Experimental assessment of solar radiation effect on the stress-strain state of a span with an orthotropic slab

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Abstract. The article is devoted to the experimental assessment of the solar radiation effect on the stress-strain state of a span with an orthotropic slab. Preliminary, comprehensive instrumental measurements of the road surface temperature distribution and the span elements were carried out at different times of the year. A detailed picture of the temperature distribution over the cross-section height was determined at different air temperatures and the Sun positions. To assess the solar radiation effect, instrumental measurements of deflections and deformations of the span’s main beams under the influence of solar radiation were carried out and the nature of the change in the stress-strain state of the span during the day was determined. The measurements were carried out using the deflection meters and strain gauges mounted on the main beams that experience uneven heating throughout the day. Using the developed and previously tested finite element model, the calculated values of the span bearing elements’ stress-strain state parameters for each case of exposure to solar radiation have been determined, taking into account the experimentally obtained temperatures. Comparison of the calculation results obtained on the basis of field measurements and calculation in the program of the finite element method has been carried out. The most unfavorable cases of the solar radiation effect on the main beams’ displacement have been revealed.

1. Introduction
In the construction industry, it is mandatory to conduct comprehensive tests of building structures when inspecting buildings and structures, including bridge spans. A complex system of loads acts on the structure. In addition to transport, wind and self-weight loads, the span perceives temperature effects, which contribute to uneven heating of the elements. At the same time, this research area is poorly understood, but it can affect the stress-strain state (SSS), due to the constantly changing temperature field during the day and year. Therefore, in order to identify the features of the span operation under solar radiation conditions, it is necessary to carry out the field measurements and accumulate the data to form a complete picture of the temperature effect nature.

A review of the scientific articles devoted to the solar radiation effects’ analysis has been carried out. In the articles [1-2], the temperature influence on the stress-strain state of the span has been noted and the calculation of temperature fields and stresses in the beams of the span has been made on the basis of the field measurements. In the works [3-5], the most unfavorable cases of exposure to solar radiation have been identified and its effect on the strength of the structure has been studied. The numerical results of the temperature distribution at different times of the year have been compared with the experimental measurements. The main problems and promising research of this topic have been noted.

The authors of the article carried out a number of works devoted to the solar radiation effects’ analysis. In the articles [6-8], the temperature distribution along the steel-reinforced concrete span cross-
section height has been studied and its effect on the strength of the asphalt concrete pavement has been identified. Based on the results of the works [9-11], a technique for performing full-scale temperature measurements on a span with an orthotropic slab at different times of the year has been developed and tested, a complete picture of the temperature distribution over the height of the cross-section has been compiled at various air temperatures and sun positions. The calculation of the stress-strain state has been carried out using the field measurements’ results in various cases of exposure to solar radiation. Comparison of the calculation results obtained according to the recommendations of regulatory documents and on the field measurements basis has been made.

2. Research Objectives

2.1. To perform instrumental measurements of deflections and deformations of the main span beams when exposed to solar radiation

2.2. To study the change nature in SSS during the day based on the results’ analysis of the in-situ temperature measurements, deflections and deformations of the elements

2.3. Using the developed finite element model of the span, to calculate the stress-strain state of the span for each case of exposure to solar radiation

2.4. To compare the results obtained on the basis of instrumental measurements and theoretical calculations.

3. The instrumental measurements’ description

Instrumental measurements were carried out on a span with an orthotropic slab L = 43.1m road bridge across the river Vorona near Borisoglebsk in Voronezh region. A detailed description of the span is given in [10].

Site tests were carried out during daylight hours on July 21, 2020. The temperature measurements were taken in the span elements and instrumental measurements of the main beams’ deflections were carried out at various air temperatures and sun position.

Temperature measurement was performed using a non-contact pyrometer “Megeon 16400”. To verify the data, a contact thermometer “multimeter PM838” was used.

The deflections of the main beams were measured with the 6-PAO deflection meters of the Maximov’s system with an absolute error ± 0.01 mm. The deflection meters 6-PAO are designed to measure linear displacements of individual points in structures. Deflection meters are used when testing building structures, engineering and construction surveys and when inspecting buildings, structures and bridge spans.

The deformations of the longitudinal fibers of the lower chord in the main beams were measured by the deformometers using dial gauges with a scale of 1 μm.

The installation diagram of the devices is shown in Figure 1.

Temperature measurements were carried out at 3 points of each span element (asphalt concrete pavement, main beam in the sun, main beam in the shadow). Deflection meters and deformometers were installed on the lower chord of the two main beams, 1/4 of the span length. Figure 2 shows the instruments’ location during the field measurements on the span.
Figure 1. Installation diagram of measuring devices

Figure 2. Devices for measuring the temperature of the span elements, deflections and deformations of the main beams
4. Results of instrumental measurements

The air temperature on the day of the study at the object changed from 22°C to 29 °C. The temperature comparison of the main beams in the sun and in the shade is shown in Figure 3.

![Figure 3. The temperature comparison of the main beams in the sun and in the shade](image)

The maximum temperature of the main beams on the day of field measurements was 28.3°C. During the day, the temperature on the main beam under the influence of sunlight changed by 19.9%.

The deflection meter indicator with timekeeping in the process of field measurements is shown in Figure 4. The deflections and deformations’ values obtained on the field measurements’ basis are presented in Table 1 and in the diagram in Figure 5.

**Table 1.** Deflections, mm

|     | 8-30 | 9-30 | 11-00 | 13-00 | 14-00 | 16-00 | 17-00 |
|-----|------|------|-------|-------|-------|-------|-------|
| beam in the sun | 0 | -0.12 | -0.63 | -1.96 | -1.99 | -2.72 | -2.36 |
| beam in the shade | 0 | -0.09 | -0.43 | -0.14 | -0.17 | -0.68 | -0.8 |

**Deformation, mm**

|     | 8-30 | 9-30 | 11-00 | 13-00 | 14-00 | 16-00 | 17-00 |
|-----|------|------|-------|-------|-------|-------|-------|
| beam in the sun | 0 | 0.03 | 0.03 | 0.07 | 0.08 | 0.08 | 0.09 |
| beam in the shade | 0 | 0.01 | 0.01 | 0.01 | 0.02 | 0.02 | 0.02 |
As a result of field measurements, it can be noted that, under the influence of solar radiation, the displacements of the main beams have negative values, i.e. the lower fibers are compressed. The maximum movement of the main beam during the day in the sun was -2.72 mm, of the main beam in the shade -0.8. In the first half of the day, when heating intensity has not reached its maximum values, the difference in the displacements of the two main beams does not exceed 0.2 mm. However, in the afternoon, as the temperature difference of the main beams increases, the beam movement in the sun is much higher than that of the beam in the shade. The movement of the beam in the sun at the same time is 2.04 mm higher than the movement of the beam in the shade.

5. The numerical studies’ results analysis
One of the main criteria for evaluating the span work under the load action is the correspondence of the values obtained in field studies to the calculation results. To determine the bridge span bearing elements stress-strain state parameters’ calculated values, a spatial finite element model has been developed. Spatial finite element model of the span is implemented in the complex “PC Lira CAD”.
A detailed description of the finite element model was presented in [10]. The nature of the temperature distribution in the pavement layers was determined using the ELCUT Student software package for modeling thermal fields [7].

When performing the calculation of the finite element method (FEM), the displacements and stresses of the span elements were obtained. The comparative analysis of calculation results has been performed.

Figure 6 shows the main beam displacements’ iso-fields, obtained in the FEM complex. A comparison of the obtained values of the main beams’ displacement, obtained on the basis of instrumental measurements and theoretical calculations for each case of exposure to solar radiation, is shown in Figures 7 and 8.

Figure 6. Iso-fields of the main beam’s displacements obtained in the FEM complex
As it can be seen from the graph, the experimental deflections of the beam in the sun in the first half of the day are close to the calculated values. In the afternoon, with an increase in the solar radiation intensity, the experimental movement of the beam in the sun is much higher than the calculated values. In the measuring range from 13h to 17h, the discrepancy is 10% greater.

Experimental and calculated displacements of the main beam in the shade have a similar change pattern during the day. Moreover, the calculated values are predominantly higher than the experimental ones. Throughout the day, the discrepancy in the results varies from 0.7 mm to 0.27 mm.

Thus, the analysis of the results shows that the effect of solar radiation has a significant effect on the main beams’ movement.
Summary
1. Under the solar radiation influence in the observed time range, the movements of the main beams decrease.
2. The movement of the beam in the sun at a fixed point in time is 2.04 mm higher than the movement of the beam in the shade.
3. The results of numerical studies made it possible to establish that, as the intensity of solar radiation increases, there is a decrease in the convergence of the main beams’ displacements results according to the results of instrumental measurements and FEM calculation.

Conclusion
Experimental studies of the span main beams’ deflections and deformations under the influence of solar radiation have been carried out, and the nature of the change in the stress-strain state of the span during the day has been determined. With the help of the developed and previously tested finite element model, the SSS was calculated for each case of exposure to solar radiation, taking into account the experimentally obtained temperatures of the span elements. A comparison of the results obtained on the basis of experimental studies and theoretical calculations showed in most cases their satisfactory coincidence. The most unfavorable cases of the solar radiation effect on the main beams’ displacement have been revealed.

References
[1] Mishutin V O 2014 The need to take into account temperature deformations in the design and construction of bridge structures Modern technologies. System analysis. Modeling 3 (43) 203-208.
[2] Bezbabicheva O I, Bilchenko A V, Kislov A G 2010 Prediction of temperature stresses in facade beams of bridge structures Science and progress of transport. Bulletin of the Dnipropetrovsk National University of Railway Transport 33 28-31.
[3] Linren Zhou, Yong Xia, James M W, Brownjohn Ki, Young Koo 2016 Temperature Analysis of a Long-Span Suspension Bridge Based on Field Monitoring and Numerical Simulation Journal of Bridge Engineering 21 (1).
[4] XuMing Song, Hani Melhem, Jun Li, QingYuan Xu, LiJun Cheng 2016 Effects of Solar Temperature Gradient on Long-Span Concrete Box Girder during Cantilever Construction Journal of Bridge Engineering 21 (3).
[5] Bo Chen, Yu-zhou Sun, Gan-jun Wang, Ling-yan Duan 2014 Hindawi Publishing Corporation Mathematical Problems in Engineering 639867.
[6] Podlesnykh I S, Gridnev S Yu, Barchenkova N A 2018 Analysis of the solar radiation influence on the stress-strain state of the steel-reinforced concrete span of the highway bridge Internet journal “Transport facilities” 2. Title from the screen. Language. Russian, English. DOI: 10.15862/12SATS218
[7] Gridnev S Yu, Podlesnykh I S 2018 Influence of solar radiation on the safety of the upper layer of the pavement of the steel-reinforced concrete span Collection of materials of the XIX International Scientific and Technical Conference “Actual problems of construction, construction industry and industry” 34-36.
[8] Gridnev S Yu, Podlesnykh I S 2018 Temperature distribution over the highway bridge steel-reinforced concrete span cross-section height Collection of materials of the XIX International Scientific and Technical Conference «Actual problems of construction, construction industry and industry» 36.
[9] Podlesnykh I S, Gridnev S Yu, Barchenkova N A 2019 Verifying Regulatory Documents for Solar Radiation Level Control When Estimating Stress-Strain State of the Spans Based on the Orthotropic Slab Proceedings of 24th International Conference “MECHANIKA 2019”, Kaunas University of Technology 116-121.
[10] Gridnev S.Yu., Podlesnykh, I.S. The influence of uneven heating on the stress distribution in the elements of the span with an orthotropic slab / Materials collection of the XX International Scientific and Technical Conference “Actual problems of construction, construction industry and architecture”. – 2019. – 108-110 Pp.

[11] Gridnev S.Yu., Podlesnykh, I.S. Features of the temperature field in the elements of the span of a road bridge at negative temperatures close to zero / Materials collection of the XX International Scientific and Technical Conference “Actual problems of construction, construction industry and architecture”. – 2019. – 110-112 Pp.

[12] Gridnev S.Yu., Podlesnykh, I.S. Method of measuring the temperature field of a span with an orthotropic slab under the influence of solar radiation / Materials collection of the XXI International Scientific and Technical Conference “Actual problems of construction and construction industry”. – 2020. – 62-68 Pp.