Computation of Core Floor Slabs of Different Length

A S Vasilyev¹, V L Zemlyak², E A Pleanova³

¹Department of technical disciplines Sholom-Aleichem Priamursky State University, 70, Shirokaya str., Birobidzhan, 679015, Russia
²Department of technical disciplines Sholom-Aleichem Priamursky State University, 70, Shirokaya str., Birobidzhan, 679015, Russia
³Department of technical disciplines Sholom-Aleichem Priamursky State University, 70, Shirokaya str., Birobidzhan, 679015, Russia

E-mail: ¹ vasil-grunt@mail.ru, ²vellkom@list.ru

Abstract. The purpose of this research is to study what the crosscurrent representation format of core slabs is for samples of different length, by investigating the effect of the above factors on the load-bearing and stress-related properties, as well as the cracking load. The authors examined samples of slabs of different length, freestanding and working in bending, with a cross-section in a natural form, in comparison with samples of similar length in an I-beam shape. The samples were systematically loaded an interval of one kN until the yield point of reinforcement in the tension area was reached. The authors completed a numerical study of core slabs in a nonlinear setting. The researchers designed load-deflection plots when modeling the corresponding lengths of samples with a natural and I-beam form of section. The scholars received and compared results with loading of the cracked condition, midspan deflections with a rupturing load. They found out that the length of the slab affects the calculation results of the shapes issued: the shorter the length, the more highlighted deviation in the load-deflection plots. The authors suggested correction coefficients to perform a refined calculation of slabs for cracking, deflection, and rupturing loads.

1. Introduction
Hollow core slabs are built-up constructions made of pre or post-tensioned concrete, commonly used in the construction of floors in high-rise apartment buildings. Such slabs were especially popular in the countries of Northern Europe, as well as the former Soviet Union. The popularity of prefab reinforced concrete is relevant, first of all, for the areas with a low seismic activity. Besides, the use of prefabricated reinforced concrete slabs is characterized by efficiency due to the rapid assembly of buildings and decreasing the dead load of structures. A prefab reinforced concrete core slab has tubular voids along the entire length of the slab, typically with a diameter of approximately two thirds or three quarters of the slab thickness. This makes the slab much lighter when increasing running load and reducing in material and transport costs. Such slabs usually have an average width of 1200 mm and a standard thickness, usually from 150 to 500 mm. Reinforcement steel in the tensile zone of the slab provides resistance to bending.

The main advantage of core slabs is their relatively lightweight, which allows increasing the running load on the floor structures or using longer floor structures for long spans.
Many authors carried out surveys of concrete core slabs. Abdulaziz I. Al-Negheimish [1] presents experimental research of core slabs with prestressing using self-tensioning concrete. The study performed research with long-term and short-term loading. The studies of Foubert S. [2], Prakashan L. V. [3], Pachalla [4] were devoted to the conduct of reinforced concrete core slabs influenced by distortion, cracking, and wrecking because of direct stresses. The scientific works of Tae-Sung Eom [5] and Mateusz Surma [6] discuss the study of core slabs affected by the shearing stress distribution.

Russian researchers N.I. Karpenko [8,9], S.F. Klovanich [9,10] carried out the study of floor slabs using numerical methods, including FEM (finite element method), theories of mechanics of reinforced concrete. A.S. Vasiliev [11, 12, 13] investigated the conduct of reinforced concrete slabs on load and applied the models of reinforced concrete mechanics that had been developed and described by the above researchers, using recent software systems and numerical methods. In the study of M.F. Javed et al. [14] searched out the running efficiency of concrete-filled-steel-tubes. Many authors, such as Yuanli Wu [15], G.M. Chen [16], and M.L. Bennegadi [17] examined methods for strengthening hollow core composite slabs. The stressed and strained state of reinforced concrete slabs with prestressed reinforcement was carried out in the studies of P. Kankeri [18], Al-Negheimish [19], V. Albero [20]. Kankeri’s research is devoted to strengthening hollow-core slabs after cracking in concrete.

As known that the I-beam shape is used to simplify the calculations of hollow-core slabs, and to present them in the form of bar beam finite elements. Within the theory of calculation of reinforced concrete structures, not only the presence of reinforcement inside the concrete (i.e. the presence of reinforcing material inside the reinforced one) is taken into account, but also the redistribution of forces between these materials when cracks appear and concrete breaks. Nevertheless, the properties of cross-sections can also affect the calculation results of reinforced concrete when redistributing power and forming a plastic centroid in a structure.

2. Materials and methods
The paper covers hollow core floor slabs of various lengths according to the State All-Union standard 9561-91 «Reinforced concrete hollow core floor slabs for buildings». Standard slabs with a thickness of 220 mm with round voids with a diameter of 159 mm and a height of 220 mm were taken as a foundation. The width was constant and amounted to 1000 mm. This type of floor slabs was designed to support on two sides. 9 × 2 slab samples were considered depending on the length. These samples are shown in Table 1.

| No | Lengths, mm | Natural form | I-beams form |
|----|-------------|--------------|--------------|
| 1  | 2400        | sample 1.1   | sample 1.2   |
| 2  | 2700        | sample 2.1   | sample 2.2   |
| 3  | 3000        | sample 3.1   | sample 3.2   |
| 4  | 3300        | sample 4.1   | sample 4.2   |
| 5  | 3600        | sample 5.1   | sample 5.2   |
| 6  | 3900        | sample 6.1   | sample 6.2   |
| 7  | 4200        | sample 7.1   | sample 7.2   |
| 8  | 4500        | sample 8.1   | sample 8.2   |
| 9  | 4800        | sample 9.1   | sample 9.2   |

Slab material: heavy concrete, heat-treated, class B25 (Rb1 = 14.5 MPa, Rbt1 = 1.05 MPa, Eb1 = 3 • 104 MPa); working longitudinal reinforcement A- 400 (Rs = 365MPa, Es = 2·105 MPa) - 6 bars with a diameter of 12 mm. A protective concrete layer is 30 mm. The geometric characteristics of the cross section samples and typical calculated scheme of a slab are shown in Figure 1.
The authors performed their calculations in ANSYS 19R2 software. Discrete models numbered from 70,000 to 150,000 cells and from 100,000 to 200,000 nodes, depending on the type of cross-section and the length of the sample. Finite elements were in the form of a hexahedron; their maximum size was 20 mm. To reduce stress concentration at the edges, the authors simulated round supports at the supports.

During a numerical experiment, each sample was gradually loaded, starting from zero loads, with a load interval \( \Delta F = 1 \) kN, to wrecking resulting from the influence of the moment of flection in the middle of the span of the samples, when the yield point of reinforcement in the tension area was reached. At each step of the load, the authors obtained a corresponding deflection. They also modelled the conduct of concrete based on Willam-Warnke strength condition [21], using SOLID 65 finite element. Based on the model used, cracks formed along with the site normal to the main stresses when they exceeded the specified tensile strength. They also took into account a volumetric stress state.

3. Findings and discussion
The graphs below present the main findings of the study.

![Graph](image)

**Figure 2.** Cracking loading of samples of different length for a natural form of hollow-core slabs (ANSYS), I-beam slabs (ANSYS), and slabs analytically designed according to regulatory documents.

---

**Figure 1.** Geometric characteristics of reinforced concrete hollow slabs: a - cross sections of the natural shape, b - cross sections of I-beam shape, c - typically calculated scheme of a slab.
Figure 2 shows the cracking load for samples of different length. Here, along the ordinate axis, the values of breaking loads for each sample are presented, and along the abscissa, directly, the corresponding lengths of each sample. As can be noted, the more the length of the samples for all three types of calculations, the fewer deviations between the results, but the results correlate better.

Figure 3 shows the results of maximum deflections for samples of different length. As can be seen, on samples of shorter length, the results correlate better with each other for analytical calculation and calculation of the slab in natural form (ANSYS). However, ANSYS calculation results for I-beam and the natural form begin to correlate better with each other with a length greater than 3600 mm, and they are almost equal for the length of 4500 mm and 4800 mm.

![Figure 3](image)

**Figure 3.** Maximum deflections of samples of different length for the natural form of hollow-core slabs (ANSYS), I-shaped slabs (ANSYS), and slabs analytically designed according to regulatory documents.

Figure 4 shows the results of the analytical computation are loosely correlated to the results of numerical ones (ANSYS).

Deviations of the numerical calculation for the I-beam slab from the numerical calculation of the slab in its natural form turned out to be not significant. The deviation of cracking load for different samples
averaged about 2.8%, the deviation of the maximum deflections was approximately -10.84%; and the deviation in the rupturing load was about 4.3%.

The analytical findings concerning Building Regulations by the Code of recommended practice have considerable deviations from the numerical. For a load of crack starts, the deviation of the computation according to Building Regulations from the numerical with the natural section form of the slab showed an average value of -3.5%, with a maximum value of about -15%. The maximum deflections in the analytical calculation dominated over the numerical results in all cases by an average of 7.5%. The maximum deviation was equal to more than 10% for the sample with 4500 mm. long. However, the load-bearing ability of core slabs in their natural form is less than the load-bearing ability calculated analytically by Building Regulations by an average of 29%.

4. Conclusions

Drawing from the findings, the authors can make the following conclusions.

• The longer the samples, the more the correlation coefficient and it tends to unity. It stands for an increasing correspondence between the load-deflection diagrams.
• The longer the samples considered the fewer deviations in the load of crack starting. Moreover, they reduce to zero for samples 3900 mm or more. However, for the slabs from 2400 mm to 3600 mm, the results of calculations of I-beam slabs are to be multiplied by a factor of 1.03. If one performs the calculation analytically, according to regulatory documents, then this coefficient will be approximately 0.97.
• Potential deviations of deflections are similar to the pattern of the load of crack starting. However, deviations in the deflections between the samples have a rather large difference. In this regard, one should multiply by a factor of 0.85 for the slabs from 2400 to 3000 mm. One should multiply the slabs from 3300 to 3600 mm by 0.9 and the samples of more than 3600 mm - by 0.95 to clarify the results when presenting hollow-core I-beam slabs.
• The load-bearing ability because of the analytical calculation has a very large safety factor, which can cause overspending the material when designing reinforced concrete structures and calculations for the first group of limit states. The authors tend to conduct further research and develop coefficients to make the calculations of the load-bearing ability of core slabs more precise. For the slabs of 1 meter wide, the results of the load-bearing ability obtained from analytical calculations according to Building Regulations, one can reduce by an average of 30%. Nevertheless, it is worth taking into account that this load, carried out during a numerical experiment in ANSYS PC, is momentary, while the calculations are performed a permanently acting load.

5. References

[1] Abdulaziz I Al-Negheimish, Ahmed K El-Sayed, A Majed O Khanbari, Abdulrahman M Alhozaimy 2018 Long-term deflection of prestressed SCC hollow core slabs Construction and Building Materials vol 189 pp 181-191
[2] Steven Foubert, Karam Mahmoud, Ehab El-Salakawy 2016 Behavior of Prestressed Hollow-Core Slabs Strengthened in Flexure with Near-Surface Mounted Carbon Fiber-Reinforced Polymer Reinforcement Journal of Composites for Construction vol 20 (ASCE) pp 1943-5614 0000692
[3] Prakashan L V, Jessymol George, Jeena B Edayadiyil, Jerin M George 2016 Experimental Study on the Flexural Behavior of Hollow Core Concrete Slabs Applied Mechanics and Materials vol 857 pp 107-112
[4] Pachalla, Sameer Kumar Sarma, Prakash S Suriya 2017 Experimental Evaluation on Effect of Openings on Behavior of Prestressed Precast Hollow-Core Slabs ACI Structural Journal Vol 114 pp 427-436
[5] Tae-Sung Eom, In-Hye Hwang, Seung-Jae Lee, and Tae-Won Park 2018 Failure Mode and Shear Strength of Nonprestressed Hollow-Core Slabs in One-Way Shear ACI Structural Journal Farmington Hills I 115 pp 1131-1141
[6] Mateusz Surma, Wit Derkowski and Andrzej Cholewicki 2019 Analytical model for determining the influence of support flexibility on shear capacity of hollow core slabs (MATEC Web of Conferences 262) 08005

[7] Karpenko N I, Mukhamediyev T A, Petrov A N 1986 Original and transformed deformation diagrams of concrete and reinforcement (Stress-strain state of concrete and reinforced concrete structures) pp 7–25

[8] Karpenko N I 1996 General models of reinforced concrete mechanics (Moscow: Stroiizdat) p 416

[9] Klovanich S F, Bezushko D I 2009 Using Finite element method in calculations for spatial reinforced concrete constructions (Odessa: House of Odessa National Maritime University) p 356

[10] Klovanich S F, Mironenko I N 2007 Using Finite element method in reinforced concrete mechanics (Odessa: ONMU) p 65

[11] Vasilyev A S, Bazhenov R I, Gorbunova T N 2018 The Influence of Cross Section Shape on Strengthening of Hollow Core Slabs Materials Science Forum 931 pp 24–29

[12] Vasilyev A S, Odinokova O A, Nazarova V P 2019 Investigation of the Effect of Reinforcing Diaphragms Ribbed Panels on their Carrying Capacity Materials Science Forum 931 pp 577-582

[13] Vasilyev A S 2020 Research of stressed-state stiffened hollow strengthened concrete slabs in cracked condition IOP Conference Series: Materials Science and Engineering vol 687 I 3

[14] Javed M F, Sulong N H R, Memon S A, Rehman S K U and Khan N B 2017 FE modelling of the flexural behaviour of square and rectangular steel tubes filled with normal and high strength concrete J Thin-walled structures vol 119 pp 470–481

[15] Yuanli W U 2015 Shear Strengthening of Single Web Prestressed Hollow Core Slabs Using Externally Bonded FRP Sheets Electronic Theses and Dissertations p 124

[16] Chen G M, Chen J F and Teng J G 2012 On the finite element modelling of RC beams shear-strengthened with FRP J. Construction and Building Materials pp 13–26

[17] Bennegadi M L, Sereir Z, Amziane S 2013 3D nonlinear finite element model for the volume optimization of a RC beam externally reinforced with a HFRP plate J. Construction and Building Materials vol 38 pp 1152–1160

[18] Kankeri P, Prakash S, Pachalla S K S 2018 Experimental and Numerical Studies on Efficiency of Hybrid Overlay and Near Surface Mounted FRP Strengthening of Pre-cracked Hollow Core Slabs Structures vol 15 pp 1–12

[19] Al-Negheimish A I, El-Sayed A K, Khanbari M O, Alhozaimy A M 2018 Structural behavior of prestressed SCC hollow core slabs J. Construction and Building Materials vol 182 pp 334–345

[20] Albero V, Saura H, Hospitáler A, Montalvà J M and Romero M L 2018 Optimal design of prestressed concrete hollow core slabs taking into account its fire resistance Advances in Engineering Software vol 122 pp 81–92

[21] Willam K J and Warnke K J 1974 Constitutive model for the triaxial behavior of concrete Seminar of concrete structures subjected to triaxial stresses Bergamo p 31