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NUMERICAL ANALYSIS OF THE DEFORMATION OF THE CORNER PART OF SLAB-COLUMN STRUCTURES

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Abstract: *The paper resents the results of a numerical analysis of the corner part of a slab-column structure performed on the scale 1:2. The analysis is based on laboratory tests of a reinforced concrete slab with dimensions of 4000 × 4000 × 100 mm. The aim of the performed calculations was to illustrate the observed phenomena and to provide more detailed information concerning them. The results of calculations have been compared with the results obtained in the course of laboratory investigations.*

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

1. Introduction

One of the types of structural systems applied in the construction of buildings are slab-column structures. The resistance of such structures to exceptional loads is, however, less than that of other structural systems. Therefore, every unusual effect (impacts of vehicles, internal explosions of gas or assassinations) may lead to a progressive catastrophe. This phenomenon is characterized by the appearance of damages which are unproportional to the incident by which it has been caused. Therefore, it is so important to counteract them. From the economical point of view, an optimal solution is to secure protect the structure already while it is being designed, either by increasing its reinforcement or by changing its arrangement. The aim of the present investigations was to construct a numerical model of the corner part of such a slab-column structure. The developed numerical models permitted to determine the values of displacements, the deformation of the reinforcement and the reaction of the supports. These values were then compared with the results of tests in the laboratory.

2. Description of the Tested Model and the Test Stand

The model for these investigations was designed in such a way that it would illustrate in the course of testing the behaviour of the corner part of an actual slab-column structure in the scale 1:2. Taking into account the axial dimensions of the supports - 3000×3000 mm - a flat reinforced concrete slab was used with the dimensions 4000×4000×100 mm (Fig. 1). The reinforcement of the model was determined in compliance with the recommendations given in the standard EC2 (2010), taking into account the loads quoted in EC1 (2010). The statistically calculated values of the bending moments permitted to determine the number and diameter of the reinforcement, which was then constructed in the form of two parallel grids. In accordance with the recommendations suggested in standards (CSA, 2004, EC, 2010, GSA, 2003) and papers (Wieczorek B., 2013, 2014), in the axes of the columns an additional reinforcement was provided in order to prevent a development of damages typical for a progressive collapse. The model, the distribution of reinforcement and the strength parameters of the applied materials have been described in detail in some papers (Wieczorek M., 2013). The test stand consisted of four prefabricated supports with a height of 2400 mm, which were fixed to the slab on the floor of the laboratory. On these supports the dynamometers measuring the reactions of the support were imbedded in a specially prepared clamping. In the place where the loss of support was simulated, instead of prefabricated reinforced concrete a hydraulic cylinder with a large extension was applied.

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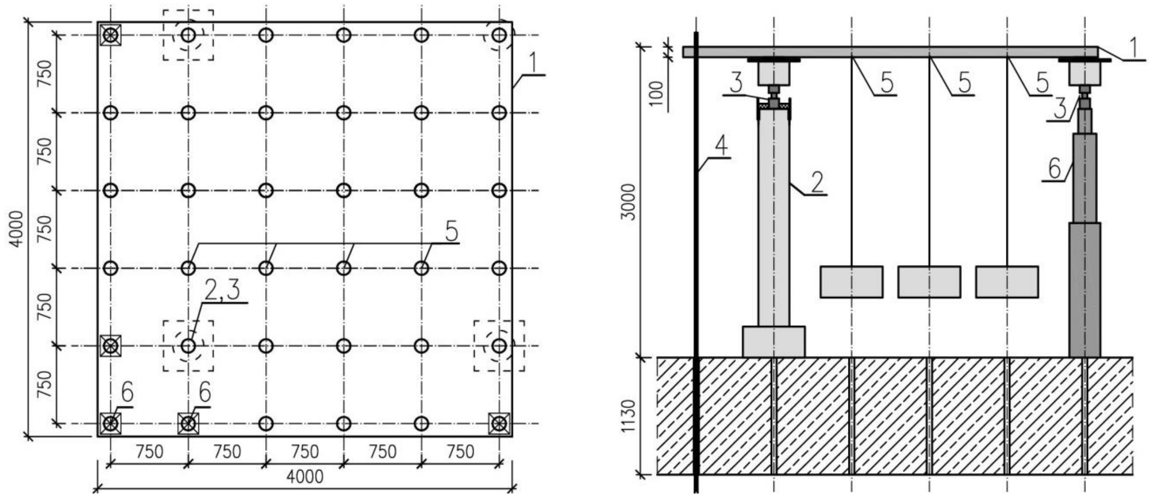

Fig. 1: View of the test stand and the model (Wieczorek M., 2013) (1 – tested model, 2 – prefabricated column, 3 – dynamometers measuring the reactions of the supports, 4 – steel rod used to stabilize the model vertically, 5 –points of the load application (concrete weights), 6 – hydraulic cylinder).

3. Description of the Numerical Model

The phenomenon of destruction of the investigated model presented by M. Wieczorek (2013) is a rather complex problem. In every cross-section the element is affected simultaneously by axial forces, bending moments and shear forces. Moreover, due to the considerable redistribution of the internal forces (large displacements, plastification of the reinforcement, scratching and cracks in the concrete) classic methods of calculations cannot be applied. In the numerical analysis dealt with further on two calculation models have been taken into account, independently of each other. The geometrical parameters and the parameters of strength of the used material were in each of these models the same. Precise data may be found in the paper (Wieczorek M., 2013).

3.1. Description of Model 1

The Model 1 was developed in compliance with the programme ABC-Slab. This programme permits to determine vertical displacements and internal forces in accordance with the assumptions EC2 (both concerning the elastic behaviour of the element and after its scratching). In compliance with the assumptions EC2 the programme assumes in the calculations characteristics of the strength of materials, neglecting in the calculations the effect of axial forces. Calculations of reinforced concrete elements in the elastic state are completed when in anyone of the finite elements the value of the tensile strength of the concrete is exceeded. Next, the rigidity of each finite element is determined by means of the iterative method. The rigidity of scratched elements is determined basing on deformations of the reinforcement.

3.2. Description of Model 2

The Model 2 constitutes the author's own suggestion concerning the modelling of strongly deformed reinforced concrete structures. Similarly as Model 1 this model was constructed applying the software ABC-Slab. In the first stage of the analysis, based on results (Wieczorek M., 2014), the ultimate values of the bending moments were determined basing on calculations of the strength according to EC2. In the second stage the load was gradually increased by 50 kg (0.5 kN). Then at each increase of the load (in each finite element) the obtained values of the bending moments (calculated statically) were compared with the ultimate values of the bending moment resulting from calculations of the strength. If the moment resulting from statical calculations exceeded the value of the ultimate moment, the rigidity of the given finite element was manually changed by reducing its thickness, after which again statical calculations were carried out. When the value of the statical moment was less than or equal to the ultimate value, its value was increased to the next step of loading. In the case of a higher value of the load, the comparison of the values of the moments was repeated and the rigidity of the selected finite elements was reduced.

4. Results of Laboratory Tests and Numerical Calculations

The main aim of laboratory tests was to observe the behaviour of the investigated model and to describe the mechanism of the damage (Wieczorek M., 2014). Besides that, the reaction of the supports and the vertical displacements of the upper surface of the model were automatically measured. Basing on observations it has been found that the most reliable points describing the deformation of the whole model are the points situated at the corner and in the centre of the investigated field. Fig. 2a (taken over from Wieczorek M., 2013) presents diagrams of the vertical displacement of the characteristic points in the load function. As the investigations of the model required 60 days and were divided into several stages of loading and releasing, Fig. 2a displays perturbations, denoted by the numbers 1÷7. In the following stage the values of displacements attained in the course of investigations and numerical calculations have been gathered in Fig. 2b. As the next stage, the values of displacements attained in the tests and numerical calculations have been gathered in Fig. 2b,c. The reaction of the supports was measured at eight points (Fig. 3a) by means of dynamometers (reaction R1, R2 and R3) and electric resistance wire strain gauges which had been glued on the steel rod used to stabilize the model vertically (reactions R4, R5, R6, R7 and R8). The obtained results are shown in Fig. 3b, c.

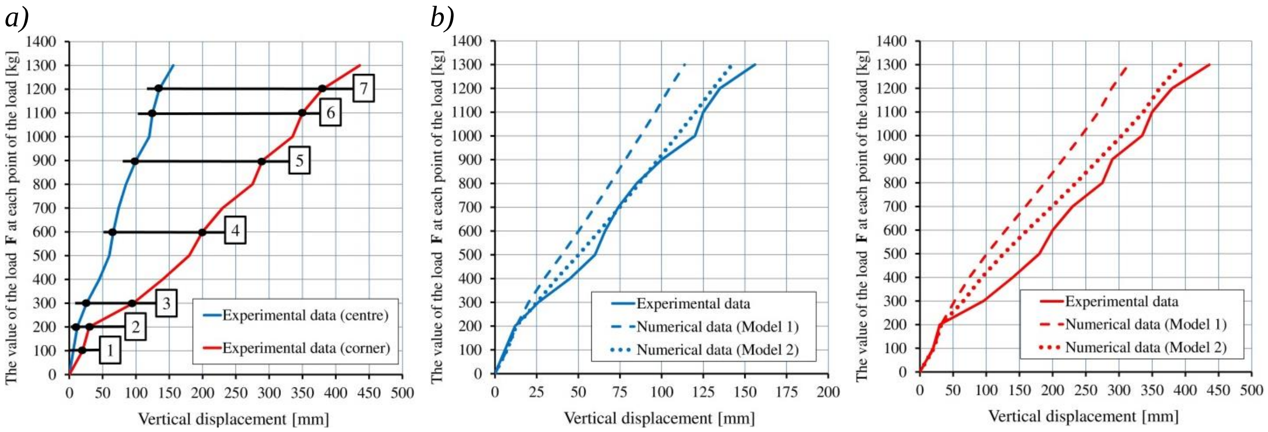

Fig. 2: Results - displacement of the corners and the centre of the slab as a function of the load: a) Experimental data (1 ÷ 7 - points of changes in the graph resulting from the disruption of investigation); b) Experimental and numerical data of the centre of the slab; c) Experimental and numerical data concerning the corner of the slab.

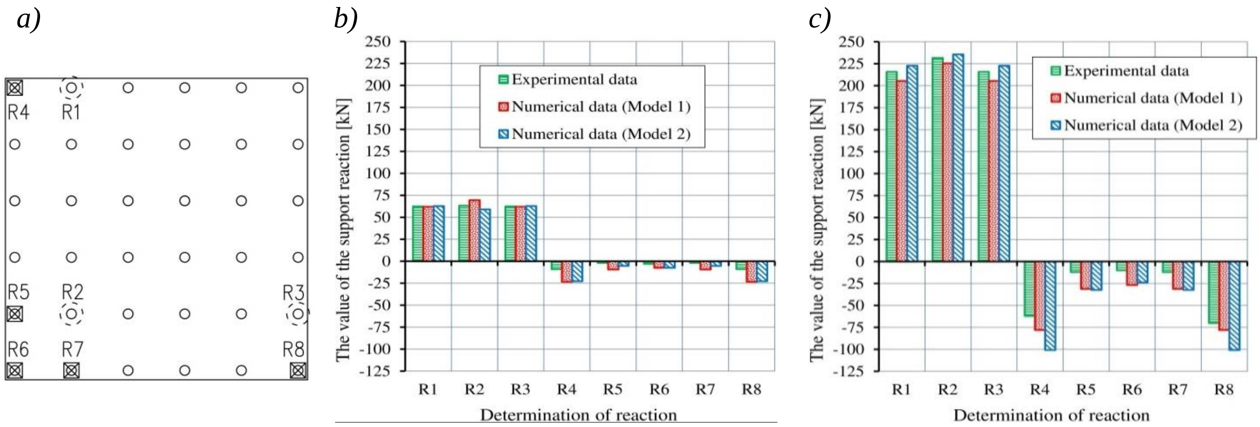

Fig. 3: Results - support reactions: a) Determining support reactions; b) Experimental and numerical values of support reactions under load F = 300 kg (3 kN); c) Experimental and numerical values of support reactions under load F = 1300 kg (13 kN).

5. Summary and Conclusions

The aim of the analysis dealt with in this paper was to represent the mechanism of destruction of the corner part of a slab-column structure in its state of a possible break-down, caused by the removal of the support at its corner. This problem is extremely complex due to the material heterogeneity of the model (the joining of steel and concrete), the application of nonlinear material models (the definition of steel as elastic-plastic material and concrete as elastic-brittle material) and the occurrence of internal forces (axial force, bending moment and shear force) in two directions perpendicular to each other. The application of two approaches in the analysis (two different models) has made it possible to determine approximately the range in which a satisfying approximation to the investigated model could be achieved. The performed analysis leads to the following conclusions:

- The assumptions governing the calculations of procedures determining the rigidity of reinforced concrete elements quote in EC2 permit to attain good results in the elastic range. The non-elastic range revealed considerably differing results, decreasing with the growing value of the load. The obtained results prove that the algorism of calculations suggested in EC2, based on a regular distribution of the scratches, is correct. In the experimental model the formation of scratches depended mainly on local parameters. Just preceding the destruction regular (symmetrical) scratches turned up. A drawback of the applied model is the impossibility of reading off the values of stresses in the reinforcing bars, which can be calculated basing only on the values of the bending moments.
- The proposed model of calculations (Model 2) has made it possible to get the values of displacements much more approximated to the experimental ones than in the case of Model 1. A particularly adequate mapping of the results was achieved in the first part of the non-elastic range. In the break-down situation the obtained values of displacement were almost the same as in Model 1.
- Each one of all these models permitted to get a very good approximation of the values of the reaction of the supports; these latter ones were measured on the supports. The values of reactions measured on steel bars with a diameter of 28 mm (stabilizing the model) differ considerably from the values resulting from numerical calculations. The reason of these differences is the application of the method of measuring the force in a steel bar. This measurement was accomplished by the electric resistance wire strain gauges glued on to the bar, and then measuring its deformation and determining the force in the bar.

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