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The application of reliability analysis in engineering practice – reinforced concrete foundation

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Abstract

In recent years, the importance of assessment of structural reliability has increased significantly. This is confirmed by the recommendations of the standard PN-EN 1990 in which the rules and requirements to ensure safety, serviceability and durability of the structure are specified. It also sets out the basis for calculation and verification of constructions and provides guidance to ensure their reliability. Reliability design focuses on the ability to meet specific design requirements, taking into account the planned period of use. The concept of the planned period of use should be considered as the adopted in the project interval in which the structure or a part of the structure is to be used for its intended purpose without the need for general repairs. Typically, reliability is expressed in probabilistic metrics - using an index of reliability or probability of failure. Reliability of building structures depends on a number of correlated factors, mainly on the quality of materials, building precision and level of control, protection against environmental influences and maintenance level during exploitation, specific period of use, adopted solutions for the construction materials, design details and technologies, adopted loads (both their values and combinations), standard requirements regarding capacity, exploitation and durability, quality of computational models used in the design process and methods for assessing reliability of the structure. The performed reliability analysis concerns a reinforced concrete foundation, for which reliability index and probability of failure has been specified using the following methods: analytical method FORM, simulation methods FORM and SORM as well as Monte Carlo simulation.

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Keywords: reinforced concrete foundation; reliability index; FORM; SORM; Monte Carlo simulation;

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1. Structural assessment and reliability analysis

The assessment of existing structures aims at producing evidence that they will function safely over a specified residual service life. It is mainly based on estimating the material properties and strength capacity of structural members taking into account the present state of the structure, and evaluating its ability to withstand anticipated hazards and future loads. Nowadays, this problem is particularly important in the case of structures and primarily infrastructure. In fact, the rate and extent of the deterioration of existing structures have lately significantly increased. Indeed, the current low funding in the building sector of several European countries has forced agencies to postpone necessary investments in a new load and consequently stretch the service life of their existing old stock. The prioritization of the distribution of funds among maintenance, repair and rehabilitation activities is a major problem everywhere [1,2,3].

In the assessment and designing of structures, the probabilistic methods can be used widely. The aim of structural design is to realize structures that meet the expected performance, which can be often represented by a target reliability level [4,5,6,7,8]. There are different approaches for reliability verification: deterministic, semi-probabilistic, and probabilistic.

The most common deterministic safety measure is the global factor of safety, defined as the ratio of the resistance over the load effect. The concept of the allowable stresses is a traditional deterministic method, where failure of the structure is assumed to occur when any stressed part of it reaches the permissible stress. Deterministic verification methods which are based on a single global safety factor do not properly account for the uncertainties associated with strength and load evaluation. The semi-probabilistic approach is based on the limit state principle and makes use of partial safety factors for checking the structural safety. The partial factors have been calibrated so that a structure which satisfies the safety check using a set of design parameters will also satisfy the target reliability level. The semi-probabilistic verification method is still a simplified method but it can much better account for the uncertainties of some design parameters. Probabilistic verification procedures are also based on the principle of limit states, by checking that predefined target structural reliability levels are not exceeded. This approach takes into account explicitly the uncertainties.

Regardless of the uncertainties in different parameters accounting for the analysis and design of a structure, it is very difficult to measure its absolute safety using deterministic analysis. Therefore, one of the most important ways to specify a rational criterion for ensuring the safety of a structure is evaluating its reliability or probability of failure. The reliability of a structure is defined as its ability to fulfil the design purpose for some specified design lifetime [9, 10]. Reliability is often understood as the probability of not losing the intended function of the structure. The term failure of a structure does not necessarily mean catastrophic failure but it is used to indicate that the structure does not perform as desired. In structural reliability calculations, the probability of failure is taken as quantitative measure of a structural safety.

Most of the modern codes for constructions have recognized the need of using advanced reliability based design methods that allow taking into account various sources of uncertainty. To verify whether or not a structural design is acceptable, the uncertainties are modelled by using statistical tools and the failure probability is estimated with respect to all relevant limit states. The three main documents, that have been drawn on reliability based design, are the standard ISO 2394 [11], the probabilistic model code developed by the Joint Committee on Structural Safety (JCSS) [12] and the structural Eurocode [13].

The code ISO 2394 [11] is an important international standard that specifies general principles for the verification of the reliability of structures subjected to different types of actions. Reliability is considered in relation to the performance of the structure throughout its design working life. This international standard is applicable in all the stages of the construction process as well as during the use of the structure, including maintenance and repair, applicable to the structural appraisal of existing constructions or assessing changes of use.

The probabilistic model code developed by the Joint Committee on Structural Safety [12] represents an important step in the direction of the necessary standardization of the reliability based method. In 1971, the Liaison Committee, which coordinates the activities of six international associations of Civil Engineering (FIB, CIB, ECCS, IABSE, IASS, and RILEM), created the Joint Committee on Structural Safety with the aim of improving the general knowledge in structural safety. In 1992, the JCSS set as a long term goal the development of a probabilistic model code for new and existing structures. The JCSS code gives guidance on the modelling of the random variables in