ANALYSIS OF THE BEHAVIOR OF COMPOSITE STEEL-CONCRETE SLAB BRIDGE SUPERSTRUCTURE

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Abstract: *The paper presents an optimization of the calculation of slab bridge superstructures with composite steel-concrete section, dealing with three types of composite structures of this kind, for which the calculation methods in the elastic-plastic field have been complied with the provisions of the European norms in force. In this respect, the paper will present the calculation algorithm and the Newline CSD (Composite Structure Design) railway bridge design program. The obtained results conducted to the conclusion that composite slab bridges can be included in the high reliability construction category, in condition of a minimal maintenance works during their lifetime, respectively could reach or even exceed the usually forecasted life time (about 100 years).*

Key words: *composite, slab, bridge, Newline, design*

1. Introduction

Current trends in the development of rail transport are imposing the development of technical requirements in terms of infrastructure and superstructure of bridges, which would among other things ensure an increase in the speed of trains. Starting from this premise, a prime requirement for the rehabilitation or construction of small and medium span railway bridges is to ensure the continuity of the ballast cushion. [7].

This requirement of continuity of the ballast cushion on the bridge is possible by changing the traditional solution of the "open type" track, where the superstructure of the track (sleepers and rails) rests directly on the structural elements of the bridge superstructure (longitudinal girders, main beams), with the "closed type" track where the superstructure of the railroad track rests by means of a layer of broken stone supported by a tank [2].

In the Romanian technical literature, there are only a few works that deal with the calculation and design of mixed steel-concrete structures for railroad construction and not only.

Over time, the slab bridges were made by various structural solutions of the superstructure, such as:

- slab superstructure with concrete embedded rails;
- slab superstructure with concrete embedded steel beams;
- slab superstructure made of reinforced concrete

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2. Objectives

The present study contributes to the optimization of the calculation of the superstructures with the mixed steel-concrete section by presenting three types of mixed slab structures for which have been developed calculation methods in the elastic and plastic field, respecting the provisions of the European norms in force [7]:
- Mixed section slab with steel structure made of plat-bands;
- Folded slab with composite steel-concrete section;
- Mixed section slab with steel structure made of steel pipes.

3. Composite Steel-concrete Slab Bridges

Both the railway and road routes, especially in the hilly and mountain areas, where the need for water evacuation occurs more often, there are used the so-called slab bridges in a mixed steel-concrete structure, the type of tank. These structures can also be used for eco-ducts, having the role of reducing the undesirable effects that traffic would have on the environment they cross, preventing fragmentation of the habitat [7].

Composite steel-concrete slab bridges are presented below, namely:
- Mixed section slab with steel structure made of steel plates:
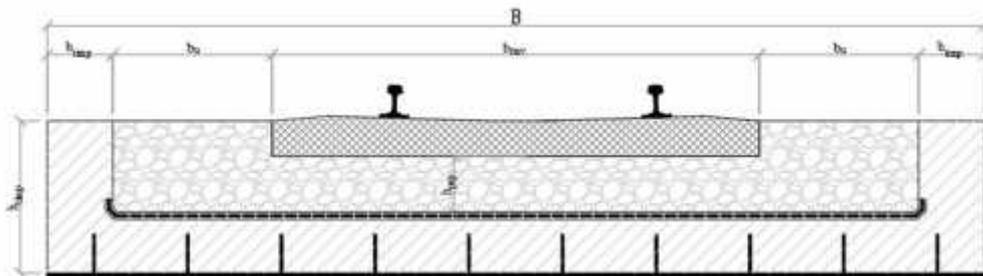

Fig. 1. *Composite steel-concrete slab bridge superstructure cross section – steel structure made of steel plates*

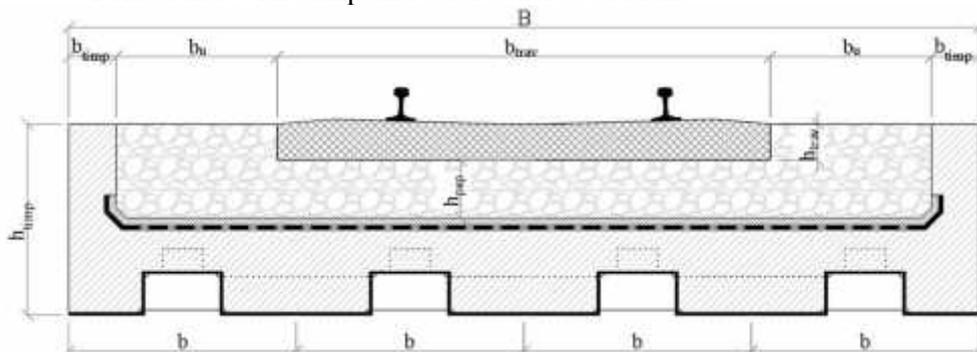- Folded slab with composite steel-concrete section:

Fig. 2. *Composite steel-concrete folded slab bridge superstructure cross section*

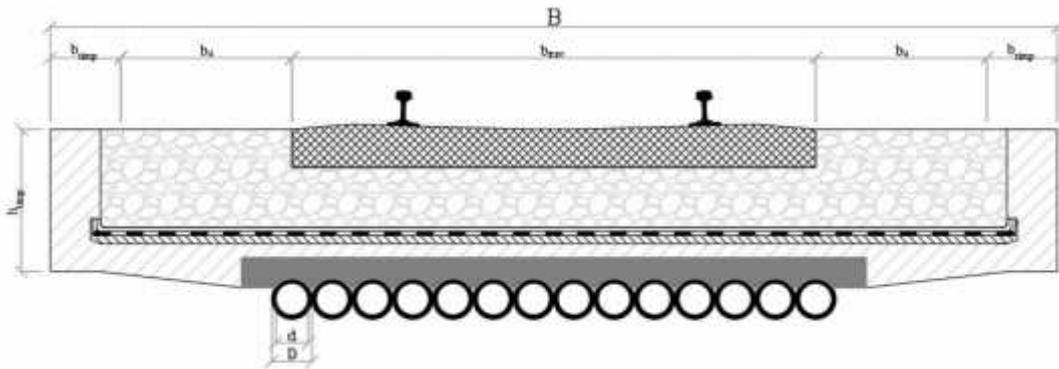- Mixed section slab with steel structure made of steel pipes:

Fig.3. *Composite steel-concrete slab bridge superstructure cross section – steel structure made of tangent steel pipes*

The real advantage of these bridges is that they ensure the continuity of the ballast bed on the bridge, so no changes are needed in the superstructure of the railway. Other advantages of these types of mixed structures compared to conventional ones are as follows:

- the possibility to modify the path of the track in the horizontal plane and the level of the longitudinal profile;
- derailments on mixed structure bridges have less serious consequences than on conventional ones;
- the height of the superstructure is smaller in the mixed structure bridges, at the same time the structure is more rigid and more favorable from the point of view of the dynamic actions by alleviating the fatigue phenomenon;
- the construction of mixed structure bridges is much faster than conventional reinforced concrete bridges, a much smaller amount of formwork is needed;
- replacement of wooden sleepers with pre-stressed concrete sleepers. Special type of sleepers can be also used, like a frame sleeper which provides increased railway track stability compared to the classical sleeper used in present in the majority of railway network [6].
- ensuring the maintenance of the track on bridges with high productivity equipment, operating continuously;
- track elasticity is the same as in the current line due to the ballast prism.[7]

4. Calculation of Mixed Steel Structures

The methods for dimensioning and verifying the stresses that are developed in the composite steel-concrete sections are based on the following general assumptions [2]:

- the validity of Hooke's hypothesis, the proportionality between stress and strains;
- the validity of Navier-Bernoulli's principle, the plane sections before deformation remain flat after deformation;

- it is assumed a perfect connection between the concrete slabs and the steel structure, not allowing sliding (elastic or retentive) on the contact surface of the composite elements with perfect connection;
- the deformations resulting from shear forces are neglected

Taking into account these hypotheses, the stress on the cross sections of the steel-concrete composite structures can be calculated by two methods:
- Transforming the non-homogeneous section of concrete and steel into a homogeneous steel one, by an elastic equivalence coefficient n (equivalent section method);
- Load distribution method [4].

The calculation of the stresses is done by using the equivalent section method. In the calculation, the non-homogeneous section of concrete and steel will be replaced by a homogeneous steel section (ideal section) and the geometric characteristics of the concrete section will be considered reduced by the equivalence coefficient "n_0", which represents the ratio between the modulus of elasticity of the steel and concrete, depending on the nature of the loads acting on the composite structure considered:

$$n_0 = \frac{E_a}{E_{cm}}$$ (1)

where: E_a – modulus of elasticity for the structural steel;
            E_{cm} – secant modulus of elasticity for the concrete.

Stretched concrete sections may not be considered.

The coefficient of equivalence "n" shall be differentiated according to the creep of the concrete and the long and short duration loads as well as their frequency as follows [5]:

$$n_L = n_0 \cdot \left[1 + Œ_2 \cdot \{(t)\right]$$ (2)

where: n_0 – coefficient of equivalency;
            $\{(t)$ - function which describes the creep of the concrete $\{(t, t_0)$ according to EN1992-1-1, Sect. 3.1.4. or 11.3.3;
            Œ - creep multiplier depending on the creep and ageing coefficient according to EN 1992-1-1, with the following values:
- 1,10 - for permanent loads including prestressing by tendons after the shear connection has become effective;
- 0,55 - isostatic and hyperstatic effects due to shrinkage and time depending hyperstatic effects;
- 1,50 – prestressing by imposed deformations. [6]

For dimensioning the slab it was used the calculation model in Fig. 5 and after determining the dimensions of the slab, the maximum stresses are checked by calculation. The calculation model is based on two hypotheses:
    I.   The hypothesis I - the neutral axis is in steel section (Fig. 5).
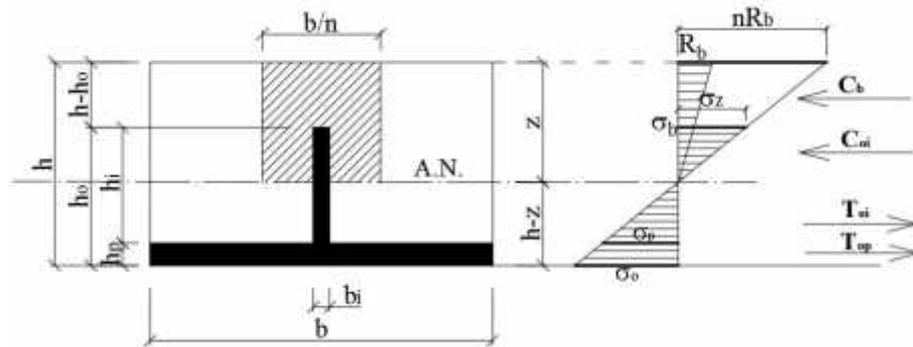   II.   The hypothesis II - the neutral axis is in concrete section

Fig. 5. *Calculation model for the composite steel-concrete sections with steel structure made of plat-bands – neutral axis in steel section*

From the equilibrium condition the following equation results:

$$C_b + C_{oi} = T_{op} + T_{oi} \tag{3}$$

The equilibrium equation components (3) are:

$$C_b = \frac{b \cdot z \cdot R_b}{2} - \frac{(z - h + h_o)^2}{2 \cdot z} \cdot R_b \cdot b_i \tag{4}$$

$$C_{oi} = \frac{(z - h + h_o)^2}{2 \cdot z} \cdot n \cdot R_b \cdot b_i \tag{5}$$

$$T_{oi} = \frac{(h - z - h_p)^2}{2 \cdot z} \cdot n \cdot R_b \cdot b_i \tag{6}$$

$$T_{op} = \frac{\left(2h - 2z - h_p\right)}{2z} \cdot n \cdot R_b \cdot h_p \cdot b \tag{7}$$

By developing the equilibrium equation (3) it will be obtained a second degree equation in z (8). Solving this equation will lead to the neutral axis position (9):

$$(b - b_i) \cdot z^2 + 2 \cdot \left[n \cdot b_i \cdot \left(h - h_p \right) + n \cdot b \cdot h_p - b_i \cdot (n - 1) \cdot (h - h_0) \right] \cdot z +$$

$$+ \left[b_i \cdot (n - 1) \cdot (h - h_0)^2 - n \cdot b_i \cdot \left(h - h_p \right)^2 - n \cdot b \cdot h_p \cdot \left(2 \cdot h - h_p \right) \right] = 0 \tag{8}$$

$$\cdot z^2 + \cdot z + = 0 \tag{9}$$

The calculation of the z-value and of the characteristics of the section (cross section area, static moment of the compressed section, moment of inertia) is differentiated according to the equivalence coefficient taken into account depending on the type of loading: long-term (permanent) , short-term, repeated (fatigue).

5. Newline CSD (Composite Structure Design) Slab Bridge Design Program

Newline CSD is a Visual Basic application based on all the theoretical aspects of calculating this type of bridges and it helps design engineers to make the most economical yet safe design of these structures. The program complies with the European norms (Eurocodes) regarding both the evaluation and grouping of the actions as well as the calculation of the composite steel-concrete sections.

The elaborated programming mode is a different approach to other computing programs, focusing mainly on a user-friendly presentation. These features make the program useful both in education and design, with the obvious benefits of not having to study additional documentation. Thus, the study of a large number of solutions does not involve a great deal of time and does not involve user made calculations.

Fig. 6. *Newline CSD (Composite Structure Design) bridge design program*

Structure dimensioning is the most important stage in design. At this stage the user has to go through seven sizing steps, structured in different tabs of the same window. These steps require the input of the geometrical dimensions, choose of materials, railway characteristics, speed of train, type of train loads, type of connectors.

Normal and tangential stresses are calculated for each load case and for combinations of these loads. Verification of the calculated stresses shall be made within the tolerances of each material chosen, applying the partial safety factors of the materials used.
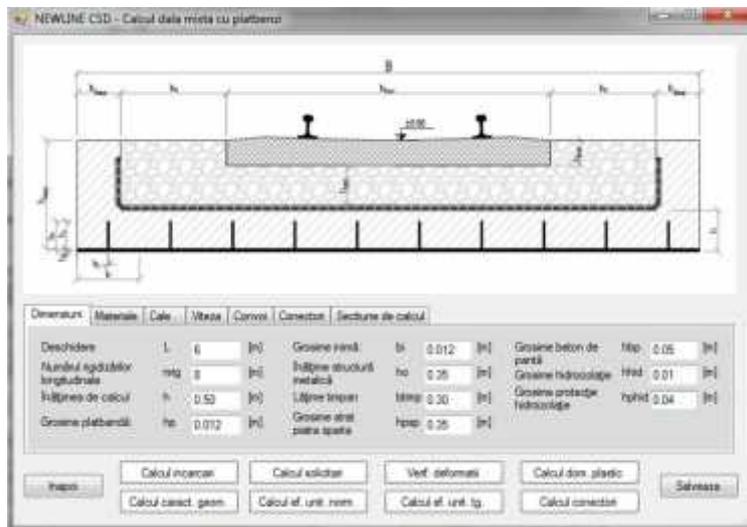
Fig. 7. *Structure dimensioning window – geometrical dimensions*

For each type of concrete and structural steel chosen, the limit stresses are compared to the design stresses, which will give the user an indication of when the stresses does not check. The same goes for the calculation of the deflections. Warning is done by a message that appears in the results display window next to each verified unit effort.
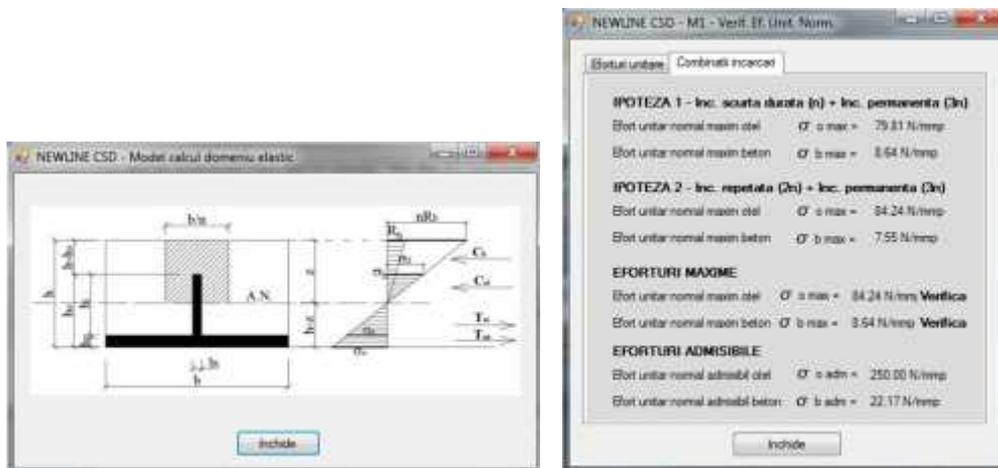

Fig. 8. *Calculation and checking of the normal unitary efforts*

The calculation of the connectors is based on the sliding forces for all load cases in the bearing area in the middle of the opening. Total sliding force is the maximum value of possible load combinations. The program automatically calculates the strength for sliding of the connector.

In the future, the NEWLINE CSD program will be completed by developing other computational modules, both in the field of railway and road construction, as well as a drawing editing option. This will allow the automatic computation of data for the mixed structures and also editing drawings in order that the NEWLINE CSD program should be

a flexible, reliable and last but not least easy to use design program.

6. Conclusions

Within the railway rehabilitation works in our country, bridges in a mixed steel-concrete section are increasingly chosen for the reconstruction of bridges with small and medium spans (up to 30 m). Of these, the most commonly used construction solution is the concrete embedded metallic beams (GMIB).

Although this constructive solution has its advantages by using the favorable properties of steel and concrete, providing the structure with durability, simplicity and rapidity in execution [4], in light of those presented in this paper, we can state that for spans up to 10 m, even the slabs in mixed steel-concrete structure would find its applicability in rehabilitation works of this kind with the advantages that it offers, namely:

- Reducing the construction height of the superstructure and the consumption of materials respectively, thus reducing the costs;
- There is no need for lost formwork, which involves increased execution time to be made on site, respectively increased labor costs;
- The reinforcement of these tiles is simpler and quicker, providing a more convenient space for the worker than the embedded metal beams
- It is a flexible solution that can be easily adapted to oblique crossings.
- It can be executed in prefabricated system, so the scaffolding can be removed.

In conclusion, it can be stated that the goal established by the research theme was fully realized by developing calculation models for slabs in a mixed steel-concrete structure, respectively elaborating a calculation program that brings great advantages to the designers in this field of activity giving them the opportunity to choose the optimal solution design for the composite slab for a particular span.

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