The Evaluation of Deformability of Highway Bridges Superstructures in the Climatic Conditions of the Republic of Karakalpakstan

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**Abstract.** The purpose of this work is to develop a methodology for assessing the thermal stress state and engineering calculation of reinforced concrete beam highway bridges, taking into account the peculiarities of regional and climatic conditions of the Republic of Karakalpakstan. In the Republic of Karakalpakstan, the climate is characterized by sharp continentality, which is expressed in significant fluctuations in temperature and relative humidity, not only during the season of the year, but also during the day. The calculation model was selected based on the generalization and analysis of existing calculation methods and studies that allow considering the deformability state of precast-monolithic bridge structures taking into account temperature factors. A specific example is used to calculate the effect of the temperature of the main joint of the grouting structure and the effect of solar radiation on the stress-strain state of the superstructure of a reinforced concrete highway bridge. The calculation method can be effectively used by design institutes for the general assessment of the strength of road bridges.

**Keywords:** Highway Bridges, Climatic conditions, Deformation, Stress

# INTRODUCTION

Bridge structures occupy a leading place in transport construction with the total volume of materials and structures used. Their durability is significantly affected by climatic factors, especially such as intense solar radiation, temperature and air humidity, which is typical for the conditions of Central Asia, as well as the Republic of Karakalpakstan. In the republic today, reinforced concrete bridges are mainly used. A significant temperature difference during the day also causes an uneven distribution of temperature deformations and stresses across the sections of structures, which affects the stress-strain state of reinforced concrete structures, as well as a decrease in their crack resistance, bearing capacity and rigidity, and in general, the operational reliability of bridges (Figure 1).

Development of scientifically based calculation methods that ensure the required operational reliability of reinforced concrete bridge structures is one of the most important tasks in designing bridges in the temperature and climatic conditions of the republic. This requires not only experimental but also theoretical studies of the influence of climatic conditions on the operation of reinforced concrete bridge bending and compressed elements, which are of particular interest.



**FIGURE 1:** Free penetration of water through the beam slabs

# METHODS

Numerous studies show that the influence of temperature and climatic factors on the operation of reinforced concrete structures is ambiguous.

Therefore, correct consideration of the cyclic nature of this impact in combination with the picture of the temperature distribution fields in the body of the structure will allow the most objective assessment of the stress-strain state of the structure at all stages of operation. The initial condition of the calculation is a given constant temperature over the volume and contour of the structure. Taking into account temperature effects, the relationship between deformations and stresses is established according to Hooke's law, in this case as the main equation of thermo elasticity. To calculate the values of temperature stresses arising during the operation of the structure, traditional calculation methods are used, in particular, the finite element method (FEM) [1]. Assuming that the temperature distribution in the elements of the bridge structure is stationary and specified in the FEM equation system, additional deformations arising due to heating are taken into account, which are added to the elastic deformations:

(1)

where σ is the column vector of stresses, D is the elasticity matrix, , are the vectors of elastic and temperature deformations, respectively.

For a plane problem, the vector  has the following form [2]:

(2)

where Δ*Т* is the element temperature increment; αi (*i* =1, 2) are the coefficients of linear thermal expansion of the material [3]. In accordance with the traditional FEM scheme, the vector of additional nodal forces caused by the temperature load and reduced to the nodes of the discrete model of the structure will be determined by the following expression:

(3)

where is the transposed matrix of the finite element shape functions, Ω is the area of the plane in which the solution is sought [4].

The stresses in the body of the structure satisfy the equilibrium equations:

(5)

The temperature effects on bridge structures are taken into account by reducing them to volumetric forces.

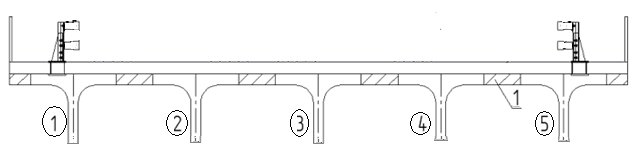
(6)

We determine for each separately considered element the relative deformations from the effect of temperature along these sections and, if necessary, their mutual displacements. The total temperature deformation of the structure consists of individual temperature deformations [5, 6]. This allows, by realistically assessing the stress-strain state of each section, to create a general picture of the uneven stress-strain state of the entire section. At the moment of concrete mix placement, its temperature is designated as tb. The concrete mix gradually warms up due to cement exothermic, and its temperature is Δt1 higher than the temperature of the structures. The adhesion of concrete to the core of the concreted section begins soon after the concrete mix is placed, but this bond is so weak that it is completely or partially destroyed. It has been established that concrete can be considered to have bonded with the blocks with sufficient accuracy for practice when it reaches a strength of 0,25R28, where R28 is the design strength of concrete [7].

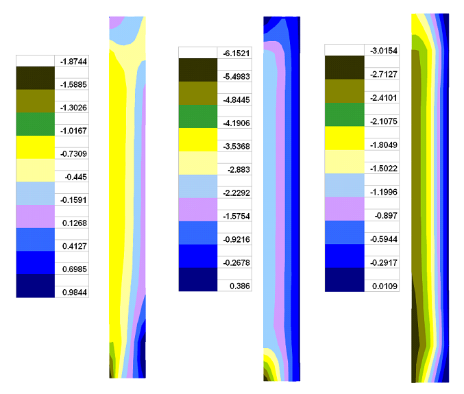
At this point, the concrete reaches temperature tк, and the temperature difference between the core and the factory blocks becomes equal. After this, the concrete can further heat up to temperature tmax. In this case, the temperature difference between the core and the blocks will be equal to Δtк + Δt1. Then, the core of the concreted section begins to cool (after the concrete has finished hardening) [8]. At some intermediate point, the temperature of the concrete will be equal to t2, and the temperature difference will be Δtк - Δt2. And finally, after some time, the temperatures of the concreted section and the factory blocks will equalize. At this point, it can be assumed that the temperature is again equal to tн. The increase in the average monthly air temperature due to the action of solar radiation on a vertical surface Δtb is determined as the quotient of dividing the average monthly sum of the solar radiation balance by the heat absorption coefficient [9, 10].

# RESULTS AND DISCUSSIONS

To study the process of thermal stress state, we will consider the bridge superstructure (span) consisting of two different types of concrete - beams and a monolithic joint (Figure 2). Beams are made of high-grade concrete, which has greater crack resistance and ultimate tensile strength (up to 2.4·10-4 1/cm) compared to the concrete filling the monolithic joint (up to 1.2·10-4 1/cm). The analysis was performed using the example of a span structure of five beams connected along the roadway slab through monolithic joints. Since the beam slab has a thickness much less than the length, the average vertical cross-section is taken into account. And given the symmetry of heat flows in this section, only half is considered.

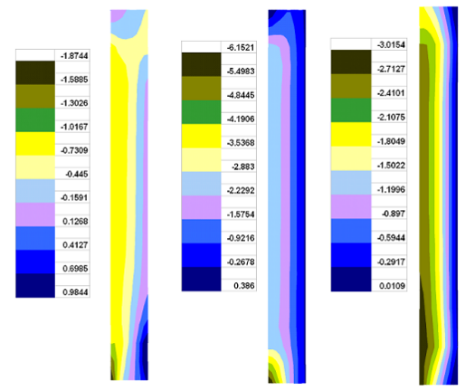


**FIGURE 2.** Bridge span, 1- monolithic joint



**FIGURE 3.** Field of thermal stress state in the monolithic joints concreting at maximum self-heating of concrete

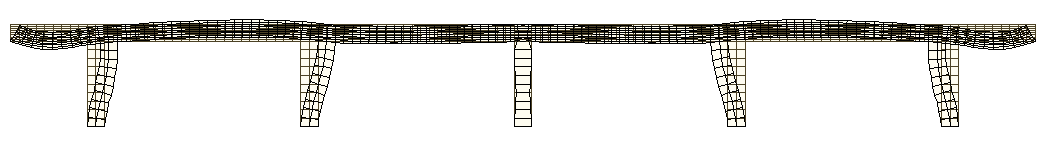
The initial conditions are that concreting is carried out in warm weather, in which plus 35°C is maintained, the temperature of the laid concrete is plus 20°C, and the closure of the beams is plus 15°C. Figure 3 shows the stress field in concrete, from the temperature distribution. It is evident from it that the stresses and ultimate tensile strains reach high values in this formulation, which does not take into account a number of other important factors.



**FIGURE 4.** Field of thermal stress state in monolithic joints with a sharp drop in outside air temperature

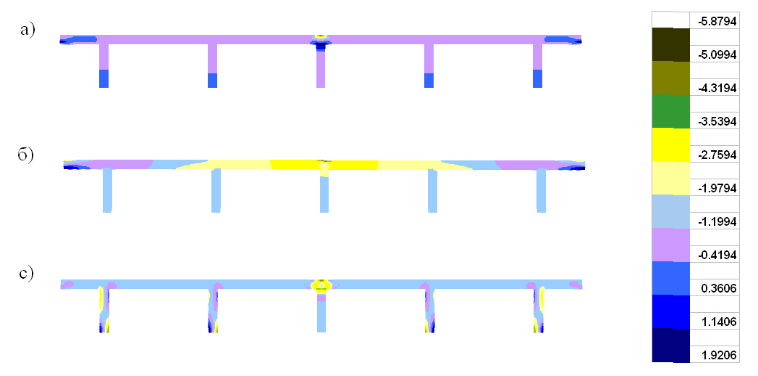
Now let us consider the case of a sharp decrease in the ambient temperature, i.e., the outside air temperature to 8°C. Figure 4 shows the stress field in concrete, from the temperature distribution. In this case, deformations arose in the concrete, which approached the limit values for tensile strength for the core. In the process of hardening of the filling concrete, two main stages were identified: maximum self-heating and complete temperature equalization. The stresses in the core in these two periods are practically opposite in their effect, but have different quantitative values, since the core first expands under the influence of temperature, causing tensile stresses on the surface of the joint, and then cools, contracts, and compressive stresses arise in the beams.

Solar radiation can increase the temperature of the illuminated surface by 20÷30°C compared to the shaded surface of the same span. With its long-term impact, an uneven temperature field arises in the body of the span, and, accordingly, constrained deformations and temperature stresses arise. This factor was studied using the initial data of the city of Nukus in Karakalpakstan, where the bridge is being built. In the first stage of the calculations, the largest value of the temperature additive from solar radiation was calculated. The deformation and field of temperature stresses at the moment of maximum self-heating of the span, taking into account the impact of the sun, are shown in Figure’s 5-6.



**FIGURE 5:** Deformation of span taking into account the impact of solar radiation

The upper part of the slab of the span structure is in the sun, the lower part is in the shade. From Figure 6 it is evident that in this case the addition to the air temperature from solar radiation practically significantly affects the stress values. Solar radiation can increase the temperature of the illuminated surface by 20÷30°C compared to the shaded surface of the same span structure. With its long-term effect, an uneven temperature field arises in the body of the span structure, and, accordingly, constrained deformations and temperature stresses arise.



**FIGURE 6.** Field of temperature stresses on span taking into account the impact of solar radiation

CONCLUSION

In the Republic of Karakalpakstan, the climate is characterized by sharp continentality, which is expressed in significant fluctuations in temperature and relative humidity, not only during the season of the year, but also during the day. The calculation model was selected based on the generalization and analysis of existing calculation methods and studies that allow considering the deformability state of precast-monolithic bridge structures taking into account temperature factors. A specific example is used to calculate the effect of the temperature of the main joint of the grouting structure and the effect of solar radiation on the stress-strain state of the superstructure of a reinforced concrete highway bridge.

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