



# **PERFORMANCE-BASED DAMAGE ASSESSMENT OF STRUCTURAL WALLS**

## ***A Thesis***

Submitted to the Faculty of Engineering  
Ain Shames University for the Partial Fulfillment  
of the Requirements of The Degree of Master of Science  
In Civil Engineering

## **Prepared by**

**ENG. MOHAMED MAHMOUD MOHAMED ELKHESHEN**

B.Sc. in Civil Engineering, August 2010  
Higher Technological Institute – Tenth of Ramadan City

## **Supervisors**

**Prof. Dr. OSAMA HAMDY ABDELWAHD,**

Professor, of Concrete Structures,  
Ain Shams University, Cairo, EGYPT

**Dr. MARWAN TAREK SHEDID**

Assistant Professor of Structural Engineering Department,  
Ain Shams University, Cairo, EGYPT

**Dr. HUSSEIN OSAMA OKAIL**

Assistant Professor of Structural Engineering Department,  
Ain Shams University, Cairo, EGYPT

**2015**



# **PERFORMANCE-BASED DAMAGE ASSESSMENT OF STRUCTURAL WALLS**

A Thesis For  
**The M.Sc. Degree in Civil Engineering  
(STRUCTURE ENGINEERING)**

By  
**ENG. MOHAMED MAHMOUD MOHAMED ELKHESHEN**

B.Sc. in Civil Engineering, August 2010  
Higher Technological Institute – Tenth of Ramadan City

## **THESIS APPROVAL**

### **EXAMINERS COMMITTEE**

### **SIGNATURE**

**Prof. Dr. MASHHOUR AHMED GHONEIM**

Professor, of Concrete Structure,  
Faculty of Engineering , Cairo University.

.....

**Prof. Dr. OMAR ALI ELNAWAWY**

Professor, of Concrete Structure,  
Faculty of Engineering, Ain Shams University.

.....

**Prof. Dr. OSAMA HAMDY ABDELWAHD**

Professor, of Concrete Structure,  
Faculty of Engineering, Ain Shams University.

.....

# STATEMENT

This dissertation is submitted to Ain Shams University, Faculty of Engineering for the degree of M.Sc. in Civil Engineering.

The work included in this thesis was carried out by the author in the department of Structure Engineering, Faculty of Engineering, Ain Shams University, from 2010 to 2015.

No part of the thesis has been submitted for a degree or a qualification at any other University or Institution.

The candidate confirms that the work submitted is his own and that appropriate credit has been given where reference has been made to the work of others

Name: - **MOHAMED MAHMOUD MOHAMED ELKHESHEN**

Signature: -

Date: -     /     /2015

# ABSTRACT

The main objective of the research reported in this thesis is to investigate the behaviour of reinforced masonry shear walls subjected to quasi-static loading. To achieve the aforementioned goal and better understanding of masonry shear walls behaviour, a large number of reinforced masonry shear walls is needed to experimentally tested under cyclic loading. Laboratory testing of full-scale masonry shear walls can be impractical due to space limitation, construction, and financial restriction.

Hence, the need for analytical model emerged to analyze a lot of reinforced masonry shear walls. A nonlinear program CANNY is selected to model reinforced masonry shear walls. To check the validity of the nonlinear program, it is required to compare the results of RM walls tested experimentally before with the results of the same walls modeled with the nonlinear program CANNY. The nonlinear program CANNY obtained results is found in good agreement compared with experimental results. Thus, the program is capable of simulating the response of reinforced concrete masonry shear walls under lateral loading.

The subsequent phase of model verification entailed in conducting parametric study. Parametric study was performed to investigate the different parameters that affect the behaviour of reinforced masonry shear walls. The parameters which were varied in this analysis include: Axial compressive stress, vertical reinforcement ratio ( $\rho_v$ ) and the height/length ( $h_w/l_w$ ) aspect ratio. The axial compressive stress varied from zero to 2.25 MPa, vertical reinforcement ratio varied from 0.31% to 1.3%, and aspect ratio varied from 1.5 to 3.95.

The behaviour of rectangular reinforced masonry shear walls is investigated by evaluating flexure strength, lateral displacement and drift at ultimate, yield and 15% strength degradation. For each mentioned parameters displacement ductility and idealized displacement ductility at 15% strength degradation are obtained. Analytical results showed that by increasing the vertical reinforcement and axial compressive stress, ultimate and yield flexure strength increase. On the contrast, the lateral displacement and drift at maximum load, at first yield, and 15% degradation in strength decrease with this increase. Lateral displacement at maximum load had insignificant effect with vertical reinforcement ratio. Based on results the displacement ductility at 15% strength degradation and idealized displacement ductility decreased with the increase of vertical reinforcement and axial compressive stress. Although the displacement ductility at maximum load increased by increasing axial compressive stress and vertical reinforcement ratio. The aspect ratio had a great effect in all parameters and this effect appeared in all charts includes vertical reinforcement and axial compressive stress.

# DEDICATION

It is a great pleasure to dedicate my

M.Sc. Thesis

To the most persons I love in my life

*My Father, My Mother*

## ACKNOWLEDGEMENT

**All praise and gratitude be to ALLAH with the blessings of whom the good deeds are fulfilled.**

I am eager to take this opportunity to thank everyone who helped me during my work in this research and special mention my thesis committee members.

I am particularly indebted to **Prof. Dr. OSAMA HAMDY**, Professor, of Concrete Structure, Ain Shams University, for his valuable help, caring, advice and encouragement as supervisor of this project

I would like to express my great debt for help beyond measure to **Dr. MARWAN TAREK SHEDID**, Assistant Professor, of Concrete Structure, Ain Shams University, for his excellent guidance, endless support, encouragement, valuable advice he has given me during this research. His comments and suggestions during the preparation of this thesis are sincerely appreciated.

I would also like to gratitude **Dr. HUSSEIN OSAMA OKAIL**, Assistant Professor, of Concrete Structure, Ain Shams University, for providing his assistance, patience and guidance during my work in this research.

Acknowledgements also extended to the staff of the Higher Technological Institute, 10<sup>th</sup> of Ramadan City, for their help and cooperation. I am also, very grateful to Dr. MORCOS FARID in Structural Department for continuous guidance, motivation and help.

Last, but certainly not the least, I take this opportunity to express the profound gratitude from my deep heart to my beloved parents, grandparents, and sisters for their continuous support, lover, prayer, and encouragement throughout my life. I cannot imagine my life without them.

# TABLE OF CONTENTS

ABSTRACT.....	i
DEDICATION .....	iii
ACKNOWLEDGMENT .....	iv
TABLE OF CONTENT .....	v
LIST OF FIGURES.....	ix
LIST OF TABLES .....	xiii
LIST OF SYMBOLS .....	xv

## CHAPTER ONE - INTRODUCTION

1.1 Background .....	1
1.2 Problem Statement .....	3
1.3 Research Significance and Objectives .....	4
1.4 Scope of The Research.....	5
1.5 Organization of The Dissertation .....	6

## CHAPTER TWO - LITREATURE REVIEW

2.1 Introduction .....	7
2.2 Study on Flexure-Dominated Masonry Walls.....	7
2.2.1 Shing et al.(1989) and (1990).....	7
2.2.2 Paualy and Priestly (1992) and (1993) .....	8
2.2.3 Priestly et al. (1993) .....	10
2.2.4 Shedid et al (2008) and (2010) .....	11
2.2.5 Vaughan (2010) .....	13
2.2.6 Sherman (2011) .....	15
2.2.7 Kapoi (2012) .....	16
2.3 Study of Shear-Dominated Masonry Walls .....	17
2.3.1 Shing et al. (1989) and (1990).....	17
2.3.2 Sucuoglu and McNiven (1991) .....	19
2.3.3 Brunner and Shing (1996) .....	19
2.3.4 Sutter and Ibrahim (1999) .....	20
2.3.5 Voon and Ingham (2006) .....	20



2.3.6	Vaughan (2010)	21
2.4	Modeling Shear Walls Using CANNY	21
2.4.1	Ghobrah et al. (2004)	21
2.4.2	Laezza et al (2004)	24
2.4.3	White and Adebar (2004)	25
2.4.4	Galal and El-Sokkary (2008)	26
2.5	Displacement Ductility	26
2.6	Related Study	29
2.6.1	Kattab and Drysdale (1993)	29
2.6.2	Tikalsky et al. (1995)	29
2.6.3	Kenji Kikuchi et al. (1999)	30
2.7	Codes and Standards	30
2.8	Conclusion	35

### **CHAPTER THREE – NONLINEAR BEHAVIOUR OF REINFORCED CONCRETE MASONRY SHEAR WALLS**

3.1	Introduction	36
3.2	Nonlinear Structural Program	37
3.3	Wall Element	38
3.4	Material Modeling	40
3.4.1	Concrete Masonry	40
3.4.2	Steel Bars	41
3.5	Nonlinear Analysis Method	42
3.6	Experimental Verification	43
3.6.1	Three Storey and Two Storey Half Scale Shear Walls	43
3.6.2	Full Scale Reinforced Concrete Masonry Shear Walls Model	46
3.7	Comparison of Experimental and Analytical Results	49
3.7.1	Ultimate Flexure Strength	49
3.7.2	Displacement at Maximum Load	55
3.7.3	Displacement at 15% Strength Degradation	56
3.7.4	Displacement at 20% Strength Degradation	57
3.8	Closure	58

## CHAPTER FOUR – PARAMETRIC STUDY

4.1	Introduction .....	59
4.2	Characteristics of Masonry Walls .....	59
4.3	Presentation of The Results .....	60
4.4	Results of The Parametric Study .....	60
4.4.1	Effect of Axial Compressive Stress .....	61
4.4.1.1	Ultimate Flexure Strength .....	61
4.4.1.2	Yield strength .....	63
4.4.1.3	Idealized Yield strength.....	65
4.4.1.4	Lateral Displacement and Drift .....	67
4.4.1.4.1	Lateral Displacement at Maximum Load .....	67
4.4.1.4.2	Lateral Displacement at First Yield.....	69
4.4.1.4.3	Lateral Displacement at Idealized Yield .....	71
4.4.1.4.4	Lateral Displacement at 15% Strength Degradation .....	73
4.4.1.4.5	Drift at Maximum Load.....	76
4.4.1.4.6	Drift at First Yield .....	77
4.4.1.4.7	Drift at Idealized Yield .....	78
4.4.1.4.8	Drift at 15% Degradation in Strength.....	79
4.4.1.5	Displacement Ductility and Idealized Ductility .....	80
4.4.1.5.1	Displacement Ductility at Maximum Load .....	80
4.4.1.5.2	Displacement Ductility at 15% Strength Degradation .....	81
4.4.1.5.3	Idealized Displacement Ductility at 15% Strength Degradation .....	82
4.4.2	Effect of Vertical Reinforcement .....	83
4.4.2.1	Ultimate Flexure Strength .....	84
4.4.2.2	Yield Strength.....	85
4.4.2.3	Idealized Yield Strength.....	86
4.4.2.4	Lateral Displacement and Drift .....	87
4.4.2.4.1	Lateral Displacement at Maximum Load .....	87
4.4.2.4.2	Lateral Displacement at First Yield.....	88
4.4.2.4.3	Lateral Displacement at Idealized Yield .....	89
4.4.2.4.4	Lateral Displacement at 15% Degradation in Strength .....	90

4.4.2.4.5	Drift at Maximum Load.....	91
4.4.2.4.6	Drift at First Yield .....	92
4.4.2.4.7	Drift at Idealized Yield.....	93
4.4.2.4.8	Drift at 15% Degradation in Strength.....	94
4.4.2.5	Displacement Ductility and Idealized Displacement Ductility .....	95
4.4.2.5.1	Displacement Ductility at Maximum Load .....	95
4.4.2.5.2	Displacement Ductility at 15% Strength Degradation .....	96
4.4.2.5.3	Idealized Displacement Ductility at 15% Strength Degradation .....	97
4.5	Closure .....	99
<b>CHAPTER FIVE –CONCLUSIONS</b>		
5.1	Summary .....	100
5.2	Conclusion.....	101
5.3	Future work .....	103
REFERENCES .....		104
APPENDIX .....		108

# LIST OF FIGURES

Fig. 1. 1: Flexure failure mechanism .....	2
Fig. 1. 2: Shear failure mechanism.....	3
Fig. 2. 1: Diagonal crack sequence .....	18
Fig. 2. 2: Idealization of the tested wall for the dynamic response analysis .	23
Fig. 2. 3: Application and schematization of Viscous Damper .....	24
Fig. 2. 4: Displacement ductility definitions .....	27
Fig. 3. 1: Fiber Model for 3D wall .....	39
Fig. 3. 2: The Area Contributed to Corresponding Displacement .....	39
Fig. 3. 3: Concrete material skeleton curve .....	40
Fig. 3. 4: Steel material skeleton curve .....	41
Fig. 3. 5: Details of vertical and horizontal reinforcement of test specimens	44
Fig. 3. 6: Reinforcement details for 3 and 2-storey test specimens .....	45
Fig. 3. 7: Reinforcement details for one storey test specimens .....	48
Fig. 3. 8: Experimental and analytical load-displacement relationship for 3and 2-storey reinforced masonry shear walls .....	50
Fig. 3. 9: Experimental and analytical load-displacement relationship for one storey reinforced masonry shear walls .....	51-53

Fig. 4. 1: Effect of axial compressive stress on Ultimate capacity .....	62
Fig. 4. 2: Relationship between $(Q_u/Q_{u_0})$ and axial compressive stress .....	63
Fig. 4. 3: Effect of axial compressive stress on wall resistance at first yield capacity .....	64
Fig. 4. 4: Relationship between $(Q_y/Q_{y_0})$ and axial compressive stress .....	65
Fig. 4. 5: Effect of axial compressive stress on wall resistance at idealized yield capacity .....	66
Fig. 4. 6: Relationship between $(Q_y/Q_{y_0})$ and axial compressive stress .....	66
Fig. 4. 7: Effect of axial compressive stress on lateral displacement at maximum load .....	67
Fig. 4. 8: Modified chart for effect of axial compressive stress on lateral displacement at maximum load .....	68
Fig. 4. 9: Relation between $(\Delta_u/\Delta_{u_0})$ and axial compressive stress .....	69
Fig. 4. 10: Effect of axial compressive stress on lateral displacement at first yield .....	70
Fig. 4. 11: Relation between $(\Delta_y/\Delta_{y_0})$ and axial compressive stress .....	71
Fig. 4. 12: Effect of axial compressive stress on lateral displacement at idealized yield .....	72

Fig. 4. 13: Relation between idealized ( $\Delta_y/\Delta_{y_0}$ ) and axial compressive stress .....	73
Fig. 4. 14: Effect of axial compressive stress on lateral displacement at 15% degradation in strength .....	74
Fig. 4. 15: Relation between ( $\Delta_{0.85u}/\Delta_{0.85u_0}$ ) and axial compressive stress .....	75
Fig. 4. 16: Effect of axial compressive stress on Drift by using displacement at maximum load .....	76
Fig. 4. 17: Effect of axial compressive stress on Drift at first yield.....	77
Fig. 4. 18: Effect of axial compressive stress on Drift at idealized yield.....	78
Fig. 4. 19: Effect of axial compressive stress on Drift at 15% degradation in strength .....	79
Fig. 4. 20: Displacement ductility at maximum load ( $\mu_{\Delta u}$ ).....	80
Fig. 4. 21: Displacement ductility at 15% degradation strength ( $\mu_{\Delta 0.85u}$ ) ....	82
Fig. 4. 22: Idealized displacement ductility at 15% strength degradation ( $\mu_{\Delta eq 0.85u}$ ) .....	83
Fig. 4. 23: Effect of vertical reinforcement on ultimate capacity .....	85
Fig. 4. 24: Effect of vertical reinforcement on wall resistance at first of yield strength .....	86

Fig. 4. 25: Effect of vertical reinforcement on wall resistance at idealized of yield strength .....	87
Fig. 4. 26: Effect of vertical reinforcement on lateral displacement at maximum load .....	88
Fig. 4. 27: Effect of vertical reinforcement on lateral displacement at first yield .....	89
Fig. 4. 28: Effect of vertical reinforcement on lateral displacement at idealized yield .....	90
Fig. 4. 29: Effect of vertical reinforcement on lateral displacement at 15% degradation in strength .....	91
Fig. 4. 30: Effect of vertical reinforcement on drift by using lateral displacement at maximum load .....	92
Fig. 4. 31: Effect of vertical reinforcement on drift by using lateral displacement at first yield.....	93
Fig. 4. 32: Effect of vertical reinforcement on drift by using lateral displacement at idealized yield.....	94
Fig. 4. 33: Effect of vertical reinforcement on drift by using lateral displacement at 15% degradation in strength .....	95
Fig. 4. 34: Displacement ductility at maximum load $\mu_{\Delta u}$ .....	96
Fig. 4. 35: Displacement ductility at 15% strength degradation $\mu_{\Delta 0.85u}$ .....	97
Fig. 4. 36: Idealized displacement ductility at 15% strength degradation $\mu_{\Delta eq 0.85u}$ .....	98