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Probabilistic analysis of shear resistance assured by concrete compression

Roman Jaskulski[a,*], Piotr Wiliński[a]

[a]*Warsaw Uniwersity of Technology, Faculty of Civil Engineering, Mechanics and Petrochemistry (Płock), Łukasiewicza 17, 09-400 Płock, Poland*

Abstract

The aim of the work was to assess the safety margin of reinforced rectangular concrete cross-sections subjected to shear. Monte Carlo simulations were performed of the shear resistance assured by concrete compression. Analyzed models of resistance were taken from standards. Two of them from formerly used Polish standards: PN-84/B-03264, PN-B-03264:2002 and the third one from the European standard EN-1992-1-1:2004. The analyses included assessment of the safety margin, influence of the differences in selected assumptions on the results and "sensitivity" of the models to changes of the individual random variables distribution parameters. Results showed that all the analyzed models guarantee similar safety margin and the most important variable that influences the safety margin level is the variability of the compression strength distribution.

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Keywords: Monte Carlo simulation; reinforced concrete; shear; concrete compression; reliability.

1. Introduction

Monte Carlo simulation method is a useful and widely used tool in research [1,2]. Its applications cover wide range of issues [3,4,5]. The shear resistance of reinforced concrete elements is not a common subject of Monte Carlo simulations, although some articles related to this issue can be found [6,7,8] as well as those devoted to the probabilistic shear capacity analysis in itself [9]. The general aim of this work is to enrich the resources with results

* Corresponding author. Tel.: +48-24-3672-182.
E-mail address: romanjas@pw.plock.pl

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of reliability calculations of the shear resistance of reinforced concrete cross-sections. In the work only selected shear resistance models were utilized. The selection was limited to the models of shear resistance assured by the concrete compressive strength. The models, as well as all necessary assumptions related with them, were taken from Polish and European standards: PN-84/B-03264 (hereinafter referred to as the PN-84 model), PN-B-03264:2002 (the PN-02 model) and EN-1992-1-1:2004 (the EC-2 model). The chosen PN models for many years were the basis for the design of the concrete structures in Poland and the EC-2 model is a part of the currently used Polish standard.

The subject of the performed probabilistic analysis was the influence of some differences in assumptions on the results of safety level assessment. The selected models were also evaluated in terms of their "sensitivity" to changes of the basic parameters of distribution functions of selected random variables. The research is a continuation of issues researched and presented in [10]. It was performed with use of Monte Carlo simulation method. The original software, which was prepared by one of the authors, was utilized.

2. Models and assumptions

2.1. General description of the models

There are numerous models of shear resistance of reinforced concrete elements and in this work only three of them were analyzed. The PN-84 model is based on the research made by Borishanskii [11]. Description of this model can be found in [12,13]. The PN-02 and the EC-2 models are based on the Mörsch truss analogy in which Kupfer-Rüsch modifications were adopted. All the models are described below. Due to different systems of symbols used in the standards, all of the formulas presented below were reformulated using the same symbols for the same variables (taken from the EN-1992-1-1:2004). Due to some initial assumptions the models were also modified. Thus, it was assumed that the analyzed element is a beam of rectangular section, loaded and supported directly, not subjected to any compressive stress. Deterministic design values were replaced with mean values of corresponding random variables. These assumptions were the base for transforming original formulas to the formulas that were used in the Monte Carlo simulation.

2.2. The PN-84 model

Presented model is in details described in [14]. Fig. 1 shows the balance of the internal forces in an oblique section used to derive the formula for the shear resistance model. The symbols of internal forces and other parameters in the figure, are as per the Polish standard PN-84/B-03264.

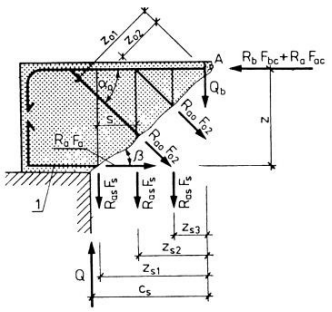

Fig. 1. Internal forces in the cross-section of a concrete element subjected to shear according to PN-B/84-03264 (symbols in brackets – as per EN-1992-1-1:2004 or modeled on it): Q – design value of the applied shear force (V_{Ed}), R_b – design value of concrete compressive strength (f_{cd}), F_{bc} – cross sectional area of concrete compression zone (A_{cc}), R_a – design yield strength of reinforcement (f_{yd}), R_{ao} – design yield strength of bent reinforcing bars (f_{ybd}), R_{as} – design yield strength of shear reinforcement (f_{ywd}), F_a – cross sectional area of tension reinforcement (A_{s1}), F_{ac} – cross sectional area of compression reinforcement (A_{s2}), F_{ao} – cross sectional area of bent reinforcing bars (A_{sb}), F_s – cross sectional area of shear reinforcement (A_{sw}), Q_b – projection of the resultant of the ultimate forces in concrete on the direction perpendicular to the longitudinal axis of the beam (V_c).

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