DETERMINATION OF BEARING CAPACITY AND CALCULATION OF THE GAIN OF THE DAMAGED SPAN OF A RAILWAY OVERPASS BY THE FINITE ELEMENT METHOD

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Abstract

The subject of the study the possibility of applying the finite element method to determine the bearing capacity of a damaged reinforced concrete structure and the subsequent selection of its reinforcement parameters with composite materials.

Research methodology – the studying of finite element models of the serviceable destroyed and restored structure and determination of design parameters of the structure before destruction, after the destruction, and after its strengthening.

The goal – identification of the possibility of further operation of the damaged structure using the finite element method, finding the most dangerous places in the construction, selection of parameters for its amplification.

Conclusion of the study. The proposed research method made it possible to more accurately and at a lower cost, identify the most dangerous areas in the damaged structure, and verify the effectiveness of the applied method of its restoration. The method showed high efficiency in assessing the bearing capacity of a structure with complex reinforcement in which part of the reinforcement is in a destroyed state.

1. Introduction

The need to restore the bearing capacity of reinforced concrete structures arises, usually in two cases. The first is due to the reconstruction of buildings and structures and the associated increase in the intensity of the operational load. The second case is due to the restoration of the bearing capacity lost during operation due to corrosion, mechanical damage, manufacturing, or installation defects.

One of the innovative ways to restore the load-bearing capacity of reinforced concrete structures is the method of constructing a reinforcing system made of composite materials [1-4]. This method successfully used throughout the world and is gaining great popularity in Ukraine.

Based on carbon fiber, composite materials usually used as an external reinforcement system in the construction industry for reinforcing the load-bearing construction structures of buildings and structures. The advantage of carbon composite materials is their manufacturability, low weight, relatively high strength, resistance to aggressive external factors, minimal material size, minimum requirements for installation work, high installation speed.

The main elements of the external reinforcement system of flexible reinforced concrete structures are fabrics and lamellas of various grades. They are gluing to the surface of building structures in a polymer matrix, which provides tight adhesion of the reinforcing filler to the reinforced structure. The most common reinforcement method is carbon lamellas. The article considers the calculation of the bearing capacity and reinforcement of a damaged reinforced concrete structure using the finite element method in the ANSYS software package.

2. Object of study

The strengthening calculation was made for the railway bridge overpass Zaporizhia Ferroalloy Plant. The three-span beam overpass has a longitudinal scheme -16.5 +13.5 +16.5 m. The angle of intersection of the overpass with the street - 39° (Fig. 1).

Fig. 1. General view of the overpass

Spans consist of two monolithic main reinforced concrete beams, which are connected by a slab and diaphragms. Longitudinal working reinforcement of class A-II ☛28 mm, located in 4 rows in height (9 rods in one row). Part of the rods does not reach the support and diverted into the compressed zone of concrete (Fig. 2).

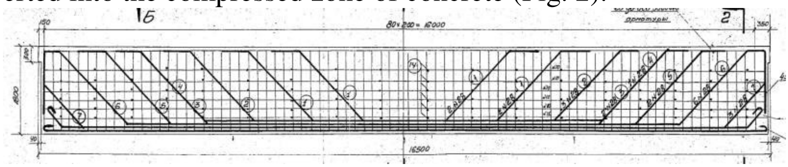

Fig. 2 Span beam reinforcement

Long consoles on which a railing installed arranged to create a ballast trough. The design load on the span construction — H 7.

The examination found that one of the spans, located on the side of the ferroalloy plant, has defects in the form of destruction of concrete in the stretched zone and destruction of part of the rods of the working reinforcement. In one rib, the torn two lower rows of reinforcement. The concrete strength of monolithic beams and diaphragms was determined using an ADA Schmidt Hammer 225 sclerometer and is in the range of 25.8-26.8 MPa, which is higher than the design grade of concrete - M250, except for damaged places where the average concrete strength was 18.8 MPa.

Damage (Fig. 3) occurred as a result of the transverse impacts of freight road transport on the lower edge of the beams due to a decrease in the size of the roadway. The reason for the decrease in size is an increase in the height of the carriageway during the repair of road works.

To checking the load-bearing capacity of the beam, 3D models were created in the ANSYS software package that takes into account the geometry of the structure before (Fig. 4) and after its damage (Fig. 5). The load C14 applied to the model following DBN B.1.2-15: 2009 [5] and DBN B.2.3-14: 2006 [6].

In the computational finite element model for numerical analysis, the symmetry of the computational domain taken into account. When creating the calculated finite element (FEM) model, the elements were used: for concrete (B35) - SOLID186, for reinforcement (A-300 steel) - REINF264. When generating a mesh of the reinforcement, the MESH200 element used.

Fig. 3. Damaged span beams

Solid186 - is a higher-order 3-D 20-node solid element that exhibits quadratic displacement behavior. The element defined by 20 nodes having three degrees of freedom per node: translations in the nodal x,y, and z directions. The element supports plasticity, hyperelasticity, creep, stress stiffening, large deflection, and large strain capabilities [7].

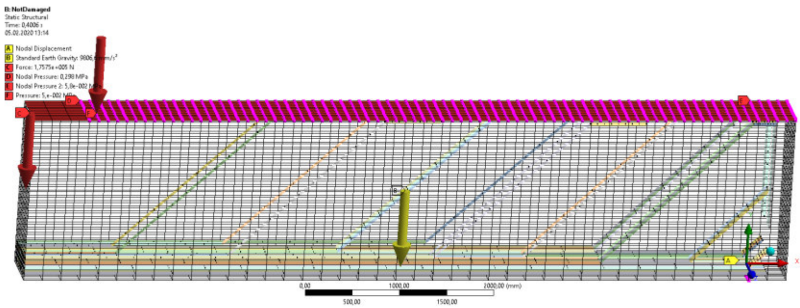

Fig. 4. FEM beam model before damage

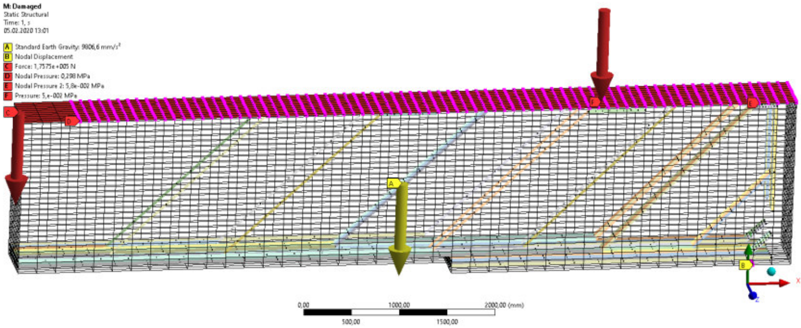

Fig. 5. FEM beam model after damage

Reinf264 used in the analysis of structural reinforcement of 3D beams, shells, and solid elements. The element is suitable for modeling reinforcing fibers with arbitrary orientation. Each fiber is modeled separately as an element that has only uniaxial rigidity. REINF264 has plasticity, stress stiffening, creep, large deflection, and large strain capabilities.

The characteristics of the materials used in the calculations shown in table 1.

Table 1

Structural characteristics of the materials used in the calculations

№	Parameter	Value
	Concrete	
1	Young's Modulus	22360 MPa
	Poisson's Ratio	0,18000
	Bulk Modulus	11646 MPa
	Shear Modulus	9474,6 MPa
	Compressive Ultimate Strength	41,000 MP
	Tensile Ultimate Strength	5,0000 MPa
	Structural Steel	
	Young's Modulus	2e+05 MPa
	Poisson's Ratio	0,30000
	Bulk Modulus	1,6667e+05 MPa
	Shear Modulus	76923 MPa
	Compressive Ultimate Strength	0 MPa
	Compressive Yield Strength	250,00 MPa
	Tensile Ultimate Strength	490,00 MPa
	Tensile Yield Strength	295,00 MPa
	Carbon fabric-tape-1000-12K-420.Ct-11083	
	Young's Modulus X direction	1,21E+05 MPa

	Young's Modulus Y direction	8600 MPa
	Young's Modulus Z direction	8600 MPa
	Poisson's Ratio XY	0,27
	Poisson's Ratio YZ	0,4
	Poisson's Ratio XZ	0,27
	Shear Modulus XY	4700 MPa
	Shear Modulus YZ	3100 MPa
	Shear Modulus XZ	4700 MPa
	Orthotropic Stress Limits	
	Tensile X direction	2231 MPa
	Tensile Y direction	29 MPa
	Tensile Z direction	29 MPa
	Compressive X direction	-1082 MPa
	Compressive Y direction	-100 MPa
	Compressive Z direction	-100 MPa
	Shear XY	60 MPa
	Shear YZ	32 MPa
	Shear XZ	60 MPa

3. Results of the research

As a result of the calculations, data obtained on the stress and strain states of concrete and beam reinforcement before and after damage (Fig 6 -15).

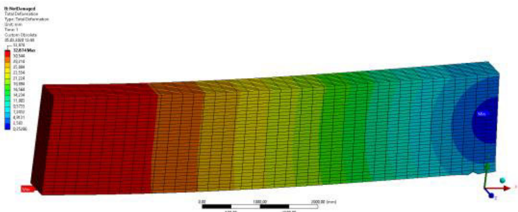

Fig. 6. Estimated beam deformation before damage

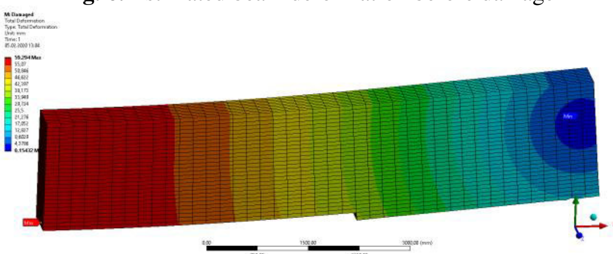

Fig. 7. Estimated deformation of a damaged beam

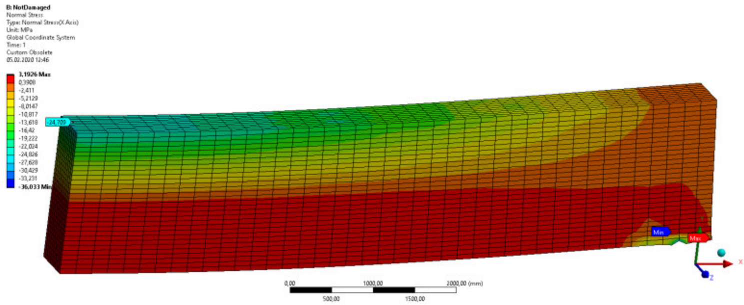

Fig. 8. Normal Stress distribution in the concrete of the beam before damage

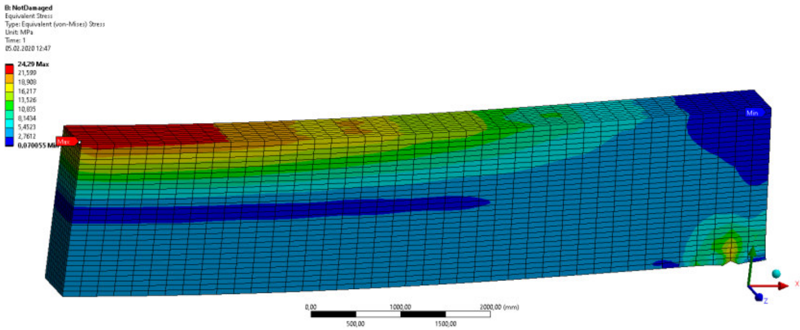

Fig. 9. Equivalent Stress distribution in the concrete of the beam before damage

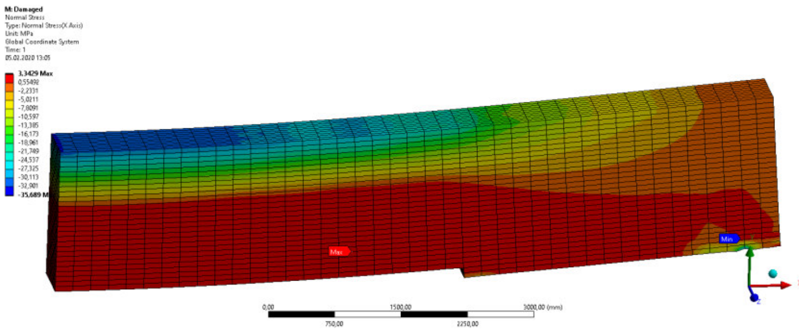

Fig. 10. Normal Stress distribution in the concrete of a beam after damage

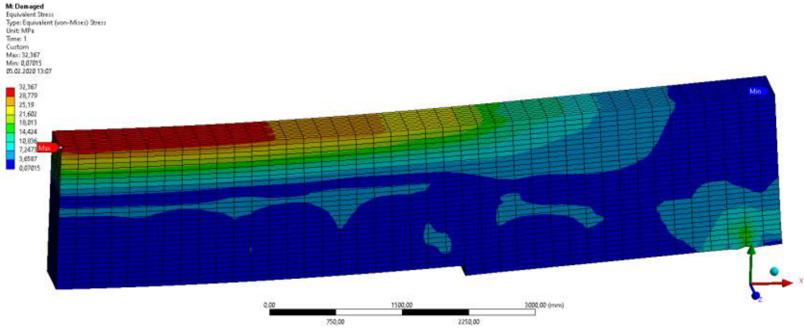

Fig. 11. Equivalent Stress distribution in the concrete of a beam after damage

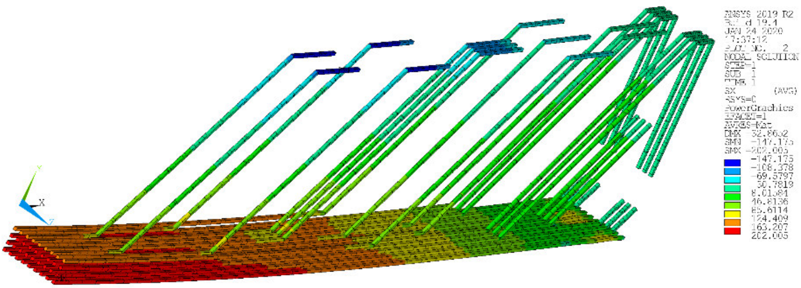

Fig. 12. Distribution of Normal Stresses in the beam reinforcement before damage

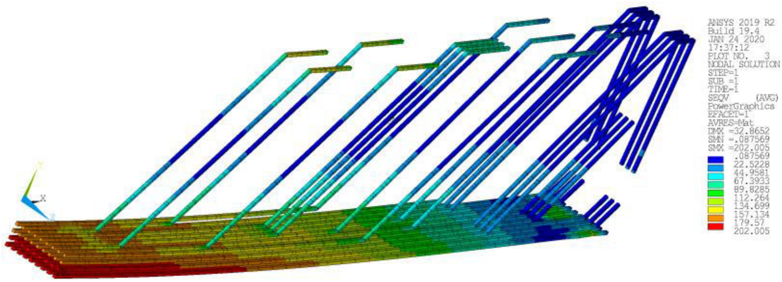

Fig. 13. Distribution of Equivalent Stresses in the beam reinforcement before damage

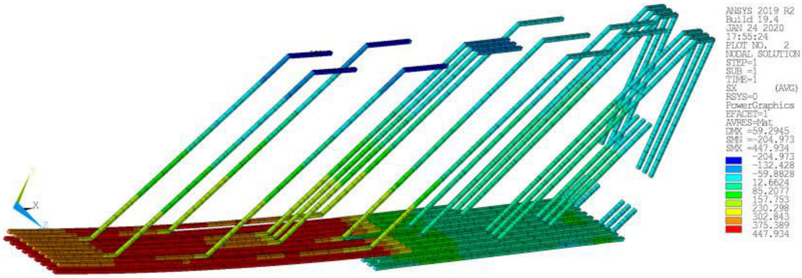

Fig. 14. Distribution of Normal Stresses in the beam reinforcement after damage

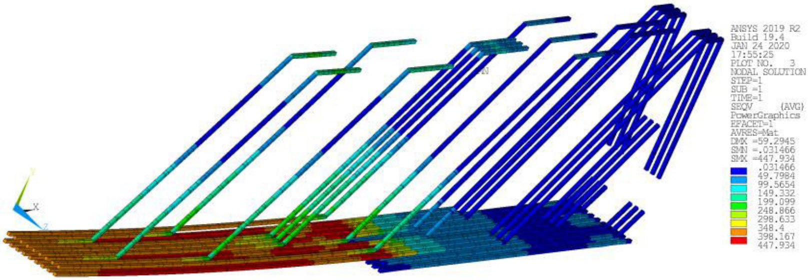

Fig. 15. Distribution of Equivalent Stresses in the beam reinforcement after damage

The maximum values of the data shown in table 2.

Table 2

Maximum deformations and stresses in the structure before and after damage

Maximum parameter value	Before damage	After damage	Δ, %
Beam deflection	32.87	59.29	59.1
Normal stress in concrete			
tension	3.2	3.3	0.3
compression	24.3	32.37	33.2
The normal stresses in the reinforcement	202.00	447.93	217.5

Although stresses in reinforcement after damage increased by almost two times, the static load-bearing capacity of the beam remains sufficient. However, the deflection of the damaged beam does exceed the permissible values.

To preventing further destruction of the beam to ensuring its bearing capacity and to preventing's corrosion of the reinforcement, additional reinforcement was developed by gluing a unidirectional carbon fiber Carbon fabric-tape-1000-12K-420.Ct-11083 onto the lower belt of the beam. The concrete coating restored in the zone of damage to the lower belt before gluing the CFRP. The structural characteristics of carbon fiber given in table 1 and figure 16.

The adhesive bonding of concrete and carbon fiber is modeled by Cohesive Zone Material (CZM) using Separation-Distance based Debonding. Contact algorithm: Penalty method. Contact detection at the Gauss integration point. The system generated elements SURF154 and SURF156 to implement the model.

The FEM model of the reinforced beam shown in Figure 17. The distribution of deformations and stresses in concrete and reinforcement shown in Figures 18-22.

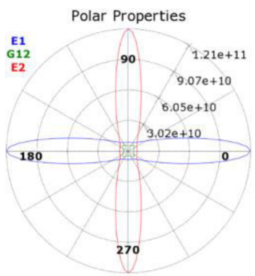

Fig. 16 . A properties of Carbon fabric-tape-1000-12K-420.Ct-11083:

E1 - Orthotropic Young's Modulus in-plane, in fiber direction;

E2 - Orthotropic Young's Modulus in-plane, orthogonal to fiber direction;

G12 - Orthotropic Shear Modulus in-plane, in fiber direction

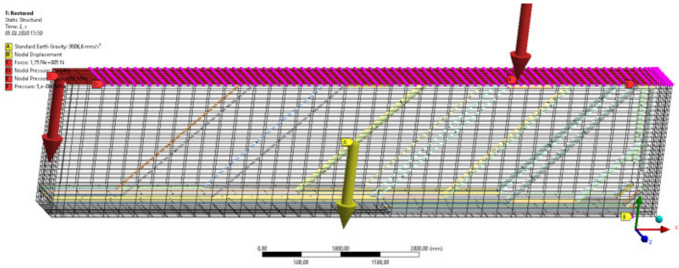

Fig. 17. Intensified beam design model

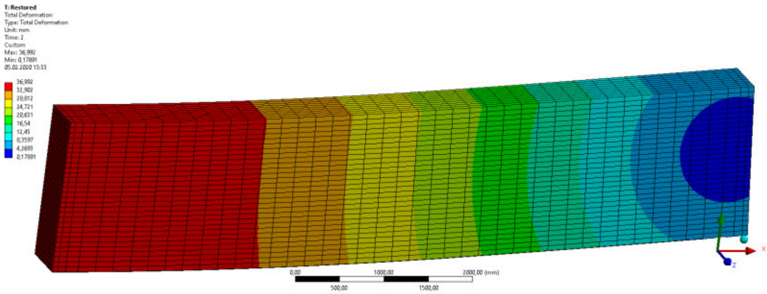

Fig. 18. Deflection of the intensified beam

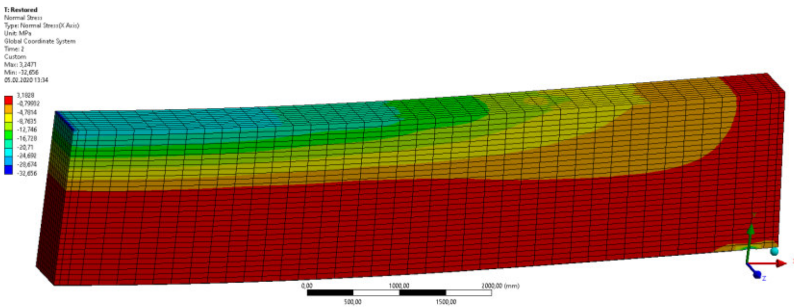

Fig. 19. Normal Stresses in the concrete of intensified beam

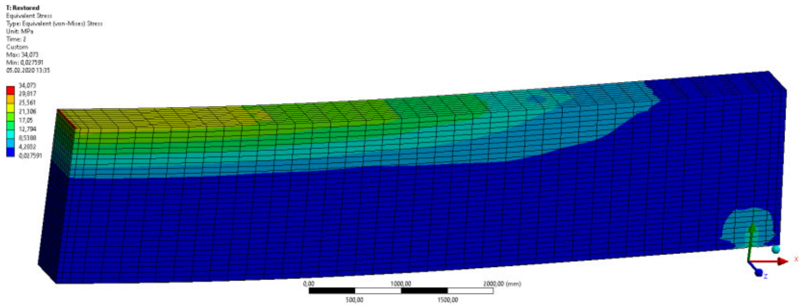

Fig. 20. Equivalent Stresses in the concrete of intensified beam

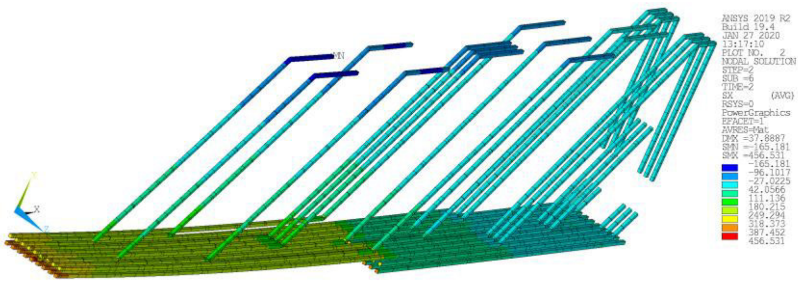

Fig. 21. Normal Stresses in the reinforcement of the intensified beam

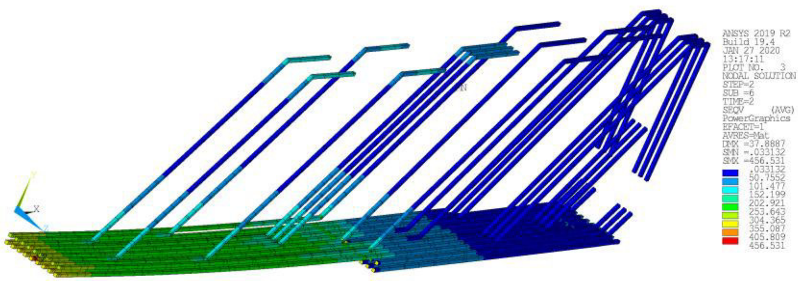

Fig. 22. Equivalent Stresses in the reinforcement of the intensified beam

The parameters of deformation and stresses in concrete and the reinforcement of intensified beams shown in table 3.

Table 3

Maximum deformation and stress in the structure before damage and after intensified

Maximum parameter value	Before damage	After intensified	Δ, %
beam deflection	32.87	38.5	17,1
normal stress in concrete			
tension	3.2	3.7	15.6
compression	24.3	26.3	8.2
the normal stresses in the reinforcement	202	345	70

An analysis of the results shows that reinforcing the structure with unidirectional carbon fiber with a thickness of 1 mm reduces the increase in deflection from 59 to 17 %, stresses in the stretched zone from 33 to 8 %, and in the reinforcement from 217 to 70 % compared with the unreinforced structure.

Analysis of the reinforced structure in the ANSYS software package revealed a picture of the normal stress distribution in the gain element, frictional stress between the gain element and the beam, and distribution of pressure in contact zone (Fig. 23-25).

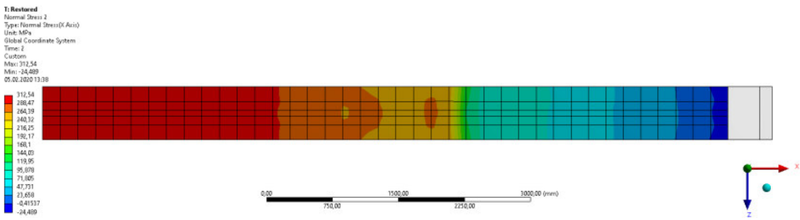

Fig. 23. Normal Stress in the carbon gain element

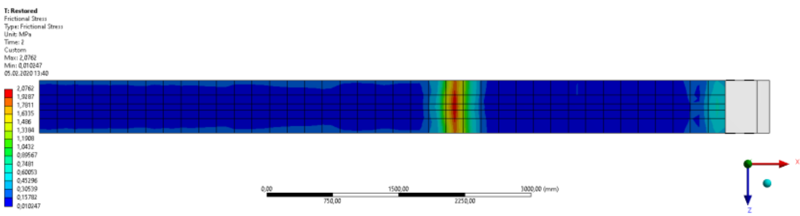

Fig. 24 .Frictional Stress in the carbon gain element

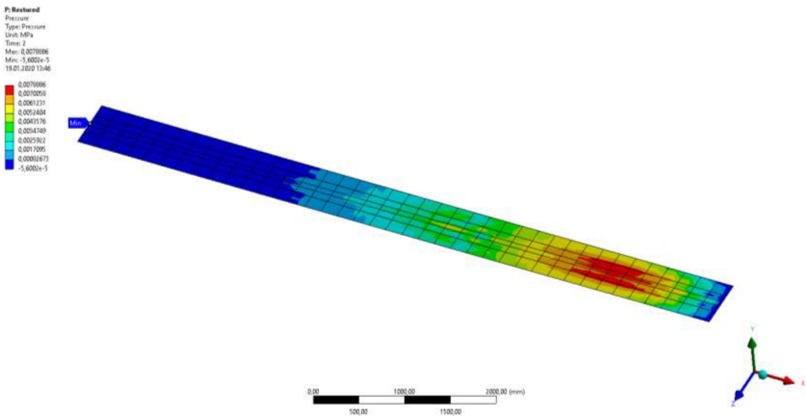

Fig. 25. Pressure in contact between concrete and carbon gain element

Analysis of the obtained data shows that the maximum stresses in carbon fiber do not exceed 20% of its bearing capacity. The maximum frictional stress between the beam and the carbon element is 3.25 MPa, and maximum pressure in glue is 0.008 MPa, which does not require bonding with high-quality epoxy adhesives.

Conclusions.

The use of the ANSYS software package in calculations of reinforcement of reinforced concrete structures allows a comprehensive analysis of the stress state of a damaged structure, to identify the most dangerous zones in the structure and to develop optimal schemes for its amplification.

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