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Performance of Seismic Design Reinforced Concrete Building Under Different Wind Velocities

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Abstract:

The purpose of this paper is to know the performance of sixteen-storeyed reinforced concrete seismic design building with the basic wind velocity of 80 mph under five tropical cyclone categories 95,110,130,155 and 170 mph (Saffir-Simpson Hurricane Scale). In order to study the performance of selected building under different wind velocities, ETABS software is used to analyze the superstructure of the building but substructure analysis is not considered. Only four loading cases - dead load, live load, wind load and earthquake load are considered and total of twenty-six load combinations are used according to (CQHP) recommendation. Required data for analysis and design specifications of structural elements is used in accordance with UBC-97 and ACI 318-02. Equivalent static analysis is used for seismic design. Considering the effect of lateral load, Intermediate Moment Resisting Frame (IMRF) is chosen for seismic zone 2A. Firstly, the superstructure was analyzed with the basic wind velocity of 80 mph and checked by Storey Drift limitations, P-Δ effects, Torsional Irregularity, Overturning Moment and Sliding. Then, the seismic design of proposed building was repeated with five tropical cyclone categories respectively with the same seismic zone, strengths and rigidities. Similarly, they are also checked their performance. Finally, detailed comparisons are made between the analysis results such as deflection,storeydrift,storey moment andstorey shearof the structural members. It is also investigated the performance and potential deformation or damage to predict how and where the deformation could begin.

Keywords: wind velocity, five tropical cyclone categories, deflection, storey drift, storey moment, storey shear

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I. INTRODUCTION

Myanmar is situated in a secondary belt which is the junction of two major belts called Alps-Himalaya and Circum-Pacific belts so that it is likely to meet such a destructive damage to the buildings in some areas. Myanmar is also vulnerable to cyclone from Bay of Bengal during pre and post monsoon seasons from April to May and October to November. These cyclones cause the heavy rains, floods and storms, especially in the coastal region of Rakhine State-the disaster that afflicts the region every 3-4 years.

Nowadays, the high-rise reinforced concrete buildings are widely used in Myanmar according to political, social and economical demands and the potential of its popularity will be grater in future. In our country, committee for quality control of high-rise building construction projects (CQHP) recommended that more than eight-storey buildings have to be designed by taking into account not only gravity load but also lateral forces like wind earthquake and so on. People encounter an estimated 1 million earthquakes a year around the world. And Cyclone Nargis struck Myanmar on 2 and 3 May, 2008. Cyclone Nargis was a strong tropical cyclone that caused the deadliest natural disaster in the recorded history of Myanmar.

Generally reinforced concrete buildings are designed as seismic design with the basic wind velocity 80 mph in our country. Thus, we need to know the performance of the high-rise buildings designed under the experiences of severer wind and seismic zone. Mawlamyine is chosen as case study location. Today, high-rise reinforced concrete buildings are constructed in Mawlamyine according to several demands. Mawlamyine is situated in seismic zone 2A.

In this study, the structural elements are designed to resist only basic wind velocity 80 mph in seismic zone 2A.The main purpose of this study is to know the performance of the seismic of proposed building under different wind velocities. So, five tropical cyclone categories 95,110,130,155 and 170 mph (Saffir-Simpson Hurricane Scale) are chosen as different wind velocities.By understanding wind-structure interaction clearly, it can predict the behaviors of structure and wind as close as the real behavior of wind-structure interaction effect in practice, and so the most suitable design.

II. TECHNICAL REVIEW

A. Behavior of Tall Building

Tall buildings are designed primarily to serve the needs of an intended occupancy, whether residential, commercial, or, in some cases, a combination, of the two. The dominant design requirement is therefore the provision of an appropriate internal layout for the building. At the same time, it is essential for the architect to satisfy the client's expectations concerning the aesthetic quantity of the building's exterior. The main design criteria are, therefore, architectural, and it is within these that the engineer is usually constrained to fit his structure. Only in exceptionally tall building will structural requirement become a predominant consideration.

Loading on tall building differs from loading on low-rise buildings in its accumulation into much larger structural forces. The lateral loading due to wind or earthquake is the major factor that causes the design of high-rise buildings to differ from those of low-to medium-rise buildings. For buildings of up to about 10 stories and of typical proportions, the design is rarely affected by wind loads. Above this height, however, the increase in size of the structural members, and the possible rearrangement of the structure to account for wind loading, incurs a cost premium that increases progressively with height. Earthquake loading consists of the inertial forces of the building mass that result from the shaking of its foundation by seismic forces. Earthquake resistant design concentrates particularly on the translational inertia forces, whose effects on a building are more significant than the vertical or rotational shaking components. In addition, a check must be made on the most fundamental condition of equilibrium, to establish that the applied lateral forces will not cause the entire building to topple as a rigid body about one edge of the base. Taking moments about that edge, the resisting moment of the dead weight of the building must be greater than the overturning moment for stability by an acceptable factor of safety.

B. Wind Loading in Tall Building

The lateral loading due to wind or earthquake is the major factor that causes the design of high-rise buildings to differ from those of low-to medium-rise buildings. For buildings of up to about 10 stories and of typical proportions, the design is rarely affected by wind loads. Above this height, however, the increase in size of the structural members and the possible rearrangement of the structural members to account for wind loading, incurs a cost premium that increases progressively with height. With innovations in architectural treatment, increases, in the strengths of materials and advances in methods of analysis tall building structures have become more efficient and lighter and consequently, more prone to defect and even to sway under wind loading.

The following review of some representative code methods, which includes ones that are relatively advanced in their consideration of gust loading, summarizes the state of the art. The first method described is a static approach in that it assumes the building to be a fixed rigid body in the wind. Static method is appropriate for tall buildings of unexceptional height, slenderness or susceptibility to vibration in the wind. The second method described dynamic methods are for exceptionally tall, slender, or vibration-prone buildings. These may be defined, for example as in the Uniform Building Code, as those of height greater than 400 ft (123 m), or of a height greater than five times their width, or those with structures that are sensitive to wind-excited oscillations.

III. PREPARATION FOR THE ANALYSIS AND DESIGN OF THE STRUCTURE

A. Selection of Site Location and Structural System

Location-Mawlamyine(Zone 2A)
Type of structure-16-storeyed R.C.C building
Type of occupancy-Residential
Number of apartment-32 units (2units for one storey)
Area of structure -Maximum length 64 ft
Minimum length 40 ft
Height of structure - Typpicalstoreyheight 11 ft
Overall height 198 ft
Shape of building - Rectangular shape
Type of structure - Regular type

B. Material Properties of the Structure

Weight of concrete-150 pcf
Modulus of elasticity- 3.122×10^6
Poisson's ratio - 0.2
Coefficient of thermal expansion - 5.5×10^{-6}in/in per degree F
Reinforcing yield strength (f_y) - 50000 psi
Concrete cylinder strength(f'_c) - 3000 psi

C. Loading Consideration of the Structure

Dead load:
Unit weight of concrete- 150 pcf
4½ inches thick wall weight- 55 pcf (including plaster)
9 inches thick wall weight- 100 pcf (including plaster)
Weight ofceiling-10 psf
Weight of finishing- 12.5 psf
Weight of glass area - 30 psf
Weight of elevator- 3 tons
Live Load:
Live Load on bed Room - 30 psf
Live load on other area - 40 psf
Live load on stairs - 100 psf
Live load on roof - 20psf
Wind Load:
Exposure type - B
Effective height for wind load - 186 ft
Basic wind velocity - 80 mph, 95mph, 110mph, 130mph, 155 mph and 170mph
Structure - Primary frames and systems
Method - Normal force method
Seismic Load:
Seismic zone - 2A
Seismic zone factor - 0.15
Soil profile type - S_D
Seismic source type - C
Seismic coefficient, C_a- 0.22 N_a
Seismic coefficient, C_v- 0.32 N_v

Structural framing system - Intermediate Moment Resisting Frame (IMRF)
Importance factor - 1
Response modification factor - 5.5

D. Load Combination of the Structure

The following load combinations are used for design process according to CQHP recommended.

1.1.4 DL
2.1.4 DL + 1.7 LL
3.1.05 DL + 1.275 LL + 1.275 WINX
4.1.05 DL + 1.275 LL – 1.275 WINX
5.1.05 DL + 1.275 LL + 1.275 WINY
6.1.05 DL + 1.275 LL – 1.275 WINY
7.0.9 DL + 1.3 WINX
8.0.9 DL – 1.3 WINX
9.0.9 DL + 1.3 WINY
10.0.9 DL – 1.3 WINY
11.1.05 DL + 1.28 LL + EQX
12.1.05 DL + 1.28 LL – EQX
13. 1.05 DL + 1.28 LL + EQY
14. 1.05 DL + 1.28 LL – EQY
15. 0.9 DL + 1.02 EQX
16. 0.9 DL – 1.02 EQX
17. 0.9 DL + 1.02 EQY
18. 0.9 DL – 1.02 EQY
19. 1.16 DL + 1.28 LL + EQX
20. 1.16 DL + 1.28 LL – EQX
21. 1.16 DL + 1.28 LL + EQY
22. 1.16 DL + 1.28 LL – EQY
23. 0.79 DL + 1.02 EQX
24. 0.79 DL – 1.02 EQX
25. 0.79 DL + 1.02 EQY
26. 0.79 DL – 1.02 EQY

E. Structural Framing System

For proposed model, soil profile type S_D and seismic zone 2A are chosen. So, IMRF (Intermediate Moment Resisting Frame) is used as one structural system.

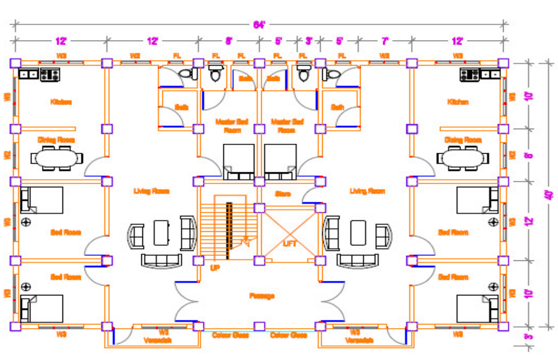

Fig.1 Typical Floor Plan of 2-unit 16-storeyed Building

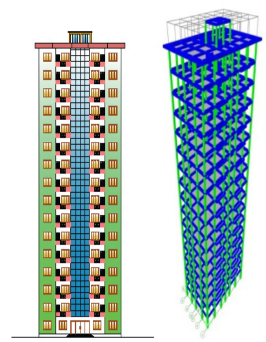

Fig.2 Front Elevation and 3D Model of Case Study Building

F. Structural Stability

The superstructure is needed to check the followings for stability of building.

1. Check for overturning
2. Check for sliding
3. Check for storey drift
4. Check for torsionsl irregularity
5. Check for P-Δ effect

In the checking for overturning moment, the ratio of resisting moment to overturning moment of the proposed building is greater than 1.5. So, overturning moment checking is safety. The factor of sfety for sliding is greater than 1.5. Therefore, there is no sliding occur in the structure. In checking for storey drift, it is found that storey drift all storey do not exceed limit. And the torsional irregularity and P-Δ effects are satisfied for all check. Therefore, the proposed building is satisfied for all stability check.

IV. ANALYSIS AND DESIGN FOR SUPERSTRATURE WITH DIFFERENT WIND VELOCITY

The structure must be analyzed and designed by using basic wind velocity 80 mph to obtain stability seismic design and to reach the final acceptable results by the analysis and design procedures are repeated process. Then, this structure is repeated with five tropical cyclone categories (95, 110, 130, 155 and 170 mph) and the same seismic zone, structural system, material properties and load consideration are used as design input data but they are not redesigned.For all analysis and design of case study building are divided into six categories by the following group name:

For wind velocity 80 mph – Case 1
For wind velocity 95 mph – Case 2
For wind velocity 110 mph – Case 3
For wind velocity 130 mph – Case 4
For wind velocity 155 mph – Case 5
For wind velocity 170 mph – Case 6

V. COMPARISON OF ANALYSIS AND DESIGN RESULTS

A. Comparison of Deflections

Comparison of deflections in X and Y directions at joints by earthquake and wind load for the analysis with different wind velocities 80 mph and five tropical cyclone categories (95, 110, 130, 155 and 170 mph) are shown in Fig.3 and Fig.4.

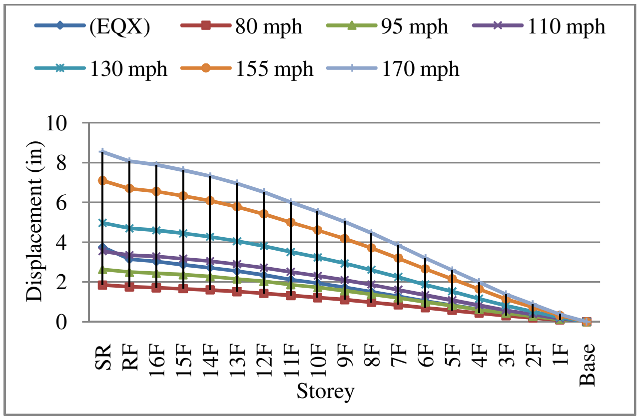

Fig.3 Comparison of Deflection in X direction

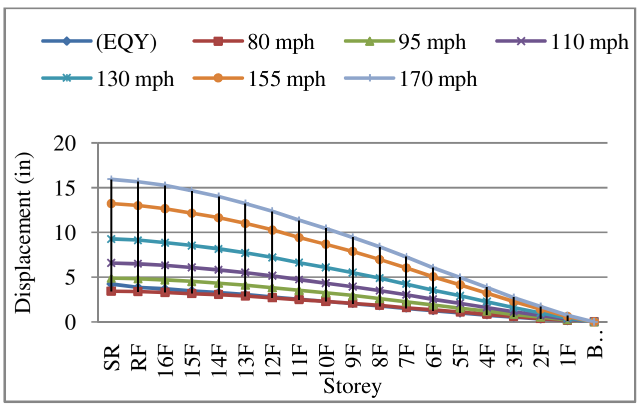

Fig.4 Comparison of Deflection in Y direction

B. Comparison of Maximum Storey Drift

Comparison of maximum storey drifts in X and Y directions for the analysis wind different wind velocities 80 mph and five tropical cyclone categories (95, 110, 130, 155 and 170 mph) are shown in Fig.5 and Fig.6.

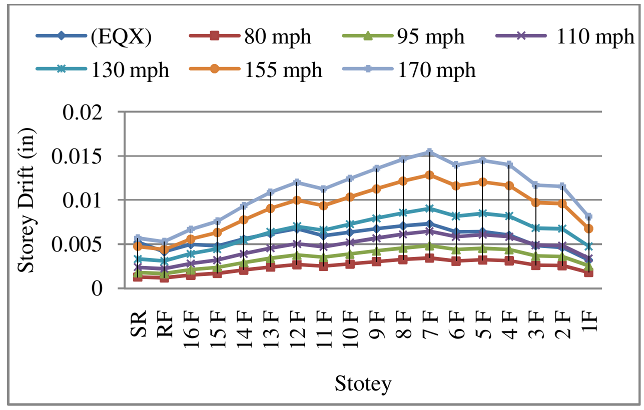

Fig.5 Comparison of Maximum Storey Drift in X-Direction (ΔM_X)

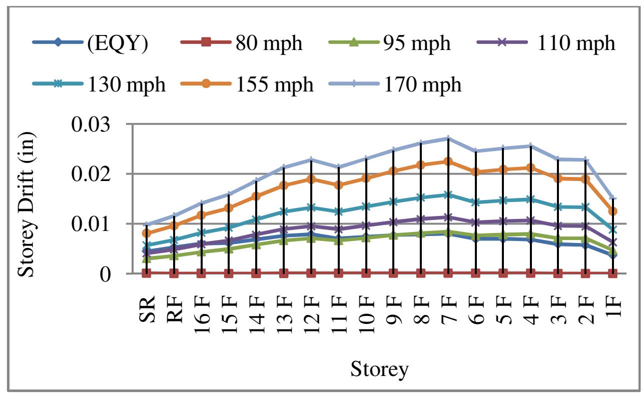

Fig.6 Comparison of Maximum Storey Drift in Y-Direction (ΔM_Y)

C. Comparison of Storey Moment

Different wind velocities used in the analysis. So, the analysis results are changed. The story moments at all level under different wind velocities are also compared. These comparison results are shown in Fig.7and Fig.8.

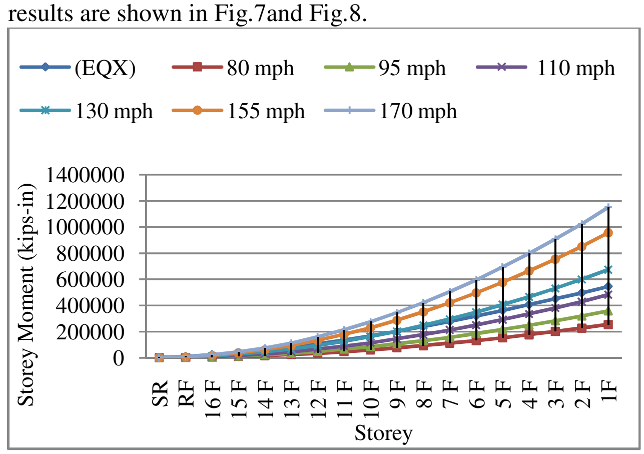

Fig.7 Comparison of Storey Moment in X-Direction for all Level

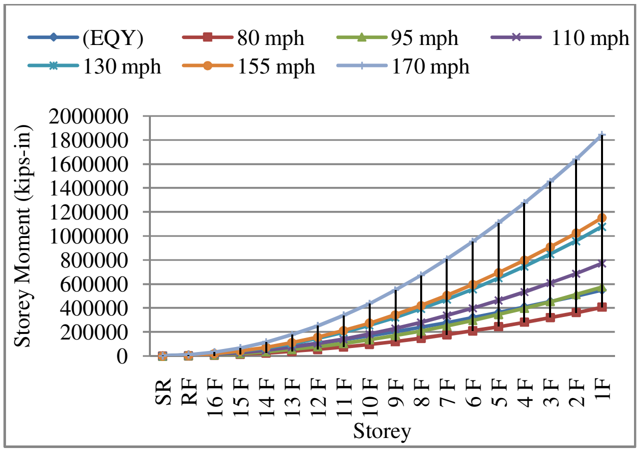

Fig.8 Comparison of Storey Moment in Y-Direction for all Level

D. Comparison of Storey Shear

Different wind velocities used in the analysis. So, the analysis results are changed. And the storey shears at all level under different wind velocities are also compared. These comparison results are shown in Fig.9 and Fig.10.

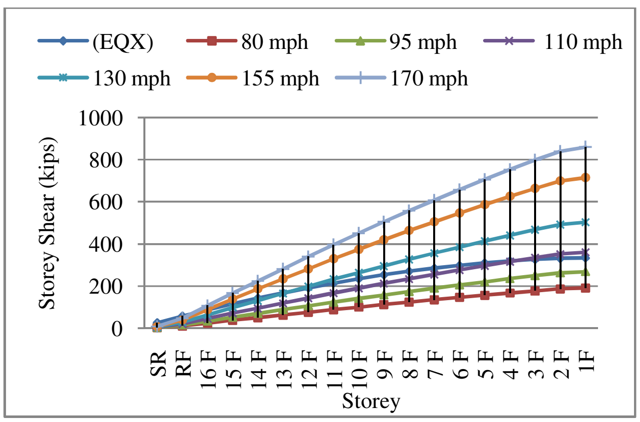

Fig.9 Comparison of Storey Shear in X-Direction for all Level

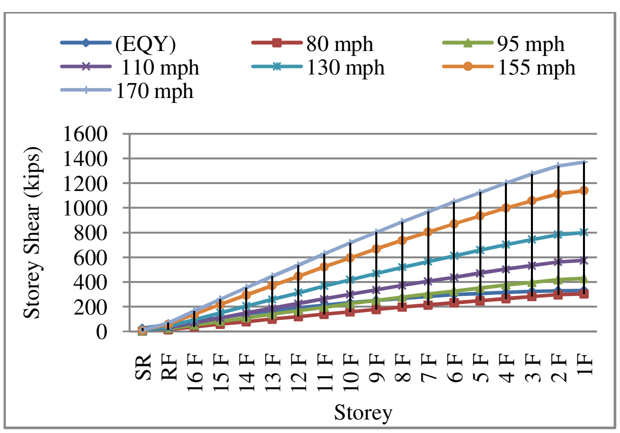

Fig.10 Comparison of Storey Shear in Y-Direction for all Level

E. Comparison of Safety Factors for Different Wind Velocities

Comparison of safety factor of overturning, sliding and torsional irregularity for different wind velocities are shown in Table 1.

Table.1 Comparison of safety factor for all Case

Case	1	2	3	4	5	6	Limit
Overturning For X-direction	7.9	5.6	4.2	3.0	2.1	1.8	>1.5
For Y-direction	3.1	2.2	1.6	1.2	0.8	0.7	
Sliding For X-direction	6.9	4.9	3.6	2.6	1.8	1.5	>1.5
For Y-direction	4.3	3.1	2.3	1.6	1.2	0.9	
Torsional Irregularity	1.0	1.0	1.0	1.0	1.0	1.0	<1.2

F. Comparison for Failure of Columns and Beams

When the structure analysis and design is done by the change of wind velocity, the failure of column and beam are found in case 2 to 6 and storey 1 to 14. The failures of column are found in only case 5 and 6 and the failure percentage of column are 8.16% and 20.41% of the whole structure respectively. And the failures of beam are found in case 2 to 6 and the failure percentage of beam are 2.19%, 5.66%, 20.98%, 39.17% and 45.96% of the whole structure respectively. The failure number of columns and beams are shown in Figure 12 and 13.

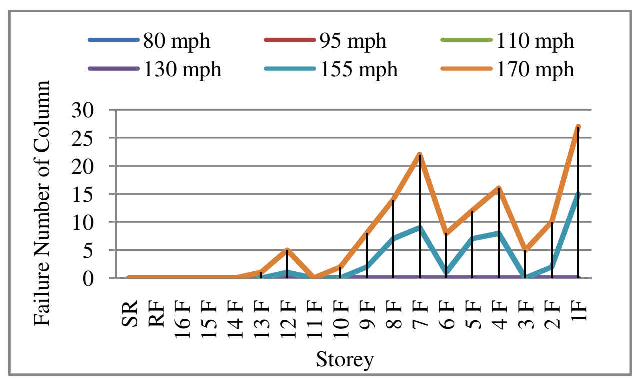

Fig.11 Comparison of Failure Number of Columns in Different Wind Velocities

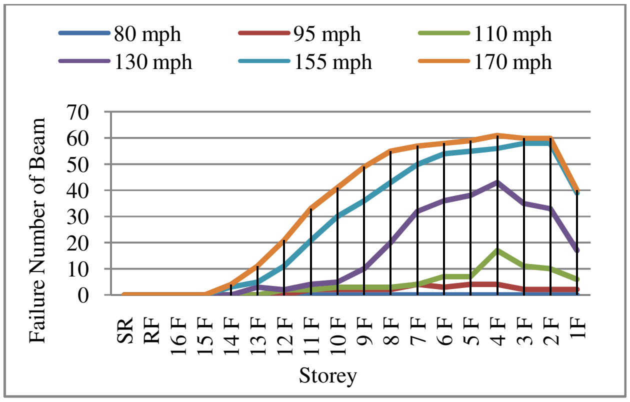

Fig.12 Comparison of Failure Number of Beams in Different Wind Velocities

VI. DISCUSSIONS AND CONCLUSIONS

Firstly, the proposed building is designed according to ACI 318-02 with basic wind velocity 80 mph by using ETABS software. According to UBC-97, storey drift, P-Δ effect, torsional irregularity, overturning and sliding was checked for the structural stability. Then, the structure analysis and design process was repeated in this structure by using five tropical cyclone categories (95, 110, 130, 155 and 170 mph) respectively without any change of design input data except wind velocity. The primary analysis and design results from these analyses were studied without the change of suitable design member size and the analysis results are checked for the structural stability. Then, comparative studies are made. The storey shear, storey moment, storey drifts, displacement, safety factors and failure of beam and column are compared under wind and earthquake loading. The maximum critical forces of beam and column are also compared for all case. Finally, the study is focused on the performance and critical forces of the structural members under different wind velocities with the same structure and the same rigidity. But they are not redesigned.

From the comparative study, it is found that the maximum storey drift increments are large. But those are within the allowable limit, P-Δ effect and torsional irregularity for all case under earthquake and wind loading are also found within the allowable limit. From the result of overturning check, the proposed building can withstand the overturning moment up to wind intensity 110 mph since the height of the case study building is not too much. The sliding effect of the proposed building is less than overturning effect. The proposed building can withstand the sliding effect up to wind intensity 130 mph.

In all comparison results, the influence of seismic and wind loads on the proposed building are (WX of Case 1 to 3) < (EQX) < (WX of Case 4 to 6) for X direction and (WY of Case 1) < (EQY) < (WY of Case 2 to 6) for Y direction. The forces and force increments are large mostly in lower stories, if wind load act from Y direction and if wind load act from X direction, they are large mostly in middle stories. The maximum the failure of structural elements are also found in those stories. So, the structural damage of the proposed building will be initiated at those stories. Among then, the maximum structure failure are also found in those stories. So, it may started that damage will be initiated at those stories.According to the comparison results from this study, the proposed building can not withstand five tropical cyclone categories 95, 110, 130, 155 and 170 mph. So, the proposed building should be designed according to experiences of severer wind and seismic zone to reduce the structural failure due to natural disaster, gust forces.

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