The choice of the rational parameters of three-layer reinforced concrete inclosing structures with monolithic bond of layers by computer simulation

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Abstract. For the selection of the rational physical, mechanical and geometric parameters of three-layer reinforced concrete structures with monolithic bonding layers, it is necessary to have numerous data on the stress field and patterns of their deformation upon loading, changes in the energy parameters of the strength of concrete and the thickness of the layers. The important condition for the analysis of the stress-strain state by computer simulation is verification with experimental studies. This research is a confirmation of the reliability of the partitioning of the model into finite elements, the choice of their size and configuration. Modeling of three-layered enclosing structures with overall dimensions of attic overlappings allows obtaining strains and deformations in the outer and middle layers at different levels of loads and performing their comparison with limiting values. Due to the high rigidity of the three-layered enclosing structures with a monolithic bond of the layers and the use of structural concrete in the outer layers, the strength of which is more than 10 times higher than that of the middle one, there are no cracks in the operating loads. In order to recommend considering the stress-strain state, there are more dimensional three-layer coating plates with monolithically bonded layers with different geometric and strength parameters, with different degrees of reinforcement and levels.

1. Introduction

This research is aimed at studying the development of methods for calculating multi-layer reinforced concrete structures, based on the use of the results of both experimental and theoretical studies, including computer modeling.

Multilayer structures consisting of materials with different physical and mechanical characteristics have a contact layer on the contact boundary, when influence on the construction of computational models was investigated by numerical methods [1-7].

The experimental results reflect within the limits of the accuracy of the experiment the actual parameters of the stress-strain state of the structures and are associated with the correct development of physical models.

As shown by the theoretical and experimental studies, which were carried out earlier by the author [8-10], the stresses in the stretched zone of the investigated three-layer reinforced concrete structures under the operational load do not reach the ultimate tensile strength, therefore formation of cracks does not occur.

2. Materials and methods

The cross-section of the investigated three-layer bending reinforced concrete structures consists of two types of concrete. Their outer layers are made of structural concrete of class B12.5 - B30, and the middle layer is made of structural and heat-insulating class B1.5 and less.

After preliminary analysis [13,14] for further work, the ZSOIL software package developed by Zace Service Ltd. (Switzerland). The possibilities of this program allowed entering various material parameters without their mutual dependence. The program allows you to set the data and generate the grid of the finite elements in manual mode. This software allows using flat, isoparametric and subparametric finite elements of the second order.

To approximate a three-layer structure from different types of concrete with a monolithic bond of layers, as preliminary studies showed, rectangular or triangular flat finite elements are the most suitable. The dimensions of the final elements were correlated with the thickness of the layers of the structure, the smallest of which was 40 mm. In order to be able to compare the results of the simulation with the actual picture of the deformation of the tested three-layer reinforced concrete beam-type samples, the parameters of the layers of beam samples were taken for the first model [8] based on the results of previous experimental studies [11,12]. In the first approximation, taking into account the rare arrangement of the reinforcement and the low percentage of reinforcement (up to 0.05%), the beam reinforcement was not taken into account in the calculation.

The reliability of the model has a significant importance, when the beam is divided into triangular Fes. Comparison of the calculation results with the experimental data on deflections, strain measurements along the direction of the main stresses in the middle of the span and on the landing areas gives a convergence in the range 95-97%.

In general, the analysis of the operation of three-layer beam element model without longitudinal reinforcement shows that the bulk of the effort is assumed by the outer layers of the construction made of structural concrete, and in the middle layer of low strength concrete, the level of maximum stresses is lower by an average of 15 times. The destruction of the structure will occur starting with the outer layers, and on the average, a layer of internal destruction and excessive deformation is not observed.

The parameters of the finite elements (FE) and the characteristics of the concrete layers of the structure are given in Table 1.

Table 1. FE parameters and the characteristics of the concrete layers of the structure.

Construction layer	External 1	Internal 1	External 2	Internal 2
The size of rectangular elements, m	0.04×0.10	0.0425×0.10	0.04×0.10 0.02×0.10	0.0425×0.10
Prismatic strength of concrete R_b, MPa	10.1	1.15	21.0	1.01
Strength of concrete for tensile strength R_{bt}, MPa	1.02	0.35	1.75	0.28
Initial modulus of elasticity E0, MPa	10400	950	12000	890
Poisson's ratio $\nu = 0.00189 \mid R_b \mid + 0.12$	0.139	0.122	0.16	0.122
The shear modulus $G = E_0 / 2 (1 + \nu)$, MPa	4570	423	5172	397
Average density of concrete, kg / m3	1700	440	1800	440

In the first version of the model, the three-layer construction was represented by rectangular finite elements: the lower and upper layers in one row, the middle one in the form of 4 rows of finite elements. As the calculation results showed, the deflections of beam models correspond to the results of full-scale tests with an accuracy of up to 95%. The magnitudes of the principal stresses in the layers of the elements are also close to those experienced at the corresponding load levels. However, the direction of the main tensile and principal compressive stresses shown in adjacent finite elements on opposite diagonals, somewhat distorts the true picture of the stress field. Therefore, the representation of the structural layers by rectangular finite elements with a length more than two times the height of the element is not convenient in deriving the calculation results in the form of principal stresses. In the second model, the length of the rectangular finite elements is reduced to 0.05 m. With a decrease in the size of the final element by half, the overall picture of the stresses did not change, but the angle of inclination of the principal stresses somewhat decreased. Differences in stress level do not exceed 0.1% upwards. In the third model, the same construction is represented in the form of triangular finite elements (Figure 1), that is, each rectangular FE with a width of 0.1 m is replaced by four triangular elements, dividing it by diagonals. In this case, we obtain triangular FEs of two types-with the side of the parallel lines separating the layers (1a) and with the side perpendicular to these lines (1b). The reinforcement was adopted with a diameter of 8 mm in increments of 15 cm, the reinforcement percentage was 0.29%. The FE model grid and the results of the the loading of beam calculations are shown in Figures 1, 2.

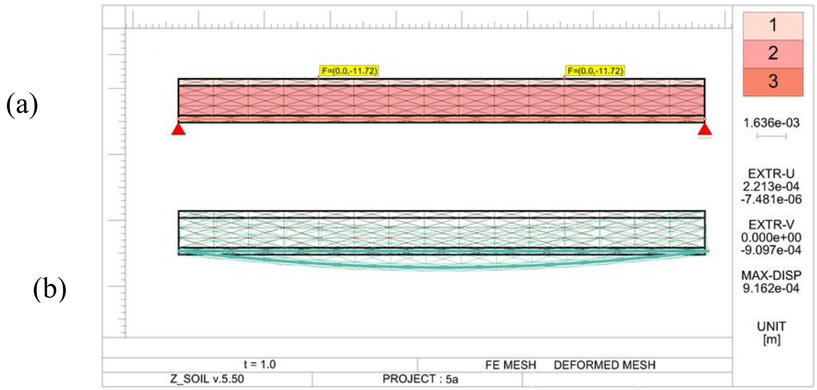

Figure 1. Model of a beam with longitudinal reinforcement: (a) scheme of grid layout of the FE model 4; (b) deformation of the beam.

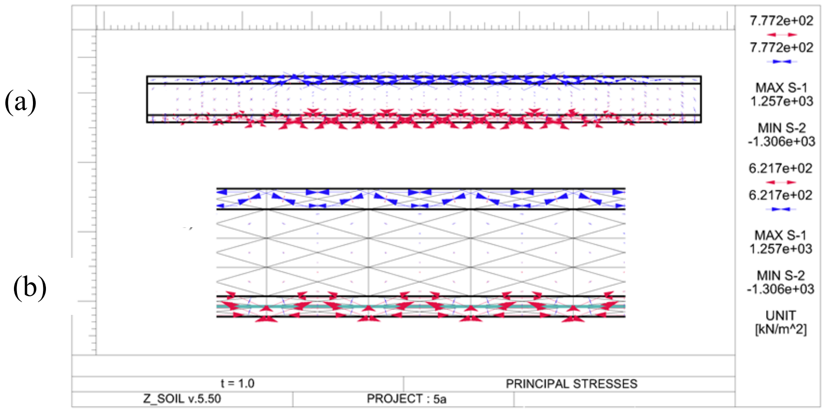

Figure 2. Pattern of the distribution of principal stresses in a model with longitudinal reinforcement: (a) distribution of principal stresses in the model; (b) enlarged fragment of principal stresses.

In this study the following model of the effect of increasing the degree of reinforcement on the work of a three-layer structure was considered. With an increase in the percentage of reinforcement to 3% and a decrease in the strength of the concrete of the outer layers to the value indicated in the Table 1, the stress field in concrete changes and the reinforcement will have a significant effect on the design work. The main tensile stresses in the lower zone of the beams in the middle of the span are below the boundary compressive stresses by 57.3%.

This is important in practice: the work of the slabs and attic overlaps of a three-layer structure with a monolithic bond of layers: a slab of a 6.0 m length and a thickness of 50 cm with external layers of structural concrete 8 and 4 cm thick and a medium layer of low strength concrete - 38 cm; minimum allowable reinforcement level of 0.05% (a reinforcement with a diameter of 8 mm step of 15 cm). The total calculated value of the uniformly distributed load from the roof mass and the temporary snow load is 2.2 kN / m2.

The model with the bottom layer of concrete 8 cm thick is divided in height into two rows of FE – 2 cm and 6 cm, the reinforcement is provided between layers 2 cm and 6 cm thick was composed in this researching. Further, the middle layer of 38 cm thick is represented by three rows of FE with a height of 5.6 cm. The upper layer 4 cm thick is single-row. The length of the element is divided into 15 sections, i.e., the maximum length of the FE is 20 cm. The FEs are triangular (Figure 3).

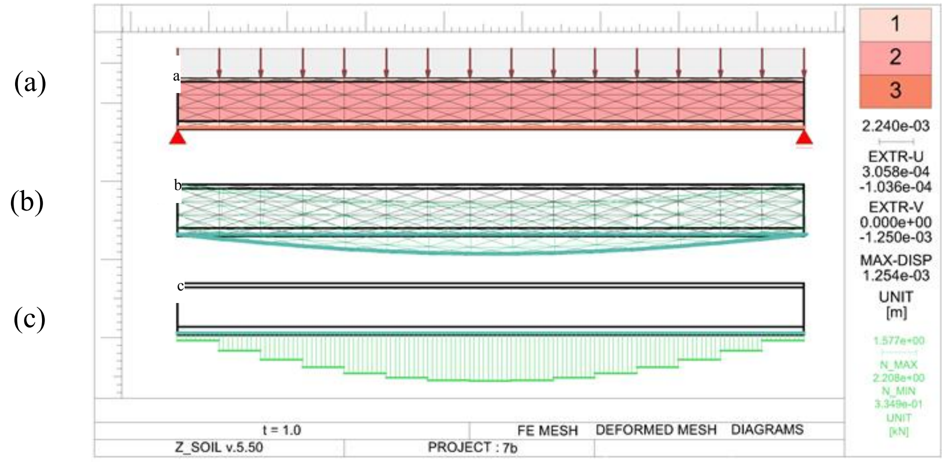

Figure 3. Model of a plate of a covering: (a) scheme of splitting on final elements; (b) deformation of the plate; (c) diagram of the distribution of longitudinal forces in the reinforcement.

Deflections, the pattern of distribution of principal stresses, the diagram of normal stresses and also the distribution fields of normal stresses and relative deformations of concrete are shown in Figures 4, 5. The maximum vertical deflection of the structure was 0.125 cm.

In addition, the cross section in the middle of the span of the plate was considered. In the 5 upper triangular cells of the cross-section 1, normal compressive stresses of the level of 0.086-0.012 MPa (at Rb = 1.15 MPa) act in the middle of the slab of the structural concrete layer; and only in the lower FE there is an insignificant stretching of 0.022 MPa (at Rbt = 0.35 MPa). Such a distribution of efforts will positively affect the reliability of the work of such a design. Efforts in the outer layers of the plate are as follows: in the stretched zone 0.259-0.526 MPa (at Rbt = 1.02 MPa); in the compressed zone 0.96 – 1.1 MPa (at Rb = 10,1 MPa).

The stress diagram for the reinforcement shown in Figure 5, shows that the effect of reinforcement due to the rigidity of the structure is insignificant, because the ratio of the maximum force in the armature at the design load (2.2 kN) to the design (18.34 kN) is 12%.

As the calculation of the design model with the dimensions of the offered full-scale plates showed, the concrete of the middle layer of such boards will experience compressive stresses of 85% of the thickness that does not exceed 8% of the prismatic strength of concrete, while the remaining part exhibits insignificant tensile stresses that do not exceed 6% of the tensile strength of the concrete.

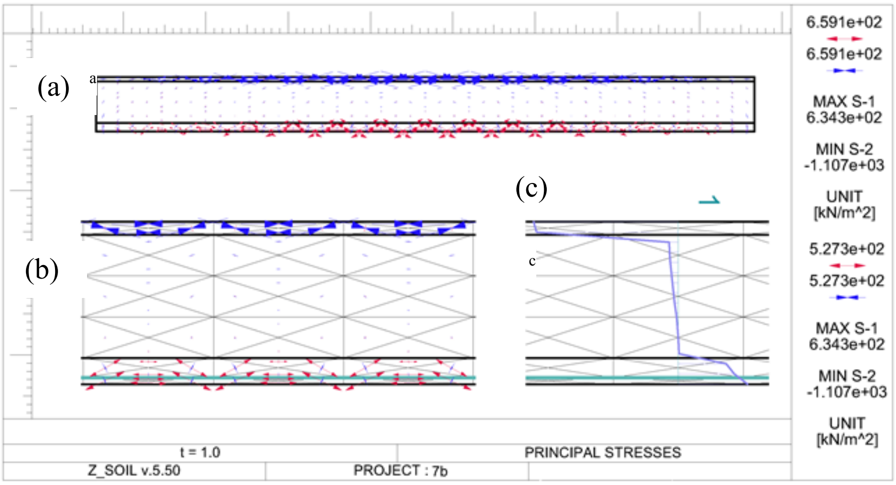

Figure 4. The pattern of stress distribution in the plate model: (a) the main stresses along the length of the plate; (b) enlarged fragment of principal stresses; (c) diagram of normal stresses in the middle section of the plate.

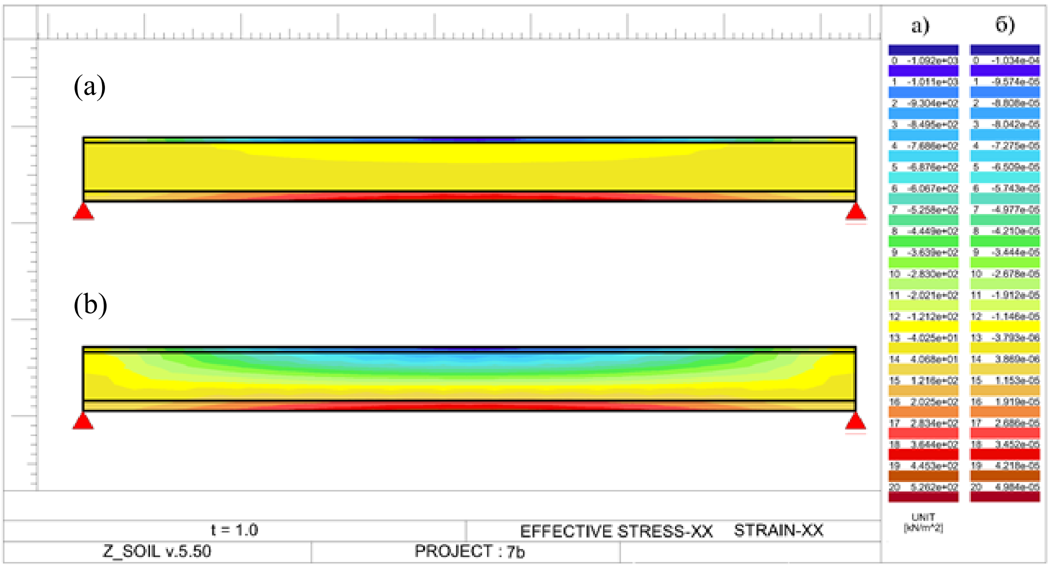

Figure 5. Distribution of stresses and strains in the model plate: (a) field distribution of normal stresses in the plate; (b) field of distribution of the relative deformations.

3. Conclusions

The convergence of the experimental and calculated results makes it possible to recommend considering the stress-strain state of large-sized layered slabs with different thicknesses of monolithically bonded layers at different reinforcement levels and loading levels on the recommended finite element models.

The use of modern calculating software on the basis of the finite element method (FE) makes it possible to simulate the stress-strain state of a reinforced layered structure with monolithically bonded layers. It is recommended to use flat triangular cells with dimensions close to the thickness of the layers.

The analysis of the operation of three-layer beam structures shows that the middle layer of low-strength concrete undergoes insignificant stresses, which are close to the operational ones, 5-10% of the design tensile strength of concrete, which confirms the rational layout of the section from the point of view of the stress-strain state,

These researches with application of a computer modeling method allow varying in a wide range by changing the design parameters (thickness of layers, strength properties of concrete, types of reinforcement and the degree of reinforcement) and, ultimately, choose a rational design solution.

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