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CHAPTER 12 - INNOVATIVE BRIDGE STRUCTUES

THE EFFECTIVE METHOD OF STRENGTHENING OF REINFORCED CONCRETE BEAM BRIDGES BY ARRANGEMENT OF THE HORIZONTAL STEEL-CONCRETE COVER SYSTEM

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Abstract

The article reviews the method of strengthening distressed reinforced concrete road bridges by arrangement of steel-concrete system which consists of transverse (and where necessary longitudinal) discharging steel beams connected to a cast reinforced concrete cover slab. The need for such strengthening is often connected with the width of the bridge roadway or increasing dynamic loads.

The concept of reconstruction of beam bridge structures with widening of the roadway by arrangement of the cast reinforced concrete cover slab is widely known nowadays. The above mentioned cover slab works well if the bridge span beams are sufficiently reliable and powerful. With insufficient bearing capacity of the span elements, it is common practice to demount the longitudinal constructions completely and to replace them with the more reliable ones or to add elements of external reinforcement and to install additional bridge piers. These strengthening methods lead to significant material expenditures and negative economic consequences due to the temporary decommissioning of the bridge structure.

The proposed strengthening concept allows to integrate completely into the common work the existing beam elements of the bridge structure and to redistribute effectively forces between them without complete freeze or decommissioning of the bridge structure. The method is implemented as follows. The upper part of the strengthening in the form of the cast reinforced concrete slab is placed above the distressed beam structures. The stainless steel anchor studs come out from the above mentioned concrete slab into the space between the beams. The transverse steel beam elements are fixed to the metal studs. The number of them depends on the overcapacity degree of the bridge constructions. In case of needs longitudinal steel beams are attached to them. In that way, steel-concrete strengthening constructions form a system of two hardness discs. The overloaded span balk constructions are clamped in the space between the discs.

The modelling program of stress-strain distribution of strengthened steel concrete cover systems of bridges was developed on the basis of the proposed method and proved itself well during the reconstruction of the road bridges in Vinnytsia region.

Keywords: *Bridge structure, precast reinforced concrete spans, breakdown, strengthening of structures, hanging metal beams.*

1. Introduction

Global progress dictates strict demands of intensifying the national and international turnover of each country, which joins the world economy. The Trans-Eurasian corridor could stretch over the territory of Ukraine, which also connects the developed economies of East and West. Unfortunately Ukraine cannot use all its economic benefits of the transit state. Good geographical position is mitigated by the terrible conditions of the automobile roads – the main transport arteries in the modern world.

The vast majority of the roads in Ukraine were built in the 1950s and 1970s, survived a series of not successful modernizations in the 1980s and haven't been changed since then till now. Only local roads were partially repaired. Out of date automobile road system does not meet the requirements of the modern standards of carrying and traffic capacity and requires immediate reconstruction.

One of the most demanding and constructively complex elements of the automobile road is the bridge structure. At present, the vast majority of the total stock of road bridges in Ukraine is made up of beam structures (Fig. 1), which were built more than fifty years ago under the work load NK-80 (A-11). The standard construction of such bridges is a system of longitudinal span pre-stressed reinforced concrete beams of I-shaped cross section with 6 – 12 m span (3), united in a continuous caisson slab system by connecting adjacent transverse diaphragms of beams located at a pitch of about 2.5 – 3 m, which takes the load from the road pavement and sidewalks (4). I-beams are rested on transverse transoms (2), which transfer the load to the system of standing piles (1).

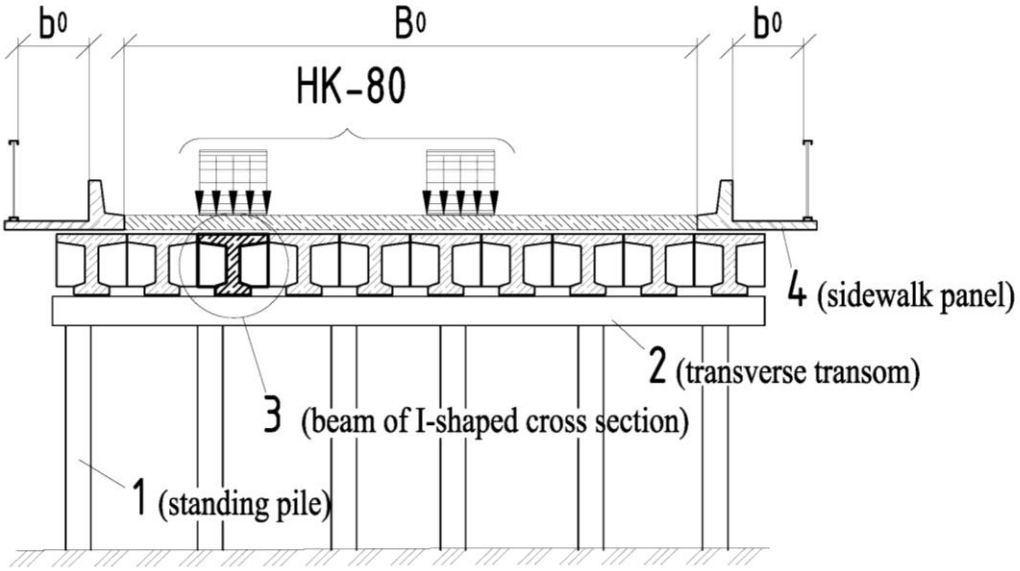

Figure 1.
Cross sectional view of a typical beam bridge structure before reconstruction. (Note. HK-80 = 8 x 98 (kN). A11 = 4 x 105,3 (kN) + 2 x 8,10 (kN/m))

In the early 1980s in Ukraine there was an urgent problem of increasing the road capacity in general and the bridge structures, in particular, which was caused by the growth of industrial traffic flow, as well as military needs. Preference was given to the reconstruction project that required the smallest investment (Fig. 2, at the bottom).

Most of the beam bridge structures in the country were reconstructed according to this typical project by arranging two-way ride height broadening (B1) and pavement part (b1) using enlarged pavement panels (8), drop pavement (9) over the system of new hollow span beams (7), hingedly rested on the ends of new piles and beam systems (5, 6) and not connected by the side surface with existing continuous slabs from I-beams.

After the reconstruction, a complex span system was formed from a caisson slab in the center and swivel span hollow slabs-beams on both sides. The connectivity of the old and new span elements was ensured exclusively in the plane of the posts due to the hardness of the supporting transverse transoms. In the span, the hollow beams and the caisson slab work separately. This design solution was not successful from the very beginning, because the non-reinforced asphalt pavement cannot contain in operation the hollow beam and the marginal I-beam of the caisson slab simultaniously.

The behavior of this system under load depends on the location of the wheel track and is not described in the regulatory documentation. The worst thing for a reinforced concrete caisson span slab of the bridge structure is the arrangement of the wheel of the nominal design load (HK-80 or HK-100) above the marginal I- beam (Fig. 2, circled from the left side), and for hollow beams - directly above the beam, (Fig.2, circled from the right side). Operating experience has shown that longitudinal cracks in the road surface may appear at the junction of new beam and older slab-caisson structures.

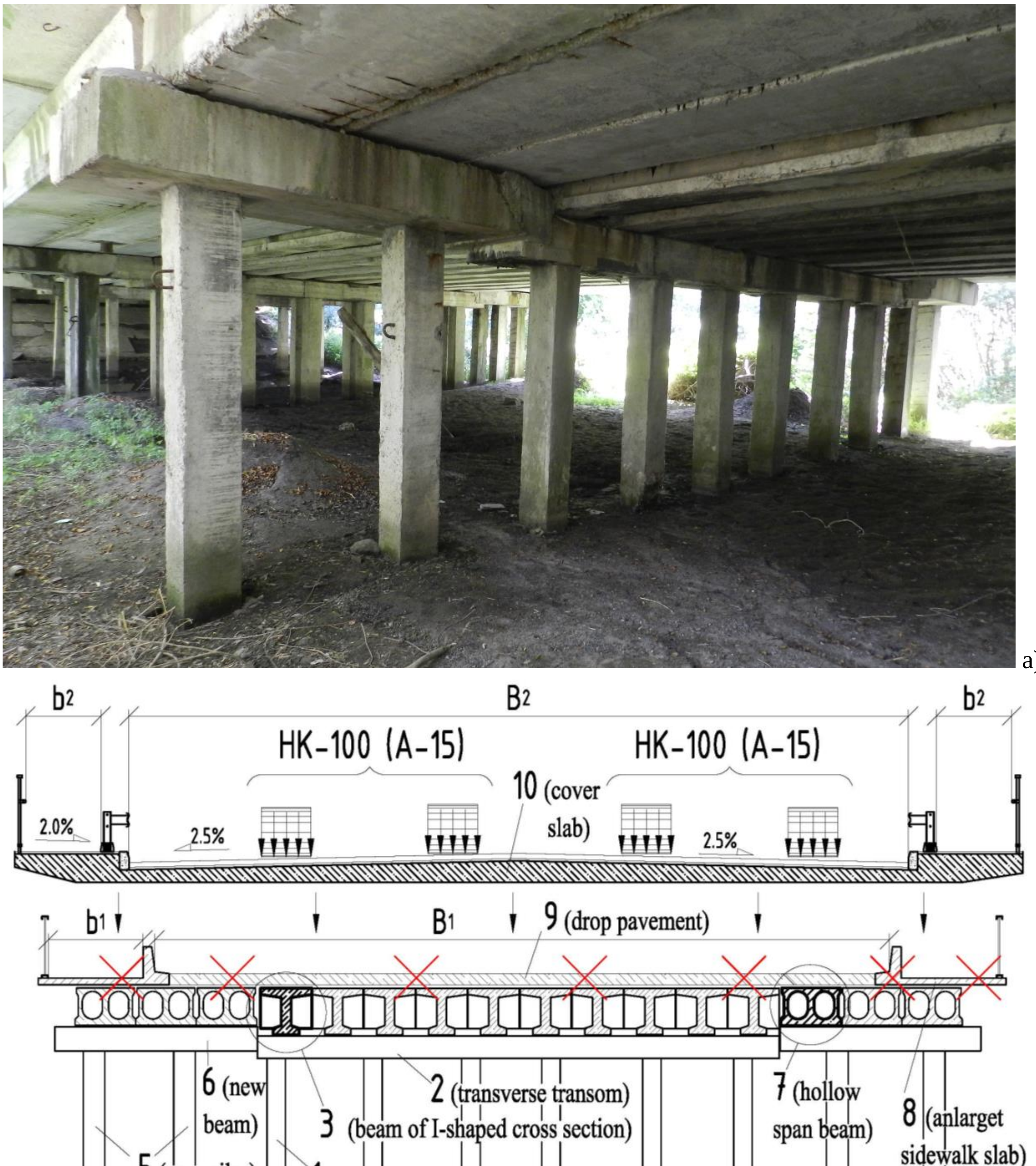

Figure 2.
Bridge structures after the reconstruction, which was carried out in the 1980s. a) – nature condition; b) – scheme of a modern way of strengthening by the arrangement of the cover slab. (Note. HK-100 = 8 x 122,5 (kN). A15 = 4 x 143,5 (kN) + 2 x 11,05 (kN/m)).

Except the operational defects of the bridge structures, nowadays there is a new problem in the additional increase of the loads on the bridge structures of the main highways because of the further increase of the traffic flow and increase of the design bearing capacity (from HK-80 (A-11) to HK-100 (A-15)). The difficult economic status of the country provides for the reconstruction of structures where possible, without stopping the operation of bridges.

2. Problem statement.

At this time, the problem is solved in the classic way, by the arrangement of the cover ground reinforced concrete slab for the broadening of the bridge cross-section and the load redistribution between the structures. The cover slab (10) can be made in two turns, which allows to use the half of the bridge roadway in a limited way (Fig. 2, from the top).

This method solves completely the problem of the non-connected operation of the span bridge elements (longitudinal deformation cracks) by redistributing the forces and deformations between the span elements by the cover hardness disk. However, in order to bring the bridge structure in line with current regulations, the precondition is the strength reserve of the span and supporting structures. As experience shows, only load carrying bridge structures with spans up to 6 m have got a sufficient reserve of strength.

Express assessment of the bearing capacity of the main load carrying elements of existing reinforced steel concrete bridge structures with spans over 9 m, designed under the running load of HK-80 (A-11), using simplified (bilinear) material strain diagrams, proves that neither cross beams nor span elements are unable to take the additional loads from the monolithic cover slab and growing wheel road impacts (HK-100 (A-15)).

Nowadays, the standard engineering solution in the case of reinforcement of overfed span elements is as follows:

- arrangement of additional supporting pier systems, which unload the structures;
- dismantling of overloaded elements and arrangement of new ones, reinforced for heavier loads.

However, these methods have got several disadvantages, namely:

Full engagement of intermediate support systems in the work of a stressed structure is not possible. Partial engagement can be only achieved after appearing of certain deformations because of the overload structures, which can be higher than the allowable maximum. Thus, the effectiveness of intermediate support systems in relation to the investments for their arrangement is quite low. Regarding the new span elements, the costs for such reconstruction are often higher than the costs for the new bridge structure. So far, there is no universal effective solution for strengthening the bridge beam structures.

That is why, it is reasonable and crucial to find an effective constructive solution for the reinforcement of bridge structures with spans more than 9 m by the arrangement of steel reinforced cover systems.

In order to achieve the set goal it is necessary to complete the following tasks:

- to develop a method for strengthening the span elements of the bridge beam structures with steel reinforced concrete cover systems and technology of reinforcement arrangement;
- to confirm the reliability and effectiveness of the proposed solution by means of finite element modeling ;
- to develop design recommendations for cover system arrangement.

3. Main part.

The method is implemented as follows. The upper part of the strengthening, i.e. the classical cast reinforced concrete slab is placed above the distressed beam structures. The stainless steel anchor studs come out from the above mentioned concrete slab into the space between the beams. The steel beams system is fixed to the metal studs. In that way, steel-concrete strengthening constructions form a system of two hardness discs: the upper disk is a cast reinforced concrete cover slab, the lower disk is a metal beam system. The overloaded span balk constructions are clamped in the space between the discs.

The proposed strengthening concept allows to integrate completely into the common work the existing beam elements of the bridge structure and to redistribute effectively forces between them without complete freeze or decommissioning of the bridge structure. The concept can be implemented in two variants - the upper slab with bottom transverse unloading steel beams, or with bottom transverse and longitudinal beams, which can additionally rest on the transverse load bearing transoms (Fig. 3, Fig. 4).

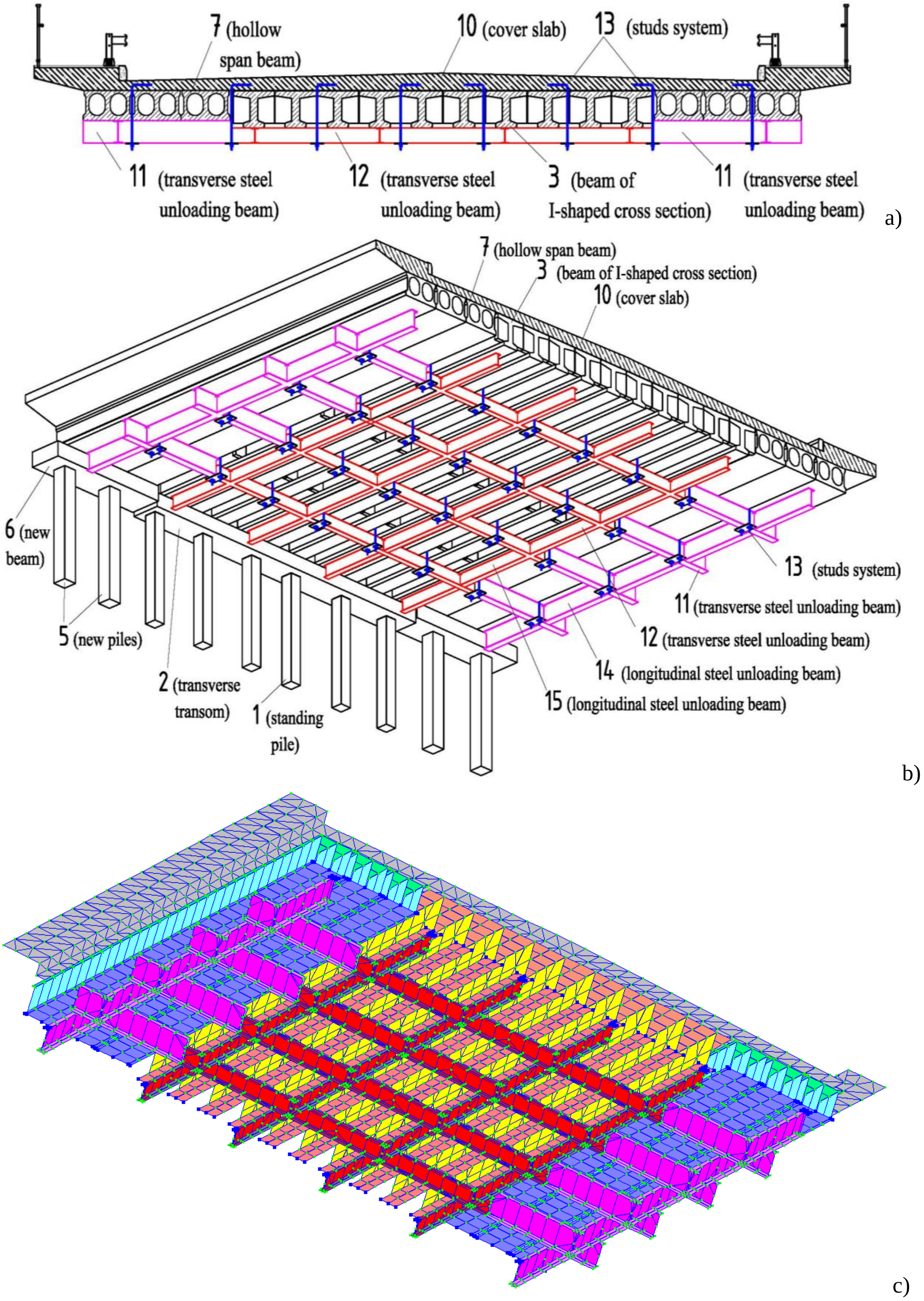

Figure 3.

The proposed method of strengthening of beam span structures by the arrangement of the cover slab and hanging beam system. a) – typical cross-section, b) – axonometric image, c) – finite-elements model of the span fragment.

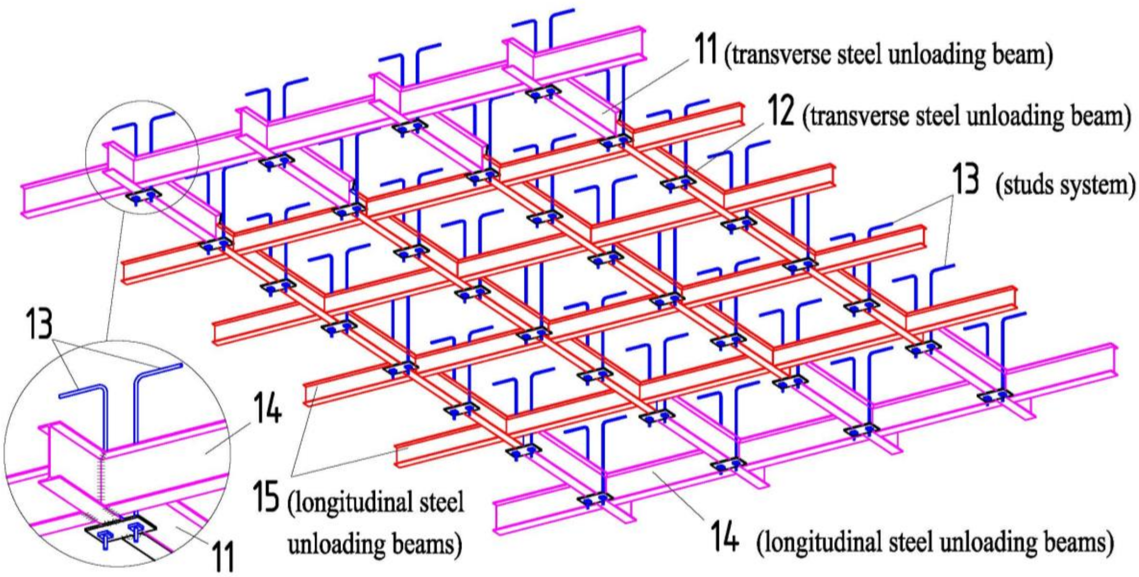

Figure 4.

Metal structures of the hanging beam reinforcement system with studs.

At the stage of preparatory works, it is necessary to limit the load capacity of the bridge structure, to install appropriate temporary road signs, edging, crash barriers and markings.

The sequence of reconstruction works (see together with Fig. 3 and Fig. 4):

- dismantling of existing pavement and sidewalks;
- arrangement of studs system (13);
- arrangement of reinforcement and concreting of cover steel concrete slab (10), including road and sidewalk parts;
- arrangement of transverse steel unloading beams, which are hung to the metal studs (11, 12);
- arrangement (if necessary) of longitudinal load-bearing beams of the steel part of the cover system (14, 15);
- arrangement of edging, protective barrier systems and handrails;
- arrangement of basic and finish asphalt concrete covering of the road and pedestrian parts;
- dismantling of temporary signs and structures, which were set at the preparatory stage of works.

The bridge structure is reconstructed in separate work zones, the width of which depends on the width of the bridge structure. For the bridges with a roadway width of 13.5 m (2 traffic lanes with 3.75 m each and 2 safety lanes 3 m each) (Fig. 3), works on the arrangement of the cover slab (10) should be carried out in the zone, which is ½ larger from the total roadway width (about 7 m) in order to give the opportunity for traffic flow, at least, for car traffic and barriers-free pedestrian traffic. The studs system (13), which is installed to ensure the connectivity of upper and lower hardness discs, should be made of high-strength stainless steel (E.g. 40X steel) and installed between the span load-bearing elements.

Two studs should be fixed on each place of slab attachment to the beams. The upper part of the studs should be bent toward the arrangement of the cover slab reinforcement (10). Recommended reinforcement of the cover slab is double row, reinforcing steel A500, diameter and pitch are determined by the calculation. As the works on concreting the cover slab (10) are performed in work zones, a reliable concrete joint should be arranged between them.

The height of the lateral steel unloading reinforcement beams (11, 12), which are installed later, should be defined by the design requirements and calculation. It is recommended to use hot dip galvanized H-sections. Suspension to metal studs is carried out using support metal plates with holes. The screws which are used for fixing the elements should be tightened on the stud with a guaranteed tension (up to 70% of the stud bearing capacity).

In appropriate cases, if the load-bearing capacity of the system is not sufficient, transverse beams should be fixed to the longitudinal beams (14, 15). The system of longitudinal and transverse beams should be secured by welding, and the longitudinal beams themselves should be rested on the transverse transoms of the bridge.

4. Conclusions

As a result of the carried out research of finite element models of the stress-strain state of the existing beam bridge structures, which can be overloaded at the time of increased traffic density (load HK-100 or A-15), we can draw the following conclusions.

An effective method of strengthening the beam bridge structures, increasing the carrying capacity from road transport up to 30%, using the system of reinforced steel concrete structures consisting of two hardness discs was proposed: the upper disk is a cast reinforced concrete cover slab, the lower disk is a steel beam system. The overloaded span balk constructions are clamped in the space between the discs. Disc connectivity is ensured by the stainless steel stud system which can be pre-stressed under certain conditions.

The reliability and efficiency of the proposed reinforcement system is confirmed by a thorough analysis of finite element models of stress-strain state and strength calculations.

During the carrying out of the works, it was found out that the reconstruction with the extension of the structure carried out in the 1980s, was not rationally performed, because the full connectivity of the slab caisson part and hollow expansion beam structures was not ensured. Longitudinal deformation cracks in the asphalt concrete bridge covering were visible during the inspection and are the evidence for the above mentioned lack of connectivity.

The proposed method was implemented in the real engineering practice during designing of bridge structures reconstruction on the traffic roads E50 (M12), E583 (M21) in Vinnytsia region.

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