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Verification of selected calculation methods regarding shear strength in reinforced and prestressed concrete beams

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Abstract

The purpose of this article was an attempt to compare selected calculation methods regarding shear strength in reinforced and prestressed concrete beams. Several calculation methods were tested. This included codes: PN-EN 1992-1-1:2008 [1], ACI 318-14 [2] and *fib* Model Code for Concrete Structures 2010 [3]. The analysis also consists of methods published in technical literature. Calculations of shear strengths were made based on experimental works found in literature. The shear strength ratios V_{test}/V_{calc} were chosen to be the yardstick of comparison, where V_{test} is the experimental shear strength and V_{calc} is the calculated shear strength. A wide range of variables including shear span/depth ratio, compressive strength of concrete, longitudinal steel percentage helped to verify the applicability of calculation methods. Although most of authorial techniques proved to be unstable, they succeeded to show that codes' formulas for calculating shear strength could still be improved.

Keywords: shear strength; shear design; building codes; reinforced concrete; prestressed beams; stirrups

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1. Introduction

Over the years much research and many debates have taken place all around the world to explore the shear mechanism in beams [4,5,6,7]. Although many experiments and analysis have been carried out, the provisions regarding shear strength provide results that often differ from experimental data [8,9,10]. Therefore it seemed reasonable to assess if the observed growth in shear design equations [11] resulted in noticeable improvement.

Nomenclature

a	shear span
b_w	web width
d	effective beam depth
f_c	compressive stress in concrete
f_y	yield stress of steel
s	spacing of shear reinforcement
ρ_w	longitudinal reinforcement ratio

1.1. Primary assumptions

To ensure the coherence of the analysis, initial restrictions were taken:

- Beams were either reinforced concrete or prestressed concrete;
- All cross sections were either rectangular or T-beams;
- All beams had stirrups as transverse reinforcement;
- All beams failed in shear;
- All beams were single – span;
- No limit on material properties was imposed;
- In order to compare analytical results with experimental data, all units were taken without reduction factors.

2. Selection of calculation methods

The fundamental approach to the shear problem is the truss analogy model presented by Mörsch [12]. Being modified many times it became a leading model in most European Codes. In the following analysis PN-EN 1992-1-1:2008 [1] (eq. (1)) was chosen to be its representative. Eurocode 2 (with Polish Annexes) is based on evaluation of truss model with variable angle of inclination of the struts and without concrete contribution. Experiments held by members of the American Concrete Institute proved that the truss analogy model does not cover the concrete contribution that was observed during laboratory tests. Therefore a semi - empirical formula was developed and adopted in ACI 318 - 14 [2] (eq. (2, 3a, 3b, 4)). The last standard that was taken into consideration in the following analysis is Model Code 2010 [3] with its levels of approximation that each base on different shear model. The second (eq. (5)) and the third (eq. (6)) level of approximation were analyzed.

In addition to the standards, three authorial methods published in technical literature were taken into consideration. All three pose an attempt to improve ACI 318-11 [2] provisions. Frosch Method [9] (eq. (7)) modified Standard's provisions in two ways. First it replaced the effective beam depth (d) with a cracked transformed section neutral axis depth (c). Secondly it eliminated longitudinal reinforcement ratio (ρ_w) in the expression for V_c as it is already taken into account in calculating c. Another attempt to modify ACI 318-11 provisions was carried at the University of Houston [13] (eq.(8)). The UH Method, dedicated to prestressed concrete beams, introduced a function of a shear span to depth radio ($(a/d)^{-0,7}$) that reflects the arch action in the beam. The last method is a compound of the two former. Kuo, Hsu and Hwang [13], later called KHH method, ((eq. (9)) used shear span to depth radio ($(a/d)^{-0,7}$) according to UH Method and the depth of uncracked compression zone.