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.

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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 kolum. 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 pembandingan 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.

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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
ε_c'	-	Unconfined strain
f_{cc}'	-	Confined concrete compressive strength
ε_{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
υ_{cc}	-	Poisson's ratio of confined concrete
f	-	Compressive strength in the nonlinear portion
k_3	-	Material degradation parameter
c	-	Cohesion
φ	-	Angle of internal friction
ψ	-	Dilatancy angle
ξ_c	-	Confinement factor
A_s	-	Area of steel cross section
A_c	-	Area of concrete cross section
E_s	-	Elastic modulus of steel
σ_s	-	Steel stress
ε_s	-	Steel strain
E_s'	-	Tangent modulus of steel after yielding
E_c	-	Elastic modulus of concrete
υ_c	-	Poisson ratio of concrete
υ_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
φ_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
δ	-	Steel contribution ratio
α	-	Imperfection factor
χ	-	Buckling reduction factor

$N_{b,Rd}$	-	Buckling resistance
γ_{M0}, γ_{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

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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 obtained 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 stud column instead of slender column. For the material properties, the concrete cube strength used is 35 N/mm^2 as it is commonly used in the market and yield strength of steel is 350 N/mm^2.

There are few factors not taking 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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