Calculation and Construction of Combined Steel Concrete Beams

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Abstract. The article considers combined steel-concrete beams of floors and coverings, crane structures, bridge spans, and analyzes methods for evaluating the stress-strain state of a steel-concrete beam. A number of steel-concrete beam designs protected by utility model and invention patents are proposed for use. A method for calculating a steel-concrete beam of a closed contour of any shape filled inside with concrete has been developed.

1. Statement of the research problem
SP 266.1325800.2016 [1] legitimized the use of combined structures of building frames and structures (steel-concrete and steel-reinforced concrete). The nomenclature of combined structures is very diverse [2,3], and is widely applied in foreign construction practice [4]. The use of steel concrete in beam structures in Russia is not yet developed, but it is very promising and will compensate for the shortcomings of traditional structures of floors and coverings, bridge spans, crane structures. In beam structures using reinforced concrete, a significant problem is the formation and opening of cracks [5], as well as a large weight, in steel beams – the appearance of fatigue cracks, as well as loss of stability, problems of fire resistance and corrosion wear [6,7].

The most effective constructions of steel-concrete beams are closed-loop solutions (Fig.1,2), in which the maximum strength characteristics of concrete and steel are used, as well as other advantages characteristic of combined structures are realized [8,9].

With the participation of the author, a number of promising steel-concrete beam structures were developed and patented [10...17] (Fig.1,2). The proposed design of beams will be very effective in conditions of heavy, dynamic impacts with a limited size of the structure.

At the same time, methods for evaluating the stress-strain state of such structures, as well as strength calculations in modern standards [1] are not sufficiently developed.

2. Improving the construction of steel concrete beams
It is obvious that it is rational to place concrete in the compressed zone of the bent steel-concrete element, and sometimes in the stretched zone, but under the condition that the concrete is compressed due to pre-stress.

The outline of the walls of steel-concrete beams (Fig.1) in order to save material, it can have a curved shape corresponding to the shape of the plot of normal stresses in the concrete of the compressed zone. Parameters for the shape of curved walls are selected in such a way as to ensure that the concrete is equally stressed in this zone. This outline of the beam walls also provides good aerody-
Dynamic characteristics of the cross section under the action of wind action, which is relevant, for example, for the beams of bridge structures.

Figure 1. Structural solutions of steel-concrete beams of floors, coverings, bridge spans:
   a) patent RU 2621247, b) patent RU 2627810, c) patent RU 176462, d) patent RU 2675002, e) patent RU 2677188;
   1-steel shell, 2-concrete, 3-stops, 4-tie rods, 5-wall, 6-prestressed element, 7-perforation, 8-tube liner.

Figure 2. Structural solutions of steel concrete crane structures:
   a) patent RU 170094, b) patent RU 182163; 1-steel shell, 2-concrete, 3-wall/grating, 4-tie rods, 5-brake structure,
   6-elastic gasket, 7-sub-rail element, 8-prestressed element.
Filling closed steel profiles with concrete (Fig.1,2) increases their bearing capacity under the action of compressive stresses, General and local bending stresses. Concrete, being in a closed loop of a steel shell, has increased strength characteristics.

Filling the lower belt of the crane truss with concrete (Fig.2) increases its bearing capacity for the period of tension, as well as reduces the flexibility of the belt.

Tie rods and stops in elements of steel-concrete beams and trusses (Fig.1,2) ensure reliable joint operation of the steel shell and concrete, perceive shear forces in the cross section, compress the concrete, increasing its strength. Tie rods also work together with concrete to increase the local stability of the steel shell walls.

The presence of tightening inside the beams and trusses (Fig.1,2) allows you to adjust the normal stress of the General bending in the structure, to perceive the forces of the strut, and also allows you to ensure the compression of concrete, which leads to its effective operation.

The sub-rail element of the crane beam (Fig.2), being the support platform of the crane rail, increases the bending stiffness of the upper belt, which allows you to distribute the local pressure from the crane wheels over a long length and reduce the stress in the wall. Elastic padding in the sub-rail element dampens the dynamic impact from the crane wheels in both vertical and horizontal directions, respectively, reduces the stress in the crane beam.

3. Method of calculation of steel concrete beams

SP 266.1325800.2016 [1] offers methods for calculating steel-concrete and steel-reinforced concrete beams depending on their design solution, but there is no method for calculating a steel-concrete beam of a closed contour of any shape filled inside with concrete. Problems of a similar nature exist in foreign norms.

In General, the stress-strain state of a steel-concrete beam can be evaluated in several ways:
- calculation of a steel concrete beam according to the provisions of SP [1];
- calculation of the beam as an element of heterogeneous elasticity [18];
- calculation of a combined beam as an element consisting of two rods (steel and concrete) United by rigid inserts;
- software calculation of a volumetric-spatial model, for example, in a software and computing complex (SCC).

The results of calculating a steel-concrete beam according to the provisions of SP 266.1325800.2016 [1], as a beam consisting of a steel I-beam and a reinforced concrete slab made along the upper girder belt (the section shown), have significant deviations from the results of static calculation of the spatial model in the SCC [19]. Therefore, it is not possible to use this method for calculating closed-loop steel-concrete beams filled with concrete.

The calculation of a steel-concrete beam as an element consisting of non-centrally compressed concrete and non-centrally stretched steel rods United by rigid inserts allows you to accurately obtain the forces in the steel and concrete element separately, analyze the system deformations at a small labor cost of forming the design model. The values of the obtained stresses have deviations from the results of the spatial model in PVC up to 5% [19].

The calculation of the system as a beam of heterogeneous elasticity allows us to set the stress values at minimum labor costs [19]. The values of the obtained stresses have deviations from the results of the spatial model in PVC no more than 2% [19]. This calculation method can be recommended as sufficiently accurate and least expensive when evaluating the stress-strain state of a steel-concrete beam.

A beam of heterogeneous elasticity is a beam in which individual groups of fibers have different elastic modulus [20]. In this case, the beam consists of concrete and steel fiber groups.

The calculation of the cross section of a beam of heterogeneous elasticity is reduced to determining the stresses acting in the section reduced to the selected material. After determining the total stress state given section, calculation of stresses in the elements section with heterogeneous elasticity with the plot. Reducing the cross section of the beam is rational to produce steel.
Reduced cross-section area:

\[ A_{np}^s = A_s + A_b \cdot \frac{E_b}{E_s} \]  

(1)

Static moment of the reduced section:

\[ S_{np}^s = S_s + S_b \cdot \frac{E_b}{E_s} \]  

(2)

Position of the center of gravity of the reduced section (distance to the upper face of the beam):

\[ y_z = \frac{S_{np}^s}{A_{np}^s} \]  

(3)

The moment of inertia of the reduced cross section of the beam relative to the center of gravity:

\[ I_{np}^s = I_s + I_b \cdot \frac{E_b}{E_s} \]  

(4)

Using (1...4), it is possible to determine the stresses in the characteristic cross sections of the beam (Fig.3):

\[ \sigma_{si} = \frac{M_x}{I_{np}^s} \cdot y_i \]  

(5)

Figure 3. Plot of normal stresses in the cross section of the beam.

As an example for selecting the cross-section of a steel-concrete beam, a variant of a crane beam with a span of L=12 m under a medium-duty bridge crane with a load capacity of 32 t was considered (Fig.4). A metal I-beam and a reinforced concrete t-beam were considered as alternative options. The results of calculating the beams according to the proposed method, their design solution and comparative analysis are shown in table. 1.
Additionally, local stresses in the steel shell elements from the action of concentrated stresses involving SCC SCAD were analyzed. A significant decrease in local stresses in both the walls and the upper belt was found by 4...5 times (Fig.5.6).

**Table 1.** Comparative analysis of structural calculation of beams.

| Parameter               | Metal beam | Reinforced concrete beam | Steel concrete beam |
|-------------------------|------------|--------------------------|---------------------|
| Cross-section           | 1/8        | 1/8                      | 1/10                |
| 2. h/L                  | 3,8        | 0,8                      | 2,2                 |
| 3. The consumption of steel, $\tau$ | -          | 6,12                     | 3,46                |
| 4. The flow of concrete, $m^3$ | -          | -                        | -                   |
| 5. Flexural rigidity    | 1/600      | 1/1000                   | 1/600               |
4. Conclusion
A number of steel-concrete beam designs protected by utility model and invention patents are proposed for use. A method for calculating a steel-concrete beam of a closed contour of any shape filled inside with concrete has been developed.

The use of combined steel-concrete beam structures as elements of floors and coverings, bridge spans, crane beams can significantly reduce local stresses, both in concrete and steel shell, as well as increase the bending and torsional stiffness of the beam, significantly increase the local stability of steel beam elements.

The calculation of a combined structure, as a beam of heterogeneous elasticity, allows you to set the stress values in different sections with minimal labor costs. The values of the obtained stresses have deviations from the results obtained by numerical modeling in the spatial model, no more than 2%. This method of calculation can be recommended as sufficiently accurate and least expensive when evaluating the stress-strain state of a steel-concrete beam of any shape.

Increasing the rigidity of steel-concrete beam structures in comparison with steel or reducing its cross-section height by about 20% with a significant reduction in local stresses in the walls and upper belt. The reduction in the material consumption of a steel-concrete beam in comparison with its steel counterpart will be about 40%. The reduction in the material consumption of a steel-concrete beam in terms of concrete consumption in comparison with an analog made of reinforced concrete will be about 45% with a 30% reduction in mass.

Figure 5. Local stresses in the steel part of the concrete beam, \( t/\text{m}^2 \).

Figure 6. Local stresses in the steel beam (without concrete), \( t/\text{m}^2 \).
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