Rational Structural System for Roadway Slab of Road Bridges

Valery Shmukler, Yuriy Krul, Vladislav Dushin, and Asaf Aghayev

Abstract The article presents a rational constructive system of steel-reinforced concrete super-structures of road bridges, which can be used in the design of road and city bridges of plate-girder, cable-stayed and suspension systems. The span structure is a spatial two-component system consisting of metal perforated box-section blocks and an effective lightweight reinforced concrete slab of the roadway, put into operation using a shear bracing system. The article outlines the principles for the formation of these systems based on a new bionic-energy method for optimizing structures. It is based on two criteria that ensure that the structure is given positive qualities, such as strain energy and strain-elastic density. As a result os the operation of the method, the solution for perforated beam with variable hole spacing and their sizes that have a given stress–strain state with minimal material consumption. Also developed an algorithm for creating perforated beam with variable hole spacing and their sizes as for linear structural elements so for curved structural elements. The use of non-waste technology to create a metal perforated shell opens up new perspectives for manufacture of these structures.

Keywords Road bridges · Perforated metal box-section blocks · Shear connection system · Lightweight reinforced concrete slab · Bionic-energy optimization method · Strain energy · Strain-elastic density

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1 Introduction

Minimizing the weight of bridges with given bearing capacity is one of the main tasks faces designers. This provides a search for new rational solutions.

At present, steel reinforced concrete span structures of bridges are a modern and promising type of bridge structures, which combine the positive properties of reinforced concrete and metal systems [8, 10–13]. Expanding the range of their use (primarily for spans) encourages the use of lightweight structures as load-bearing metal elements [9]. Perforated elements can be used as one of the variants of lightweight constructions.

However, despite the relatively long term of use, perforated elements are high potential sort of design, leaving a field of action for designers. The main condition for the development of perforated structures is to reduce the cost of materials at a given bearing capacity, or to increase the load bearing capacity at given material costs. Improvement of the characteristics of perforated elements and structures can be achieved by changing the configuration and a hole pitch.

2 Results

The proposed design is a spatial two-component system consisting of metal perforated box-section blocks and included in the work by means of a shear connection system, an effective lightweight reinforced concrete roadway slab (Fig. 1) [1].

This solution can be used in the design of road and city bridges of plate-girder, cable-stayed and suspension systems (Fig. 2).

The metal blocks (Fig. 3) are made of perforated sheet elements by the non-waste technology. The block includes the main beams, transverse diaphragms and the lower plate. All structural elements are joined into a single finished unit at the factory with automatic welding, which, in turn, allows a strict control of the quality of welds. The diaphragms of the block have a ridge on the upper facet, on which a corrugated steel sheet is laid, which is further a permanent formwork for reinforced concrete slabs. The sheet in plan of the upper chord of the structure is immobilized with self-tapping screws or rivet welds (Fig. 4).

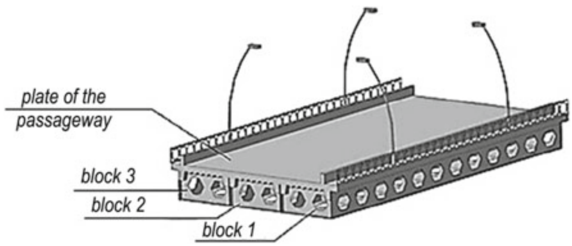


Fig. 1 Fragment of a proposed composite reinforced concrete (CRC) span structure

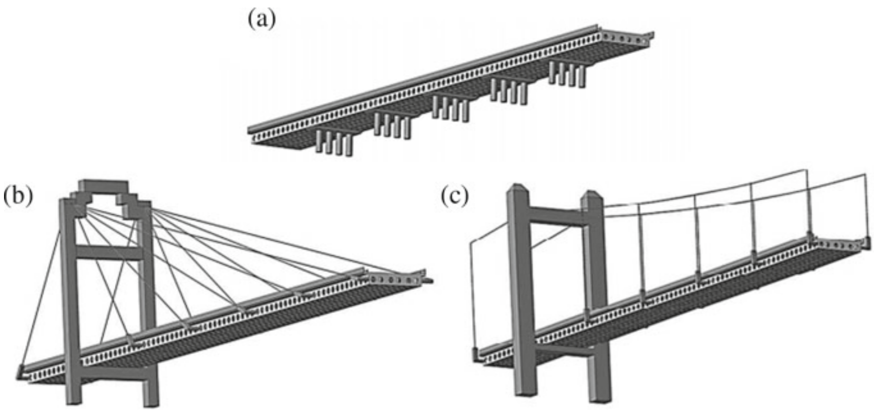


Fig. 2 Variants of bridges of different systems with the proposed span structure: **a** a fragment of the plate-girder bridge; **b** a fragment of the cable-stayed bridge; **c** a fragment of the suspension bridge

Fig. 3 Metal CRC block of the span structure

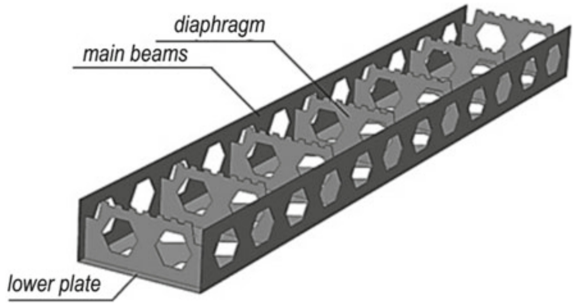
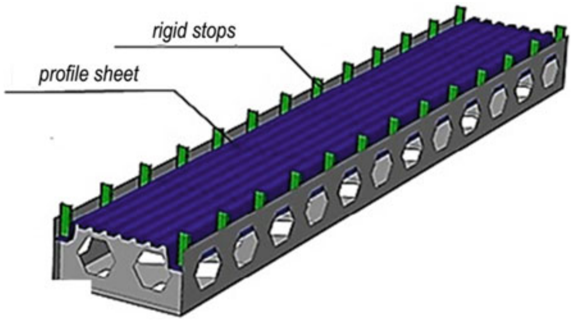


Fig. 4 Factory-built metal block



The blocks are integrated into a single spatial structure, first, by means of HSFG bolts arranged with a calculated pitch along the span length (Fig. 5) and, secondly, by using the proposed connection system connecting the shell with monolithic effective concrete slab of the roadway.

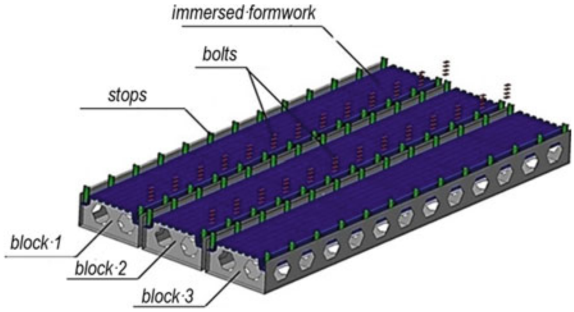


Fig. 5 Joining blocs with HSFG bolts

The aforementioned discrete continuous shear connection system is represented as rigid stops made of segments of the I-beam. To perceive tensile stresses and to prevent the separation of the slab from the metal beams, the stops in two levels, in the transverse and longitudinal directions, are interconnected by reinforcing bars of the deformed section (Fig. 6). The main difference between the proposed system and existing solutions is that the reinforced concrete roadway does not have a metal support element. Reinforcement meshes are laid on the upper and lower rods before concreting, which are a structural upper and respectively lower reinforcement of the reinforced concrete slab (Fig. 7).

The roadway slab is also made of a lightweight reinforced concrete slab (Fig. 8). The upper and lower panels of the slab are made of reinforced concrete, the rest of the height is filled with non-removable foamed polystyrene inserts, between the panels inside the slab along and across the span, stiffeners are made with the calculated pitch. The height of the stiffeners is equal to the full height of the slab. If the design height of the slab increases, so does the cylindrical rigidity, which reduces the cost of reinforcement without increasing the concrete consumption [7].

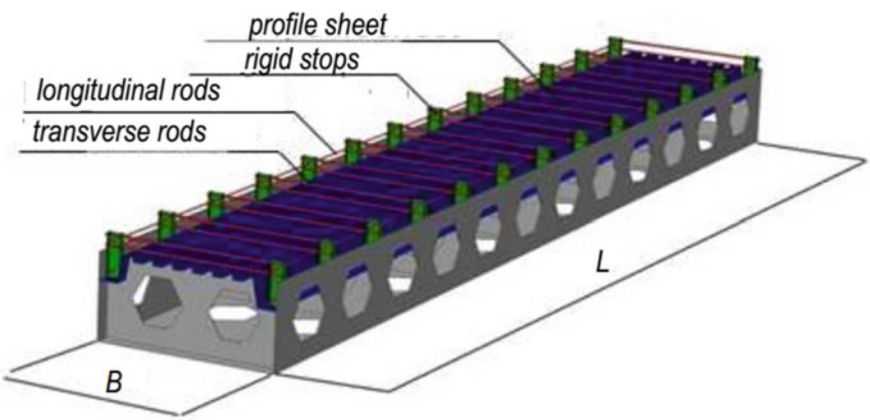


Fig. 6 Discrete continuous shear connections

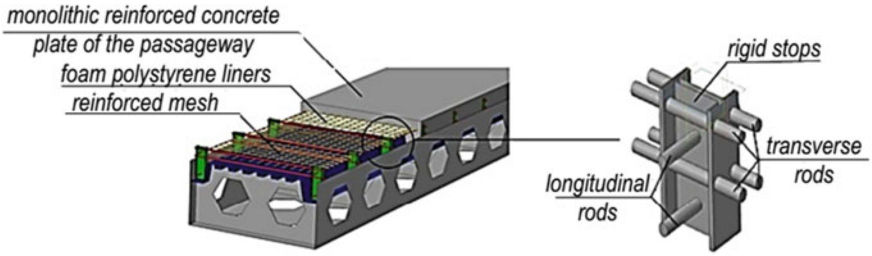


Fig. 7 General view of the discrete continuous shear connection system

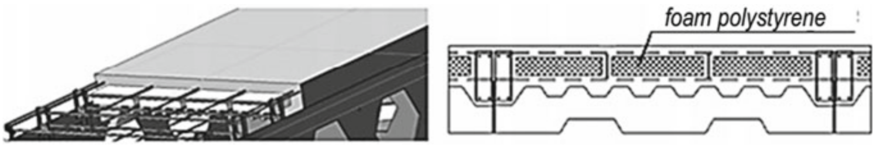


Fig. 8 Roadway slab

In this paper, the principal of a new method for manufacturing such structures are outlined [3]. A feature is fact that the structures themselves are designed on the basis of the bionic-energy optimization (BEO) method [1]. It is based on two criteria that ensure that the structure is given positive qualities [2]:

– the statement that for regulated system with a constant volume of material, the number of external and internal ligaments (external parameters) under the action of static external load—of its own weight, the strain energy after the reconstruction reaches the lower limit on rational combination of geometric parameters values:

$$U = inf U(a_k), \quad k = 1, 2, \ldots\ldots..\infty, \tag{1}$$

where U—strain energy (SE); k—number of equation variant; $a \in M$; M—set of admissible values of external geometric parameters [4].

– the requirements of the isoenergetic state of the system (structure), that is, a state in which

$$e|\{x\}| = const \tag{2}$$

where e—strain-elastic density (SED); $\{x\}$—vector of internal parameters [5].

As a result os the operation of BEO-method, the solution for split beams is obtained in the form of a structure with a stepwise changing height of the sections [6]. Further, according to the developed algorithm, this beam is replaced by an equivalent perforated beam with variable hole spacing and their sizes. The essence of the method is as follows.

Solid billets are cut along the vertical beam web into semi-beams with a broken line and connected to each other along the existing ridges. For the manufacture of perforated elements, two solid billets are used, which are cut with an identical cut into two pairs of identical half-beams. They are connected along the existing ridges, having first turned one of the semi-beams at an angle of 180° relative to the longitudinal axis. As a result, two perforated beams with open and closed ends are obtained, which are later combined into a single beam.

In addition, for the production of perforated elements with equal strength, the billets are cut using a beam web cut, which allows varying the size of intermediate ridges and cutouts. This ensures a variable step and variable sizes of holes in the finished beams. At the same time, the sizes of the intermediate ridges and cutouts are arbitrary, and the billets are cut in such a way that the total length of the workpiece is equal to $L = 2n + (2n - 1) + 2x(2n - 1)p$, where 2n—pair number of intermediate

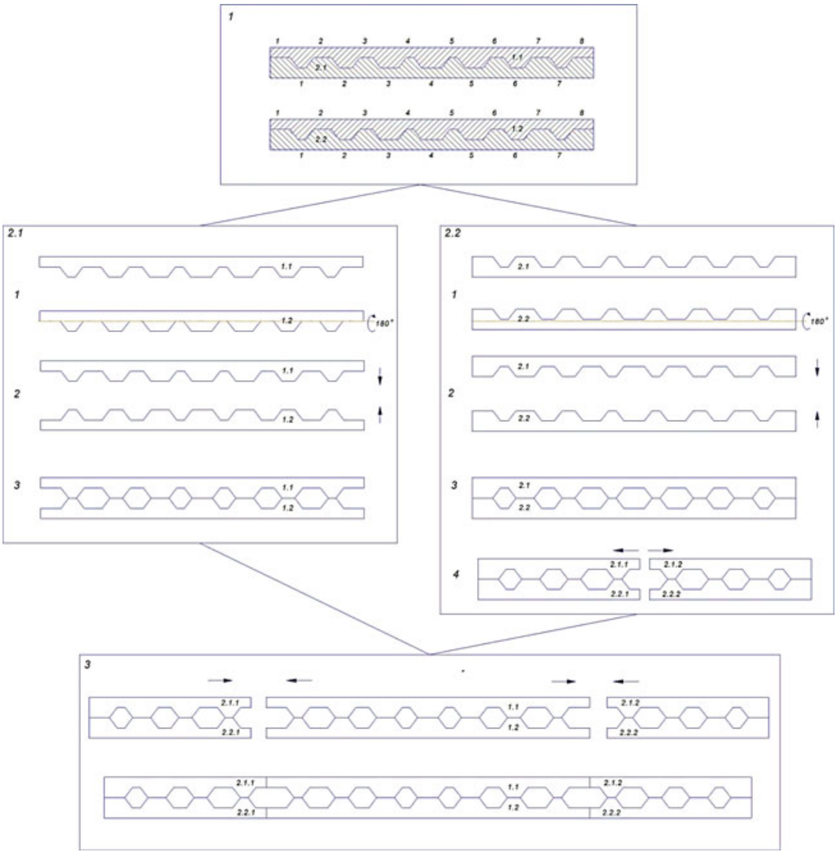


Fig. 9 Principle of forming an equivalent perforated beam (linear structural element)

ridges, (2n − 1)—unpaired number of intermediate cutouts, p—the length of the projection of the inclined part of the hole on the horizontal axis.

Before connecting and welding the finished beam, the beam with closed ends is cut in half. After that, docking is performed on both sides to form a single structure.

For the manufacture of a curved perforated energetically equal strength element and elements of variable height, cut of the beam web of the billets along a curve or at an angle to the longitudinal axis are used. At the same time, for the manufacture of equal-strength perforated elements, the workpieces are cut with a cut, in which the ridges are parallel to the longitudinal axis of the beam, and the cutouts are located at an angle to the longitudinal axis, or vice versa.

Examples of solutions obtained in this way are illustrated in Figs. 9, 10, 11 and 12.

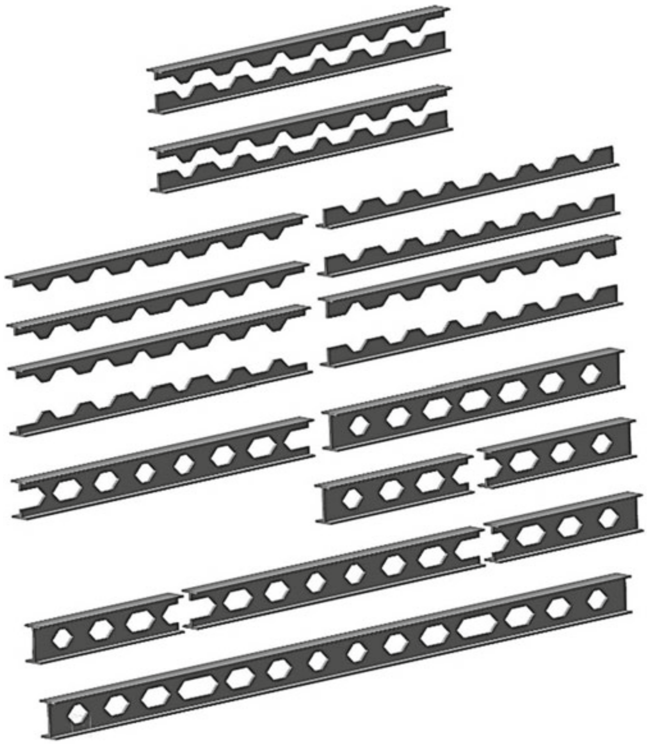


Fig. 10 View of the formed perforated beam (linear structural element)

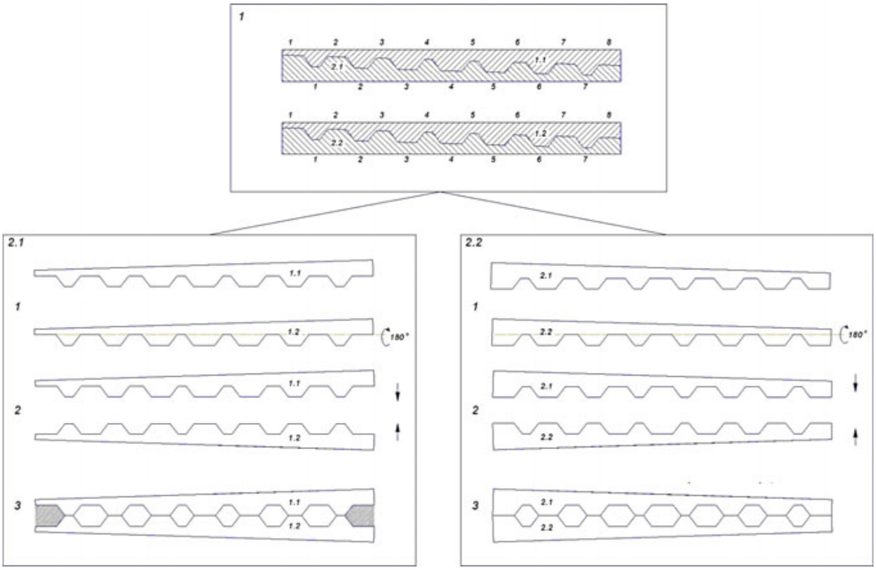


Fig. 11 Principle of forming an equivalent perforated beam (curved stuctural element)

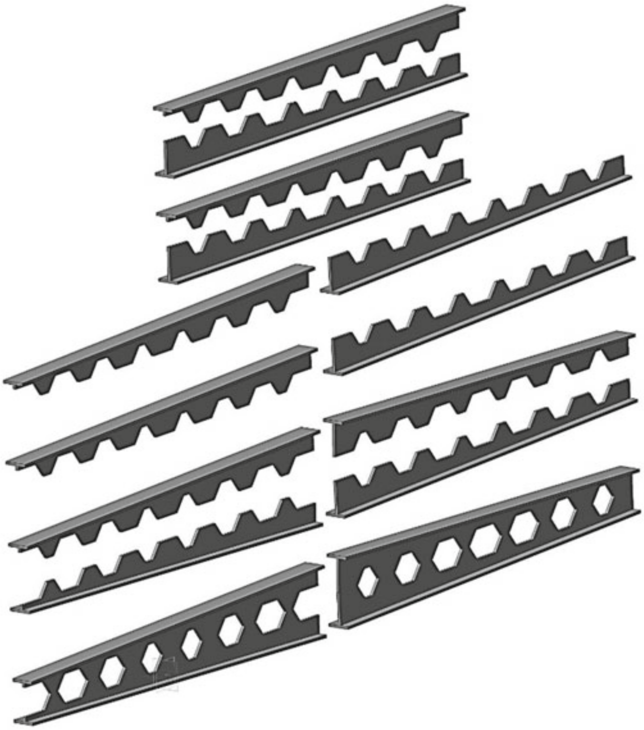


Fig. 12 View of the formed perforated beam (curved stuctural element)

Fig. 13 Composite reinforced concrete bridge in Barvenkovo (author's photo)

3 Conclusions

The priority of the BEO-method is due to the possibility of direct formation of the geometric form and, if necessary, the physical and mechanical content of a large structural system. It can be stated that the final erected construction is a modern efficient system of combining metal girders with the concrete of the roadway slab with discrete continuous shear connections, which minimizes the overall cost and complexity of the process of building steel and steel. The use of non-waste technology to create a metal perforated shell opens up new perspectives for manufacture of structures that have a given stress–strain state with minimal material consumption (Fig. 13). The latter is a consequence of the accepted universal criteria.

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