



Ain Shams University
Faculty of Engineering
Department of Structural Engineering

Behavior of steel tubular poles partially filled with concrete

A Thesis submitted in the Partial Fulfillment for the
Requirement of the Degree of
Master of Science in civil engineering (Structural)

Submitted by

Moamen Ahmed Khalifa Salem

B.Sc. in Civil Engineering -Structural Engineering
Ain Shams University - Faculty of Engineering

Supervised by

Dr. Amr Abdelsalam Shaat

Associate Professor
Structural Engineering Department
Ain Shams University

Dr. Sherif Mohamed Ibrahim

Associate Professor
Structural Engineering Department
Ain Shams University

November 2017

Cairo-Egypt



Ain Shams University
Faculty of Engineering
Structural Engineering Department

Behavior of steel tubular poles partially filled with concrete

By

Moamen Ahmed Khalifa Salem

B.Sc. in Civil Engineering -Structural Eng.-2012
Ain Shams University – Faculty of Engineering

EXAMINERS COMMITTEE:

Prof. Ashraf Mahmoud Gamal El-din Osman

Professor of Steel Structures.

Structural Engineering Department

Cairo University

Prof. Adel Helmy Salem

Professor of Steel Structures.

Structural Engineering Department

Ain Shams University

Dr. Sherif Mohamed Ibrahim

Associate Professor

Structural Engineering Department

Ain Shams University

Dr. Amr Abdelsalam Shaat

Associate Professor

Structural Engineering Department

Ain Shams University

STATEMENT

This thesis is submitted to Ain Shams University, Cairo, Egypt, in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering (Structural department).

The work included in this thesis was carried out by the author at steel lab of the faculty of engineering, Ain Shams University.

No part of this thesis has been submitted for a degree or qualification at any other university or institute.

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.

Date: / 2017

Name: Moamen Ahmed Khalifa

Signature: *Moamen Khalifa*

ACKNOWLEDGEMENTS

First of all, I thank GOD who guided and helped me to finish this work in the proper shape.

The author would like to express extremely his gratefulness to Dr. Sherif Ibrahim Associate professor, Faculty of Engineering, Ain Shams University, for his highly appreciated effort and support in completing this work.

The author would like to express his deepest appreciation to Dr. Amr Shaat Associate professor, Faculty of Engineering, Ain Shams University, for his experienced advice, continuous and deep encouragement through all phases of the work.

This work was performed in the Structural Steel Laboratory of the Faculty of Engineering, Ain Shams University (Egypt). The author is very grateful for the support of the under graduate student Mohamed Shaker from Ain Shams University

The author would also like to express his gratitude to all the staff of steel structures in the department for their great feelings and support.

Finally, the author would like to express his deepest gratitude and appreciation to his beloved father, mother, brothers for their continuous support, encouragement and guidance.

ABSTRACT

Steel circular poles are superior to be traditional poles, as they are more durable and lighter in weight. Thin walled steel circular poles often fail by local buckling in bending, before reaching the max. tensile strength of steel. This problem can be solved by increasing wall thickness, but this solution will increase material cost significantly. An economical and simple solution is to stuff the pipe partly with concrete. this research aims to conduct the optimum concrete stuffed length to achieve the max. moment strength with possible least self-weight in steel poles.

The study consists of both testing and analytical phases. Nine steel pipes are divided equally into three groups. All of nine pipes have the same length (2000 mm) and the same wall thickness (2 mm) but with different diameters. Diameters are 114.3, 160, and 202mm.

The three pipes of each group were stuffed with different lengths of concrete, ranging from 11 to 100% of the cantilevered length. The specimens were tested until reaching failure under bending from a single concentrated load at the free end. The results showed that the obtained optimum concrete stuffing ratios were 0.32, 0.43, and 0.50 of the cantilevered length for specimens with diameters 114.3, 160, and 202 consecutively. This is known as the least stuffing length which specimen needs to get the fully stuffed pipe strength.

Analytical methods have been improved for studying the behavior of partly concrete stuffed steel pipes and used to predict the optimum length percentage of concrete stuffing. The methods integrate ovalization methods improved for fully stuffed and empty pipes. The method accounts

for the non-linearity of concrete and plasticity of steel. The method also accounts for local buckling and ovalization of the empty part. The method was verified successfully with testing results. Also, it used in a parametric study to study the influences of key parameters which are D/t ratios, steel yield and ultimate strengths. It was determined that the optimum stuffing length percentage increase as D/t ratio is increased. Also, the optimum stuffing length percentage increases when the ratio between ultimate and yield strength increases.

LIST OF CONTENTS

EXAMINERS COMMITTEE:	II
STATEMENT	III
ACKNOWLEDGEMENTS	IV
ABSTRACT.....	I
LIST OF CONTENTS.....	VII
LIST OF FIGURES	XI
LIST OF TABLES	XV
NOTATIONS	XVI
1 INTRODUCTION.....	1
1.1 Introduction	1
1.2 Research Significance.....	1
1.3 Hypothesized Design Approach	3
1.4 Objectives	Error! Bookmark not defined.
1.5 Scope	Error! Bookmark not defined.
1.6 Thesis Outline	Error! Bookmark not defined.
2 LITERATURE REVIEW.....	6
2.1 Introduction	6
2.2 General Behavior of Hollow Tubes in Flexure.....	6
2.3 Preventing Buckling in Steel Tubular Poles and Other Retrofit Methods	8

2.3.1	Concrete-Filled Steel Tubes (CFST)	8
2.3.2	Composite Concrete-Steel Monopoles (Partially Filled)	12
2.3.3	Partially Filled Circular Steel Poles	13
2.3.4	Steel-Concrete Sectional Composite Poles... Error! Bookmark not defined.	
2.3.5	Strengthening Steel Monopoles with Externally Bonded CFRP Error! Bookmark not defined.	
3	EXPERIMENTAL PROGRAM.....	20
3.1	Introduction	20
3.2	Materials used for Test Specimens.....	20
3.2.1	Steel Tubes.....	21
3.2.2	Concrete.....	21
3.3	Description of Test Specimens.....	22
3.4	Fabrication of Specimens.....	22
3.5	Experimental Setup and Loading	23
3.5.1	Experimental Setup of specimens	23
3.5.2	Instrumentation	24
4	EXPERIMENTAL RESULTS AND DISCUSSION.....	35
4.1	Introduction	35
4.2	Ancillary Tests Results.....	36
4.3	Results of Cantilever Bending Tests	36
4.3.1	Results of First Group Tests	37
4.3.1.1	<i>Load-Deflection Behavior and Failure Modes</i>	<i>37</i>
4.3.1.2	<i>Load-Strain Behavior.....</i>	<i>41</i>
4.3.1.3	<i>Moment-Curvature Behavior</i>	<i>42</i>

4.3.2	Results of Second Group Tests	42
4.3.2.1	<i>Load-Deflection Behavior and Failure Modes</i>	43
4.3.2.2	<i>Load-Strain Behavior</i>	46
4.3.2.3	<i>Moment-Curvature Behavior</i>	47
4.3.3	Results of Third Group Tests	47
4.3.3.1	<i>Load-Deflection Behavior and Failure Modes</i>	47
4.3.3.2	<i>Load-Strain Behavior</i>	51
4.3.3.3	<i>Moment-Curvature Behavior</i>	52
4.4	Neutral axis position	52
5	ANALYTICAL MODELLING AND PARAMETRIC STUDY	71
5.1	Introduction	71
5.2	Analytical Model for Partially Concrete Filled Steel Tubes	72
5.2.1	Model Procedure.....	Error! Bookmark not defined.
5.2.2	Moment-Curvature Response of Concrete-Filled Tubes	72
5.2.2.1	<i>Section Geometry</i>	74
5.2.2.2	<i>Material Constitutive Properties</i>	74
5.2.2.3	<i>Stresses Acting on Cross-section</i>	76
5.2.2.4	<i>Internal Forces and Moments</i>	77
5.2.3	Moment-Curvature Response of Hollow Steel Tube	80
5.2.4	Load-Deflection Response of Partially Filled Tubes	85
5.3	Model Validation	86
5.3.1	Load-Deflection behavior	87
5.3.2	Load-Strain behavior	87
5.4	Optimal Length of Concrete Filling.....	88

5.5	Parametric Study	88
5.5.1	Effect of D/t ratio	89
5.5.2	Effect of Diameter Variation	90
5.5.3	Effect of Steel Grade.....	90
6	SUMMARY & CONCLUSIONS.....	121
6.1	Summary	121
6.2	Conclusions	122
6.3	Recommendations for Future Work.....	124
	REFERENCES.....	125
	APPENDIX (A)	129
	APPENDIX (B) implementation of Analytical models	133
	B.1 Moment-Curvature Response of Concrete-Filled Tubes.....	133
	B.2 Moment-Curvature Response of Hollow Steel Tube	138

LIST OF FIGURES

Figure 1-1: (a) Problem schematic (b) Effect of concrete fill length on moments	Error! Bookmark not defined.
Figure 1-2: Design parameters for partially filled tubes	5
Figure 2-1: Hollow tube ovalization behavior (Karamanos, 2002)	16
Figure 2-2: Model for predicting capacity of a CFST (Elchalakani, 2001)	Error! Bookmark not defined.
Figure 2-3: Load-deflection responses of hollow steel tube (Test 6) and partially concrete-filled steel tube (Test 7) (Fouad, 2005)	Error! Bookmark not defined.
Figure 2-4: Load-deflection response of partially concrete-filled steel tubes (PCFST 2 & 3), hollow steel tube (PCFST 1), and fully filled tube (PCFST 4) (Mitchell, 2008)	17
Figure 2-5: Predicted and experimental optimal concrete-filling length ratio (Mitchell, 2008)	18
Figure 2-6: Steel poles Strengthened with externally bonded CFRP (Lanier, 2005) ..	19
Figure 3-1: Details of steel coupons	Error! Bookmark not defined.
Figure 3-2: Details of test specimens	Error! Bookmark not defined.
Figure 3-3: Fabrication of specimens.....	Error! Bookmark not defined.
Figure 3-4: Test setup	Error! Bookmark not defined.
Figure 3-5: Loading jack detail	Error! Bookmark not defined.

Figure 3-6: Details at point of load to avoid crushing of tube **Error! Bookmark not defined.**

Figure 3-7: Reloading of specimen after stroke is fully utilized....**Error! Bookmark not defined.**

Figure 3-8: Instrumentation details**Error! Bookmark not defined.**

Figure 4-1: Steel coupons after failure.....**Error! Bookmark not defined.**

Figure 4-2: Steel stress-strain curves**Error! Bookmark not defined.**

Figure 4-3: Load-deflection behavior for 1st group specimens**Error! Bookmark not defined.**

Figure 4-4: Failure modes of 1st group specimens ...**Error! Bookmark not defined.**

Figure 4-5: Load-strain behavior for 1st group specimens **Error! Bookmark not defined.**

Figure 4-6: Moment-curvature for 1st group specimens..... **Error! Bookmark not defined.**

Figure 4-7: Comparison between 1st group specimens results**Error! Bookmark not defined.**

Figure 4-8: Load-deflection behavior for 2nd group specimens....**Error! Bookmark not defined.**

Figure 4-9: Failure modes of 2nd group specimens..**Error! Bookmark not defined.**

Figure 4-10: Load-strain behavior for 2nd group specimens..**Error! Bookmark not defined.**

Figure 4-11: Moment-curvature for 2nd group specimens **Error! Bookmark not defined.**

Figure 4-12: Comparison between 2nd group specimens results...**Error! Bookmark not defined.**

Figure 4-13: Load-deflection behavior for 3rd group specimens ..**Error! Bookmark not defined.**

Figure 4-14: Failure modes of 3rd group specimens **Error! Bookmark not defined.**

Figure 4-15: Load-strain behavior for 3rd group specimens .. **Error! Bookmark not defined.**

Figure 4-16: Moment-curvature for 3rd group specimens **Error! Bookmark not defined.**

Figure 4-17: Comparison between 3rd group specimens results ...**Error! Bookmark not defined.**

Figure 4-18: Variation of neutral axis depth for the three tested groups**Error! Bookmark not defined.**

Figure 5-1: Stress and strain distributions on the cross-section of concrete-filled tubes**Error! Bookmark not defined.**

Figure 5-2: Schematic of idealized concrete-filled tube model**Error! Bookmark not defined.**

Figure 5-3: Stress-strain behavior of steel tubes**Error! Bookmark not defined.**

Figure 5-4: Stress-strain behavior of concrete in compression and tension.....**Error! Bookmark not defined.**

Figure 5-5: Ovalization of cantilevered tube (adopted from Ibrahim, 2000)....**Error! Bookmark not defined.**

Figure 5-6: Variation of moment of inertia and diameter for a circular and an ovalized cross-section**Error! Bookmark not defined.**

Figure 5-7: Cross-section geometry of ovalized hollow steel tube **Error! Bookmark not defined.**

Figure 5-8: Properties of steel stress-strain curve**Error! Bookmark not defined.**

Figure 5-9: Constructing the load-deflection response from the moment-curvature responses of concrete-filled and hollow sections.....**Error! Bookmark not defined.**

Figure 5-10: Load-deflection behavior for 1st group specimens ...**Error! Bookmark not defined.**

Figure 5-11: Load-strain behavior for 1st group specimens ... **Error! Bookmark not defined.**

Figure 5-12: Load-deflection behavior for 2nd group specimens..**Error! Bookmark not defined.**

Figure 5-13: Load-strain behavior for 2nd group specimens.. **Error! Bookmark not defined.**

Figure 5-14: Load-deflection behavior for 3rd group specimens ..**Error! Bookmark not defined.**

Figure 5-15: Load-strain behavior for 3rd group specimens .. **Error! Bookmark not defined.**

Figure 5-16: Variation of ultimate load with concrete fill length ratio.....**Error! Bookmark not defined.**

Figure 5-17: Variation of optimal concrete filling ratio with D/t ratio for various steel grades.....	Error! Bookmark not defined.
Figure 5-18: Effect of tube diameter on optimal concrete filling ratio for various D/t ratios.....	Error! Bookmark not defined.
Figure 5-19: Effect of F_u/F_y on optimal concrete filling ratio for various D/t ratios	Error! Bookmark not defined.
Figure B-1: Input data for filled tubes	144
Figure B-2: Calculated parameters for filled tubes	144
Figure B-3: Table for calculating area, strain, stress, force and moment in each layer for filled tubes	144
Figure B-4: Results table for filled tubes	145
Figure B-5: Input data for filled tubes	146
Figure B-6: Calculated parameters for hollow tubes	146
Figure B-7: Table for calculating area, strain, stress, force and moment in each layer for hollow tubes	146
Figure B-8: Results table of mid-span section for hollow tubes	147
Figure B-9: Results table for any of remaining sections for hollow tubes.....	147

LIST OF TABLES

Table 2-1: Details of PCFST test specimens (Mitchell, 2008)	15
---	----