Investigation of Enhanced Modal-Based Techniques for Structural Damage Detection, Localization, and Severity Estimation in Framed Structures

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Master of Science

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Thesis/Dissertation submitted in partial fulfillment of the requirements for the degree

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DECLARATION

I declare that this is my own work, and this thesis/dissertation does not incorporate without acknowledgement any material previously submitted for a degree or diploma in any other University or Institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text. I retain the right to use this content in whole or part in future works (such as articles or books).

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Name of Supervisors: Dr. H. G. H. Damruwan
Prof. C. S. Lewangamage

Signature of the Supervisors:

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Dr. H. G. H. Damruwan Date: 08/02/2026

Prof. C. S. Lewangamage Date: 08/02/2026

DEDICATION

To my loving parents and partner, whose unwavering encouragement, support, and motivation have guided me through every milestone of my life. This work is dedicated to you with deepest gratitude and love.

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ABSTRACT

Structural damage detection and estimation have become essential in ensuring the safety, functionality, and longevity of civil engineering structures, particularly framed systems that form the backbone of modern infrastructure. Traditional inspection techniques, although widely used, suffer from limitations such as subjectivity, accessibility challenges, and inefficiency when dealing with large-scale structures. This has driven the development of vibration- and modal-based methods, which utilize dynamic properties such as natural frequencies and mode shapes to identify and quantify structural damage. This research aims to enhance modal-based structural damage detection techniques for framed structures by integrating experimental and computational approaches. Scaled-down steel framed structures were tested on a shake table under both intact and damaged conditions to investigate the impact of damage on modal parameters. Complementary finite element (FE) models were developed and validated in ABAQUS, enabling a comprehensive parametric study of different damage scenarios. The study evaluated the Difference in Mode Shape Slope (DMSS), Difference in Mode Shape Curvature (DMSC), and Grey Relation Coefficient (GRC) methods for their effectiveness in detection, localization, and severity estimation of damages. Results demonstrated that both DMSS and DMSC methods are highly effective for single and multiple damage detection in simple beam structures, while DMSC showed superior reliability in complex framed structures. However, both methods exhibited sensitivity limitations near structural boundaries. The GRC-based approach successfully estimated damage severity in beams but showed reduced accuracy in higher damage cases and in complex frame models. Overall, the combined methodology highlights the potential of enhanced modal-based approaches for improving accuracy and reliability in structural damage detection. The findings contribute valuable insights into the practical application of modal-based techniques in structural health monitoring and provide a foundation for further research on refining severity estimation methods and extending these techniques to large-scale real-world structures.

Keywords: Structural Health Monitoring (SHM), Modal Analysis, Structural Damage Detection (SDD), Finite Element Modelling (FEM), Difference in Mode Shape Slope (DMSS), Difference in Mode Shape Curvature (DMSC), Grey Relation Coefficient (GRC)

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LIST OF ABBREVIATIONS

Abbreviation	Description
SHM	Structural Health Monitoring
SDD	Structural Damage Detection
DMSS	Difference in Mode Shape Slope
DMSC	Difference in Mode Shape Curvature
FEM	Finite Element Modelling
GRC	Grey Relation Coefficient