The impact of conformity control on the value of the reliability index

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Abstract. The article presents the impact of conformity control on the value of the reliability index. The performed reliability analyses were related to the quality of C20 / 25 class concrete verified on the basis of the compliance criteria for a number of samples, $n = 3$ and $n = 15$. It was found, that the type of concrete conformity criteria significantly influences the value of the reliability index, especially for the low number of samples n . The level of reliability for concrete construction decreases when the conformity control is carried out for the number of sample $n = 3$. In any case of doubts concerning the quality of C20 / 25 building concrete, the influence of conformity control for number sample $n = 3$ should be taken into account, especially the case when the concrete is produced with a standard deviation greater than 4.0 MPa.

1 Introduction

Reliability, safety and good quality of components, elements and structures have at least two meanings in the subject literature, generally qualitative and narrower in quantity [1–3].

The reliability of the structure is its ability to meet specific design requirements, taking into account the planned period of use. The concept of the design period of use should be understood as the time interval in which the structure or its part is to be used in accordance with the intended purpose, without the need for major repairs. Usually, reliability is expressed in probabilistic measures - using the reliability index or the probability of failure. The reliability of building structures depends on many correlated factors, mainly on: the quality of materials, the accuracy of execution and the level of control, the impacts of the environment and maintenance, the proper period of use, accepted construction and material solutions, construction details and applied technologies, accepted loads, their values and combinations, the standard requirements regarding load bearing capacity, use and durability, the quality of calculation models used in the design process and methods for assessing structural reliability.

Construction safety is a concept that is narrower than reliability, which in the traditional general sense is associated with the lack of danger and often equated with the risk of a threat to people's lives and health and economic, social and ecological losses in the planned time of use. In a narrower sense, safety is called conditional reliability, it is defined as a conditional probability that a structure that has met the relevant conditions during the process will not reach certain limit states during the assumed exploitation period [3].

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Good quality is, in general, a good condition of elements, connections and the entire structure; or in a narrower sense, the probability that the structure at the time of receipt has no defects. The quality of the element or structure is determined at the time of its receipt, while the safety as well as the reliability during the assumed period of operation [3].

During concrete works, the verification of concrete quality is carried out in accordance with the principles set out in PN-EN 206 [4] (fig. 1). The basic quality control, obligatorily, lies with the concrete producer.

Fig. 1. The verification of concrete quality.

2 Reliability index and concrete conformity criteria

The decision to pass the considered batch of concrete into its designed class depends on the fulfillment of the conditions imposed on the average and the lowest strength of the specimen. In the standard CEB-FIP Model Code from 1978 [5] formulated the basic criteria for the conformity control for concrete compressive strength, the forms of which were preserved in all the later versions of standards for concrete.

In order to achieve a sufficient level of the reliability required for a concrete structure, the strength distribution and parameters of concrete supplied to a construction site should be in accordance with the assumptions specified in design. Thus, in each lot of concrete the conformity of the compressive strength should be verified using an adequate conformity criterion. Statistical conformity criteria specified in different codes and standards [1–3] usually consist of two elements and can be expressed as follows (1):

$$f_{cm} \geq f_{ck} + k_1 \quad \text{and} \quad f_{ci} \geq f_{ck} - k_2 \quad (1)$$

where f_{cm}, f_{ci} are the sample mean and minimum value of the compressive strength of concrete, f_{ck} is the characteristic value of the concrete compressive strength specified by the producer, k_1, k_2 are parameters that depend on different factors, for example: $k_1 = \lambda s_n$, $\lambda = (1.4 \div 1.87)$; λ is the parameter that depends on the tolerance limit and the fractile considered, s_n is the sample standard deviation, or $k_1 = (1 \div 5)$ MPa and $k_2 = (1 \div 5)$ MPa [4, 6–27].

According to EN 206 [4] for small number samples $n < 15$, these criteria are (2):

$$f_{cm} \geq f_{ck} + 4, \quad f_{ci} \geq f_{ck} - 4 \quad (2)$$

where: f_{cm} – average strength in the n -element sample, f_{ck} – characteristic strength of concrete, f_{ci} – the lowest strength in the n -element sample.

For a number of sample $n \geq 15$, the conformity criteria are dependent on the standard deviation of the sample, and have the form (3):

$$f_{cm} \geq f_{ck} + 1,48 \cdot \sigma, \quad f_{ci} \geq f_{ck} - 4 \quad (3)$$

The defined conformity criteria for concrete may affect the value of the reliability index. Statistical conformity criteria show numerous disadvantages. The rational conformity criteria should fulfill at least the following requirements [6–27]:

- for larger sample sizes the probability of acceptance of the offered lot of good quality concrete should increase, and the probability of acceptance of the offered lot of concrete not satisfying requirements should decrease,
- for the lot of good quality concrete the probability of acceptance should increase with the decrease of the standard deviation of concrete strength.

Therefore, the impact of compliance validates the value of the reliability index [6–27].

According to Eurocode 1990 [10], the compressive strength f_{cd} is equal to the strength of the characteristic f_{ck} divided by the partial coefficient (in Poland) $\gamma_c = 1.4$. With this assumption, the reliability index for concrete constructions can be saved as (4):

$$f_{cd} = f_{cm} - \alpha_i \beta \sigma \quad (4)$$

The reliability index for realized construction objects according to the compliance criteria for $n < 15$ according to the formula (2) can be saved as (5):

$$\beta = \frac{f_{cm} - (f_{cm} - 4) / 1.4}{0.8 \cdot \sigma} \quad (5)$$

When verifying the quality of material according to the criterion for $n \geq 15$ according to the formula (3), the reliability index has the form (6):

$$\beta = \frac{f_{cm} - (f_{cm} - 1,48 \cdot \sigma) / 1.4}{0.8 \cdot \sigma} \quad (6)$$

The reliability index β is related to the failure probability of an element or structure by the dependence (7):

$$P_f = \Phi(-\beta) \quad (7)$$

where: $\Phi(\dots)$ – Laplace function.

The structure can be considered reliable if the calculated value of the reliability index according to the formulas (5) and (6) is not less than or equal to the target value (8):

$$\beta \geq \beta_d \quad (8)$$

The recommended minimum target values of the reliability index β_d for the Ultimate Limit State of structures with different reliability classes and reference periods $T_0 = 1$ year and 50 years are given in Annex B to PN-EN 1990 [10].

The performed reliability analyses were related to the quality of C20 / 25 class concrete verified on the basis of compliance criteria for the number of samples $n = 3$ and $n = 15$.

3 Case study

The influence of conformity control on the reliability level of concrete structures was carried out for the most commonly used concrete class - C25/30. It was assumed that the construction element is the RC 2 of the reliability class and, in accordance with Annex C to PN-EN 1990 [10], the target value of the reliability index $\beta_d = 3.8$ ($P_{fd} = 7.23E-05$).

The calculations of the reliability index for a construction element has been made according to the formulas (5), (6) and (8).

In the analyzed case, it can be noticed that the conformity control and number of samples have a significant impact on the level of reliability of concrete structures, whose safety and reliability depends on the characteristic strength of concrete (Fig. 2).

Fig. 2. Calculated values of reliability indexes in accordance with formulas (4) and (5), for a number of samples n=3 and n=15.

4 Conclusions

The type of concrete conformity criteria significantly influences the value of the reliability index, especially for the low number of samples n. The level of reliability for concrete constructions decreases when the conformity control is carried out for the number of sample n = 3. In case of any doubts concerning the quality of C20 / 25 building concrete, the influence of the conformity control for the number of samples n = 3 should be taken into account, especially in the case of concrete produced with a standard deviation greater than 4.0 MPa.

References

1. J. Murzewski, (*Niezawodność konstrukcji inżynierskich*, Arkady, 1989)
2. Sz. Woliński, K. Wróbel, (*Niezawodność konstrukcji*, OWPRz, Rzeszów, 2001)
3. Sz. Woliński, (*Budownictwo ogólne, elementy budynków, Podstawy Projektowania*, t.3, Arkady, 2006)
4. EN 206 Beton. Wymagania, właściwości, produkcja i zgodność.
5. CEB-FIP Model Code 1978 CEN Bulletin d'information, CEB No.124–125, (1978)
6. G. Konig, D. Soukhov, F. Jungwirth, , in 12–th ERMCO Congress, Proceedings, **1**, (1998)
7. D. Soukhov, F. Jungwirth, LACER , **2**, 199–222, (1997)
8. I. Skrzypczak, Sz. Woliński Sz., AIL, **53**(3), 479–495 (2007)
9. PN-EN 1992 Eurokod 2: Projektowanie konstrukcji z betonu
10. PN-EN 1990 Eurokod 0: Projektowanie konstrukcji
11. PN-ISO 2394:kwiecień 2000, Ogólne zasady niezawodności konstrukcji budowlanych
12. Comité Euro-International du Beton, *CEB-FIB Model Code 1990*, Bulletin d'Information No. 213–214, Lausanne (1993)
13. I. Skrzypczak, (*Statistical and fuzzy control of concrete strength*, [in Polish], Rzeszów UT, PhD Thesis, Rzeszów, 2005)
14. L. Taerwe, Mater Struct, **21**, p.13-20, (1988)
15. R. Caspeele, M. Sykora, L. Taerwe, Mater Struct, **47**(1–2), 105–116, (2014)
16. R. Rackwitz, Mater Struct, **16**, 259–267 (1983)
17. J.M. Juran, F.M. Gryna, R.S. Bingham, (*Quality control handbook*, McGraw Hill, New York, 1979)
18. R. Caspeele, L. Taerwe, Mater Struct **44**(7), 1219–1231 (2011)
19. L. Taerwe, R. Caspeele, in: D. Proske, M. Mehdianpour, L. Gucma (eds) (*Proceedings of 4th international probabilistic symposium*. Berlin, 57–70, 2006)
20. M. Holický, M. Sýkora, in: M. H. Faber, J. Köhler, K. Nishijima, (*Proceedings of ICASP11, 11th International Conference on Applications of Statistics and Probability in Civil Engineering*, ETH Zurich, Switzerland, 969–976, 2011)
21. Skrzypczak I., Buda-Ozog L., Kokoszka W., Slowik M., JCEEA 32(62-3/I/15), 403–412, (2015), <http://doi.prz.edu.pl/pl/pdf/biis/295>
22. Skrzypczak I., Wolinski Sz., AIL, **53**(3), 479–495 (2007)
23. Szczygielska E., Tur V., Budownictwo i Architektura, **12**(3), 223–230 (2013)
24. Beal A.N., The Structural Engineer, **87**(10), 12–13 (2009)
25. Toplis, P., The Structural Engineer, **86**(23/24) 43 (2008)
26. Pawlikowski J., *Systemy zapewnienia jakości w budownictwie*, ITB, 2003)
27. Mirza S. A., MacGregor J. G., Journal of the Structural Division, **105**(6), 1021–1037, (1979)