

# Experimental research of punching shear strength on reinforced concrete test samples

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**Abstract.** The article presents the results of experimental studies on the samples of flat reinforced concrete slabs of a girderless frame under the punching by columns of round, square and rectangular cross-section. The description of sample design, the results of determining the physical and mechanical characteristics of materials, as well as the test procedure are given. The results of testing the samples are given. A comparative analysis of the experimental values of failure loads is performed depending on the shape of the section and the ratio of the column sides. The comparison of the experimental values of failure loads and calculated values determined by normative methods SP 63.13333.2012, ACI 318 and EC 2 shows that the design model of SP 63.13333.2012 gives a good fit to the experimental values for square column and overestimates the punching force for flat reinforced concrete slab at a ratio of the sides of rectangular column more than two. The results of the performed experimental studies show that the design model of SP 63.13333.2012, when calculating for punching, does not take into account the influence of the geometrical shape of the column, which can lead to a decrease in the structural safety of the flat slabs of reinforced concrete floors.

## 1. Introduction

The issues of ensuring the constructive safety of buildings and structures, the survivability of constructive systems in modern conditions are becoming increasingly relevant in domestic and foreign practice of scientific research [1]. One of the aspects of ensuring the structural safety of buildings is the improvement of existing methods for calculating reinforced concrete structures that allow a correct calculation of the strength and deformation parameters of structures under different design situations [2-5], in particular, in the calculation of flat reinforced concrete slabs for punching. In modern normative documents of different countries, this calculation is performed on the basis of similar design models that have an empirical basis. Due to the empirical nature of the design models, the effect of structural parameters and material characteristics on the punching shear strength of slabs is revealed mainly experimentally, for subsequent theoretical analysis and accounting in calculation methods. The proposed methods for calculating flat plates for punching, including [6-10], are based on the results of previously published experimental studies, generally accepted views on the nature of deformation of structures and the approaches to calculating the strength of the slab developed by the authors that allow the most complete reflection of the effect of design parameters, impacts and other design factors. A significant number of experimental studies of the resistance of flat reinforced concrete slabs



to the action of shear forces [11-17] testify to the urgency of the issue of improving the normative design model of punching for plates.

The results of experimental studies by foreign authors [11-14] show that one of the constructive factors affecting the strength of reinforced concrete slabs during punching is the ratio of the sides of the section of the column (loading area). When the ratio of the sides of rectangular column is more than two, the punching shear strength of the plate is reduced. This factor is taken into account in the design standards of the US and Europe [18-19]. In SP 63.13333.2012 [20] this parameter is not considered. A possible approach to take into account the ratio of the sides of the column section when calculating for punching according to the technique of SP 63.13330.2012 is proposed in [9-10].

The purpose of the research on the test samples is to obtain experimental data on the strength and the nature of deformation of flat concrete slabs by punching a column of rectangular cross-section, depending on the ratio of its side. In domestic practice, the influence of this constructive parameter has not been experimentally investigated.

## 2. Methodology

The test samples were a fragment of a monolithic joint of a column with rectangular cross-section and a flat plate. The variable parameter was the ratio of the sides of the column section (loading area). Four samples tested:

- CMR-D – a column of round section with a diameter of 210 mm.
- CMR-1 – a column of square section with a side size of 200 mm.
- CMR-2.5 – a column of rectangular section of the size 200×500 mm.
- CMR-4 – a column of rectangular section of the size 200×800mm.

The formwork dimensions of the plate in the plan for the samples CMR-D, CMR-1 were 2000×2000 mm, for the samples CMR-2.5 and CMR-4 were 2000×2200 mm and 2000×2400 mm, respectively. The thickness of the plates of all samples was 140 mm.

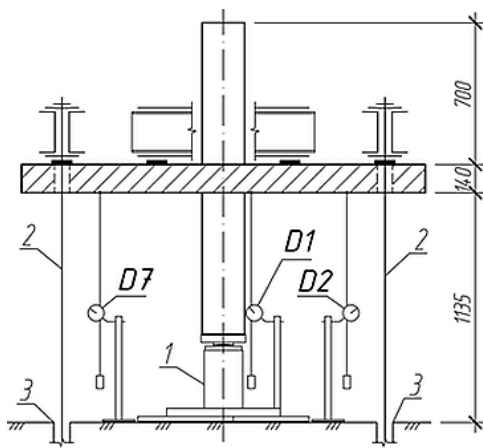
Plates of samples were reinforced with grids at the top and bottom face. Transverse reinforcement in the plates was absent. Reinforcement at the upper (tensioned) edge of the plate was carried out by reinforcing bars with a 14 mm diameter of A500 class with a step of 100 mm, at the lower (compressed) face the reinforcement was accepted as minimum (rods 5 mm in diameter B500 class with a step of 100 mm) to study the stress-strain state of compressed concrete when perceiving the punching force. Longitudinal reinforcement of the column fragment in the samples is accepted as follows: CMR-D - 8 rods of 12 mm diameter A500, CMR-1 - 4 rods 18 mm in diameter A500, CMR-2.5 - 6 rods 16 mm in diameter A500 and CMR-4 - 8 rods with a diameter of 16 mm class A500. The transverse reinforcement in the columns was carried out by stirrups diameter 4 mm class B500 with a step of 100 mm. Crushed dolomites' limestone was used for the concrete with a maximum aggregate size of 20 mm.

The physical-mechanical characteristics and the " $\sigma$ - $\epsilon$ " diagram of concrete during compression were determined from the test cube and prism tests. After the end of the tests, cores were selected from the samples, which are tested for compression and splitting. All tests were carried out in accordance with standards GOST 10180-2012 and GOST 24452-80. The physical-mechanical characteristics and the " $\sigma$ - $\epsilon$ " diagram of the longitudinal reinforcement of plates and columns were determined from the tensile test data in accordance with standard GOST 12004-81. The main results of determining the physical-mechanical characteristics of the samples materials are given in table 1.

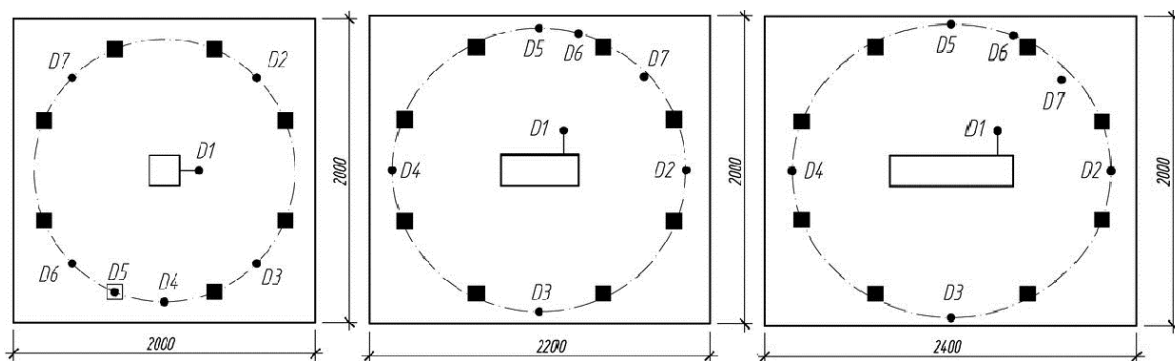
Loading of samples was carried out in a power frame. The concentrated load was created by a hydraulic jack with a carrying capacity of 1000 kN and applied to the lower edge of the column. Load on the plate of samples was transmitted through four metal crossheads, having two hinged support points on the upper edge of the plate. The crossheads were held by tie rods passing through the sleeves in the sample plate and fixed in the power floor (figure 1). To transfer uniform pressure to the surface of the slab over all eight points, all tie rods and crossheads were taken in the same size. To control the uniformity of the load application, two strain gauges were mounted on each tie rod along diametrically opposite sides.

**Table 1.** Characteristics of the samples materials.

| Test sample | Concrete         |             |                |             | Reinforcement                             |                  |                  |
|-------------|------------------|-------------|----------------|-------------|-------------------------------------------|------------------|------------------|
|             | $R_{cube}$ , MPa | $R_b$ , MPa | $R_{bt}$ , MPa | $f_c$ , MPa | $\sigma_{0,2} / \sigma_{ult}$ , MPa / MPa |                  |                  |
|             |                  |             |                |             | $\varnothing 14$                          | $\varnothing 16$ | $\varnothing 18$ |
| CMR-D       | 42.5             | 34.4        | 2.2            | 35          | 585/708                                   | –                | –                |
| CMR-1       | 40,0             | 31,6        | 2,0            | 28.9        | 585/708                                   | –                | 592/684          |
| CMR-2.5     | 29,0             | 22,2        | 1,6            | 22.3        | 619/747                                   | 597/687          | –                |
| CMR-4       | 32,8             | 25,6        | 1,7            | 25.6        | 619/747                                   | 597/687          | –                |

**Figure 1.** The sample loading scheme: 1 – hydraulic jack; 2 – tie rods; 3 – power floor.

Deflections of slab were measured by means of dial gauges as the difference in slab displacements at a given point and near the surface of the column. Arrangement schemes of dial gauges and load application points on the test samples slabs are presented in figure 2. Width of cracks opening on a slab surface was measured by means of microscope.

**Figure 2.** Schemes of dial gauges location and points of load application on the plates of samples

To measure concrete deformations on the compressed face of the slab, strain gauges with a base of 50 mm were used. To measure the deformations of plate and column reinforcement before concreting the sample on the pre-prepared sections of the reinforcement, plugs were attached, which were removed when preparing the sample for testing. Then on reinforcement strain gauges with a base of 20 mm were pasted.

Loading of the sample was carried out by steps of 5% of the theoretical failure load. The exposure time of the sample under load at each step was 15 minutes. At each loading stage was made fixing values of strain gauges, indications of dial gauges, schemes of cracks formation and its development. Sample CMR-D in the process of testing is shown in figure 3.

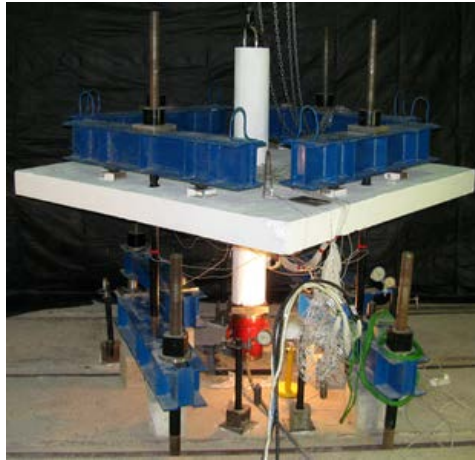


**Figure 3.** Testing of sample CMR-D.

### 3. Results and Discussion

The deflection graphs of the plates of CMR-D and CMR-1 samples, shown in figure 4, allow us to conclude that the movement of the plate relative to the column at the fixation points (figure 2) was almost symmetrical. The maximum divergence of deflections on opposite sides of the plate does not exceed 4%.

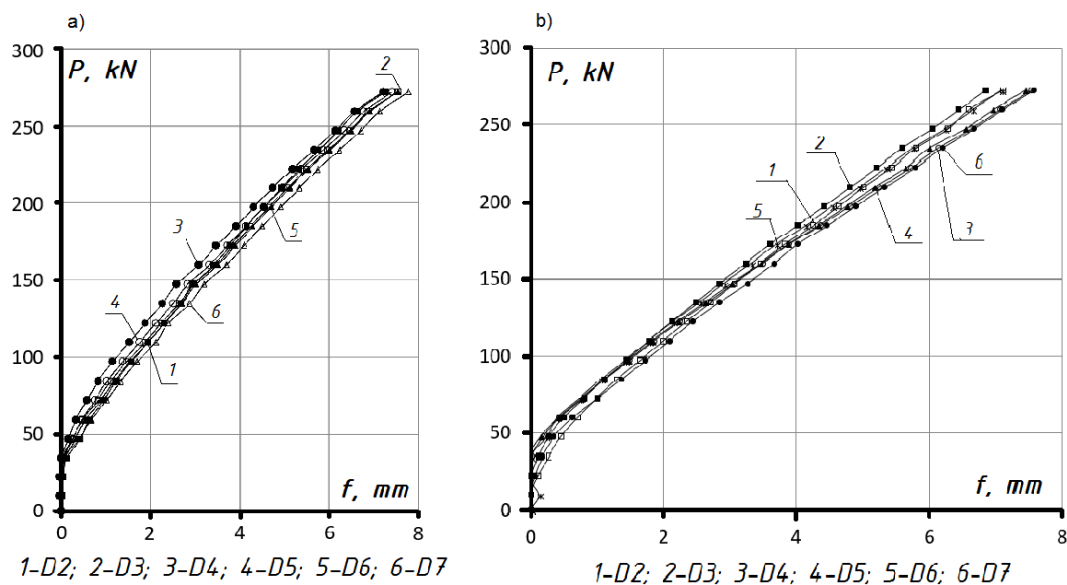


**Figure 4.** Deflection graphs of the plates samples CMR-1 (a) and CMR-D (b).

Failure of the samples was brittle due to punching plate by column. Experimental ( $V_{exp}$ ) and calculated values of failure loads are given in table 2. Calculated values of failure loads were determined in accordance with the SP 63.13330.2012 ( $V_{SP}$ ), ACI-318 ( $V_{ACI}$ ) and EUROCODE 2 ( $V_{EC}$ ) procedure.

Comparison of the calculated and experimental values of the strength of the tested samples shows that with an increase in the ratio of the column cross-section more than two the method of calculation SP 63.13330.2012 overestimates the bearing capacity of the samples to punching. The calculation procedure for ACI-318 most accurately estimates the load-bearing capacity of the samples compared to the conservative estimate of the EUROCODE 2. Satisfactory convergence of the calculated and

experimental values is a consequence of the adjustment of the calculated perimeter, which is provided in the methods of ACI-318 and EUROCODE 2.

**Table 2.** Experimental and calculated values of samples strength.

| Test sample    | $V_{exp}$ , kN | $V_{SP}$ , kN | $V_{SP} / V_{exp}$ | $V_{ACI}$ | $V_{ACI} / V_{exp}$ | $V_{EC}$ | $V_{EC} / V_{exp}$ |
|----------------|----------------|---------------|--------------------|-----------|---------------------|----------|--------------------|
| <b>CMR-D</b>   | 284.9          | 243.3         | 0.854              | 218.1     | 0.766               | 209.2    | 0.734              |
| <b>CMR-1</b>   | 272.0          | 266.1         | 0.978              | 238.4     | 0.876               | 204.8    | 0.753              |
| <b>CMR-2.5</b> | 281.3          | 312.9         | 1.11               | 277.1     | 0.985               | 218.8    | 0.778              |
| <b>CMR-4</b>   | 328.4          | 451.4         | 1.37               | 335.9     | 1.023               | 235.6    | 0.717              |

The results of the performed experiments show that the relative strength of flat plates during punching decreases with increasing ratio of the column section sides of more than two. The same regularity was noted in the experimental studies of the authors [11-14], which indicates the systematic influence of the constructive parameter under consideration on the strength of flat reinforced concrete slabs during punching.

#### 4. Conclusion

Experimental data on the strength and deformability of flat reinforced concrete slabs under punching by rectangular column depending on the ratio of its sides are obtained. The results of the study and the results of other author's investigations [11-14] allow us to conclude that the structural parameter under consideration is systematically influencing the decrease in strength of flat reinforced concrete slabs during punching.

A significant decrease in the strength of the plates during the punching, observed in experiments (in the case of column pylons more than 30%), demonstrates the need to take this parameter into account in the normative methodology for calculating the punching strength of reinforced concrete slabs to ensure the structural safety of flat slabs of reinforced concrete floors.

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