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The comparison analyses of nonlinear calculations of flat plate systems with and without shear reinforcement

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ABSTRACT:
Linear, nonlinear and test comparison analyses of flat plate slabs with shear reinforcement are presented in the article. Analyses of slabs with and without shear reinforcement by nonlinear simulations are introduced. The calculations of slabs without and with 0.16 m eccentricities were performed. For analyses finite element method were used. Design models of flat slab with column by "Lira SAPR" software were carried out. After the calculations whole results with experimental investigations were compared. The comparison analyses were shown, that presence of shear reinforcement far increase the capacity of slabs. Furthermore, the presence of shear reinforcement depends on eccentricity increases the axial force approximately 25%. Moreover, the difference between tests and nonlinear analyses results are about 6.4%.

KEYWORDS:
reinforced concrete structures; flat plate; nonlinear analyses; finite element method; shear reinforcement

1. Introduction

Buildings which are erected by flat plate systems became widespread in the Republic of Armenia, because of free planning and they are economically and ecologically profitable. A flat plate floor system is a two–way concrete slab supported directly on columns with reinforcement in two orthogonal directions. This system, which is popular in residential buildings (hotels, apartments and restaurants), has the advantages of simple construction and formwork and a flat ceiling, the latter of which reduces ceiling finishing costs because the architectural finish can be applied directly to the underside of the slab.

Armenia is located in a seismic region. The territory is divided in three seismic zones, where the accelerations of ground can be equal to 0.2g, 0.3g and 0.4g respectively and the formation of damages in the joints of the columns with a slab can lead to the destruction of the plate. The main parameter affecting both on the bearing capacity of a slab and on its local stress–strain state is the bending moment in columns. During the seismic action the bending moments can be significant.

One of the important roles is the opening in slabs. Openings in slabs are usually required for stairs, elevations, air conditioning, wires and pipes. Consequently, the size and location have their own influences on the stress–strain state of the slab.

Several types of nonlinear analyses are exist. One of the most using is Newton–Raphson method.

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Suppose that the simulation proceeds at a certain time step, where the displacement is D_0 the external force is F_0 and P_0 represents the point at the response curve described by equation (1). Now, the time is increased one substep further so that the external force is increased to $F_0+\Delta F$, and we want to find the displacement at next time step (Fig. 1).

Starting from point P_0, we can calculate a tangent stiffness, the linearized stiffness, and solve the following equation:

$$K(D_0) \times \Delta D = \Delta F \tag{1}$$

The displacement D_0 is increased by ΔD to become D_1: Now, in the D–F space, we are at (D_1, $F_0+\Delta F$), far from our goal P_4. To proceed, we need to come back from the point P_1' to the actual curve (P_1).

Substituting the displacement D_1 into the left–hand side of the governing equation (1), we can calculate the actual force F_1 which will balance the displacement:

$$K(D_1) \times D_1 = F_1 \tag{2}$$

Now we can locate the point (D_1, F_1), which is on the actual force–displacement curve. The difference between the external force ($F_0+\Delta F$) and the balanced force (F_1) is called the residual force of that equilibrium iteration:

$$F_1^R = (F_0 + \Delta F) - F_1 \tag{3}$$

If the residual force is smaller than a criterion, then the substep is said to be converged, otherwise another equilibrium iteration takes place. The iterations repeat, until the convergence criterion satisfied.

The procedure described above is called the Newton–Raphson method [1].

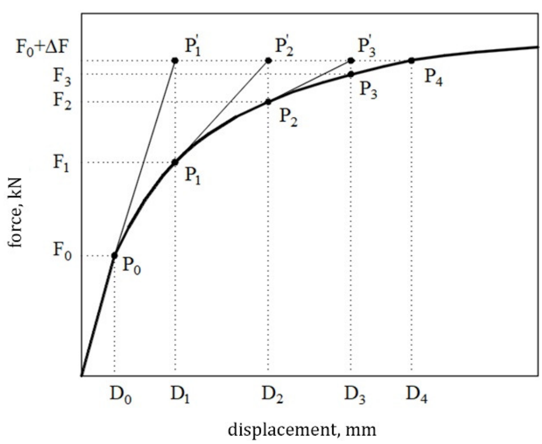

Fig. 1. Force–displacement relation according to Newton–Raphson method [1]

2. Input datum

Cast–in–situ reinforced concrete flat plate designed models without eccentricity with 0.16 m and 0.32 m eccentricities are presented in the article. Slab calculations with shear reinforcement were carried out and finite element method were used (Fig. 2). The flexural reinforcement ratios in each direction 1.3% were taken. The diameter of flexural reinforcement 16 mm and the step 120 mm were chosen. As shear reinforcement diameter with 10 mm was taken (Fig. 3).

For calculations by finite element method the boundary conditions with two elastic elements, which have 10 cm height were described. The high compression and low tension strengths to these elements were given.

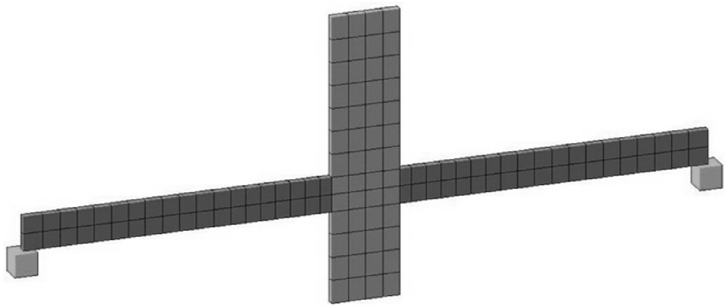

Fig. 2. 3D modeling of flat plate by finite element method

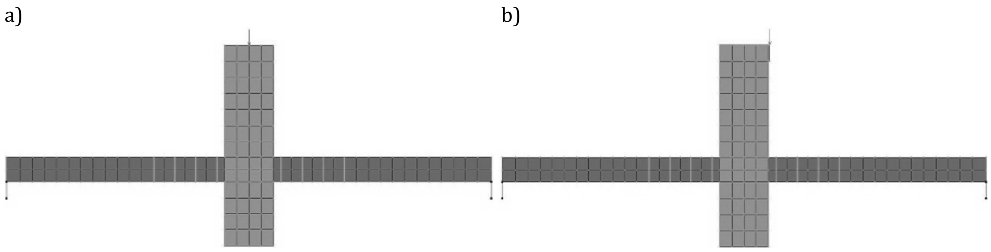

Fig. 3. With shear reinforcement slab model without (a) and with 0.16 m eccentricities (b)

With 3 m length and 15 cm height slab was presented in the paper. The cross section shape of column is square and equal to 0.3 × 0.3 m, apart from, the height is 1.25 m. The lower and upper parts of column are 0.4 m and 0.7 m respectively. The compression cube strength of concrete is 45 MPa and the yield strength of steel bar is 400 MPa [2].

The all calculations by “Lira SAPR” software [3] were implemented.

Tests in the structures laboratory of the Swiss Federal Institute of Technology were carried out. Six reinforced concrete flat slabs with a square column in the middle of the slab were performed. A special shape to the column was given to apply the axial force with an eccentricity. The moment is thus proportional to the force. The tests were implemented with a deformation–controlled hydraulic jack with a constant loading rate of 4 kN per minute. During each test, the load was applied in steps of 40 kN. Between load steps the deformation was kept unchangeable about 10–15 minute for inspection and measurements [4].

After the maximum load was reached, the deformation was further grown to record the post–punching behaviour of the slabs. The tests ended when the column had penetrated into the slab or when the rotation of the column exceeded 5%.

Automatic data acquisition devices were taken each minute on a computer. Crack pattern was inspected and the manual measurements of radial and tangential deformation at the bottom surface of the slab were performed. The measuring devices are the following:

- 35 inductive displacement sensors;
- 32 strain gauges on the compressive side in radial and tangential direction;
- 4 strain gauges glued on the longitudinal bars near the column in the punching zone;
- 3 inclinometers on the column;
- 2 inductive displacement sensors measuring the opening of the punching cracks across the section of the slab;
- 1 force sensor on the jack;
- 66 manual measurements on the tensile side to measure opening of the cracks [4].

3. Results

In accordance with results of finite element method deflections of slabs with stirrups in the case of linear analyses without and with 0.16 m eccentricities are equal to 4.98 and 3.97 mm respectively and in the case of nonlinear analyses are 31.7 and 24.6 mm correspondingly (Fig. 4).

a) b)

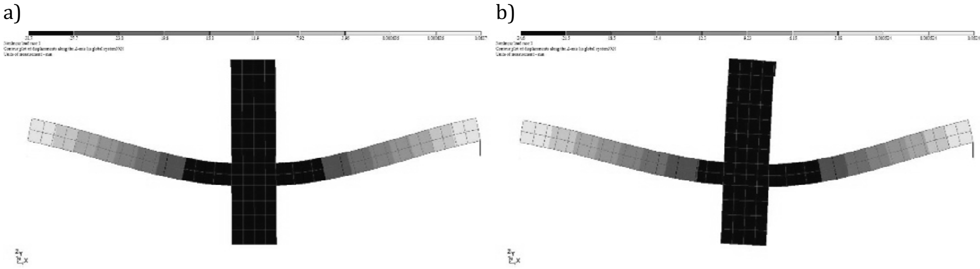

Fig. 4. With shear reinforcement the slab deflections according to finite element method in the case of nonlinear analyses without (a) and with 0.16 m (b) eccentricities

The deflections which are mentioned above from maximum axial forces were obtained. The ultimate axial forces without and with 0.16 m eccentricities are equal to 578 and 432 kN ccordingly.

Depends on eccentricities and axial forces, the maximum deflections of slabs with shear reinforcement in the case of linear, nonlinear and test analyses were shown in Figure 5. Here we can notice, that the results of linear calculations are changed linearly, however, the results of nonlinear calculations are changed nonlinearly.

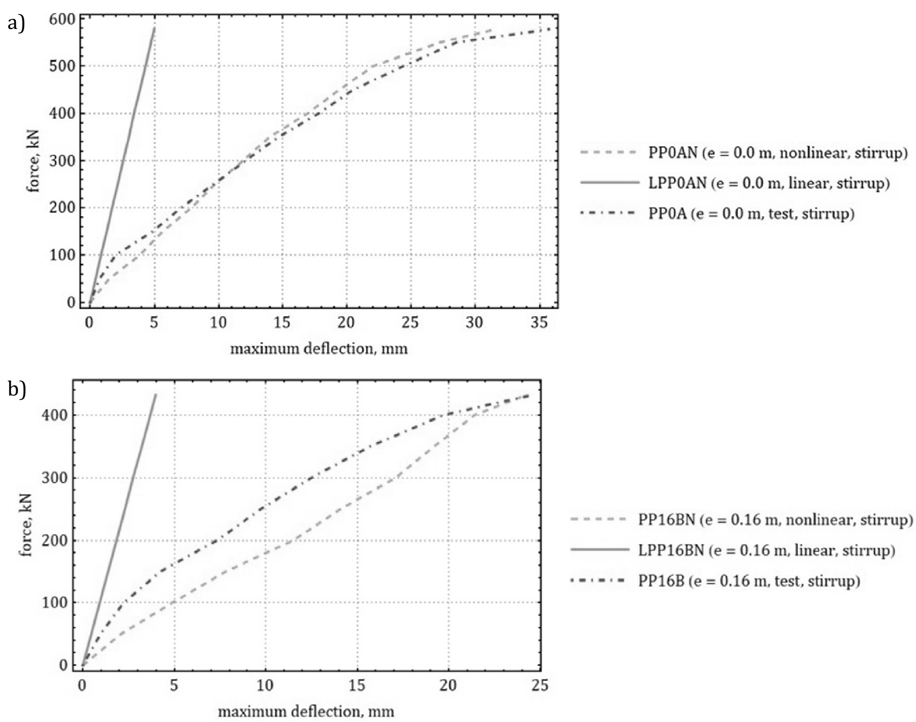

Fig. 5. The relation of force–displacement with shear reinforcement of slab in the case of linear, nonlinear and test results

Figure 5 shows, that the deviations of calculation results of slabs with shear reinforcement without and with 0.16 m eccentricities compare with the tests results are 11.5 and 1.3% respectively. The deflection of slabs with shear reinforcement in case of nonlinear analyses according to 0.0 and 0.16 m eccentricities is about 6.3 and 6.1 times larger than in linear cases.

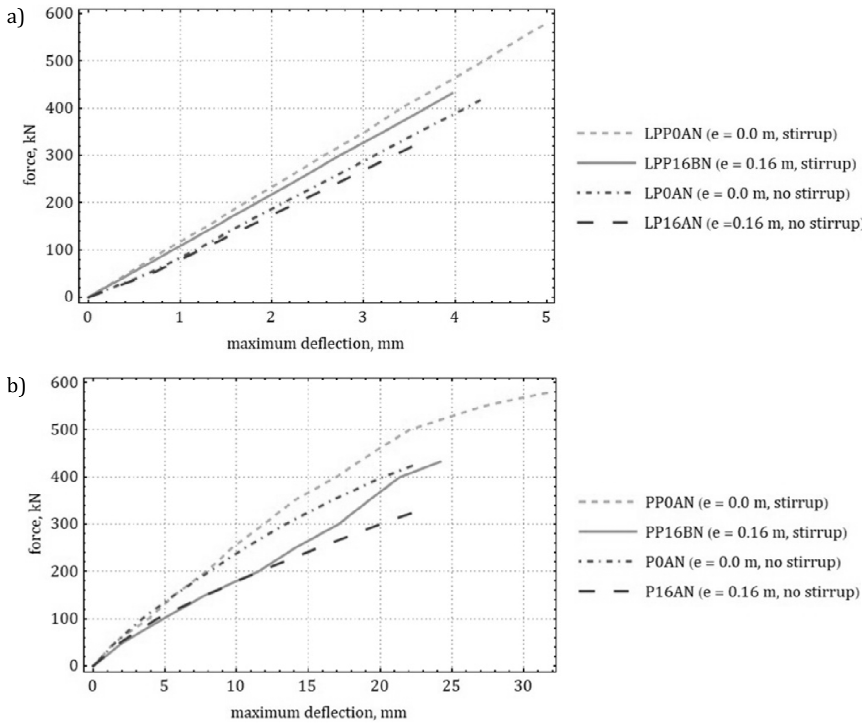

Fig. 6. The relation of force–displacement with and without shear reinforcement of slabs in the case of linear (a) and nonlinear (b) results

Figure 6 shows, that the ultimate axial force in the case of 0.16 m eccentricity decreases 25.2% compare with 0.0 m eccentricity case. Besides that, we should mention, that without eccentricity the presence of shear reinforcement increases the ultimate axial force about 27% and with eccentricity approximately 23%.

4. Conclusions

The investigations of slab capacities with and without shear reinforcement shown, that the presence of shear reinforcement absolutely increases the slab capacity. Current and previous [5] comparison analyses results shown, that depending on eccentricity the presence of shear reinforcement increases the ultimate axial force 23–27%. Besides that, comparing the nonlinear results with test results depending on eccentricity the deviation is about 1.3–11.5%. Finally, depending on eccentricity the results of slab deflections obtained by nonlinear analyses are 6.1–6.3 times larger than by linear analyses, consequently during calculations it is necessary to take into account the nonlinearity of material.

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Analiza porównawcza nieliniowych obliczeń systemów płaskich płyt ze zbrojeniem i bez zbrojenia

STRESZCZENIE:
W artykule przedstawiono liniowe, nieliniowe i doświadczalne analizy porównawcze płaskich płyt stropowych ze zbrojeniem na ścinanie. Przeprowadzono analizy płyt ze wzmocnieniem i bez zbrojenia z wykorzystaniem symulacji nieliniowych. Wykonano obliczenia płyt bez mimośrodów i z mimośrodami 0,16 m. Do analiz wykorzystano metodę elementów skończonych. Wykonano modelowanie płaskiej płyty ze słupem za pomocą oprogramowania "Lira SAPR". Po zakończeniu obliczeń porównano wyniki z badaniami eksperymentalnymi. Analizy porównawcze wykazały, że obecność zbrojenia na ścinanie znacznie zwiększa zdolność płyt do przenoszenia obciążeń. Ponadto obecność zbrojenia na ścinanie zależy od mimośrodowości, a siła osiowa wynosi około 25%. Co więcej, różnica pomiędzy testami i wynikami analiz nieliniowych wynosi około 6,4%.

SŁOWA KLUCZOWE:
konstrukcje żelbetowe; płyty płaskie; analizy nieliniowe; metoda elementów skończonych; zbrojenie na ścinanie