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IMPLEMENTATION OF FLAT SLAB COLUMN REINFORCED CONCRETE FRAMES IN LOW COST HOUSING CONSTRUCTION

Summary

In research presents an analysis of flat slab column reinforced concrete frames in low cost housing construction. The features of precast flat slab column conduit within reinforced concrete frame building have been analyzed. The problems in designing flat slab column frame to improve its reliability are under consideration. Suggestions concerning the ways of improving flat slab column frame building calculations are presented.

Precast flat slab column frame constructive system is promising for construction of residential and public buildings.

In order to reduce the values of bending moments in the joints of columns, it is suggested to apply solid diaphragms with the functions of taking up the vertical loads in order to take up horizontal loads. It seems reasonable to define the required amount of reinforcement bars in plates by means of the kinematic limit equilibrium method.

Key words: Flat slab column conduit, reinforced concrete framework of building, low cost housing.

1. Introduction

The current stage of construction is characterized by the problem of the necessity to reduce the cost of buildings and structures by reducing the labor intensity of their construction, saving the costs of materials, application of energy-saving walling. One the ways of solving this problem is the use of industrial constructions, which have significant advantages over monolithic ones. Today, there are many examples of efficient application of such constructions, both at new housing construction and in the process of reconstruction. Among them, industrial flat slab frame (the system of the "CUBE" type) is standing out in a particularly convincing manner. It has been applied since the late 60s of the previous century, and today it has undergone many modifications in the process of its application for solving the targets of the program on providing people with low cost housing [1].

Application of this frame is almost solving the contradiction between strength and heat transfer resistance of the walling materials in wall constructions by dividing the bearing and fencing functions of walls. Therefore, the use of industrial flat slab frames is increasingly gaining more and more popularity [2–3].

2. Literature Overview

Flat slab column conduit is a further development of the flat slab floor (Fig. 2.1). Flared column heads and capitals were removed from the floor slab structures by D. Di Stasio [4] in 1940 during the housing construction in Newark and Atlantic City (USA).

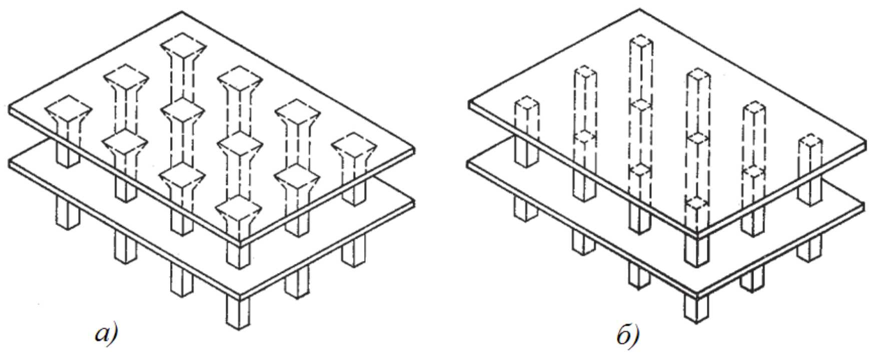


Fig. 2.1. Flat slab floors: a) with capitals; b) without capitals (flat slab column conduit)

In the middle of the 20-th century, this floor slab design began to be widely used in Australia. In the USSR, flat slab column conduits were in mainstream use for housing construction by means of lifting floors. [5] In "TsNIIEPzhylishcha" (Central Scientific Research Institute of Experimental Projects, Moscow) unified precast frame structures for public and household buildings were developed [6]. In March, 2008, according to the design of the State Urban Development Design Institute "Miskbudproekt", within the pilot experimental building program, first in Poltava, the advanced "CUBE" system [7] was applied in low cost housing buildings as well as in buildings for other purposes (Fig. 2.2).

Flat slab column constructive system (FSCCS) is still poorly understood and used in buildings as experimental, therefore it requires thorough research of its operation and developing recommendations for calculating the strength of its separate elements. Insufficient study of this system’s operation is proved by the fact that, for example, [7] a static calculation of flat slab column frame is suggested to be performed as for a system of mutually perpendicular frames. But this approach does not reflect the actual function of the frame elements as part of the building, and therefore leads to inefficient use of reinforcement.

a)

b)

c)

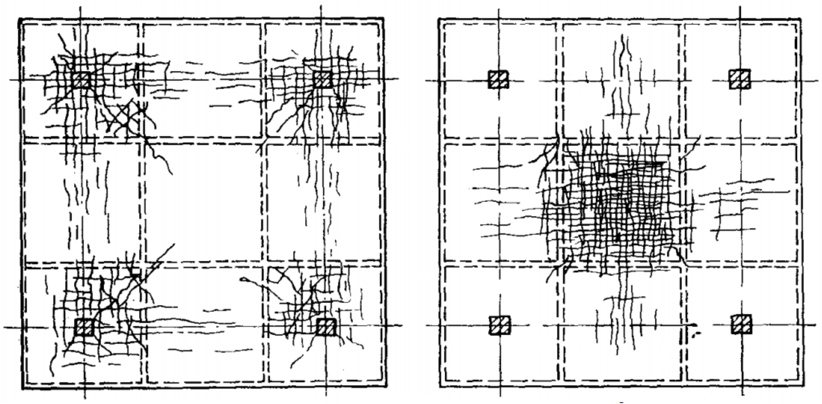
d)

Fig. 2.2. Buildings in the city of Poltava: a – residential, 16-storeyed house, in the avenue of Bohdan Khmelnytsky, 21; b – residential, 16-storeyed house, in October street, 60; c – hostel in Pershotravnevyi Avenue, 5; d – office center inn Frunze street, 2

Slab-column connection is also considered as keyed joint in the calculations. But cracks arise in this joint due to the bending moment action in the plate, which significantly reduces the initial height of the key, making it an undetermined value.

Separate plates within the floor are interconnected with loop starter bars (joint by G.P. Perederiy). Design of such joint does not guarantee formation of a plastic linear hinge in it, therefore, the plates themselves will undergo complicated deformation in two directions, other than prescribed in the study [6] (Fig. 2.3).

The columns connection, provided by the design [7], is, actually, located in the site of the maximum bending moment's action that does not match the design bending moment diagrams in the static calculation frames. Thus, constructively, in the assumed calculation frames hinges are formed, while according to the design diagram [7], the maximum bending moment arises in such places.



the surface from above *the surface from below*

Fig. 2.3. Diagrams of cracks located in the elements of the floor slab fragment, when tested

Strategic aim of the study is to analyze the structural features of the flat slab column reinforced concrete frame of buildings, with the purpose of improving the calculation of its separate elements' bearing capacity in order to save materials.

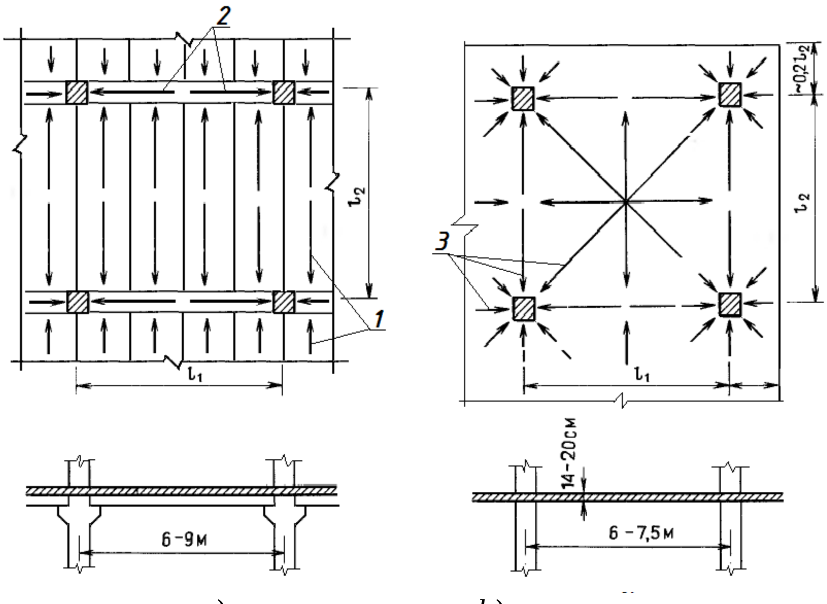
3. TEST METHODS

Flat slab column constructive system is suggested to serve as basis for the low cost housing construction, as the most efficient among the other ones. FSCCS peculiarity is the absence of the traditional cross beam bars and, consequently, using multi-storey columns without cantilevers.

Precast plates, applied as part of floor slab panel, are connected by means of loop junctions into a solid disc, which is locally based directly on the columns through column drops. Spatial rigidity and stability of the above frame, which can operate according to the frame or braced frame structural diagrams depending on design solutions, should be ensured by the reliable operation of bonded joints between the elements [7].

Preliminary experimental data [6] show that some features of the precast floor slab operation under load (Fig. 2.3) are characterized by the presence of cracks in two directions in each of its plate. These features can be explained by differences in the load transfer from plates to the columns compared with beamed floor slabs. Thus, the traditional beam systems (Fig. 3.1 a) load is transferred sequentially from plates to the beams, and then to the columns' cantilevers.

Since FSCCS floor slab rests on columns directly through column drops, the static operation of such a system is characterized by the collection of vertical load on the column from all directions along the shortest distances (Fig. 3.1 b).



) b)

Fig. 3.1. Diagrams of collecting loads on the columns: a – in the beam structural systems; b – in the flat slab frames; 1 – line of the load transfer from precast panels; 2 – line of the load transfer from precast cross-beams to the columns; 3 – lines of the load transfer in flat slab floors to columns of the frame

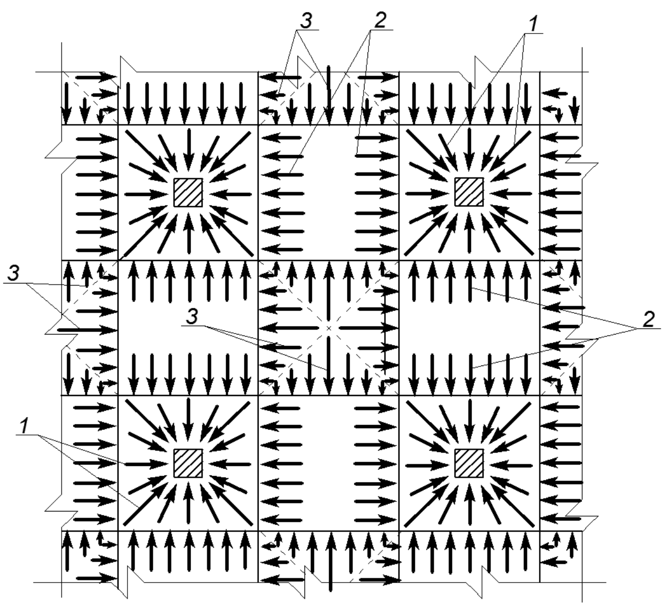


Fig. 3.2. Design diagram of the load transfer in the precast flat slab column frame: 1 – from the column drops to the column; 2 – from the intercolumnar plates to the column drops; 3 – from the central plates to the intercolumnar plates

Having analyzed the floor slab disc operation as a system of connected precast panels, we found out that the following sequence of load transfer: the central panel transfers the load to the four neighboring intercolumnar plates; intercolumnar plates transfer the load to column drops; column drops transfer the load to the column. Therefore, reinforcement of plates is efficiently performed according to the calculations that implement the scheme of load transfer from plate to plate in the precast flat slab column frame, presented in Fig. 3.2.

However, it should be noted that such calculations can only be guaranteed with the formation of linear plastic hinge in the slab joints. Additionally, at this load transfer scheme, each plate will have its own destruction scheme which is implemented as the basis for the plate's calculation.

It seems reasonable to take kinematic limit equilibrium method as a basis of calculation, which is generally described by the balance between the virtual work of external and internal efforts in the possible relevant movements in the direction of the load and effort *M*:

, (1)

where – plate's moving due to the load; – plate's moving under the load ;
M – moment in the *i* – linear plastic hinge per a unit of its length; – angle of the disc turn in the *i* – linear plastic hinge; – length of the *i* – plastic-hinge; *n* – the number of linear plastic hinges sites under consideration.

4. Discussion

The feature of slab-column connection [7] (Fig. 4.1) is that the plate's working armature does not cross the faces of the column. Therefore, plates connected with each other along the axes of the columns, are working, with account of the floor slab load, as a single structure: a continuous multispan beam. Reinforcement of this plate is performed as of the one containing a "hidden" distributed crossbar. Taking the above into account, according to [7], it is suggested to perform the frame's calculation by means of its replacement with single frame trestles. However, this approach, as the analysis of these frames demonstrates, does not reflect the real picture: the lack of common slab-column operation (because they are not connected with reinforcement bars).

At the same time, the series developers [7] believe the given connection to be rigid, able to perceive the bending moment and to redistribute it between the column and the plate. But if we carefully consider the design of the given connection, taking into account the insignificant cross-beam's height (160 mm), the quality of welds and concrete, we can conclude that it is only partially rigid, i.e. it takes up the transverse force and the limited bending moment that can be perceived due to welds in the concrete insert.

Also in this connection, when it is made a captive assembly, the column's bearing capacity may be weakened due to poor compaction of concrete and its shrinkage. Therefore, the frame's stud is actually artificially receiving a hinge in the cross-section, where a maximum bending moment can operate according to the frame calculation. It is reasonable to take into account the action of vertical and horizontal loads in the frame calculation.

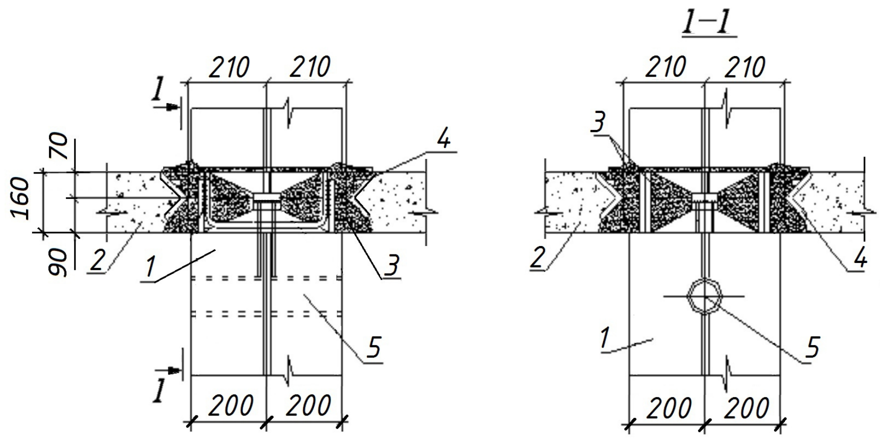
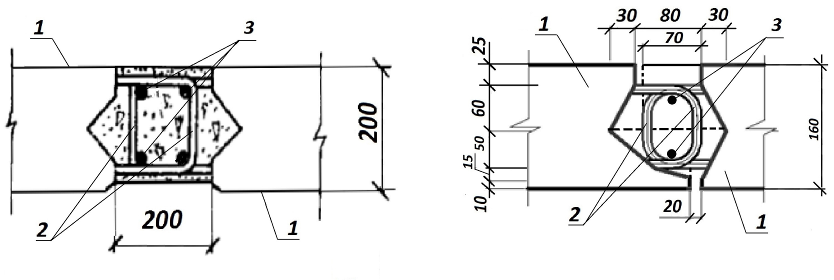


Fig. 4.1. Structure of column drop-column connection: 1 – column; 2 – plate; 3 – concrete key; 4 – steel trim of a hole in the plate; 5 – hole for installation of hardware for plates mounting

Disc floor slab consists of separate plates, connected with each other by means of loop starter bars after concreting joints [7] (Fig. 4.2). This joint is universal, it must ensure share behavior, bending strength and stretching work of the composite construction. Observing the conditions of anchoring reinforcement bars, the junction's length should be designed not less than $(35 \div 56)d$. Analysis of the size of the junction structure in Fig. 4.2, we can make the conclusion that it can take up transverse force, i.e. work as a key, but failure to comply with reinforcement bars anchoring conditions calls into question the authors' affirmation [10] that the junction structure can provide taking up of the bending moment M = 5.2 kN·m per an area of 6 m width.



а) *б)*

Fig. 4.2. Structure of the floor slab plates connection with each other: a) the first version [9]; b) the improved version of the "CUBE 2.5" series; 1 – plate; 2 – loop starter bars; 3 – mounting hardware

In the case of concrete and reinforcement debonding due to overload or low concrete quality, junction is not destroyed, but it becomes a hinge, and consequently the central or intercolumnar plate starts working as a hinge supported. Basing on the above, we can conclude that a plastic hinge plate is not realized in the plate, because the size of the loop junction does not provide reliable reinforcement anchoring in it. Therefore, it seems reasonable to replace the rigid plates connection with a cylindrical hinge. Insertion of a cylindrical hinge clearly defines the place of the zero point of the bending moment diagrams in the floor slab, and the static operation of plates under load will gain uniqueness and reliability, the process of plates reinforcement will be simplified.

5. Conclusions

Precast flat slab column frame constructive system is promising for construction of residential and public buildings. In order to reduce the values of bending moments in the joints of columns, it is suggested to apply solid diaphragms with the functions of taking up the vertical loads in order to take up horizontal loads. It seems reasonable to define the required amount of reinforcement bars in plates by means of the kinematic limit equilibrium method.

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