edges (5) by continuous welding, and to the belts (1) by means of broken welds, which distinguishes it from the previous one, while providing savings in weld metal. The peculiarity of the beam is that the sections of corrugations are not transmitted longitudinal deformation, which provides a more uniform loading of the beam wall from the shelves.

Intermittent welds provide a uniform redistribution of forces in the shelves on the wall of the beam, as in the continuous seams forces quickly fall to a minimum. This occurs without action in the operation of most of the wall. In this case, intermittent welds (length of individual sections from 50 to 150 mm, and the distance between the sections, usually 1.5–2.5 times the length of the site) give some savings in production costs and provide sufficient stability of the wall, which does not perceive the efforts of the beam plane.
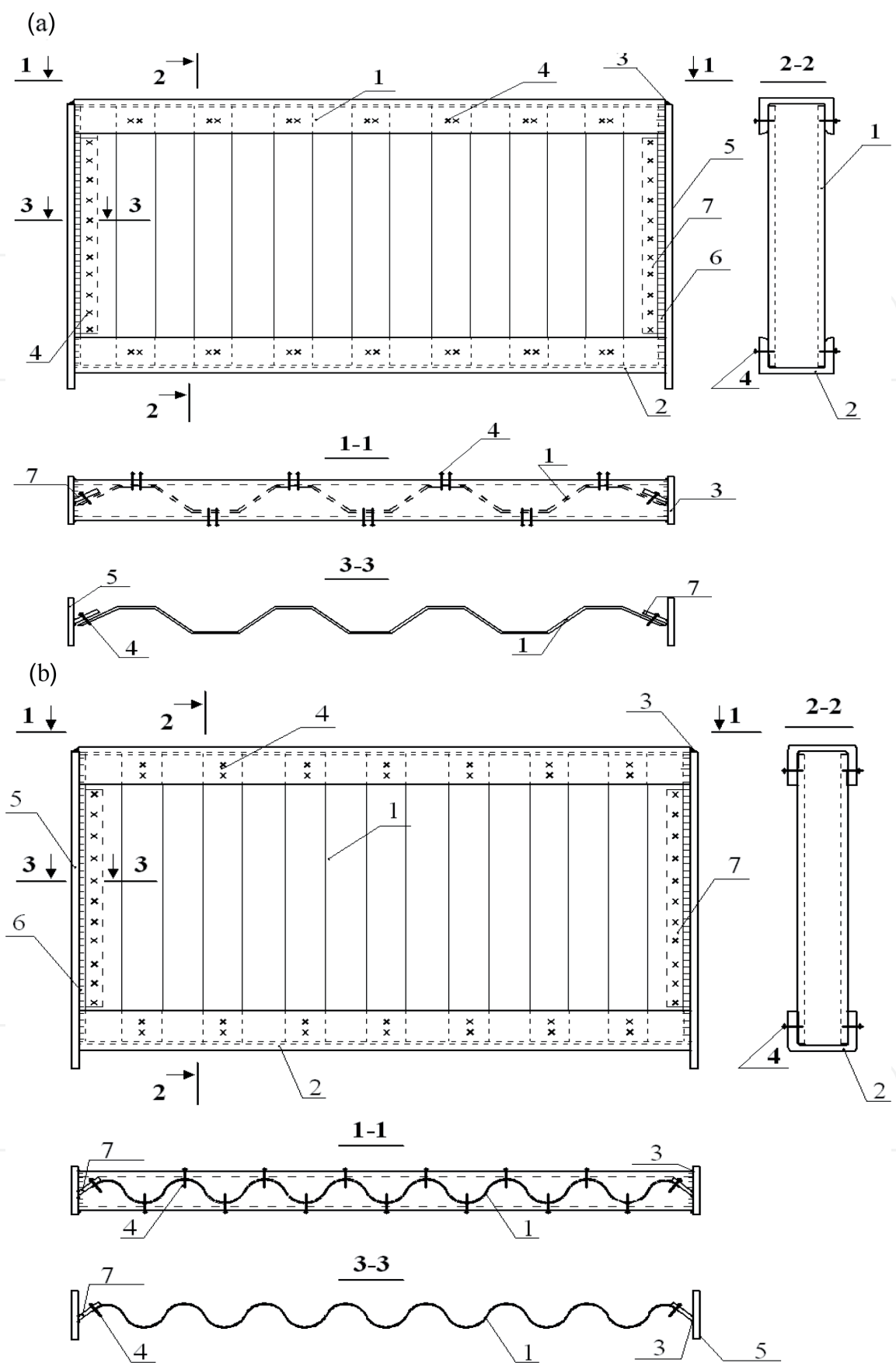
Figure 1.
Beam with cross-profiled wall with belts of channels on self-tapping screws: (a) trapezoidal wall [10]; (b) sinusoidal wall [11].

New designs of steel beams with cross-profiled box-section wall with welded-brand belts are proposed (**Figure 4**) and with the t-belt from rolling- (**Figure 5**). The profiled wall (2) of the beam has a trapezoidal shape, which is formed from the
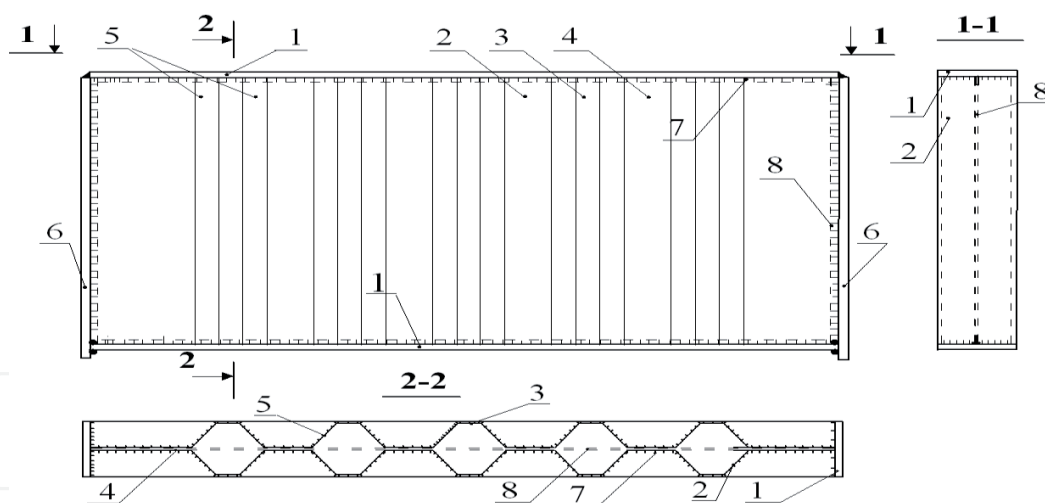
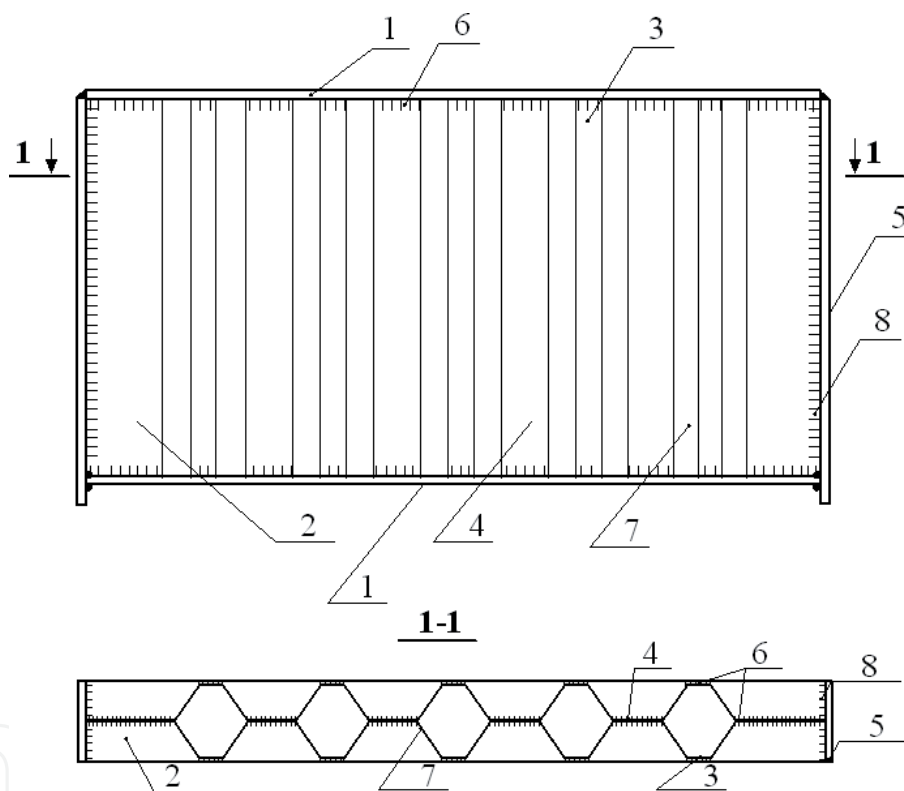**Figure 2.**
Beam with a cross-profiled box-section wall with uneven pitch of corrugations [12].

Figure 3.
Beam with cross-profiled box-section wall with intermittent welds [13].

inclined section of the corrugation (7), long (4) and short (3) horizontal sections of the profiled sheet. The wall of the beam consists of two profiled sheets (2), fixed by spot welding (6) belt (1), which consist of welded or rolled brands parallel to the axis of the beam. The wall in the support ribs (5) is attached by continuous welding (8). In this case, spot welds are used to attach the t-belts and the wall, which leads to the elimination of complex stress state. Attachment of the wall sections, which are close to the belt by spot welding, gives some flexibility to the wall along the beam and provides rigidity of the beam as a whole, as well as reversible perception of local stresses in the beam wall.

The wall does not reach the shelf and does not perceive normal forces, but only transverse force (shear stresses). The normal stresses are perceived only t-belts, as in an ideal I-beam. On the support parts of the beam, composite welded t-bar
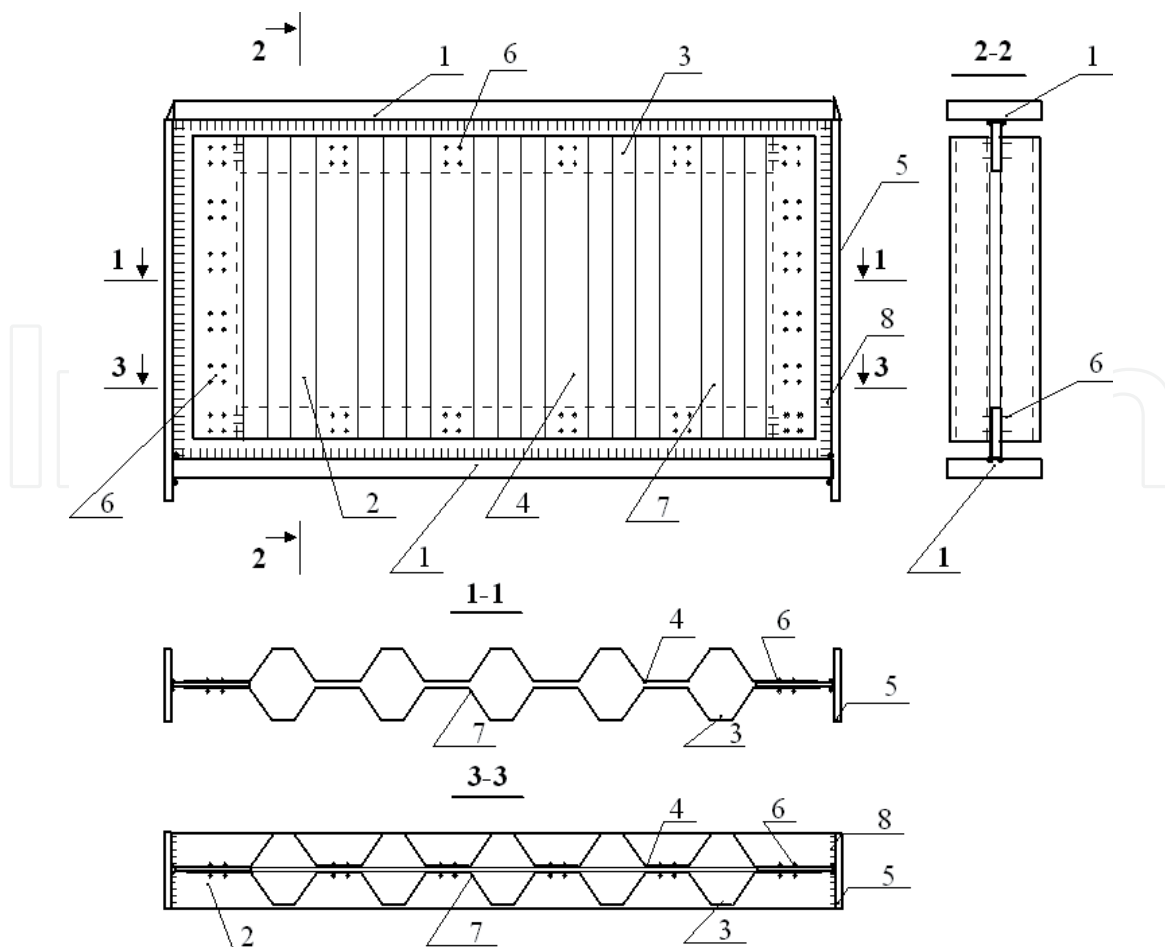
Figure 4.
Beam with cross-profiled box-section wall with welded-brand belts [14].

support ribs are used, which provide stability. The main advantage of such structures is that the belts from the brands perceive the action of the bending moment in the beam and work on tension and compression as an ideal I-beam, and the wall perceives the transverse force. In the areas of connection of the wall and shelves in the form of brands there is no zonal normal stresses in the upper and lower parts of the wall. In addition, the installation of t-bearing ribs provides stability and elimination of wall buckling in the area of the support unit. The wall of the rolling brand has a significant height, which ensures the strength of the belt and the upper part of the beam wall at normal stresses. The change in normal stresses is indicated by a hyperbolic dependence, which has maximum values at the top of the wall. Small local loads on the upper beam belt are more evenly distributed on the beam wall due to the t-belt.

A steel beam with profiled box-section wall with polystyrene foam is shown in **Figure 6**.

This construction (**Figure 6**) consists of profiled sheets (walls)(7) and support ribs (3). The space between them is filled with polystyrene foam (5). Belts (1) and guides (4) are made of square tubes, which are attached by solid welding. The wall is attached to the guides with self-tapping screws (2). The production of the beam begins with welding the initial billet. The wall of the beam is performed first by installing the profile on one side of the beam. In the future, the beam is in a horizontal position, where the polystyrene is applied in layers with subsequent installation of the upper profiled sheets.

The attachment of the profiled sheets is performed by self-tapping screws and installation through the mounting guides to prevent wall buckling. This course provides the opportunity to use a profiled wall of a smaller thickness (galvanized
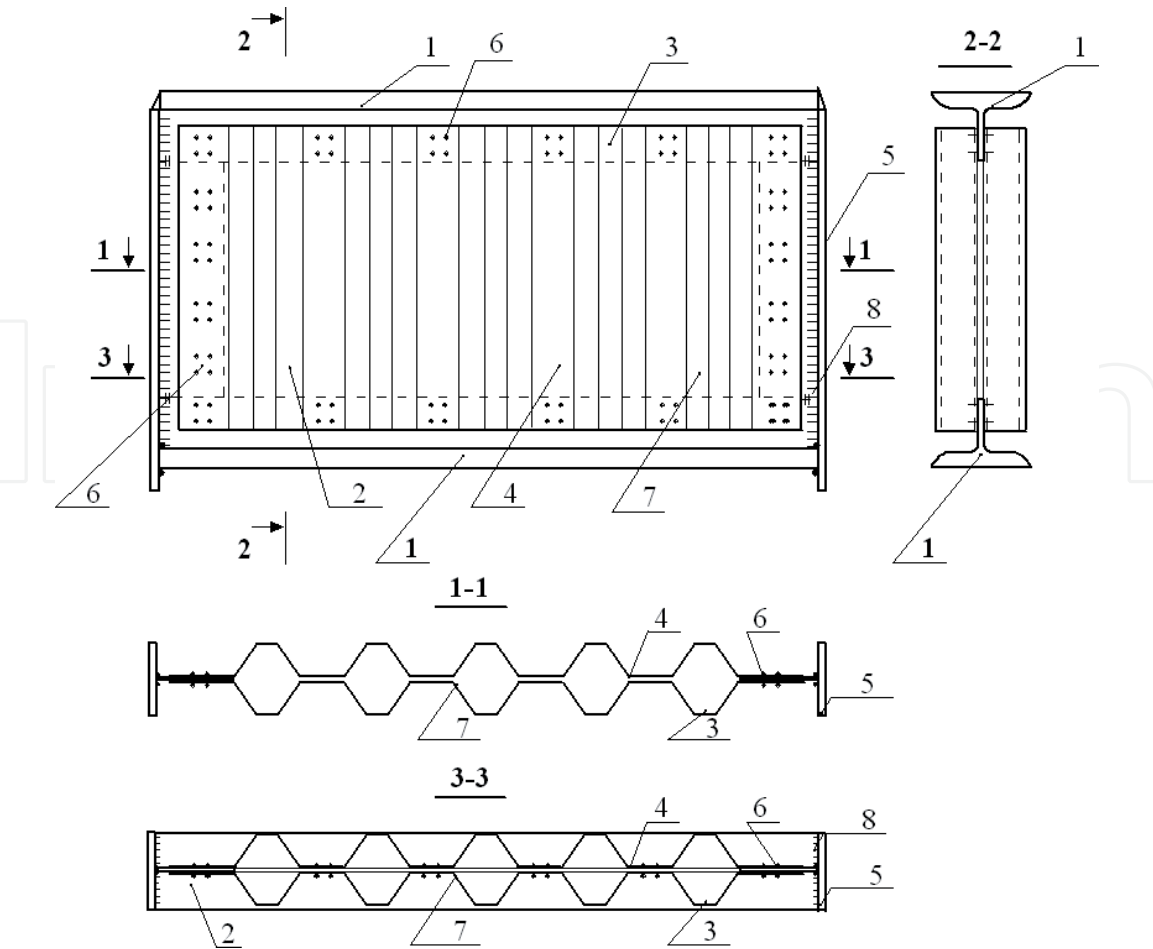
Figure 5.
Beam with cross-profiled box-section wall with the t-belt from rolling [15].

sheets), which is impossible or very difficult to weld. The sheets are joined together and fixed with screws. The use of polystyrene filling allows the use of this design with high thermal protection and sound insulation characteristics.

A new form is a beam with cross-profiled box-section wall and with belts of bent channels (fastening on screws) (**Figure 7**). This design allows the use of thin belts profiled sheets from 1 to 2 mm (welding is difficult). The structure of this design includes a profiled wall (1), which has a trapezoidal shape and consists of two profiled sheets, which are fixed to the belts (2) in the form of bent or rolled channels with screws (4). Profiles can be fastened together with self-tapping screws. The support ribs (5) are welded marks that are attached to the belts by welding (3) and to the wall by screws (4). The wall of this design can be single and have a wavy outline.

Below are steel beams with transversely profiled box-section wall, unfastened by diagonal lattice (**Figure 8**) and cross lattice (**Figure 9**), lattice in the form of arch elements (**Figure 10**).

In these structures, the profiled wall (7) of the beams is trapezoidal and consists of two profiled sheets, which are fixed in the guides (4) in the form of square pipes with self-tapping screws (2). The guides are attached to the belts (1), which consist of square tubes, by means of continuous welding (6). The support ribs (8) are made of sheets taking into account the work of crushing and cutting. The grate (3) is attached to the profiled sheets by self-tapping screws (2). Holes can be made to attach beams to a possible column (5).

Initial blanks for this type of structures, as well as for the following are performed at the beginning of the manufacture of beams. The location of the diagonal of the lattice must match the local load on the top chord of the beam. If you are
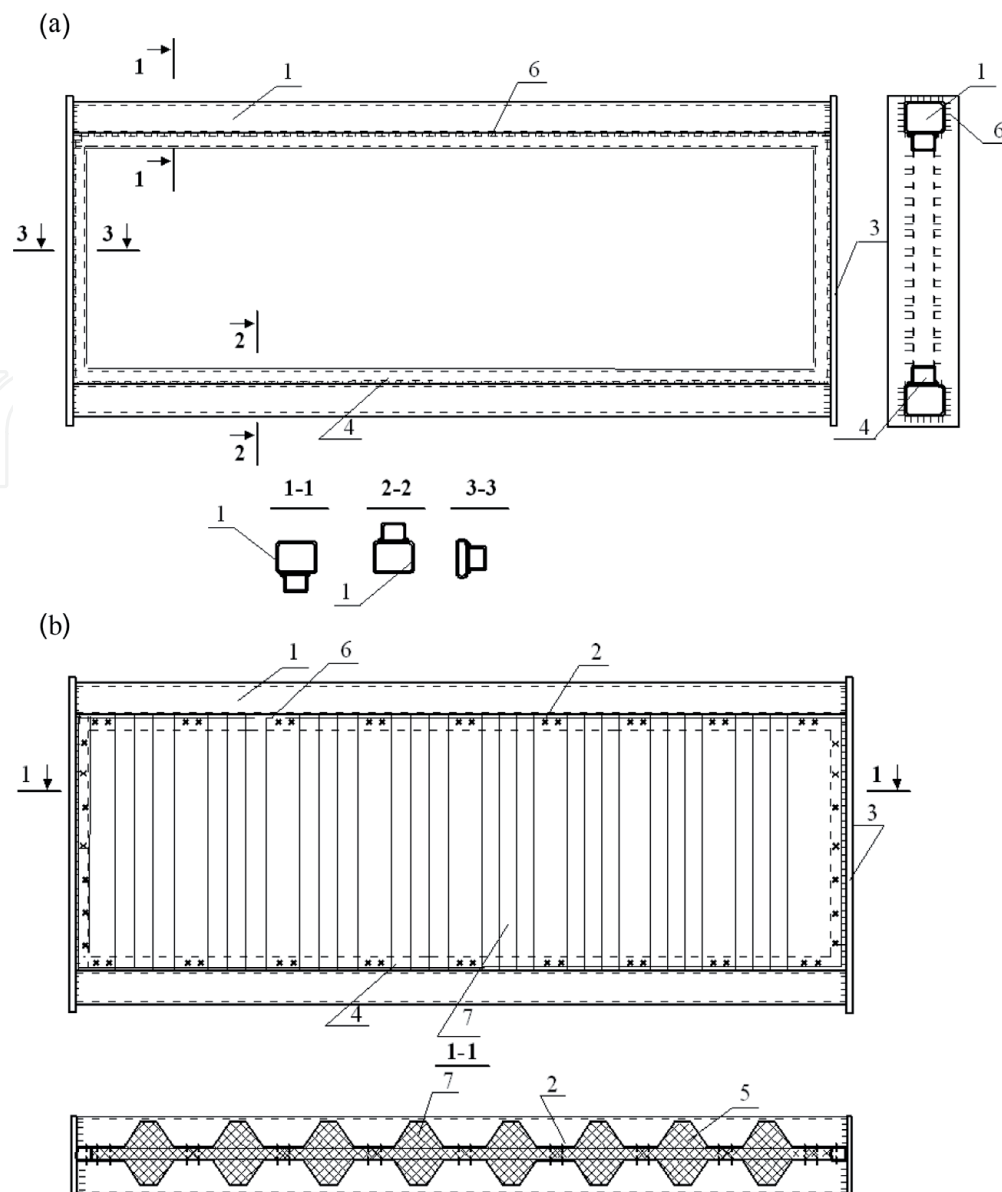
Figure 6.
Beam with profiled box-section wall with polystyrene foam [16]: (a) initial blank; (b) ready compartment.

installing a diagonal lattice, you can avoid using stiffeners under local load. Another feature of this type of construction is that the elements of the lattice in combination with the profiled wall provide greater stability than the individual struts of the lattice and the wall. Considering the cross lattice (**Figure 9**), it is possible to note its superiority in rigidity of a wall and ensuring stability of a wall on all height of a beam. Cross grid distributes the action of bending moment along the length of the span and unfastened profiled sheet to ensure sustainability.

Lattice of arched elements (**Figure 10**) and their shape reproduce the plot points and take some of the action. In areas close to the supports, the arches intersect and perceive additional forces in the zone of inclined cross-sections of the beam. In the span, the cross-section of the I-beam is close to the "ideal I-beam", which is the optimal cross-section for the perception of bending moment. In order to obtain less metal-nitrate structures, it is rational to use an arched lattice, which can be both double and single.

The calculation of combined beams from sheet or tubular belts is performed on a PC using a full-dimensional continuous description in the calculation complexes or on models with a breakdown into separate systems taking into account the physical and geometric nonlinearity. The use of the presented structures is not limited to truss structures, but extends to floor beams, crossbars of single—and multistory
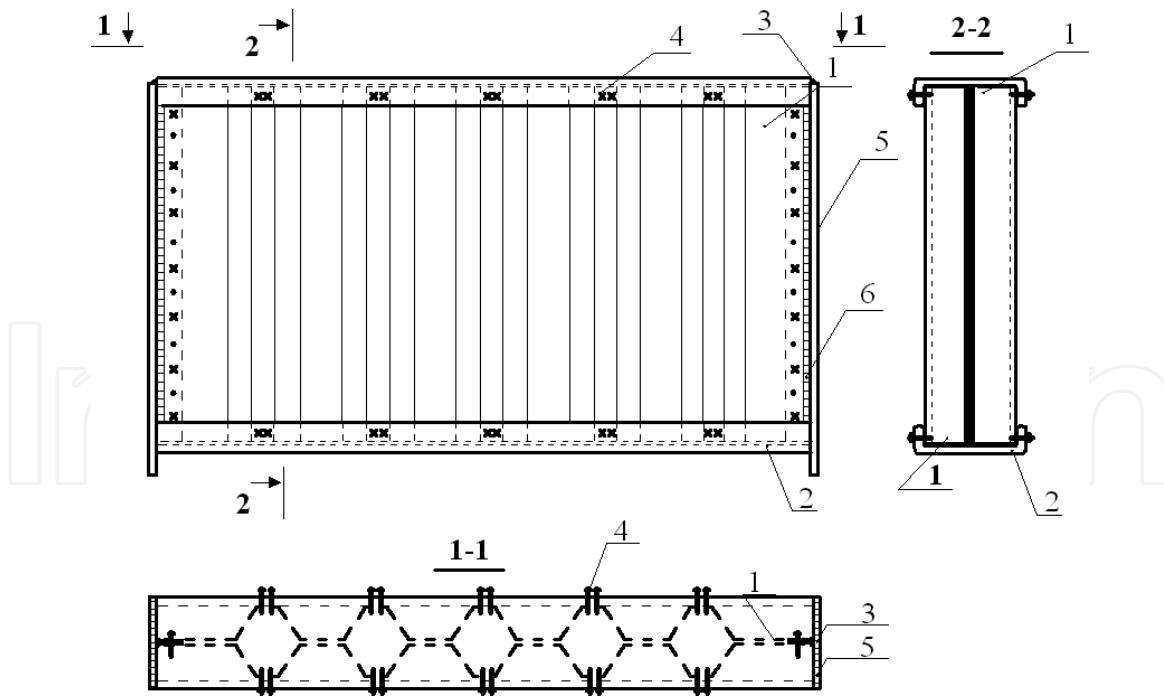
Figure 7.
Beam with cross-profiled box-section wall with belts of bent channels [17].

buildings, arches, galleries, technological platforms, span structures of bridges and the like. There is a possibility of application of the presented designs in beam systems with static loading.

The use of this type of beams provides a number of advantages in comparison with conventional ones, namely esthetic appearance, strength and reliability, durability of structures, low operating costs, but their main advantage is ease and stability.

One of the ways to improve light load-bearing structures, in our opinion, is the use of structural elements of closed profiles, which can have different sections, in particular square, rectangular and oval. Considering the technological features of manufacturing, we note that the pipe section is primarily round, and eventually deformed by various methods (hot and cold), acquiring different shapes.

New design solutions of combined resource-efficient metal structures of trusses and arches are proposed (**Figures 11**–**14**). In particular, **Figure 11** shows the combined metal structure of the truss with belts in the form of rectangular pipes, the lower belt in the form of a curved down arch that works on tension. This lower belt design is more economical than compressed belt. The upper belt in the form of two compressed rectangular pipes and unfastened by Breweries works as a whole system and can perform additional functions of fencing. This design feature provides an opportunity to reduce the material consumption and generally improve the efficiency of the whole structure.

So, the composition of the proposed combined metal truss structure include (**Figure 11**): (1, 3) to the upper belt in the form of two rectangular pipes (section pipe size from 120 to 200 mm); (2) the lower zone of the rectangular pipes in the form of an arched element (section pipe size from 120 to 200 mm); (4, 5) bearing edges of the continuous sheet (thickness from 6 to 10 mm); (6) reference sheet (thickness from 10 to 20 mm); (7) retaining wall (thickness from 8 to 12 mm); (8) lattice (section pipe size from 80 to 100 mm); (9) element of the lattice of the upper belt and at the same time enclosing structure (half arches, section pipe size from 40 to 60 mm).

The combined metal structure of the truss is proposed due to the paired upper arched belt and the lower belt, which works on tension, provides multivariance of application and significantly reduces material costs. The load from the coating in the
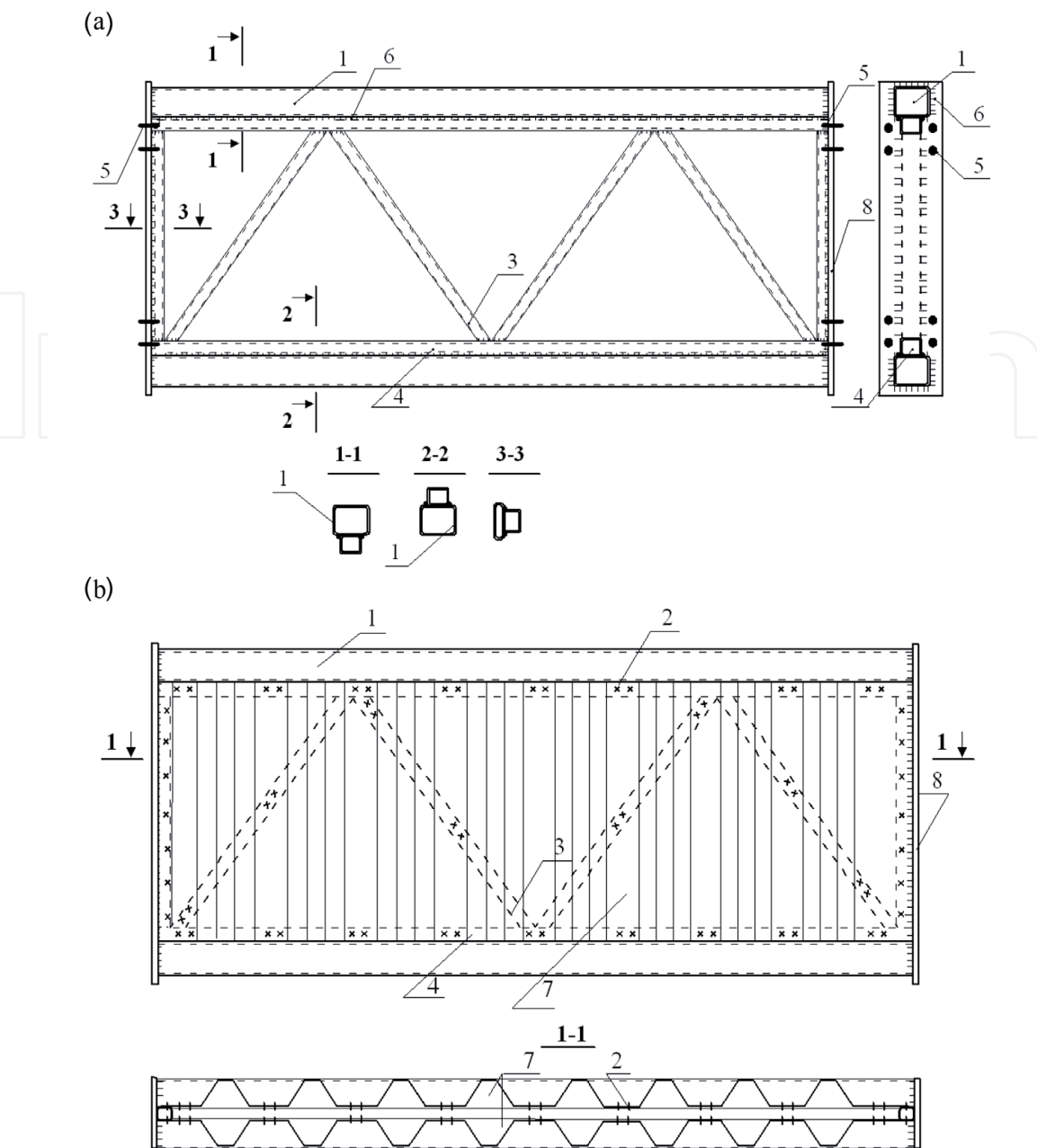
Figure 8.
Beam with transversely profiled box-section wall, unfastened by diagonal lattice [18]: (a) initial blank; (b) ready compartment.

form of transverse beams (beam cage) is transmitted to the lower part of the upper belt, which is unfastened from the plane of the farm and works with the flooring as a spatial system. The upper part of the upper belt, if necessary, can be unfastened from the plane by triangular dual-purpose supports for communications (pipelines, etc.). The rational use of the proposed structures for spans of 24–36 m is recommended.

The development of combined structures in the form of trusses can occur through the use of spatial triangular rod elements for the upper belt, which will increase the stability of the truss plane and reduce the cost of the structure by weight compared to solid sections. Note that the complexity of such structures is growing, so you need to evaluate these projects at the given cost.

Considering the traditional forms of arched structures, we note that their solid elements work as compressed curved and additionally perceive transverse forces. For this type of compressed curved arches optimal design solution is considered to be I-section with a solid wall. In our opinion, the use of corrugated walls in the arches of the composite I-section is quite controversial, since the corrugated wall
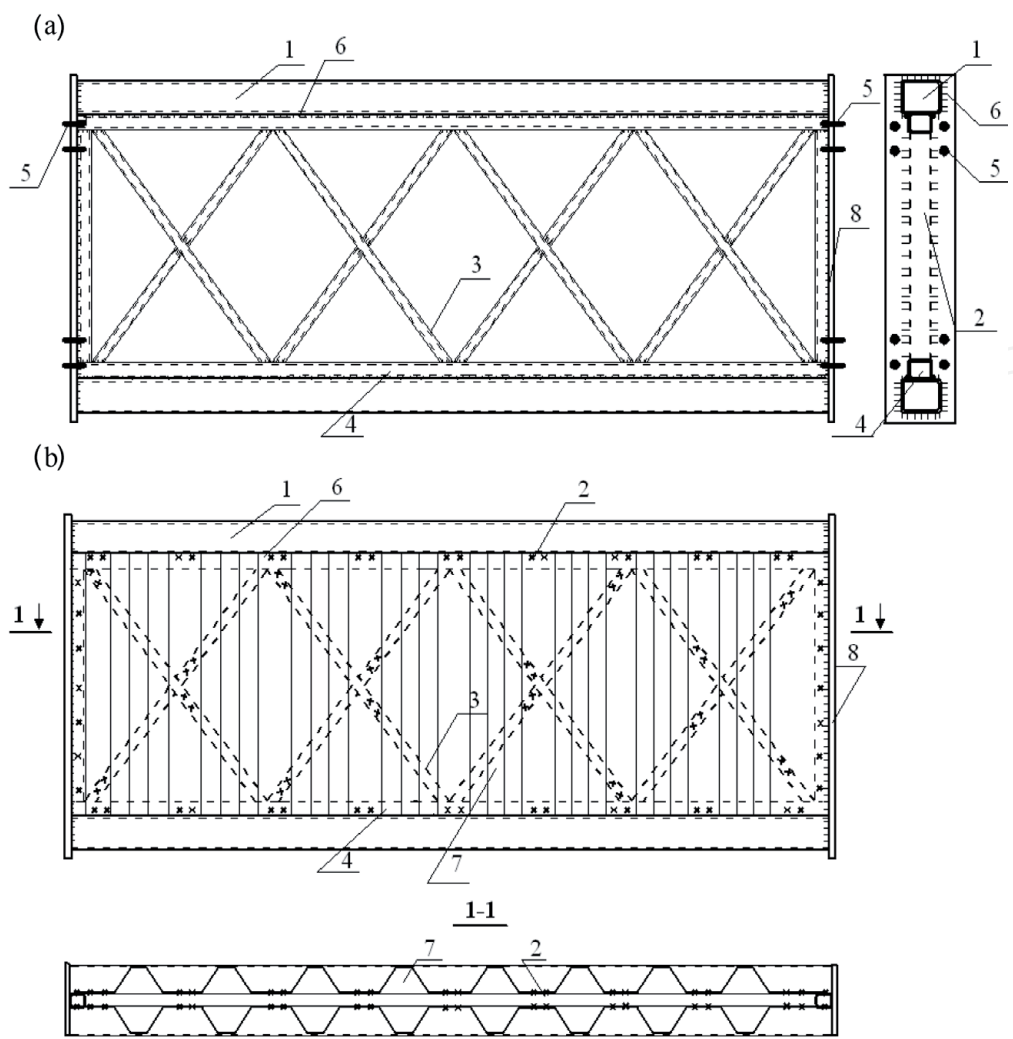
Figure 9.
Beam with transversely profiled box-section wall, unfastened by cross lattice [19]: (a) initial blank; (b) ready compartment.

perceives the transverse force, and for the perception of the longitudinal force there is a constructive need for the use of additional elements, for example, cross lattice. Such a constructive move increases the cost of arches, increases the metal consumption and the complexity of manufacturing such types of structures. Consequently, the use of continuous wall corrugation, both in arches and columns will not provide the necessary technical and economic effect and as a result, is not very rational.

If we consider the design of the truss, the lower belt which works as a stretched curved element, and the upper belt works on compression (for the case without a wall—Central compression, and in General, off-center compression), it is possible to use in these structures corrugated wall, which would perceive the transverse load. For this type of construction, the stiffness of the corrugated wall in the longitudinal direction will be minimal, however, these efforts will only perceive the belt, and a significant proportion of the transverse forces will be perceived corrugated wall compatible with the belts. Corrugated wall also loosens the belt in the plane of the structure.

The combined structure with the upper and lower belts in the form of square pipes is presented. The latter works as an arched element (**Figure 12**): (1) the upper belt of rectangular pipes (section pipe size from 120 to 200 mm); (2) the lower belt of rectangular pipes in the form of an arched element; (3) ribs (thickness from 6 to 8 mm); (4) the wall of a single sheet (thickness from 6 to 8 mm); (5) corrugated wall wavy shape (possible thickness from 2 to 3 mm); (6) support sheet (thickness
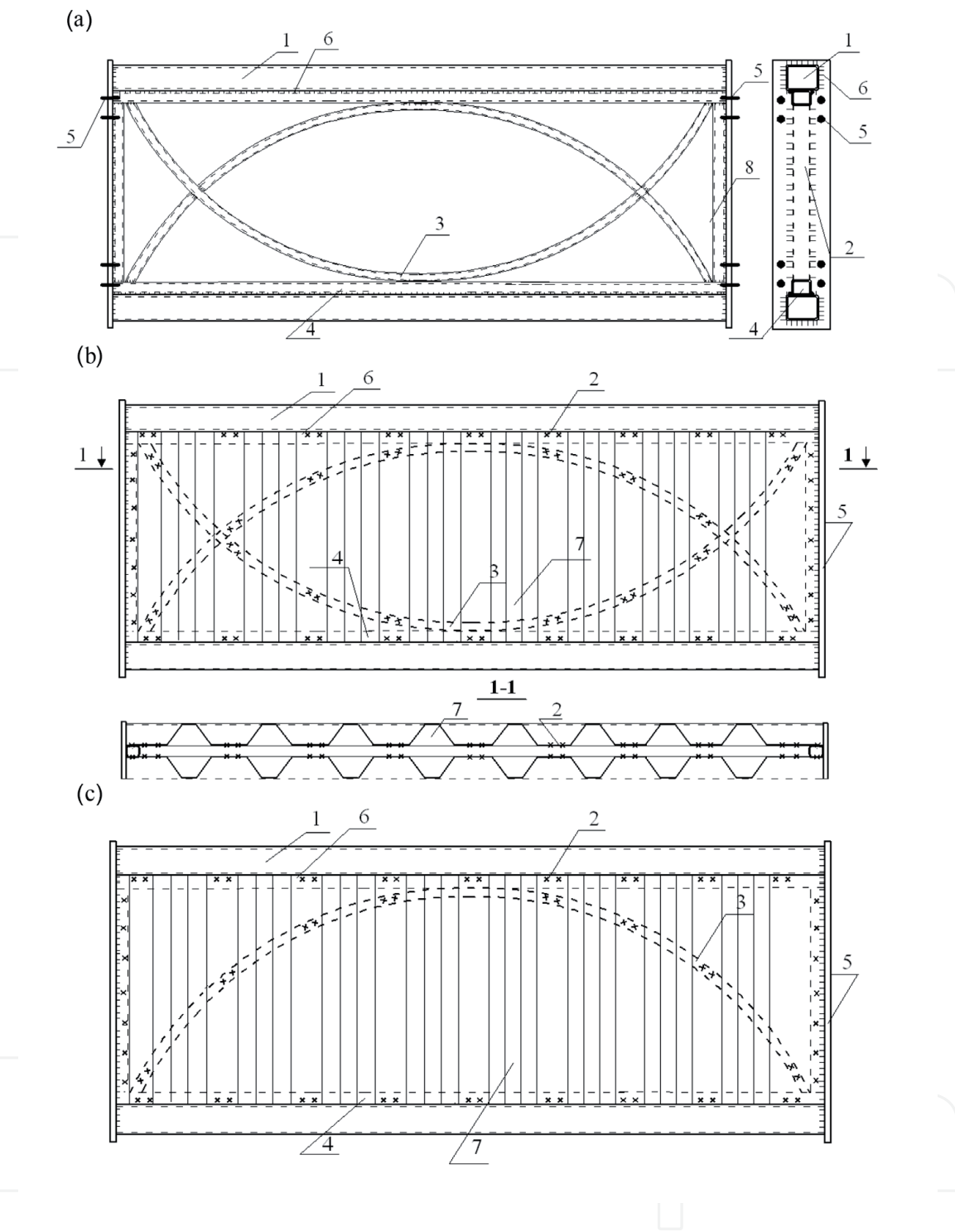
Figure 10.
Beam with transversely profiled box-section wall, unfastened by lattice in the form of arch elements: (a) initial blank with double arched elements; (b) ready compartment with double arched elements [20]; (c) ready compartment with one arched element [21].

from 8 to 10 mm); (7) support edge (thickness from 10 to 12 mm); (8) angular welding (thickness from 4 to 6 mm).

There is a possibility of performing the supporting sections of such structural solutions with the use of steel sheets, which will provide greater bearing capacity under the action of transverse forces. In turn, the corrugation must be performed in the span areas. It should be noted that under the condition of perception of local concentrated loads by the design, there is a need to install stiffeners both in traditional composite beams and in the above structures, since they perform the functions of ensuring the stability of the wall. The combined design is shown
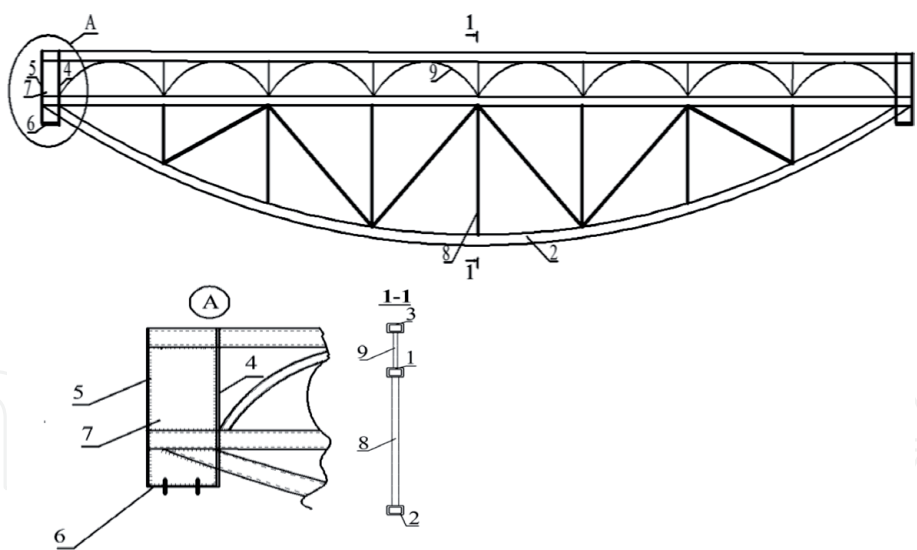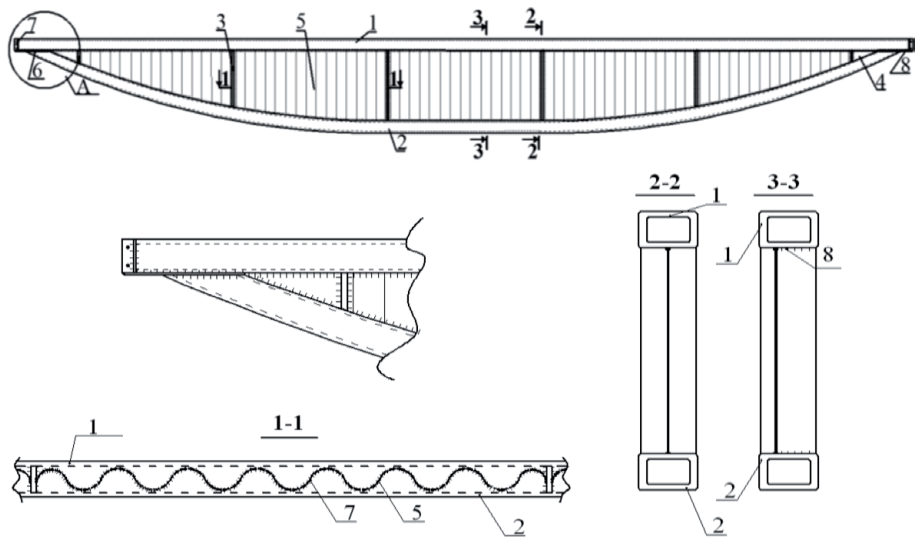
Figure 11.
Truss combined metal structure [22].

Figure 12.
Resource-saving combined metal structure (length from 8 to 30 m) [23].
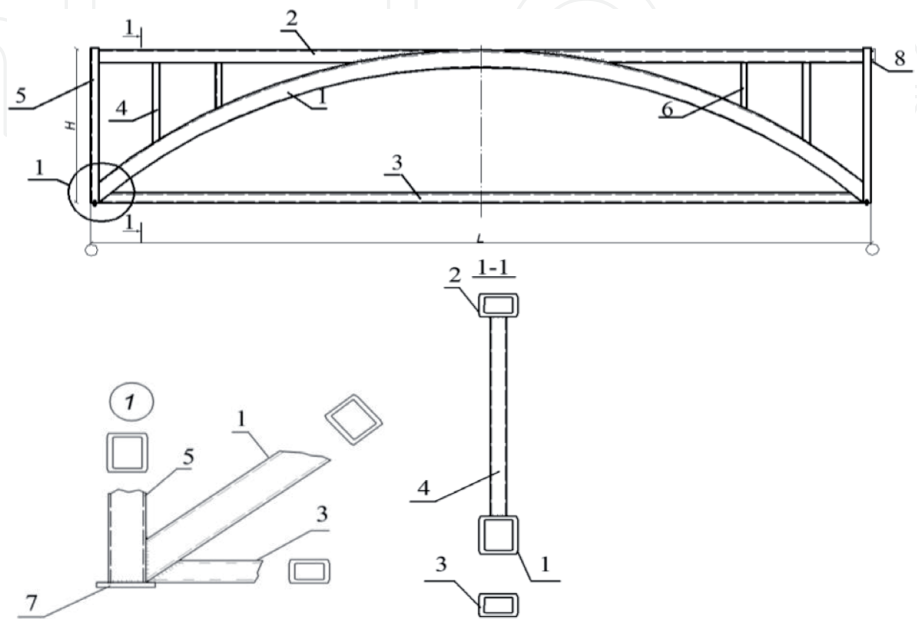

Figure 13.
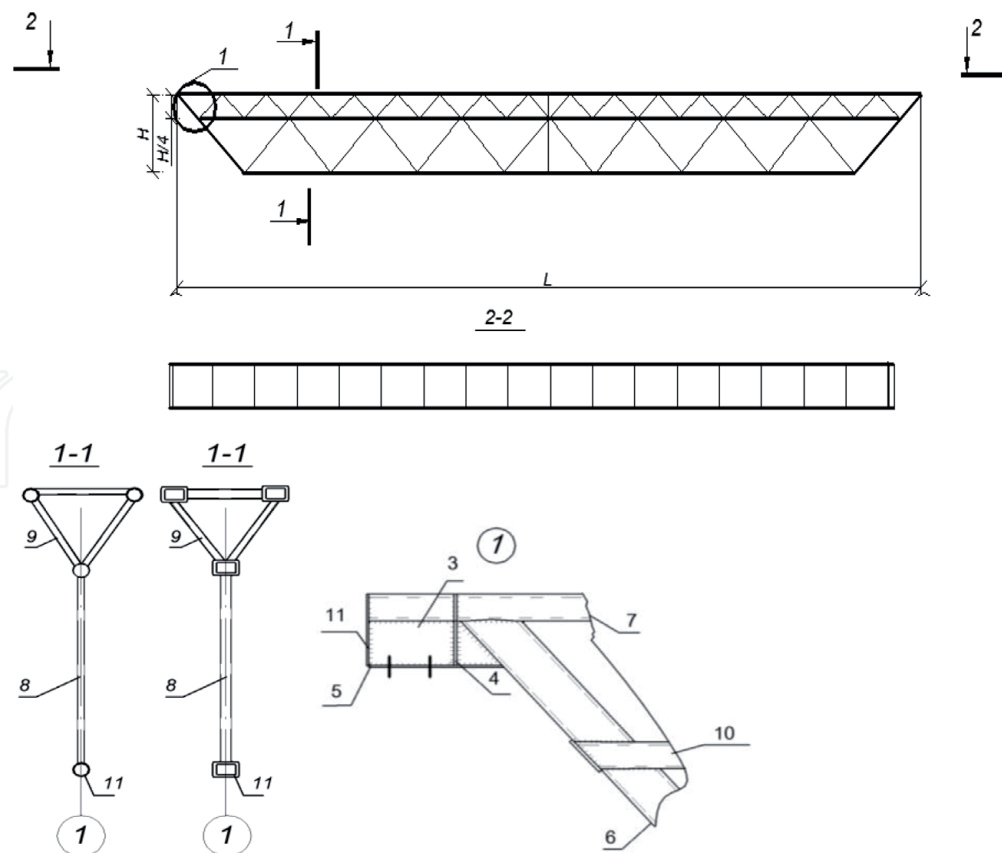*Combined structure of a metal arch with racks [24].*

Figure 14.
Combined structure of metal trusses with upper spatial zone [25].

(**Figure 12**) are an alternative to conventional beams and trusses, which provides a reduction in the construction height (can simultaneously perform the function of the enclosing structure), transport and installation costs.

The combined structure of metal trusses with upper spatial zone is presented (**Figure 13**). This design solution can be used as a single-arched system, reinforced with a system of racks with optimal performance, in particular, with an optimal ratio of height and span of the supporting structure. The design feature of this type of structures is the use of elements in the form of rectangular pipes and cantilever arch support system.

The main elements of the presented design are: (1) the main element of the arch- a rectangular pipe (section pipe size from 120 to 200 mm); (2) the upper belt of a rectangular pipe (section pipe size from 120 to 200 mm); (3) the lower belt of a rectangular pipe (section pipe size from 80 to 100 mm); (4, 5, 6) racks (section pipe size from 80 to 100 mm); (7) the base plate of the sheet (thickness from 6 to 10 mm); (8) the support edge of the sheet (thickness from 10 to 20 mm). Considering the technological advantages of such a structural form, we note that it is possible to use reduced corrosion-resistant sections of the optimal shape (rectangular pipes) to obtain resource-economic structures with a minimum weight. Outlining the stages of manufacturing this welded arch with racks, a necessary step is to secure the installation with bolts of high strength. The authors recommended the rational use of combined structures of metal arches with racks for spans 12–36 m.

With the aim of obtaining optimal performance constructive solutions have been proposed combined structure metal truss with upper spatial zone (**Figure 14**): (1) runs; (2) ties; (3) longitudinal edge of a solid sheet (thickness from 8 to 12 mm); (7, 10) branches of the upper belt in the form of three round (rectangular) pipes (section pipe size from 80 to 100 mm); (4, 11) transverse support ribs of a solid sheet (thickness from 6 to 10 mm); (5) support sheet (thickness from

10 to 20 mm); (6) lattice element; (9) struts of the through belt of the truss (section pipe size from 80 to 100 mm); (8) element of the truss lattice (section pipe size from 100 to 160 mm).

This design form can be used in light load-bearing coating structures with profiled steel flooring. For this type of structures span can vary from small (24 m) to significantly large (more than 36 m). The recommended slope designs may be a standard 1.5%, and a large (as per design assignment). It is possible to use the arched shape of the truss for the corresponding spans. For this type of structures, the height of the truss is determined by the stiffness and depends on the span. Considering the design features of the combined structure of the truss with a spatial upper belt, it should be noted that the installation parts of the farms are performed according to the standards for the transportation of goods. It is recommended to connect the mounting elements of the trusses with flanges on bolts, as well as by welding, using pipes of larger diameter, which significantly reduces the metal content of the connections. Runs between truss are made of rolling profiles and fixed according to the continuous scheme, due to the wide upper belt of the farm. It should be noted that the use of this type of structures is due to economic calculations according to the above costs compared to standard coating structures.

3. Conclusion

The increase in the complexity of the manufacture of spatial structures is overlapped by a decrease in the material intensity of structures, which makes it possible to obtain more economical designs. The proposed new constructive solutions of steel space trusses, arches and frames which have the characteristics of high bearing capacity and the architectural expression, to minimize the indicators of material and labor costs. Structures of this type have increased characteristics of the overall stability of the individual elements and the system as a whole both in the plane and from the plane. As a result of the study, a number of design solutions of light combined structures are presented, which have a wide range of applications in construction. The advantages of the proposed solutions are ease, industry and great rigidity. Numerical calculations of frame structures allowed to bring the efficiency of these design solutions and track a significant reduction in effort in the racks.

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