Performance evaluation of outrigger location on the seismic load distribution of high-rise building structure

Aryo, Made Suangga

Civil Engineering Department, Faculty of Engineering, Bina Nusantara University
Jakarta, Indonesia 11480

Corresponding author: suangga@binus.edu

Abstract. Various structural systems have been developed to be able to accept the lateral force of the earthquake with an optimum and economical. One of these structural systems is the outrigger system. Outrigger is one of the structural stiffening systems that can be used on building structures, especially in high-rise buildings. Structural systems such as outriggers are used for earthquake-resistant buildings, so the performance of building structures can be increased by producing minimum displacement. This research will design the building as high as 40 and 50 floors, with the calculation of earthquake based on Indonesia Earthquake Design Code SNI 1726-2012. This study will be compared the calculation of seismic loads in the building structure with and without using outrigger, so that it can be seen the difference in the seismic loads and the performance of the structure. From this research, it is found that the outrigger system can reduce the seismic loads in the structure, and also is able to reduce the lateral displacement of the structure. The inter-story lateral displacement of 50 storey and 40 storey structure can be reduce up to 2.06% and 7.84% with one outrigger and 3.76% and 12.49% with two outrigger.

Keywords: high-rise building, outrigger, earthquake, load distribution, lateral displacement

1. Introduction

Indonesia is one of the regions where most of its territory is located on the earthquake prone area, where earthquake epicenters are distributed along the archipelago from Sabang to Merauke. The magnitude and the risk of the earthquake different from location to location as represented in Indonesian earthquake map in the earthquake resistant design regulation for building structure or Tata Cara Perencanaan Ketahanan Gempa untuk Struktur Bangunan Gedung dan non-Gedung, SNI 1726:2012.

An earthquake can occur at any time and no one can predict it. Therefore, the earthquake must be anticipated before causing a negative effect on life, especially in tall buildings. But unfortunately, the use of alternatives such as structural stiffeners is still rarely used in Indonesia.

In the designing of building structure, it is necessary to pay attention to the rigidity of the building so that the building that we will build has the resilience in anticipation of the occurrence of earthquakes especially in high-rise buildings. In the design, high building structures require prisoners to reduce the earthquake force that occurs so that the deformation of the building can be minimized. Many structural
systems are used to provide more building awareness in anticipation of the earthquake, one of which is to use an outrigger structure system. The structural system with the application outrigger as a stiffener, is useful to resist lateral forces such as earthquakes [1] [2] [3].

In this study, the effect of the use of outriggers on the earthquake force distribution that occurs as well as lateral deviations and forces generated by using an outrigger will be analyzed, which places the outrigger at the optimum location (the optimum location where the outrigger is installed at a certain height and produces the smallest deviation). Shear force due to the earthquake.

2. Objectives

The objectives of the research is to investigate the effect of outrigger location to the distribution of lateral load due to earthquake in term of load distribution, top lateral displacement and inter-storey displacement. The earthquake analysis is based on Indonesia Earthquake Design Code for Building Structure SNI 1726-2012. SAP 200 computer software is used for modelling and dynamic analyst.

3. Methodology

The methodology of this research are as follow
a. This research is conducted at 40-storey and 50-storey with one and two outrigger at various location. The layout of the building is presented in Figure 1.
b. The building is assumed located at Padang, West Sumatera. The parameter of the Response Spectrum at building location is presented in Table 1 and Figure 2.
c. For one outrigger structure, the location of the outrigger are at 0.25H, 0.50H and 0.75H. For double outrigger system, the location of the outrigger are at 0.25 + 0.50H, 0.50 + 0.75H and 0.75 + 1.00H.
d. The structures were design based on the requirement in SNI 1726-2012. The summary of the cases is presented in Table 3.
e. SAP2000 structural analysis software is used for structural modelling and dynamic analysis.
g. The earthquake load is distributed to each floor in accordance with SNI 1726-2012. The requirement of 90 % mass participating factor has been fulfilled in accordance with SNI 1726-2012.
h. The stiffness of the structure in term of natural period, the distribution of earthquake to each floor and the top drift of each case then compared.

![Figure 1. Building layout](image-url)
**Table 1.** Response spectrum – Padang, west sumatera

| Parameter                        | Value                        |
|----------------------------------|------------------------------|
| Rick Category                    | II                           |
| Importance Factor ($I_e$)        | 1,0                          |
| Passive Spectral Acceleration    | $S_S = 1,350; S_I = 0,600$   |
| Site Class                       | SE                           |
| Site Class Coefficient           | $F_S = 0,900; F_V = 2,400$   |
| Accelerated Response Spectral    | $S_{DS} = 0,810; S_{DI} = 0,960$ |
| Seismic Design Category          | E                            |

**Figure 2.** Response spectra – Padang, west sumatera

**Table 2.** Seismic load parameter

| Lateral Systems | Concrete Frame - Special moment resisting system | Concrete frame system with eccentric bracing |
|-----------------|--------------------------------------------------|---------------------------------------------|
| Response        | 8                                                | 6,5                                         |
| Modification    | 0,1013                                           | 0,1246                                      |
| Coefficient $R$ |                                                  |                                             |
| Seismic         |                                                  |                                             |
| Response        |                                                  |                                             |
| Coefficient $C_s$ |                                              |                                             |

**Table 3.** Cases study

| No  | Outrigger Location | Case ID for 40 storey | Case ID for 50 storey |
|-----|--------------------|-----------------------|-----------------------|
| 1   | -                  | 40A                   | 50A                   |
| 2   | 0,25 H             | 40B                   | 10th floor            |
|     |                    |                       | 50B                   |
|     |                    |                       | 12th floor            |
| 3   | 0,5 H              | 40C                   | 20th floor            |
|     |                    |                       | 50C                   |
|     |                    |                       | 25th floor            |
| 4   | 0,75 H             | 40D                   | 307th floor           |
|     |                    |                       | 50D                   |
|     |                    |                       | 37th floor            |
| 5   | 0,25H and 0,5 H    | 40E                   | 10th and 20th floor   |
|     |                    |                       | 50E                   |
|     |                    |                       | 12th and 25th floor   |
| 6   | 0,5 H and 0,75 H   | 40F                   | 20th and 30th floor   |
|     |                    |                       | 50F                   |
|     |                    |                       | 25th and 37th floor   |
|     | 0,75H and 1.00H    | 40G                   | 30th and 40th floor   |
|     |                    |                       | 50G                   |
|     |                    |                       | 37th and 50th floor   |
4. Theory

4.1 Static and Dynamic Analysis

Analysis of the earthquake load in buildings goes through several stages, where these stages depend on the height and complexity of the structure. Building height determines the analysis used to design earthquake resistant buildings, where analysis of earthquake resistant buildings is divided into 2 namely equivalent static analysis and dynamic analysis. Equivalent static analysis is one method for analyzing building structures against earthquake loading using nominal static earthquake loads. Equivalent static analysis is also a structural analysis method for earthquake loading using only the mass of the building, so this analysis is suitable for low-rise buildings (buildings under 10 floors).

Dynamic analysis is a method for building structure analysis of earthquake loading which is used to analyze high-rise and complex buildings.

4.2 Building Rigidity

The stiffness of the building is indicated by the natural vibrational period of the building structure. According to SNI 1726-2012, the building meets the level of rigidity if the first natural period of the building less or equal to its allowable value [4]:

\[
T_{structure} \leq T_{allowable}
\]  

\[
T_{allowable} = C_t h_n^x
\]

\(h_n\) is height of structure in (m); \(C_t\) and \(x\) are coefficients determined based on the structural system adopted for the building. For moment resisting concrete frame the values are 0.0466 and 0 respectively.

The first natural period of the structure indicates the stiffness of the building structure where the smaller the first natural period value the more rigid the structure. But the shorter the natural period of the structure the bigger the earthquake force of the building and vice versa.

4.3 Building Weight (W_t)

The magnitude of the earthquake load is strongly influenced by the weight of the building structure, therefore the weight of the building needs to be calculated from each building floor. The Weight of a building consist of dead load including the self-weight of the structure itself and also the live load caused by the building user. When an earthquake occurs the change of full live load on a building is relatively small, the live load can be reduced by multiplying the live load by the reduction of live load for earthquake consideration. According to SNI 1726-2012 the live load reduction factor for office and apartment is 0.3 [4].

4.4 Base Shear

Dynamic analysis is carried out to determine the natural frequency and vibration mode of the building structure. According to SNI 1726-2012, the analysis must include a sufficient number of vibration mode so that the building mass participation ratio at least 90% of the actual mass of the building. This is because when an earthquake occurs the building mass also participates in resisting the magnitude of the earthquake.

According to SNI 1726-2012 the earthquake base shear from dynamic analysis, \(V_{dynamic}\), shall not more than 80 % than the Earthquake base shear from Static Analysis, \(V_{static}\). If \(V_{dynamic}\) more than 80 % \(V_{static}\), it is necessary to adjust \(V_{dynamic}\) to fulfill the requirement [4].
4.5 Lateral Displacement

Lateral displacement in buildings determine how the performance of the structure to the lateral load from the earthquake. Lateral displacement occur due to shear forces that arise in buildings caused by the earthquakes. The Lateral displacement is divided into two namely the top floor displacement or top drift and the inter-storey displacement, where both displacements need to be reviewed as structural performance parameter and for structural design control.

The magnitude of top floor displacement or drift is limited to 4% of the building height [6] while the inter-storey displacement is limited by allowable value as indicated in SNI 1726-2012 based on structural risk categories. This is to prevent the damage of non-structural element and inconvenience of the occupants due to moderate earthquake.

4.6 Outrigger Structure System

An outrigger structure of skyscrapers or high rise buildings consists of a main core which can be reinforced concrete (shear wall) or steel that is connected to the exterior column by a rigid horizontal cantilever. Cores may be placed between two columns connected by outriggers or may be placed on one side of the building with a cantilever connecting cores to columns on the other side [5].

In addition to the stiffness of the column connected to the end of the outrigger, other column peripherals are usually installed to help hold the outrigger. This can be achieved by using high beams or belts around the structure at the level of outrigger mounted (bracing). To make the outriggers and belts rigid enough for flexural and shear forces, these elements are made of at least one or no more than one use, the height of the floor consequently to minimize the disturbance that these elements can cause, usually these elements are placed at a level which is used for building mechanical or electrical sources.

The magnitude of the reduction of the drift and moment of the core depends on the relativity of the stiffness of the core, outrigger, and column. The amount of reduction also depends on the location of the outrigger in the structure. A building can be effectively reinforced by installing an outrigger at the top of the structure, which is often referred to as the 'top hat' structure. Each outrigger addition increases lateral scaffolding, but with a smaller increase than the previous outrigger addition to the use of four outriggers in one tall building.

Outrigger systems are able to optimally increase structural stiffness, but do not increase shear resistance which will be held mostly by cores. But the use of outriggers is able to reduce the amount of material that must be used and the costs incurred.

![Figure 3. Outrigger system with core (a) in the centre and (b) at one side](image-url)
4.7 Benefits of Using Outriggers
The use of an outrigger will provide rigidity with good results if installed correctly and correctly. From this, the following are the benefits of using outriggers in structures, including:

a. Reducing deformation that occurs due to earthquake forces;
b. Distribute the earthquake force optimally both in the upper structure and towards the foundation, which holds the earthquake force due to the earthquake;
c. Reducing the Moments at the core of the building and deformation.

5. Results and Discussion

5.1 Natural Period of the Structure and the Based Shear
The natural period of the structure and the base shear for each cases are presented in Table 4 and Table 5. The use of structural systems using outriggers provides better lateral stiffness to the structure of the building as indicated by reduction in the natural period of the structure. Building structures with outriggers will receive a larger earthquake load than the building structure without outrigger. This is due to several factors such as the the structure's natural period and the response modification coefficient value.

| Cases              | 40 storey building | 50 storey building |
|--------------------|--------------------|--------------------|
|                    | \( T_{\text{max}} \) | \( T_{\text{structure}} \) | \( T_{\text{max}} \) | \( T_{\text{structure}} \) |
| No Outrigger       | 4.49 \( \geq \) 4.46 | 5.49 \( \geq \) 5.26 |
| Outrigger 0.25H    | 4.49 \( \geq \) 4.45 | 5.49 \( \geq \) 5.25 |
| Outrigger 0.50H    | 4.49 \( \geq \) 4.26 | 5.49 \( \geq \) 5.21 |
| Outrigger 0.75H    | 4.49 \( \geq \) 4.25 | 5.49 \( \geq \) 5.24 |
| Outrigger 0.25+0.50H | 4.49 \( \geq \) 4.24 | 5.49 \( \geq \) 5.24 |
| Outrigger 0.50+0.75H | 4.49 \( \geq \) 4.08 | 5.49 \( \geq \) 5.19 |
| Outrigger 0.75+1.00H | 5.49 \( \geq \) 5.20 | 5.49 \( \geq \) 5.20 |

| No | Case     | 40 storey building | 50 storey building |
|----|----------|--------------------|--------------------|
|    |          | Weight (tonf)      | Base Shear (tonf)  | Increment (%) | Weight (tonf) | Base Shear (tonf) | Increment (%) |
| 1  | A        | 64881,17           | 6572,46            | 0,00          | 88517,94      | 8966,87            | 0,00          |
| 2  | B, C, and D | 64915,97           | 8088,53            | 23,07         | 88552,74      | 11033,67           | 23,05         |
| 3  | E, F, and G | 64950,77           | 8092,87            | 23,13         | 88587,54      | 11038,01           | 23,10         |

5.2 Distribution of Seismic Load
The distribution of seismic load for 40-storey building and 50-storey building are presented in Figure 5. The pattern of the load distribution is relatively the same for structure with and without outrigger system.
Figure 4. Seismic load distribution for 40-storey and 50-storey building

5.3 Lateral Displacement at Top Level

The Lateral displacement at top level or top drift for 40-storey building and 50-storey building are presented in Table 6. The use of outriggers in high rise buildings will minimize the top lateral displacement of the structure. For High Rise Buildings, where the higher the building, the more flexible the structure, the interaction generated by the use of an outrigger will reduce the lateral displacement from the earthquake.

Table 6. Lateral displacement at top

| Cases                        | 40 storey building | 50 storey building |
|------------------------------|-------------------|-------------------|
|                              | Δ(max)            | Reduction (%)     | Δ(max)            | Reduction (%)     |
| No Outrigger                 | 85,68             | 0,00              | 149,42            | 0,00              |
| Single Outrigger 0,25H       | 83,68             | 2,39              | 149,24            | 0,12              |
| Single Outrigger 0,50H       | 83,42             | 2,71              | 148,39            | 0,69              |
| Single Outrigger 0,75H       | 79,46             | 7,84              | 146,34            | 2,06              |
| Double Outriggers 0,25+0,50H | 81,88             | 4,65              | 148,26            | 0,78              |
| Double Outriggers 0,50+0,75H | 78,43             | 9,25              | 146,26            | 2,12              |
| Double Outriggers 0,75+1,00H | 76,17             | 12,49             | 143,81            | 3,76              |
5.4 Inter-storey Displacement

The inter-storey displacement for 40-storey and 50-storey building is presented in Figure 6. For structure with outrigger, the use of the outrigger is able to reduce inter-storey displacement at that level where on the outrigger is located. It can also be seen that the higher the outrigger position the greater the inter-storey displacement reduced. This happens due to the interaction in the structural system using outriggers can reduce deflection that occurs mainly on the level where the outrigger located.

![Inter-storey Displacement](image)

**Figure 5.** Inter-storey displacement for 40-storey and 50-storey building

6 Conclusion

Based on the results of the analysis of the research conducted it can be concluded that:

a. Building structures that use outriggers, will receive a larger earthquake load than the building structure that does not utilize outrigger system. This is due to several factors such as the value of the structure's natural vibration period, and the response modification coefficient value.

b. The use of outriggers provides better lateral stiffness to the structure of the building, where the use of outriggers can reduce inter-storey displacement by the earthquake in the building structure, by reduction of 2.06% for the 50-storey building with 1 outrigger and 7.84% for a 40-storey building structure. Application of 2 outriggers can reduce of 3.06% for 50-storey building structure and 12.49% for a 40-storey building structure.

c. The optimum location of the outrigger installation is on the highest floor, the higher the location of the outrigger, the greater the reduction of top displacement of the structure.

References

[1] Alok Rathore, Dr. Savita Maru (2017). The Behavior of Outrigger Structural System in High-Rise Building: Reviews. International Journal of Science, Engineering and Technology Research (IJSETR).
[2] Fauzan Kurnianto, Faimun dan Tavio (2017). Desain Modifikasi Struktur edung Apartemen Gunawangsa Tidar Surabaya Menggunakan Struktur Beton Bertulang dengan Sistem Outrigger dan Belt-Truss. Departemen Teknik Sipil, Teknik Sipil dan Perencanaan, Institut Teknologi Sepuluh Nopember.

[3] Gerasimidis S., Efthymiou E. & Baniotopoulos C. C. (2009). Optimum Outrigger Locations of High-Rise Steel Buildings for Wind Loading. Institute of Metal Structures, Department of Civil Engineering, Aristotle University of Thessaloniki, GR-54124, Thessaloniki, Greece.

[4] Badan Standardisasi Nasional (2012). Tata Cara Perencanaan Ketahanan Gempa untuk Struktur Bangunan Gedung dan non-Gedung. SNI 1726:2012.

[5] Goman Wai-Ming Ho, Arup (2016). The Evolution of Outrigger System in Tall Buildings. International Journal of High-Rise Buildings, Volume 5 Number 1.

[6] Prof. DR. Ir. Wiratman Wangsadinata (2013). Struktur Unik Gedung MNC Media Tower Bertingkat 56 Di Jakarta. Konferensi Nasional Teknik Sipil ke-7, Universitas Sebelas Maret Solo.