Design of prefabricated reinforced concrete structures: comparative analysis of prefabricated reinforced concrete floor slab

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Abstract. The article describes application of precast, cast-in-situ and composite structures on construction site. Importance of Analysis of Russian (SP) and European design standards (EuroCodes) is underlined. Historical review of Russian codes for composite reinforced concrete structures is given. Methods of composite structures calculating according to current Russian Codes are given. Ultimate and service limits states are listed for describing structures. Advantages and disadvantages of cast-in-situ, prefabricated and complex technologies are discussed. Comparison of prefabricated, monolithic and complex technologies is given on example of intermediate floor slab. Examples of sections of prefabricated reinforced concrete composite structures are summarized. Composite structures detailing is given on example of real project of Parking building of Okhta-Mall shopping and entertainment center, Saint-Petersburg. Constructive solutions are presented that increase the bearing capacity and resistance to progressive collapse of structures. Manufacturing photos of prefabricated ready-made reinforced concrete slabs as a part of future composite slab are presented. Examples of detail drawings for composite concrete slabs, executed in accordance to Eurocode, are given. Suggestions for improving the existing Code of Practice are given. Reference to similar scientific papers is presented related to composite reinforced concrete elements. Article is developed with financial and technical information support of AFRY Oy Finland.

1. Introduction
Currently, it is important to improve the quality of construction installation works in combination with an increase of technical safety of design solutions, a reduction of construction period and minimization of operations on the building site. One of the promising areas is construction of prefabricated reinforced concrete structures. The article provides an overview of the domestic and foreign design regulatory framework and gives recommendations for its improvement, makes a comparative analysis of precast reinforced concrete structures, offers modern design solutions and protection measures against progressive destruction. Relevance of the current topic is confirmed by wide amount of researches in field on composite concrete structures [1–8].

2. Current state of the regulatory framework
The remain in force documents of the Russian Federation of the design of precast reinforced concrete structures are the Design Codes "Precast reinforced concrete structures. “Design rules” [9] and
“Concrete and reinforced concrete structures. Guidelines” [10]. Previously, the guidelines of the calculation of the precast reinforced concrete structures were presented by Design Code [11] and Guide [12], which also contains examples of structural analysis.

The main European standards for the design of precast reinforced concrete structures are the Eurocode "Design of concrete structures. General rules and rules for buildings” [13] and the Eurocode for precast reinforced concrete structures. For example, EN 13474: 2005 + A2 applies to the design of precast slab consist of precast prestressed slabs and cast-in-situ concrete on the top of the structure. According to Eurocode’s Appendix F, the strength and stability of composite slabs is determined by the adhesion of the precast elements to the cast-in-situ concrete. If shear forces are transmitted through the contact area of the precast and cast parts, the design of the floor is carried out similarly to the design of cast-in-situ slabs.

According to the Design Code [10], the calculation is presented for two stages of construction work:

- the calculation of the prefabricated element (before cast-in-situ part reach the certain strength) is carried out according to SP 63.13330, taking into account the loads of the cast part and assembling loads;
- the calculation of a precast reinforced concrete structure (after cast-in-situ part reach the certain strength) is carried out according to the recommendations of SP 337.1325800 for working loads, taking into account stresses and deformations, which arose before the cast-in-situ concrete achieve exact strength.

The guidelines of the calculation for the Design Code [10]:

- calculation of strength for normal and inclined sections (taking into account the different concrete strength of precast element and cast-in-situ part);
- calculation of the contact joint strength between the concrete of precast element and cast-in-situ part of the structure (calculation of the contact joints is based on the limiting state along the joint’s surface, limited by inclined cracks);
- calculation of the formation and opening of cracks;
- calculation of the deformations.

At the same time, both in Russia and in the European Union countries, the most serious attention is paid to the problem of protecting public and residential buildings from progressive collapse [14, 15]. Science groups are working with developing of current approaches [16–24].

3. Comparative analysis of prefabricated, precast reinforced concrete and cast-in-situ structures

The choice of building technology is one of the most important stages affecting on the assembling technology of structures, quality of elements, installation speed and many other characteristics of future building. Consider the advantages and disadvantages of various technologies for construction of prefabricated, cast-in-situ and prefabricated reinforced concrete frames.

Construction experience shows that the producing of structures at the factory ensures their quality, high work mechanization, production speed and operational processes control. The advantages also include high speed and installation of structures in different weather conditions. The disadvantages of prefabricated structures are lower resistance to progressive collapse, necessity of elements transportation from the factory, lack of flexibility in case of changes in the design, arrangement of technological holes, installation of embedded parts and anchors.

Cast-in-situ frame provides freer planning solutions by using structures of complex shapes, the possibility of making changes during construction and reconstruction, higher fault-tolerance and survivability.

The disadvantages of cast-in-situ structures are their large weight, significant increase in the labor intensity of work on construction site, lack of favorable weather conditions for large amount of concrete work or necessity temporary shelters, including winter conditions. Quality control of cast-in-situ structures at the site is significantly complicated and requires more skilled workers.
Recently, in search of optimal solutions, prefabricated reinforced concrete technology has been increasingly used, combining the best qualities of prefabricated and cast-in-situ structures and providing a solution to the following tasks:

- implementation of the main bearing elements at the factory (comfortable working conditions, high productivity and quality of products);
- protection of the structure from progressive collapse;
- reduction of construction time by formwork decrease when prefabricated elements are used as permanent formwork (Figure 1);
- reducing weight of the structure;
- layout flexibility;
- perception of significant life loads;
- flexible execution of openings and installation of embedded parts and anchors;
- the aesthetic role of prefabricated elements in interior design.

![Figure 1. Examples of sections of prefabricated reinforced concrete structures (cast-in-situ part of the concrete is shaded).](image)

4. Structural solutions for prefabricated reinforced concrete structures

Consider precast reinforced concrete floor (Figure 2), which used in the Okhta Mall Parking building in the Saint-Petersburg. Project was designed by AFRY. The floor structure is 120 mm prefabricated slab and 100 mm cast-in-situ upper part (Figure 3). Precast slab has a rough surface and starter bars into cast-in-situ part of floor to ensure their joint work. The slab rests on the cantilevers of cast-in-place poststressed beams, located with 8.4 m step. Upper reinforcement is located in cast-in-situ part of floor. It passes between adjacent slabs above the beam by that ensures joint operation of the slab as a continuous beam and protection against progressive collapse.

From an aesthetic point of view, lower part of the floor is smooth and corresponds to the A1 surface finish class in accordance with GOST 13015.2012, which does not require additional processing on the construction site. Precast slab also works as a permanent formwork that does not require installation of mounting racks. It is greatly simplifies process of cast-in-situ work. On top of the finished structure provides a finish reinforced concrete screed 70 mm. Coating allow obtaining required class of finishing of upper slab surface, to hide seams and irregularities of the casted floor and to protect the upper reinforcement over the beam.
Figure 2. Scheme of prefabricated reinforced concrete floor slab of the Okhta Mall Parking: 1 – cast-in-situ part of the slab, 2 - precast slab (reinforcement is not shown conventionally), 3 - poststressed beam, 4 - reinforcement for prevent of progressive slab collapse.

Figure 3. Precast slab of the Okhta Mall Parking floor structure.
Structure of precast reinforced concrete floor by using prefabricated solid slabs was also used in construction of the Mega shopping malls in St. Petersburg, Moscow, Novosibirsk, etc.

The important requirement to connection of prefabricated reinforced concrete structures is design solutions that prevent progressive collapse. In the case of floor failure in the span area, support reinforcement is provided above the beams in the middle floor supports (Figure 2) and starter bars from wall panels or beams along to the end supports (Figure 4).

![Figure 4. Scheme of end reinforcement of floor.](image)

Collaboration of beams and floor slabs is ensured by outlets from the beam into the cast-in-situ part of the floor slab (Figure 5). The formation of the T-section further increases the bearing capacity of the beam.

If opening in the floor is required, cast-in-situ part allows installation bordering reinforcement. It provides support of clipped prefabricated slabs over the adjacent ones (Figure 6).

A nuance in the design of these precast slabs is also the use of outlets for upper monolithic part as lifting loops (Figure 7).
Figure 5. Scheme of reinforcement of slab and beam connection.

Figure 6. Scheme of reinforcement of floor openings. An example of the drawing according to Eurocode.
5. Conclusion

Based on the experience of design, operation and requirements of European standards, we can talk about necessity similar requirements in the mandatory sections of domestic Design Codes. Frequent publications [7-9] and development of recommendations [10-12] on the subject of progressive collapse confirm this.

Each of the reinforced concrete technologies has its own limits of applicability and, if properly implemented, it can bring significant economic, planning, aesthetic and other benefits. The prefabricated reinforced concrete frame is a promising direction in construction and attracts more and more attention from customers, architects, designers and developers.

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References

[1] Yakubov E N 2011 StroyProfil 8 8-11
[2] Gurov E P 2010 StroyProfil 4 5-10
[3] Nedviga E S and Vinogradova N A 2016 Construction of unique buildings and structures 4 87-102
[4] Abramyan S G and Gnatyuk D V 2017 Naukovodienie 9(1)
[5] Koyankin A A and Mitasov V M 2015 Vestnik MGSU 9 28-35
[6] Koyankin A A and Mitasov V M 2015 Vestnik MGSU 10 32-39
[7] Rudenko D V and Rudenko V V 2009 Engineering and Construction J. 3 38-41
[8] Chakrabarti S, Nayak G and Paul D 1988 ACI Structural J. 85
[9] SP 63.13330.2018 Precast reinforced concrete structures. Design rules
[10] SP 337.1325800.2017 Concrete and reinforced concrete structures. Guidelines
[11] SNIIP 2.03.01-84 Design of precast reinforced concrete structures
[12] Guidelines to SNIIP 2.03.01-84 Design of precast reinforced concrete structures
[13] EN 1992-1-1:2004 Design of concrete structures. General rules and rules for buildings
[14] SP 385.1325800.2018 Protection of buildings and structures from progressive collapse. Design rules. Guidelines
[15] EN 1991-1-7 Action on structures. General actions – Accidental actions
[16] Perelmuter A V, Kriksunov E Z and Mosin N V 2009 Engineering and Construction J. 2 13-18
[17] Rastorguev B S 2003 Seismic construction. Safety of Structures 4 45-48
[18] 2006 Recommendations for protection of high-rise buildings from progressive collapse (Moscow: Moskomarkhitektura)
[19] 2005 Recommendations for protection of cast-in-situ residential buildings from progressive collapse
[20] 1999 Recommendations for preventing progressive collapse of large-panel buildings
[21] Ramin Vagheia, Farzad Hejazia, Hafez Taheria, Mohd Saleh Jaafarb and Abang Abdullah Abang Alic 2014 APCBEE Procedia 9 285-290
[22] Belov V V and Nikitin S E 2013 Int. Offshore and Polar Engineering 4 142-147
[23] Ong K, Hao J and Paramasivam P 2006 ACI Structural J. 5 103
[24] Frosch R J 1999 ACI Structural J. 4 96