The Discrete Rotation Behaviour of Reinforced Concrete Beams under Shear Loading

by

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Abstract

This thesis presents a body of research into the behaviour of reinforced concrete (RC) beams under combined shear and flexural loading. This research is presented in the form of a series of manuscripts that are either accepted, submitted or in preparation for journal publication.

Currently, many code approaches are built around the assumption that the shear and flexural capacities of RC beams can be assessed separately despite acknowledging that there is an interaction between the two. This is due to the fact that quantifying this interaction and specifically the shear resistance of RC members has been found to be a very complex problem as the inclined sliding planes along which failure occurs transcend both initially cracked and uncracked planes.

This thesis introduces a mechanics based mechanism built around simulating the observed physical behaviour. Developing a mechanism that simulates what is seen in practice provides valuable insight into the complexities of the shear and flexural interaction. The mechanism developed is built upon the well established research areas of rigid body displacement, shear friction theory and partial interaction theory. Generic equations based on this mechanism are derived for RC beams both with and without transverse reinforcement and implemented into numerical models for RC members under both direct shear loads and combined flexural and shear loading.

Comparison between the failure loads predicted by the developed numerical models and empirically derived results show good agreement in magnitudes and more importantly exhibits similar trends in behaviour. As a consequence, the numerical models are used to conduct an in-depth investigation into the variables that have a significant effect on the shear resistance of RC beams and used to examine the physical behaviour behind the observed trends. This knowledge is used to further advance and calibrate the derived numerical models. In addition, the numerical models are used to demonstrate various advantages that can be obtained through the use of structural mechanics based approaches.

Statement of Originality

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Wade Doyle Lucas　　　　　　Date

List of Publications

Journal Papers

Our Obsession with Curvature in Reinforced Concrete Modelling
Oehlers, D.J, Haskett, M., Mohamed Ali M.S., Lucas, W., and Muhamad, R.
Advances in Structural Engineering 2011: v 14, n 3, p 391-404.

A Generic Unified Reinforced Concrete Model
Oehlers, D.J., Mohamed Ali M.S., Griffith, M.C., Haskett, M., and Lucas, W.
Proc. ICE , Structures and Buildings 2010: accepted paper

FRP Reinforced Concrete Beams – A Unified Approach Based On IC Theory
Oehlers, D.J., Mohamed Ali M.S., Haskett, M., Lucas, W., Muhamad, R., and Visintin, P.
ASCE Composites for Construction 2010: accepted paper

The Formulation of a Shear Resistance Mechanism for Inclined Cracks in RC Beams
Lucas, W., Oehlers, D.J., Mohamed Ali, M.S.
ASCE Journal of Structural Engineering 2011: accepted paper

The Shear Friction Mechanism of Reinforced Concrete
Lucas, W., Oehlers, D.J., Mohamed Ali, M.S., Griffith, M.C.
Text in Manuscript

Shear Friction Behaviour in FRP Reinforced Concrete
Lucas, W., Oehlers, D.J., Mohamed Ali, M.S., Griffith, M.C.
Advances in Structural Engineering 2011: accepted paper

Simulation of Shear Failure in RC beams without Stirrups
Lucas, W., Oehlers, D.J., Mohamed Ali, M.S.
Engineering Structures 2011: submitted paper

The Failure Mechanism of RC Beams with Stirrups
Lucas, W., Oehlers, D.J., Mohamed Ali, M.S.
ASCE Journal of Structural Engineering 2011: submitted paper

Conference Papers

Design of FRP Reinforced Concrete Beams against Shear Failure
Lucas, W., Oehlers, D.J., Mohamed Ali, M.S., Griffith, M.C.
Proceedings of the 9th International Symposium of the Fiber-Reinforced Polymer Reinforcement for Reinforced Concrete Structures (FRPRCS-9) 2009, Sydney, Australia.

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Proceedings of the Asia-Pacific Conference on FRP in Structures 2009: pp. 117-122.

FRP Design using Structural Mechanics Models
Oehlers, D.J., Haskett, M., Mohamed Ali, M.S., Lucas, W. and Muhamad, R.
Keynote Paper, Proceeding CICE 2010 – The 5th International Conference on FRP Composites in Civil Engineering, Beijing, China, September 27th-29th, pp. 37-44.

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Introduction & General Overview

When dealing with the calculation of the failure load of reinforced concrete (RC) members, many code approaches have found it convenient to assume a separation of shear and flexural capacities, the use of highly ductile reinforcing elements and a good bond between the reinforcing elements and the surrounding concrete. This has enabled the development of simple yet conservative design equations. However, with the increasing number of options in reinforcing materials, including some that exhibit little to no ductile behaviour, and new techniques of applying reinforcing elements, these assumptions are becoming increasingly invalid and hence the design equations are reaching the limit of their usefulness. This thesis investigates a new, alternative method for calculating the failure load of RC beams, with an emphasis on the shear sliding phenomenon associated with shear failure.

This thesis is a collection of manuscripts that are either in preparation, submitted or accepted for publication in internationally recognised journals. Each of the Chapters 1-5 are titled according to how they fit into the overall research objectives and take the following format: an introduction explaining the aims of the chapter in terms of the overall research objectives; a list of all the manuscripts presented in the chapter; and finally presentation of each manuscript.

Chapter 1 provides the general background information about the current approaches to designing RC beams and also details the alternative "unified reinforced concrete model" that is currently being developed. This chapter discusses in detail the limitations involved in the current approaches and the advantages that can be obtained from the alternative approach. As the unified reinforced concrete model is an extensive topic, this thesis focuses solely on the shear failure mechanism of RC beams.

Chapter 2 provides a detailed investigation of the shear failure mechanism of RC beams. It examines the physical behaviour associated with the shear failure phenomenon and attempts to replicate that behaviour using a structural mechanics model that simulates both flexural rotation and shear sliding. Ultimately this chapter identifies two relationships that are critical in the application of this mechanism: the partial interaction relationship that links the force in a reinforcing bar intersecting a crack with the associated width of the crack; and the shear-friction relationship that defines the ability of a sliding plane to resist shear stresses in terms of the confining stresses and the lateral displacement.

Chapter 3 investigates the shear sliding phenomenon that forms one half of the shear failure mechanism of RC beams. This is achieved through the development of a numerical model to replicate an experimental series of reinforced concrete blocks under direct shear loading. By doing this it was possible to both investigate the key factors involved in the shear sliding phenomenon and identify potential relationships that could be implemented into the shear failure mechanism of RC beams.

Chapter 4 implements the partial-interaction and shear friction relationships identified in Chapter 3 into the shear failure mechanism of longitudinally reinforced RC beams. From this analysis it was found that in the case of RC beams without stirrups it is the strength prior to the onset of shear sliding that controls the critical failure load. This made it possible to further improve the shear friction properties using a regression analysis of the predicted failure loads of theoretical RC beams without stirrups.

Chapter 5 shows the completion of the research objectives by developing a numerical model that predicts the failure load of RC beams with stirrups. This numerical model implements the mechanics based shear friction mechanism introduced in Chapter 2 and the improved shear friction relationships developed in Chapter 4. Importantly it was found that for RC beams with stirrups the numerical model could predict both the failure load and failure mechanism. The predicted failure mechanisms included shear sliding, concrete crushing and reinforcement rupture.