Reliability Evaluation of Strengthened Reinforced Concrete Members

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Abstract – This paper is devoted to a brief analytical overview of study a problem of reliability evaluation of strengthened reinforced concrete (RC) members. The question of definition of real level of strengthened RC members, that are in use, are considered. The effect of external strengthening composite materials (FRP and CFRP strips) on reliability of RC members is presented, considering the statistical character of the design variables (geometry, material properties etc.). The probabilistic calculations, that are considered in this paper, are based on the Monte Carlo method. The importance of determination of reliability indexes of strengthened RC members is presented in the conclusions.

Key words – reliability evaluation, reliability index, reinforced concrete (RC), strengthened RC members, probability of failure, safety factor, reconstruction, FRP composites.

I. Introduction

From the first day of life cycle of the building (structures) in its units and constructions are changes, that lead to a deterioration in the project indicators. Depending on the importance and intensity of these changes are different: some cause deterioration of comfort areas, others – the destruction of all the buildings [1]; some quick fix, others – generally fatal (Fig. 1); some occurring slowly and continuously in time, others – randomly and unsystematically. However, all these changes, after a certain period of time, violates the workability of the all system. Thus, for the all duration of the normal functioning of the building or structure is a probable failure of the entire building or its individual members.

Fig. 1. Importance of safety factors: collapse of a 5-storey RC building in Christchurch (New Zealand) after the 22 February 2011 earthquake

Than smaller the probability, the more reliable the structure itself [2]. Accordingly, the calculation of RC structures as systems, that contain stochastic parameters and conditions (geometric dimensions of the elements, the characteristics of materials, load and effects), should be conducted in a probabilistic statement [3] based on the methods and theories of probability and of random functions. In this case, the guarantee of non-occurrence limit state a certain member of a building or structure may be provided with a certain probability (determinated reliability level) – probability of failure-free operation [4].

II. Analysis of Researches

Today, scientists carried out a sufficiently large number of the scientific researches, concerning a problem of reliability evaluation of load-supporting RC members various types (beams, plates, columns etc.) [4]. The largest contribution to the development of fundamental methods of definition of such an evaluation for building constructions various types implemented such Soviet scientists (founders of the reliability theory) as M.S. Streletsky, A.R. Rzhanitsyn and V.D. Raizer. Among the global researchers of this issue, should single out the names K.A. Cornell and G.O. Madsen. The most famous Ukrainian scientists – A.V. Perelmuter, S.F. Pichugin and A.I. Lantukh-Liashchenko. The study of reliability of RC members have begun to actively engage with the beginning of the XXI century, especially taking into account the efficiency methods themselves strengthening, and increase the amount of work of restoration and reconstruction of load-supporting members of buildings all over the world [4]. Among the modern scientists, concerned with the study of reliability of RC constructions, reinforced with composite materials under load, first of all will notes the names J.A. Barros [5], B.R. Ellingwood [6], J.R. Casas [7], V.M. Karbhari [8] and others.

The advantage of [5] is that it reliability analysis was conducted according to the experimental results of shear strength of more than 250 RC beams strengthened with external FRP strips, fixing at the load. To assess the reliability of its, author used the following variables condition: sections of beams – rectangular, T types, double-T types; range of strengthening options – orientation of FRP strips, their step, width etc.; the most common types of reinforcement FRP strips, depending on the type of sectional beams. Here, the best convergence of coefficients of safety has been achieved in accordance with European standards of design CNR-DT200 [9], worse – in accordance with American standards ACI 440.2R-02 [10]. However, according to the analysis results of reliability indexes, large variation of safety factor, in this case, can not provides an monosemantic criterion of understanding the influence on the overall reliability of strengthening. In addition, considered work has not been investigated and does not include such things as a significant effect on the overall reliability the transverse reinforcement of RC beams, which compensates a largely external strengthening contribution (by the objective evaluation of reliability (in this research – a "safety factor")).

More perfect, in terms of taking into account the common performance of elements in RC structure and approach to the assessment of its reliability, is the research [6]. It was proposed to the modern method of reliability evaluation of flexural RC members, reinforced with external fixing FRP composites under load, based on reaching the limit state in accordance with ACI 318-05 [11]. With this fixed, at the action of load to the lower borders of flexural RC members, FRP strips included in the construction work at some stage, and increase its strength and deformability. An important advantage of this method is that, it used to RC elements, that don't sufficient

bending strength (research concerns the strength of normal sections, not sloping sections – unlike discussed above [5]), that provides to the investigation of exceptional topicality concerning of the real conditions of reconstruction of flexural RC members. Moreover, for the determination of reliability (in this work – reliability index β) of reinforced members, are used not only RC beams as flexural elements, but also large-span stringers and plates (Fig. 2). The only one disadvantage of this work can be called, that it is adapted to American standards of design [10], [11].

Fig. 2. Illustrations of FRP debonding limit state: debonding at interface between FRP reinforcement and concrete

The method of calculation of the coefficients (factors) security (for analysis of reliability) of flexural RC bridges, strengthened outside with CFRP carbon strips (this method was applied to the seven being bridges, strengthened with insufficient bending strength), was designed in the paper [7]. It should also be added, that in accordance with the conducted researches was received the dependence – coefficient (factor) of safety, that strictly related to the accepted model of predicted debonding of elements (layers) of strengthened construction. The disadvantage of work [7] – the applicability of the developed method only for large-span beam structures (bridge stringers etc.), that are in use.

V.M. Karbhari [8] in his work used the two most common prognostic approaches for reliability evaluation as to long-term deterioration of a number of characteristics of the materials of strengthening (wet layers of carbon or epoxy resin), which are then compared with experimental data, obtained for a period of three years of influence. The resulting reliability forecasts was compared with the coefficients of safety, that proposed regulations ACI 440.2R-02 [10]. The disadvantage of this work include the approach to reliability prognostication, that can only be applied for the material of strengthening.

It is also actual work O.P. Voskobiinyk, in which a whole chapter devoted to the research project and the real level of reliability of different types of steel-reinforced concrete constructions (SRCC) at all stages of their life cycle. In particular, it has been developed the method of determining of probability of failure and the provision calculated resistance of SRCC, that formed by strengthening of flexural RC members with different degrees of damages by using of a rigid steel bars [4].

Conclusion

Significant progress in the developing of methods for reliability evaluation of strengthened constructions, which happened in the XXI century, primarily caused by overall development of the reliability theory, and active implementation of modern materials and systems for strengthening of load-supporting members of buildings and structures, that are in use. Some studies of reliability evaluation of RC members are also in the works of such scientists as R. Al-Mahaidi, E. Ferrier, J. Weselek [4].

The results of analyzed above studies, can be the start point for growth of interest of researchers (from the field of construction) as to develop effective methods of approach to reliability evaluation of RC members, strengthened under load not only FRP composites, but also other materials.

Prospects of development for this issue is extremely large – the probabilistic approach to design is able to bring calculation to actual work of strengthened members (with providing guaranteed safety (given level of reliability) for all their life cycle) [4]. In addition, the probabilistic approach allows us to accurately take into account the efficiency of design (especially for strengthened members), that is extremely important its advantage.

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