COMPARATIVE STUDY OF EXTERNAL AND INTERNAL DIAGRID SYSTEM OF BUILDING STRUCTURES USING ETABS

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DEDICATION

This thesis is dedicated to my family, research supervisor and friends who contributed input to this study.

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ABSTRACT

Diagrid structure become more popular choice of structure design since millennium due to it distinguish appearance and outstanding performance to resist lateral load. This study intends to evaluate the performance of external and internal diagrid system of building structures from the aspects of top deflection and quantity of material used. The model, design and analysis of the structure was carried out using ETABS 18 software. A 21 storey office building measure 38mx38mx79.8m was modelled for the study. Structure members were of combination steel and concrete. Beam, vertical column and slab were designed as composite structure which diagonal structures were designed as steel structure according to EN 1993 (Eurocode 3). Floor loads and wind loads imposed to the building were as per proposed in EN 1991 (Eurocode 1) with average windspeed in Malaysia was considered. The stress/capacity ratio generated by software was referred to ensure most appropriate members size were used. The result showed external diagrid is more effective and efficient that internal diagrid. External diagrid was 26.6% less top deflected and 18% less diagonal structural steel consumed than internal diagrid model. It was also observed that position of diagrid structure will affect the column group position in the building which indirectly affect the column size due to distribution of loads.

ABSTRAK

Disebabkan keunikan dari segi rupabentuk dan prestasi cemerlang dalam menangani beban sisi, struktur diagrid menjadi pilihan popular sejak alaf baru ini. Penyelidikan ini adalah untuk mengkaji keberkesanan dan kecekapan untuk diagrid jenis luaran dan dalaman serta membandingkan pesongan pada hujung teratas antara kedua-dua jenis reka bentuk ini. Reka bentuk tersebut direka dan dianalisis menggunakan perisian Etabs18. Sebuah bangunan pejabat 21 tingkat berukuran 38mx38mx79.8m dimodalkan untuk penyelidikan ini. Anggota struktur terdiri daripada bahan keluli dan konkrit. Rasuk, tiang menegak dan papak dirancang sebagai struktur komposit mengikut Eurocode 1994 manakala struktur diagrid dirancang sebagai struktur keluli mengikut Eurocode 1993. Beban lantai dan beban angin yang dikenakan pada bangunan seperti yang diusulkan dalam Eurocode 1991. Nilai halaju purata angin di Malaysia digunaka. Nisbah tegasan / kapasiti yang dihasilkan oleh perisian digunakan untuk memastikan saiz anggota yang paling sesuai digunakan. Hasil kajian menunjukkan diagrid luaran lebih berkesan dan cekap daripada diagrid dalaman. Selain itu, Diagrid luaran juga 26.6% kurang terpesong di penghujung atas bangunan dan 18% kurang keluli struktur yang digunakan untuk struktur diagrid berbanding model diagrid dalaman. Juga diperhatikan bahawa kedudukan struktur diagrid akan mempengaruhi kedudukan tiang tegak di dalam bangunan maka secara tidak langsung mempengaruhi saiz struktur yand digunakan.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

DL	-	Dead load
LL	-	Live load
WL	-	Wind load

LIST OF SYMBOLS

$c_s c_d$	-	Structural Factor
z_0	-	Elevation
z_{min}	-	Minimum Elevation
z_{max}	-	Maximum Elevation
k_l	-	Turbulence Factor
c_o	-	Orography Factor
I_v	-	Turbulence Intensity
k_r	-	Terrain Factor
$c_r(z)$	-	Roughness Facto
ρ	-	Air density
δ_{all}	-	Allowable deflection

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Overview

With the aid of software design and analysis, more complicated calculation for building design able to perform. Therefore, it become a trend to Architect to design something new and different in term of aesthetic expression of the building. Diagrid design became more familiar after the millennium due to its structural efficiency and distinguish aesthetic potential. 30 St Mary Axe in London (previously known as Swiss Re Building) which completed in 2003 and The Hearst Tower in New York which completed in year 2006 are well known diagrid system designed by Norman Foster (Moon, 2009). Guangzhou International Financial Centre, China which completed in 2010, CCTV Headquarter in Beijing, which completed in year 2012, The Bow Tower in Canada which completed in 2012, Lotte World Tower in Seoul which completed in 2016 are among famous diagrid structure building.

Figure 1.1 30 St Mary Axe

Figure 1.2 The Hearst

Figure 1.3 Guangzhou Finance center

Figure 1.4 The Bow

Diagrid – come from the word diagonal + grid which is in a form of space truss where structure members intersect with each other diagonally and form a triangulated truss system. Diagrid structure is well known for its ability to resist lateral load compare to conventional structure thanks to the triangulated truss system where lateral load will be carried axially by the diagonal member while for the conventional structure the lateral force is to be carry by bending of vertical column.

Diagrid structure is designed to be at the external part of the building. It is the distinctive of diagrid structure where vertical column at the periphery of the building could be eliminated. Internal vertical column normally located in the internal or centre core of the building and were designed to carry gravity load only as lateral load imposed to the building effectively carried by the diagrid structure.

1.2 Background

Diagrid structure is well known for its efficiency and distinctive aesthetic appearance. It could also save as much as 20% steel compare to conventional steel structure (Nawale,U,K., and Kakade,U,N., 2017). However, still many designers prefer to conventional orthogonal design which mean structure with horizontal and vertical design rather than structure which give triangulated or diagonal shape. It is merely due to not every designer can accept the diagonal shape structure due to its dimension is bulkier than conventional method.

In order to hide the diagonal structure, massive façade design may require. As diagrid design still new in the industry, most façade connection require special design or custom made to suit the diagrid structure. The different diagrid structure material and diagonal angle will again affect the façade frame and connection design. More effort required for selection and design of façade compare to conventional orthogonal structure. This could be one of the reasons for designer opt for the conventional design which require simpler façade or architectural finishes compare to diagrid design.

1.3 Problem Statement

Diagrid structure is well known for it distinctive appearance. However the connection of these diagonal member is the disadvantage in this type of building system. The connection or the node (Boake, 2016) could be complicated and very bulky which can reach to 6 tonnes for 1 connection. Special façade design to cover the node could be very costly. The huge joint connector also require special expertise to fabricate and install. 'In particular, gravity forces are not adversarial when it comes to the erection of orthogonal steel framed buildings. Gravity forces naturally pull the columns into position during lowering.' (Boake,2016). Installation of diagrid structure is very challenging where lifting point must be determined accurately to accommodate the angled elements. For some lower diagrid project where temporary support to maintain the geometry of diagrid is practical, the temporary structure will be provided as temporary support or shoring to the structure system during erection. (Boake,2016). For high rise building where temporary support is costly, the node and members have to be deigned to have adequate stiffness to resist gravity induces deformation and to maintain dimensional stability during the erection process.

Figure 1.5 Prefabricated node. (source: http:buildcivil.wordpress.com/2013/)

When the nodes are required to be covered, special design façades are to be deployed. The cost for facades would be significant impact to the overall construction cost. Custom made or special design façade will also require experience contractor to ensure the façades are secured, safe and weather resistant.

By erecting the diagrid structure at the internal of the building, the aforementioned problems might be able to reduce. The node can be box up and hide within the party wall. The cost for box up wall will be cheaper than external façade and less complicated. The erection of diagrid structure internally also comparatively simpler than external diagrid as vertical column at periphery of building can act as temporary support to diagonal structure during erection.

1.4 Objectives

The scope of study is to figure out the appropriateness to construct diagrid structure at the internal side of the building instead of at the external periphery of the building. Shall this is applicable, it will give the designer an efficient lateral load carrier structure while external periphery of building able to design as orthogonal shape which carry only gravity load.

Changing the diagrid from external to internal will definitely affect the strength due to changes of overall dimension. Therefore, the quantity of material used will be considered for comparison of effectiveness of each diagrid system. This research will also compare the top deflection of building between the 2 different diagrid structure (External & Internal) under the same lateral and load.

The objective of this research is to compare the 2 diagrids design and its effectiveness to design diagrid structure within internal of building instead of externally. A comparison of top deflection and materials quantity will be developed to determine the appropriateness and effectiveness to design the diagrid structure internally.

1.5 Scope and significant of study

The purpose of this study to provide numerical data after the 2 models are compared in term of top deflection and material quantity. 2 structure system with same geometry and loading will be modelled using Etabs software. 3 different load combination will be analysed and the quantity of material for combination which give maximum top deflection will be generated for comparison. Only top deflection due to lateral wind load is consider due to geographical location of our country which fall under low seismic zone.

The building will be modelled as steel structure building system. Materials quantity will be compared in terms of tonnage. Each structural element such as vertical column, beams and diagonal structure will be compared separately. Compared data of material quantity will help to provide fundamental knowledge of impact of diagrid structure location in the building to the design and analysis.

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