Investigation of Stress-Strain State of Edge-Column Slab Connections on Finite Element Models

V B Filatov¹, Z Sh Galyautdinov¹, M V Kovalenko¹

¹Chair of Building Structures, Samara State Technical University, Molodogvardeyskaya str., 194, Samara 443001, Russia

E-mail: vb_filatov@mail.ru

Abstract. The article presents the results of numerical research on finite-element models of flat girdelass floors. The influence of geometric parameters on the magnitude and ratio of force factors that occur during the operation of a flat reinforced concrete slab was studied. Force factors include the combined action of the punching force and the bending moment. The variable parameters in the study were the flexibility of the column and the size of its cross-section. The purpose of the study was to substantiate the ratio of the bending moment and the longitudinal force in the column for the development of methods for conducting experimental studies on test samples. Based on the results of the study, the influence of the column’s flexibility and the dimensions of its cross-section on the ratio of the studied force factors was established. The study made it possible to choose the best option for loading test samples. The results of the study were used to conduct experimental studies on the punching of flat reinforced concrete slabs.

1. Introduction
Numerical research on finite element models was carried out to define loading scheme when samples tests. It is known that deformations of slabs under uniformly distributed load and under concentrated forces is different. In the design of reinforced concrete structures is generally considered the action of uniformly distributed loads, while the test samples during the test load is applied in the form of concentrated forces. When testing linear construction (beams and columns) this distinction isn't so essential or can be compensated by a design procedure, however, for slab constructions, working in two directions, influence of the loading scheme can be considerable [1]. Numerical methods are the effective tool for the research of stress-strain condition of reinforced concrete constructions and are successfully applied by the authors [2–5].

Investigation was carried out on the finite element models developed for three test samples. The test samples made of heavy concrete represent a fragment of monolithic joint of a column of rectangular section with flat plate. The varied parameter was the sides of the column cross-section. Testing of samples was supposed to be carried out in the test frame by the application of loading when reinforced concrete slab will be punching by the column. The aim of the numerical research was to define such scheme of application of concentrated forces on the plate, at which displacements of slab points would best correspond to displacements of the same slab points under the action of uniformly distributed load.
The calculation of bending elements (plates) for punching is performed when a concentrated force and bending moment are applied to them. For elements without shear reinforcement, the strength condition is as follows:

\[
\frac{F}{F_{b,ult}} + \frac{M}{M_{b,ult}} \leq 1
\]  

(1)

In equation (1) it is assumed:
- \(F\) – concentrated force from external load;
- \(M\) – bending moment from external loads;
- \(F_{b,ult}\) and \(M_{b,ult}\) – the maximum concentrated force and bending moment that can be perceived by concrete in the calculated cross-section when they act separately.

It should be noted that according to [6] the value of \(M\) is equal to half the sum of the moments in the column sections above and below the plate, in addition, the ratio \(\frac{M}{M_{b,ult}}\) is assumed to be no more than 0.5\(\frac{F}{F_{b,ult}}\).

As the contour of the calculated cross-section, we consider the area located around the zone of force transfer normally to its longitudinal axis at a distance of 0.5\(h_0\) from the load application contour, which is taken as the column cross-section (\(a\times b\)), where \(h_0\) is the working height of the floor slab. Tangential forces from the concentrated force and bending moment act on the surface of the calculated cross-section. These forces must be perceived by concrete with the calculated concrete tensile strength \(R_{bt}\).

The main formulas and dependencies for calculating the bearing capacity of plates for punching are derived from experimental data and are semi-empirical in nature. At the same time, most of the research is related to the study of the resistance of plates during central punching, when there is no bending moment [7-10].

Currently, experimental studies of plates on the combined effect of the punching force and bending moment are given considerable attention both in our country and abroad [11-16]. For off-center punching, the ratio of the bending moment to the punching force \(M/F\) is a significant factor. The authors [17-25] assumed this ratio to be 0.3 when conducting experimental studies on experimental samples. The experimental studies were carried out on test samples with square-shaped cross-section columns.

2. Methodology

To identify the force factors that act during off-center punching and their quantitative ratio, a numerical experiment was performed on finite element models. The finite element model (figure 1) was a four-story frame building with a grid of columns 6×6 m and a floor slab thickness of 200 mm.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{finite_element_model.png}
\caption{The finite element model.}
\end{figure}
Finite element models were developed in the LIRA-SAPR environment and represented a reinforced concrete flat plate (finite element - "shell") in the middle of which the column fragment (finite element - "rod") is located. The connection of rod elements of columns with plate elements of floors was performed taking into account their rigid coupling. Plate and column connection was modelled by the options "absolutely rigid body" which was set in plate nodes and "absolutely rigid element" which was set in rods (column). The sizes of "absolutely rigid body" varied and corresponded to column cross-section – 300×300 mm, 400×400 mm and 500×500 mm. For the analysis of force factors, parameters such as the height of the floor and the cross-section of columns were varied.

The floor was loaded with a uniformly distributed load. The calculation results were used to analyze the ratio of bending moment $M$ and punching force $F$ for the edge column at the second floor (figure 2).

**Figure 2.** Plots of longitudinal forces $N$ (kN) and bending moments $M$ (kN×m) for edge column.

### 3. Results and discussion

The geometry and dimensions of the columns can significantly influence the punching resistance of concrete flat slabs, since they affect the stress distribution in the slab-column connection. The results of a numerical study of the $M/F$ value depending on the flexibility of the columns and the size of their cross-section are presented in table 1.

| $\lambda$ | $a\times b$, mm | $300\times300$ | $400\times400$ | $500\times500$ |
|-----------|-----------------|----------------|----------------|----------------|
| 5         |                 | 0,299          | 0,348          | 0,365          |
| 10        |                 | 0,282          | 0,344          | 0,371          |
| 15        |                 | 0,259          | 0,333          | 0,367          |
| 20        |                 | 0,239          | 0,320          | 0,360          |

Analyzing the results obtained (figure 3), it can be noted that the ratio of the bending moment to the punching force $M/F$ varies in the range of 0.24-0.37, depending on the flexibility and size of the cross-section of the column. It can also be noted that with the same flexibility of the column, the ratio of the bending moment to the punching force $M/F$ increases with increasing cross-section of the column.
In addition, analyzing the graphs in figure 3, it can be noted that the most significant effect of column flexibility is on the ratio of bending moment to punching force $M/F$ for columns with a smaller cross-section. So for columns with cross-sectional dimension of $300 \times 300$ mm to increase the flexibility of $\lambda$ from 5 to 20 led to a decrease of the ratio $M/F$ by 20% and for columns with cross-sectional dimension of $500 \times 500$ mm by increasing the flexibility of $\lambda$ between 5 and 20 a change of attitude $M/F$ does not exceed 2%.

![Figure 3. Graph of the M/F ratio depending on the cross-section size and column flexibility.](image)

4. Conclusion
The results of a numerical study of the influence of geometric parameters of flat girderless floors on the value and ratio of force factors $M/F$ that occur during the operation of a flat reinforced concrete slab on the combined effect of the punching force and bending moment allow us to conclude that when testing prototypes, it is advisable to take the value of the $M/F$ ratio in the range of 0.25 – 0.3.

It should be noted that the authors [17-25] when testing samples of reinforced concrete slabs for the combined effect of the punching force and bending moment also took the value of the $M/F$ ratio in the range of 0.25 – 0.3, which confirms the validity of the results of the numerical study.

5. References
[1] Sagaseta J, Tassinari L, Fernandez Ruiz M and Muttoni A 2014 Eng. Struct. 77 17–33
[2] Setiawan A, Vollum R L, Macorini L and Izzuddin B A 2020 Structures 27 2048–68
[3] Sagaseta J, Muttoni A, Fernandez Ruiz M and Tassinari L 2011 Mag. Conc. Res. 6 441–457
[4] Filatov V B and Galyautdinov Z Sh 2018 IOP Conf. Series: Mater. Sci. Eng. 451 012061
[5] Tamrazyan A G and Zvonov Yu N 2016 Industrial and civil engineering (Moscow) 7 24–28
[6] SP 63.13330.2018 Concrete and won concrete construction. Design requirements (Moscow)
[7] Karpenko N I and Karpenko S N 2012 Concrete and reinforced concrete (Moscow) 5 10–16
[8] Trekin N N and Pekin D A 2014 Industrial and civil engineering (Moscow) 7 17–20
[9] Muttoni A 2008 ACI Str. J. 4 440–450
[10] Susanto T, Cheong H, Kuang K and Geng J 2004 ACI Str. J. 5 678–687
[11] Hawkins N M, Falsen H B and Hinojosa R C. 1971 ACI Spec. Publ. SP-30 127–46.
[12] Vanderbilt M D 1972 J. Struct. Div. Proc. ASCE ST5 961–73
[13] Filatov V B 2017 MATEC Web of Conferences 117 00045
[14] Broms C E 1990 ACI Str. J. 3 292–304
[15] Bolgov A N and Sokurov A Z 2014 Conf. on concrete and reinforced concrete IV 139–149
[16] Filatov V B 2018 E3S Web of Conferences 33 0200
[17] Ritchie M, Ghali A, Dilger W H and Gayed R B 2006 ACI Str. J. 1 74–82
[18] Edward A and Susanto T 2008 ACI Str. J. 5 541–551
[19] El-Salakawy E F, Polak M A and Soudki K A 2003 ACI Str. J. 3 297–304
[20] Ferreira M, Oliveira M H and Melo G S 2019 Eng. Struct. 196 109311
[21] Kruger G, Burdet O and Favre R 1998 Simposium in Civil Engineering 1-8
[22] Mortin J D and Ghali A 1991 ACI Str. J. 2 191–198
[23] El-Salakawy E F, Polak M A and Soliman M H 1999 ACI Str. J. 1 79–87
[24] Sherif A G and Dilger W H 2000 ACI Str. J. 3 455–467
[25] Anggadjaja E and Susanto T 2008 ACI Str. J. 5 541–551