

Numerical and Experimental Investigations of Vibration-based Assessment of Timber Beams Rehabilitated by Fibre-Reinforced Polymer

By

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CERTIFICATE OF ORIGINAL AUTHORSHIP

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

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ABSTRACT

Timber has been traditionally used all over the world as a construction material. Built timber structures may require repair and/or strengthening because of a number of factors such as age-related deterioration, fungus or termite attacks and damage caused by overloading. In recent years, a great deal of research and development has been focused on utilizing vibration based methods to detect structural damage and use of fibre reinforce polymer (FRP) on timber for strengthening or repair damaged timber structural members in various types of structures. Although the application of FRP for repair and/or strengthening of structures has been researched for a decade, non-destructive evaluation of the effectiveness and reliability of the FRP repaired or strengthened structure are yet to be investigated.

In this study, the damage index method, i.e. a robust vibration-based damage detection method, is proposed to localize and quantify damage in timber beams and to evaluate the effectiveness of repair for the damaged timber beams, in which the damaged timber beams are repaired by applying carbon fibre reinforced polymer (CFRP).

In addition to numerical investigation using Finite Element (FE) analysis, an experimental program comprising of static and dynamic testing was carried out on five laminated veneer lumber (LVL) beams. Different damage cases (severe, moderate, minor) are introduced on these beams. The experimental results indicate that the use of CFRP was effective in repairing the damaged timber beams. Both numerical and experimental investigations have also shown that the proposed damage index method is able to accurately detect damage location and severity, and evaluate the repair effectiveness for damaged timber beam after repairing with CFRP.

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2. Xiao, R., Li, J. & Shrestha, R. (2014), 'A Novel Vibration Based Assessment Approach for Repair Effectiveness of Damaged Timber Beam Rehabilitated by Fibre Reinforced Polymer', *In Preparation*.

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2. Xiao, R., Li, J. & Shrestha, R. (2014), 'A Novel Vibration Based Assessment Approach for Repair Effectiveness of Damaged Timber Beam Rehabilitated by Fibre Reinforced Polymer', *In Preparation*.

TABLE OF CONTENTS

| | |
|--|-------------|
| ABSTRACT | ii |
| ACKNOWLEDGEMENT | iii |
| LIST OF PUBLICATIONS BASED ON THIS RESEARCH | iv |
| Table OF CONTENTS | v |
| LIST OF FIGURES | viii |
| LIST OF TABLES | x |
| LIST OF NOTATIONS | xi |
| CHAPTER 1 INTRODUCTION | 1 |
| 1.1 Background | 1 |
| 1.2 Objective of the Study | 3 |
| 1.3 Scope of the Work | 4 |
| 1.4 Significance of the Research Work | 5 |
| 1.5 Organisation of the Thesis | 6 |
| CHAPTER 2 LITERATURE REVIEW | 7 |
| 2.1 Vibration Based Damage Detection | 7 |
| 2.1.1 Methods Based on Natural Frequency | 7 |
| 2.1.2 Mode Shape Method | 8 |
| 2.1.3 Dynamic Flexibility Based Method | 10 |
| 2.1.4 Modal Strain Energy Based Method | 11 |
| 2.2 FRP Application on Timber Structures | 16 |
| 2.3 FE modelling on Timber and FRP | 21 |
| 2.3.1 Modelling of Timber | 21 |
| 2.3.2 Modelling of CFRP Rehabilitation | 22 |
| CHAPTER 3 EXPERIMENTAL INVESTIGATION | 24 |
| 3.1 Introduction | 24 |
| 3.2 Material Properties | 24 |
| 3.2.1 LVL Beam | 24 |
| 3.2.2 Property of Carbon Fibre Reinforced Polymer | 24 |

| | |
|--|-----------|
| 3.3 Design of Specimens..... | 25 |
| 3.3.1 Dimensions of LVL Timber Beams..... | 25 |
| 3.3.2 Inflicted Damage in Test Beams..... | 26 |
| 3.3.3 Procedures of Using CFRP to Repair Damaged Timber Beams..... | 27 |
| 3.4 Four-point Bending Test for the Specimens..... | 28 |
| 3.4.1 Static Test Set up..... | 28 |
| 3.4.2 Static Test Results..... | 29 |
| 3.5 Modal Testing and Experimental Modal Analysis..... | 30 |
| 3.5.1 Modal Test Set Up..... | 30 |
| 3.5.2 Data Post-processing..... | 33 |
| 3.5.3 Results of Natural Frequency..... | 33 |
| Summary..... | 37 |
| CHAPTER 4 FINITE ELEMENT MODELLING..... | 38 |
| 4.1 Introduction..... | 38 |
| 4.2 Finite Element Model for Intact Timber Beam..... | 38 |
| 4.3 Mesh Density..... | 40 |
| 4.3.1 Meshes Considered for Modelling..... | 41 |
| 4.3.2 Comparison of Different Mesh Densities..... | 41 |
| 4.4 Methods of Modelling Damage in LVL Beam..... | 44 |
| 4.5 Methods of Modelling Damaged Beam Repaired with CFRP..... | 45 |
| 4.7 The Results and Discussions on Load-deflection Relationship..... | 46 |
| 4.6 Correlation Analysis Using Dynamic Results..... | 48 |
| 4.6.1 Natural Frequencies..... | 49 |
| Summary..... | 50 |
| CHAPTER 5 Structural Damage Detection and Repair Evaluation of Timber Beams Using the Modal Strain Energy Method..... | 51 |
| 5.1 Introduction..... | 51 |
| 5.2 Review of Proposed Damage Detection Methods..... | 51 |

| | |
|---|-----------|
| 5.3 Numerical Results Discussion | 52 |
| 5.3.1 Obtaining Modal Parameters by Experimental Modal Analysis (EMA) | 52 |
| 5.3.2 Identifying the Location of Single Notch Damage | 54 |
| 5.3.4 Estimation of Severity of Damage | 57 |
| 5.3.5 Evaluating the Effectiveness of CFRP Rehabilitation | 61 |
| 5.4 Experimental results discussion | 66 |
| 5.4.1 Identifying the Location of Single Notch damage | 66 |
| 5.4.2 Estimation of Severity of Damage | 72 |
| 5.4.3 Evaluate the Effectiveness of CFRP Rehabilitation..... | 75 |
| 5.5 Comparison between Numerical and Experimental Results..... | 79 |
| 5.5.1 Comparison in Locating Damage Results..... | 79 |
| 5.5.2 Comparison in Damage Severity Estimation Results | 80 |
| 5.5.3 Comparison in Evaluating the Effectiveness of CFRP Rehabilitation | 84 |
| Summary | 87 |
| CHAPTER 6 CONCLUSIONS AND RECOMMENDATIONS | 88 |
| 6.1 Conclusions | 88 |
| 6.2 Recommendations and Future Work..... | 91 |
| REFERENCES | 93 |
| APPENDIX A: Static Test Results | 96 |
| APPENDIX B: Comparison in Locating Damage Results | 97 |

LIST OF FIGURES

| | |
|--|----|
| Figure 1. 1 Timber structures | 1 |
| Figure 2.1 Different investigations to increase wood flexural properties (Andre 2006) 16 | 16 |
| Figure 2.2 Load-deflection curves for CFRP-reinforced wood beams in three-point bending (Plevris and Triantafillou 1992) | 18 |
| Figure 2.3 Reinforcing schemes for the three samples (Johns and Lacroix 2000) | 19 |
| Figure 2.4 Reinforcement schemes (Schober and Rautenstrauch 2005)..... | 21 |
| Figure 2.5 FEA model: (a) meshed beam with boundary condition (cut-away view of Beam DF5); (b) strain contour (Beam DF4)..... | 22 |
| Figure 3.1 Laminated veneer lumber..... | 24 |
| Figure 3.2 CFRP sheets..... | 25 |
| Figure 3.3 Dimension of Specimen..... | 26 |
| Figure 3.4 Side view of a typical damage inflicted in test beams..... | 27 |
| Figure 3.5 LVL Timber beams repaired by CFRP..... | 28 |
| Figure 3.6 CFRP rehabilitation | 28 |
| Figure 3.7 Four points bending test set up | 29 |
| Figure 3.8 Load-deflection curve comparison for Beam 1 | 30 |
| Figure 3.9 Modal test set up..... | 31 |
| Figure 3.10 Piezoelectric accelerometer | 31 |
| Figure 3.11 Impact hammer | 32 |
| Figure 3.12 Multi-channel signal conditioner..... | 32 |
| Figure 4.1 The geometrics properties of SOLID45..... | 39 |
| Figure 4.2 A typical FE model of a LVL timber beam..... | 39 |
| Figure 4.3 First three flexural mode shapes for the FE beam model | 40 |
| Figure 4.4 Different mesh models of the timber beam | 41 |
| Figure 4. 5 The mode shapes of intact FE beam with different mesh densities..... | 43 |
| Figure 4.6 Numerical static test results comparison for different mesh size | 43 |
| Figure 4.7 Configuration of a typical damage case..... | 44 |
| Figure 4.8 The geometrics properties of SHELL63..... | 45 |
| Figure 4.9 Load-Deflection comparison between numerical and experimental results.. | 46 |
| Figure 4.10 Over-cut damaged..... | 47 |
| Figure 4.11 Load-deflection curve comparison | 48 |
| Figure 5.1 The applied impact loading in the transient dynamic analysis..... | 53 |

| | |
|--|----|
| Figure 5.2 Single Notch Damage Located at Mid-span..... | 55 |
| Figure 5.3 Single severe damage at quarter-span..... | 55 |
| Figure 5.4 Multi damage cases located at mid-span and quarter-span | 57 |
| Figure 5.5 Damage estimation index for single damage at mid-span | 59 |
| Figure 5.6 Comparison of actual and estimated severity of damage | 60 |
| Figure 5.7 Comparison of actual and calibrated severity of damage..... | 61 |
| Figure 5.8 Results of single severe damage at mid span before and after repairing..... | 64 |
| Figure 5.9 Results of single severe damage at quarter span before and after repairing.. | 64 |
| Figure 5.10 Results of double severe damage before and after repairing..... | 64 |
| Figure 5.11 Load deflection curve for beam D1 | 65 |
| Figure 5.12 Single notch damage located at mid-span | 68 |
| Figure 5.13 Single severe damage located at quarter span | 68 |
| Figure 5.14 Double damage cases located at mid-span and quarter-span..... | 70 |
| Figure 5.15 Damage estimation index for single damage at mid-span | 73 |
| Figure 5.16 Comparison between actual and estimated results | 74 |
| Figure 5.17 Comparison between actual and calibrated results..... | 75 |
| Figure 5.18 Results of single severe damage at mid span before and after repairing..... | 76 |
| Figure 5.19 Results of single severe damage at quarter span before and after repairing | 76 |
| Figure 5.20 Results of double severe damage before and after repairing..... | 76 |
| Figure 5.21 Load deflection curve for single damage located at mid-span | 77 |
| Figure 5.22 Comparison between numerical and experimental results for 4L | 79 |
| Figure 5.23 Comparison between numerical and experimental results for 2M4S..... | 80 |
| Figure 5.24 Comparison of severity estimation between numerical and experimental results | 81 |
| Figure 5.25 Comparison of estimated severity between numerical and experimental data | 82 |
| Figure 5.26 Comparison of calibrated severity between numerical and experimental data | 84 |
| Figure 5.27 Comparison of repaired severity estimator between numerical and experimental results | 85 |

LIST OF TABLES

| | |
|--|----|
| Table 3.1 The size of different damage scenarios..... | 26 |
| Table 3.2 Comparison of natural frequencies of Beam 3 | 34 |
| Table 3.3 Comparison of percentage of drop in natural frequencies of Beam 3 | 34 |
| Table 3.4 Comparison of natural frequencies of Beam 2 | 35 |
| Table 3.5 Comparison of percentage of drop in natural frequencies of Beam 2 | 35 |
| Table 3.6 Comparison of natural frequencies of Beam 1 | 35 |
| Table 3.7 Comparison of percentage of drop in natural frequencies of Beam 1 | 36 |
| Table 3.8 Comparison of natural frequencies of Beam 4 | 36 |
| Table 3.9 Comparison of percentage of drop in natural frequencies of Beam 4 | 36 |
| Table 4. 1 Comparison of natural frequencies of the LVL beam..... | 49 |
| Table 5.1 Estimation of severity of damage..... | 58 |
| Table 5.2 Calculation of calibration factor | 60 |
| Table 5.3 Results of calibrated severity of damage | 61 |
| Table 5.4 Comparison of effectiveness estimator for single damage at mid-span..... | 66 |
| Table 5.5 Comparison of effectiveness estimator for single damage at quarter-span ... | 66 |
| Table 5.6 Comparison of effectiveness estimator for double damage case | 66 |
| Table 5.7 Estimation of severity of single damage case | 73 |
| Table 5.8 Calculation of calibration factor | 74 |
| Table 5.9 Results of calibrated severity of damage | 75 |
| Table 5.10 Comparison of effectiveness estimator for single damage at mid-span..... | 77 |
| Table 5.11 Comparison of effectiveness estimator for single damage at quarter-span .. | 78 |
| Table 5.12 Comparison of effectiveness estimator for double damage case | 78 |
| Table 5. 13 Comparison of estimated severity between numerical and experimental data | 82 |
| Table 5.14 Comparison of calibration factor | 82 |
| Table 5. 15 Comparison of calibrated severity between numerical and experimental data | 83 |
| Table 5.16 Comparison of effectiveness estimator between numerical and experimental results | 84 |

LIST OF NOTATIONS

| | |
|--------------------|---|
| Δ | change in the flexibility |
| φ_i | eigenvector of mode I of undamaged model |
| φ_j | eigenvector of mode I of damaged model |
| \emptyset | mode shape vector |
| \emptyset_i | mode shape of mode i |
| \emptyset_{ij} | mode shape vector of the i^{th} mode and j^{th} element of undamaged beam |
| \emptyset_{ij}^* | mode shape vector of the i^{th} mode and j^{th} element of damaged beam |
| δ | deflection of the LVL beam |
| β | damage indicator |
| β_j | damage indicator of j^{th} member |
| α | severity estimator |
| α_j | severity estimator of j^{th} member |
| α_{cj} | calibrated severity estimator of j^{th} member |
| η | calibration factor |
| $\Delta\alpha_d$ | indicator of effectiveness of the repair calculated from dynamic test results |
| $\Delta\alpha_s$ | indicator of effectiveness of the repair calculated from static test results |
| α_s | severity estimation of damage |
| α_r | severity estimation of the repair |
| 3-D | three-dimensional |
| 9-nodes | 9 measuring points taken from the VEMA |
| CFRP | carbon fibre reinforced polymer |
| COMAC | coordinate modal assurance criterion |
| DD | damage detection |
| Denom | denominator |
| DOF | degree of freedom |
| E | modulus of elasticity |
| E_j | j^{th} equivalent elemental modulus of elasticity of undamaged beam |
| E_j^* | j^{th} equivalent elemental modulus of elasticity of damaged beam |
| EI | flexural stiffness |
| EMA | experimental modal analysis |
| F | system force vector |
| FE | finite element |
| FEA | finite element analysis |
| FEM | finite element model |

| | |
|----------|---|
| FFT | fast Fourier transform |
| FRF | frequency response function |
| I | moment of inertia |
| K | system stiffness matrix |
| L | light damage |
| LVDT | linear variable differential transformer |
| LVL | laminated veneer lumber |
| M | medium damage |
| MAC | modal assurance criterion |
| MSE | modal strain energy |
| $NError$ | natural frequency difference between FE and experimental models |
| Num | numerator |
| VEMA | Virtual Experimental Modal Analysis |
| Z | system displacement vector |
| Z_j | damage location index |