Investigation of transportation infrastructure elements on the example of spherical bridge bearing

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Abstract. Transportation infrastructure consists mainly of critical elements. They are subjected to a large set of requirements for strength, rigidity, reliability. The article considered deformation behavior of spherical bridge bearing at different introduction depth parameters of sliding layer. The influence of contact surface treatment on the character of contact parameters distribution is studied. Earlier the polymers and composites behavior was viewed as an elastic-plastic material. However, for predicting their life-cycle it is necessary to consider them as viscoelastic. The article compared the parameters obtained by modeling elastic-plastic and viscoelastic materials behavior. The influence of sliding layer thickness on the deformation structure behavior was also discussed. It is revealed that sliding layer modeling as an elastic-plastic body is sufficient for numerical calculations on determination of strength characteristics. However, it is necessary to consider the sliding layer as a viscoelastic/viscous-elastic-plastic material to design the life cycle of the structure taking into account rheology, thermomechanics and cyclic loads in different directions.

1 Introduction

Polymeric and composite materials have found wide application as anti-friction coatings and sliding layers [1]. One such material is fluoroplastic. It is widely used in industry. However, the use of pure fluoroplastic has a number of disadvantages [2]. These include its deformation behavior under extreme working conditions and large temperature differences. Therefore, the most commonly used materials are its various modifications, such as radiation modified fluoroplastic [3], carbon fluoroplastic, composite materials [4] based on fluoroplastic with various bronze inclusions, polyether ether ketone, etc. [5] These materials have improved physical and mechanical properties, which in turn can increase the service life of mechanisms by reducing frictional interaction and deformation characteristics. Structures in which they are used are designed for a relatively long period of operation, such as bridge bearings, rolling bearings, rails, optical fibers, etc. Therefore, it is necessary to model the materials performance taking into account a large set of parameters and properties that influence the structure life cycle [6]. In particular, this paper examines the depth influence of the sliding

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layer implementation of different thicknesses in bridge bearings. Additionally, the article describes material rheology using Prony series. The modeling of the PTFE behavior in the viscoelasticity context is considered.

2 Materials and methods

The article considers two numerical models (Figure 1): a steel indenter and a half-sphere with antifriction sliding layer; numerical model based on spherical bridge bearing by "AlfaTech", Perm, Russia.

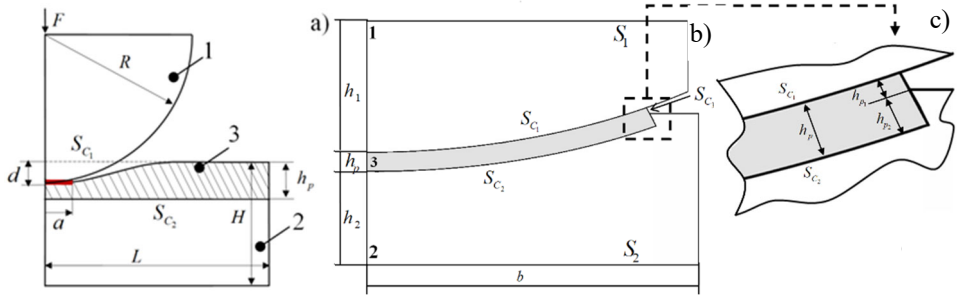

Fig. 1. Numerical scheme a) model task; Bridge bearing: b) design scheme; c) the design scheme fragment of the sliding layer.

The model problem of contact between a steel indenter and a half-space with antifriction sliding layer is discussed in the first approximation framework of viscoelastic material behavior modeling. Numerical model spherical bridge bearing is considered within the investigation framework of influence of sliding layer introduction in lower steel plate.

The main geometrical parameters of the model problem and spherical bearing were described earlier [7]. The mathematical formulation of the problem in the framework of the theory of elasticity and elastoplasticity is considered in [7], the viscoelastic formulation of the problem is formulated in [6]. The material properties have been obtained experimentally [6, 7], and the numerical identification procedure is based on the experimental data.

The standard thickness of sliding layer is 4 mm. The sliding layer embeds approximately ~ 50 % of its total thickness into the bottom steel plate. However, manufacturers are interested in research on the thickness effect of the sliding layer on the deformation structure behavior. In addition, analyzing the influence of the sliding layer depth into the bottom steel plate is a relevant issue for them (Figure 1b). In the third part of the study, the paper considers the effect of introducing sliding layer into the bottom steel plate. In the scope of this problem, a sliding layer from PTFE is considered. Article considers several variations in the sliding layer thickness and the ratio of its free and fixed edge ($\frac{h_{p_1}}{h_{p_2}}$). For a 6 mm thick layer, the $\frac{h_{p_1}}{h_{p_2}}$ varies 1/1, 1/2, 2/1; for an 8 mm thick layer, 1/1, 1/3, 3/1. Ratios of thicknesses at which $h_{p_1} = 2$: for 6 mm – 1/2; for 8 mm – 1/3.

3 Results

3.1 The influence investigation of introduction depth of sliding layer in lower steel plate

Polymer sliding layer behavior was obtained by modeling spherical bridge bearing with different ratios of thickness relative to free volume h_{p_1} of the sliding layer to the thickness

of the part of the sliding layer pressed into the lower steel plate. Figure 4 shows the distribution of contact pressure on the S_{C_1} surface along which the spherical segment can be rotated and displacement occurring on surface S_{C_3} in spherical bearing with layers of different thicknesses: 4 – 8 mm.

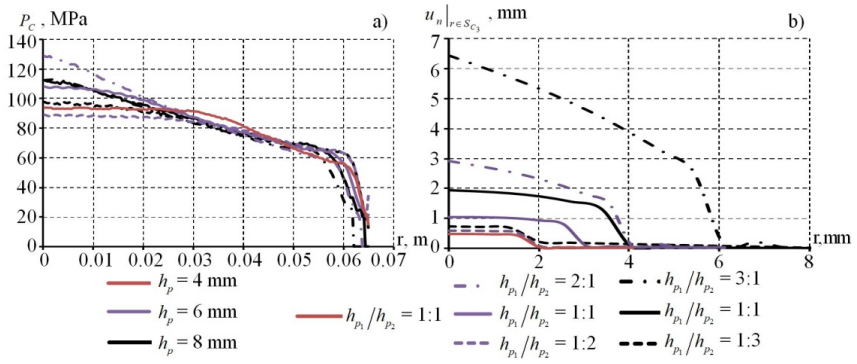

Fig. 2. Contact pressure (a) of surface S_{C_1} and displacement along the surface normal S_{C_3}.

The smallest values of the maximum contact parameters have a 6 mm thick interlayer with a thickness ratio $\frac{h_{p_1}}{h_{p_2}}$= 1:2. In general, it can be noted that the layers with all variants of the thicknesses considered and the free edge of the sliding layer end equal to 2 mm have similar contact pressure values.

However, it is important to note a couple of points. First, the 6 mm thick interlayers have a greater gap in the values of maximum contact parameters at different shoulder positions than the 8 mm thick sliding layer, which has generally similar results at a free edge of 4 and 6 mm.

Almost all of the considered models have the area of the contact pair in the "stick-slip" state. In this state it is very important to analyze the displacements of the surface of the S_{C_3}. Since large areas of contact surface divergence and shearing of the layer near the shoulder of the bottom steel plate can occur due to high displacements.

Thus, Figure 4b presents the displacements occurring on the relatively contact-free face surface of the sliding layer.

As one would expect, the maximum values of the displacement along the normal of the sliding layer face increase with increasing dimensions relative to the free surface by S_{C_3}. And the most unfavorable cases we observe at layers with the ratio of sides: $\frac{h_{p_1}}{h_{p_2}}$= 2:1 and $\frac{h_{p_1}}{h_{p_2}}$= 3:1 – for layers of 6 and 8 mm, respectively.

3.2 The influence investigation of material behaviour model on structure deformation parameters

The paper considers the choice influence of the material mathematical model, and the character of the contact surfaces interface on the polymer deformation behavior. Within the task framework the influence of the contact character between polymer sliding layer and target steel elements (half-space, bottom steel plate with spherical cutout (2) of sliding bearing) is investigated: ideal contact (node to node); full adhesion (tearing thread); frictional contact (friction coefficient μ = 0.04). In the contact zone of the spherical metal surface with the sliding layer, frictional contact is always realized.

As an example Figure 3 presents the distribution of contact pressure on the surface of the S_{C_1} for different material behavior models of the sliding layer (elastic, elastoplastic and viscoelastic) for the problem.

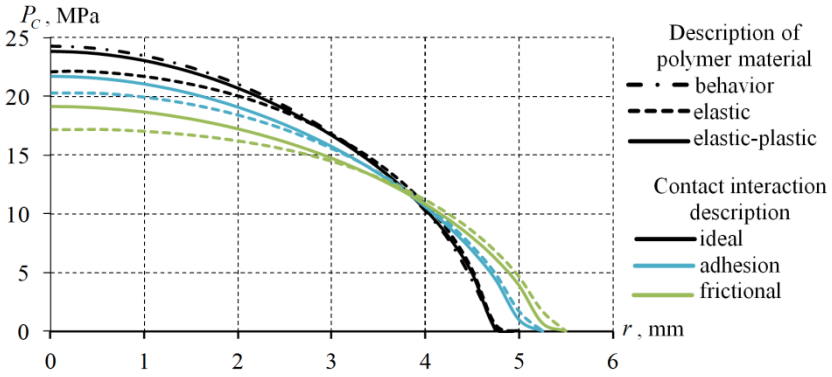

Fig. 3. Character of the contact pressure distribution of the sliding layer in the model task.

In general, the character of the contact pressure distribution is close to the canonical solution of the Hertz problem for the contact of a die with a half-space. The model of material behavior has an influence on quantitative indices. The elastic-plastic model of material behavior has a minimum level of , which may be due to modeling only the case of active loading without taking into account the material relaxation, which was observed in full-scale experiments. The nature of the interface between the interlayer and the target surface of the half-space also affects the maximum level of the parameter, especially the contact area size.

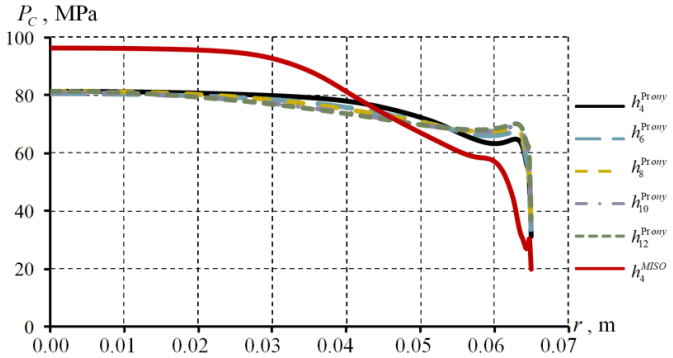

Fig. 4. Displacements along the face normal of the sliding layer.

It was previously found that the most negative effect on the contact parameters is caused by the displacements along the normal of the face normal of the sliding layer of a spherical bearing [6]. Therefore, Figure 4 presents the distribution of displacements along the face normal at a standard thickness of 4 mm for two polymer behavior models (elastic-plasticity, viscoelasticity).

Taking viscosity into account in the model of material behavior leads to a decrease in the maximum level of displacements along the normal of the sliding layer face by more than a factor of 2. This effect can be related to the relaxation of the material during iterative load application. It is observed that the material tends to flow out of the recess designed for the polymer sliding layer. It is required to analyze the influence of the nature of the interface of

the sliding layer with steel structural elements, as well as to take into account the time factor at a wide range of operating temperatures.

4 Conclusions

The influence of the thickness of the sliding layer and its position in the bottom steel plate has been investigated. It is revealed that for the interlayers of the considered thicknesses of 6 and 8 mm the most favorable case of deformation behavior of the spherical support part is observed at the aspect ratio: $\frac{h_{p_1}}{h_{p_2}}$= 2:1 and $\frac{h_{p_1}}{h_{p_2}}$= 3:1 – for both ratios the size of the free face from contact interaction is 2 mm.

The largest values of displacements along the face normal, top steel plate settlement, contact pressure and contact tangential stress are observed for interlayers with a pressed edge of the interlayer equal to 2 mm.

The comparative analysis of the materials behavior models of antifriction sliding layer in conditions of contact interaction on deformation of the sliding layer is conducted. The problem is considered on the test model, transition to the model of real design of spherical bearing is performed.

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