3D NONLINEAR ANALYSIS OF RC BEAMS SHEAR-STRENGTHENED WITH FRP SHEETS

By
AbdelRahman Gamal Mohamed Mabrouk

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the Requirements for the Degree of
MASTER OF SCIENCE
in
Structural Engineering

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Under the Supervision of

Prof. Dr. Adel Yahia Aql
……………………………..
Professor of Structural analysis and mechanics
Head of Structural Engineering Department
Faculty of Engineering
Cairo University

Prof. Dr. Osman Mohamed Osman Ramadan
……………………………
Professor of Structural analysis and mechanics
Structural Engineering department
Cairo University

Dr. Ebtisam Abdel-Aziz Yehia Mohammed Ahmed
………………………………
Assistant professor at construction and building engineering department
Arab Academy for Science and Technology and Maritime Transport

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Approved by the
Examining Committee:

____

Prof. Dr. Adel Yehia Akl (Professor of Structural Analysis and Mechanics, Faculty of Engineering, Cairo University, Main Advisor)

____

Prof. Dr. Osman M. O. Ramadan (Professor of Structural Analysis and Mechanics, Faculty of Engineering, Cairo University, Advisor)

____

Prof. Dr. Hany Mohamed EL-Hashimy (Professor of Reinforced Concrete Structures, Faculty of Engineering, Cairo University, Internal Examiner)

____

Prof. Dr. Ahmed AbdelFattah Mahmoud (Professor Concrete Structures, Faculty of Engineering at Shobra, Banha University, External Examiner)

FACULTY OF ENGINEERING, CAIRO UNIVERSITY

GIZA, EGYPT

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Engineer`s Name: AbdelRahman Gamal Mohamed Mabrouk
Date of Birth: 03/06/1990
Nationality: Egyptian
E-mail: agmabro6@hotmail.com
Phone: +201148072621
Address: #75, 4th zone, 1st district, 5th settlement
Registration date: 01/10/2012
Awarding date: .../…/2017
Degree: Master of Science
Department: Structural engineering

Supervisors:
Prof. Dr. Adel Yahia Aql
Prof. Dr. Osman Mohamed Osman Ramadan
Dr. Ebtisam AbdelAziz Yehia Mohamed

Examiners:
Prof. Dr. Adel Yehia Akl
Prof. Dr. Osman Mohamed Osman Ramadan
Prof. Dr. Hany Mohamed EL-Hashimy
Prof. Dr. Ahmed AbdelFattah Mahmoud

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3D Nonlinear analysis of RC beams Shear-strengthened with FRP sheets

Keywords:

RC beams, shear-strengthened, FRP sheets, finite element, ABAQUS

Summary:

This study presents a three-dimensional finite element (FE) model of RC beams shear-strengthened with side bonded CFRP sheets using ABAQUS software. The obtained results are compared with the

published ones to verify the accuracy of the suggested model. A parametric study using is conducted to investigate some of the parameters that affect the shear strength of RC beams.

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Dedication

I dedicate this thesis to my mother, my father, my wife, my sisters, my brothers, and my little men Adam and Elyas.

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Abstract

Fibre Reinforced Polymers (FRP) are very common in strengthening of Reinforced Concrete (RC) beams due to their lightweight, high strength, non-magnetic properties, and resistance to corrosion. The shear design of RC beams is of great concern because it is based on empirical equations. This study presents a three-dimensional finite element (FE) model of RC beams shear-strengthened with side bonded CFRP sheets using ABAQUS software. First, the obtained results are compared to published ones to verify the accuracy of the suggested model. This comparison is performed for strengthened and un-strengthened beams where good correlation is observed with a maximum difference of not more than 20%. Then, the numerical model is used to conduct a parametric study for beams subject to either uniformly distributed load or 4-point load schemes. This study focuses on the effects of: aspect ratio of beam cross-section, shear span-to-depth ratio, FRP-widths to beam-length ratio, longitudinal steel ratio, concrete compressive strength, FRP sheets spacing, and amount of steel stirrups. The results showed that- when other variables are preserved- the increase in ultimate load due to FRP strengthening of beams was 23% and 16% for beams with aspect ratios (width/depth) of 0.5 and 0.83, respectively. However, for variable thickness of FRP (in proportion to beam width), the increase in ultimate load due to strengthening was constant at 23%. The ultimate load increased from 210 kN to 394 kN when the shear-span to depth ratio decreased from 1.73 to 1.00. Finally, it is shown that beam strengthening by CFRP is more effective for low and normal strength concrete beams rather than for high strength beams.

Chapter 1

Introduction

1.1 General

Deterioration of reinforced concrete (RC) structures is one of the major problems of the construction industry today. Moreover, a large number of structures constructed in the past using the older design codes in different parts of the world need to be checked under the current service loads and concrete conditions, since the design equations are based on semi-empirical approaches [1]. The beams in these structures may suffer flexural or shear failures which are the two primary modes of failure in RC beams. Flexural failure of a beam is ductile in nature, i.e., it occurs gradually with large deflections and cracking, which provide a warning of primary failure. In contrast, shear failure is brittle in nature and does not allow redistribution of loads; thus, shear failure occurs without any prior warning and is often catastrophic. Poorly designed beams may fail in shear before reaching the flexural strength. Hence, RC beams must have sufficient shear strength, higher than flexural strength, in order to ensure a ductile failure mode. Shear failure of RC structures may be due to many factors, e.g., insufficient shear reinforcement, reduction of steel area due to corrosion and damage of concrete caused by aggressive environmental conditions, increased service load due to change in usage of the structure, and any detailing, design, and/or construction error. Thus, strengthening and rehabilitation of RC structures may be needed to increase the ultimate load carrying capacity of shear-deficient beams. Structures that are deficient in shear can be strengthened or repaired by using various methods. Since replacement of such deficient structures incurs a huge amount of public money and time, strengthening has become the acceptable way of improving their load carrying capacity and extending their service lives. Strengthening with fiber reinforced polymers (FRP) has been established as an effective method applicable to different reinforced concrete elements such as columns, beams, slabs, and shear walls. FRP materials are noncorrosive, nonmagnetic, resistant to various types of chemicals, flexible, easy to apply, and has higher tensile strength when compared with steel. Therefore, FRP can be used for strengthening and repair of RC structures in spite of it is not fire resisting material.

1.2 Objectives and scope

The estimation of shear capacity of RC beams strengthened with externally bonded FRP laminates is a big challenge in the field of structural engineering [1]. There is still a difference between the predicted values of many existing models and experimental results, taking in mind that some of these models are used in the present design codes. The objective of this research is to present a parametric study which will consider different parameters that may influence the shear capacity and flexural Stiffness of RC beams shear strengthened with FRP stirrups. The proper modeling of concrete, steel, and FRP will simulate the behavior of RC beams externally reinforced with FRP. A three-dimensional finite-element (FE) analysis will be carried out; using a computer software package (ABAQUS). Experimental results collected from previous published work will be used to verify the accuracy of the proposed model. A parametric study will be applied on strengthened RC beams under concentrated and uniform loads to study the effect of: compressive strength of concrete, area of longitudinal steel, spacing between FRP sheets, spacing between steel stirrups on shear crack pattern, beam width, beam depth, and length of FRP strengthening relative to the beam span. Although some of the existing guidelines took into consideration a part of the aforementioned factors with their models, there is no unique one which addresses all the parameters [2].

1.3 Outline

This thesis includes six chapters as follows, an introduction, literature review, Finite element (FE) modeling using ABAQUS, Finite Element Model verification using experimental published work, parametric study, and conclusions and recommendations for future work.

Chapter 1: Introduction

This chapter presents the research objective, and scope of work.

Chapter 2: literature review

This chapter provides a part of previous researches concerning the behaviors of RC beams, crack patterns and shear failure mechanisms, and the different failure modes of RC beams shear-strengthened with externally bonded CFRP laminates.

Chapter 3: Finite element modeling of RC beams strengthened with FRP

This chapter introduces the creation of a Finite Element Model for the RC beams strengthened with externally bonded CFRP laminates.

Chapter 4: FE model verification using experimental published work

This chapter describes a study of FE model verification as one part of the overall process of model validation for structural analysis of RC beams shear- strengthened with CFRP. It presents the comparison between the FE and the experimental results from literature.

Chapter 5: Parametric study