

PERFORMANCE OF EARTH MASONRY UNDER DYNAMIC LOADING

Karapitiye Pathiranage Indunil Erandi Ariyaratne

(178026M)

Degree of Master of Science

Department of Civil Engineering

University of Moratuwa

Sri Lanka

September 2018

PERFORMANCE OF EARTH MASONRY UNDER DYNAMIC LOADING

Karapitiye Pathirana Indunil Erandi Ariyaratne

(178026M)

Thesis submitted in partial fulfillment of the requirements for the degree Master of
Science in Civil Engineering

Department of Civil Engineering

University of Moratuwa

Sri Lanka

September 2018

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.

Also, I hereby grant to University of Moratuwa the non-exclusive right to reproduce and distribute the thesis, in whole or in part in print, electronic or other medium. I retain the right to use this content in whole or part in future works (such as articles or books).

Signature:

Date:

The above candidate has carried out research for the Masters under my supervision

Name of the supervisor: Prof. (Mrs.) C. Jayasinghe

Signature of the supervisor:

Date:

Name of the supervisor: Prof. M.T.R. Jayasinghe

Signature of the supervisor:

Date:

Name of the supervisor: Prof. Peter Walker

Signature of the supervisor:

Date:

ACKNOWLEDGEMENTS

Under the Research Project, I had the opportunity of gaining a very valuable experience of how to apply the theoretical knowledge gathered throughout the four years as an undergraduate to produce important findings for the well-being and development of the community.

There are number of persons whom I must pay my gratitude for their help towards the successful completion of the research project and report.

First, I am very grateful for the valuable guidance and encouragement given by my research supervisors, Prof. (Mrs.) C. Jayasinghe, Senior Professor in the Department of Civil Engineering, University of Moratuwa, Prof. M. T. R. Jayasinghe, Senior Professor in the Department of Civil Engineering, University of Moratuwa and Prof. P. Walker, Professor in the Department of Architecture and Civil Engineering, University of Bath. Further I am thankful to senior professor, Prof. A.A.D.J. Perera and senior lecturer, Dr. H.M.Y.C. Mallikarachchi for evaluating and giving us valuable instructions regarding the research findings we presented during the research progress presentations.

Finally, I pay my appreciation to Mr.T.P.D.G. Indika Yohan, M.L. Perera, P.P.R. Peris and D.U. Jayasinghe, non-academic staff of Department of Civil Engineering, University of Moratuwa who helped us in experimental work.

Ariyaratne, K.P.I.E.
Department of Civil Engineering
University of Moratuwa
06.09.2018

ABSTRACT

Masonry buildings are the most typical structural type which is commonly used for ancient historical structures and low to medium rise residential units from early days to present. However, increase in world population and their housing needs with limited resources tend to promote the usage of alternative building materials in the construction industry as much as possible. Among those alternatives, earth masonry has become one of the building materials in sustainable development process since its in-built properties such as economy, low embodied energy, low in CO₂ emissions, etc. However, the structural elements made from earth masonry such as rammed earth and compressed earth blocks (stabilized/un-stabilized), have not been much assessed on their seismic performance.

The main objective is to comparatively assess the in-plane and out-of-plane seismic performance of Cement Stabilized Earth Blocks (CSEB) and Cement Stabilized Rammed Earth (CSRE) walls with similar dimension via a series of shake table test and to recommend a most suitable numerical method for analysing the seismic performance of CSEB and CSRE walls.

For this purpose, a set of small scale physical models of compressed stabilized earth blocks and rammed earth were tested under scaled versions of El-Centro (EIC) earthquake north-south component and sine waves with different frequencies and amplitudes using one degree of freedom shaking table equipment.

For experiments, 110 mm thick compressed stabilized earth blocks and 150 mm thick rammed earth wall panels were selected. Two wall panels of each earth masonry type were prepared for around 596mm and 460mm height respectively. A 38 mm thick concrete layer was laid bottom and top of each specimen for confinement of the element. The tests were carried out under series of shake table tests and observed the deflection and acceleration behaviour at bottom, middle and top of wall panels, base shear values, failure mode and magnitude.

According to the experimental results from moderate to severe earthquakes, both CSEB and CSRE wall panels performed well without any visible cracks. In CSEB wall panels, maximum acceleration and displacement at the crest of the wall and base shear is 8.2%, 1.2% and 7.6% greater in out-of-plane loads than the in-plane walls under severe earthquake. But in RE wall panels those above considered values remain same for both in and out-of-plane walls.

To investigate the progressive damage behavior of earth walls, they subjected to sine waves with increasing amplitudes and frequencies. In CSEB walls, there were no visible cracks both in and out-of-plane walls until the 4Hz sine wave. But when the frequency become 6Hz, base crack was initiated and spread throughout the wall width in the out-of-plane wall and no visible cracks in the in - plane wall. In RE walls, there were no visible cracks both in and out-of-plane walls until the 4Hz sine wave. But when the frequency become 6Hz, base crack was developed through the wall width with rocking mode in the out-of-plane wall and base crack was developed with some translation to the loading direction in the in-plane wall.

Numerical models were prepared with Structural Analysis Program (SAP 2000) and ABAQUS with the intension of using experimental results to validate. It is found the ABAQUS model is capable of predicting the behaviour of earth masonry under seismic loading.

Key words: Earth masonry, Shake table test, In-plane loading, Out-of-plane loading, Numerical modelling.

TABLE OF CONTENTS

DECLARATION	i
ACKNOWLEDGEMENTS	ii
ABSTRACT	iii
TABLE OF CONTENTS.....	iv
LIST OF FIGURES.....	vi
LIST OF TABLES.....	vii
LIST OF ABBREVIATIONS.....	vii
LIST OF APPENDICES.....	vii
1. INTRODUCTION.....	1
1.1 RESEARCH BACKGROUND	1
1.2 OBJECTIVE.....	2
1.3 METHODOLOGY	2
1.4 THE ARRANGEMENT OF THE THESIS	3
2. LITERATURE REVIEW	4
2.1 INTRODUCTION.....	4
2.2 SEISMIC PERFORMANCE OF MASONRY STRUCTURES	5
2.2.1 CONVENTIONAL MATERIALS	5
2.2.2 EARTH MATERIALS	14
2.2.3 OBSERVED TRENDS IN DYNAMIC PERFORMANCE OF MASONRY STRUCTURES THROUGH EXPERIMENTAL STUDIES.....	21
2.2.4 SUMMARY OF IDEALIZATIONS USED IN NUMERICAL MODELLING OF MASONRY STRUCTURES.....	22
3. EXPERIMENTAL STUDY	25
3.1 INTRODUCTION.....	25
3.2 SELECTION OF PARAMETERS	25
3.2.1 COMPRESSED STABILIZED EARTH BLOCKS WALL PANELS.....	25
3.2.2 RAMMED EARTH WALL PANELS	26
3.3 MATERIAL PROPERTIES	27
3.3.1 CSEB	27
3.3.2 CSRE.....	28
3.4 TEST SET UP.....	30
3.5 CONSTRUCTION SEQUENCE.....	36
3.5.1 CSEB WALLS	36
3.5.2 CSRE WALLS	38
3.6 SEQUENCE OF LOADING	40
3.7 SUMMARY	42
4. RESULTS AND DISCUSSION.....	43
4.1 GENERAL.....	43
4.2 PERFORMANCE OF CSEB WALLS UNDER SEISMIC LOADS.....	43
4.3 PERFORMANCE OF STABILIZED RAMMED EARTH WALLS UNDER SEISMIC LOADS.....	44

4.4	COMPARISON OF RESULTS	45
4.5	SUMMARY	48
5.	NUMERICAL MODELLING	49
5.1.1	DEFINING NEW MODEL	50
5.1.2	GEOMETRY	51
5.1.3	MATERIAL PROPERTIES	51
5.1.4	RESTRAINTS	52
5.1.5	LOADING	53
5.2	THE PROCESS OF NUMERICAL MODELLING IN ABAQUS	56
5.2.1	STRUCTURAL ANALYSIS USING ABAQUS	56
5.2.2	GEOMETRY	57
5.2.3	MATERIAL PROPERTIES	57
5.2.4	ASSEMBLING OF THE REAL OBJECT	58
5.2.5	INTERACTION	59
5.2.6	LOADING	59
5.2.7	MESHING	60
5.3	COMPARISON OF SAP AND ABAQUS NUMERICAL RESULTS	61
6.	CONCLUSION AND FUTURE WORK	68
6.1	FUTURE WORK	69
	REFERENCE LIST	70
	ANNEXURE	74
	APPENDIX A: El-Centro earthquake data	75
	APPENDIX B: Acceleration and displacement results of CSEB wall panels under moderate sized earthquake	77
	APPENDIX C: El-Centro earthquake full data sheet and acceleration and displacement results of CSEB and CSRE wall panels from moderate to severe sized earthquake (CD Attachment)	

LIST OF FIGURES

Page

Figure 1.1: Damaged structures due to Nepal earthquake in 2015.....	2
Figure 1.2 : Flow Chart of Methodology	3
Figure 2.1 : Prevailing Studies relevant to Seismic Performance of Masonry Structures.....	4
Figure 2.2: Experimental set up with steel frames	5
Figure 2.3: FEM (ABAQUS with explicit solver with openings).....	7
Figure 2.4: New construction method with trussed reinforcement.....	8
Figure 2.5: Experimental setup and discrete model	11
Figure 2.6: Un-bonded brick work and interlocking masonry unit	11
Figure 2.7: Non-retrofitted and retrofitted walls and the numerical model.....	13
Figure 2.8: Experimental wall and the numerical model.....	14
Figure 2.9: Experimental and numerical model	15
Figure 2.10: Load application using hydraulic jack	16
Figure 2.11 : Wall panel sections selected for Research	23
Figure 3.1: Geometry of CSEB wall panels	26
Figure 3.2: Geometry of CSRE wall panels	27
Figure 3.3: Jar Test.....	28
Figure 3.4: Casting of CSRE cubes.....	29
Figure 3.5: Moratuwa University one-degree shaking table	30
Figure 3.6: Equalization of Input and Output signals.....	35
Figure 3.7: Construction steps of CSEB wall panel	37
Figure 3.8: Construction steps of CSRE wall panels	39
Figure 3.9: Final view of wall specimens.....	40
Figure 3.10: Test specimens loading directions	42
Figure 4.1: Variation of acceleration and displacement in CSEB panels.....	43
Figure 4.2: Base crack in CSEB out-of-plane wall	44
Figure 4.3: Variation of acceleration and displacement in RE panels.....	44
Figure 4.4: Base crack in CSRE wall panels.....	45
Figure 4.5: Base Shear distribution during load category 1	47
Figure 5.1: Steps in SAP model	50
Figure 5.2: Grid type model	51
Figure 5.3: Block and mortar as one unit	51
Figure 5.4 : Defining material properties	52
Figure 5.5: Effect of edge area constraint	52
Figure 5.6: Steps in defining the loading.....	54
Figure 5.7: Analysis of SAP results	55
Figure 5.8: Steps of ABAQUS Modelling	56
Figure 5.9: Defining the units	57
Figure 5.10: Tensile and compression behaviour in CDP model	58
Figure 5.11: Assembly of the real object in ABAQUS	58
Figure 5.12: Loading in ABAQUS.....	59
Figure 5.13: Meshing the object in ABAQUS	60
Figure 5.14: Analysis of ABAQUS results	60
Figure 5.15: SAP numerical results.....	61
Figure 5.16: ABAQUS numerical results.....	62
Figure 5.17: CSEB wall numerical model.....	65
Figure 5.18: CSEB Displacement vs. Time.....	66

Figure 5.19: CSRE Displacement vs. Time.....	66
Figure 5.20: Failure Stresses of CSEB walls.....	67
Figure 5.21: Failure Stresses of CSRE walls.....	67

LIST OF TABLES

	Page
Table 2.1: Observations of each model	12
Table 2.2: Collapse frequencies for single room models with different blocks	17
Table 2.3: Summary of few experimental and numerical research studies carried out relevant to the dynamic performance of different masonry structures	20
Table 2.4: Experimental results for different elements retrofitted with FRP	21
Table 3.1: Loading Steps.....	41
Table 4.1: Responses during loading category 1	46
Table 4.2: Occurrence of visible cracks	47
Table 5.1: Comparison of two computational models.....	63
Table 5.2: Comparison of Numerical Modelling Results with Experimental	66

LIST OF ABBREVIATIONS

Abbreviation	Description
CSEB	Cement Stabilized Earth Block
CSRE	Cement Stabilized Rammed Earth
EQRF	Earthquake Resistant Feature
EIC	El-Centro
FEM	Finite Element Method
FRP	Fibre Reinforced Polymer
GFRP	Glass Fibre Reinforced Polymer
PGA	Peak Ground Acceleration
PP	Polypropylene
NZS	New Zealand Standard
RM	Reinforced Masonry
SAP	Structural Analysis Program
SLS	Serviceability Limit State
URM	Unreinforced Masonry

LIST OF APPENDICES

Appendix	Description	Page
Appendix A	El-Centro earthquake data	75
Appendix B	Acceleration and displacement results of CSEB wall panels under moderate earthquake	77
Appendix C	El-Centro earthquake full data sheet and acceleration and displacement results of CSEB and CSRE wall panels from moderate to severe sized earthquake (CD Attachment)	