Determination of Stress Concentration Coefficient in Anchors’ Area of Composite Span Structures of Road Bridges

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Abstract: The article presents the results of analysis of the stress-strain state of a five-span composite structure of a road bridge, made on a beam unbroken circuit. The calculation is performed in the LIRA program complex under the elastic work of materials on the action of shearing and tearing forces. The main purpose of the work was to determine the coefficient of stress concentration coefficient (SCC) in the zone of rigid anchors for concrete slabs of the roadway. For this purpose, a section of a plate with a metal beam and unifying elements was modeled, broken down into small volumetric and lamellar bodies. This allowed us to analyze in detail the nature of the distribution of normal stresses along the height and length of the span structure. The obtained coefficient can be used when calculating the existing designs for endurance and strength, and also when determining the residual life of bridge structures to predict their service life.

1. Publication purpose
This paper presents theoretical calculations performed to determine changes in the stress concentration coefficient (SCC) in zone of rigid anchors along the length of the beam elements of the composite span structure. These structures have a high bearing capacity and are less material consumption than structures made of steel and concrete separately.

Knowledge of SCC is necessary for the calculation of structures to endurance, which is an important parameter in determining their reliability, durability and forecasting the residual resource after a certain period of exploitation.

2. Research object
Steel rolling beam of the bridge span structure, combined with a reinforced concrete plate of the roadway. The shear connectors are two-wall rigid anchors, perceiving shear and tearing forces.

3. Analysis of carried out researches
Theoretical and experimental researches of the combination of reinforced concrete and steel by rigid anchors made by many organizations in the USSR, Germany, France, USA, Canada and several other
countries [1, 2, 3]. Static load tests of composite structures on shear with repeated loads and unloadings revealed the inelastic nature of the work of rigid anchors and the accumulation of residual shear displacements during repeated loads [4, 5]. Residual displacements with the magnitude of the same order as the elastic ones arise already in the first load steps. Was noted the characteristic decrease in the modulus of elastic deformations with the accumulation of residual displacements. Exhaustion of the bearing capacity of the pool in most cases occurred as a result of the destruction of the concrete slab due to deformation of the crumpling [6].

4. Need for computer design
The distribution of stresses between the elements is rather difficult to describe with existing techniques oriented towards analytical calculation. To solve such problems, often, are used numerical researches using modern software and computing systems that implement the finite element method (FEM) [7, 8]. In this work we performed numerical researches of SCC using PC Lira Sapr.

5. Design model determination of bridge span structure
For the simulation the supporting structure of the span construction was considered I-beam cross-section 90B2 with a plate section wide 2.5 m (figure 1). The selected section is due to the complexity of solving the problem on a computer (more than 2.5 mil. FE) for all span construction. The calculation was performed for a spatial scheme (type 5), the nodes of which have six degrees of freedom - three linear displacements and three angles of rotation (X, Y, Z, Ux, Uy, Uz).

![Figure 1. Cross-section of beam model](image)

Displacements are limited by links located along the axes of intermediate supports (movement along Z is prohibited) and along the edges of the beam near the shore supports (movement along Z, X, Y is prohibited). Span lengths are 16.76 m.

The roadway plate (figure 2) was simulated by volumetric FE (34-universal spatial six-node isoparametric FE and 36-universal spatial eight-node isoparametric FE). The span beam with stiffening ribs and anchors (figure 3) was used to simulate shell envelope (41-universal rectangular shell FE, 42-universal triangular shell FE, 44-universal quadrangular shell).
Figure 2. Fragment of design model of roadway plate

Figure 3. Fragment of beam design model with transverse stiffening ribs and rigid double-walled anchors

The dimensions of the FE grid were assigned in such a way that the results' error obtained did not exceed 5%, while the characteristic size of the FE grid was:
- in horizontal direction 50 mm;
- in vertical direction 30 mm;
- in the anchors' zone the grid step was condensed for the purpose of more detailed modeling of the anchors and the SCC researching.

For the simulation of unifying seam between plate and beam's upper belt the scheme was punched out with further merging movements in the direction of the vertical Z axis. Thus, during the bending of span beam all the shearing forces along the seam joint were transferred to rigid anchors, and the adhesion forces between the upper belt of the steel beam and the reinforced concrete plate were not taken into account.

6. Definition of loads to design model
During the process of simulation the design scheme the following loads were taken into account:
1. Own weight of metal and reinforced concrete structures;
2. Band load A15 (with loading sections of the corresponding line of influence);
3. A15 trolley in the center of the span;
4. A15 trolley near the support.

Own weight load was set uniformly distributed in the nodes of design model along its longitudinal axis.

According to the analytical calculation results was determined such loading scheme with a temporary moving load at which the maximum bending and shear forces in the model under consideration model - this is the trolley and the track-borne A15 load. The load of NK-100 was not taken into account in the calculations because from its impact was obtained the less efforts. Since in this work is simulated only the plate's section with one metal beam, it is required to determine the total load from A15 carriages and A15 strip track load for each lane along the influence line of the reference pressure (Figure 4).

The maximum support pressure on the outermost beam of the span construction from loading with loads of A15 trolley is by (2):

$$ P_{\text{cons}} = \sum y_i \cdot G_{\text{trol}} = 0.5(0.536 + 0.384 + 0.296 + 0.144) \cdot 15 = 10.2 \text{t} $$

(1)

where, $\sum y_i$ – the sum influence line’s ordinates; $G_{\text{trol}}$ – the trolley’s axle weight A15 – 15 ton [10].

The pressure from the wheel to the plate's surface is by (2):

$$ g = \frac{P_{\text{cons}}}{b \cdot a} = \frac{10.2}{0.6 \cdot 0.2} = 85 \frac{t}{m^2} $$

(2)

where $a$ – the length of wheel contact of the A15 trolley A15 with the roadway plate; $b$ - the wheels' width of the A15 trolley;

The support pressure to the beam from lane load A15 (3):

$$ P_{\text{lane}} = \sum y_i \frac{G_{\text{lane}}}{2} = 0.5(0.536 + 0.384 + 0.296 + 0.144) \cdot 1.5 = 1.02 \text{t} $$

(3)

where, $\sum y_i$ – the sum influence line’s ordinates from lane load (figure 4).

Figure 4. Scheme for load determining to extreme beam
a) The loading scheme to the span construction over the width of the temporary mobile load A15;
b) Influence line of the support pressure to the extreme beam (method of eccentric compression);

To determine the maximum span-bending moment, the load from the A15 trolley was applied on an area of 0.6 x 0.2 m in the center of the first span, as well as the band-gauge load in accordance with the loading of the influence line of the span-bending moment (figure 5). The axles of the trolley’s wheels are located above the tops of the influence line.

Figure 5. Influence line for loading of spans in determining maximum span bending moment

To determine the maximum reference bending moment the load from the A15 trolley was applied on an area of 0.6x0.2 m in the first and second spans at a distance of 20.0 m, as well as a band load in the first, second and fourth spans (figure 6).

Figure 6. Influence line for loading spans when determining maximum support bending moment

According to the static calculation results, the design combinations of loads were determined which are listed in Table 1.

| №  | Force factor name                        | Loads, included to the load complex (downloadable span)                     |
|----|-----------------------------------------|----------------------------------------------------------------------------|
| 1  | Span bending moment                     | Own weight (1-5), band load (1,3,5), A15 (1)                             |
| 2  | Support bending moment                  | Own weight (1-5), band load (1,2,4), A15 (1, 2)                           |
| 3  | Support pressure (reaction force)       | Own weight (1-5), band load (1,2,4), A15 (1)                             |

7. Result’s analysis of the nodes’ design models
The nature of the normal stresses’ distribution for the considered model is fully consistent with the generally accepted theory given in the regulatory documentation [9, 11] (figure 7, 8). The difference in normal stresses between the upper flange and volume finite elements, simulation the work of concrete, is clearly expressed and changeable along the section height. SCC was determined by equation (4):
where, $\sigma_{\text{max}}$ - maximum normal stresses in concrete in anchors zone;
$\sigma_{\text{nom}}$ - nominal normal stresses in concrete between the anchors away from the concentrators.

To determine SCC all obtained normal stresses (near the anchors and between the anchors) in the first span are summarized in Table 2. It is in the first span that the maximum values of bending moments and shear forces and, accordingly, shear forces occur.

**Table 2.** Values of normal stresses in concrete plate along first beam's span

| №  | № of anchor | Stress in the anchor’s zone, MPa | Stress between the anchors, MPa | Stress concentration coefficient |
|----|-------------|---------------------------------|---------------------------------|---------------------------------|
| 1  | №1          | 0.16                            | 0.10                            | 1.6                             |
| 2  | №2          | 1.13                            | 0.79                            | 1.43                            |
| 3  | №3          | 2.18                            | 1.83                            | 1.19                            |
| 4  | №14         | 6.44                            | 6.38                            | 1.009                           |
### Table of Normal Stresses

| №  | 1   | 2   | 3   |
|----|-----|-----|-----|
| 5  | 6.43| 6.35| 1.0125 |
| 6  | 6.37| 6.32| 1.008  |
| 7  | 1.5 | 1.35| 1.11   |
| 8  | 1.4 | 1.12| 1.25   |
| 9  | 1.2 | 1.00| 1.2    |

**Figure 9.** Distribution of normal stresses along first span

**Figure 10.** SCC distribution in concrete plate along first beam’s span.

### 8. Conclusions

1. The maximum difference for normal stresses in the plate's concrete is 37.5% near the anchor number 1 and in the interval between 1 and 2 anchor.
2. The minimum difference in normal stresses in the plate's concrete (0.78%) is determined in the area of the anchor number 16 in the place of the maximum bending moment.
3. The maximum SCC $\alpha_{max} = 1.6$ occurs in plate’s concrete in the first span near the shore support, due to significant shear forces along the joint seam.
4. Minimal SCC $\alpha_{min} = 1.01$ occurs in the plate's concrete in the first span at the shore support due to significant shear forces along the seam joint.
5. The difference in normal stresses between the results obtained in LIRA-SAPR 2013 and by the analytical analyze according to [5] is 8-26%.

6. In the beam continuous system the uneven distribution of normal stresses across the roadway plate's width is more pronounced than in the split system of the same span. The greatest non-uniformity of stresses through the plate's width occurs above the supports of the continuous beam, including intermediate supports.

7. The difference in normal stresses between the upper flange and volume FE, simulation the work of concrete, is clearly expressed and changeable along the section height. In the compressed zone the difference is 80-85%, in the stretched zone - 75-80%.

8. The results of presented researches allow to supplement the engineering methodology for determining the concentration coefficients of elastic stresses and in the future can be used to calculate bridge steel-reinforced concrete structures for endurance as well as in predicting the residual life of bridge structures.

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