

SIMILITUDE RELATIONSHIP FOR CIRCULAR CONCRETE  
FILLED STEEL TUBE

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## DEDICATION

This project report is dedicated to my father, who taught me that the best kind of knowledge to have is that which is learned for its own sake. It is also dedicated to my mother, who taught me that even the largest task can be accomplished if it is done one step at a time.

## ACKNOWLEDGEMENT

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## ABSTRACT

In high-rise building construction, concrete filled steel tubular (CFST) column has been widely used. It comprises of a hollow steel tube infilled with or without additional reinforcement or steel section. The concrete core prevents or delay the local buckling of the outer steel tube while the steel tube confining the concrete core provides enhancement in strength and ductility under high compressive load. During experimental work in studying CFST, if huge amount of sampling is required, researchers might face issue such as insufficient materials if budget is not allowed, capacity limitation of the testing machine that is readily accessible for the researchers to conduct compression test and also huge amount of waste created. The purpose of this study is to investigate the applicability of using similitude relationship to determine the axial capacity of circular concrete filled steel tube for prototype and model scaled specimen, using dimensional analysis to determine the scaling factors for each variable considered relevant to the nature of the problem. BC4: 2015 and nonlinear analysis using ANSYS software have been used to determine the axial capacity for the same prototype and model specimen to serve as reference for counter check purpose to verify if the axial capacity determined using similitude relationship is reasonable. For the nonlinear analysis using ANSYS, nonlinear material properties have been included whereby the Drucker-Prager model is used for concrete and bilinear kinematic hardening is used for steel tube. From the results obtained, it is observed that the axial capacity determined from similitude relationship shows result with maximum deviation of 0.41 % whereas ANSYS analysis results shows a percentage of maximum deviation of 2.47 % when comparing to BC4: 2015. The scaling factor of axial load capacity for model and prototype using similitude shows a percentage deviation of 0.42 % and ANSYS analysis shows a percentage deviation of 4.1 % comparing to scaling factors obtained using BC4: 2015. This shows that the current physical quantities or variables selected for dimensional analysis is reasonable where the similitude relationship developed does not distort the model by much from its prototype.

## ABSTRAK

Dalam pembangunan bangunan pencakar langit, tiub keluli bulat diisi konkrit telah banyak digunakan sebagai kolom. Ia mengandungi tiub keluli diisi dengan konkrit samaada dengan atau tanpa telulang keluli. Teras konkrit menghalang atau melewatkan lengkokan tiub keluli manakala tiub keluli yang mngurungkan teras konkrit memberi peningkatan dari segi kekuatan dan kemuluran di bawah beban mampatan yang tinggi. Jikalau jumlah persampelan yang besar diperlukan ketika kerja eksperimen, penyelidik mungkin menghadapi masalah bahan mentah yang tidak mencukupi disebabkan had bajet, had kapasiti mesin ujian untuk menjalankan kajian mampatan atau masalah jumlah sisa yang besar diciptakan. Kajian ini dilakukan bertujuan mengkaji penggunaan hubungan similitude bagi pcnentuan kapasiti paksi untuk tiub keluli bulat diisi konkrit untuk prototaip dan spesimen model, dengan penggunaan analisis dimensi untuk menentukan faktor penskalaan bagi pembolehubah yang dianggap berkaitan dengan jenis masalah yang dipertimbangkan. Kapasiti paksi untuk tiub keluli bulat diisi konkrit juga ditentu dengan mengguna BC4: 2015 dan analisis tak linear menggunakan software ANSYS bagi tujuan pengesahan kapasiti paksi yang ditentu melalui hubungan similitude. Untuk analisis tak linear yang menggunakan software ANSYS, Drucker-Prager model telah digunakan untuk sifat bahan tak linear untuk konkrit dan bilinear kinematic hardening untuk tiub keluli. Daripada keputusan yang didapati, kapasiti paksi yang didapati melalui hubungan similitude menunjuk sisihan maksimum 0.41 % manakala software ANSYS menunjuk sisihan maksimum 2.47 % apabila dibanding dengan keputusan yang didapati menggunakan BC4: 2015. Faktor penskalaan yang didapati melalui perbandingan kapasiti paksi antara prototaip dan model menggunakan hubungan similitude menunjuk sisihan maksimum 0.42 % dan software ANSYS menunjuk sisihan maksimum 4.1 % apabila dibanding dengan factor penskalaan yang didapati melalui BC4: 2015. Ini menunjuk pembolehubah yang dianggap dan digunakan dalam analisis dimensi ini adalah munasabah dan hubungan similitude yang dicipta tidak memutarbelitkan sifat model jauh dari sifat prototaip.

## TABLE OF CONTENTS

	TITLE	PAGE
	<b>DECLARATION</b>	<b>ii</b>
	<b>DEDICATION</b>	<b>iii</b>
	<b>ACKNOWLEDGEMENT</b>	<b>iv</b>
	<b>ABSTRACT</b>	<b>v</b>
	<b>ABSTRAK</b>	<b>vi</b>
	<b>TABLE OF CONTENTS</b>	<b>vii</b>
	<b>LIST OF TABLES</b>	<b>x</b>
	<b>LIST OF FIGURES</b>	<b>xi</b>
	<b>LIST OF ABBREVIATIONS</b>	<b>xvi</b>
	<b>LIST OF SYMBOLS</b>	<b>xvii</b>
	<b>LIST OF APPENDICES</b>	<b>xx</b>
<b>CHAPTER 1</b>	<b>INTRODUCTION</b>	<b>1</b>
1.1	Introduction	1
1.2	Problem Background	2
1.3	Problem Statement	2
1.4	Research Goal	3
	1.4.1 Research Objectives	4
1.5	Research Scope	4
1.6	Organization of the Thesis	5
<b>CHAPTER 2</b>	<b>LITERATURE REVIEW</b>	<b>7</b>
2.1	Introduction	7
	2.1.1 Buckingham Pi Theorem	8
2.2	Previous Related Researches	9
	2.2.1 Similitude Relationship	10
	2.2.2 Concrete Filled Steel Tube	10

2.3	BC4: 2015	11
2.4	Nonlinear Analysis	12
2.5	Concrete Modeling	13
2.6	Steel Modeling	16
2.7	Elements used for modeling	17
2.7.1	SOLID 65	17
2.7.2	SOLID 186	19
2.7.2.1	Homogeneous Structural Solid	19
2.7.2.2	Layered Structural Solid	21
2.8	Material properties required for modelling	23
<b>CHAPTER 3</b>	<b>RESEARCH METHODOLOGY</b>	<b>25</b>
3.1	Defining Similitude relationship for Concrete Filled Steel Tube using Buckingham Pi theorem	25
3.1.1	Selection of variables	26
3.1.2	Determine numbers of Pi terms	27
3.2	Similitude Relationship – Sample Calculation	28
3.2.1	Derivation of dimensionless groups	28
3.3	Capacity Determination of Concrete Filled Steel Tube based on BC4: 2015	34
3.3.1	Buckling resistance determination based on BC4: 2015	34
3.4	Sample calculation based on BC4: 2015	42
3.5	Axial capacity determination for circular hollow section based on BS EN 1993-1-1	47
3.6	Analysis of Concrete Filled Steel Tube using ANSYS software	51
3.6.1	Finite Element Analysis	52
3.6.2	Material model input	53
3.6.2.1	Concrete	53
3.6.2.2	Steel Tubular	53
3.6.3	Loading Procedure	54

<b>CHAPTER 4</b>	<b>ANALYTICAL &amp; MODELLING USING ANSYS</b>	<b>55</b>
4.1	Concrete Filled Steel Tube (Model Specimen)	55
4.1.1	Element Type	59
4.1.2	Material Properties	60
4.1.3	Geometry Modelling	64
4.1.4	Meshing	65
4.1.5	Boundary Condition	73
4.1.6	Contact Elements	79
4.1.7	Assigning Loading and Solving Model	87
4.1.8	Results	95
<b>CHAPTER 5</b>	<b>RESULTS &amp; DISCUSSION</b>	<b>98</b>
5.1	Similitude Relationship	98
5.2	Capacity of concrete Filled Steel Tube using BC4: 2015	100
5.3	Analysis using ANSYS software	100
5.3.1	Controlled Specimen – Steel tube without concrete core	100
5.3.2	Model Specimen	100
5.3.3	Prototype Specimen	100
5.4	Capacity of empty circular steel tube based on BS EN 1993-1-1	106
5.5	Results Comparison	106
<b>CHAPTER 6</b>	<b>CONCLUSIONS &amp; RECOMMENDATIONS</b>	<b>111</b>
6.1	Conclusion and recommendations for future works	111
<b>REFERENCES</b>		<b>113</b>



## LIST OF TABLES

TABLE NO.	TITLE	PAGE
Table 2.1	Model properties data required for concrete and steel	23
Table 3.1	Variables and their dimensions	28
Table 3.2	Similitude requirements for compression of concrete filled steel tube	33
Table 3.3	Strength classes of normal strength concrete	35
Table 3.4	Strength classes of high strength concrete	35
Table 3.5	Partial factors of materials	36
Table 3.6	Maximum values (d/t), (h/t) for local buckling	37
Table 3.7	Imperfect factors for buckling curves	40
Table 3.8	Buckling curves and member imperfections for CFST composite columns	40
Table 3.9	Selection of buckling curve of a cross-section	49
Table 3.10	Material properties input for concrete	53
Table 3.11	Material properties input for steel tubular	53
Table 5.1	Similitude requirements for compression of concrete filled steel tube	98
Table 5.2	Results after applying scaling factor	99
Table 5.3	Capacity of Concrete Filled Steel Tube using BC4: 2015	100
Table 5.4	Results comparison between different types of analysis	106
Table 5.5	Scaling factor and percentage of results deviation for similitude and ANSYS nonlinear analysis comparing to BC4: 2015	107

## LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
Figure 2.1	Equivalent uniaxial stress-strain curve for concrete	13
Figure 2.2	Elastic perfectly plastic model for steel tube	17
Figure 2.3	SOLID65 3-D Reinforced Concrete Solid	18
Figure 2.4	SOLID 186 Homogeneous Structural Solid Geometry	20
Figure 2.5	SOLID186 Layered Structural Solid Geometry	21
Figure 3.1	Procedure for defining similitude relationship	25
Figure 3.2	Design procedure for concrete filled steel tube based on BC4: 2015	34
Figure 3.3	Types of double symmetric CFST sections	36
Figure 3.4	Equivalent buckling lengths $L_{cr}/L$	50
Figure 3.5	Flow chart of modelling procedure	51
Figure 4.1	Interface for creating keypoints	56
Figure 4.2	Input for first keypoint	56
Figure 4.3	Input for second keypoint	56
Figure 4.4	Input for third keypoint	56
Figure 4.5	Aligning workplane with keypoints	57
Figure 4.6	Input for reference point	57
Figure 4.7	Changing coordinate system to amended work plane	58
Figure 4.8	Deleting unused keypoints	58
Figure 4.9	Interface for adding element	59
Figure 4.10	Adding SOLID 65 for concrete element	59
Figure 4.11	Adding SOLID 186 for steel element	60
Figure 4.12	Interface showing elements added	60
Figure 4.13	Interface for adding material properties	61
Figure 4.14	Elastic properties for concrete material	61
Figure 4.15	Input for elastic concrete material properties	61

Figure 4.16	Nonlinear properties for concrete material (Drucker-Prager)	62
Figure 4.17	Input for nonlinear concrete material properties	62
Figure 4.18	Adding new material for steel	62
Figure 4.19	Elastic properties for steel material	62
Figure 4.20	Input for elastic steel material properties	63
Figure 4.21	Nonlinear properties for steel material (Bilinear Kinematic Hardening Plasticity)	63
Figure 4.22	Input for nonlinear steel material properties	63
Figure 4.23	Graph for Bilinear Kinematic Hardening Plasticity for steel	64
Figure 4.24	Interface for creating volume for concrete core solid model	64
Figure 4.25	Input for creating steel tube solid model	65
Figure 4.26	Solid model for concrete filled steel tube	65
Figure 4.27	Interface to plot line element in current view	66
Figure 4.28	Interface of selecting middle face line elements for division of element sizes	66
Figure 4.29	Input for dividing middle line elements into desired sizes (5 <i>mm</i> for each divided line element in this case)	67
Figure 4.30	Interface for selecting top face and bottom face line elements for division of element sizes	67
Figure 4.31	Input for dividing top and bottom line elements into desired sizes (5 <i>mm</i> for each divided line element in this case)	68
Figure 4.32	Divided line elements	68
Figure 4.33	Interface for selecting concrete material for meshing purpose	69
Figure 4.34	Selection for sweeping of mesh for concrete model	69
Figure 4.35	Interface prompted for selecting intended solid volume for meshing	70
Figure 4.36	Selecting concrete core for meshing purpose	70
Figure 4.37	Meshed concrete core	71
Figure 4.38	Interface for selecting steel material for meshing purpose	71
Figure 4.39	Selection for sweeping of mesh for steel model	72

Figure 4.40	Selecting steel tube for meshing purpose	72
Figure 4.41	Meshed concrete filled steel tube	73
Figure 4.42	Interface for prompting entities selection	73
Figure 4.43	Interface for selecting and plot bottom face node	74
Figure 4.44	Plotted bottom face nodes	74
Figure 4.45	Selecting bottom face nodes for assigning degree of freedom	75
Figure 4.46	Assign fixed to all degree of freedom	75
Figure 4.47	Fixed bottom face	75
Figure 4.48	Creating master node for top surface	76
Figure 4.49	Nodes created at top surface	76
Figure 4.50	Selecting top face nodes	77
Figure 4.51	Plotted top face nodes	77
Figure 4.52	Tie all the nodes at top surface to a master node	78
Figure 4.53	Selection of all nodes at top surface for assigning coupling	78
Figure 4.54	Coupled degree of freedom for master node and slave node	79
Figure 4.55	Coupled master node and slave nodes	79
Figure 4.56	Interface for creating contact element	80
Figure 4.57	Creating pilot node	80
Figure 4.58	Selecting of existing node as pilot node	81
Figure 4.59	Selection of the intended target node as master node	81
Figure 4.60	Selecting contact surface	82
Figure 4.61	Selection of intended contact surface	82
Figure 4.62	Selection of constraint surface type and constrained degree of freedom on target node	83
Figure 4.63	Contact element between target pilot node and contact surface created	83
Figure 4.64	Creating contact element between concrete and steel tube contacting surface	84
Figure 4.65	Selecting concrete core outer surrounding surface by steel tube as target element	84

Figure 4.66	Interface for creating contact face for the contact element	85
Figure 4.67	Selecting steel tube surface surrounding concrete core as contact element	85
Figure 4.68	Interface for defining material identity for contact element	86
Figure 4.69	Interface for defining contact behavior for the contact element	86
Figure 4.70	Contact element for contact surface between concrete core and steel tube created	86
Figure 4.71	Prompt interface for selection of master node entities	87
Figure 4.72	Selection of surface entities of master node	88
Figure 4.73	Prompt interface for assigning load	88
Figure 4.74	Input intended loading to be assigned to the master node for the first load step	89
Figure 4.75	Select option for results of every substep to be written	89
Figure 4.76	Input for solution controls	89
Figure 4.77	Input for solution option	90
Figure 4.78	Input for nonlinear option	90
Figure 4.79	Input for advanced nonlinear option	90
Figure 4.80	Solution printout for load step options	91
Figure 4.81	Creating first load step file	91
Figure 4.82	Changing load step time frame for second load step	92
Figure 4.83	Loading applied for second load step	92
Figure 4.84	Creating second load step file	92
Figure 4.85	Changing load step time frame for final load step	93
Figure 4.86	Loading applied for final load step	93
Figure 4.87	Creating final load step file	93
Figure 4.88	Select everything prior to start analysis	94
Figure 4.89	Solving model for all the load step files created	94
Figure 4.90	Interface showing nonlinear analysis	95
Figure 4.91	Choose desired set of result file	96
Figure 4.92	Choose desired results output to be plotted	96

Figure 4.93	Interface showing plotted result for Von Mises Stress	97
Figure 5.1	Empty steel tube before yielding ( $P = 473 \text{ kN}$ )	101
Figure 5.2	Empty steel tube after yielding – Isometric view ( $P = 500 \text{ kN}$ )	101
Figure 5.3	Empty steel tube after yielding – Front view ( $P = 500 \text{ kN}$ )	102
Figure 5.4	Model specimen at initial yielding of steel (Axial load, $P = 948 \text{ kN}$ )	102
Figure 5.5	Model specimen after yielding of steel (Axial load, $P = 970.85 \text{ kN}$ )	103
Figure 5.6	Model specimen loads up to $1200 \text{ kN}$	103
Figure 5.7	Prototype specimen before yielding (Axial load, $P = 3247 \text{ kN}$ )	104
Figure 5.8	Prototype specimen after yielding of steel tube (Axial load, $P = 3392 \text{ kN}$ )	104
Figure 5.9	Prototype specimen loading up to $3500 \text{ kN}$ (Isometric view)	105
Figure 5.10	Prototype specimen loading up to $3500 \text{ kN}$ (Front view)	105

## LIST OF ABBREVIATIONS

BCA	-	Building and Construction Authority
BKIN	-	Bilinear Kinematic Hardening Model
CIDECT	-	International Committee for the Development and study of Tubular Structures
CFST	-	Concrete Filled Steel Tube
DP	-	Drucker-Prager
SMX	-	Maximum Von Mises Stress

## LIST OF SYMBOLS

$M$	-	Mass
$L$	-	Length
$T$	-	Temperature
$V$	-	Velocity
$f'_c$	-	Unconfined concrete cylinder compressive strength
$\varepsilon'_c$	-	Unconfined strain
$f'_{cc}$	-	Confined concrete compressive strength
$\varepsilon'_{cc}$	-	Confined strain
$k_1, k_2$	-	Constants obtained from experimental data
$f_l$	-	Lateral confining pressure around the concrete core
$f_y$	-	Yield strength of steel
$D$	-	External diameter of steel tube
$t$	-	Thickness of steel tube wall
$E_{cc}$	-	Young's modulus of confined concrete
$\nu_{cc}$	-	Poisson's ratio of confined concrete
$f$	-	Compressive strength in the nonlinear portion
$k_3$	-	Material degradation parameter
$c$	-	Cohesion
$\varphi$	-	Angle of internal friction
$\psi$	-	Dilatancy angle
$\xi_c$	-	Confinement factor
$A_s$	-	Area of steel cross section
$A_c$	-	Area of concrete cross section
$E_s$	-	Elastic modulus of steel
$\sigma_s$	-	Steel stress
$\varepsilon_s$	-	Steel strain
$E'_s$	-	Tangent modulus of steel after yielding
$E_c$	-	Elastic modulus of concrete
$\nu_c$	-	Poisson ratio of concrete
$\nu_s$	-	Poisson ratio of steel



$l$	-	Length of specimen
$d$	-	Internal diameter of steel tube
$P$	-	Axial load
$S_L$	-	Scaling for length
$l_p$	-	Length of prototype specimen
$l_m$	-	Length of model specimen
$S_{E_c}$	-	Scaling for modulus elasticity of concrete
$E_{c_p}$	-	Modulus elasticity of concrete for prototype
$E_{c_m}$	-	Modulus elasticity of concrete for model
$S_{E_s}$	-	Scaling for modulus elasticity of steel
$E_{s_p}$	-	Modulus elasticity of steel for prototype
$E_{s_m}$	-	Modulus elasticity of steel for model
$P_p$	-	Axial load for prototype
$P_m$	-	Axial load for model
$d_p$	-	Internal diameter of steel tube for prototype
$d_m$	-	Internal diameter of steel tube for model
$D_p$	-	External diameter of steel tube for prototype
$D_m$	-	External diameter of steel tube for model
$t_p$	-	Thickness of steel tube wall for prototype
$t_m$	-	Thickness of steel tube wall for model
$u$	-	Perimeter
$E_{c,eff}$	-	Elastic modulus of concrete considering long-term effect
$\varphi_t$	-	Creep coefficient
$(EI)_{eff}$	-	Effective flexural stiffness of cross-section
$N_{cr}$	-	Elastic critical Euler buckling resistance
$N_{pl,rk}$	-	Characteristic plastic resistance of cross-section
$\bar{\lambda}$	-	Relative slenderness ratio
$N_{pl,rd}$	-	Design plastic resistance of cross-section considering the confinement effect
$\delta$	-	Steel contribution ratio
$\alpha$	-	Imperfection factor
$\chi$	-	Buckling reduction factor

$N_{b,Rd}$	-	Buckling resistance
$\gamma_{M0}, \gamma_{M1}$	-	Partial factors for resistance
$N_{c,Rd}$	-	Design resistance of the cross section to compression
$N_{b,Rd}$	-	Design buckling resistance
$i$	-	Radius of gyration

## LIST OF APPENDICES

<b>APPENDIX</b>	<b>TITLE</b>	<b>PAGE</b>
Appendix A	Spreadsheet Calculation for CFST based on BC4: 2015	115
Appendix B	Spreadsheet Calculation for Circular Hollow Section based on BS EN 1993-1-1	123

# CHAPTER 1

## INTRODUCTION

### 1.1 Introduction

The two most commonly used constructional materials in building, bridge and civil engineering construction are steel and concrete. Steel exhibits the characteristic of high tensile strength, greater elastic modulus and excellent ductility. This often results in small cross-section and slender member in design where buckling behaviour often need to be taken into consideration. Concrete exhibits high compressive but low tensile strength. Compared to steel, per unit weight of concrete has lower material cost and lower thermal conductivity. The characteristic of concrete often results in bulky members. The long-term structural performance of concrete affected by brittle tensile cracking, creep and shrinkage properties (Richard Liew et. al., 2015).

Both advantages of steel and concrete materials in achieving overall enhancement in strength and stiffness is combined in steel-concrete composite structures. In high-rise building construction, concrete filled steel tubular (CFST) column has been widely used. It comprises of a hollow steel tube infilled with or without additional reinforcement or steel section. The concrete core prevents or delay the local buckling of the outer steel tube while the steel tube confining the concrete core provides enhancement in strength and ductility under high compressive load. In concrete casting, the steel tubular member leads to fast track construction as it eliminates the need of additional work by serving as permanent formwork (Richard Liew et. al., 2015).

## **1.2 Problem Background**

In the research field, researchers often need to carry out extensive amount of experimental works in order to obtain satisfactory results to justify their hypothesis of their research subject and also to produce meaningful contribution to the industry. There are few issues that researchers commonly faced when conducting experiment. The first would be preparation of specimen. If huge amount of sampling is required, researchers might face issue of insufficient materials if budget is not allowed. Next is the capacity limitation of the testing machine that is readily accessible for the researchers. Take the example of this study, say the specimen of concrete filled steel tubes requires a compression load of 1200 *kN* in order to compress up to failure. The availability of the testing machine that can fulfill this requirement might not be available to the researchers in the current laboratory where his research works are being carried out. This would limit the scope and extent of the research work intended to be carried out due to constraint of testing equipment capacity. Not to mention with increasing amount of sampling of specimen, more waste is created. If the specimen sizes are bulky and in large volume, the researchers would face difficulty in handling the waste.

## **1.3 Problem Statement**

Providing result as part of prototype and final build of any application result is one of the primary goal of any experiment. This can be achieved with the measurements made for one system in the laboratory environment used to represent the behavior of other similar system in real world and outside the laboratory by using the concept of similitude. Model is a system built in laboratory while prototype is the first build of the similar systems based on behavior of its model, often beyond laboratory frame. Reducing the size of specimen by applying scaling factor in accordance to similitude requirements is one of the method to overcome part of the issues mentioned in Section 1.2. In this study, the similitude relationship between prototype and model will be studied whereby focusing in determining the capacity of concrete filled steel tube.

Another method that researchers often used is to conduct simulation and analysis using finite element software whereby researchers can model the testing of specimen and analyze to get results which are near to the experimental results provided sufficient comparison and cross-checking with experiment work has been conducted. In this study, ANSYS software will be used to simulate the model specimen and compare the results obtained through nonlinear analysis with the results obtained after applying scaling factor to the prototype.

As existing standards or references are available in determining the capacity of concrete filled steel tube, it can be utilized to serve as crosscheck purpose in this study to verify if the results obtained through similitude and software analysis is compatible. BC4: 2015 which is an extension of Eurocode 4 published by the Building and construction Authority (BCA) will be used in this study.

#### **1.4 Research Goal**

The purpose of this study is to investigate the applicability of using similitude relationship to determine the axial capacity of circular concrete filled steel tube for prototype and model scaled specimen, using dimensional analysis to determine the scaling factors for each variable considered relevant to the nature of the problem. BC4: 2015 and nonlinear analysis using ANSYS software are used to determine the axial capacity for the same prototype and model specimen to serve as reference for counter check purpose to verify if the axial capacity determined using similitude relationship is reasonable.

### 1.4.1 Research Objectives

The objectives of the research are:

- (a) To determine the similitude relationship between prototype and model for circular concrete filled steel tube.
- (b) To determine the axial capacity of circular concrete filled steel tube based on BC4: 2015.
- (c) To obtain the capacity of circular concrete filled steel tube through nonlinear analysis using ANSYS software.
- (d) To check the compatibility of the results between similitude, BC4: 2015 and also software analysis.

### 1.5 Research Scope

In this research, only circular CFST will be used. The length of the specimen is controlled so that it behaves as a stub column instead of a slender column. For the material properties, the concrete cube strength used is  $35 \text{ N/mm}^2$  as it is commonly used in the market and yield strength of steel is  $350 \text{ N/mm}^2$ .

There are few factors not taken into consideration during the determination of similitude relationship in this study. The loading velocity and acceleration during compression test, friction between the interface of concrete and steel tube are not taken into consideration in the dimensional analysis step.

As for software analysis, the material properties of both linear and nonlinear for concrete and steel tube is specified in Table 3.10 and Table 3.11. The capacity of CFST is determined by applying axial loads up to the yielding of steel tube. Fixed support is applied at the bottom face where as the top surface only allow displacement in vertical direction.

## **1.6 Organization of the Thesis**

The following chapters include Chapter 2 literature review which discuss on similitude requirement, BC4: 2015, nonlinear analysis and also material modeling, Chapter 3 methodology for determining the similitude requirement, capacity of CFST determination based on BC4: 2015 and also nonlinear analysis using ANSYS software, Chapter 4 on analytical and modelling using ANSYS, Chapter 5 on results and discussion and lastly Chapter 6 which is conclusion and recommendations for future works.



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