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ESTIMATING THE INFLUENCE OF SOLAR RADIATION AT DIFFERENT SEASONS ON THE MODE OF DEFORMATION OF A SPAN STRUCTURE WITH AN ORTROTROPIC PLATE

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ABSTRACT

The article studies the effect of solar radiation at different seasons on the mode of deformation (MD) of a span structure with an orthotropic plate. The temperature fields of the elements of the structure were measured during daylight hours at different times of year at various air temperatures and sun positions. Cases were identified in which it is necessary to clarify the temperature values of the asphalt concrete road surfacing and the main beams obtained using a non-contact pyrometer, and by measuring the temperature with a contact thermometer.

During the year the elements of the span are in a wide temperature range. Using the developed finite element model of the span, taking into account the layers of road surfacing, the MD calculations were performed for each case of exposure to solar radiation according to the corrected results of field measurements. An analysis of the results of numerical studies allows us to conclude that diurnal and seasonal temperature fluctuations create significant additional stresses in the span, which should be taken into account when calculating the MD of spans of road bridges.

Key words: *span, orthotropic plate, solar radiation, field measurements, finite element model*

INTRODUCTION

The surface of the elements of a span structure is under the constant influence of solar radiation. During the entire period of operation, the span sustains diurnal and annual temperature fluctuations, accompanied by uneven heating of elements from exposure to solar radiation. Span elements receive thermal energy from direct, dissipated and reflected radiation. The time-varying climatic effects, which depend, inter alia, on the air temperature and the position of the structure with respect to the sun, have a significant effect on the mode of deformation (MD) of the span.

Research in this direction is relevant since this problem has not yet been adequately studied. The works of Russian authors devoted to the analysis of the effects of solar radiation note the effect of temperature on the mode of deformation of spans and the need for its consideration in designing and constructing bridge structures [1].

In [2], temperature fields and stresses in the facade beams of bridge structures were calculated based on field measurements of the temperature distribution using a non-contact device.

The works of foreign authors [3,4,5] analyzed the temperature distribution in span structures with the use of modern finite element software packages, marking the most adverse events of solar radiation impact and investigating its effect on the structural strength. In [6], the authors evaluate the model of solar radiation impact on abridge span structure.

The model takes into account the changes in solar intensity throughout the day, as well as possible obstacles in the form of clouds, mountains and surrounding buildings. The analysis of heat transfer of the bridge components was made to calculate temperature distributions based on the proposed method. The numerical results of temperature distribution at different seasons are consistent with in field measurements obtained during the monitoring of the bridge.

In [7], the authors present an overview of current research and developments in the field of thermal loads in bridges, which focuses on models of thermal loads found by numerical analysis and field measurements. The work gives the theoretical formulations and boundary conditions of heat transfer in a span and shows the existing problems and promising research of the issue.

We carried out a number of works devoted to the analysis of the influence of solar radiation and temperature exposure.

In [8], the authors studied the temperature distribution along the height of the cross section of the steel-concrete composite span structure and studied its impact on the durability of asphalt concrete road surfacing.

In [9], the authors studied the effect of solar radiation on the mode of deformation of the span structure with an orthotropic plate.

Using a non-contact pyrometer they carried out field measurements of elements' temperature and determined the detailed temperature distribution across the thickness of the road layers, orthotropic plate and the height of the main beams depending on the position of the sun. Then they compared the results of calculations received according to the recommendations of normative documents and on the basis of field measurements.

In [10], they verified the readings of the pyrometer according to the readings of a contact thermometer. They calculated the mode of deformation using the results of field measurements at different cases of solar radiation taking into account the results of the two measuring devices. Then they compared the calculation results obtained based on the readings of a contact thermometer and non-contact thermometer.

The main objectives of this work are:

1. To compare the results of field measurements of the temperature of the elements of the span when exposed to solar radiation at different times of year
2. Using the developed finite element model, to calculate the MD of the span using the results of field measurements for various cases of exposure to solar radiation
3. To analyze the calculation results and evaluate the effect of diurnal and annual temperature fluctuations on the magnitude of stresses in the elements of the span

ANALYSIS OF THE RESULTS OF FIELD MEASUREMENTS

Field measurements of temperature were carried out on the span L = 43.1 m of the road bridge over the Vorona River in Borisoglebsk (Figure 1). Design features of the structure are described in article [9].

There were 3 stages of field measurements at different times of year: September 7, 2018, November 17, 2018, and August 15, 2019. At each stage, we registered the temperature at several points of the asphalt concrete coating of the structure and the temperature along the height of the main beams at various air temperatures and sun positions.

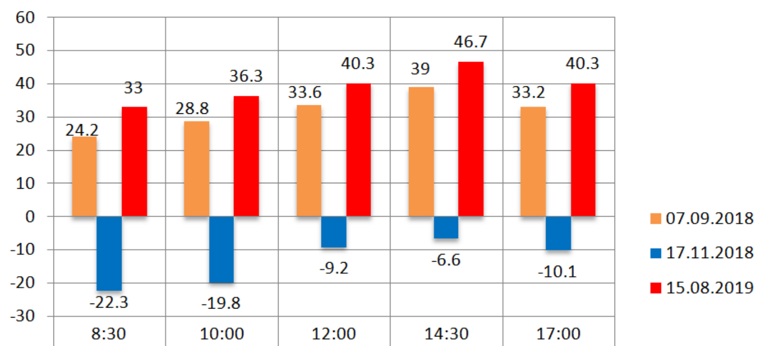
Figure 1 Bridge span over the Vorona River in Borisoglebsk

There were 3 stages of field measurements at different times of year: September 7, 2018, November 17, 2018, and August 15, 2019. At each stage, we registered the temperature at several points of the asphalt concrete coating of the structure and the temperature along the height of the main beams at various air temperatures and sun positions. The temperature was measured using a “Megeon 16400” non-contact pyrometer (Figure 2a). To verify the accuracy of measurements, the results were refined using a contact thermometer "multimeter PM838" (Figure 2b). The capabilities of the devices and a comparison of the measurement results are described in [9,10].

a)  b) 

Figure 2 Devices for measuring the temperature of the span elements:
a) non-contact pyrometer Megeon 16400, b) contact thermometer PM838

A comparison of the maximum temperature of the top layer of the road coating of the span at different times of year is presented in Figure 3.

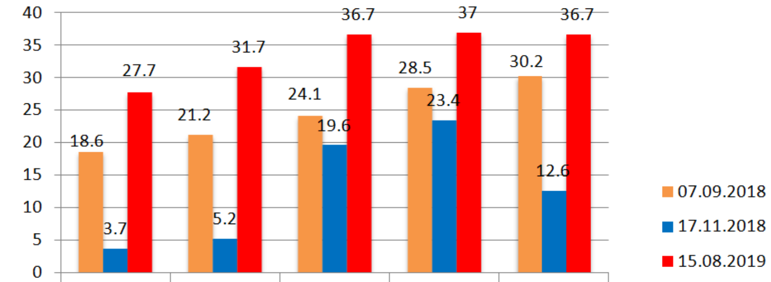


	8:30	10:00	12:00	14:30	17:00
07.09.2018	24.2	28.8	33.6	39	33.2
17.11.2018	-22.3	-19.8	-9.2	-6.6	-10.1
15.08.2019	33	36.3	40.3	46.7	40.3

Figure 3 The annual fluctuation in temperature of asphalt concrete coating

In cold weather, the lowest possible temperature of the asphalt concrete coating was -22.3 °C. During the day, under the influence of sunlight, it warmed up to -6.6 °C. In the summer season, the temperature of the asphalt reached 46.7 °C.Thus, the annual temperature fluctuation, sustained by the span, can reach 69 °C.

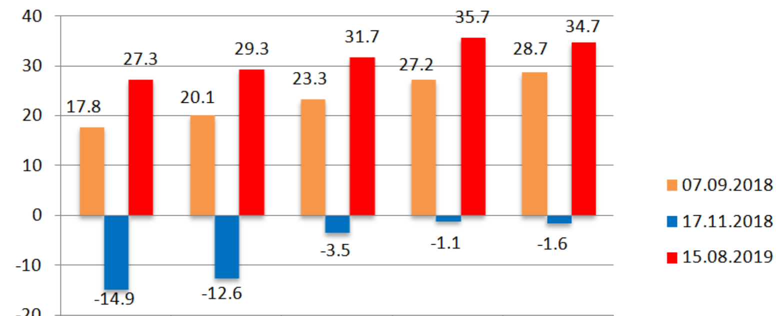
The change in the maximum temperature of the main beam in the sun during the year is shown in Figure 4.



	8:30	10:00	12:00	14:30	17:00
07.09.2018	18.6	21.2	24.1	28.5	30.2
17.11.2018	3.7	5.2	19.6	23.4	12.6
15.08.2019	27.7	31.7	36.7	37	36.7

Figure 4 The annual temperature fluctuation of the main beam in the sun

One of the main beams is oriented in such a way that it is almost constantly exposed to solar radiation. However, depending on the time of year, the sun is at different heights above the horizon. For example, in summer, when the sun is high, the paving console forms a shadow zone, reducing the intensity of solar radiation on the main beam. Thus, the largest temperature difference of the main beam was 33.3 °C. The annual temperature fluctuation of the main beam in the shade is shown in Figure 5.



	8:30	10:00	12:00	14:30	17:00
07.09.2018	17.8	20.1	23.3	27.2	28.7
17.11.2018	-14.9	-12.6	-3.5	-1.1	-1.6
15.08.2019	27.3	29.3	31.7	35.7	34.7

Figure 5 The annual temperature fluctuation of the main beam in the shade

Solar radiation has no effect on the second main beam. Due to the lack of heating in the cold season, the main beams can have a large temperature difference at the same time, and with the opposite sign. The annual temperature fluctuation of the shadow main beam was 50.6 °C.

DESCRIPTION OF THE FINITE ELEMENT MODEL

When analyzing the span’s MD, we used the spatial finite-element model developed in the PC Lira CAD (Figure 6), the model includes layers of coating and allows you to take into account the uneven temperature distribution along the height of the cross section of the bridge structure.

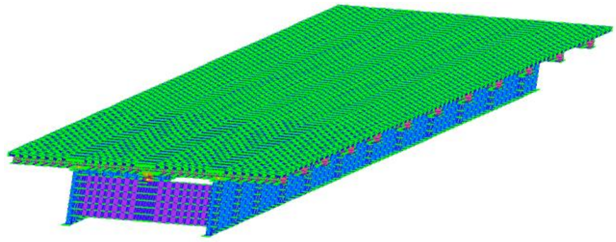
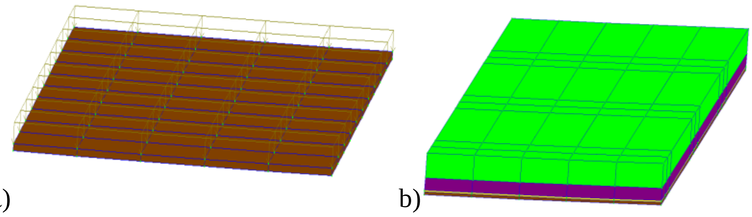


Figure 6 Finite element model of the span

A detailed description of the finite element model was made in [10].

Currently, when designing the span, structure of the coating is taken into account only as an additional load. However, in order to adequately assess the mode of deformation of the layers of a road, the coating must be considered as a structural element of the span. With this approach, it becomes possible to study different types of asphalt concrete coating and take into account the temperature distribution across the layers of the road. Variants of the surfacing in the finite element model are shown in Figure 7.



a) b)

Figure 7 Coating in a FE model:
a) in the form of surface loads, b) in the form of a structural element

A comparison of stresses in the span with two approaches to accounting for layers of the coating is performed in Figure 8.

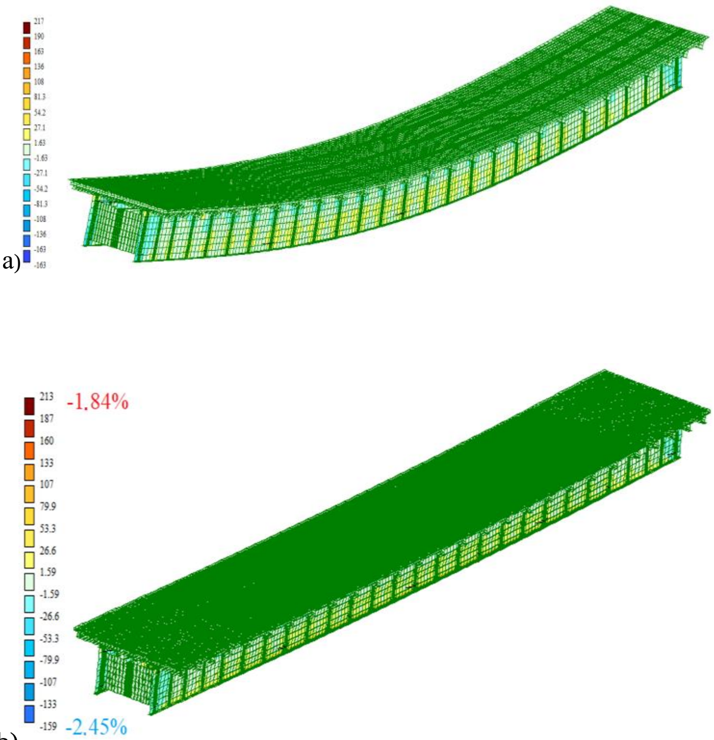


Figure 8 Stresses in the span:
a) excluding layers of the coating, b) taking into account layers of the coating

When layers of the coating were included in the FE model of the span, tensile stresses decreased by 1.84%, and compressive ones by 2.45%. With the second approach, the deflection of the span is reduced.

ANALYSIS OF THE RESULTS OF NUMERICAL STUDIES

When performing the calculation, the values of the stresses of the elements of the span were obtained. A comparative analysis of the calculation results for each case of exposure to solar radiation at different times of year was carried out.

A comparison of the stresses in the main beams at different times of year is performed in Figure 9.

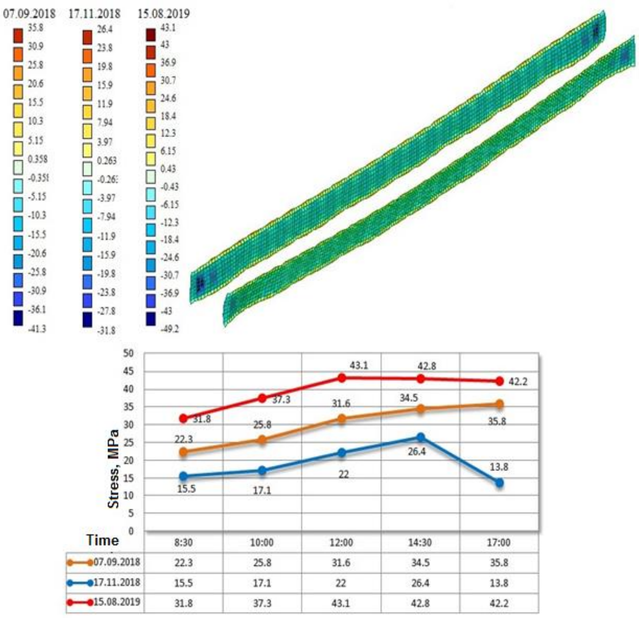


Figure 9 Comparison of the stresses in the main beams at different times of year

The highest stresses from exposure to solar radiation are observed in summer when the air temperature was 31 °C. The maximum stress drop during the day was 13.5 MPa. At the same time, the annual stress fluctuation reaches 29.3 MPa. A comparison of the maximum stresses in the upper layer of the coating at different times of the year is shown in Figure 10.

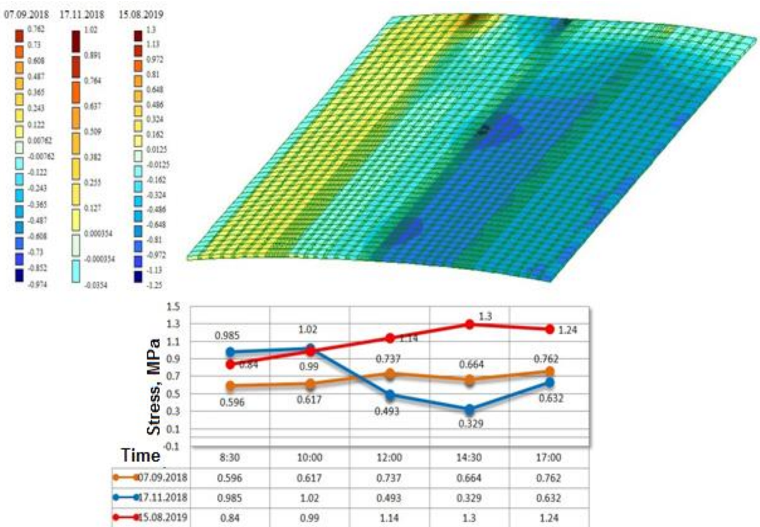
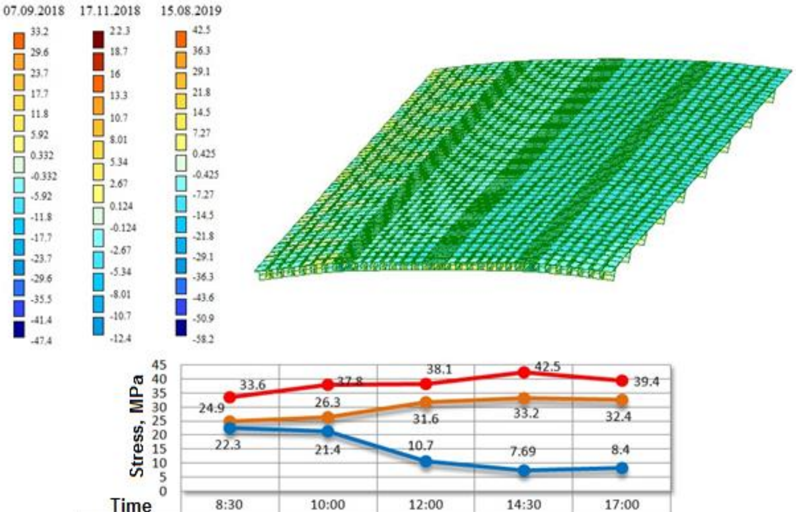


Figure 10 Comparison of the stresses in the upper layer of the coating at different times of year

Tensile stresses in the upper layer of the coating during the year vary from 0.329 MPa to 1.3 MPa. A comparison of the maximum stresses in an orthotropic plate at different times of year is made in Figure 11.



Time	8:30	10:00	12:00	14:30	17:00
07.09.2018	24.9	26.3	31.6	33.2	32.4
17.11.2018	22.3	21.4	10.7	7.69	8.4
15.08.2019	33.6	37.8	38.1	42.5	39.4

Figure 11 Comparison of the stresses in an orthotropic plate at different times of year

As can be seen from the graph, stresses in the cold season vary from 7.69 MPa to 24.9 MPa. In the hot season, the maximum value reaches 42.5 MPa. That is, the annual stress drop reaches 34.8 MPa.

Thus, exposure to solar radiation during the year creates additional stresses with significant diurnal and seasonal fluctuations.

CONCLUSIONS

Analysis of the results of field measurements showed that during the year the elements of the span are in a wide temperature range. So, the annual temperature fluctuation, sustained by the span, can reach 69 °C.

The results of numerical studies showed that diurnal and seasonal temperature fluctuations create significant additional stresses in the span. The maximum stress difference during the year was 34.8 MPa.

Thus, the neglect of seasonal and diurnal fluctuations in temperature and the intensity of solar radiation can lead to an unreliable estimate of the MD of the span elements. Therefore, at the design stage, it is important to take into account the temperature and climatic conditions corresponding to a particular region and their particular effects on the span of road bridges.

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