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Research paper

Modeling of the Stress-Strain State of Through-Reinforced Concrete Structures with External Sheeting Reinforcement by the Finite Element Method

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Abstract

The article deals with the research of the stress-strain state of through- reinforced concrete structures with external sheeting reinforcement by the finite element method (FEM), the comparison of the results of numerical modeling with the results of the physical experiment of testing of through- reinforced concrete structures with external sheeting reinforcement for bending and compression

Keywords: *through-reinforced concrete structures with external sheeting reinforcement, stress-strain state, finite element method.*

1. Introduction

The use of software systems for structural calculations using the finite element method is noted by the visibility of the results in the form of distributions of displacements and stress fields in the given structures and is widely used to study the stress-strain state of structures [1, 2, 3].

The object of the research is the through-steel reinforced-concrete structures with external sheeting reinforcement combining advantages and eliminating the drawbacks of similar reinforced concrete and metal structures. The investigated structures have a number of advantages compared to reinforced concrete structures due to the use of working tape reinforcement on the outer edge of the section, which increases the working height of the section and reduces the overall height of the structure. The loss of general or local stability, which is typical for metal structures, in the investigated structures is excluded due to the joint operation of tape reinforcement and concrete. Therefore, the creation [4, 5, 6] of the research of the bearing capacity [7, 8] and the stress-strain state of through-reinforced concrete structures with external sheeting reinforcement and the development of their calculation methods is relevant.

2. Main body

The modeling was carried out for steel-reinforced concrete elements (SRCE), produced by a monolithic method with the use of external sheeting reinforcement as a non-removable formwork. The investigated elements were designed in accordance with the physical experimental researches of steel-concrete elements SRCE-1, executed on bending and compression [7, 8].

When calculating a solid three-dimensional model of the investigated structures, an element of type Brick 8 node 45 - element SOLID 45 was used.

The following types of finite elements were used to simulate the investigated structure:

a) external sheeting reinforcement, cross-section reinforcing core and a column of the steel section were simulated by the following elements: 8-nodal quadrangular prisms and 6-nodal triangular prisms;

b) concrete was simulated by elements SOLID 65 - 8-nodal quadrangular prisms and 6-nodal triangular prisms.

The elements of the construction are divided into finite elements in such a way that the grid concentration is near the welds of the sheet steel and in the places where the reinforcing bars and the outer sheet reinforcement are welded, in order to detect the stress-strain state of the structural elements more accurately.

When creating a three-dimensional model of reinforcement of the investigated structure (Fig. 1), the outer sheeting reinforcement was given by plates, the cross-section core reinforcement was given by the elements of cylindrical shape.

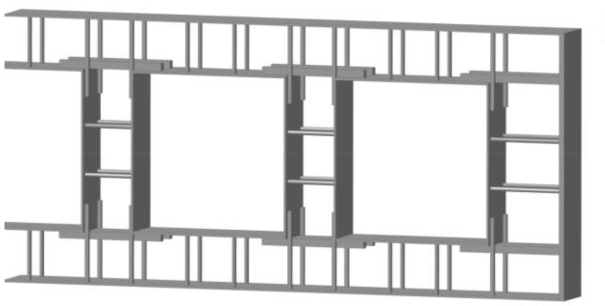


Fig. 1: Three-dimensional model of through-reinforced concrete structures with external sheeting reinforcement.

Welding of core reinforcement and external sheeting reinforcement was simulated by gluing. In further modeling, the internal reinforcement cores, which had to be touched by the tangent to the outer sheeting reinforcement, had to be replaced on cores with a rectangular cross-section of the equal area. The three-dimensional model of the reinforcement of the investigated structure and the shape of the sample, which has already been broken into the finite elements, is depicted in Fig. 1 and Fig. 2

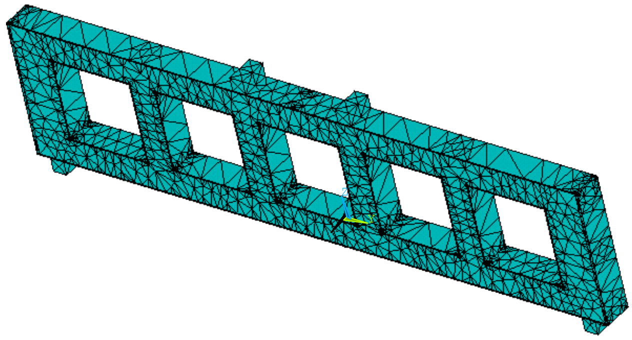


Fig. 2: Investigated structure was divided into finite elements: external sheeting reinforcement, cross-section reinforcing cores and concrete array.

Loading of structures at numerical modeling of a stress-strain state is occurred step by step and it was destructive according to experimental research [7, 8]. The load was applied in the form of a uniformly distributed load on the area corresponding to the hinges' area used in experimental researches. The maximum applied loads to simulated structures are given in Table 1.

Table 1: Applied load to simulated samples

A series of samples	Type of loading	F, N
SRCE-1-1	bending (loading A)	10000
SRCE-1-2	bending (loading B)	19000
SRCE-1-3	off-center compression	40000
SRCE-1-4	central compression	24000

Research of Flexible Elements. The first stage of numerical modeling was to check the sheeting frame without concrete as one of the types of load for a general idea of the work of the structure. The frame was loaded according to the experimental test of the sample SRCE-1-1 [7, 8]. The appearance of a sheeting frame without concrete, which has already been broken into the finite elements, is given in Fig. 3

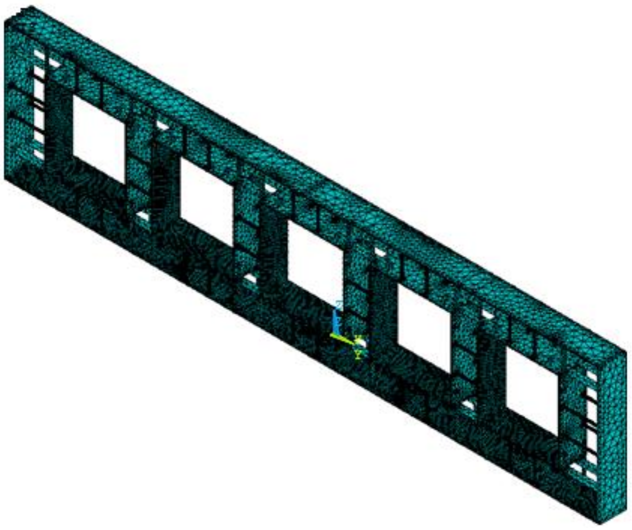


Fig. 3: Sheeting frame without a concrete array broken into finite elements

For a comparison of experimentally test samples and a sheeting metal frame we consider a deformed frame scheme (Fig. 4).

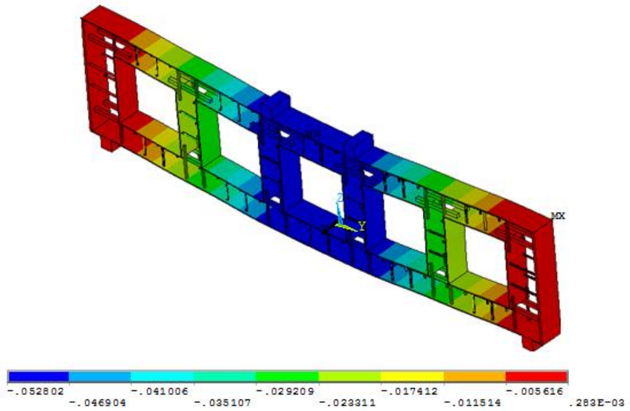


Fig. 4: Sheeting frame without a concrete array: distribution of displacements along the Z axis in a sheeting frame without concrete.

As it can be seen from the deformed scheme and the graph of the dependence of the deflection magnitudes on the results of numerical modeling and experimental research (Fig. 5), the maximum value of the deflection of a sheeting frame without concrete of 52.8 mm significantly exceeds the experimental data of deflections of 38 mm for a sample SRCE-1-1.

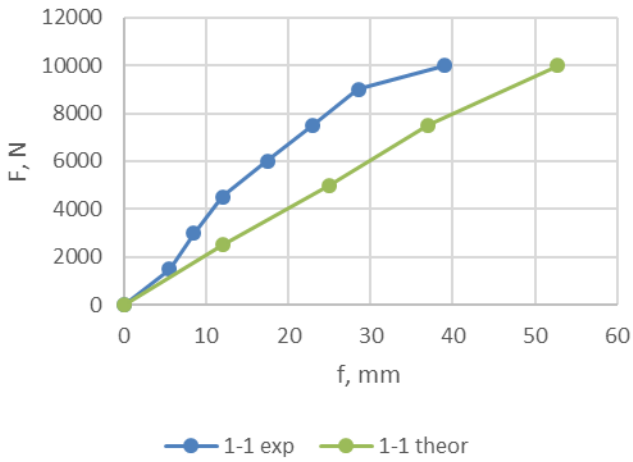


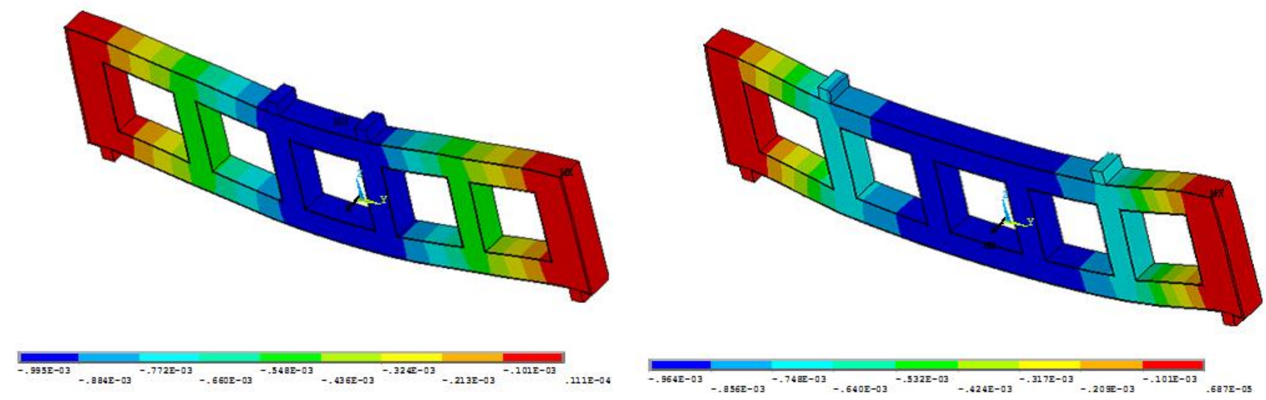
Fig. 5: The graph of the dependence of the size of the deflections on the loading of the sheeting frame without concrete based on the results of numerical modeling and the sample SRCE-1-1 by the results of experimental research [7, 8]

The obtained results make the possibility to come to the following conclusions: the sheeting frame without a concrete array under load loses the bearing capacity (stability), the numerical modeling of a structure proves the advantages of the proposed structure instead of the metal frame.

The next step of numerical modeling of through-reinforced concrete structures with external sheeting reinforcement by the finite element method is the calculation of a "reinforced concrete frame" broken into the finite elements. The sample is given in Fig. 2. The loading of the model is according to experimental research, both for the sample SRCE-1-1 and SRCE-1-2 - 10000 and 19000 N, respectively.

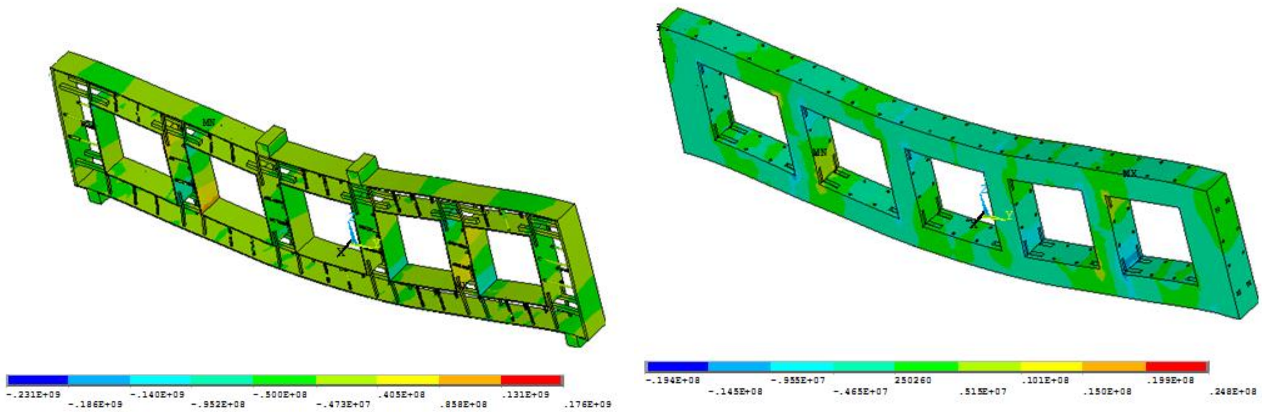
The distribution of displacements in the samples SRCE-1-1 and SRCE-1-2 is given in Fig. 6.

The obtained results during numerical modeling of the stress field in the test samples SRCE-1-1 and SRCE-1-2 are given in Fig. 7, 8.



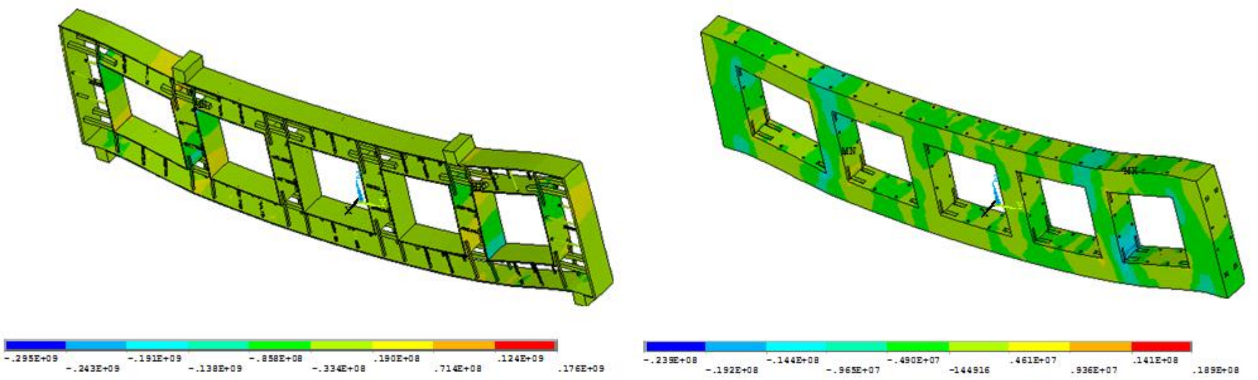
a) b)

Fig. 6: The distribution of displacements along the Z axis in the experimentally studied samples: a) sample SRCE-1-1; b) sample SRCE-1-2



a) b)

Fig. 7: The distribution of stresses along the Z axis in the sample SRCE-1-1: a) in the external reinforcement; b) in concrete



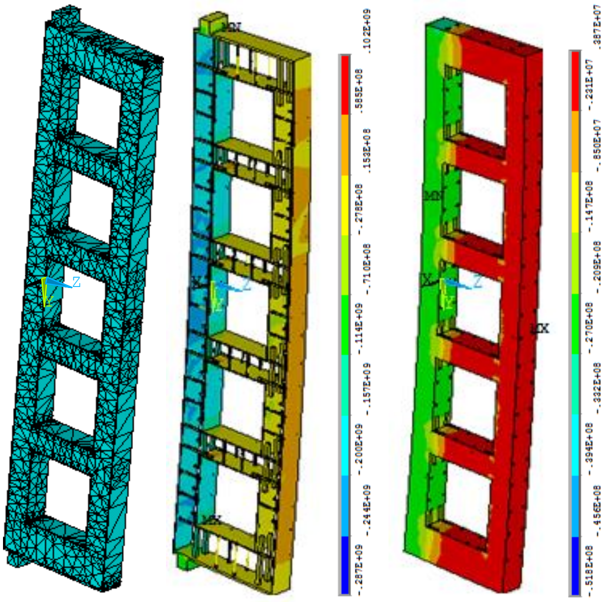
a) b)

Fig. 8: The distribution of stresses along the Z axis in the sample SRCE-1-2: a) in the external reinforcement; b) in concrete.

Analyzing the obtained results of numerical modeling of bended through-reinforced concrete structures with external sheeting reinforcement, it can be made the following conclusions:

- according to the numerical modeling the local stresses in the external reinforcement and the concrete array are located in the structure knots, it corresponds to the nature of the destruction of the prototype samples SRCE-1-1 and SRCE-1-2 during the tests;
- the maximum values of the deflections for samples SRCE-1-1 and SRCE-1-2 according to the numerical modeling are respectively 0.995 mm and 0.964 mm;
- the obtained results of the numerical modeling coincide with the static calculation, confirming the earlier conclusion on the necessity of installing an additional internal core or external sheeting reinforcement in the structure's joints ;
- in the further numerical modeling of the tested structures for bending, it is necessary to take into account the fact of the formation of cracks in the joints;
- when designing the through-reinforced concrete structures with external sheeting reinforcment for bending, it is necessary to take into consideration the obtained results, providing the reinforcement of the structure's joints by additional internal or external reinforcement.

Research of compressed elements. The loading of the compressed element model is taken according to experimental tests, as for a sample SRCE-1-3 - 40000 N. The sample broken into the finite elements is given in Fig. 9, a. The obtained stress fields of the test sample SRCE-1-3 during the numerical modeling is given in Fig. 9, b, c.



a) b) c)

Fig. 9: The research of compressed elements: a - the test structure SRCE-1-3 broken into the finite elements: b - the distribution of stresses along the Y axis in the sample SRCE-1-3 in the external reinforcement; c - the distribution of stresses along the Y axis in the sample of SRCE-1-3 in concrete.

a) б) c)

Fig. 10: The nature of the destruction of the test elements' joints during the physical experiment: a - the structure SRCE-1-1, tested for bending; b - the structure SRCE-1-2, tested for bending; c - the structure SRCE-1-3, tested for compression.

Analyzing the obtained results of the numerical modeling of compressed through-reinforced concrete structures with external sheeting reinforcement, it can be made the following conclusions:

- the nature of the deformations of the test structures for compression corresponds to the behavior under the load and the nature of the destruction of the test samples SRCE-1-3 and SRCE-1-4;
- local stresses in external reinforcement and concrete array according to the numerical modeling are located in the sample SRCE-1-4 in the place of the load, where there is significant bending of the core, and in the joints of structures adjacent to it;
- when designing the through-reinforced concrete structures with external sheeting reinforcement for compression, it is necessary to take into account the obtained results providing the reinforcement of the structure's joints by additional internal or external reinforcement in the places of the load.

Analyzing the nature of the destruction of structures (Fig. 10), it should be noted that the formation of cracks in the structures' joints corresponds to quantitative and qualitative results of the modeling of the through- steel reinforced concrete structures.

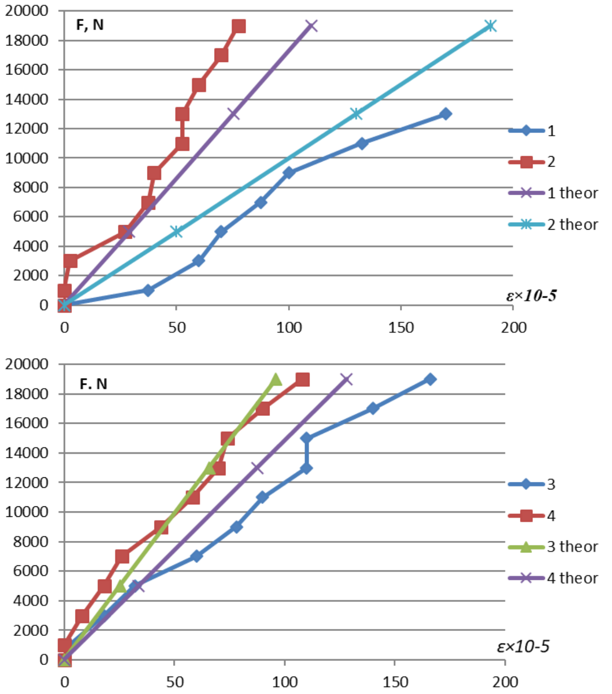


Fig. 11: The dependence of longitudinal deformations on the load for a sample SRCE-1-2 tested for bending: 1, 2, 3, 4 - the numbers of the electro-tensor resistors; 1,2,3,4 : theor. is theoretical deformations as for FEM

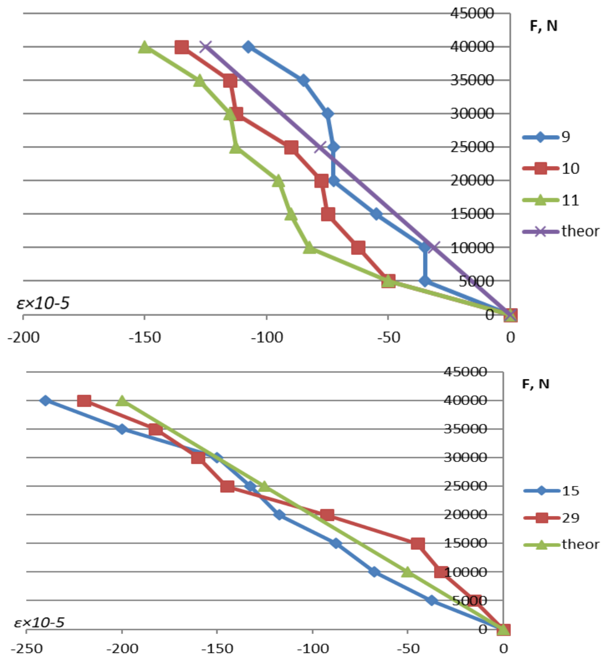


Fig. 12: The dependence of longitudinal deformations on load for a sample of SRCE -1-3 tested for compression: 9, 10, 11, 15, 29 - numbers of the electro-tensor resistors; theor. is theoretical deformation as for FEM

In order to compare the results of thenumerical modeling with the physical experiment results, the graphs of the dependence of relative strains on the load accoding to the stress parameters in the places corresponding to the location of strain gauges on the test samples were done (Fig. 11, 12).
The comparison of theoretical and experimental values shows that during the elastic calculation the nature of the dependence of relative strains on the load when modeling with the volume finite element is generally coincided but the parametres of the strain gauges indicate the unevenness of deformation connected with the cracking in concrete and the non-linearity of the compressed concrete. Although after cracking and changing the calculation scheme from hard joints to the hinge ones, the almost elastic nature of the work of the folded section remains up to the separation of the sheeting elements from the concrete, which quickly leads to the destruction of test samples.

3. Conclusions

The result of the comparison of deformations in the numerical and physical experiment shows that with accuracy up to 10-15% deformation of the middle parts of the elements of the through structures (in the location of strain gauges) can be considered elastic at almost all stages of loading.
When designing the through-reinforced concrete structures with external sheeting reinforcement for bending, it is necessary to take into account the obtained results, providing the reinforcement of the structure's components by additional internal or external reinforcement.
In the subsequent numerical modeling of the test structures for bending, it is necessary to take into considerationt the fact of the cracks formation in the joints.

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