AIN SHAMS UNIVERSITY
FACULTY OF ENGINEERING

UPGRADING AND RETROFITTING TIMBER ELEMENTS USING ADVANCED COMPOSITE MATERIALS

BY

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A THESIS

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STATEMENT

This dissertation is submitted to Ain Shams University to fulfill the requirements of the Doctorate of Philosophy degree in Structural Engineering. The work included in this thesis has been carried out by the author - in the Department of Structural Engineering, Ain Shams University - from October 2006 to December 2015. No part of this thesis has been submitted for a degree or a qualification at any other university or institution.

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UPGRADING AND RETROFITTING TIMBER ELEMENTS USING ADVANCED COMPOSITE MATERIALS

SUMMARY

Over the years, the number of trees capable of providing quality structural timber has been declining. This necessitates a more efficient use of the resource through the many existing/available techniques of timber strengthening. Such techniques can be used to reduce the size of beams and allow the utilization of weaker species of timber; creating a more efficient use of the timber supply. The same strengthening techniques could be used to increase the load-carrying capacity of existing timber elements to support higher loads than the original design of the structure thus saving on the cost and material of a replacement structure.

The strength of the timber is largely dependent on the fiber direction of the grain. Defects such as knots, bows, checks and wormholes typically decrease the strength of the structural properties of timber. The failure to understand the actual characteristics of timber beams will render the constructed structure to have unpredictable strength. Therefore, it is of utmost importance to acquire a rounded comprehension of the characteristics and behavior of timber elements. Nevertheless, the accurate analysis of timber beams is complex due to its non-linear and orthotropic behavior. Furthermore, it is equally important to understand the performance of timber elements strengthened with composite materials.

This Thesis is mainly concerned with the study of the different factors affecting the bond between the timber elements and the FRP sheets. Emphasis is also given to the shear and flexure behavior of FRP strengthened timber beams.

Keywords: Timber; Bond stress, Fiber-reinforced polymers (FRP) sheets, environmental conditioning, moisture content, ambient temperature, relative humidity; Analytical Modelling, Artificial Neural Networks (ANN)

To fulfill the previously mentioned objectives, this research is divided into the following chapters:

- ***Chapter One:*** is an introduction to this study. This chapter includes the background and problem definition of the thesis, research objectives and originality, methodology and thesis structure.
- ***Chapter Two:*** In this chapter, a detailed literature review is conducted on (i) the types of timber, particularly their mechanical and physical properties; (ii) types of FRP and adhesives along with the associated mechanical and physical properties; (iii) commonly known strengthening systems for timber elements using FRP sheets and/or bars; (iv) earlier efforts in the timer-FRP strengthening domain.
- ***Chapter Three*:** An elaborate description of the experimental program is presented herein, mainly focusing on FRP-to-timber bond behavior. Primarily, the influencing parameters (temperature, moisture content, bonded length and FRP stiffness) and relevant sample details (type of wood; type of FRP and type of resin) are presented The test

set-up and means of testing 151 FRP-to-timber samples - regarding bond behavior – are also included within.

Similarly, an experimental program comprising the flexural behavior as well as the shear behavior of FRP-strengthened timber beams is demonstrated. The details of thirteen samples are described in terms of study parameters (span to depth ratio and thickness of FRP sheet). The test set-up and means of testing are mentioned accordingly. The main parameters for the latter program included: (i) the FRP wrapping technique and (ii) the applied FRP-sheet thickness

- ***Chapter Four*:** This analysis-based chapter relates the obtained experimental results to existing analytical models (linear analysis of bonded joints, local bond stress-slip relationship and fracture energy). Computing and calibration of coefficients originally calculated for FRP-to-timber bond interface. This is followed by an elaborate discussion of the results and corresponding analysis.
- ***Chapter Five*:** In this chapter, an Artificial Neural Network (ANN) model for predicting the bond strength of FRP-to-timber elements is proposed in this study. A database of one hundred and fifty one experimental data points from this study's experimental program - was used for training and testing the ANN. The data used in the ANN is arranged in a format of six input parameters including: (i) timber species; (ii) moisture content in timber at time of application; (iii) type of resin; (iv) type of FRP sheets; (v) ambient temperature and (vi) relative humidity. The one corresponding output parameter is the bond strength. A parametric study was carried out using ANN to study the influence of each parameter on the bond strength and to compare

results with common existing analytical models. The results of this study indicate that the ANN provides an efficient alternative method for predicting the bond strength of FRP-to-timber, when compared to experimental results and those from existing analytical models.

- ***Chapter Six:*** This chapter contains the overall conclusions for all previous chapters. Recommendations are proposed for subsequent research studies in the same domain.

TABLE OF CONTENTS