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THE USE OF OUTRIGGER AND BELT TRUSS SYSTEM FOR HIGH-RISE CONCRETE BUILDINGS

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ABSTRACT

The outrigger and belt truss system is commonly used as one of the structural system to effectively control the excessive drift due to lateral load, so that, during small or medium lateral load due to either wind or earthquake load, the risk of structural and non-structural damage can be minimized. For high-rise buildings, particularly in seismic active zone or wind load dominant, this system can be chosen as an appropriate structure.

This paper studies the use of outrigger and belt truss system for high-rise concrete building subjected to wind or earthquake load. Eight 40–storey two dimensional models of outrigger and belt truss system are subjected to wind load; and five 60–storey three dimensional models are subjected to earthquake load, analyzed and compared to find the lateral displacement reduction related to the outrigger and belt system location. For the two dimensional 40–storey model, 65% maximum displacement reduction can be achieved by providing first outrigger at the top and second outrigger at the middle of the structure height. For the three dimensional 60–storey structural model subjected to the earthquake load, about 18 % reduction in maximum displacement can be achieved with optimum location of the outrigger truss placed at the top and the 33rd level.

Keywords: outriggers, high-rise buildings, wind load, earthquake load, optimum outrigger location.

INTRODUCTION

The outrigger and belt truss system is one of the lateral load resisting system in which the external columns are tied to the central core wall with very stiff outriggers and belt truss at one or more levels (Figure 1). When the lateral load acts on the building, the bending of the core rotates the stiff outrigger arms, which is connected to the core and induces tension and compression in the columns (Figure 2).

One example of building which uses the outrigger and belt system is Chifley Tower, 53 storey with 4 levels of basements, located in Sydney, Australia (constructed 1992). The building is made of composite floor on steel decking, steel columns and central steel braced frame core structure. The building was designed for wind speed of 50 m/s on 1000-year return period with a maximum lateral deflection of 0.565 m for a 50-year return. The outriggers are placed at two levels of the building (Figure 3).

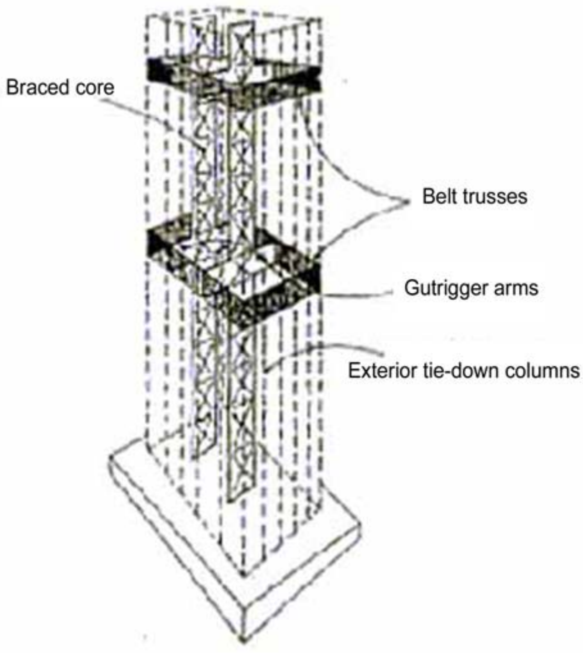

Figure 1. The belt truss system [4]

Note: Discussion is expected before June, 1st 2001. The proper discussion will be published in "Dimensi Teknik Sipil" volume 3 number 2 September 2001.

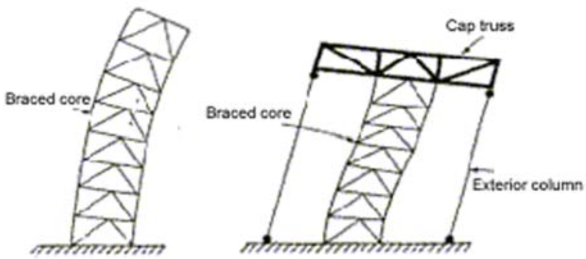

Figure 2. The Braced Core and The Braced Core, Exterior Column, and Cap Truss [1]

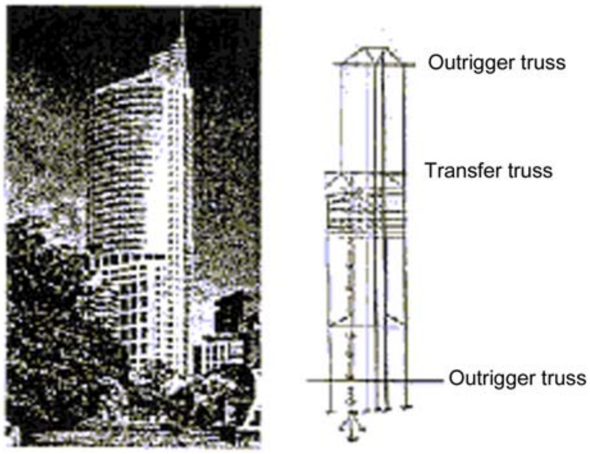

Figure 3. The Chifley Tower, Sydney, Australia [1]

There are some factors affecting the effectiveness of outrigger system. They are the stiffness and location of the outrigger and belt truss system, the geometry, the core, and floor-to-floor height of the building.

One of the disadvantages of using this system is usable space reduction due to outrigger at that level. However, this problem can be solved by using diagonal outrigger over two or more floors. Wolfgang Scueller [2] presented in his book that the efficiency of the building structure might be improved by about 30% by using horizontal belt trusses to tie the frame to the core.

Taranth [1], demonstrated that the optimum location for a single outrigger is approximately in the middle height of the building for minimizing the roof lateral displacement under wind load, but such a location may not always be available.

Iyengar [3], documented the use of outrigger and belt trusses, which connect planar vertical trusses and exterior frame columns. By using outrigger and belt steel trusses in a two-dimensional model of a 85 storey structure, it was presented that the steel core alone had defection of 437 mm and reduced to 107 mm or to about 25% with outrigger trusses. When concrete core was used, the lateral deflection was 272 mm and it was reduced to 87 mm or to about 32 % with the same outrigger trusses, and exterior steel columns.

Smith, et al [4], presented the performance of outrigger-braced structures. He proposed the offset outrigger systems in which the outrigger and belt trusses may be located elsewhere than in the planes of the core-walls or to move, or offset, the outrigger arms horizontally within the floor plan, away from the central core. The aim of this method is to reduce obstructed space compared to the conventional method.

Xiaoxuan Qi and Shuang Chen [5] presented the effectiveness of outrigger beam system with a two-dimensional structural model, which consists of a channel-shaped core-wall, two exterior columns, and a series of pair outrigger beam connecting the core wall and the columns. It was shown that the lateral displacement was minimum when having three outrigger beams.

This paper proposed to study the use of diagonal outrigger and belt truss placed at different location subjected to wind or earthquake load. The design of wind load was calculated based on CP 3, British Standard [6] and the earthquake load obtained using was Indonesian response spectra zone 4 [7]. With computer analysis program, the locations of outrigger and belt truss for reducing lateral displacement, building drift, and core moment, can be obtained. The GT-Strudl [8] package program is used to analyze the structure subjected to wind load in two-dimensional analysis, while ETABS [9] software program is selected to perform three-dimensional structure subjected to earthquake load in static and dynamic analysis (modal analysis).

MODELLING THE STRUCTURE

Two-Dimensional Model

A two-dimensional, 40-storey building with 6 m central shear wall and 12 m bays on either side was considered (Figure 4). The typical floor height is 3.5 m giving a total height of 140 m. The beams, columns, shear walls and outriggers are assumed as concrete structure.

The basic wind speed of 32 m/s was used and the wind speed design was calculated based on CP3-British Standards [6], assuming 30m x 30m class B building located at city center, for a 50 year return period with probability level 0.63 using the force coefficients Cf.

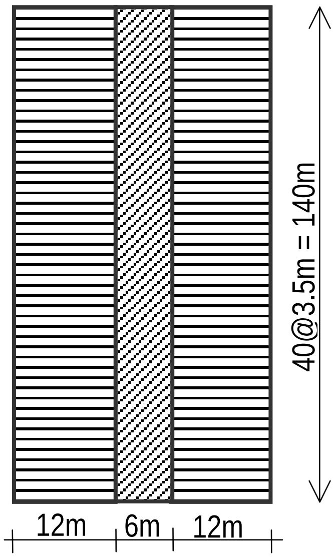

Figure 4. A 40-storey building model

A total of 8 different arrangements of outriggers analyzed using GT-Strudl software program [8] were:

1. Structural Model without outrigger (SMO)
2. Structural Model with one outrigger at the top floor (SOD-Top)
3. Structural Model with one outrigger at 3/4th of building height (SOD-3/4)
4. Structural Model with one outrigger at the middle of building height (SOD-1/2)
5. Structural Model with one outrigger at 1/4th of building height (SOD-1/4)
6. Structural Model with one outrigger at top and another at 3/4th of building height (SOD-Top & 3/4)
7. Structural Model with one outrigger at top and another at the middle of building height (SOD-Top & 1/2)
8. Structural Model with one outrigger at top and another at 1/4th of building height (SOD-Top & 1/4)

Three-Dimensional Model

A three-dimensional typical floor structural model will be used for the study. The model is a 60-storey reinforced concrete consisting frame at the periphery and core wall in the center. The building is viewed as an assemble of vertical frames interconnected at each storey level by diaphragm floor slab while the secondary beam was considered as point load on main beam. The static and dynamic computer analysis was carried out using ETABS program [9].

The outrigger systems are employed to utilize the full capacities of the structural form. The outrigger system models used in the analysis are described below:

1. Structural Model without outrigger (SMO)
2. Structural Model with single outrigger diagonal- Model A (SOD1-A)
3. Structural Model with single outrigger diagonal- Model B (SOD1-B)
4. Structural Model with double outrigger diagonal- Model A (SOD2-A)
5. Structural Model with double outrigger diagonal- Model B (SOD2-B)

The model with double outriggers means one outrigger is fixed at the top level and the location of the other outrigger is changed along the storey or level of the building to find the optimum location of outrigger based on lateral displacement under seismic load. The models are illustrated in Figures 8 and 9.

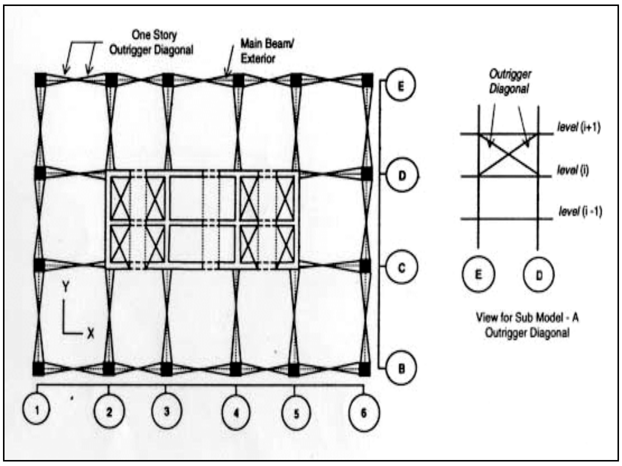

Figure 8. The Structural Model with single or double outrigger diagonal- Model A

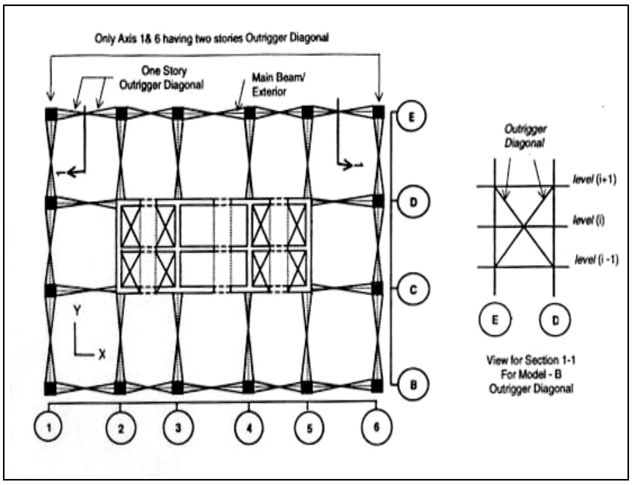

Figure 9. The Structural Model with single or double outrigger diagonal- Model B

ANALYSIS RESULTS

Two–Dimensional Model

The lateral displacement is shown in Figure 5 and Figure 6. It can be seen from those figures that single SOD-1/2 reduces top displacement by as much as 56% while SOD-Top & 1/2 reduces the top displacement by 65 %.

The magnitudes of top floor deflection of different system are presented in a non-dimensional form in Figure 7. The horizontal ordinate is the ratio of lateral displacement at the top floor to a particular position of outrigger to the lateral displacement at the top floor without outrigger. From the Figure 7, the optimum location of single outrigger can be predicted at 22nd storey of the building. With double outrigger system the optimum location is providing 1st outrigger at the top floor and 2nd outrigger at the middle of the height. Without the outrigger, the resistance is mainly provided by cantilever action of shear wall alone.

Three–Dimensional Model

The curve in Figure 10 and 11 represent the optimum location for single and double outrigger system. For single-outrigger (Figure 10), the optimum location is at level 36th, which is 0.425 times of the total height from the top. Using double outrigger (Figure 11), with one outrigger at roof level, the location of second outrigger is at 0.475 times of the total height from the top. The lateral displacement and inter-storey drift ratio distribution (δi) along the height of building for the optimum location of outriggers for all different models and for the model without outrigger are shown in Figure 12 and 13.

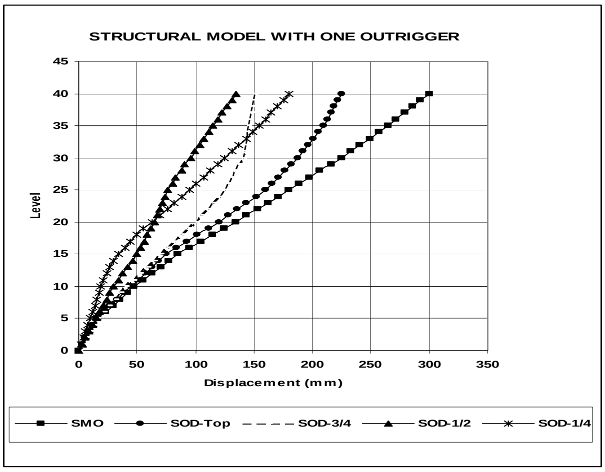

Figure 5. The Lateral Displacement of Structural Model with One Outrigger.

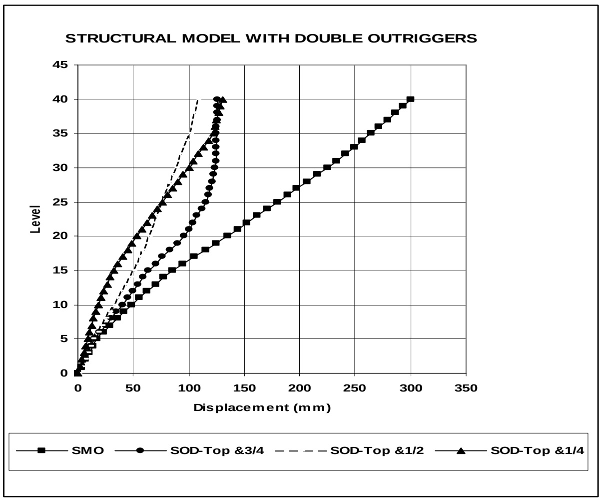

Figure 6. The Lateral Displacement of Structural Model with Double Outrigger

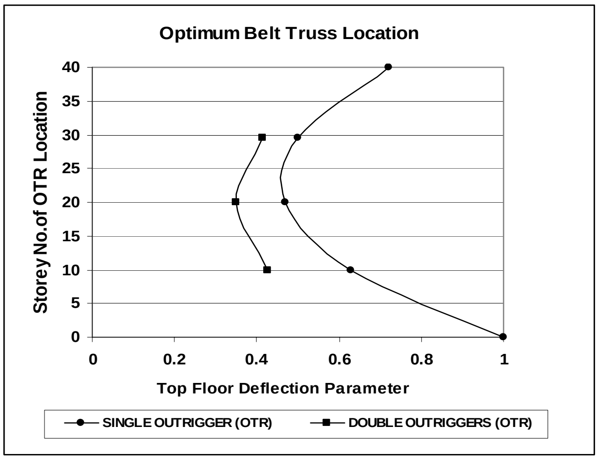

Figure 7. The Optimum Belt Truss Location

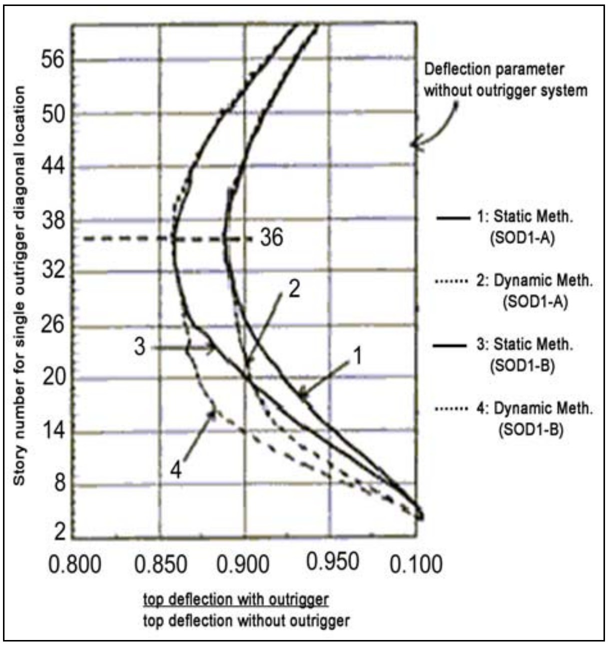

Figure 10. The Optimum Location for Structural Model with single Outrigger.

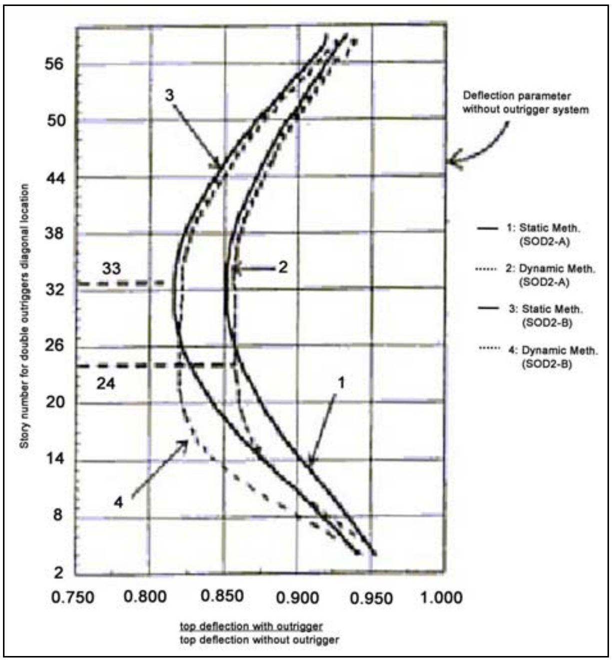

Figure 11. The Optimum Location for Structural Model with double outrigger.

Table 1 and 2 summarize the roof lateral displacement (Δ roof), maximum inter-storey drift ratio (δmax), and percentage (%) of reduction for different models (for the optimum location of the outriggers) and compared with the model without outrigger in y-direction. From Table 1 and 2, it can be seen that single outrigger at optimum location reduces lateral displacement by 14% compared to model without outrigger, while double outrigger diagonal reduces the roof lateral displacement about 18%.

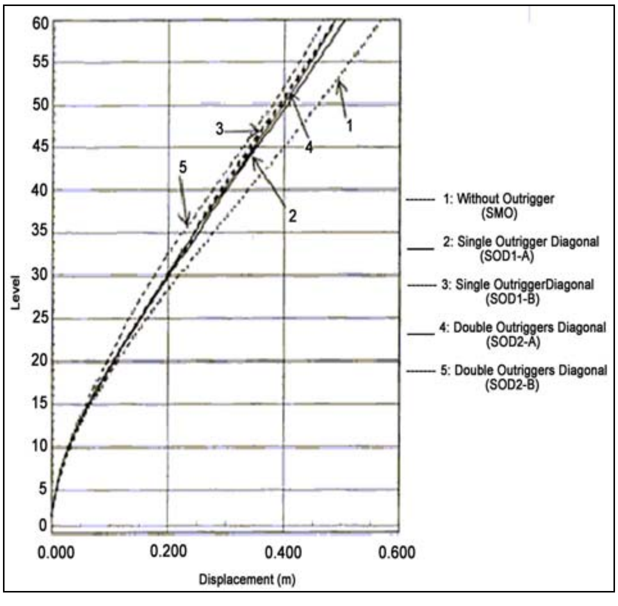

Figure 12. The Lateral Displacement ratio (For optimum location of the outrigger diagonal with dynamic analysis)

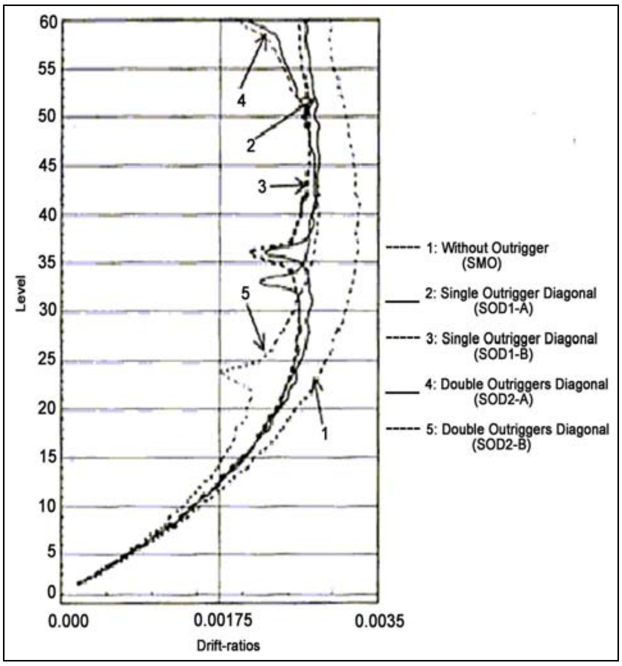

Figure 13. The Inter-storey drift ratio (For optimum location of the outrigger with dynamic analysis).

Table 1. Maximum Displacement (Δy) and Inter-Storey Drift Ratio (δ) for Single Outrigger Diagonal

	Model SMO (Without Outrigger)		Model SOD1-A		Model SOD1-B	
	Static	Dynamic	Static	Dynamic	Static	Dynamic
Δy (displ) – m	0.7761	0.5696	0.6914	0.5064	0.6681	0.4892
% Δy (displ)	0.00%	0.00%	10.91%	11.10%	13.92%	14.12%
δ max	0.449e-2	0.327e-2	0.395e-2	0.305e-2	0.384e-2	0.314e-2

Table 2. Maximum Displacement (Δy) and Inter Storey Drift Ratio (δ) for Double Outrigger Diagonal

	Model SMO (Without Outrigger)		Model SOD2-A		Model SOD2-B	
	Static	Dynamic	Static	Dynamic	Static	Dynamic
Δy (displ) – m	0.7761	0.5696	0.6635	0.4886	0.6442	0.4667
% Δy (displ)	0.00%	0.00%	14.51%	14.22%	17.00%	18.07%
δ max	0.449e-2	0.327e-2	0.384e-2	0.303e-2	0.395e-2	0.305e-2

CONCLUSION

The use of outrigger and belt truss system in high-rise buildings increase the stiffness and makes the structural form efficient under lateral load. For two-dimensional model, single outrigger provided at the middle of the structure height reduces the maximum displacement by 56 %, while providing first outrigger at the top and second outrigger at the middle of the structure height reduces displacement by 65%. For three dimensional structural model sub-jected to the earthquake load, about 18%

reduction in lateral displacement can be achieved with optimum location of the outrigger truss at the top and 33rd level. (In order to improve the performance of the structural aspect, the maximum displacement at the top floor becomes one of the most important factors affecting the occupant's comfort).

REFERENCES

1. Taranath, B. *Structural Analysis & Design of Tall Buildings*. New York, Mc Graw Hill, 1998.

2. Schueller, Wolfgang. *The Vertical Building Structures*. New York, Van Nostrand Reinhold, 1990.

3. Iyengar, Hal, *Composite and Steel High Rise Systems*. Habitat and The High-Rise, Tradition & Innovation. In Proceedings of The Fifth World Congress. 14-19 May 1995. Amsterdam, The Netherlands, Bethlehem, Pa : Council on Tall Building and Urban Habitat, Lehigh University.

4. Smith B.S et al, *Offset Outrigger Concepts for Tall Building Structures*. Tall Building Structure-A World View. In Proceedings of 67th Regional Conference in Conjunction with ASCE Structures Congress XIV.15-18 April 1996, Chicago, Illinois, USA. Bethlehem, Pa : Council on Tall Building and Urban Habitat, Lehigh University.

5. Xiaoxuan Qi and Shuang Chen, *Design Issues Associated with Outriggers in Concrete High-Rise Buildings*. Tall Building Structure-A World View. In Proceedings of 67th Regional Conference in Conjunction with ASCE Structures Congress XIV. 15-18 April 1996. Chicago, Illinois, USA. Betlehem, Pa: Council on Tall Building and Urban Habitat, Lehigh University.

6. British Standard Institution, , CP 3, *Code of Basic Data for Design of Buildings*, Chapter V. Loading, Part 2. Wind Loads, 1972.

7. Departemen Pekerjaan Umum, *Pedoman Perencanaan Ketahanan Gempa untuk Rumah dan Gedung*, 1987.

8. GTSTRUDL. *Integrated CAE System for Structural Engineering Analysis and Design* . Georgia Institute of Technology, Atlanta, Georgia, USA, 1993.

9. Habibullah, A. *ETABS, Three Dimensional Analysis of Building System*, User's Manual, Berkeley, California, 1995.