Comparative statement analysis of span structures with a reinforced concrete and orthotropic plate under the exposure of solar radiation

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Abstract. Carried out a comparative analysis especially the exposure to solar radiation on the stress-strain state (SSS) of span structures with orthotropic slabs of reinforced concrete. Determine the character limit of the temperature distribution in the elements of the two types of spans according to the results of field measurements. Conducted calculation of Stress-Strain State on specific cases of solar radiation with the use of the developed finite element (FE) models of two types of span structures in the platform LIRA SAPR. The results of SSS features obtained for a steel-reinforced concrete superstructure and a metal superstructure with an orthotropic slab are compared. It is shown that the uneven daytime change in the temperature field under the influence of solar radiation has a significantly different nature of effect on the stress-strain state of elements of metal and steel-reinforced concrete span structures.

1 Introduction

In the practice of bridge construction, various types of road bridges are used. Today, one of the most common are steel-reinforced concrete and metal spans with an orthotropic slab. Such spans, which are internally statically indeterminate many times over, perceive temperature effects in a complex way, especially when their elements are unevenly heated. In this case, the nature of the temperature distribution for each type of superstructure can be very diverse. Therefore, the stress-strain state (SSS) from the effect of solar radiation for each type of superstructure has its own characteristics and depends on many factors (design features, materials used, location, etc.) and their combination.
When analyzing scientific publications on the topic of research, the articles [1-2] devoted to the influence of solar radiation on the work of spans were noted.Foreign experience in the

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field of the influence of solar radiation [3-7] is mainly aimed at studying the strength of structures under the influence of temperature loads.
The authors of the article carried out a number of works devoted to the construction of the technique and, with its help, the study of the temperature effect on spans with reinforced concrete and orthotropic slabs.The article [8] examines the stress-strain state of the steel-reinforced concrete span structure together with the clothing of the driving track for the purpose of preservation and durability of the top layer of asphalt concrete. The work [9] is devoted to the analysis of the temperature distribution in the layers of the pavement of the steel-reinforced concrete span structure and its influence on the formation of longitudinal cracks in the asphalt concrete pavement in the area above the main beams. In studies [10-12], the nature of the distribution of the temperature field along the height of the cross-section was studied, the influence of solar radiation on the stress-strain state and the safety of the asphalt concrete pavement was noted.The article [13] defines the temperature limits at which there are discrepancies in the results of calculating the SSS based on field measurements of the span under the influence of solar radiation with the results of calculations, in accordance with the recommendations of regulatory documents. In works [14, 15], studies were carried out during the cold season and a significant effect of temperature effects on the distribution of stresses in the elements of the bridge structure was noted. Recommendations on the need to verify the results of measurements by a non-contact pyrometer of the span structure elements under the influence of solar radiation according to the readings of a contact thermometer are given in article [16]. Work [17] is devoted to assessing the effect of daily and annual temperature fluctuations on the magnitude of stresses in the elements of the span with an orthotropic slab. The article [18] describes a technique for performing field measurements on a span structure when exposed to solar radiation. Full-scale measurements were carried out at the object of study, which make it possible to determine in detail and comprehensively the nature of the temperature distribution in the elements of a metal span with an orthotropic plate.
To take into account the asphalt concrete pavement in terms of the effect of solar radiation, modern approaches to the design of pavement structures for driving tracks have been studied. Articles [19-21] are devoted to the analysis of the design features of road pavements on spans, the main provisions for the design of pavement structures on orthotropic and reinforced concrete slabs are described.

2 Objectives of the study

1. Based on the results of field measurements, determine the nature of the temperature distribution over the thickness of the pavement layers and the height of the cross-section in the steel-reinforced concrete and metal span structures from the effects of solar radiation
2. Reveal the features of the temperature fields of elements of two types of spans in similar cases of exposure to solar radiation
3. To carry out a comparative calculation of the SSS in two typical cases of exposure to solar radiation, using the developed finite element models of span structures
4. Comparison of the SSS results obtained for the steel-reinforced concrete superstructure and the metal superstructure with an orthotropic slab.

3 Description of research objects

The object of research is two spans:
1) steel-reinforced concrete superstructure of the road bridge over the Malaya Kozhva River. (Fig. 1, a) [10]

2) a metal superstructure with an orthotropic slab of the road bridge across the river. A crow near the town of Borisoglebsk in the Voronezh region (Fig. 1, b). [13]

a) b)

Fig. 1. Object of study:
a) steel-reinforced concrete superstructure; b) metal superstructure

The main characteristics of the span structures are summarized in Table 1.

Table 1. Main characteristics of the Span Structures

Main characteristics	**Reinforced concrete span structure**	**Span structure with orthotropic slab**
Span length	4 2.5 m	43.1 m
Span width	13.20 m	11.34 m
The height of the superstructure	2.52 m	2.4 m
Pavement layers	1. Waterproofing layer 2. Crushed stone-mastic asphalt concrete 3. Cast asphalt concrete	1. Waterproofing layer 2. Cast asphalt concrete 3. Dense asphalt concrete

4 Approaches to accounting for exposure to solar radiation

Comparison of the nature of the effect of solar radiation in the summer season on two types of superstructures is carried out.
Under the conditions of exposure to solar radiation, a series of field measurements of the fields of daily temperature fluctuations of the span were performed using two types of instruments to verify the results obtained. The temperature was measured at several points of the span structure elements. On the day of the field measurements, a reading of 35 ° C of the maximum air temperature was recorded.
The air temperature for the steel-reinforced concrete superstructure is assumed to be 36 ° C, which corresponds to the peak reading in July in Voronezh 2017.
For two types of spans, 2 similar cases of the effect of solar radiation on the spans were considered:
1. Heating is observed mainly in the main beam, due to the low position of the sun above the horizon (Fig. 2);
2. Heating is observed predominantly of the upper layer of the pavement, due to the high position of the sun above the horizon (Fig. 3).

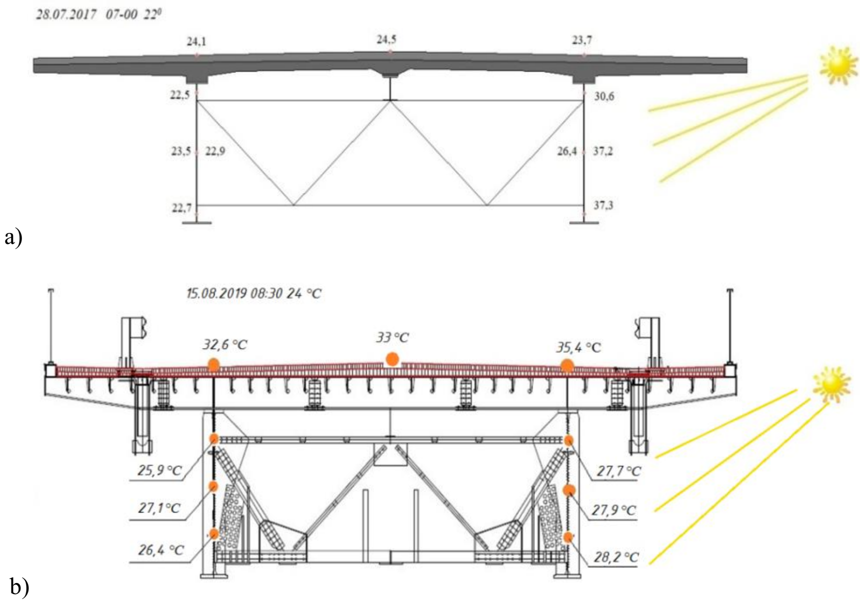


Fig. 2. The first case of exposure to solar radiation (heating of the main beam):
a) steel-reinforced concrete superstructure; b) superstructure with orthotropic slab

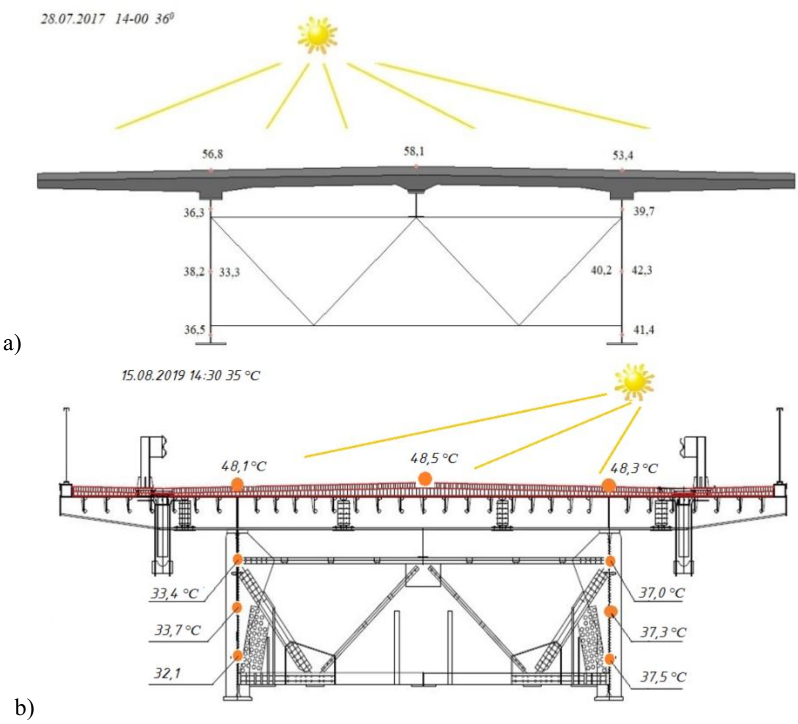


Fig. 3. The second case of exposure to solar radiation (heating of the upper layer of the pavement):
a) steel-reinforced concrete span structure; b) span structure with orthotropic slab

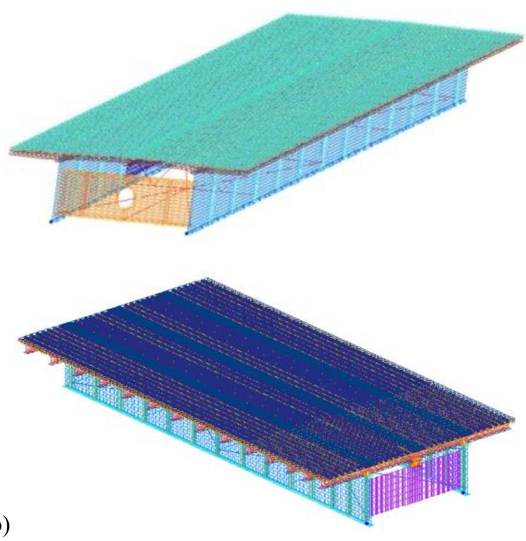
At a similar air temperature at the same time, the main beam in the steel-reinforced concrete spam structure heats up more than the main beam in the metal spam structure by 4.8 ° C.
When exposed to direct sunlight on the top layer of the pavement, the surface temperature of the cast asphalt concrete (in the steel-reinforced concrete spam structure) was 9.6 ° C higher than the surface of the dense asphalt concrete (in the metal spam structure). The main results are summarized in Table 2.

Table 2. Temperature of span structure elements

Temperature of span structure elements	In a span structure with a reinforced concrete slab	In a span structure with an orthotropic slab
Maximum air temperature	36 °C	35 °C
Maximum pavement temperature	58,1 °C	48,5 °C
Maximum temperature of the main beam	42,3 °C	37,5 °C

5 Description of the FE model used

Models of two types of superstructures were developed in a specialized modern FE complex (Fig. 4), including layers of pavement and allowing the calculation of temperature loads.



a)

b)

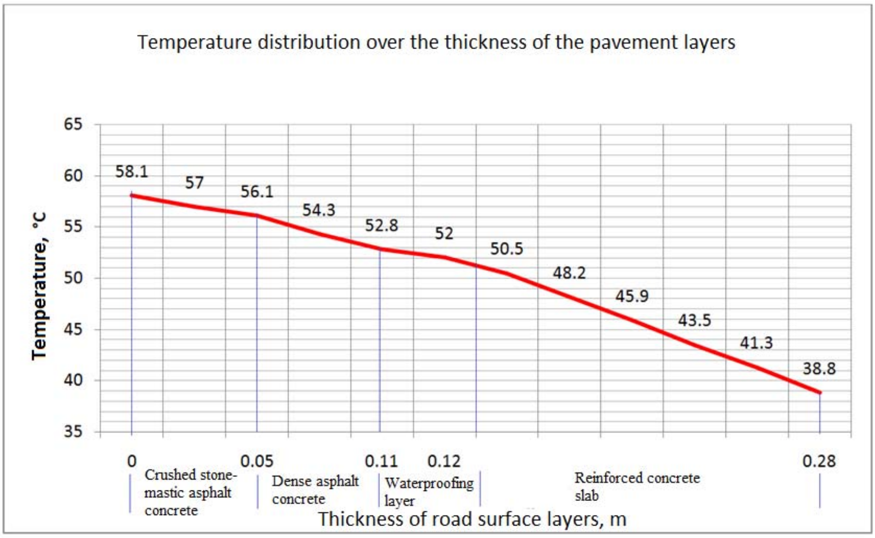
Fig. 4. FE model of span structure:
a) steel-reinforced concrete span structure; b) span structure with orthotropic slab

The main parameters of the elements of spans [19-21] used in the design models are given in table. 3.

Table 3. Parameters of superstructure elements

Construction type	Elastic modulus, MPa	Poisson's ratio	Volumetric weight, kN / m3
Metal Constructions	206000	0.3	77.0
Reinforced concrete slab (class B30)	32500	0.2	24.5
Waterproofing layer	687	0,3	17.66
Crushed stone-mastic asphalt concrete	10704	0,22	22.56
Cast asphalt concrete	8503	0,22	22.56
Dense asphalt concrete	4501	0,22	22.56

Using a software package for modeling thermal fields, the nature of the temperature distribution over the thickness of the pavement layers and the height of the cross-section of the span structure was determined, taking into account the difference in material properties (Fig. 5).



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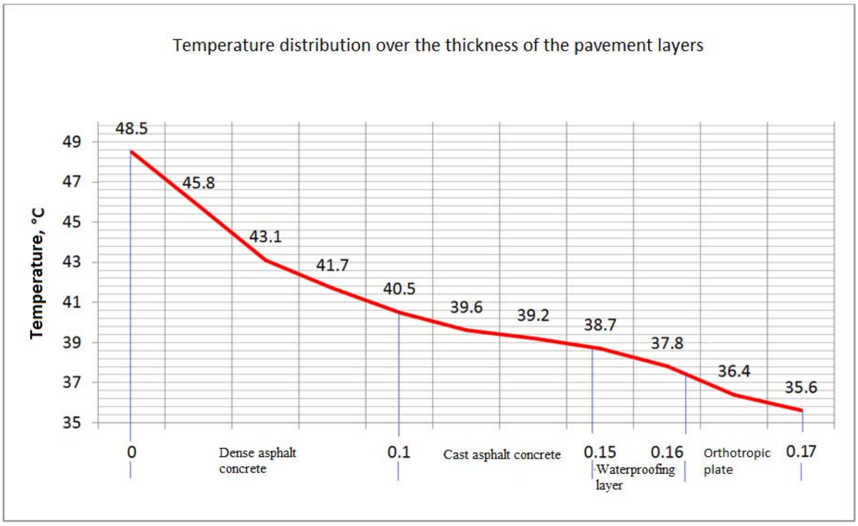

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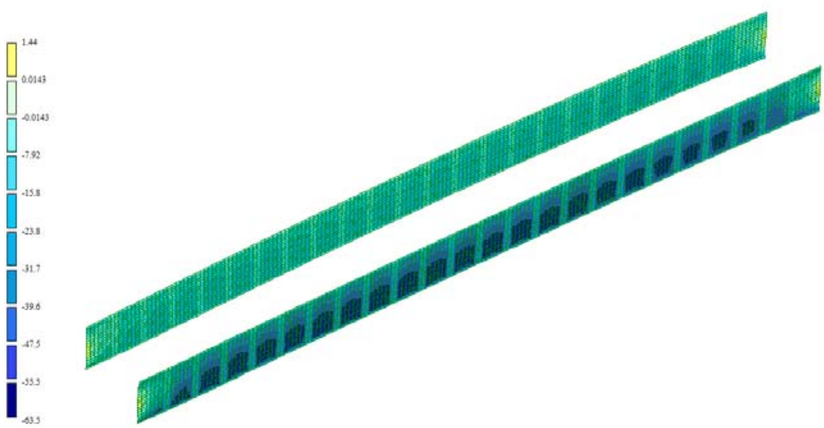
Fig. 5. Temperature distribution over the height of the cross-section:
a) in a steel-reinforced concrete span structure, b) in a span structure with an orthotropic slab

6 Analysis of the results of numerical studies

The features of the change in the stress-strain state of the span structure during the day in the summer season at high temperatures are revealed on the basis of the analysis of the results of field measurements. A comparative analysis of the calculation results for two types of spans is made.
Comparison of stresses in the main beams is shown in Figure 6.



a)

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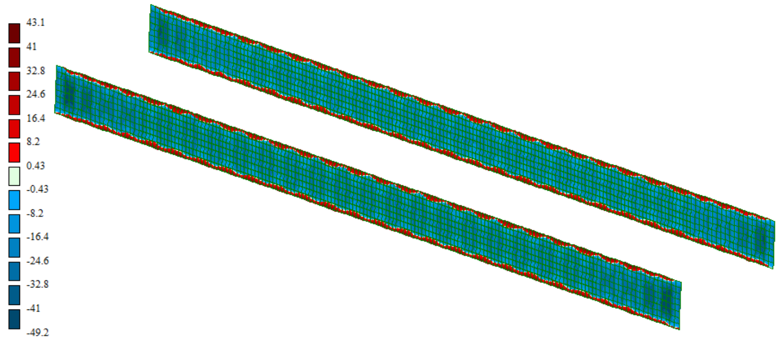
b) 

Fig. 6. Stresses in the main beams:

a) in a steel-reinforced concrete span structure, b) in a span structure with an orthotropic slab

The maximum stress in the main beam in the steel-reinforced concrete span structure is 14.3 MPa higher than the stress in the main beam in the metal span structure. Comparison of stresses in the upper pavement layer of two spans is carried out in a similar way. Despite the lower temperature of the top layer of the pavement in the metal superstructure, the stress of dense asphalt concrete is 21.5% higher than the stress of poured asphalt concrete (in the steel-reinforced concrete superstructure).The maximum stresses in the orthotropic slab exceeded the stresses in the reinforced concrete slab by 20.9 MPa. The maximum voltages from exposure to solar radiation in two types of spans, for ease of comparison, are given in Table 4.

Table 4. Comparison of stresses in two types of span comparisons

Span structure element	**Reinforced concrete span structure**		**Metal span structure with orthotropic slab**	
	1 case	2 case	1 case	2 case
Top layer of pavement	0,78	1,07	0,9	1,3
Main beams	-63,5	-68,5	-35,7	-49,2
Reinforced concrete and orthotropic slab	10,9	21,6	33,6	42,5

7 Conclusions

1. Analysis of the results of field measurements showed that when exposed to solar radiation, the surfaces of the elements in the steel-reinforced concrete span structure heated up more than in the metal span structure with an orthotropic slab.
2. It was found that the stresses in the main beam in the steel-reinforced concrete span structure exceed the stresses in the main beam in the metal span structure.
3. The results of numerical studies showed that the maximum stresses in the orthotropic slab exceeded the stresses in the reinforced concrete slab. In this case, the stress of dense asphalt concrete exceeds the stress of poured asphalt concrete.
4. It is shown that the uneven daytime change in the temperature field under the influence of solar radiation has a significantly different nature of the effect on the SSS of elements of metal and steel-reinforced concrete spans. Therefore, at the design stage, it is important to

take into account not only the temperature and climatic conditions, the features of the effect of solar radiation, but also the design features of the bearing systems of the transport structure.

The methodology for calculating the stress-strain state of two main types of load-bearing systems of transport structures on the effect of solar radiation has been developed and tested. The nature of the temperature distribution in the steel-reinforced concrete and metal spans from the effects of solar radiation has been determined based on the results of comprehensive field measurements. A comparative analysis of the temperature fields of elements of two types of spans in similar cases of exposure to solar radiation has been carried out. Comparison of the results of stress-strain state of the bearing systems of a steel-reinforced concrete span structure and a metal span structure with an orthotropic slab is carried out.

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