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Simplified Shear Design of Prestressed Concrete Members

Introduction

The behavior of structural concrete beams subjected to shear has been investigated since the advent of reinforced concrete. Due to the number of variables involved, a general shear theory has been evasive. Consequently, design has been based on empirical evidence. This basis has provided a multitude of design equations for the design of structures in shear. For instance, the ACI 318 Building Code (ACI 318-02) provides five different equations to evaluate the concrete contribution to shear resistance, V_c, for nonprestressed members and three different equations to evaluate V_c for prestressed members. To calculate V_c according to the AASHTO design specifications is dependant on the version of specifications used. In general, the 16th edition conforms to the ACI Building Code. However, the AASHTO LRFD bridge design specifications have introduced substantially different provisions for shear design and produced a new method that designers must consider.

The AASHTO LRFD specifications are based on the Modified Compression Field Theory (MCFT) and on Strut-and-Tie modeling. There are advantages to the LRFD method such as unified treatment of nonprestressed reinforced members and prestressed members. However, the LRFD has been identified as being complex, requiring time-consuming iteration, producing illogical answers in some situations, and providing excessive amounts of reinforcement for certain cross sections. ACI 318, while generally providing ease in calculation, has also been identified as having many shortcomings including lack of conservatism for lightly reinforced cross-sections, for sections utilizing high strength concrete, and large sections.

Recent research conducted at Purdue University has developed a model and simplified design equation for calculating the shear strength of nonprestressed members which eliminates many of the shortcomings of current design methods. Through an analysis of reinforced concrete sections, this model conservatively calculates shear strength through varying concrete strength, reinforcement ratio and effective depth. The objective of this research was to investigate the applicability of this shear model and simplified design method developed for reinforced concrete members to prestressed concrete members. The primary goal was to develop a simple design method which can be used for the calculation of shear strength for both nonprestressed and prestressed sections enabling unification and simplification of design procedures.

Findings

The shear model was used to analyze a database of 84 specimens which were tested in shear. The combination of flexural and shear stresses in the compression zone of the cracked section were calculated and principal tension stresses were determined to evaluate the shear strength of the section. Through the analysis, it was concluded that the shear model is applicable to prestressed concrete sections and provides a method to calculate the flexure-shear strength of prestressed concrete. Consistent results were obtained over a range of initial axial precompression stresses.

Although the shear model is applicable to prestressed concrete, it is not a practical procedure for the calculation of shear strength. Several analyses were performed to simplify the model for rectangular and irregular cross-sections. The following conclusions were made from these investigations:

1) An average shear stress of $5\sqrt{f_c'}$, distributed over the compression zone, can be used to calculate the flexure-shear strength of prestressed rectangular sections. Therefore, the flexure-shear strength of prestressed concrete can be calculated according to:

$$V_{ci} = 5\sqrt{f_c'}A_{eff}$$

where:

f_c' : compressive strength of concrete, psi

A_{eff} : effective compression zone area, in^2

2) The effective compression zone area (A_{eff}) accounts for the contribution of the flanges of I and T-sections to shear strength. This effective shear area is calculated using the web portion of the compression zone plus an additional effective overhang. The effective overhang flange width on each side of the web should not exceed 0.5 t_f.

3) Analysis of a database of prestressed concrete sections indicated that the simplified design equation accurately and consistently calculates the shear strength of prestressed sections for a wide range of effective prestress levels. This equation matches the equation proposed for the design of nonprestressed sections. Therefore, this research indicates that a single design equation can be used to evaluate the shear strength of both reinforced and prestressed concrete members.

4) An equation was determined to calculate a lower-bound value for the neutral axis depth to simplify the calculation of the effective compression zone area. This equation, based upon an empirical investigation of neutral axis depths of a multitude of sections, provides a method to calculate the shear strength of prestressed concrete sections which can be performed easily by hand calculations.

Implementation

The recommendations provided through this study can be easily implemented as a method to calculate shear strength. Implementation should proceed primarily through the INDOT Design Division as this equation will be used for design. The primary goal of this study was to develop a design equation which would be adopted by the ACI Building Code and both AASHTO specifications.

The most effective avenue to have the recommendations of this study adopted by the ACI Building Code and both AASHTO specifications is to publish a paper through the ACI Structural Journal and the PCI Journal. By informing ACI and AASHTO committee members of the provisions detailed in this research, interest in implementing these provisions can be created.

Through this shear design equation, the design of prestressed concrete beams can be simplified. Currently, with the various equations in the different design codes, the calculation of shear strength can be confusing. By unifying the method to calculate shear strength into a single, simple equation, the design method can be simplified.

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