Theoretical Study of the Conditions of Combined Action of Materials of Old and New Concrete in the Repair and Restoration of the Structures of Transport Facilities

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Abstract

When carrying out repair work on the restoration of reinforced concrete structures of transport facilities, the technical requirements for repair compounds are determined by a number of factors, namely: adhesion and chemical compatibility of materials, compatibility with linear expansion coefficient, technology repair, cost of material, etc. Very often, the combined action of the materials of the old and the new concrete is not considered at all, although the durability and quality of the repair work depends on it.
Estimation of factors that influence on structural compatibility of old and new concrete is performed in this paper. Attempt of review and choice of tools of finite element analysis with the help of which may be modeled combined action of multiplayer concrete designs is also performed.
KEY WORDS: *compatibility, combined action, repair of concrete structures, stress, shear, method of finite-element analysis, mathematical modeling*

1. Introduction

Analysis of existing technologies for repair and restoration of reinforced concrete structures showed that, despite the many years of experience in the use of reinforced concrete in construction, the issue of repair of structures made of concrete and reinforced concrete remains open and insufficiently researched. It should be noted that, as a rule, decision-making on repairs, restoration and replacement of structures is mainly carried out on the basis of inspection of structures. Such expertise in most cases results in adoption of unreasonable solutions to replace defective structures with the new ones. This leads to increased cost of repair and restoration work.

The experience in construction of heavy-duty concrete structures has raised a number of problems that resulted in involvement of modern information technologies. The conducted researches with the use of the latest information technologies and in particular mathematical modeling led to the development of a complex system for rehabilitation of reinforced concrete structures. The block diagram of the developed system is presented in Fig. 1.

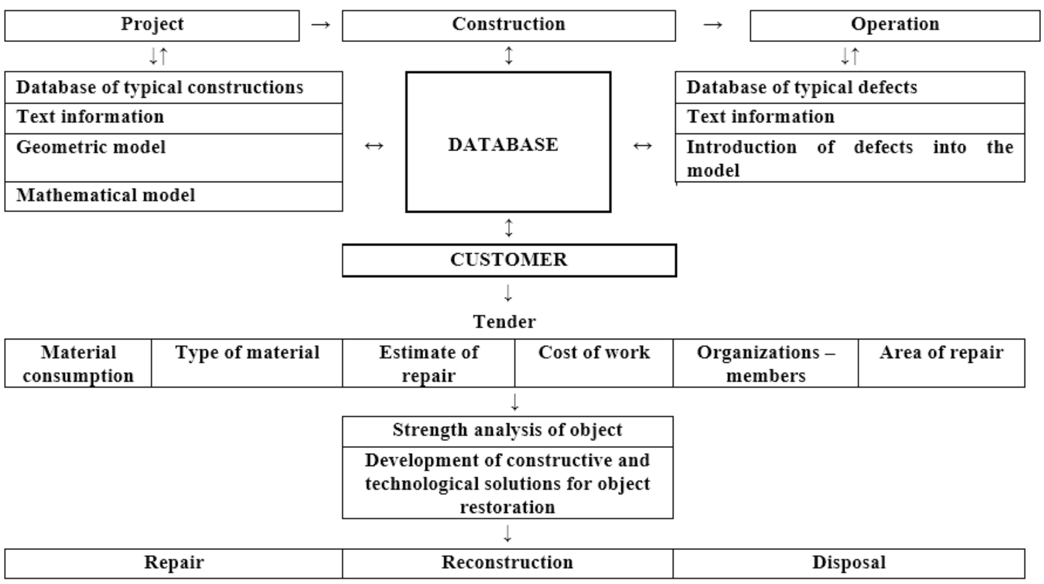


Fig. 1 Block diagram of the complex system for rehabilitation of reinforced concrete structures

The efficiency of the proposed system depends essentially on filling the database of man-made structures. At present, the customers of the restoration of man-made structures do not understand the importance and necessity of creating mathematical models of structures that can have a significant economic effect at all stages of the structure operation.

The development of the system is associated with the creation of mathematical models of both typical and original designs of man-made structures and the account of defects in structures during the analysis of the bearing capacity of the investigated structure.

As a result of the research, practical data on the implementation of both individual units and the entire system are obtained. When designing and refining mathematical models of a number of structures, the structure design errors were identified due to the imperfection and limitations of existing methods for calculating the structural strength. It is also necessary to mention the lack of a regulatory framework for the repair of reinforced concrete structures with the use of modern materials and technologies.

At the next stage, the system involves the completion of various constructional and technological solutions for repairs and the use of modern repair materials based on the results of computational experiments on the developed models. Another important task during the repair work on the restoration of reinforced concrete structures is the definition of technical requirements for repair compositions and the creation of the model that will reflect the combined action of the repair material and the existing structure.

2. Research

When carrying out repair work on the restoration of reinforced concrete structures, the technical requirements for repair compositions are determined by a number of factors, namely: adhesion and chemical compatibility of materials, compatibility by the thermal linear expansion coefficient, technology of repair, cost of materials, etc. [1-3]. Very often the combined action of materials of old and new concrete during repair and restoration is not considered at all [4, 5]. Under the combined action we mean the compatibility of materials by such a parameter as mechanical strength.

For the research, a mathematical model was developed. The design scheme for testing a laboratory sample to study the combined action of materials of old and new concrete is presented in Fig. 2.

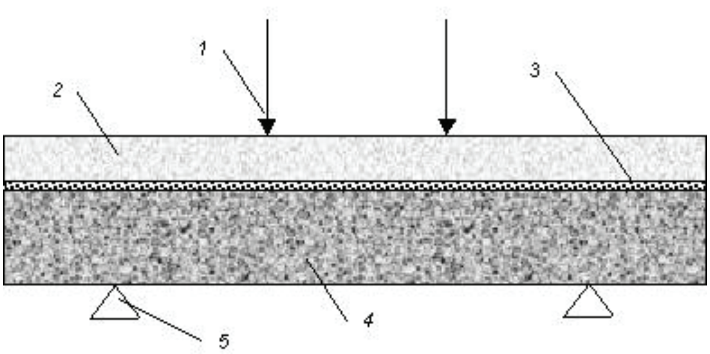


Fig. 2 Design scheme for testing a laboratory sample: *1* – loading; *2* – new concrete; *3* – contact layer; *4* – old concrete; *5* – support conditions

The geometric and finite element models of the sample are developed in the finite element program pre-processor. Fig. 2 shows the finite-element model of a two-layer sample.

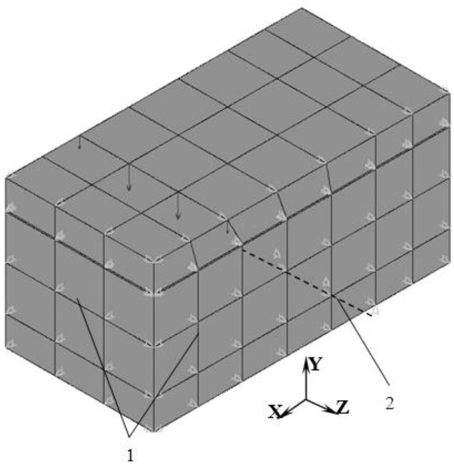


Fig. 3 Finite element model with loads and boundary conditions: *1* – symmetric boundary conditions; *2* – support condition

The boundary conditions are taken in the form of negation along the line (indicated by a dotted line) of the displacements along the Y axis and the symmetry conditions on the axes X and Z, respectively, as shown in Fig. 3.

The first stage of the study provided the choice of the method for modeling the conditions of interaction of the old and new concrete layers when adding the load. A comparative analysis of various conditions for the interaction of the new and old concrete layers was carried out using a computational experiment.

To simulate the conditions of interactions of the old and new concrete layers we tested a linking element. The linking element combines in parallel the properties of the elastic shear, damping and the series-connected gap. The mass may be associated with one or both central nodal points. The element has one degree of freedom in each node or a central shear, rotation, pressure and temperature. The mass, elasticity, shear, damper and / or clearance can be removed from the element. The linking element is shown in Fig. 4.

The element is determined by two nodes, two elastic constants *K*1 and *K*2 (N/m), damping coefficient *C* (N×c/m), mass *M* (N×c^2/m), gap size *GAP* (m or radian) and friction force (slide restriction) *FSLIDE (N).*

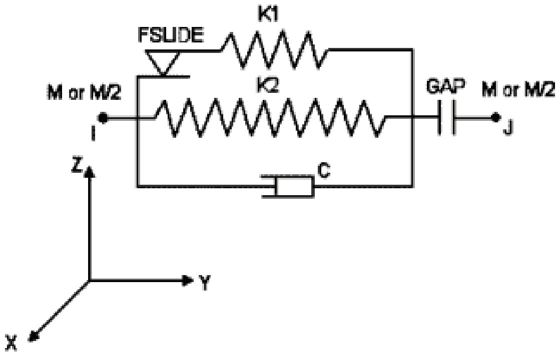


Fig. 4 Linking element

To analyze the conditions of contact interaction of layers of the two-layer concrete sample, we used the surface-to-surface contact elements. The analysis of the stress-strain state of the two-layer samples from materials of new and old concrete was carried out. We studied the conditions of combined action of materials with setting of the contact interaction conditions and the linking elements in the contact layer. The Figs. 5 and 6 present the analysis results. The dotted line represents the initial state of the unloaded sample. The displacements are increased by 2000 times for illustration purposes. The displacements normal to the contact surface for the condition of the contact interaction are equal to:

– maximum: $-0{,}431\cdot10^{-5}$ m;
– minimum: $0{,}166\cdot10^{-5}$ m;

and for linking elements:

– maximum: $-0{,}434\cdot10^{-5}$ m;
– minimum: $0{,}165\cdot10^{-5}$ m.

Normal stresses for the condition of contact interaction are:

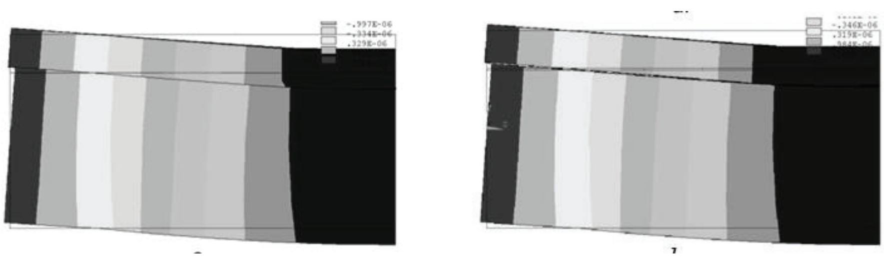
– maximum compression: $-0{,}165\cdot10^{7}$ Pa;
– maximum tension: 398792 Pa;

and for linking elements:

– maximum compression: $-0{,}165\cdot10^{7}$ Pa;
– maximum tension: 365427 Pa.

The comparative analysis of the stress-strain state of the two-layer samples showed both qualitative and quantitative convergence of the calculation results when setting the conditions of contact interaction (with friction coefficient equal to zero) and interaction of the layers through the linking element.

To simulate different conditions of the shear strength of the contact layer of the two-layer sample, the conditions for contact interaction between the layers were set with different values of the friction coefficient (μu = 0; 0,3; 0,7).



a b

Fig. 5 Field of displacements (m), normal to the contact surface: a - conditions of contact interaction; b - linking elements

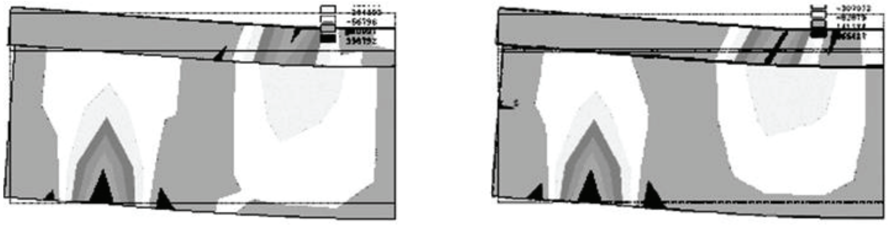


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Fig. 6 Field of normal stresses (Pa): a - conditions of contact interaction; b - linking elements

Table 1 shows the numerical values of the combined action parameters: displacements normal to the contact surface, stresses and intensity of stresses, both in the entire sample, and in its individual layers.

Table 1

Numerical values of combined action parameters

Index			Friction coefficient μu		
Normal displacements, m	Max		0	0,3	0,7
			$0,166 \cdot 10^{-5}$	$0,151 \cdot 10^{-5}$	$0,131 \cdot 10^{-5}$
	Min		$-0,431 \cdot 10^{-5}$	$-0,390 \cdot 10^{-5}$	$0,334 \cdot 10^{-5}$
Normal stresses, MPa	Compression		$-0,165 \cdot 10^{7}$	$-0,160 \cdot 10^{7}$	$-0,156 \cdot 10^{7}$
	Tension	Entire sample	398792		374952
		Bottom layer	264173	251380	235171
Intensity of stresses, MPa	Contact layer		-	$0,208 \cdot 10^{7}$	$0,197 \cdot 10^{7}$
	Bottom layer		$0,293 \cdot 10^{7}$	$0,265 \cdot 10^{7}$	$0,227 \cdot 10^{7}$

Fig. 7 shows a qualitative change in the field of the intensity of stresses, depending on the coefficient of friction between the layers.

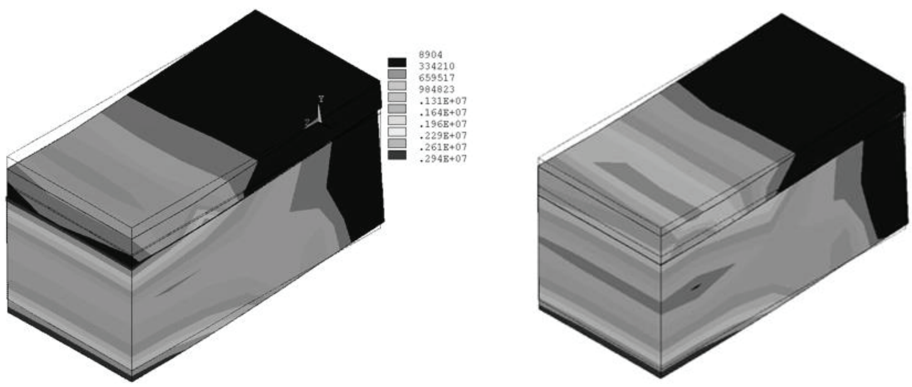

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Fig. 7 Field of intensity of stresses (Pa): a - $\mu u = 0$; b - $\mu u = 0.7$

The shear strength is one of the most important parameters that determines the combined action of the repair composition and the repaired surface. One of the options for an adequate modeling of this parameter is the task of friction coefficient.

For the purpose of conducting a comparative analysis of the stress state of the two-layer samples under different conditions of contact interaction modeling and the accounting of multimodal materials, we studied the conditions for combined action of multimodal materials under different conditions of contact modeling. Modulus of elasticity: of the top layer – $2 \cdot 10^{10}$ Pa, of the bottom layer – $2 \cdot 10^{10}$ Pa. Fig. 8 shows the analysis results. The displacements are increased by 2000 times for illustration purposes.

The displacements normal to the contact surface for the option with the contact layer setting are as follows:

– maximum: $0,144 \cdot 10^{-5}$ m;
– minimum: $-0,487 \cdot 10^{-5}$ m;

for the condition of contact interaction:

– maximum: $0,718 \cdot 10^{-5}$ m;
– minimum: $-585 \cdot 10^{-5}$ m;

and for the option with linking elements:

- maximum: 0,167·10^{-5} m;
- minimum: -587·10^{-5} m.

Modification of the modulus of elasticity of the repair layer under different conditions of contact interaction of materials leads to significantly different results of the combined action of these materials [6, 7].

To adequately model the conditions for contact interaction of multilayered concrete samples using the finite element method, it is necessary to use an element that would work well for compression and shear and, moreover, would allow to model the bond gap between the nodes it connects (that is, between the layers) when it reaches the overstresses. The condition of the contact interaction between the concrete layers allows to adequately model the compression and shear strength (by setting the friction coefficient), but does not allow to model the separation / detachment, since it does not provide any connections between the surfaces of the contact. The linking element, in its turn, works only in one direction (does not work in shear) and as the studies showed (comparison with the contact task), it works adequately. The linking element allows modeling the bond gap when reaching a certain stress level. Thus, neither the contact element nor the linking element fully satisfies our requirements for solving the set task. One of the solutions to this problem is to modify the most similar element or to develop a new element with given characteristics based on existing ones. When determining the strength properties of the repair composition, it is also necessary to take into account the sign and the amount of deformation to the surface under repair (which in most cases is not performed to date), which in turn depends on the geometry and the magnitude of the loads acting thereon.

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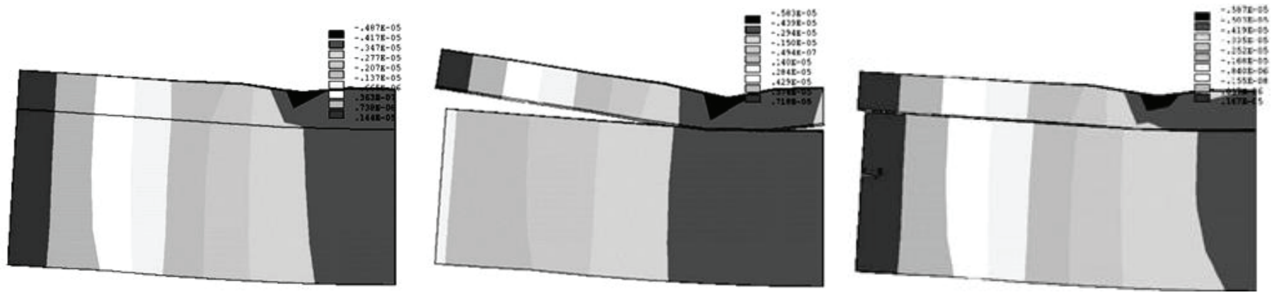

a b c

Fig. 8 Field of displacements (m) normal to the contact surface: a - set contact layer; b - set condition of contact interaction; c - set linking elements

One of the solutions to this problem is to modify the most similar element or to develop a new element with given characteristics based on existing ones. When determining the strength properties of the repair composition, it is also necessary to take into account the sign and the amount of surface deformation of the structure under repair (which in most cases is not performed to date), which in turn depends on the geometry and the magnitude of the loads acting thereon.

3. Conclusions

The conducted researches with the use of the latest information technologies, in particular mathematical modeling, led to the development of a complex system for rehabilitation of reinforced concrete man-made structures.

The main task of the developed system is to ensure the objectivity and efficiency of decision-making for repair and reconstruction of reinforced concrete structures. For this purpose, based on the created and corrected models, it is proposed to carry out in the first stage a refined assessment of the residual bearing capacity of defective structures and the identification of the most dangerous zones of structures requiring special control.

The application of the proposed system and the methodology for modeling the interaction of the repair layer with the construction in the practice of repair and restoration of reinforced concrete structures can significantly reduce the cost of repairs due to rational choice of materials and effective technological solutions [4-6]. The use of such a system in leading organizations controlling a large number of facilities will increase the efficiency and reduce the cost of repair and maintenance works on man-made structures during their maintenance.

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