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THEORETICAL ALGORITHM TO ASSESS THE VALUES OF THE BREAKING LOAD OF BARS SITUATED IN THE SUPPORTING ZONE OF THE SLAB-COLUMN CONNECTION

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Abstract: *Catastrophes of reinforced concrete building structures, particularly slab-column structures, which happened so far, indicate the necessity of analyzing the behaviour of this type of structures exerted by additional loads. The destruction of the supporting zone due to punching and the lack of adequately constructed reinforcement may result in a progressive catastrophe. Instructions concerning the prevention of such situations are to be found only in CSA A23.3 (2011) and ACI 318 (2004). The present paper deals with a model of calculations which permits to assess the values of reserves of the load-bearing capacity of the supporting zone after its destruction by punching. The presented considerations are based on results of experimental investigations carried out on reinforced concrete models of slab-column connections in the scale 1:1. The model of calculations permits to assess the values of the forces of the load, at which the bars situated immediately in the supporting zone fail. This model was verified basing on the results of experimental investigations, performed on simplified tested models.*

Keywords: Reinforced concrete structure, Progressive collapse, Punching, Slab-column connections, Two-way slabs structural integrity reinforcement, Experimental research.

1. Introduction

Slab-column structures are very common and provide an economical structural system. Investigative analyses of the behaviour of the supporting zone of slab-column structures within the range of their destruction due to punching permitted to develop various methods of calculations in this respect. But over the past years several failures of buildings have occurred, resulting in progressive collapses. The catastrophes in Boston, in Bailey Crossroads, in Cocoa Beach Florida, in Warsaw, in Mexico City and in Switzerland indicate the need of careful designing the reinforced concrete slab-column connections in order to prevent a progressive collapse. An inadequately constructed supporting reinforcement may result in a complete destruction of the whole structure.

Some research programs have been carried out to investigate the post-failure behaviour of slab-column structures. Research results, and also the technical and engineering procedure of modelling a flat slab of reinforced concrete slab-column structures were presented in literature (Wieczorek M, 2013, 2014). The application of continuous bottom reinforcement was recommended (Mitchell et al., 1979, 1984, 2012) as a practical and economical solution. Melo and Regan (1998) reported tests of slabs which were aimed at identifying the type of failure and predicting the post-punching resistance. The influence of the top and bottom reinforcement, the size of the reinforcing bars, the layout of the reinforcement and the stress-strain characteristics of the reinforcement were investigated by Mirzaei (2010). In order to assess accurately the reserve of the load capacity of the supporting zone after its destruction due to punching, reinforced concrete models of slab-column connections have been investigated in the scale 1:1 (Wieczorek B., 2013, 2014).

2. Description of the Problem

In order to assess accurately the reserve of the load capacity of the supporting zone after its destruction due to punching, reinforced concrete models of slab-column connections have been investigated

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in the scale 1:1 (Wieczorek B., 2013, 2014). The column was placed in three different positions in relation to the centre of the slab, viz. axially, on the unidirectional and the bidirectional eccentricity. Moreover, investigations concerning the load-bearing capacity of bars crossing each other above the column were carried out on a simplified model. Similarly as in the case of basic models, the column was situated in three different positions. The investigations were performed basing on basic and simplified models, which permitted to verify the assumption of possible simplifications of the tested models. The conformity of the obtained results on the level up to 5% justifies the statement that the results of investigations concerning the load-bearing capacity of slab-column connections based on simplified models provides a rather exact approximation. Basing on these investigations of simplified models, a numerical model was developed.

Due to practical reasons it proved to be expedient for the designers to elaborate a model of calculations which would make it possible to assess the load-bearing capacity of a slab-column connection, depending on the applied reinforcement.

These considerations were based on the results of investigations performed on a simplified model of a slab-column connection (Wieczorek B., 2013). This model consisted of the column element, through which passed two bars with a diameter of 16 mm. The test was carried out on a test stand in accordance with the diagram presented in Fig. 1. The reinforcing bars were fastened permanently on the test stand (Fig. 2), and the load was exerted on the base of the column. The aim of this test was to determine the relation between the vertical displacement of the column and the exerted load, and also to determine the value of the force of the load, at which the bars passing above the column fail.

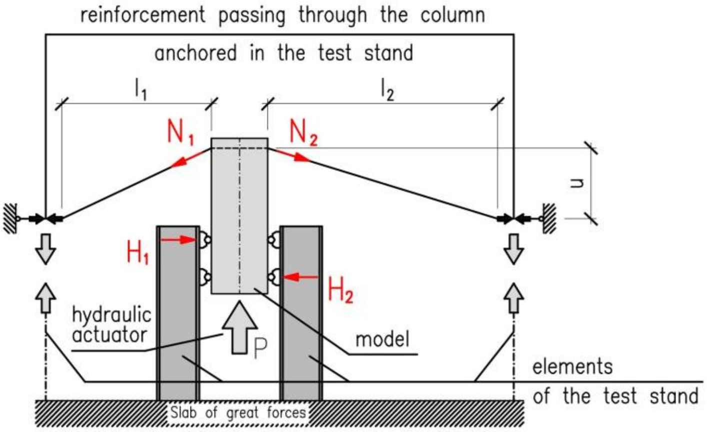

Fig. 1: Diagram of the load exerted on the model with the arrangement of forces taken into account in the model of calculations.

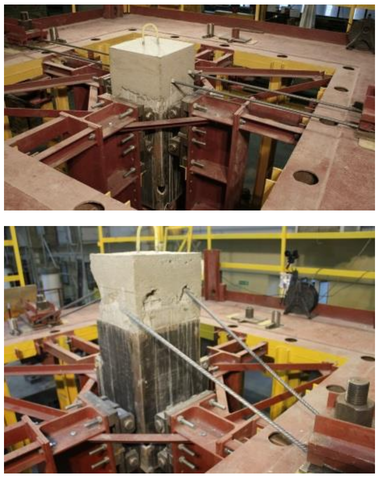

Fig. 2: Model situated on the test stand: a) Before the test; b) After the rupture of the bar.

The experimental investigations were carried out on reinforcing bars of class C in compliance with the Eurocode 2 (2010) with a diameter of 16 mm and an entire length of 2800 mm, the width of the column zone amounting to 400 mm. Two different situations of the column versus the test stand were considered, viz. axial ($l_1 = l_2 = 1200$ mm) and eccentrically equal to 285 mm ($l_1 = 915$ mm and $l_2 = 1485$ mm).

The model of calculations was constructed basing on the diagram corresponding to the performed tests, as shown in Fig. 1. Due to the forced vertical displacement of the column, caused by the load P exerted on its base, in the bars crossing the column above there occur, respectively, axial forces N_1 and N_2, resulting from the lengthening of the bars on the left and right-hand side of the column in relation to their initial length l_1 and l_2, measured from the point where the reinforcing bars are fastened to the test stand to the point at the edge of the column.

Basing on the diagram in Fig. 1, an algorithm was derived which permits to determine the values of the forces N_1 and N_2 occurring in the bars. The values of these forces depend directly on the value of the vertical displacement of the column and the initial length of the bars, as well as on the physical parameters of the reinforcing steel and the diameter of the bars. Besides that, also the horizontal interaction of H_1 and H_2 upon the column were taken into consideration. These forces result from the construction of the test stand, ensuring the vertical displacement of the column in the course of testing.

3. Synthesis of the Results

The results of calculations carried out basing on the derived algorithm were compared with the results of experimental investigations. The values of the force F obtained in tests were compared with the values of the forces N_1 and N_2. These values and their resultant in the vertical direction $W_y=N_{1y}+N_{2y}$ depending on the displacement of the column u have been presented in Fig. 3. The compatibility of the force W_y with the force P amounts to 3%. Larger differences in the initial range of displacements up to 170 mm are due to matching of the elements of the model with the test stand at the beginning of the tests.

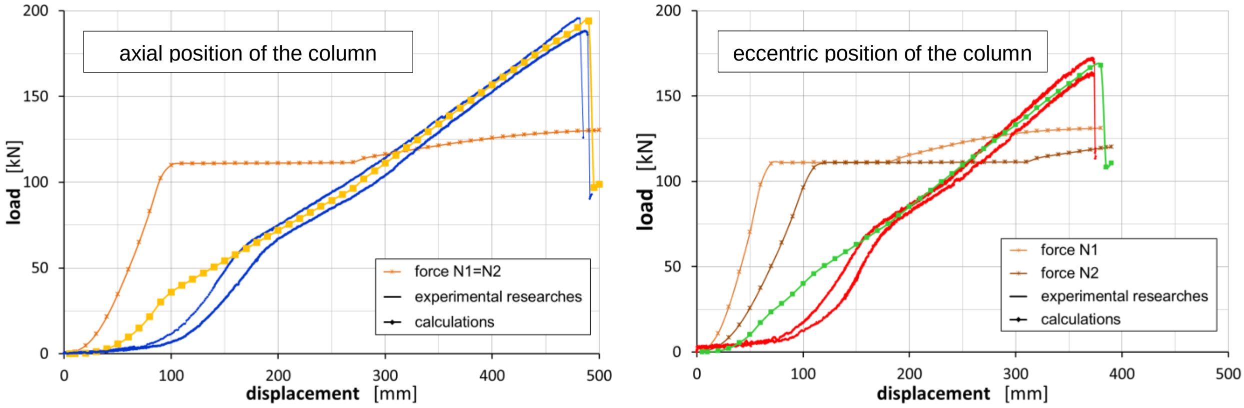

Fig. 3: Graph of changes of the loads as a function of the displacement of the column.

When investigating the strength of reinforcement steel in order to determine the relation between the stresses and deformations, the mean value of the force N_{max} was found, at which the bar ruptures. In the case of the applied reinforcing bars of the class C with a diameter of 16 mm the value of the force N_{max} amounted to 130.3 kN. It has been observed that the moment when the highest value of the force of the load P_{max} occurs, corresponds exactly with the moment when in one of the bars the value of the longitudinal force is equal to the value of the force of breaking N_{max}, whereas the force in one of the other bars is close to the value N_{max}. The difference between the forces N_1 and N_2 amounts then to about 5%. Such a compatibility was attained both in the case of an axial and eccentric position of the column.

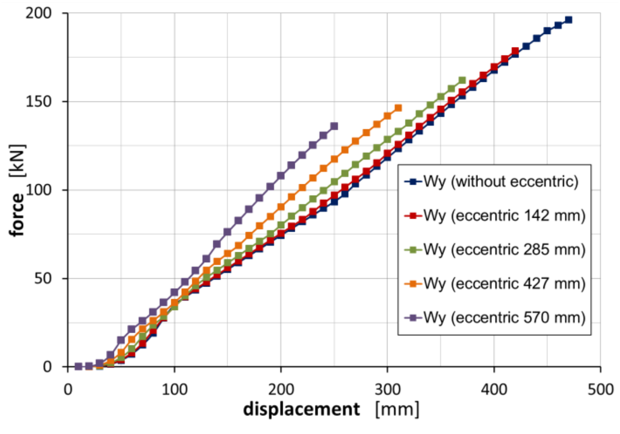

Fig. 4: Graph of changes of the forces W_y at different positions of the column.

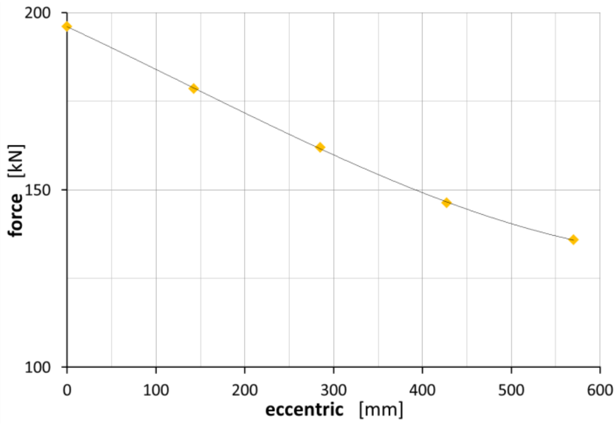

Fig. 5: Dependence of the force $W_{y,max}$ on the eccentric position of the column.

Making use of the elaborated algorithm, the influence of the eccentric position of the column on the value of the destructive force $W_{y,max}$ was analyzed, corresponding to the force of the load P_{max}. The position of the column was considered, respectively in the eccentric equal to 142.5 mm, 285 mm, 427.5 mm and 570 mm. The obtained results have been presented in Fig. 4. A linear decrease of the value of the force $W_{y,max}$ was observed when the column was shifted in relation to its axial position (Fig. 5). The relation between the value of the force $W_{y,max}$ and the shift of the axis of the column is denoted by the function $W_{y,max}(e)= 10^{-7}e^3 - 5^{-5}e^2 - 0.1168e + 196.05$.

4. Conclusions

The elaborated model of calculations permits to assess the value, of the destructive force $W_{y,max}$, at which the bars of the reinforcement passing just above the column in its connecting with the slab rupture. The value of this force depends on the amount of the applied reinforcement and the length of anchoring the reinforcing bars, taking also into account the possibility of an eccentric position of the column with regard to the surface of the slab. The application of this model requires, however, very exact information about the relation σ–ε concerning the applied reinforcing steel. In spite of the assumed simplifications in relation to actual slab-column structures, this model provides results rather close to those obtained experimentally.

Basing on already published results of investigations and the performed analyses, as well as the results of numerical calculations (Wieczorek B., 2013, 2014), this suggested model of calculations may be used to assess preliminarily the reserve of the load-bearing capacity of a slab-column connection after its destruction by punching.

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