Analysis of Octagon-shaped Commercial Steel Tower with Altered Bracing Systems  

**KAY KHINE SU**, **KYAW LIN HTAT**

1Dept of Civil Engineering, Mandalay Technological University, Mandalay, Myanmar, Email: kaykhinesu2010@gmail.com.  
2Dept of Civil Engineering, Mandalay Technological University, Mandalay, Myanmar, Email: kyawlinhtat@gmail.com.

**Abstract:** In this study, an octagon-shaped commercial steel tower is analyzed with altered bracing system, its frame members are designed and stability of the structure is checked. Moreover, there is the comparison of story drift, shear and maximum overturning moment between static and dynamic approach. Dynamic analysis is considered by Response Spectrum Cases. The proposed tower is a 35-storeyed steel tower and its overall height is 394ft. Both maximum width and maximum height of the tower are 115ft. The structure is located in high seismic risk zone, Mandalay. Wind speed 80 mph is used. This structure is composed of special moment resisting frame with bracing. Dead loads and live loads are used according to ACI code. For earthquake and wind forces, loading data were referenced from UBC-97. The load combinations required for the whole structure is used according to AISC-LRFD 1999. The structural steel used for the building is A572 Grade 50 and wide flange W-section. Material properties used in analysis of the steel tower are compressive strength of 3500psi and yield strength of 50000psi. The tower is analyzed by ETABS software.

**Keywords:** An Octagon-Shaped, Commercial Steel Tower, 35-Storeyed Steel Tower, Altered Bracing Systems, Special Moment Resisting Frame With Bracing.

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**I. INTRODUCTION**

Myanmar is a developing country in South-East Asia and the population is also increasing more and more. And Mandalay, the second largest city of Myanmar, is also highly populated. So, the multi-storeyed buildings are widely used and the potential of its popularity will be greater in future. Tower is a structure in which structural system must be modified to make it sufficiently safe and economical. Today, many building materials are available in the market. Among them, steel members are widely used all over the world because of high strength, long life, ease of fabrication, and fire resistance. Structural steel frame have higher construction speed, availability of various grade and shape that reduced foundation costs due to its light weight, etc. Tower is a vertical cantilever so that elements of structure are to resist axial loading by gravity and to resist transverse loading by wind or earthquake. The proposed structure for this study is selected as a steel frame structure. In this study, a 35-storeyed commercial steel tower is designated at Mandalay. Design of structure before construction work, it gives safely and economy to the owner.

The effects of loads on structures are determined through structural analysis. Then, checking the resistant of structure gives that the strength is safely or not during the life of the building. The strengthening of structure must be suggested when which is necessary. Nowadays, in the era of computer, creation and modification of the structural model, execution of the analysis and checking, and optimization of the design are all done through single interface by computerized application. This reason essentially make computer aided design and analysis the most economical and time saving means to obtain a reliable design.

**II. CASE STUDY**

A. **Modeling of Proposed Tower**

The proposed structure is the 35-storeyed steel structural tower located in seismic zone IV. The shape of the structure is Octagonal shape. The proposed tower is modeled by using ETABS software. And then, loading specification for modeling is used by ACI code. Type of occupancy is commercial tower in which 1st Floor to 4th Floor are shopping mall areas, 5th, 9th and 12th Floors are restaurant areas, 6th to 8th Floors are bank areas, 13th to 20th Floors are class-room areas and upper stories are office areas. The tower is analyzed with altered bracing system.

B. **Profiles of the Tower**

Profiles of structure are prescribed as follows. Dead load, live load, wind load and earthquake loads are considered in proposed tower. Line plan and 3D view of proposed tower are described in Figure 1 and 2.

Type of structure : 35 - storeyed steel tower  
Location : Seismic zone 4  
Type of occupancy : Commercial
Shape of building : Octagonal shape
Size of building : Length = 115 ft. Width = 115 ft.
Height of building : Typical story height = 11 ft.
Bottom story height = 12 ft.
Overall height = 394 ft.

C. Material Properties
Analysis property data;
Strength of concrete = 3.5 ksi
Yield strength of reinforcing bars = 50 ksi
Modulus of Elasticity = 29000 ksi
Poison ratio (steel) = 0.3
Yield strength of structural steel = 50 ksi
Ultimate strength of structural steel = 65 ksi

D. Load Consideration
There are two kinds of load considered in this study which is gravity load, that include dead, superimposed dead and live load, lateral load that include wind and earthquake load. Design load considerations are according to AISC-LRFD 99 and UBC 97 Code.

Data for dead load are as follows:
- Unit weight of concrete = 150 pcf
- Unit weight of steel = 490 pcf
- Superimposed Dead Load = 35 psf
- Glass wall weight = 20 psf
- Weight of lift = 3 tons

Data for live load are as follows:
- Live load on class-room area = 40 psf
- Live load on office area = 50 psf
- Live load on shopping mall area = 100 psf
- Live load on restaurant area = 100 psf
- Live load on roof floor = 20 psf
- Live load on corridors = 100 psf

Data for wind load are as follows:
- Wind speed = 80 mph
- Exposure type = C
- Importance factor = 1
- Windward coefficient = 0.8
- Leeward coefficient = 0.5
- Normal forced method is used for this type of structure.

Data for earthquake load are as follows:
- Seismic zone = 4
- Seismic zone factor = 0.4
- Seismic source type = A
- Soil profile type = SD
- Seismic response coefficient, C v = 0.64
- Seismic response coefficient, C a = 0.44
- Response modification factor, R = 8.5
- Seismic importance factor, I = 1

A. Load Combination
According to AISC-LRFD 99, load combinations for design check of proposed structure are as follows:
- 1.4 DL
- 1.2 (DL+SD)+1.6 LL
- 1.2( DL+SD)+LL+1.6 WX
- 1.2 (DL+SD)+0.8WX
- 1.2 (DL+SD)+0.8 WX
- 1.2( DL+SD)>0.8 WY
- 1.2( DL+SD)+0.8 WY
- 0.9(DL+SD)+1.6WX
- 0.9(DL+SD)+1.6WX
- 0.9(DL+SD)+1.6WY
- 0.9(DL+SD)+1.6WY
- 1.2(DL+SD)+LL+EX
- 1.2(DL+SD)+LL-EX
- 1.2(DL+SD)+LL+EY
- 1.2(DL+SD)+LL-EY
- 1.2(DL+SD)+EX
- 1.2(DL+SD)-EX
- 1.2(DL+SD)+EY
- 1.2(DL+SD)-EY
- 0.9(DL+SD)+EX
- 0.9(DL+SD)-EX
- 0.9(DL+SD)+EY
- 0.9(DL+SD)-EY

Figure 1. Line Plan of Proposed Tower
Figure 2. 3D View of Proposed Tower.
II. ANALYSIS RESULT FOR TOWER

The proposed steel tower is analyzed with altered bracing system. The bracing systems are classified as Type 1, 2, 3, 4 and 5 and located at the sides of the tower. Double diagonal bracing system is used around the lift for all structural analysis. Types of altered bracing system are described in Figure 3. Although braced sections of the compared bracing systems are same, the analysis results are different according to bracing system. Although the story drift range and maximum overturning moment range are in middle range, Type 1 bracing system is chosen for the factors such as satisfied stability resistance, economy and ease of fabrication.

![Figure 3. Types of Altered Bracing System](image)

A. Comparison of Story Drift with Altered Bracing System

From the analysis data, the comparisons for story drifts of the structure with altered bracing systems are graphically presented as shown in Figure 4 and 5.

![Figure 4. Comparison of Story Drift in X-direction](image)

![Figure 5. Comparison of Story Drift in Y-direction](image)

B. Comparison of Maximum Bending Moment with Altered Bracing System

For both X-direction and Y-direction, the comparisons for maximum overturning moment of the proposed tower with altered bracing systems are graphically presented as shown in Figure 6.

![Figure 6. Comparison of Maximum Overturning Moment for both X-direction and Y-direction](image)

III. DESIGN RESULT OF FRAME MEMBERS

After the proposed tower is modeled and analyzed by using ETABS Software under UBC-97 Code load consideration, structural members are designed according to AISC-LRFD 99. The design results for the structure are as follow:

A. Design Results for Columns

The whole structure consists of 3664 numbers of columns. Each story level consists of 104 numbers of columns except for roof 100 columns and for stair roof 28 columns. The design sections for columns of each floor level are shown in Table I. Column layout plan is shown in Figure 7.
Table I. Column Sections for the Structure

<table>
<thead>
<tr>
<th>Name</th>
<th>Story</th>
<th>Sections</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>Story 1 to 3</td>
<td>W14x233</td>
</tr>
<tr>
<td></td>
<td>Story 4 to 6</td>
<td>W14x211</td>
</tr>
<tr>
<td></td>
<td>Story 7 to 15</td>
<td>W14x176</td>
</tr>
<tr>
<td></td>
<td>Story 16 to 25</td>
<td>W14x159</td>
</tr>
<tr>
<td></td>
<td>Story 26 to Stair Roof</td>
<td>W14x145</td>
</tr>
</tbody>
</table>

Figure 7. Typical Column Layout Plan

B. Design Results for Beams

The whole structure consists of 7864 numbers of beams. Each floor level consists of 219 numbers of beams except for roof 198 beams and for stair roof 48 beams. Designed beam sections for typical floor beam, roof beam and stair roof beam of the structure are shown in Table II. For landing, the beam sections are W14X34. Typical floor beam layout plans is shown in Figure 8.

Table II. Beam Sections for the Structure

<table>
<thead>
<tr>
<th>Name</th>
<th>Story</th>
<th>Sections</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
<td>Story 1 to 11</td>
<td>W14X43</td>
</tr>
<tr>
<td></td>
<td>Story 12 to 21</td>
<td>W14x38</td>
</tr>
<tr>
<td></td>
<td>Story 22 to Stair Roof</td>
<td>W14x34</td>
</tr>
<tr>
<td>B2</td>
<td>Story 1 to 11</td>
<td>W14x26</td>
</tr>
<tr>
<td></td>
<td>Story 12 to 21</td>
<td>W14x22</td>
</tr>
<tr>
<td></td>
<td>Story 22 to Stair Roof</td>
<td>W12x22</td>
</tr>
<tr>
<td>B3</td>
<td>Story 1 to 11</td>
<td>W10x26</td>
</tr>
<tr>
<td></td>
<td>Story 12 to 21</td>
<td>W10x22</td>
</tr>
<tr>
<td></td>
<td>Story 22 to Stair Roof</td>
<td>W8x21</td>
</tr>
</tbody>
</table>

Figure 8. Typical Floor Beam Layout Plan.

C. Design Results for Bracings

The whole structure consists of 1484 numbers of bracings. Diagonal bracing design is used sides of the structure and Cross bracing design is used around the lift. Designed brace sections for the structure are shown in Table III.

Table III. Brace Sections for the Structure

<table>
<thead>
<tr>
<th>Name</th>
<th>Sections</th>
<th>Story</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>BR1</td>
<td>W10x60</td>
<td>Story 1 to 5</td>
<td>Around the lift</td>
</tr>
<tr>
<td>BR2</td>
<td>W10x33</td>
<td>Story 6 to 21</td>
<td>Around the lift</td>
</tr>
<tr>
<td>BR3</td>
<td>W8x21</td>
<td>Story 22 to Stair Roof</td>
<td>Around the lift</td>
</tr>
<tr>
<td>BR1</td>
<td>W10x60</td>
<td>Story 1 to Stair Roof</td>
<td>Sides of the structure</td>
</tr>
</tbody>
</table>

IV. CHECKING FOR STRUCTURAL STABILITY

In this study, the stability of structure such as overturning moment, torsional irregularity, sliding, story drift, stiffness irregularity and vertical geometric irregularity are checked by the specification of UBC-97.

A. Checking for Overturning Moment

For X-direction,

\[
\text{Overturning moment} = 3017012.842 \text{ kips-in} \\
\text{Resisting moment} = 0.9 \times \text{Total dead weight} \times XCM \\
= 0.9 \times 27137.263 \times 689 \\
= 16827816.79 \text{ kips-in} \\
\text{Factor of safety} = \frac{\text{Overturning Moment}}{\text{Resisting Moment}} = \frac{3017012.842}{16827816.79} = 0.18 \text{ (safe)}
\]
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\[ \Delta M_y = 1.19 \quad < \quad 2.64 \]
\[ \Delta M_x = 1.06 \quad < \quad 2.64 \]
\[ \therefore \] Ok
\[ \therefore \] All story drifts are within story drifts limitation, the structure is stable.

D. Checking for Torsional Irregularity

In proposed structure, the maximum drift at one end of the structure transverse to its axis is not more than 1.2 times the average storey drifts of both ends. Therefore, the effect of torsional irregularity can be neglected.

E. Checking for P-Delta Effect

Based on the UBC-97, P-Delta effect needs not to be considered when:

- The ratio of secondary moment (Ms) to primary moment (Mp) does not exceed 0.10.
- In seismic Zone 3 and 4, the ratio of story drift to story height (story drift ratio) does not exceed 0.02/R.

As all story drift ratios are within limitation, P-Delta effect needs not to be considered. Structural stability checking of the proposed building is satisfied in all cases.

V. COMPARISON OF RESULTS

From the analysis data, the comparison of story drift and maximum overturning moment between static and dynamic approach are graphically presented as shown in Figure 9 and 10.

![Figure 9. Comparison of Story Drift.](image-url)

![Figure 10. Comparison of Maximum Overturning Moment](image-url)
VI. CONCLUSION

In this study, thirty five-storeyed commercial steel tower with octagon-shaped in plan is selected. The structure is analyzed with altered bracing system according to ETABS software, UBC-97 and AISC-LRFD 1999 specifications. The structure steel used in the building is A572 Grade 50 steel and wide flange W-sections are used for frame members. Bracings are provided around the lift shafts and sides of the proposed tower. There is the comparison of analysis results with altered bracing system. The bracing types are classified as Type1, 2, 3, 4 and 5. Type 1 system is single diagonal bracing system and Type 2 system is composed of single diagonal and double diagonal bracing. Type 3 is the V-bracing system while Type 4 bracing system is eccentric diagonal bracing system and Type 5 is eccentric V-bracing system. Although braced sections of the compared bracing systems are same, the analysis results are different according to bracing system. Although the story drift range and maximum overturning moment range are in middle range, Type1 bracing system is chosen for the factors such as satisfied stability resistance, economy and ease of fabrication. As an analysis result, the suitable locations of the bracing system were known. Moreover, there are different types of failure in structural member by changing bracing system. Failures can be caused when the bracing weight is too heavy. If the bracing system is not be used, the large story drift can be occur in the structure. So, the proposed structure is designed as the dual system in which the special moment resisting frame and braced frame are composed. Beam sections are changed once in ten levels and classified as B1, B2 and B3. The minimum and maximum beam sizes are W8x21 and W14x43 respectively. From 1st Floor to 6th Floor, column sections are changed once in three levels. From 7th Floor to 15th Floor, the column size is W14x176. Column sections are changed once in ten levels from 16th Floor to Stair Roof. The maximum column size is W14x233. The stability check also has been made in this study. Story drift, p-delta effect, torsion, overturning moment and sliding of the structure are within the design limitation. Therefore, the structure is stable. Moreover, comparison of analysis results between static and dynamic approach is described in this study.

VII. ACKNOWLEDGMENT

Firstly, the author really thanks to all the teachers from Department of Civil Engineering, Mandalay Technological University for their helps, invaluable guidance, suggestions and encouragement. And, the author is particularly intended to Dr. Kyaw Moe Aung, Associate Professor and Head, Civil Engineering Department, Mandalay Technological University, for his immeasurable help throughout this paper. Next, the author is deeply thanks to Dr. Zaw Min Tun, Lecturer of Civil Engineering Department, Mandalay Technological University, for his helpful suggestions, invaluable instruction, precious knowledge and kindness. Moreover, the author is very thankful to her supervisor Dr. Kyaw Lin Htat, Associate Professor of Civil Engineering Department, Mandalay Technological University, for his supervision, support, true-line guidance and encouragement throughout this study. The author specially thanks her family, especially her beloved parents, for their supports and encouragements to attain her destination without any trouble. The author is also grateful to all people who have contributed in preparation of her paper.

VIII. REFERENCES