Method of dry construction of prefabricated reinforced concrete building

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Abstract. The existing systems of dry assembly of structures from prefabricated components still require the concreting of joints, which does not allow minimizing the number of technological processes and does not eliminate the need to wait until the concrete mixture hardens. Therefore, the period of erecting a building does not reduce significantly. The present paper describes the system of dry construction assembly from prefabricated components of reinforced concrete without application of any welding or casting-in-place while performing the above-ground works, which is feasible due to the bolt connection of all components. Since no welding or concreting is required, the duration and labor intensity of the erection process reduces. The present research is aimed at working out such a system of erecting a prefabricated building of reinforced concrete, which would allow moving away from welding and joint concreting, at the same time ensuring the structural reliability. This would reduce the duration and labor intensity of the construction process. The proposed system of prefabricated dry construction assembly of reinforced concrete structures that has a plenty of advantages by virtue of its nature can be easily implemented in low- and mid-rise residential construction and for erection of industrial, public and business buildings, buildings on railway transport intended for technical operation of Railways and maintenance of transport construction objects. Moreover, the system proposed could be a perfect choice for the erection of such temporary structures as sports facilities, hospitals, parking garages and warehouses, since it is easily disassembled.

1. Introduction

Development of prefabricated construction industry propels the continuous search for innovative ideas that would facilitate the process of assembling prefabricated elements. The method of dry construction assembly that is notable for a minimal number of welding and concreting processes is one of the solutions for acceleration of the construction process. When considering the existing systems and methods for dry assembling, it was found that most of cases still require the concreting of joints, which does not allow minimizing the number of technological processes and does not eliminate the need to wait until the concrete mixture hardens [1-6]. As a result, the process of erecting a building accelerates negligibly. Moreover, the problem of resistance to fire and aggressive media is not solved for those structural connections that do not require concreting.

2. Materials and Methods

The elaborated reinforced concrete building construction system includes single-level load-bearing columns equipped with holed metal shoes, wall panels and floor slabs. In addition, columns, foundations and wall panels have bolt protrudings to be connected with overlying elements. Slabs, as well as wall
panels with bevels, are in a permanent metal formwork. These solutions allow making bolted connections for all elements of a system.

3. Results
The system of assembly proposed to improve the process of construction is pursued as follows. The foundation of a building is performed as a monolithic one. When erecting a foundation of the system proposed, firstly, reinforcement steel and bolt protrudings are installed with the help of a specially designed template. Then a formwork is installed. The foundation should be also provided with a pre-calibrated and machined base plate. After verifying the placement of a slab in a plan view, cement mortar is poured under the slab. After the cement hardens and the formwork is dismantled, the columns are installed. It is worth noting that before the assembly process, the surfaces to be connected are prepared by means of gas-flame cleaning or steel brushing. Base plates must have axial marks which when installing the columns are to be matched with marks on column shoes. As soon as all preparatory processes are completed, the column is installed in its design position, the protrudings of anchor bolts of a foundation pass through the holes in the column shoe and then gaskets are put on them. Next, the protrudings are drawn up with nuts, to which the needed torque is applied. The completed connection of the column with the foundation is shown in Figure 1.

Figure 1. Connection of a column and a foundation: 1 – pier foundation, 2 – shoes for bolt protrudings of foundation, 3 – column shaft, 4 – bolt protrudings of a column.

Shoes of columns are capable of transmitting high tensile stress and bending moment, while the bolts of this connection after being tightened take the load, so the crane may proceed to the installation of the next column [1, 8]. Temporary braces to support the columns are not required [2].

Then the wall panels of the lower storey are lowered onto the mounting level so that the protrudings in the strip foundation matched with shoe holes of the wall panels. By means of installation, the bevels of wall panels are adjusted. Bevel-placed holes for connecting wall panels in horizontal direction form a through bolt-mounting hole. Then the panel is vertically aligned so that marks on the elements coincide. After adjusting the wall panels, bolt protrudings are tightened with nuts. To connect the wall panels to each other, bolts are inserted into the holes and tightened with nuts. The connection of wall panels with the foundation and with each other in the horizontal direction is shown in Figure 2.
After mounting wall panels and columns, a stair enclosure is installed and the floor slabs are laid, starting from the corner panels. To place the stair enclosure in a system with a column spacing of 3x3, a solid three-dimensional spatial staircase is used, which is attached to the foundation with anchor bolts embedded in the foundation. There is also an option for using an external staircase. With a column grid of 6x6, it is proposed to use L-shaped staircases, which have a lower part resting on a metal plate with bolt protrudings and an interstorey platform resting on a metal angle with protrudings attached to a wall panel. Floor slabs are laid so that the bolt protrudings of wall panels and columns pass through the holes in slabs.

After the floor slabs are laid, workers proceed to the installation of second floor columns in such a way that the bolt protrudings in columns of the first floor intrude into the holes of above-installed column’s shoes. Then the nuts on the bolt protrudings are tightened and they can proceed to installation of the next column. The connection of floor slabs and columns is shown in Figure 3.

End joint of prefabricated columns and a slab bears both the longitudinal stress along the columns and the bending moment. The longitudinal compressive stress in columns and at their end sections is born by the entire cross-section of reinforced concrete. The bending moment in different sections of the joint is born by bolt protrudings (with partial unloading from longitudinal compression) in a stretched or less compressed zone of the section. In the compressed zone the moment is born by either concrete with longitudinal reinforcement of the column, or slab concrete and bolt protrudings [1, 4, 5]. The end plates
of columns and the nuts also contribute to the effective involvement of bolt protrudings in the moment bearing work.

When all the columns of the second floor are installed, the overlying wall panels are installed so that the bolt protrudings of wall panels of the first floor enter the holes of second floor wall panel’s shoes. After the alignment of panels, the bolt protrudings of wall panels are tightened with nuts. At the same time, a stairwell is installed. The connection of standard elements is shown in Figure 4.

![Figure 4. Connection of standard elements of spatial-structural system of a frame-panel building: 1 – column of the first floor, 2 – wall panel of the first floor, 3 – floor slab, 4 – wall panel of the second floor, 5 – column of the second floor.](image)

Erection of the overlying storeys is carried out according to the technology described above. The order of installation works of the proposed system is shown in Figure 5.

![Figure 5. Order of installation works of spatial-structural system of a frame-panel building.](image)
The following measures are proposed to improve the flame resistance properties of the structure. The column shoes are poured with non-shrink concrete, after the whole structure is erected. The lower storey column’s shoe is grouted when concrete floor pouring on the first storey is performed. The upper part of the metal formwork of the floor slab and the part of the end of a wall panel’s permanent formwork is covered with grout when performing screed coat.

For those metal elements that remained exposed, paintwork or structural protection must be ensured. Modern fire-protective paints provide a fire resistance limit of metal structures up to 120 minutes. The use of structural protection, such as a combination coating based on aluminum-foiled basalt plates or roll materials and adhesive compound allows metal structures to resist fire for up to 240 minutes [13-17]. The assembled system is a panel-frame building with floor slabs supported by the outer panels and pillars in the inner row.

4. Discussion
The comparison of the main indicators of prefabricated building systems with the system proposed by the authors is presented in table 1 [11].

Table 1. Comparison of Dry Prefabricated Construction system with other Russian systems of prefabricated reinforced concrete construction.

| Technical and economic indicators | Prefabricated reinforced concrete building systems | | | |
|---|---|---|---|---|---|---|---|---|
| | Large-panel | Frame-panel | AGSPKD panel-frame housing construction | ARKOS -1 | UDS | REKO N (SMK) | Dry prefab con struct. system |
| Labor effort for production, % | 100 | 100 | 94 | 120 | 145 | 124 | 122 | 122 | 156 |
| Production man-hours, per m² | 1.6 | 1.6 | 1.5 | 1.92 | 2.32 | 1.98 | 1.95 | 1.94 | 2.5 |
| Labor intensity on site, % | 100 | 100 | 200 | 60 | 60 | 70 | 70 | 70 | 50 |
| Installation labor effort for 1 m², man-hours | 1.01 | 1.01 | 2.01 | 0.51 | 0.51 | 0.6 | 0.66 | 0.66 | 0.3 |
| Rate of construction, % | 100 | 100 | 200 | 60 | 60 | 70 | 70 | 70 | 35 |
| Possibility of free layout | No | No | No | Yes | No | Yes | Yes | Yes | No |
| Possibility to make two storey layouts | No | No | No | Yes | No | Yes | Yes | Yes | No |
| Quality | Medium | Medium | Medium | Medium | Medium | High | Medium | High | |
| Building frame | 1800 | 1850 | 1700 | 850 | 1100 | 800 | 750 | 850 | 1800 |
5. Conclusions
The analysis of Dry Prefabricated Construction System proved that the system proposed has the following advantages compared to other systems:

- in the proposed solution of the spatial-structural system of a frame-panel building there is no need for welding and concreting, which entails the acceleration of building erection process and the decrease in the labor intensity of construction;
- the panel-frame system under consideration simplifies the reconstruction of a building, due to the ease of replacing the bolt element of the structure;
- the proposed system implies the possibility to dismantle structures and reuse them, which increases the economic effect and reduces the negative impact on the environment [3];
- the absence of welding processes reduces the risk of defective welding;
- due to the lack of welding and concreting processes, there is no need to arrange a workplace for a cement mason and a welding operator.

However, the proposed system has the following drawbacks:

- due to a large number of unique concrete inserts, the complexity of manufacturing prefabricated elements increases;
- large metal consumption and heavy weight of the structure;
- free layout is not possible;

lack of design guidelines for the proposed stable demountable prefabricated frame system. However, design guidelines for such systems are being developed more actively with each passing year [7].

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