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NUMERICAL ANALYSIS OF NARROW SINGLE-SPAN, GRAVITATIONALLY LOADED CONCRETE SLABS REINFORCED BY STEEL WITH A MEAN DUCTILITY

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Abstract: *In the course of the exploitation of building structures frequently situations turn up, when the structure is not adequately used (it may, for instance, be exposed to considerably greater loads than had previously been intended). In the state of an emergency the overload of the structure, essential reserves of their load-bearing capacity may turn up in the case of the self-acting work as a flexible strand. The aim of calculations was to illustrate and obtain more detailed information concerning the phenomena occurring in the course of laboratory tests. The paper presents the results of these calculations, comparing them with those obtained by laboratory tests.*

Keywords: Reinforced concrete, Progressive collapse, Failure stage, Numerical analyzes.

1. Introduction

The models applied in these investigations were designed as a cut band of a monolithic floor reinforced only in one direction. Taking into consideration the distance of the points of supporting equal to 3740 mm, four identical flat reinforced concrete slabs were made with the dimensions 3860×480×100 mm. The models were reinforced by bars with a diameter ø8 mm. The transverse reinforcement consisted of bars with a diameter of ø8 mm and a spacing of 200 mm. After 210 days these models were placed on steel supports (2 in Fig. 1). After the rectification of the models on the supports, the main reinforcement was welded onto the steel tension members (3 in Fig. 1). As the last stage of preparatory operations the steel tension members were anchored in the floor of the laboratory. The test stand and the model, the distribution of reinforcement and the strength parameters of the applied materials have been described comprehensively by Wieczorek M. (2014).

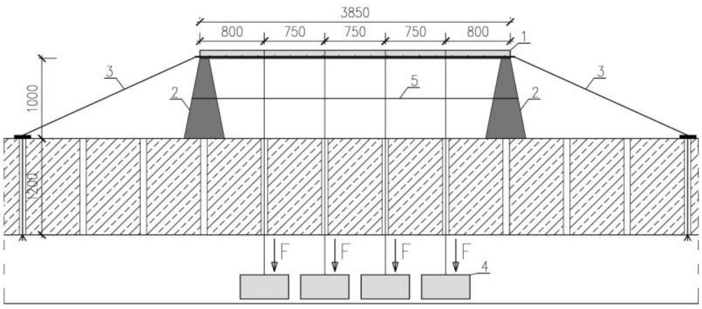

Fig. 1: Test stand (Wieczorek M., 2013): 1 - tested element, 2 - steel support, 3 - steel tension members, 4 - load, 5 - baseline for measuring the displacements.

2. Description of the Numerical Model

The phenomenon of destruction of the investigated model presented in the paper (Wieczorek M., 2013) can, due to its dimensions, be considered as a two-dimensional problem. In the first stage of investigations the tested element there occurs only a bending moment. Due to a horizontal blocking in the cross-section besides the bending moment additional longitudinal tensile forces turn up. The value

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of these forces depends mainly on the mechanical parameters of the applied reinforcing steel (the decisive parameter is the ductility of the reinforcing steel). In the numerical analysis, dealt with further on, for each investigated model two independent models of calculations were developed, viz.:

- Models of the type A. These were developed in compliance with the programme ABC-Slab, which permits to determine the vertical displacements and internal forces according to the assumptions EC2 (2010) (both in the range of elastic behaviour of the element and after its cracking). In compliance with the assumptions of EC2 the programme applied in the calculations the characteristic strength of the materials. Moreover, the programme takes into account in the calculations the effect of axial forces. The calculations concerning reinforced concrete elements are completed when the value of the tensile strength of the concrete in any finite element is exceeded. Then the rigidity of each finite element is determined separately by means of the iterative method. The rigidity of scratched elements is determined basing on the deformation of the reinforcement. An examplary view of the numerical model is given on Fig. 3.
- Models of the type B. These models were developed in the programme ANSYS (Fig. 4). Similarly as in the investigations (Barbosa, 1997; Mahmood and Ibrahim, 2009; Anthony and Wolanski, 2004; Willam and Tanabe, 2001, Wieczorek B., 2013), two kinds of finite elements were applied, viz. a solid element Solid65 and a rod element Link8. Both of them were assigned with parameters according to (Wieczorek M., 2014). The element Solid65 was used to model the concrete (SAS, 2003). This element has eight nodes with three degrees of freedom at each: node translations in the nodal x, y, and z directions. The element is capable of plastic deformation, cracking in three orthogonal directions, and crushing. The element Link8 was used to model steel reinforcement (SAS, 2003). This element is a 3D spar element and has two nodes with three degrees of freedom at each node: translations in the nodal x, y, and z directions. This element is capable of plastic deformation. During the preparation of the numerical model, the suggestions and the guidelines contained in the scientific works (Wieczorek, B., 2014) were used. Also, the methodology of numerical modeling the reinforcement bars in concrete which takes into account a plastic state of the destruction of the reinforcing steel with high ductility had been applied.

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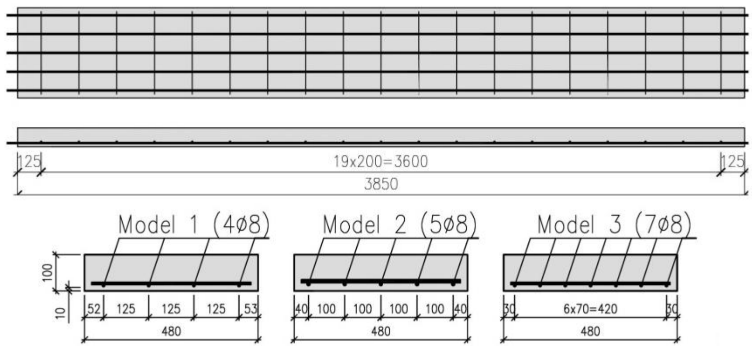

Fig. 2: Model of testing - arrangement of the reinforcement (Wieczorek M., 2013):
a) Horizontal projection and longitudinal cross-section; b) Cross-section of the models.

3. Results of Laboratory Tests and Numerical Clculations

The main aim of laboratory tests was to observe the behaviour of the investigated models after their flexural destruction and to determine the value of the boundary load. After every increase of the load the values of vertical displacements of the upper surface of the tested models were read off and also the value of deformation of the reinforcing bars. The deformations were measured by means of electric resistance wire strain gauges. Fig. 3 and Fig. 4 present examples of views of the constructed numerical models previous to and after their being loaded. For each model, diagrams of vertical displacements of the upper surface in the function of loading were obtained, which were compared with the results of experimental investigations (Fig. 5). The values of the deformation of the reinforcing bars could be directly compared only with the results of numerical calculations concerning models of the type B, accomplished in the programme ANSYS. Also the values of deformations in models of the type A were determined in a simplified way. The deflection of the numerical model was determined at each step of calculations based on the assumptions EC2. In the case of a known curvature of the deflection, the approximate value of the axial force was determined based on a "chain curve". As the next step, the values of stresses occurring in the reinforcement were calculated, and basing on material tests the corresponding values of deformations were assigned to them. The results of this comparison of the numerical values with experimental ones have been presented in Fig. 6.

a)

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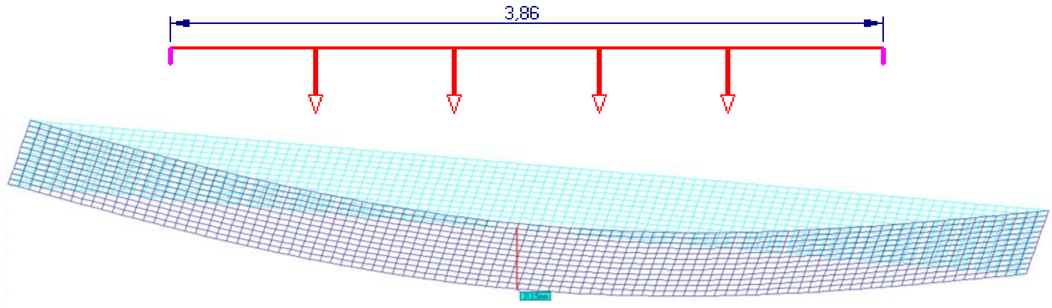

Fig. 3: Example of Model type A: a) Supporting manner;
b) View of the model previous to its deformation and after to its deformation.

a)

b)

c)

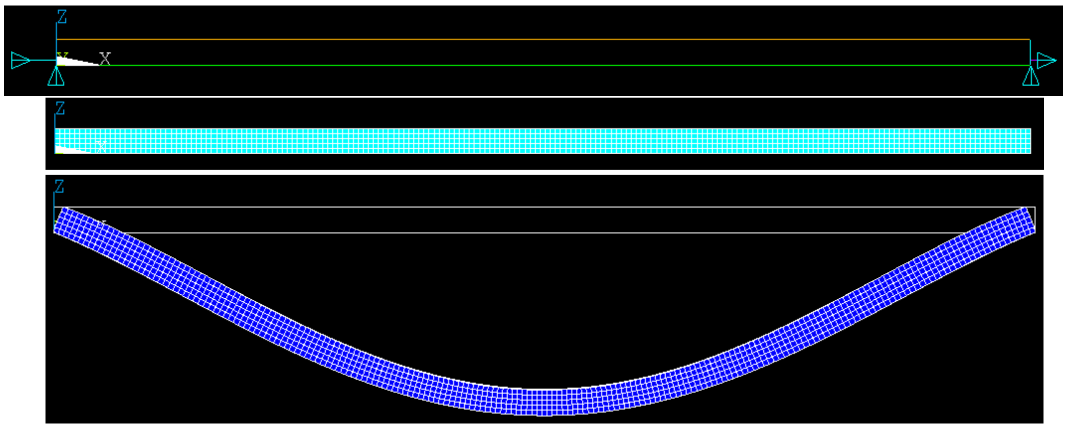

Fig. 4: Example of Model type B: a) Supporting manner;
b) View of the model previous to its deformation; c) Deformed model.

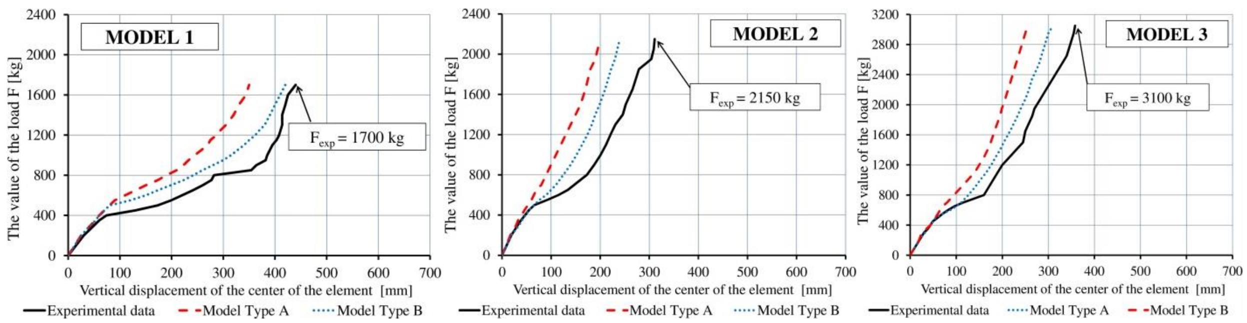

Fig. 5: Results - displacement of the center of the models as a function of the load.

a)

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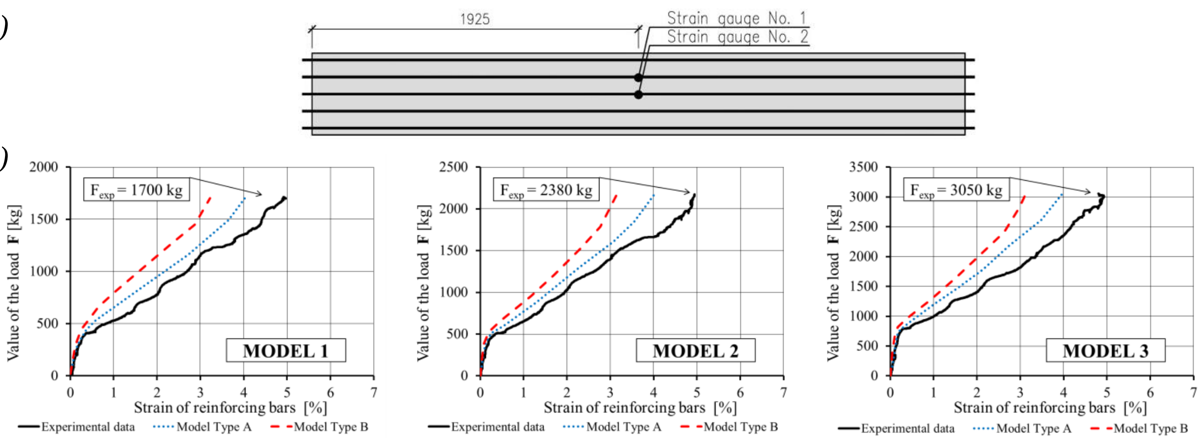

Fig. 6: Results - strain of the reinforcing bars:
a) Arrangement of the strain gauges; b) Experimental and numerical data.

4. Summary and Conclusions

The aim of the presented analysis was to attempt a numerical mapping of the behavior of narrow reinforced concrete slabs in the state of a break-down, brought about by overloading the structure. The performed tests, as well as the numerical analysis, confirmed the substance and role of the ductility of steel, permitting in some kinds of structures to make use of the reserve of load-bearing capacity, resulting from the possible self-realization of behaviour of the tension member in the structural element. In the course of performing the numerical analysis it has been found that:

- The applied procedure of determining the deformation of the bars of the reinforcement, consisting in converting the values of the bending moment and axial force into stresses followed by reading off the proper value of deformations in the diagram σ-ε. The calculated values obtained were lower deformation by 35.12%, 35.93% and 36.52% (respectively in Model 1, Model 2, Model 3 type A) from the strains obtained during experimental research. In models type B the differences amounted to 18.63%, 18.38% and 19.61%. Such large differences may result from the lack of an adequate level of the redistribution of the internal forces occurring in the experimental models, which had not been mapped fully in the numerical calculations. Thus, the values of the bending moments are considerably larger than those in numerical models of the type A.
- The values of deformations of the reinforcing bars obtained in the case of the models of type B are decidedly closer to the experimental values than those concerning models of the type A. Similarly as in the case of models of the type A, it may be assumed that the internal forces in the experimental models had undergone a considerable redistribution in comparison with numerical models, where such a redistribution did not occur.
- The differences between the values of displacements encountered in the course of laboratory testing and those obtained in numerical calculations may also be due to the applied parameters of the strength of concrete. The mechanical parameters of concrete (shear strength, tensile strength, coefficient of elasticity, Poisson's ratio), obtained basing on standard tests of the materials, may differ from the parameters of the strength of concrete in the models. One of many factors affecting the values of the parameters of the strength of concrete in the samples and the investigated models is the way of curing of fresh concrete.

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