

UDC 625.745.2

DOI: 10.15587/1729-4061.2021.238440

PROCEDURE FOR DETERMINING THE THERMOELASTIC STATE OF A REINFORCED CONCRETE BRIDGE BEAM STRENGTHENED WITH METHYL METHACRYLATE

Vitalii Kovalchuk

Corresponding author

Doctor of Technical Sciences, Associate Professor*

E-mail: kovalchuk.diit@gmail.com

Yuliya Sobolevska

PhD, Associate Professor**

Artur Onyshchenko

Doctor of Technical Sciences, Associate Professor

Department of Bridges and Tunnels****

Olexandr Fedorenko

Deputy General Director for Production Development

Kyivavtodor Municipal Corporation

Petra Bolbochana str., 6, Kyiv, Ukraine, 01014

Oleksandr Tokin

PhD, Associate Professor

Department of Manufacturing, Repair and Materials Engineering****

Andrii Pavliv

Doctor of Architecture Sciences, Associate Professor

Department of Design and Architecture Fundamentals

Lviv Polytechnic National University

S. Bandery str., 12, Lviv, Ukraine, 79013

Ivan Kravets

Assistant**

Julia Lesiv

Head of Laboratory*

*Department of Rolling Stock and Track***

Department of Fundamental Disciplines*

***Lviv Branch of Dnipro National University of Railway Transport

named after Academician V. Lazaryan

I. Blazhkevich str., 12a, Lviv, Ukraine, 79052

****National Transport University

Mykhaila Omelianovycha-Pavlenka str., 1, Kyiv, Ukraine, 01010

This paper reports the analysis of methods for determining temperature stresses and deformations in bridge structures under the influence of climatic temperature changes in the environment.

A one-dimensional model has been applied to determine the temperature field and thermoelastic state in order to practically estimate the temperature fields and stresses of strengthened beams taking into consideration temperature changes in the environment.

The temperature field distribution has been determined in the vertical direction of a reinforced concrete beam depending on the thickness of the structural reinforcement with methyl methacrylate. It was established that there is a change in the temperature gradient in a contact between the reinforced concrete beam and reinforcement.

The distribution of temperature stresses in the vertical direction of a strengthened reinforced concrete beam has been defined, taking into consideration the thickness of the reinforcement with methyl methacrylate and the value of its elasticity module. It was established that the thickness of the reinforcement does not have a significant impact on increasing stresses while increasing the elasticity module of the structural reinforcement leads to an increase in temperature stresses. The difference in the derived stress values for a beam with methyl methacrylate reinforcement with a thickness of 10 mm and 20 mm, at elasticity module $E=15,000$ MPa, is up to 3 % at positive and negative temperatures.

It has been found that there is a change in the nature of the distribution of temperature stresses across the height of the beam at the contact surface of the reinforced concrete beam and methyl methacrylate reinforcement. The value of temperature stresses in the beam with methyl methacrylate reinforcement and exposed to the positive and negative ambient temperatures increases by three times.

It was established that the value of temperature stresses is affected by a difference in the temperature of the reinforced concrete beam and reinforcement, as well as the physical and mechanical parameters of the investigated structural materials of the beam and the structural reinforcement with methyl methacrylate

Keywords: bridge reinforcement, reinforced concrete beam, methyl methacrylate reinforcement, temperature field

Received date 09.07.2021

Accepted date 20.08.2021

Published date 31.08.2021

How to Cite: Kovalchuk, V., Sobolevska, Y., Onyshchenko, A., Fedorenko, O., Tokin, O., Pavliv, A., Kravets, I., Lesiv, J. (2021). Procedure for determining the thermoelastic state of a reinforced concrete bridge beam strengthened with methyl methacrylate. *Eastern-European Journal of Enterprise Technologies*, 4 (7 (112)), 26–33. doi: <https://doi.org/10.15587/1729-4061.2021.238440>

1. Introduction

According to data from [1], examination of the technical condition of bridges in Ukraine in 2020 found that 895 arti-

ficial structures across the country need immediate repair. Of these, 169 are already in pre-emergency condition.

It should also be noted that ensuring the trouble-free operation of bridges in developed countries is also a relevant

issue. Recall the collapse of a four-lane road bridge in Italy in 2018. Therefore, the application of promising technologies for repairing defective bridges is an urgent task for bridge engineering.

To improve the bearing capacity of road bridges, a method for strengthening beams with methyl methacrylate compositions (hereinafter, methyl methacrylate) has been used in recent years. The general view of the extreme beams in a motor bridge reinforced with methyl methacrylate is shown in Fig. 1.



Fig. 1. Strengthening the reinforced concrete beams of a bridge with methyl methacrylate

Methyl methacrylate is a low-binding polymer used to reinforce the beams of road, city, and pedestrian bridges. It is characterized by increased strength and durability [2].

The reinforcement of beams involves arranging a non-removable metal formwork at the bottom of the beam at a distance equal to 20 mm from its lower shelf. This gap is covered with fine sand; a methyl methacrylate composition is then added, which freely penetrates cracks and capillaries.

When methyl methacrylate interacts with particles of fine sand, a strong structural element is formed, which fills the cavities and cracks in a reinforced concrete beam, firmly binds them, thereby contributing to the strengthening of the beam.

However, at the same time, it is necessary to take into consideration the possible impact of climatic temperature conditions on the stressed-strained state of those reinforced concrete beams in the bridges that are strengthened with methyl methacrylate.

In addition, significant and sharp changes in ambient temperatures and an increase in the ranges of their change (in summer, the maximum temperature increases; in winter, the minimum temperature decreases) over the past five years lead to an increase in the deformability of bridge beams. Therefore, it is a relevant task to study work of the structural reinforcement of bridge beams with methyl methacrylate exposed to variable ambient temperatures.

2. Literature review and problem statement

It was established that there are a number of studies on determining the temperature fields and stresses in bridge structures without reinforcement under the action of climatic temperature influences of the environment [3–9].

Paper [3] proposes mathematical models for calculating the thermal conductivity and thermally stressed state of a fragment of the metal corrugated shell of a transport structure whose side surfaces are heated to different temperatures. However, the model for assessing the thermally stressed state

of the shell takes into consideration only the homogeneous medium of the structure.

Work [4] states that the temperature difference in the boxed beams of bridges can reach values above 40 °C. However, no studies into the thermoelastic state of the box beam reinforced with methyl methacrylate compositions were carried out.

Paper [5] reports the results from a long-term monitoring of deflections of several bridges in Switzerland and shows the daily and seasonal movements of bridges under a thermal influence. The authors established a ratio between the measured temperatures and gradients and the position of a bridge and described methods for compensating thermal effects. However, no studies into the impact of daily and seasonal temperatures on the stressed-strained condition of bridges were carried out. And there are no models to assess the thermally-stressed state of bridges exposed to variable temperatures.

Work [6] reports the results of studying a temperature distribution and the corresponding reactions of a suspension bridge across the span by combining numerical analysis and monitoring on the ground. Thin finite-element models of bridge components were built to numerically assess the impact of temperature fields on the bridge structure. However, the cited work does not provide methods for assessing the thermoelastic state of bridges; it only analyzes the distribution of temperature gradients.

Paper [7] simulates the distribution of a temperature field across a concrete beam, which takes into consideration the shadow effects and changes in the intensity of solar radiation during the day. The results show that the temperature field of the concrete beam has obvious nonlinear characteristics of the distribution. That proves the need to analyze the temperature field, especially for complex structures with different cross-sections along the longitudinal axis.

Based on the experimental records for a composite beam with a steel profile and concrete overlap, a thermal analysis model was built and tested using a finite element method in work [8]. The model addresses the issue of heat conductivity in concrete and steel, taking into consideration various boundary conditions that include solar radiation, reflected radiation, air temperature, and ambient air speed.

Paper [9] reports the results of developing temperature gradient curves to forecast the temperature stresses in a structure based on data from field and laboratory monitoring. The temperature gradient curves and a temperature stress model were constructed for a composite beam.

However, works [7–9] did not assess the thermoelastic state of composite beams strengthened by methyl methacrylate compositions.

Papers [10–12] provide data on the long-term studies of climatic temperature impacts on the span structures of bridges. The authors of [10] calculated non-stationary temperature fields using a distributed analysis of the data acquired from long-term climate monitoring. The results of [11] show that the coating of the span structures plays an important role in changing temperature differences; there is a significant difference between temperature changes with or without coating. Based on research, it was established in [12] that temperature fluctuations cause temperature stresses and deformations in bridge structures. The results of calculating the temperature deformations and strains by Mises demonstrated that stresses from temperature gradients reach values up to 25 MPa, which emphasizes the mandatory consideration of taking them into account in studying the stressed-strained state of bridge structures.

Work [13] states that at the stage of bridge operation a change in the temperature and humidity conditions disrupts the hygrometric equilibrium between concrete and the environment, leads to the occurrence of volumetric deformations, and, as a result, changes the stressed-deformed state of the bridge beam. That primarily causes the evolution of microcracks, which predetermines a decrease in the characteristics of crack resistance of reinforced concrete beams.

Paper [14] notes that in the solid-structure beams, stresses due to thermal influences, according to the calculations carried out, reach values of 100 MPa during compression and 42 MPa during stretching; it is noted that it is necessary to take into consideration the environmental temperature on the stressed-strained state of bridges.

Work [15] shows that negative temperature gradients may cause higher stresses than positive ones. Analysis of the calculations revealed that an increase in ambient temperature in the daytime increases the temperature of the lower surface of the slab; in this case, the stretching stresses decrease. It is noted that the difference in the average temperatures of the upper and lower surfaces of the bridge slab is an important factor in the occurrence of stretching stresses in the lower surface of slabs.

Studies [10–15], similarly to works [7–9], reported no results in assessing the thermoelastic state of a bridge slab reinforced with methyl methacrylate compositions.

In [16], when observing temperature gradients in the span structure of a bridge and deformations in the cross-section of the structure shown in Fig. 2, 3, the authors established a correlation dependence of deformations on changes in ambient temperature.

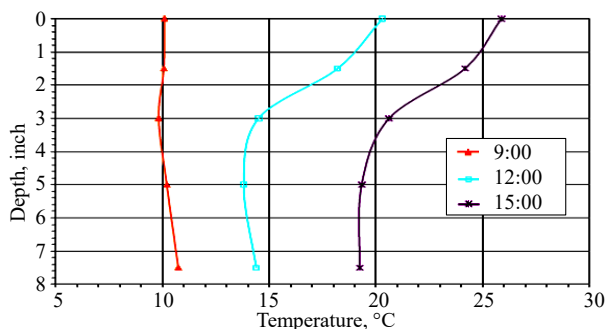


Fig. 2. Distribution of temperature gradients in a bridge slab [16]

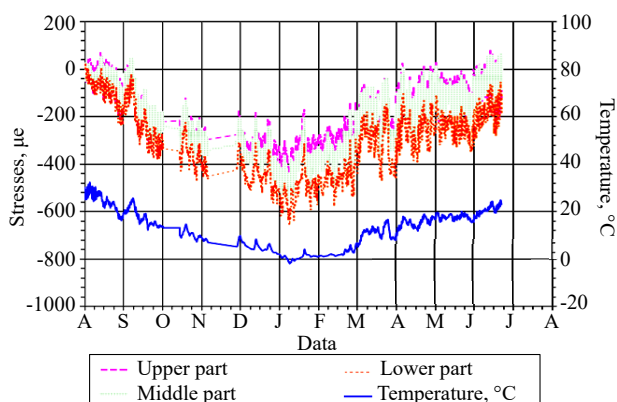


Fig. 3. Deformation chart at the upper, middle, and lower surfaces of a slab, and the air temperature based on measurements over one year [16]

Fig. 4 shows the horizontal movements of a bridge when the ambient temperature rises [17]; it demonstrates that temperature influences cause the bending of the box beam of the bridge.

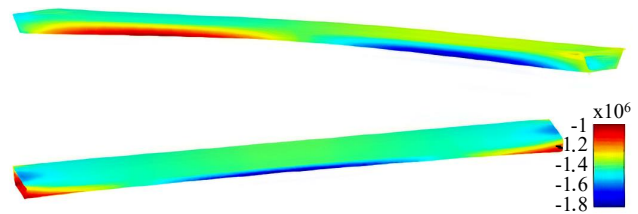


Fig. 4. Distribution of deformations in the longitudinal direction of a beam with a uniform increase in temperature

Works [18, 19] indicate that the most common in engineering practice are models for calculating the strength of structures.

Our review of the scientific papers reveals that models for determining stresses in bridge structures caused by climatic temperature changes are less common and studied. In addition, the issue related to developing practical models for determining temperature fields and stresses in the reinforced concrete beams of bridges strengthened with methyl methacrylate compositions has not been resolved up to now. It should be noted that the existence of practical models would make it possible, at the stage of planning the repair or restoration of the bearing capacity of defective reinforced concrete beams of bridges, to make constructive decisions on the choice of materials for effective repair.

3. Literature review and problem statement

The purpose of this work is to devise a comprehensive procedure for determining temperature fields and stresses in the reinforced concrete beam of a bridge strengthened with methyl methacrylate compositions, which could make it possible to practically assess the thermoelastic state of a bridge beam.

To accomplish the aim, the following tasks have been set:

- to define input data related to the numerical studies into the temperature field and stresses of the strengthened reinforced concrete beam;

- to assess the temperature field of the reinforced concrete beam of a bridge strengthened with methyl methacrylate under the influence of positive and negative ambient temperatures;

- to assess the thermoelastic state of a reinforced concrete beam strengthened with methyl methacrylate, taking into consideration the geometric and physical-mechanical parameters of structural reinforcement.

4. The study materials and methods

The thermoelastic state of bridges is estimated in two stages. At the first stage, the distribution of a temperature field is calculated; then the temperature stresses and deformations are determined.

Work [19] states that the first and very important stage in preparing a model for calculation is to set its dimensionality. It also gives a one-dimensional model to assess the temperature stresses in a reinforced concrete beam of a bridge,

depending on the thickness and the module of elasticity of structural reinforcement.

Thermal conductivity model.

To assess the temperature field and stresses, we have considered a two-layer model whose bottom is a layer of thin methyl methacrylate reinforcement, and the top is the lower shelf of the reinforced concrete beam of the bridge (Fig. 5).

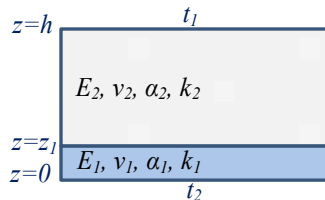


Fig. 5. Two-layer model for calculating the temperature field and stresses in a reinforced concrete beam strengthened with methyl methacrylate

Consider the rectangular Cartesian $Oxyz$ coordinate system, in which the above model would occupy the following region:

$$(V) = \{(x, y, z): 0 \leq x \leq x_1, 0 \leq y \leq y_1, 0 \leq z \leq h\}. \quad (1)$$

The coefficient of thermal conductivity of a two-layer model is determined from formula (2):

$$k = \begin{cases} k_1 & \text{at } 0 \leq z \leq z_1, \\ k_2 & \text{at } z_1 < z \leq h. \end{cases} \quad (2)$$

Assume the temperature t in a beam does not depend on the time and the x, y coordinates. The thermal conductivity equation of the beam with reinforcement then takes the following form [20]:

$$\frac{d}{dz} \left(k \frac{dt}{dz} \right) = 0. \quad (3)$$

We believe that on surfaces $z=0$ and $z=h$ the temperature field of a two-layer model accepts the following values:

$$t|_{z=0} = t_1, \quad t|_{z=h} = t_2, \quad (4)$$

and, on surface $z=z_1$, the conditions of ideal thermal contact between the reinforced concrete beam and methyl methacrylate reinforcement are met, which is expressed by the following equation:

$$t|_{z=z_1-0} = t|_{z=z_1+0}, \quad k_1 \frac{dt}{dz} \Big|_{z=z_1-0} = k_2 \frac{dt}{dz} \Big|_{z=z_1+0}. \quad (5)$$

Solving equation (3) and taking into consideration equations (4), (5), we obtain an equation to find the distribution of temperature in the vertical direction of the reinforced beam:

$$t = \begin{cases} C_1 z + C_2, & 0 \leq z \leq z_1, \\ C_3 z + C_4, & z_1 < z \leq h, \end{cases} \quad (6)$$

where the integration constants, included in equation (6), are determined from the following expressions:

$$C_1 = \frac{t_2 - t_1}{z_1 + \frac{k_1}{k_2}(h - z_1)}; \quad C_2 = t_1; \quad C_3 = \frac{k_1}{k_2} C_1; \quad C_4 = t_2 - C_3 h. \quad (7)$$

Thus, having determined the constants of integration from equation (7), equation (6) is used to find the distribution of the temperature field in a two-layer beam. Next, consider a model of the thermoelastic state of the beam.

Model of the thermoelastic state of the reinforced beam.

Let the modulus of elasticity, the Poisson coefficient, and the coefficient of linear thermal expansion of the methyl methacrylate reinforcement and reinforced concrete beam are determined from the following formulas:

$$E = \begin{cases} E_1 & \text{at } 0 \leq z \leq z_1, \\ E_2 & \text{at } z_1 < z \leq h, \end{cases} \quad \nu = \begin{cases} \nu_1 & \text{at } 0 \leq z \leq z_1, \\ \nu_2 & \text{at } z_1 < z \leq h, \end{cases} \quad (8)$$

$$\alpha = \begin{cases} \alpha_1 & \text{at } 0 \leq z \leq z_1, \\ \alpha_2 & \text{at } z_1 < z \leq h. \end{cases}$$

Assume the temperature field of the reinforced beam is determined from formula (6), and the surfaces $z=0$ and $z=h$ are free from loads. Other surfaces of the reinforced beam are rigidly fixed.

To determine the stressed-strained state of the reinforced beam, we use an equation from the theory of thermoelasticity. In this case, movements along the directions of the x, y coordinate axes, the components of a deformation tensor $e_1, e_2, e_{12}, e_{13}, e_{23}$, and the components of a stress tensor $\sigma_{12}, \sigma_{13}, \sigma_{23}$ are zero. The equilibrium equation of the reinforced beam takes the following form:

$$\frac{d\sigma_3}{dz} = 0, \quad (9)$$

where σ_3 is the stress tensor component.

Using equation (9), taking into consideration the boundary conditions $\sigma_3|_{z=0}=0, \sigma_3|_{z=h}=0$, we obtain:

$$\sigma_3 = 0. \quad (10)$$

Since $e_1=0, e_2=0, \sigma_3=0$, then the Duhamel's ratio takes the following form:

$$\frac{1}{E}(\sigma_1 - \nu\sigma_2) + \alpha t = 0, \quad \frac{1}{E}(\sigma_2 - \nu\sigma_1) + \alpha t = 0, \quad (11)$$

where σ_1, σ_2 are the stress tensor components.

Solving the system of equations (11), we find expressions to assess the temperature stresses in a strengthened reinforced concrete beam:

$$\sigma_1 = -\frac{\alpha t E}{1-\nu}, \quad \sigma_2 = -\frac{\alpha t E}{1-\nu}. \quad (12)$$

The resulting equations (12) make it possible to determine the thermoelastic state of the reinforced beam, taking into consideration the physical-mechanical parameters of the methyl methacrylate reinforcement and beam materials and ambient temperature.

5. The results of devising a comprehensive procedure for determining the temperature fields and stresses in a reinforced concrete bridge beam strengthened with methyl methacrylate compositions

5.1. Input data related to the numerical studies of the temperature field and stresses in a strengthened reinforced concrete beam

Our numerical studies in to the stresses of a reinforced beam were carried out at the values for the physical-mechanical

parameters of a reinforced concrete beam and methyl methacrylate reinforcement that are given in Table 1.

Table 1

Physical-mechanical characteristics of the reinforced concrete beam and methyl methacrylate reinforcement

No. of entry	Characteristic	Value	Dimensionality
1	Accepted modules of elasticity for methyl methacrylate reinforcement, E_1	5,000, 10,000, 15,000	MPa
2	Elasticity modulus of reinforced concrete beam, E_2	$3.6 \cdot 10^4$	MPa
3	Accepted Poisson's ratio for methyl methacrylate reinforcement, ν_1	0.3	–
4	Poisson's ratio for reinforced concrete beam, ν_2	0.25	–
5	Accepted coefficient of linear temperature expansion for methyl methacrylate reinforcement, α_1	$1.25 \cdot 10^{-5}$	$1/^\circ\text{C}$
6	Coefficient of linear temperature expansion for reinforced concrete beam, α_2	$1.0 \cdot 10^{-5}$	$1/^\circ\text{C}$
7	Accepted coefficient of thermal conductivity for methyl methacrylate reinforcement, k_1	20	$\text{W}/(\text{m} \cdot ^\circ\text{C})$
8	Thermal conductivity coefficient for reinforced concrete beam, k_2	19	$\text{W}/(\text{m} \cdot ^\circ\text{C})$

We performed numerical studies into the temperature field of a strengthened reinforced concrete bridge beam at the following values of model's geometrical parameters: $z=200$ mm; the coating thickness z_1 is variable: 10 mm, 15 mm, and 20 mm.

At positive ambient temperatures, the temperature of the beam surface is taken equal to $t_1=20$ °C, that of the coating equal to $t_2=30$ °C, and, at negative ambient temperatures, respectively, $t_1=-15$ °C and $t_2=-10$ °C.

5.2. The results of studying a temperature field in the strengthened reinforced concrete beam

The study results regarding a temperature field in the reinforced concrete beam with methyl methacrylate reinforcement at the positive and negative ambient temperatures are shown in Fig. 6.

Fig. 6 shows that the temperature is not evenly distributed in the vertical direction of the strengthened reinforced concrete beam. The higher temperature is characteristic of the reinforced concrete beam.

At the positive and negative temperature changes of the environment, the temperature of methyl methacrylate reinforcement is, respectively, +20 °C and –15 °C; reinforced concrete beam, +30 °C and –10 °C; in the contact between the reinforced concrete beam and methyl methacrylate reinforcement, there is a change in the temperature gradient.

Next, based on the known values of the temperature field, we shall assess the thermoelastic state of the strengthened reinforced concrete bridge beam. The study was conducted with respect to the geometrical parameters and physical-mechanical properties of the reinforced beam, which are given in Table 1.

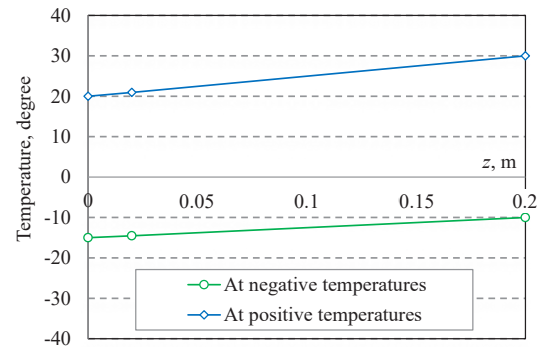


Fig. 6. Temperature field distribution in a reinforced concrete beam with methyl methacrylate reinforcement

5.3. The results of studying the thermo-elastic state of a strengthened reinforced concrete beam

The results from studying stresses in a strengthened reinforced concrete beam at the positive temperature changes of the environment are shown in Fig. 7–9. In this case, the distribution of temperature stresses was established depending on the thickness and the module of elasticity of methyl methacrylate reinforcement.

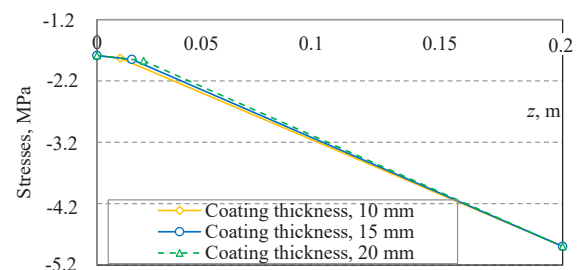


Fig. 7. Stress distribution in a strengthened reinforced concrete beam at structural reinforcement elasticity module $E=5,000$ MPa and positive temperatures

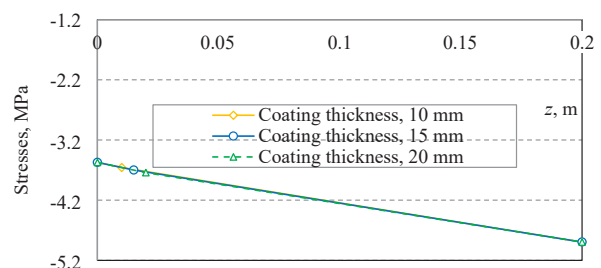


Fig. 8. Stress distribution in a strengthened reinforced concrete beam at structural reinforcement elasticity module $E=10,000$ MPa and positive temperatures

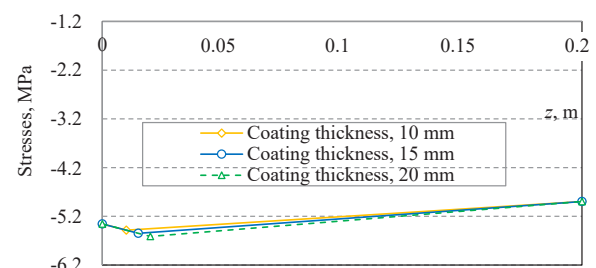


Fig. 9. Stress distribution in a strengthened reinforced concrete beam at structural reinforcement elasticity module $E=15,000$ MPa and positive temperatures

The calculation results illustrated in Fig. 7–9 demonstrate that at positive ambient temperatures there is a change in the nature of the distribution of temperature stresses in the contact between the reinforced concrete beam and reinforcement.

At the same time, temperature stresses increase with an increase in the value of the reinforcement elasticity module.

Thus, at a coating thickness of 20 mm and with a module of elasticity of the reinforcement $E=5,000$ MPa, the value of stresses in the reinforcement-beam contact is 1.87 MPa; at $E=10,000$ MPa – 3.74 MPa; at $E=15,000$ MPa – 5.61 MPa.

Fig. 10–12 show the distribution of stresses in a reinforced concrete beam with methyl methacrylate reinforcement at negative surface temperatures.

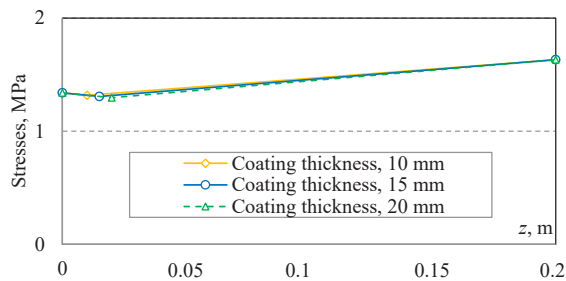


Fig. 10. Stress distribution in a strengthened reinforced concrete beam at structural reinforcement elasticity module $E=5,000$ MPa and negative temperatures

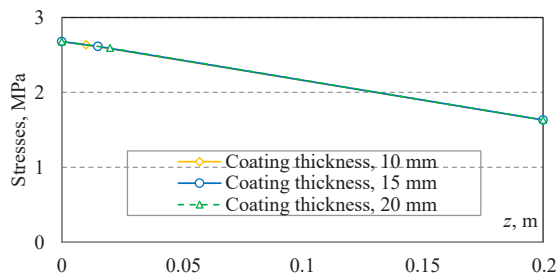


Fig. 11. Stress distribution in a strengthened reinforced concrete beam at structural reinforcement elasticity module $E=10,000$ MPa and negative temperatures

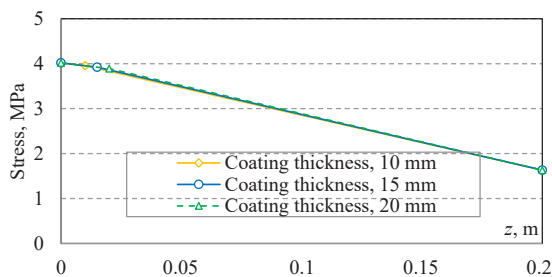


Fig. 12. Stress distribution in a strengthened reinforced concrete beam at structural reinforcement elasticity module $E=15,000$ MPa and negative temperatures

The results of studying the thermoelastic state of a reinforced concrete beam strengthened with methyl methacrylate have shown that both at positive and negative ambient temperatures there is a change in the nature of the distribution of temperature stresses in the beam-reinforcement contact (Table 2).

Table 2

Temperature stress distribution in a reinforced bridge beam

Coating thickness, mm	Coating elasticity modulus, MPa		
	5,000	10,000	15,000
Stress, MPa			
Exposed to positive temperatures			
10	-1.83	-3.66	-5.48
15	-1.85	-3.70	-5.55
20	-1.87	-3.74	-5.61
Exposed to negative temperatures			
10	1.32	2.64	3.95
15	1.31	2.61	3.92
20	1.30	2.59	3.89

The value of temperature stresses significantly depends on the module of elasticity of methyl methacrylate reinforcement and depends little on its thickness. With a coating thickness of 20 mm and with a coating elasticity module $E=5,000$ MPa, the value of stresses in the coating-beam contact is 1.3 MPa; at $E=10,000$ MPa – 2.59 MPa; and at $E=15,000$ MPa – 3.89 MPa.

6. Discussion of results of estimating the thermoelastic state of a strengthened reinforced concrete bridge beam

Based on our study of temperature distribution in the vertical direction of the reinforced concrete beam with coating (Fig. 6), it was established that there is a change in the temperature gradient in the beam-reinforcement contact. This is due to the different physical-mechanical properties of the reinforced concrete beam and methyl methacrylate reinforcement (Table 1). The higher temperature is characteristic of the reinforced concrete beam.

It should be noted that the thickness of the coating does not significantly affect the level of temperature stresses in the beam-reinforcement contact. The difference in the derived stress values for a beam with methyl methacrylate reinforcement with a thickness of 10 mm and 20 mm with an elasticity module $E=15,000$ MPa is up to 3 % (Table 2). This difference occurs both at positive and negative ambient temperatures.

However, it should be noted that with an increase in the elasticity module of the methyl methacrylate reinforcement, the value of temperature stresses in the beam-reinforcement contact increases. Thus, the value of the thermo-elastic state of the beam with methyl methacrylate reinforcement with a height of 20 mm with an elasticity module $E=5,000$ MPa and $E=15,000$ MPa, exposed to the action of positive and negative ambient temperatures, increases by three times (Table 2). This pattern must be taken into consideration when strengthening defective reinforced concrete bridge beams.

One caveat of this study is the lack of real experimental data on temperature distribution along a strengthened reinforced concrete beam, both in the vertical and longitudinal direction of the bridge beam. Therefore, scientific research is planned to be advanced by taking into consideration the distribution of temperature across the length of a strengthened reinforced concrete beam in a two-dimensional statement

of the research problem. In addition, a given model makes it possible to determine the thermo-elastic state of strengthened beams only in a vertical direction.

7. Conclusions

1. The data acquired from our numerical studies make it possible to model the temperature field and stresses in a strengthened reinforced concrete beam, taking into consideration the physical-mechanical parameters of the material for methyl methacrylate reinforcement and beams, as well as ambient temperature. It has been shown that the improved model could be practically applied for assessing the temperature fields and stresses in strengthened two-layer beams, taking into consideration the effect of climatic temperature changes in the environment.

2. Our results on temperature field distribution in the vertical direction of a strengthened reinforced concrete bridge beam have shown that at positive and negative temperature changes in the environment, the temperature of the methyl methacrylate reinforcement is, respectively, $+20^{\circ}\text{C}$

and -15°C ; the reinforced concrete beam, $+30^{\circ}\text{C}$ and -10°C ; and, in the contact of the reinforced concrete beam and methyl methacrylate reinforcement, there is a change in the temperature gradient. This phenomenon is due to the different physical-mechanical characteristics of structural materials for the beam and methyl methacrylate reinforcement.

3. There is a change in the nature of temperature stress distribution across the height of the beam on the contact surface of the reinforced concrete beam and methyl methacrylate reinforcement. The amount of stresses in the contact zone at positive temperatures was 5.61 MPa; at negative temperatures – 3.95 MPa. It was established that the thickness of the coating does not have a significant impact on an increase in temperature stresses while an increase in the coating's elasticity module leads to an increase in temperature stresses in the contact of the reinforced concrete beam with methyl methacrylate reinforcement. With a difference in coating thickness of 10 mm, the stress in the beam-reinforcement contact at the coating elasticity module $\Delta E = 15,000$ MPa increases up to 3 %, and, with the difference of elasticity modules $\Delta E = 10,000$ MPa, the value of temperature stresses increases by three times.

References

1. Mist cherez r. Zakhidnyi Buh na dorozh N-17: shcho vzhe зроблено dlia vidnovlennia rukhu. Available at: https://ukravtodor.gov.ua/press/news/mist_cherez_r_zakhidnyi_buh_na_dorozh_n-17_shcho_vzhe_zrobлено_dlia_vidnovlennia_rukhu.html
2. Usilenie stroitel'nykh konstruktsiy nizkovyazkimi polimerami na osnove metilmetakrilata. Available at: <https://injectir.ru/usilenie-konstrukcii>
3. Gera, B., Kovalchuk, V. (2019). A study of the effects of climatic temperature changes on the corrugated structure. *Eastern-European Journal of Enterprise Technologies*, 3 (7 (99)), 26–35. doi: <https://doi.org/10.15587/1729-4061.2019.168260>
4. De Backer, H., Outtier, A., Van Bogaert, P. (2009). Numerical and experimental assessment of thermal stresses in steel box girders. *Nordic Steel Construction Conference, 11th, Proceedings*, 65–72.
5. Burdet, O. L. (2010) Thermal Effects in the Long-Term Monitoring of Bridges. *Large structures and Infrastructures for environmentally constrained and Urbanised areas. 34th International symposium on bridge and structural engineering. Venice*. Available at: <https://infoscience.epfl.ch/record/163104>
6. Xia, Y., Chen, B., Zhou, X., Xu, Y. (2012). Field monitoring and numerical analysis of Tsing Ma Suspension Bridge temperature behavior. *Structural Control and Health Monitoring*, 20 (4), 560–575. doi: <https://doi.org/10.1002/stc.515>
7. Yan, Y., Wu, D., Li, Q. (2018). A three-dimensional method for the simulation of temperature fields induced by solar radiation. *Advances in Structural Engineering*, 22 (3), 567–580. doi: <https://doi.org/10.1177/1369433218795254>
8. Mussa, F. I., Abid, S. R., Tayşi, N. (2021). Design Temperatures for Composite Concrete-Steel Girders: A-Verification of the Finite Element Model. *IOP Conference Series: Materials Science and Engineering*, 1090 (1), 012108. doi: <https://doi.org/10.1088/1757-899x/1090/1/012108>
9. Peng, G., Nakamura, S., Zhu, X., Wu, Q., Wang, H. (2017). An experimental and numerical study on temperature gradient and thermal stress of CFST truss girders under solar radiation. *Computers and Concrete*, 20 (5), 605–616. doi: <https://doi.org/10.12989/cac.2017.20.5.605>
10. Sanio, D., Mark, P., Ahrens, M. A. (2017). Temperaturfeldberechnung für Brücken. *Beton- Und Stahlbetonbau*, 112 (2), 85–95. doi: <https://doi.org/10.1002/best.201600068>
11. Wang, G., Zhou, X., Ding, Y., Liu, X. (2021). Long-Term Monitoring of Temperature Differences in a Steel Truss Bridge with Two-Layer Decks Compared with Bridge Codes: Case Study. *Journal of Bridge Engineering*, 26 (3), 05020013. doi: [https://doi.org/10.1061/\(asce\)be.1943-5592.0001681](https://doi.org/10.1061/(asce)be.1943-5592.0001681)
12. Berg, M., Trouillet, P. (1988). *Ouvrages d'art-actions et sollicitations thermiques*. Bulletin de Liaison des Laboratoires des Ponts et Chaussées, 155.
13. Solodkyi, S. Y., Vaskiv, N. O. (2009). Temperaturno-volohisni umovy ekspluatatsiyi yak chynnyk vplyvu na trishchynostiykist betonu. *Mekhanika i fizyka ruinovannia budivelnnykh materialiv ta konstruktsiy*, 8, 278–288.
14. Dilger, W. H., Ghali, A., Chan, M., Cheung, M. S., Maes, M. A. (1983). Temperature Stresses in Composite Box Girder Bridges. *Journal of Structural Engineering*, 109 (6), 1460–1478. doi: [https://doi.org/10.1061/\(asce\)0733-9445\(1983\)109:6\(1460\)](https://doi.org/10.1061/(asce)0733-9445(1983)109:6(1460))
15. Prakash Rao, D. S. (1986). Temperature Distributions and Stresses in Concrete Bridges. *Journal Proceedings*, 83 (4), 588–596.
16. Lange, D. A., Roesler, J. R., D'Ambrosia, M., Grasley, Z. C., Lee, C. J., Cowen, D. R. (2003). *High Performance Concrete For Transportation Structures*. Civil Engineering Studies. Available at: <https://www.ideals.illinois.edu/handle/2142/46278>

17. Balmes, E., Corus, M., Siegert, D. (2006). Modeling thermal effects on bridge dynamic responses. In Proceedings of the 24th international modal analysis conference (IMAC-XXIV).
18. Kovalchuk, V., Onyshchenko, A., Fedorenko, O., Habrel, M., Parneta, B., Voznyak, O. et. al. (2021). A comprehensive procedure for estimating the stressed-strained state of a reinforced concrete bridge under the action of variable environmental temperatures. Eastern-European Journal of Enterprise Technologies, 2 (7 (110)), 23–30. doi: <https://doi.org/10.15587/1729-4061.2021.228960>
19. Kovalchuk, V., Hnativ, Y., Luchko, J., Sysyn, M. (2020). Study of the temperature field and the thermo-elastic state of the multilayer soil-steel structure. Roads and Bridges – Drogi i Mosty, 19 (1), 65–78. doi: <https://doi.org/10.7409/rabdim.020.004>
20. Luchko, J., Hnativ, Yu., Kovalchuk, V. (2013). Temperature field and stressed state of composite bridge sp an investigation. Visnyk ternopilskoho natsionalnoho tekhnichnoho universytetu, 2, 29–38.

At present, there are theoretical and experimental studies of such bearings without taking into account the elastic deformation of the bearing segments. The rotor bearings of powerful turbines at nuclear power plants are subjected to loads as high as tens of tons. One of the important issues in designing segmental bearings operating under these conditions consists in taking into account elastic deformations of the segments. A schematic diagram of a segmental hydrostatic bearing was presented and the principle of its operation was described. When determining the deformation of spherical support, a formula of change in volume of a solid steel ball subjected to uniform pressure was applied.

To determine the segment deformation in the axial direction, differential equation of bending of the strip beam as the initial one. The basic equation of deformation of rods with a curved axis acting in the plane of curvature was taken as a starting point of determining the segment deformation in the circumferential direction.

It was found in the studies that the maximum deformation of the segment is 4.5 % of radial clearance at a feed pressure of 5 MPa and can affect the bearing characteristics. A substantially nonlinear character of deformations along the segment axis was revealed. It was found that the pressure of the working fluid significantly affects the segment thickness. With an increase in feeding pressure from 1 MPa to 10 MPa, the thickness of the steel segment increased more than 2 times and the thickness of the bronze segment increased more than 3 times. It was established that the pressure of the working fluid exceeding 10 MPa substantially affects the deformation of the spherical support and the bearing clearance.

The study results will make it possible to determine more accurately the main characteristics of the segmental bearing and design it more efficiently

Keywords: *segmental bearing, segment deformation, bearing characteristics, differential equation, calculation results*

UDC 621.822.5.032:532.517.4

DOI: 10.15587/1729-4061.2021.239066

REVEALING DEFORMATION OF SEGMENTS AND THEIR SUPPORTS IN A HYDROSTATIC SEGMENTAL BEARING

Vladimir Nazin

Doctor of Technical Sciences

Department of Theoretical Mechanics,

Mechanical Engineering and Robotic

Mechanical Systems

National Aerospace University

«Kharkiv Aviation Institute»

Chkalova str., 17, Kharkiv, Ukraine, 61070

E-mail: v.nazin@khai.edu

Received date 29.06.2021

Accepted date 12.08.2021

Published date 31.08.2021

How to Cite: Nazin, V. (2021). Revealing deformation of segments and their supports in a hydrostatic segmental bearing. Eastern-European Journal of Enterprise Technologies, 4 (7 (112)), 33–40. doi: <https://doi.org/10.15587/1729-4061.2021.239066>

1. Introduction

High reliability and durability in all operating modes are some of the main requirements for bearings. In addition, the following requirements are imposed on them: guaranteed long-term working efficiency, high fire safety, good maintainability after storage, transportation, and overload.

Non-stationarity of loading, high rotational speeds of rotors, the possibility of the appearance of elastic deformations in segments, and the use of low-viscosity liquids as a lubricant are the main operating features of rotor bearings in power plant units. The high probability of turbulent flow of lubricant is caused by these factors.

Slider bearings of various types are used in existing designs of power units. There are many types of bearing shell bore.

The simplest cylindrical bore is used most often. Taking into account peculiarities of operation of rotor bearings in present-day power plant units, a bearing with self-aligning segments is the most reliable type of bearing that counteracts the excitation of vibrations. Unlike the conventional designs, it possesses stabilizing properties enabling expansion of the zone of stable rotor motion. In addition, it is able to compensate for shaft misalignments and has fewer frictional losses.

In 1972, for the first time in the practice of turbine construction, 0.3 and 0.4 m diameter segmental bearings were installed on a K-500-240 turbine (Russia). Capacities of nuclear power plants measure hundreds of megawatts, bearing diameters reach 0.8 m and more, and loads acting on bearings amount up to tens of tons. Taking into account the deformability of segments is one of the important issues in designing