

**STUDY ON HONEYCOMBS IN STRUCTURAL  
CONCRETE ELEMENTS**

Kuruppu Appuhamillage Bandhuka Prashastha Kuruppu

208017B

Master of Philosophy

Department of Civil Engineering  
Faculty of Engineering

University of Moratuwa  
Sri Lanka

August 2024

# **STUDY ON HONEYCOMBS IN STRUCTURAL CONCRETE ELEMENTS**

Kuruppu Appuhamillage Bandhuka Prashastha Kuruppu

208017B

Thesis submitted in partial fulfillment of the requirements for the degree  
Master of Philosophy

Department of Civil Engineering  
Faculty of Engineering

University of Moratuwa  
Sri Lanka

August 2024

## DECLARATION

I declare that this is my own work and this Thesis 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).

Signature: ***UOM Verified Signature***

Date: 22/08/2024

The supervisor should certify the Thesis with the following declaration.

The above candidate has carried out research for the Master of Philosophy Thesis under my supervision. I confirm that the declaration made above by the student is true and correct.

Name of Supervisor: Dr. K. Baskaran

Signature of the Supervisor: ***UOM Verified Signature***

Date: 22/08/2024

## **DEDICATION**

To Dr. K. Baskaran, whose inspiration ignited my passion for research from undergraduate to postgraduate levels and for emphasizing the vital importance of conducting research directly targeting the construction industry. This thesis is dedicated to you with immense gratitude for your guidance and unwavering support.

## **ACKNOWLEDGEMENT**

First and foremost, I am deeply grateful to Dr. Udaya Chinthaka Jayathilaka from the Mathematics Department at the University of Moratuwa for his invaluable guidance and expertise in the mathematical aspects of this research. His mentorship and insightful input have been integral to the success of this thesis.

I would also like to acknowledge the outstanding support provided by the laboratory staff of the Department of Civil Engineering at the University of Moratuwa. Their assistance in conducting experiments and providing resources has been indispensable in ensuring the quality and accuracy of the research conducted.

Additionally, I extend my thanks to the Lanka Steel Corporation for their generous provision of reinforcement materials for the experiments. Their collaboration has significantly enhanced the practical aspects of this research.

## ABSTRACT

Concrete structures are subjected to various types of surface defects such as honeycombs, surface voids, form streaking, etc. Proper understanding of the root causes of each type of defect is significant in preventing recurrence as well as applying remedies. An extensive field survey was conducted in connection with the construction sector of Sri Lanka to gather information on the current practices. It was found that the construction industry needs more awareness on correct practices. This study attempts to fill the gap between current field practices and standard practices. Poor workmanship in consolidation of fresh concrete leads to most of the defects, but this study shows how the understanding of technical background of each activity and the proper planning at initial stages contribute to effortless improvements in workmanship. Contradictions between codes of practices for design of reinforced concrete and codes of practices for consolidation of concrete were also discussed under this study. In order to identify the impact from reinforcement on UPV tests on concrete, a series of UPV tests (conventional approach) were done, and the drawbacks of that approach are highlighted under this study. As a modern approach, vibration pattern analysis of structural elements has emerged as a valuable technique for various purposes within the field of structural engineering. The analysis of vibrational patterns can be employed for different objectives, including damage detection, modal parameter identification, health monitoring, and structural integrity assessment. The presence of non-homogeneity in structural elements poses unique challenges in terms of analysing their behaviour, predicting their response to loads, and detecting damage or deterioration accurately. The straight-forward mathematical models based on first principles are for homogeneous elements having uniformly distributed mass and uniform distribution of stiffness. This study has developed a novel mathematical approach based on first principles for mode shapes of beams having deviated regions of mass and stiffness. This insight can help to identify key factors influencing the mode shapes and their variations. Furthermore, this study has done an extensive study on mode shape curvature analysis for identification of hidden honeycombs in concrete structures. The findings of this analysis fill research gaps in the study area. Moreover, the novelty of that approach is its extension to the analysis of portal frames. Consequently, a combination of conventional non-destructive tests and mode shape curvature analysis will provide a robust approach for hidden defect detection and assessment in structural concrete elements.

**Keywords:** Honeycombs, Mode shape curvature, Vibration, Mathematical Approach, UPV, Concrete, Compaction, First Principles

## TABLE OF CONTENTS

Declaration of the Candidate & Supervisor	i
Dedication	ii
Acknowledgement	iii
Abstract	iv
Table of Contents	v
List of Figures	x
List of Tables	xiii
List of Appendices	xiv
1 INTRODUCTION	1
1.1 Background	1
1.2 Problem Statement and Research Gap	2
1.3 Objectives	3
1.4 Scope and Limitations	4
1.5 Significance and Contribution	4
1.6 Outline of the Thesis	4
2 LITERATURE REVIEW	6
2.1 Pioneering Studies	6
2.2 Consolidation of fresh concrete	6
2.2.1 Constitutes of fresh concrete	6
2.2.2 What happens when vibrating fresh concrete?	7
2.3 Main causes for honeycomb damages and standard practices	9
2.3.1 Main causes for honeycomb damage and preventive actions	9
2.3.2 Standard practices	9
2.4 Detection of honeycombs in structural concrete elements	10
2.4.1 Conventional approaches	10
2.4.2 Modern approaches	11
2.4.3 Vibration-based damage detection	12

2.5	Research Gap and summary of Literature Review	13
3	UNDERSTANDING THE FORMATION OF HONEYCOMBS	15
3.1	Background and problem statement	15
3.2	Experimental approach	15
3.2.1	Hypothesis for development of smooth, thin cement paste layer on the surface	17
3.2.2	Formation of honeycombs and visual inspections	17
3.2.3	Hidden honeycombs	18
3.3	Importance of understanding the root cause for defects	19
4	FIELD SURVEY	20
4.1	Defect observations	20
4.1.1	Defects in a concrete retaining wall due to poor workmanship in compaction of concrete.	20
4.1.2	Defects in the concrete shear wall due to reinforcement bar congestion.	21
4.1.3	Defects in an inclined concrete column due to difficulty in compaction	21
4.1.4	Reinforcement bar congestion at a junction of four beams.	22
4.1.5	Surface defects due to concrete slurry leakage	23
4.1.6	Defects due to embedded parts	24
4.1.7	Defects due to misalignment of formwork/mold	25
4.1.8	Defects due to inadequate application of form oil	25
4.1.9	Segregation of aggregates was observed from the ready-mix concrete.	26
4.1.10	Honeycombing was detected at the bottom of columns	26
4.2	Analysis of data gathered from field survey	27
4.3	Improving workmanship by proper planning at initial stages: based on field survey	29
4.3.1	Correct use of code of practice	29
4.3.2	Incorporating general details of structural drawings to special cases	29

4.3.3	Points to be considered in improving workmanship related to shuttering	30
4.3.4	Use of self-compacting concrete and importance of experienced work groups.	30
4.3.5	Standards used for compaction of fresh concrete	30
4.4	Guidelines and recommendations for designers and contractors to mitigate the occurrence of Honeycombs and other Concrete Defects	31
4.4.1	Improving workmanship through proper planning	31
4.4.2	Correct use of Codes of practice	31
4.4.3	Incorporating general details of structural drawings into Special Cases	32
4.4.4	Improving workmanship related to shuttering	32
4.4.5	Use of self-compacting concrete	32
4.4.6	Standards for compaction of fresh concrete	32
4.4.7	Continuous education and training	33
5	Investigation on impact from reinforcement on UPV tests on concrete	34
5.1	Conventional methods used in local construction sector for defect detection in concrete structures	34
5.2	Assessing the impact of reinforcement arrangement for UPV tests	34
5.3	Specimen preparation and conduct of UPV tests	35
5.4	Experimental results	38
5.5	Analysis of results	40
5.5.1	Lightly reinforced concrete with no honeycombs	40
5.5.2	Lightly reinforced concrete with honeycombs	40
5.5.3	Heavily reinforced concrete with honeycombs	40
5.6	Conclusions	40
6	MATHEMATICAL APPROACH	42
6.1	Free vibration of a homogenous system	42
6.2	Free vibration of a non-homogenous system	43
6.2.1	Formulation of the motion equation	43
6.2.2	Applying the motion equation to a non-homogeneous element	46

6.2.3	Conclusions for mathematical approach	50
6.2.4	Importance of mathematical approach in hidden defect detection in real-world structures	51
7	MODE SHAPE CURVATURE ANALYSIS	52
7.1	Introduction	52
7.2	Mode shape curvature analysis - Methodology	52
7.2.1	Understanding the changes made to an element when there is a honeycomb	52
7.2.2	Why the curvature of mode shapes are sensitive to damages	52
7.2.3	Formula used for the determination of the curvature for a given function	53
7.2.4	Mode shape curvature of a given mode shape	53
7.2.5	Difference of Mode shape curvatures	54
7.3	Mode shape curvature analysis	55
7.3.1	Methodology	55
7.3.2	Development of the finite element models	56
7.3.3	Extracting the mode shape curvature	58
7.4	Detection of honeycombs with mode shape curvature analysis	59
7.4.1	Feasibility of using the same simulation to assess the defects within a given section	60
7.4.2	Mode shape curvature analysis	60
7.5	Impact on the mode shape curvature analysis when the severity of the damage is varying.	62
7.6	Low-intensity damage detection	65
7.6.1	Improving the finite element model in order to detect low-intensity damage regions in an element.	65
7.6.2	Limitations in detecting damages when the damage intensity is very low	67
7.7	Impact on change of mode shapes	68
7.8	Different mode shapes and mode shape curvature analysis	69
7.9	Mode shape curvature analysis for a portal frame	70

7.10	Summary of the mode shape curvature analysis	73
7.11	Practical approaches of the proposed method in real-world structures	74
8	CONCLUSIONS	75
8.1	Findings of the study	75
8.2	Conclusions	75
8.2.1	Hypothesis on development of smooth, thin cement paste layer on the surface of concrete structures	76
8.2.2	Root cause analysis in mitigating honeycombs in structural concrete elements	76
8.2.3	Identification of hidden honeycombs in concrete structures	77
8.2.4	Mathematical Modelling and Analysis of Mode Shapes for Non-Homogeneous Structural Elements	77
8.2.5	Mode shape curvature analysis	78
8.3	Recommendations for future works	78
	References	80
	Appendix A MATLAB CODES	84

## LIST OF FIGURES

<b>Figure</b>	<b>Description</b>	<b>Page</b>
Figure 1.1	Bee hive with hexagonal pattern	1
Figure 1.2	A honeycomb in the surface of a retaining wall	2
Figure 2.1	Cross section of hardened concrete [1]	7
Figure 3.1	Formation of smooth, thin cement paste layer on the surface	16
Figure 3.2	Core arrangement of fresh concrete prior to vibration	16
Figure 3.3	Cement paste and slurry following the air-entrapping path during vibration	17
Figure 3.4	Changes to the inner face of the mold during vibration	17
Figure 3.5	Visibility of honeycombs and smooth layer of cement paste in the surface	18
Figure 3.6	Defects due to slurry leakage	19
Figure 4.1	Defects in a concrete retaining wall due to poor workmanship in compaction of concrete.	20
Figure 4.2	Defects in a concrete wall due to reinforcement bar congestion.	21
Figure 4.3	Defects in an inclined concrete column.	21
Figure 4.4	Reinforcement bar congestion at a junction of four beams.	22
Figure 4.5	Surface defects due to concrete slurry leakage.	23
Figure 4.6	Defects due to embedded parts-1	24
Figure 4.7	Defects due to embedded parts-2	24
Figure 4.8	Defects due to misalignment of formwork/mold	25
Figure 4.9	Defects due to inadequate application of form oil	25
Figure 4.10	Segregation of aggregates was observed from the ready-mix concrete.	26
Figure 4.11	Improper compaction at the bottom layers of 3.5m height concrete column.	27
Figure 5.1	Sketches showing reinforcement arrangement of different specimen	35
Figure 5.2	Reinforcement arrangement of specimen with no honeycombs	35
Figure 5.3	Reinforcement arrangement of the lightly reinforced specimen with a honeycomb	36
Figure 5.4	Reinforcement arrangement of the heavily reinforced specimen with a honeycomb	36
Figure 5.5	Showing lightly (LHS) and heavily (RHS) reinforcement arrangement of specimen with honeycombs	37
Figure 5.6	Conducting the UPV test	37
Figure 5.7	Sketches showing faces where UPV tests were carried out	38
Figure 6.1	Detailed sketch for formulation of motion equation	43
Figure 6.2	Representing beam element with non-homogeneous properties	46

Figure 6.3	Mode Shape of Non Homogeneous beam	49
Figure 6.4	Normal beam vs Non-homogeneous beam Mode Shape Comparison	50
Figure 6.5	Mode Shape Difference	50
Figure 7.1	Normal beam Vs Non-homogeneous beam Mode Shape Comparison	53
Figure 7.2	Normal beam Vs Non-homogeneous beam Mode Shape Curvature Comparison	54
Figure 7.3	Normal beam Vs Non-homogeneous beam Mode Shape Curvature Difference Comparison	54
Figure 7.4	Non-homogeneity properties of beam element	55
Figure 7.5	Flow chart showing methodology for mode shape curvature analysis	56
Figure 7.6	Nodes in Finite Element Model, total 601 nodes for 6m long beam element	57
Figure 7.7	Details of the curve fitting - sum of sine - 08 Terms (MATLAB software)	57
Figure 7.8	Curve fitted plot for Mode 4 - sum of sine - 08 Terms (MATLAB software)	58
Figure 7.9	Mode shape and Mode shape curvature plot together	59
Figure 7.10	Simulated defective locations in the beam	59
Figure 7.11	Curve fitted plot for Mode 4 with two defective locations: 200-205 and 450-455	60
Figure 7.12	Mode shape and Mode shape curvature plots with two defective locations: 200-205 and 450-455	61
Figure 7.13	Mode shape curvature difference between normal beam and damaged beam: 200-205 and 450-455	61
Figure 7.14	Mode shape difference between normal beam and damaged beam: 200-205 and 450-455	62
Figure 7.15	Mode shape curvature difference between normal beam and 90% of $E$ damaged beam; Number of Nodes = 601, damaged regions = Nodes 200-205 and 450-455	63
Figure 7.16	Mode shape curvature difference between normal beam and 70% of $E$ damaged beam; Number of Nodes = 601, damaged regions = Nodes 200-205 and 450-455	63
Figure 7.17	Mode shape curvature difference between normal beam and 50% of $E$ damaged beam; Number of Nodes = 601, damaged regions = Nodes 200-205 and 450-455	64
Figure 7.18	Mode shape curvature difference between normal beam and 10% of $E$ damaged beam; Number of Nodes = 601, damaged regions = Nodes 200-205 and 450-455	64
Figure 7.19	Mode shape curvature differences for different intensities of damage	65
Figure 7.20	Mode shape curvature difference between normal beam and 50% of $E$ damaged beam; Number of Nodes = 1201, damaged regions = Nodes 400-410 and 900-910	66

Figure 7.21	Mode shape curvature difference between normal beam and 10% of $E$ damaged beam; Number of Nodes = 1201, damaged regions = Nodes 400-410 and 900-910	66
Figure 7.22	Mode shape curvature difference between normal beam and 05% of $E$ damaged beam; Number of Nodes = 1201, damaged regions = Nodes 400-410 and 900-910	67
Figure 7.23	Mode shape curvature difference between normal beam and 05% of $E$ damaged beam; Number of Nodes = 2401, damaged regions = Nodes 800-820 and 1800-1820	67
Figure 7.24	Deviations between Nodal displacement points of mode shape and the Fitted Curve	68
Figure 7.25	Mode shape - 2 ; curvature difference between normal beam and 50% of $E$ damaged beam; Number of Nodes = 1201, damaged regions = Nodes 400-410 and 900-910	68
Figure 7.26	Mode shape - 7 ; curvature difference between normal beam and 50% of $E$ damaged beam; Number of Nodes = 1201, damaged regions = Nodes 400-410 and 900-910	69
Figure 7.27	Mode shape - 2 ; curvature difference between 70% damaged (400-410) and 50% damaged (900-910) beams	69
Figure 7.28	Mode shape - 4 ; curvature difference between 70% damaged (400-410) and 50% damaged (900-910) beams	70
Figure 7.29	Finite element model of the portal frame showing defective regions in red circles	71
Figure 7.30	First five mode shapes of the portal frame considered	71
Figure 7.31	Mode shape curvature difference plot of Element 01 (Mode 5, Defective regions at nodes: 400-410 and 900-910)	72
Figure 7.32	Mode shape curvature difference plot of Element 02 (Mode 5, Defective regions at nodes: 200-210)	72
Figure 7.33	Mode shape curvature difference plot of Element 03 (Mode 5, Defective regions at nodes: 500-510)	73
Figure 7.34	Mode shape curvature analysis process	74

## LIST OF TABLES

<b>Table</b>	<b>Description</b>	<b>Page</b>
Table 4.1	Number of occurrences for each root cause for honeycombing - out of 30 construction sites	27
Table 4.2	Methods used for compaction of concrete - out of 30 construction sites	28
Table 4.3	Methods used for honeycomb detection in construction projects - out of 30 construction sites	28
Table 5.1	UPV test results for Specimen 01 - Lightly reinforced arrangement with no-honeycombs	38
Table 5.2	UPV test results for Specimen 02 - Lightly reinforced arrangement with honeycombs	39
Table 5.3	UPV test results for Specimen 03 - Heavily reinforced arrangement with honeycombs	39
Table 6.1	Property Table	46

## **LIST OF APPENDICES**

<b>Appendix</b>	<b>Description</b>	<b>Page</b>
Appendix -A	MATLAB CODES	84