Improvement of competitive edge of precast reinforced concrete by increasing the reliability level and quality control

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Abstract. Improvement of the competitive edge of precast reinforced concrete is necessary to achieve due to the high quality and level of reliability. Previously, it can be concluded that there is significant potential to increase the level of reliability of precast structures by improving the quality of concrete and control. The advantages of precast concrete were considered in the paper. Changes of requirements of modern standards to the quality indicators of concrete strength including coefficient of variation of concrete strength properties were analysed. Assessment of the influence of the stability of precast reinforced concrete structures production due to such quality indicators as the coefficient of variation of the concrete strength and the accuracy of the cross section of precast elements was performed. The estimation of the variation coefficient of concrete strength from 9 to 13% in accordance with the changes in the modern regulatory documents was carried out in the paper. The results of the calculations show that the decrease of the reliability level takes place up to 30%.

Keywords. Precast concrete, quality indicator, reliability level, coefficient of variation, accuracy of the cross section, concrete strength

Introduction

The use of precast reinforced concrete products is gradually reduced in comparison with the volume of application of monolithic structures in industrial and civil construction. There are many reasons for this. However, one can distinguish the main ones:

- development of new technology of casting of fresh concrete that reduce the defects of monolithic structures, for example self-compacting concrete, reactive powder concrete, etc. [1-5];
- improvement of equipment at the construction site. Production technology of concrete, its transportation, casting and maintenance has changed qualitatively, which leads to extensive use of monolithic structures [6-10];
- improvement of tooling and equipment. At the moment, a wide variety of effective formwork systems made of different materials and structures are available [11,12];
- absence of seams, in addition to technological seams;
- ability to build different architectural forms with high architectural expressiveness of building facades due to free space-planning solutions, possibility of building a complex configuration in the plan are also advantages of monolithic structures.

Despite these advantages of monolithic structures, precast structures have a number of advantages that retain their use in construction. Precast structures of factory production allow to improve the
quality and accuracy of the erected structures, reduce the cost of personnel on the construction site, increase the manufacturability, reduce the labour intensity and timeframe of construction of buildings, improve the level of environmental protection, reduce the noise and dust [13]. High-quality precast structures are in demand for transport construction [14,15].

The initial reasons of the decline of popularity of precast concrete structures are deeper and are determined by regulation forms. An important reason is the decrease of reliability level that determines the faultlessness, maintainability and durability of erected structures [16-18]. It should be taken into account that the reliability level affects the accident rate of building structures [19].

Confirmation of the above is that concrete and reinforced concrete structures are among the most dangerous structures according to accident statistics [20]. Analysis of statistical data in Figure 1 allows us to conclude that the accidents of concrete structures for specified period of time were more than 40% of the total number of accidents.

![Figure 1. The number of accidents of buildings and structures in various design solutions that occurred during the period 1999-2003 [20]](image)

The distribution of the number of accidents in 2003 according to the main causes of their occurrence is shown in Figure 2. It should be noted that the causes of 4% of all accidents were the imperfection of regulation forms and the poor quality of precast concrete structures. Violation of the requirements of regulatory documents and deviations in the performance of construction and installation works play a major role that is up to 35%. Poor performance of work became cause of more than 1/3 of accidents according to Figure 2.
Modern ideas about ensuring reliability assume the control of construction products at all life cycles: at the design stage, at the stage of construction and at the stage of subsequent operation [13,16,19,21].

Ensuring reliability in the design process is based on the probabilistic approach in determining the failure period taking into account the random nature of the external parameters of the impact and the internal structure of materials [22,23]. Ensuring reliability in the construction process is associated with the quality of materials, technologies and personnel that is ensured by quality control [24-28]. Ensuring reliability in the maintenance process is based on the methods of fracture mechanics and through inspections, non-destructive testing and repairs [19,29].

Thus, the question of influence of the control system on the reliability requires careful attention since the solutions will affect the reliability of the erected structures and therefore the safety of the erected and operated buildings and structures.

The aim of the paper is to assess the influence of the stability of production of precast reinforced concrete structures using the following quality indicators: the coefficient of variation of concrete strength properties and the accuracy of the cross-section of precast elements.

**Research method**

Currently, the coefficient of variation for precast concrete products is limited to the value of 13% according to the standard 18105-2010 "Concrete. Rules of control and strength assessment". However, the coefficient of variation for precast concrete products was previously limited to the value of 9% in earlier regulation dated 1983. According to the point 7.3 in the standard 13015-83 "Products of precast concrete and reinforced concrete [30]. General technical requirements" the coefficient of variation of concrete strength for structures of the highest category of quality must comply with the coefficient established by the standard for the construction of specific types. Thus, coefficient of variation of compressive strength in the batch shall be no more than 9% for concrete of all strength classes and for light concrete of the B12.5 strength class and above.
Delivery of products to consumer shall be carried out after achievement by concrete of the required handling strength according to point 5.6.4 in modern interpretation of the standard 13015-2012 "Products of precast concrete and reinforced concrete. General technical requirements". The manufacturer must ensure that the concrete products supplied with the handling strength below the strength corresponding to strength class will achieve the required strength at the in target dates provided that they harden under normal conditions according to regulatory documents [31,32].

Thus, the reduction of the requirements to the coefficient of variation for precast concrete and reinforced concrete takes place in the current regulatory document. It should be noted that this directly affects the level of reliability. For example, the increase of the coefficient of variation from 0.13 to 0.2 leads to the decrease of the probability of failure of the structure by almost 2.5 times [33-35].

Evaluation of the probability of failure - free operation is estimated in paper [36]:

\[
P_f = \frac{1}{\sqrt{2\pi}} \beta^2 - 1 \exp\left(-\frac{\beta^2}{2}\right)
\]  \hspace{1cm} (1)

where the safety feature or reliability level is provided by the dependency:

\[
\beta = \frac{K_{zan} - 1}{\sqrt{\left(v^2_R K_{zan} + v^2_Q\right)}}
\]  \hspace{1cm} (2)

\[
v_Q = \frac{S_Q}{Q}, \quad v_R = \frac{s_R}{\overline{R}}
\]

where

- \(S_r\) - standard deviation of strength properties of material and loads accordingly;
- \(\overline{R}\) - general structural strength;
- \(\overline{Q}\) - general load.

Then the safety coefficient \((K_{zan})\) can be determined by the formula:

\[
K_{zan} = \frac{(2 + \beta^2 v^2_R) + \sqrt{(2 + \beta^2 v^2_R)^2 - 4(1 - \beta^2 v^2_Q)}}{2}
\]  \hspace{1cm} (3)

**Research results**

The estimation of the variation coefficient of concrete strength from 9 to 13% in accordance with the changes in the above-mentioned regulatory documents is carried out in the paper.

The results of the calculations show that the decrease of the reliability level takes place according to Table 1.

**Table 1. Influence of concrete production stability on the reliability of concrete and reinforced concrete structures**

| Changing of \(v_R\) | \(v_R\) | \(v_Q\) | \(Kz\) | Reduction of \(\beta\) | \(P_f\) | Reduction of \(P_f\) |
|---------------------|--------|--------|--------|----------------------|--------|---------------------|
| At the maximum coefficient of variation of concrete strength equal to 13% | 0.13 | 0.47 | 2.23 | 2.419 | 0.00733776 | 30% |
| At the reduced coefficient of variation of concrete strength equal to 9% | 0.09 | 0.47 | 2.23 | 2.516 | 0.00563425 | 0% |

Estimation of changes of the accuracy of the geometric dimensions of the cross section was also performed in the paper. The accuracy of geometric dimensions for precast elements is regulated by the
standard 13015-2012 “Products of precast concrete and reinforced concrete. General technical requirements”. Values of limit deviations should be taken in dependence on the clearance values for the corresponding accuracy classes of geometric parameters according to standard 21779-82 "System for ensuring the accuracy of geometric parameters in construction. Technological clearances". Recommended accuracy classes of geometric parameters are given in Table 2.

**Table 2. Recommended accuracy classes of geometric parameters**

| Types of deviations of the geometric parameter | Geometric parameter                                                                 | Accuracy class       |
|-----------------------------------------------|-------------------------------------------------------------------------------------|----------------------|
| The deviation of the linear size               | Length, width, height, thickness or diameter of the product, size and position of ledges, notches, holes, openings: the position of landmarks (places of slinging and support, installation marks) applied to the product | From 5 to 8 inclusive |

Clearances for products depending on the accuracy class are shown in Table 3.

**Table 3. Clearances of linear sizes**

| Nominal size interval L | The clearance value for the accuracy class, mm |
|------------------------|-----------------------------------------------|
|                        | 5     | 6     | 7     | 8     |
| " 120 " 250            | 3     | 5     | 8     | 12    |
| " 250 " 500            | 4     | 6     | 10    | 16    |
| " 500 " 1000           | 5     | 8     | 12    | 20    |
| " 1600 " 2500          | 8     | 12    | 20    | 30    |
| " 2500 " 4000          | 10    | 16    | 24    | 40    |

The accuracy class is determined from the condition taking into account the acceptable level of quality AQL up to 5% and therefore the assemblability of products according to standard 23615-79 "System for ensuring the accuracy of geometric parameters in construction. Statistical analysis of accuracy«:

\[
\Delta x \leq 2tS_x, \tag{4}
\]

where \( \Delta x \) - the closest to the value \( 2tS_x \) clearance value for this interval of nominal size in the relevant tables of the standard 21779-82 "System for ensuring the accuracy of geometric parameters in construction. Process tolerances";

\( t \) - coefficient according to the standard 23615-79 depending on the value of the acceptance level of defects AQL at the control of accuracy according to standard 23616-79 "System for ensuring the accuracy of geometric parameters in construction. Accuracy control".

It should be noted the accuracy of the manufacture of precast concrete and reinforced concrete structures in terms of cross-sectional dimensions according to the normative document Code of Rules 70.13330.2012 "Load-bearing and enclosing structures":

- manufacturing tolerance is +6; -3 for monolithic products up to 200mm. For precast products the tolerance is higher only for accuracy class 5;
- manufacturing tolerance is +11; -9 for monolithic products up to 400 mm. For precast products the tolerance is higher only for 5 and 6 accuracy classes;
- manufacturing tolerance is +25; -20 for monolithic products up to 2000mm. For precast products the tolerance is higher only for 5, 6 and 7 accuracy classes.

It should be noted that not "0" connection according to standard 21778-81 "System to ensure the accuracy of geometric parameters in construction. Basic provisions" is used in monolithic structures. The value of the displacement of the mathematical expectation of the average value of \( \delta m_x \) (\( \delta x_c \) -
under the normal distribution law) in relation to the nominal size of $x_{\text{nom}}$ is shifted in positive direction, i.e. it is increased.

Therefore, the potential level of reliability of precast structures according to the factor of accuracy of geometric dimensions is higher than the reliability level of monolithic structures. This is due to the requirements of structures assemblability. The accuracy of manufacturing, the level of reliability of erected structures will be lower for precast structures of 7 and 8 classes compared to monolithic structures. This is partly compensated by the positive connection of $\delta x_c$ under normal law of distribution in relation to the nominal size of $x_{\text{nom}}$.

The bearing capacity of the structure and the products assemblability with AQL equal to 5% according to standard 23615-79 "System to ensure the accuracy of geometric parameters in construction. Statistical analysis of accuracy" are provided in compliance with the specified requirements of manufacturing accuracy, which means that the required level of reliability is also provided.

**Conclusions**

Improvement of the competitive edge of precast reinforced concrete is necessary to achieve, first of all, due to the high quality and level of reliability. The basis is to increase the potential benefits of factory manufacturing and better quality control than in-situ. Previously, it can be concluded that there is significant potential to increase the level of reliability of precast structures by improving the quality of concrete and control. Modern concrete plants achieve the production of concrete with in-series variation coefficient of concrete strength of about 4-5% but this potential is not used in calculations and in practice. It is important to change the requirements for the accuracy of the geometric dimensions of the cross section for precast concrete structures. The load-bearing capacity of structures and the products assemblability with AQL equal to 5%, and hence the required level of reliability is provided in compliance with the specified requirements of manufacturing accuracy.

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