IMPROVED JOINTS OF REINFORCED CONCRETE ELEMENTS IN PRECAST-AND-CAST-IN-PLACE CONSTRUCTION BASED ON DESTRUCTION MECHANICS

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Abstract: Systematic theoretical and experimental studies of the keyed joints of concrete and reinforced concrete elements have been carried out at PoltNTU over the recent thirty years that made it possible to formulate recommendations for their design and to improve the existing design solutions of joints. The keyed joints have higher bearing capacity. The method for calculating the strength of the joints is proposed. This method is based on the theory of concrete plasticity, the variational method and the principle of virtual velocities. It considers the stage of destruction and takes into account the full set of influence factors. The research takes into account the influence of the following factors on the joints strength: the ratio of the key depth to its height; compression level; the intensity of reinforcement and the nature of the reinforcement location. The keys of a rectangular profile of circular cross section are considered, which are formed in the voids of the slabs at their ends surface when girders concreting. For their reinforcement, a spatial cage in the form of a hollow cylinder is proposed. The results of experimental verification of the quantitative and qualitative influence on the joints strength of these factors are presented. The boundaries of the efficiency of reinforcement intensity, the degree of compression are determined, the optimal ratio of the depth of the key to its height is accepted. The design features of the joints of multi-hollow floor slabs (roofs) with a monolithic girder and between themselves in a precast-cast-in-place frame structural system, with wall panels in large-panel houses, as well as joints of wall panels on flexible loops in large-panel buildings, are taken into account. Examples of improved structural solutions for connecting elements of modern load-bearing systems based on the specifics of their work are given.

Keywords: keyed joins, structural systems, strength, influence factors, three-dimensional cage, experimental research, variational method in the plasticity theory.

1. Introduction

One of the modern construction industry tasks is to improve effective frame structural systems made of reinforced concrete, which are characterized by both a minimum set of prefabricated elements and significant opportunities to accelerate the construction time of buildings. Among them, first of all, it should be noted modern precast-cast-in-place structural systems such as SORET, KAZAN-XXI century, ARKOS, KUB-2.5 and their modifications [1, 2].

At the same time, the long-term experience of the European countries development shows that an intensive increase in the volume of construction is impossible without panel housing construction [3]. Its share in these countries ranges from 17 % to 35 % of the total housing stock.

2. Methods

The method for calculating the strength of the joints is proposed. This method is based on the theory of concrete plasticity, the variational method and the principle of virtual velocities. It considers the stage of destruction and takes into account the full set of influence factors [4]. The reliability of theoretical results is confirmed experimentally.

3. Results

Particular attention in the design of precast and precast-cast-in-place structural systems should be paid to the joints of the bearing elements, ensuring their combined work under load. Among them, a significant role is played by keyed connections with increased shear resistance. The purpose of the research conducted at Poltava National Technical University is to improve joints on an experimental and theoretical basis.

ARKOS is one of the common structural systems of multi-storey frame buildings using keyed joints [2], in which the slabs are supported on monolithic bearing girders with the help of concrete keys formed in the voids of the slabs at their ends surface when girders concreting (**Fig. 1**).

In PoltNTU, the reinforcement of the keys with 4Ø3Br1 (**Fig. 2**) was proposed on the basis of the minimum reinforcement percentage of reinforced concrete 0.05 %. The proposed spatial cage with three-level reinforcement has additional possibilities for its attachment and ensures the strength of the keys in both the vertical and horizontal plane.

Meanwhile, in all the above-mentioned structures, the reinforcement of the keys is not used as the principal reinforcement of the monolithic bearing girder.

There is an authors' proposal to improve the connecting slabs with a girder in precast-cast-in-place floors. Its essence consists in the use of longitudinal reinforcement of keys as cross reinforcement of girder. The double functional purpose of the principal reinforcement reduces the steel content and contributes to an increase in the strength of the girder in an inclined section. The key longitudinal reinforcement in the place of entry into the volume of the girder bends down or up at different angles, depending on its position relative to the sections of the girder near the supports and specified by the design scheme for placement of inclined cracks (**Fig. 3**). Its effective work is ensured by fastening to the girder cage.

Research [5] developed a vertical monolithic keyed joint with loop transverse reinforcement between wall elements.

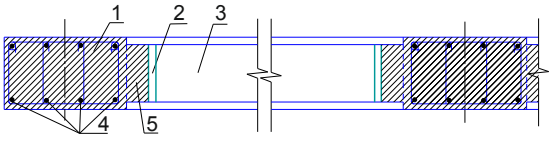

Fig. 1. The joint of the slabs with bearing girders building floor of the ARKOS structural system:
1 – monolithic bearing girders; 2 – key size limiter; 3 – precast hollow-core slabs; 4 – principal reinforcement of girders;
5 – concrete keys

The adopted structure of vertical joints of wall panels ensures that the keys perceive vertical and horizontal shear forces, steel wire rope loops – horizontal tensile forces, and grouting concrete – horizontal compressive forces.

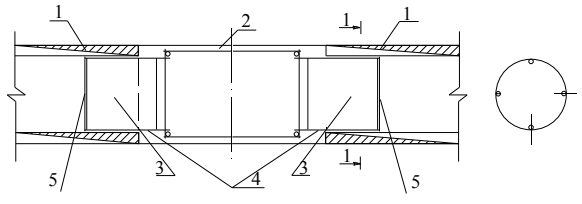

Fig. 2. Improved connection of circular hollow-core slabs with a monolithic girder in a precast-cast-in-place floor: 1 – slab supporting sections; 2 – monolithic girder; 3 – keys; 4 – cylindrical reinforcement cages; 5 – key size limiter

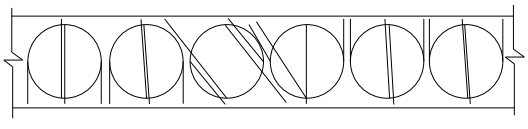

Fig. 3. Connections of reinforced concrete slabs with a girder in precast-cast-in-place floor slabs with dual functional purpose of the principal reinforcement

Its theoretical and experimental studies are conducted at PoltNTU. The method for calculating the strength of keyed joints on wire rope loops by a variational method in the theory of concrete plasticity is proposed. This takes into account the proposals [6, 7] regarding the determination of the stresses rate that act in wire rope loops in the stage of the joints destruction. Suggestions for resizing a tin box (key) are made. The existing dimensions predetermine the destruction of keys from crushing, and the effect of constrained deformation conditions is understudied. According to research results [8], the ratio of sizes l_k/h_k=0.25 is optimal from the point of view of strength. This implies a twofold increase in the depth of the keys while maintaining their existing height or an increase in the depth to 30 mm while reducing the height to 120 mm, for example, for the PVL 80.

Another direction of modernization of large-panel housing construction is the use of a wide step of bearing structures, which makes it possible at the design stage to vary a set of apartments on typical floors without changing the structural design of the building, and at the operation stage to perform re-planning inside the apartments as part of its structural cell. Floor slabs in buildings with wide wall spacing are projected from pre-stressed hollow-core slabs. No formwork hollow-core slabs are modern low-cost, high-tech structures of hollow core flooring. However, unlike serial hollow-core slabs, the no formwork slabs do not have upper longitudinal structural reinforcement and embedded parts for connection with other prefabricated structures.

Contact-platform joint of walls with floor slabs is characterized by a greater bearing capacity compared to the platform, so the thickness of the bearing walls in its application will be less than in buildings with platform joints.

The authors [9] proposed a contact-platform keyed joint of panel walls with zones of support of multi-hollow slabs with round voids, which are brought beyond their boundaries (**Fig. 4**).

Features of the design solution of the joint compared with the variant proposed in [10] consist in using reinforcing cages in the form of cylinders and adjusting the depth of the keys according to the results of the calculation of their bearing capacity performed by the authors. A multi-keyed reinforced concrete joint with round keys and multi-leveled reinforcement is considered. The maximum effect from the use of no formwork hollow-core slabs is possible only when using them also as horizontal diaphragms of rigidity. In order to create a rigidity disk of the slabs, it is necessary to arrange the keys perceiving the shear stresses along the joints between the slabs.

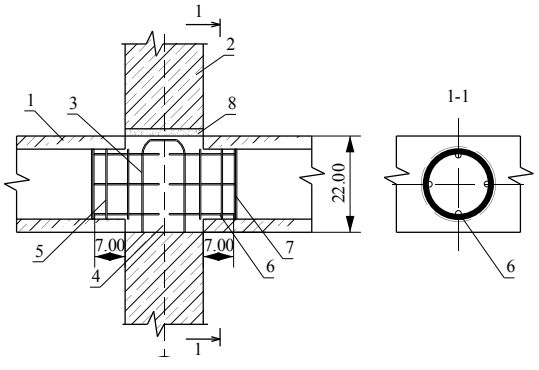

Fig. 4. Contact-platform joint of panel walls with hollow-plate support zones brought beyond the wall area: 1 – hollow-core slab; 2 – wall panel; 3 – stub bars from the wall panel; 4 – grouting concrete; 5 – key; 6 – key reinforcement cage; 7 – key size limiter; 8 – cement-sand mortar

The keys are made by sampling the concrete in the right places during the slab molding process. Multi-keyed joint with rectangular concrete and reinforced concrete keys, preferably with l_k/h_k=0.25 is considered. The proposed by authors methodology for joints calculating [4] takes into account the nature of their destruction and the main determining factors: strength characteristics of concrete f_{cd} and f_{ctd}, the ratio of the depth l_k and the height h_k of the keys, the shape of their cross section, the shape of the profile, reinforcement, the number of keys (**Fig. 5**).

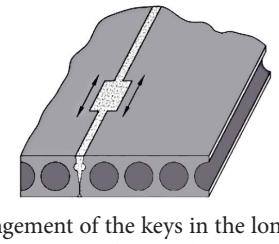

Fig. 5. The arrangement of the keys in the longitudinal edges of the no formwork slabs

In the authors' experimental researches [9], the effect of f_{cd} and f_{ctd} values was studied, as well as reinforcement (compression) on the keys strength which are destroyed by shearing. Heavy and ceramsite concrete with prism strength $f_{c,\,prizm}$=10–56.9 MPa was used. The keys were reinforced with transverse bars of class A240C in the shear plane (two types of cages were used: with the reinforcement in one level in the middle of the key height and in two levels). The reinforcement percentage varied within ranges ρ_w=0.34–1.03 %. According to the experimental studies [8], an increase in compression σ from 0 to 0.5 $f_{c,\,prizm}$ the strength of keys increases up to 2.5 times, without altering the nature of their destruction.

With an increase of the reinforcement percentage in the range from 0.34 to 1.03 %, the strength increased up to two

times. The stresses in the reinforcement at the stage of destruction at ρ_w=1.03 % reached the yield strength. With a two-level arrangement of reinforcement, the plastic properties of the keys concrete increase.

4. Discussion and conclusions

The obtained results of theoretical and experimental research made it possible to formulate the recommendations for their design and to improve existing structural solutions of joints for reinforced concrete elements of structural systems and to substantiate the prospects for the use of key joints.

An analysis of experimental studies confirmed the kinematically possible failure schemes by shear, adopted in theoretical solutions, and indicates the reliability of the proposed method for calculating joints. Reinforcement up to ρ_w=1 % can be considered as effective. The spacing of the reinforcement has led to a significant increase in the concrete plastic strain, which is an important point for the elements joints during construction in seismically dangerous regions.

For the modernization of large-panel house-building by using a wide step of bearing structures, a contact-platform joint of wall panels and slabs has been developed, which has an increased strength.

The joints solutions of multi-hollow slabs with elements of frame and wall structural systems are proposed, which increase their bearing capacity.

References

1. Pavlikov, A. M., Babich, Y. M., Mykytenko, S. N. (2014). Flat plate structural systems for building of low cost housing: structural features, conventions of calculations, suggestion for improvement. Resursoekonomni materialy, konstruktsiyi, budivli ta sporudy, 29, 451–460.
2. Mordich, A. I., Vigdorchik, R. I., Belevich, V. N., Zalesov, A. S. (1999). Novaya universal'naya karkasnaya sistema mnogoetazhnyh zdaniy. Beton i zhelezobeton, 1, 2–4.
3. Zhao, X., Riffat, S. (2007). Prefabrication in house constructions. International Journal of Low-Carbon Technologies, 2 (1), 44–51. doi: https://doi.org/10.1093/ijlct/2.1.44
4. Dovzhenko, O., Pogrebnyi, V., Yurko, I. (2018). Shear Failure Form Realization in concrete. News the national academy of sciences of the republic of Kazakhstan. Series of geology and technical sciences, 2 (428), 55–62.
5. Suuraskola, P. (2013). Technologically Advanced Product from the Company Peikko - Cable Loop PVL. Zhilishchnoe Stroitel'stvo, 3, 21–25.
6. Jørgensen, H. B., Hoang, L. C. (2015). Load carrying capacity of keyed joints reinforced with high strength wire rope loops. Proceedings of fib Symposium 2015.
7. Joergensen, H. B., Hoang, L. C., Hagsten, L. G. (2017). Strength of precast concrete shear joints reinforced with high-strength wire ropes. Proceedings of the Institution of Civil Engineers - Structures and Buildings, 170 (3), 168–179. doi: https://doi.org/10.1680/jstbu.16.00096
8. Dovzhenko, O., Pohribnyi, V., Yurko, I., Shostak, I. (2017). The bearing capacity experimental determination of the keyed joints models in the transport construction. MATEC Web of Conferences, 116, 02011. doi: https://doi.org/10.1051/matecconf/201711602011
9. Dovzhenko, O. A., Pohribnyi, V. V., Karabash, L. V. (2018). Effective keyed connections of hollow-core floor slabs with walls in modern large-panel house building. Science & Technique, 17 (2), 146–156. doi: https://doi.org/10.21122/2227-1031-2018-17-2-146-156
10. Blazhko, V. P. (2013). O primenenii mnogopustotnyh plit bezopalubochnogo formovaniya v panel'nyh i karkasnyh zdaniyah. Zhilishchnoe stroitel'stvo, 10, 7–10.

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