EFFECT OF BASE COLUMNS SPACING TO LATERAL RESISTANT AND SHEAR LAG OF MODIFIED DIAGRID STRUCTURES

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Bismillahirrahmanirrahim

Special to;

My parents,
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My supervisor,
DR. ROSLIDA BINTI ABD. SAMAT

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may ALLAH S.W.T. bless you always.

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ABSTRACT

Development in highrise building design and construction had lead to the emergence of diagrid system. Diagrid system which is a diagonal grid is widely used for tall building construction due to its efficiency in reducing steel consumption without compromised ability of the structure system to support the load acted to the structure. Full diagrid structure is a structure which has the diagonal members constructed from the ground floor to the top of the building. Full diagrid structure often has the problem of limited spacing for building entrance. In order to solve that problem, vertical base columns were introduced below the diagrid structure. Therefore, this study is carried out to analyse the effect of the addition of vertical columns at ground level to the lateral resistance of the diagrid system. The diagrid was started from the level above the columns and is connected to the columns. Furthermore, the arrangement of the base columns was uniform but the spacing between the columns was varied. The design and analysis of the model structure were accomplished by using STAAD.Pro software. Based on the result from the analysis, it shows that the lateral displacement increases when the spacing between the base column increases. The analysis of shear lag also shows that the base column spacing did not influence the shear lag effect on the axial force. In this study, the optimum spacing between the base column is 6m where the resulted lateral displacement and shear lag effect has small difference compared to the full diagrid structure. Thus, it can be concluded that the implementation of base column can reach the same efficiency as full diagrid structure if an effective design of the spacing between the base column is applied to the building system.

ABSTRAK

Perkembangan dalam reka bentuk pembinaan bangunan pencakar langit telah membawa kepada kemunculan sistem diagrid. Sistem diagrid, iaitu, grid pepenjuru luas digunakan bagi pembinaan bangunan tinggi kerana kecekapannya dalam mengurangkan pengunaan keluli tanpa mengurangkan kebolehan sistem struktur untuk menyokong beban yang dikenakan ke atas struktur. Struktur diagrid penuh ialah struktur yang mempunyai anggota pepenjuru yang dibina dari aras bawah hingga ke aras teratas sesebuah bangunan. Struktur diagrid penuh kerapkali mempunyai masalah ruang terhad bagi laluan keluar masuk bangunan. Dalam usaha untuk menyelesaikan masalah tersebut, tiang menegak telah dibina ditingkat paling bawah. Oleh itu, kajian ini telah dijalankan bagi menganalisis kesan penambahan tiang menegak tersebut kepada rintangan sisi sistem diagrid. Diagrid bermula dari aras di atas tiang dan disambungkan ke tiang. Seterusnya, susunan antara tiang adalah seragam tetapi jarak di antara tiang diubah-ubah. Rekabentuk dan analisis model struktur dibuat dengan menggunakan perisian STAAD.Pro. Berdasarkan keputusan dari analisis, ia menunjukkan rintangan sisi semakin meningkat apabila jarak antara tiang semakin jauh. Analisis susul ricih juga menunjukkan jarak antara tiang tidak mempengaruhi kesan susul ricih kepada daya paksi. Dalam kajian ini, jarak optimum antara tiang aras bawah adalah 6m iaitu apabila anjakan sisi yang dihasilkan dan kesan susul ricih mempunyai perbezaan yang kecil jika dibandingkan dengan struktur diagrid penuh. Oleh itu, dapat disimpulkan bahawa pembinaan tiang menegak di tingkat bawah bangunan diagrid boleh mencapai kecekapan yang sama seperti struktur diagrid penuh jika rekabentuk berkesan bagi jarak di antara tiang digunakan dalam sistem bangunan tersebut.

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m	-	Metre
mm	-	Millimetre
s	-	Second
kN	-	Kilo Newton
f	-	Shear Lag Ratio

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CHAPTER 1

INTRODUCTION

Increase in world population has made the development of tall building construction growth actively everywhere. Nowadays, we can see a tall building or highrise or skyscraper in every country especially in developing country. They seem like want to compete to each other to develop the highest tall building in the world. In latest record by the Emporis Data Committee, the tallest building in the world was Burj Khalifa with 828m height. As mentioned in *Tall Buildings Structural Systems and Aerodynamic Form,* tall building can be described as a multistory building generally constructed using a structural frame, provided with high-speed elevators, and combining extraordinary height with ordinary room spaces such as could be found in low-buildings. In addition, tall building is a physical, economic, and technological expression of the city's power base, representing its private and public investments.

Structural frame system is one of the common structural systems used. Structural systems in the early twentieth century buildings were basically designed to resist vertical load only. However, the development of tall building has made the wind and the earthquake induced lateral loads become the primary loads and more critical than before due to the increasing height of buildings but decreasing in their weight. Therefore, this becomes more challenging for the structural engineers to provide the strength to resist lateral loads in tall buildings as it becomes an important input required in the design of new structural systems. As the height of buildings increases, the choice of structural system decreases. The development of tall buildings structural systems has begun with rigid frame systems, and with the addition of shear frame, mega column, mega core, outrigger frame, tube systems and latest, the diagrid systems has made much taller buildings become reality.

Recently, the diagonal grid or known as diagrid structural system is widely used for tall buildings construction due to its efficiency and aesthetic potential provided by the unique geometric configuration of the system. Therefore, this diagrid structural system has attracted the interest from architectural and structural designers of tall buildings. Some of the buildings that implement diagrid system are Swiss Re London, IBM Building, Hearst Tower, New York, CCTV, China and Libskind Freedom Tower, Legos. Some research had been conducted to investigate the efficiency of the diagrid system apply to the tall buildings. For example, Jani and Patel (2013), proved that the implementation of diagrid system to high rise building reduced the lateral displacement at the top of the building more than the one using simple frame system, thus, indicating that the diagrid system is an effective tall building system.

Further, studies have proved that the diagrid structural system is one of the most efficient structural systems for tall buildings in economy terms as the diagrid system less consumption of steel and concrete due to the elimination of exterior column compared to simple frame building. As other structural system, diagrid system also has disadvantage that may cause people to refuse to use this system in their tall building construction. One of the disadvantages is the limited space entrance to the building. Commonly diagrid system involve with exterior diagrid structures from the bottom until to the top level of the structure such as design in Swiss Re London. The present of the diagrid structure at the bottom level will lead to the limited space of entrance especially when the diagonal structure angle is small. Thus, for the purpose of entrance or car park, some buildings are applied the base column at the bottom level and the diagrid structure will be start above the base columns as design in Hearst Magazine Tower, New York.

1.1 Background Problem

The development in tall buildings construction has contributed in the development in the structural system too. As one of the most efficient structural system that can be applied in any stories height of tall buildings, the development of diagrid system had been one of the most highlighted. Diagrid system is one of exterior structure with their structural efficiency as a varied version of the tubular systems (Moon and Ali, 2007). Due to that, diagrid structure has the potential as a new aesthetic trend for tall buildings nowadays.

The difference between conventional exterior-braced frame structures and current diagrid structures is in diagrid structures design almost all the conventional vertical columns are eliminated. This situation can be applied in diagrid structure because the diagonal members in diagrid structural systems can carry gravity loads as well as lateral forces due to their triangulated configuration in a distributive and uniform manner. However, eliminating all the columns including base columns had made the difficulty in the design of the ground floor and limited the entrance to the buildings. One alternative to solve this problem is by having vertical columns on the ground floor and making the diagrid to begin from the second floor and above. However, this raises a question in the effectiveness of the diagrid in reducing the lateral displacement by implementation of the base column and the bottom level. Thus, the aim of this project is to investigate the effectiveness of the diagrid structure with column base when the base column spacing varies.

1.2 Purpose of the Study

As mentioned earlier that diagrid system is one of the latest structural systems being developed, and therefore there are not many diagrid structures in the world. In Malaysia, there is no tall building that adopts diagrid structural system. However, Malaysia should learn the technologies of this diagrid structures due to its structural efficiency and sustainable point that it can give. Eventhough, the diagrid structure usually eliminate the entire perimeter columns in tall buildings, it is possible to construct the diagonal structure starting from the second floor and thus having the base columns at the bottom level to overcome some issues come out from previous construction of diagrid structure.

One of the issues to be highlighted here is the difficulty in designing the diagrid structures. Since the entire perimeter columns have already been eliminated, then it is critical to design the node to join the diagrid structures in order to get a full structural efficiency and aesthetical needed. Therefore the main purpose of this study is to investigate the efficiency of the diagrid structures with base column and the effect of base column spacing to resist lateral load and shear lag effect on the building to achieve the structural efficiency and aesthetical needed according to the design of the tall building structure.

1.3 Objectives of the Study

According to the problem statement, implementation of base column in diagrid structures can solve the entrance problem that occurs when the diagrid system is constructed started from the bottom level. However, there are some important things that need to be considered especially the lateral displacement and shear lag effect of the building in order to evaluate the efficiency of the modified diagrid structure with the introduction of base columns at bottom level. Therefore, the objectives of this study are:

1. To determine the behavior of the lateral displacement of tall building of diagrid structure with vertical base column when the spacing between the base columns is varied.
2. To determine the optimum spacing between the base column to reduce the lateral displacement.
3. To determine the pattern of shear lag of the base columns and diagrid members when the base column spacing is altered.

1.4 Scope of the Study

Diagrid system is a system of triangulated beams, straight or curved, and horizontal rings that join together to make up a structural system for a skyscraper. Diagrid structure is efficient in lateral resisting system. The main structure is composed of reinforced concrete (RC) core and steel diagrid column. RC core will behave as a cantilever beam and steel diagrid will resist the shear action. Both elements will act together to raise the stiffness of the building. To make each of the elements in diagrid structures work efficiently, there are several factors that need to be considered in the design of the diagrid system such as the number of stories of the tall buildings, the optimum angle of the diagrid structures, the material and size used in constructing the diagrid, beam and column elements, the size of the columns and the method employed to join the diagrid members.

For this study, the parameters that will be consider is the optimum spacing between the base columns. In this study, the total area of the floor plan area of the building is 36m x 36m. The model buildings studied will be 60 storey where each storey height is 4m. The spacing between the base columns will be varied in order to study the behavior of the lateral displacement and shear lag effect of the diagrid structures when the base columns are introduce to the diagrid system. The spacing will be varies to 6m, 7.2m, 9m, 12m and 18m between the base columns. Thus, 7 different building model will be analysed including a full diagrid structure and a full frame structure that will act as a control to evaluate the efficiency of the modified diagrid structure which is the diagrid structure with base column at the bottom level. The angle of the diagrid structures will keep constant as 69˚ throughout the buildings analysis.

Based on the analysis by using STAAD.Pro software, the results of the lateral displacement and the axial force will be extracted from the analysis. Then, the comparison between five different base column spacing of modified diagrid structure will be done to determine the optimum spacing of the base column. Furthermore, the result for modified diagrid structure with optimum base column spacing will be compare with full diagrid structure and full frame structure to study the efficiency of all three different type of structure.

1.5 Importance of the Study

The development of tall building construction has made the analysis of the lateral displacement becomes a primary element to be considered in the highrise structural system. Previous researches have proved the effectiveness of the diagrid system in resisting lateral load, besides it being aesthetic. The introduction of the base columns to the diagrid system will solve one disadvantage of diagrid system which is the entrance problem at the bottom level of the building. Comparison of the lateral displacements of modified diagrid structures with base column and diagrid structure will be presented. In fact, this study will determine the optimum spacing of the base columns so that the lateral displacement is minimized by the usage of the modified diagrid structures with the base columns. This study provides an alternative design of the diagrid structure system with implementation of column base.

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