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FORECASTING THE CONDITION OF PETROLEUM IMPREGNATED LOAD-BEARING CONCRETE AND REINFORCED CONCRETE STRUCTURES

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ABSTRACT

Petroleum products (PP) used in industrial processes systematically fall on the load-bearing CRC structures and gradually impregnate therein. Currently, available guidelines for the assessment of technical condition and reliability of load-bearing CRC structures do not fully take into account the effect of viscosity of PP that impregnated therein. Our study was performed on the basis of analyzing, generalizing and evaluations of experimental data on the effect of PP of different viscosities on the physical and mechanical properties (PMP) of concrete using the methods of probability theory and mathematical statistics. The obtained results allow to constitute a scientifically substantiated forecast of changes in PMP of PP impregnated load-bearing CRC structures and to provide a quantitative characterization of their technical condition.

Keywords: viscosity, strain, endurance, fatigue.

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1. INTRODUCTION

Forecasting the condition of load-bearing structures of industrial buildings is one of the most important scientific and technical tasks to ensure their technical safety. It is particularly important for CRC structures of buildings of petroleum-refineries, machineries, power plants etc. where PP and petroleum contained liquids are used in technological processes. PP systematically fall on the load-bearing CRC structures and gradually impregnated therein. As a result of PP impregnation the original design characteristics of concrete is changed significantly, such as: the endurance at multiple repetitive loads is reduced, the strain properties are deteriorated.

Currently, there are some recommendations to assess the influence of PP on the strength and strain properties of concrete at the static load, as well as on its endurance at multiple repetitive loads. Analysis of the results of study of creep and shrinkage strains of concrete is presented in some publications [1-3]. However, the patterns of strain-changes in PP impregnated concrete are not presented in these publications. Results of the study of strain properties of concrete, impregnated by petroleum oil I-20, are presented by Vasiliev N.M. [4]. However, other PP also fall to the load-bearing structures of industrial buildings during the operation. To remedy this lack there was devoted a publication of Vorobiev A.A. and Sayd Mohammad [5, 6] which present the studies of the effect of petroleum oil I-30, furnace masout, diesel, lamp kerosene, petrol A-80 on the strain properties of concrete. It was shown that under the axial compression of concrete, impregnated by the said PP, the transversal strains are increased and the longitudinal are reduced compared to control samples. Permiakova V.V. et al. [7] and Yusupova Y.F. [8] focused on the fact that the waste and fresh engine oils do not effect identically on PMP of concrete. It is due to the different viscosity of fresh and waste petroleum oil.

The patterns of changes in strength and strain properties of CRC are shown in some publications [9-13]. It was revealed that the compressive strength and the deformability of PP impregnated concrete differ from the control samples due to the fact that PP transmit the thrust to the cement stone, which contributes to more intensive growth of strains. PP, which are located in the pores and microcracks, act as the incompressible liquids in the direction of load application. At the same time, the aggressive effect of PP reduces the resistance to axial compression by 17% for the usual concrete and by 11.8% – for high strength concrete [14].

PP, that impregnated in concrete, have the negative effect not only on its strain properties, but also on the endurance of structures at the multiple repetitive loads. The accumulated fatigue of concrete at the multiple repetitive loads can lead to the structural collapse, even at the low stresses. It is experimentally established that at the multiple repetitive loads microcracks are formed in concrete [15, 16]. Microcracks are formed at relatively low stresses long before the structural collapse. The subsequent loadings lead to the increase in sizes of the existing, and to the formation of new microcracks, accumulation of which leads to the fatigue cracks of structure. Experimental studies of endurance allow to assess the residual life and to forecast the development of fatigue cracks in concrete [17]. In the study of endurance of CRC structures of industrial buildings, the most effective way of analysis is the study of physical models [18]. In the physical modelling of material fatigue, instead of actual existing irregular and accidentally changing loadings, the cyclic loadings with constant amplitude are applied. Concrete without impregnation of PP at a level of 0.45 stresses can withstand 2-2.5 million load cycles, but impregnated by PP – 700 to 900 thousand cycles [10]. At the same time, there was a statistically significant difference in endurance indicators of concrete that impregnated by PP of different viscosity.

Analysis of information sources established that the endurance and strain properties of PP impregnated concrete is substantially different from the initial parameters of non-impregnated concrete. PP and petroleum contained liquids, that are used in industrial plants, have different viscosities and negative effect on the deformability and the endurance of CRC structures is not identical. Effect of PP on PMP of CRC is not studied in full measure in the presented works, and the available recommendations for their assessment do not take into account the viscosity of PP. It holds back the solution of tasks to ensure the technical safety of industrial buildings, where PP are used in industrial processes.

2. MATERIALS AND METHODS OF RESEARCH

Study was carried out on the basis of analyzing, generalizing and evaluations of experimental data on the effect of PP on PMP of concrete. Number of test samples with dimensions of 100x100x100 mm was determined in accordance with the plan of experiment: control samples

– 3 units; impregnated by PP – 5 units each. Samples were impregnated within five months by PP of various nominal viscosities: lamp kerosene (1.1 °E), diesel (1.3 °E), petroleum oil I-30 (15 °E), masout M-40 (26 °E). Nominal viscosity of the said PP was taken from the reference tables.

Experimental studies identified: the coefficient of transversal strain ($\nu = \varepsilon_{tr}/\varepsilon_{lo}$); the differential coefficient of transversal strain ($\Delta\nu = \Delta\varepsilon_{tr}/\Delta\varepsilon_{lo}$); the specific transversal strains ($\Delta\varepsilon_{tr}/\Delta P$ or $\Delta\varepsilon_{tr}/\Delta\sigma$); variation in the external volume of concrete sample ($\Theta = 2\varepsilon_{tr} - \varepsilon_{lo}$); and variation in the external volume at each step of loading ($\Delta\Theta=2\Delta\varepsilon_{tr} - \varepsilon_{lo}$).

For analysis, we have also taken the results of experimental studies of effect of various PP on the fatigue and strain properties of concrete performed by other authors [4-9].

Mathematical processing of the experimental data was carried out on the basis of probability theory and mathematical statistics. On the basis of rank analysis, we revealed the possibility of statistically significant comparison of the data of experimental studies which were obtained by the different researchers. Patterns of changes in the longitudinal and transversal strains were established using the regression analysis. The analyzed data was verified by the Spearman criterion of independence and Wilcoxon test of homogeneity in ensuring of $\alpha \approx 0.95$.

3. RESULTS AND DISCUSSION

Effect of various PP on PMP of CRC is not identical due to their different viscosity. Viscosity of PP significantly depends on the content of resins and additives that determine the qualitative characteristics of oils and coolants used in the industry. An important factor that effects PMP of concrete is the viscosity of PP that are impregnated in it. Figure 1 shows the diagrams of changes in strains of concrete samples that are impregnated by various PP.

Analysis of the diagrams shows that PP, that are impregnated in concrete, have a significant effect on its strain properties. At the axial compression with an increasing stress the transversal and longitudinal strains are increased in both – control samples and PP impregnated samples.

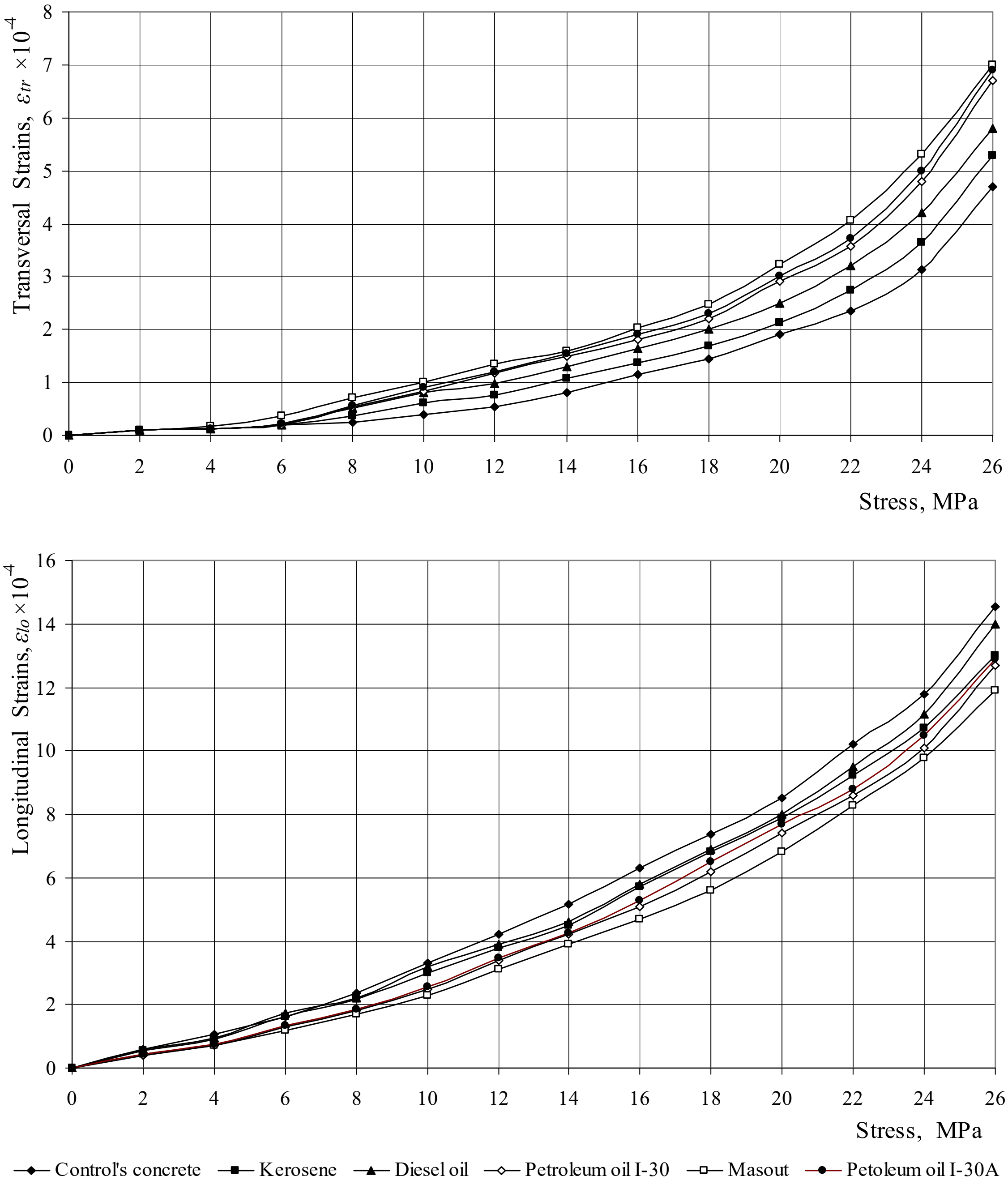

Fig.1. Changes in transversal and longitudinal strains of concrete impregnated by various petroleum products

It is established that at the stress of 0.3 R_c in concrete samples, which are impregnated by petroleum oil I-30, some characteristics are greater than in non-impregnated concrete. Such as, the elastic modulus is by an average of 21%; the transversal strain coefficient is by an average of 72%; the differential coefficient of transversal strain is by an average of 57%; the specific transversal strain is by an average of 78%.

It is revealed that at a same stress in concrete samples, impregnated by petroleum oil I-30, the volumetric deformation and the changes in volume at each level of loading are lower by 58% and 32% respectively in comparison with the non-impregnated concrete.

Transversal strains are formed due to the fact that PP (as the incompressible liquids), which are located in concrete pores, transmit the perceived pressure in all directions. Pressure creates the thrust that leads to the destruction of skeleton of cement stone in transversal direction. Growth of the deformations in concrete samples, impregnated by PP of greater viscosities, is due to the higher speeds of their movement in concrete pores and the higher speeds of energy transmission to the skeleton of cement stone.

Longitudinal strains of concrete under the axial compression are caused by the fact that PP, as the incompressible liquids in the pores, together with the skeleton of concrete, perceive part of the loads on itself and restrain the formation of strains in the longitudinal direction.

On the basis of experimental data, the empirical mathematical models of changes in transversal and longitudinal strains depending on the relative level of stresses and the relative viscosity of PP are developed. Regression models of strain changes in concrete impregnated by PP under axial static loading have the following forms:

a) for transversal strains:

$$\lg \varepsilon_{tr}^{im} = \frac{\sigma_{re} - 2.732 + 0.094 \lg V_n}{0.576} \quad (1)$$

b) for longitudinal strains:

$$\lg \varepsilon_{lo}^{im} = \frac{\lg \sigma_{re} + 0.276 (V_n)^{-0.015}}{5.988 (V_n)^{-0.0125}} \quad (2)$$

where σ_{re} – relative level of static stress, proportion of unit; ε_{tr}^{im}, ε_{lo}^{im} – relative transversal and longitudinal strains, proportion of unit; V_n – nominal viscosity of PP, Engler-degree (°E).

Analysis of calculation results by (1) and (2) and their comparison with the experimental data show that the developed empirical formulas with an accuracy of ±3-4% and the determination coefficient of $R_{tr}^2 = 0.947$ and $R_{lo}^2 = 0.963$ can simulate the changes in transversal and longitudinal strains of concrete respectively, that are impregnated by various PP, at the axial static compression.

The specified changes of properties of CRC structures are advisable to consider in the design of load-bearing elements of industrial buildings, where PP are used in the technological processes, to prevent the premature and the unexpected collapses, as well as to prevent the occurrence of emergency situations.

The index assessment of strain safety of PP impregnated concrete under the axial static load can be performed by the formulas:

a) for transversal strains:

$$\beta_{tr} = 1 - \frac{\varepsilon_{tr}^{o} - \varepsilon_{tr}^{im}}{\varepsilon_{tr}^{o}} \tag{3}$$

b) for longitudinal strains:

$$\beta_{lo} = 1 - \frac{\varepsilon_{lo}^{o} - \varepsilon_{lo}^{im}}{\varepsilon_{lo}^{o}} \tag{4}$$

where ε_{tr}^{o}, ε_{lo}^{o} – allowable relative transversal and longitudinal strains.

The proposed safety indexes can be considered as the criteria of reliability of PP impregnated load-bearing CRC structures of industrial buildings.

One of the most important factors in the technical safety of industrial buildings is the endurance of load-bearing structures that lies in their ability to withstand the multiple repetitive loads that cause the fatigue of material. Our study showed that the endurance of PP impregnated concrete is significantly lower in comparison with the control samples.

Decrease of the load-bearing capacity or even the collapse of structure by the reason of material fatigue takes place due to the accumulation of strains that caused by the frequently changing load, and may occurs even at the low stresses. At the multiple application of loading in concrete the viscous binders between the structural elements are violated. It leads to the formation of microcracks with different depth and width. After the removal of load, the indicated binders are not restored but the cracks continue to exist. PP, which are impregnated in concrete, enter into the microcracks from the pores and fill them. During the multiple repetitive loadings, the new microcracks are formed and the existing are increased in size. In this case, PP filled the formed microcracks, transmit the load not only in the direction of its impact, but also in all directions, thereby contribute to increase the degree of damages. Under the influence of PP in reinforced concrete elements a violation of adhesion of cement stone to the steel rod takes place. It leads to the decrease in fatigue resistance of PP impregnated CRC. With the increase of nominal viscosity of PP, the endurance index of concrete decreases.

In the operation of industrial buildings, the multiple repetitive and variable loadings hold the incidental and non-stationary nature. It greatly complicates the mathematical description of the process of their effects on the structure. It is also known that in a relatively short period, the load, that precedes to collapse, is typically cyclic with a constant amplitude, which allows to use the simple methods of mathematical description with a sufficient accuracy for practical purposes of the obtained results. With this assumption the accumulation of fatigue, that caused by the variable loading, can be considered as a stationary process. In these circumstances the forecast of structural behavior and the index assessment of its fatigue can be carried out on the basis of assumption of linear law of damage accumulation in structures at the fatigue of materials.

Forecasting the changes in technical condition of PP impregnated CRC structures are related to the estimation of reserve between the exposure and the load-bearing capacity of the studied elements. In construction practice, it is advisable to consider the fatigue index as a measure of reliability, even if there is a possibility to calculate the probability of failure. Endurance assessment of concrete elements of the load-bearing structures, which are influenced by PP, is advisable to perform by the fatigue index, which is determined by the formula:

$$\beta = 1 - \frac{\eta_{cn} - \eta_{cf}}{\eta_{cn}} \quad (5)$$

where η_{cn} – design level of endurance of concrete without the influence of PP; η_{cf} – relative endurance limit of concrete.

Design level of endurance of concrete can be determined by the formula:

$$\eta_{cn} = \frac{\sigma_{c\,max}}{R_{cn}} \quad (6)$$

here $\sigma_{c,max}$ – maximum normal stress in the compressed concrete; R_{cn} – design strength of concrete to the axial compression.

Relative endurance limit (of fatigue strength) can be determined by the empirical formula, which with the determination coefficient of $R_{cf}^2 = 0.86$ models the link of endurance of concrete with an appropriate compressive strength class with the number of cycles of multiple repetitive loadings and the nominal viscosity of PP. Relative endurance limit depends on the number of cycles (*N*), that sustained until the collapse, and the viscosity of PP that impregnated, and can be determined by the formula:

$$\eta_{cf} = 1.237 - 0.08 \lg V_n - 0.173 \lg N \quad (7)$$

where V_n – nominal viscosity of PP, Engler-degree (°E); N – number of loading cycles that sustained until the collapse.

Fatigue index of CRC elements, which are influenced by PP, is a measure of reliability of load-bearing structures of industrial buildings and allows to provide an objective assessment of their technical condition, and allows to forecast the threat of emergency situation in the industrial building due to the decrease of load-bearing capacity of PP impregnated CRC elements.

4. CONCLUSIONS

On the basis of experimental data, we developed the empirical mathematical models of changes in:

a) transversal and longitudinal strains depending on the viscosity of impregnated PP, concrete grade and axial load; the mentioned models allow to assess the changes in transversal and longitudinal strains of PP impregnated concrete with the accuracy of ±3-4% and the determination coefficient of $R_{tr}^2 = 0.947$ and $R_{lo}^2 = 0.963$ respectively;

b) endurance of concrete depending on the viscosity of impregnated PP, concrete grade and magnitude of multiple repetitive loading; the proposed empirical model allows to calculate the magnitude of relative endurance limit of PP impregnated concrete with the determination coefficient of $R_{cf}^2 = 0.86$.

The performed theoretical and experimental study significantly expanded the information on the influence of PP and their viscosities on PMP of CRC, and also the methodical approaches to the quantitative assessment of technical condition of PP impregnated CRC structures of industrial buildings are proposed.

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