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Comparative Study of Irregular-shaped RC Building with Different Lateral Load Resisting Systems

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Abstract: There has been a considerable increase in modern tall buildings due to the development in construction technology and structural systems. As the building height increase, lateral loads are important consideration and it is necessary to choose a structural system that can resist lateral load effectively. Lateral loads are often resisted by various lateral load resisting systems: Beam-Column System, Shear Wall and Frame System, Frame Tube System, Dia-grid System, Dual System, etc…..In this paper, a particular type of 16-storey Irregular-shaped RC building in Zone IIA is considered with different lateral load resisting systems (i.e – Beam-Column System, Rigid Frame with Shear Wall and Dual System). Modelling and Analysis of building with different load resisting systems are carried out with ETABS V 9.7.4 software. Structural members are designed according to ACI code 318-99 and load consideration is based on UBC-97. In dynamic analysis, Response Spectrum Method is used. The values of stability check such as storey drift, P-Δ effect, Overturning, Sliding in each system are compared. Since the building is irregular-shaped, torsional irregularity is also considered and soft storey and base shear are also check. All this points are considered and the results obtained are plotted and compared with graphs. This paper give information about various lateral load resisting systems and dual system gives better performance than other with same material consumption of lateral load resisting systems.

Keywords: Beam-Column System, Shear Wall, Dual System, Lateral Load, Dynamics Analysis Response Spectrum Method, ETABS, Stability, Torsional Irregularity.

1. INTRODUCTION

Nowadays, the construction of high-rise irregular-shaped residential and commercial buildings are increased in Myanmar. A building shall be considered as an irregular if it lacks symmetry and has discontinuity in geometry, mass or load resisting elements. Building having normal regular geometry in plan and in elevation suffers much less damage than irregular one. Buildings are subjected to two types of load; gravity load and lateral load. Taller the building, lateral loads such as wind load and earthquake load should be considered and it is necessary to choose an appropriate structural system. There are two components in structural system; (i) Horizontal framing system: consists of slabs and beam and (ii) Vertical framing system: consists of beams and columns. Using an appropriate structural system is critical for good seismic performance of building. Therefore, it is important for the structure to have sufficient strength against vertical loads together with adequate stiffness to resist lateral forces.

2. OBJECTIVES

- To investigate the lateral response of building in each system.
- To observe the performance of different lateral load resisting system
- To study the influence of lateral loading on structure

3. LATERAL LOAD RESISTING SYSTEMS

A typical lateral load resisting system consists of horizontal and vertical elements connected together so as to transfer lateral forces from the top of a building to the foundations. The following sections present an overview of the behavior of various structural systems under lateral loading.

3.1 Beam-Column System

In beam-column system, frames are composed of columns and beams. Beam is a horizontal member and transfers the load to column. Column is a vertical member and transfers compressive load to the foundation. Due to the rigidities of the beam and column connections and moment resisting capacities of the individual members, it can resist the lateral loads.

3.2 Rigid Frame with Shear Wall

Wall-Frame structural system is a structural system having combination of rigid frame and shear wall. Shear wall is a constructed as a part of central elevator or service core and frames are arranged in plan in conjunction with the wall. This structural system can resist lateral loads effectively by producing interaction between shear wall and frames.

3.3 Dual System

Dual system is a system consisting of RC frames interacting with RC shear wall. This system resists both gravity and lateral loads using moment resisting frames and shear wall or braced frame. The two systems are designed to resist the total design force in proportion to their lateral stiffness considering the interaction of dual systems of all floor levels. The moment resisting frames are designed to independently resist at least 25% of design base shear.

4. PARAMETRIC STUDIES

In high-rise building, it is important to choose the suitable structural system which satisfy the strength and stiffness requirement. In this paper, the comparison of beam-column system, rigid frame with shear wall and dual system is presented. Analysis is carried out in ETABS and results are compared.

(1)Model 1: Beam-Column System

(2)Model 2: Rigid Frame with Shear Wall

(3)Model 3: Dual System

4.1 Study Parameters

(a) Type of building: Irregular-shaped RC building

(b) Number of story: 16

(c) Height of building: 168ft

(d) Plan dimension: maximum length = 152.5ft

maximum width = 9ft

Table 1. Material properties

Modulus of elasticity, E	3600ksi
Poisson's ratio	0.2
Coefficient of thermal expansion	5.5x10⁻6in/in per ˚F
Reinforcing yield stress, fy	50000psi
Shear reinforcement yield stress, fs	50000psi
Concrete strength, f'c	4000psi

(f) Design Loads

(i) Dead Loads

Dead loads are permanent and result from the weight of structure and all other permanently attached materials.

Table 2. Dead load data

4 ½″ thick brick wall	50psf
9″ thick brick wall	100psf
Weight of elevator	2tons
Superimposed D.L	20psf
Unit weight of concrete	150pcf

(ii) Live Loads

Live loads consist of temporary or short duration occupancy loads. They are moveable and their intensity may vary in locations.

Table 3. Live load data

For shopping center, restaurant, ballroom & staircase	100psf
For hotel room	50psf

(iii) Wind Loads

Wind loads shall be assumed to come from any horizontal direction.

Table 4. Wind load data

Exposure type	B
Leeward coefficient	0.5
Windward coefficient	0.8
Importance factor, I	1
Basic wind speed	100mph
Method	Normal Force Method

(iv) Earthquake Loads

Earthquake loads is the result from the shaking of foundation by seismic disturbance.

Table 5. Earthquake load data

Zone factor	0.2
Soil type	S_D
Importance factor, I	1
Response modification factor, R	5.5 (6.5 for dual)
Time period, Ct	0.03
Seismic coefficient, C_a	0.28
Seismic coefficient, C_v	0.4

4.2 Load Combination

There are 26-factored load combinations used in structural analysis based on ACI 318-99 and UBC-97.
Type of analysis – Dynamic Analysis

Table 6. 26 load combinations

COMB 1	1.4 TDL
COMB 2	1.4 TDL + 1.7 TLL
COMB 3	1.05 TDL + 1.275 TLL + 1.275 WX
COMB 4	1.05 TDL + 1.275 TLL – 1.275 WX
COMB 5	1.05 TDL + 1.275 TLL + 1.275 WY
COMB 6	1.05 TDL + 1.275 TLL – 1.275 WY
COMB 7	0.9 TDL + 1.3 WX
COMB 8	0.9 TDL – 1.3 WX
COMB 9	0.9 TDL + 1.3 WY
COMB 10	0.9 TDL – 1.3 WY
COMB 11	1.05 TDL + 1.275 TLL + SPX
COMB 12	1.05 TDL + 1.275 TLL – SPX
COMB 13	1.05 TDL + 1.275 TLL + SPY
COMB 14	1.05 TDL + 1.275 TLL – SPY
COMB 15	0.9 TDL + 1.02 SPX
COMB 16	0.9 TDL – 1.02 SPX
COMB 17	0.9 TDL + 1.02 SPY
COMB 18	0.9 TDL – 1.02 SPY
COMB 19	1.16 TDL + 1.275 TLL + SPX
COMB 20	1.16 TDL + 1.275 TLL – SPX
COMB 21	1.16 TDL + 1.275 TLL + SPY
COMB 22	1.16 TDL + 1.275 TLL – SPY
COMB 23	0.79 TDL + 1.02 SPX
COMB 24	0.79 TDL – 1.02 SPX
COMB 25	0.79 TDL + 1.02 SPY
COMB 26	0.79 TDL – 1.02 SPY

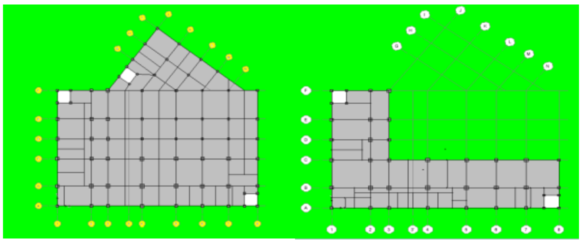
5. MODELLING IN ETABS

Table 7. Structural members sizes used in three models

Column size	16″x16″,18″x18″,20″x20″,22″x22″,24″x24″,26″x26″,28″x28″,30″x30″,32″x32″,34″x34″,36″x36″,38″x38″
Beam Size	10″x12″, 12″x18″,14″x20″,14″x24″,16″x24″
Slab Thickness	6″
Shear Wall Thickness	14″

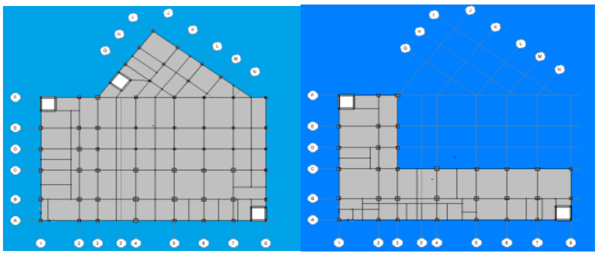
Column size change every fourth floor.

Three buildings of 16storey irregular-shaped are modelled in ETABS V 9.7.4 and plan of the building in each system and 3D model of structures are shown in figure 1, 2, 3, 4.



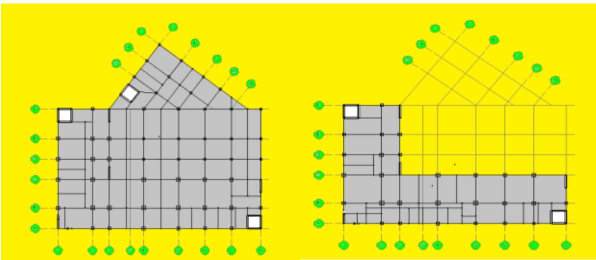
(a) (b)

Figure 1. Plan for beam-column system: (a) GF to 3rd floor & (b) 5th floor to roof



(a) (b)

Figure 2. Plan for rigid frame with SW: (a) GF to 3rd floor & (b) 5th floor to roof



(a) (b)

Figure 3. Plan for dual system: (a) GF to 3rd floor & (b) 4th floor to roof

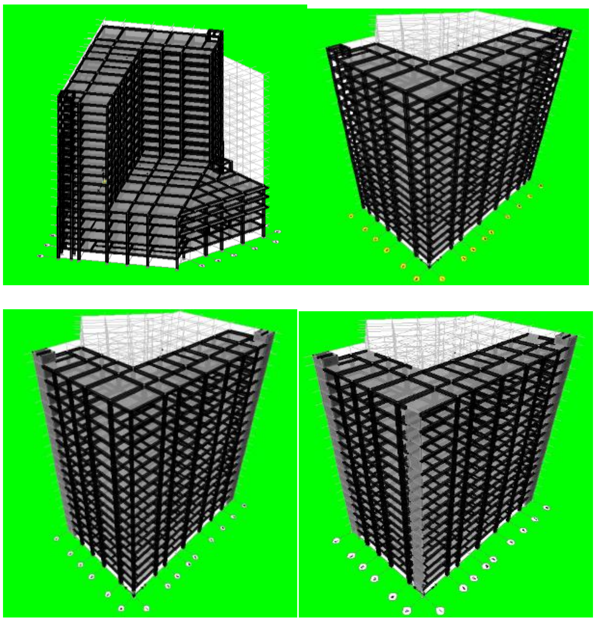


Figure 4. 3D models of structure in each system

6. ANALYSIS RESULTS

6.1 Storey Drift

Story drift is the lateral displacement (deflection)

$$\Delta m = 0.7R\Delta s$$

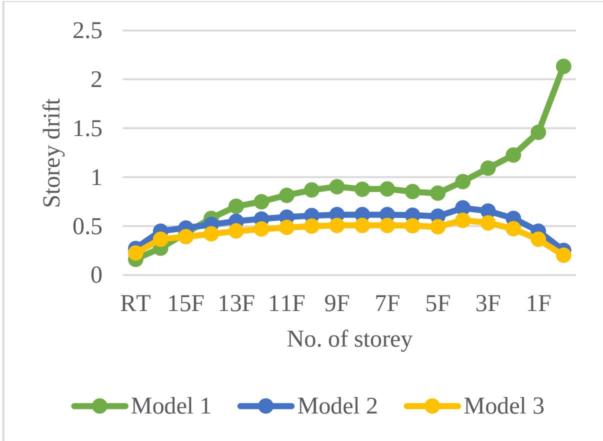


Figure 5. Storey drift in X-X direction

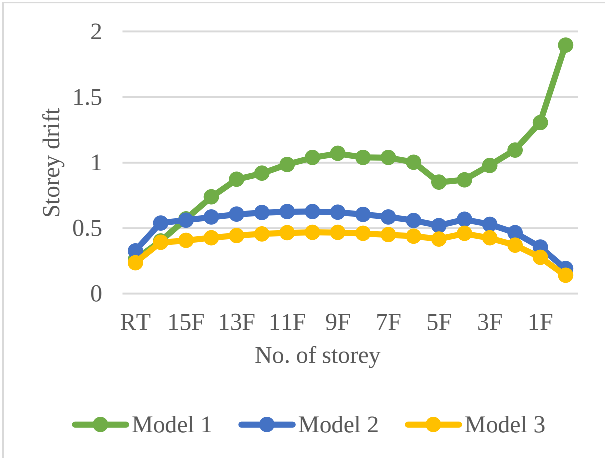


Figure 6. Storey drift in Y-Y direction

From figure 5 and 6, the results show that storey drift values in X-direction and Y-direction was found comparatively lesser in dual system than beam-column system and rigid frame with shear wall.

6.2 P-Δ Effect

When the structure is acted upon by a lateral (seismic load), the structure becomes laterally displaced and applied. According to UBC-97, the member forces, moments and story displacements are generated by P-Δ effect. It should be considered in the evaluation of overall structural frame stability.

$$\vartheta_x = P_x \, \Delta s_x / V_x \, h_x$$

The stability coefficient is much smaller than allowable limit 0.1.

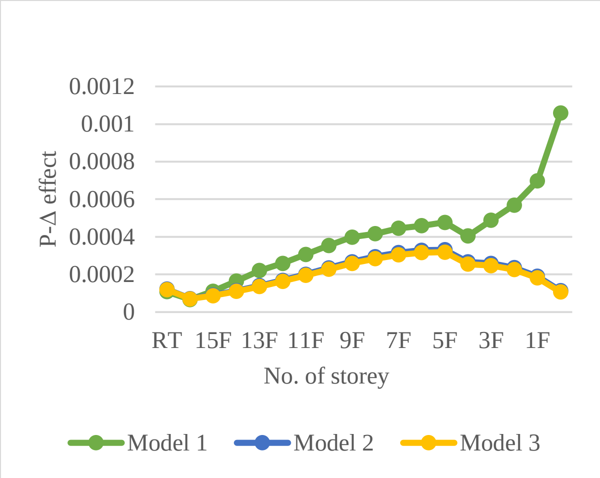


Figure 7. P-Δ effect in X-X direction

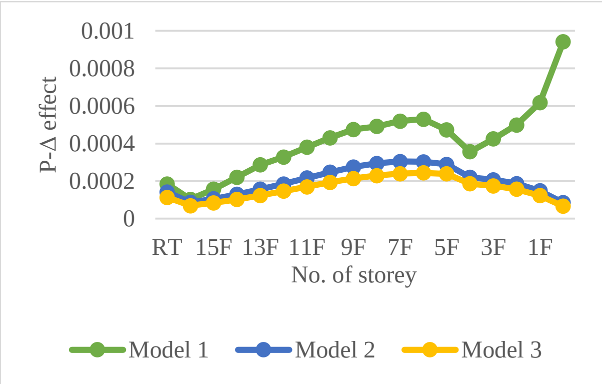


Figure 8. P-Δ effect in Y-Y direction

From above figure 7 & 8, it is observed that model 2 and model 3 gives less displacement compared to model 1.

6.3 Overturning Moment

The distribution of earthquake forces over the height of a structure cause the structure to experience overturning effect. According to UBC-97, every structure is to be designed to resist the overturning effects caused by seismic forces.

Safety Factor = Resisting Moment/Overturning Moment >1.5

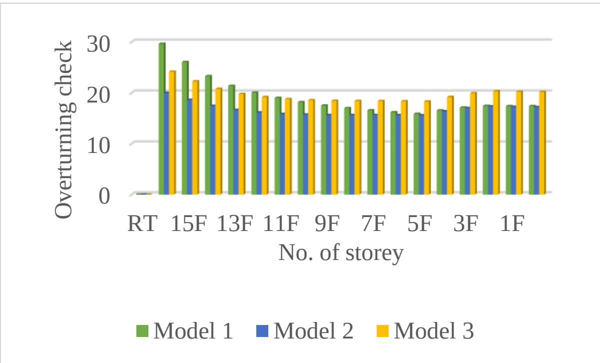


Figure 9. Overturning check in X-X direction

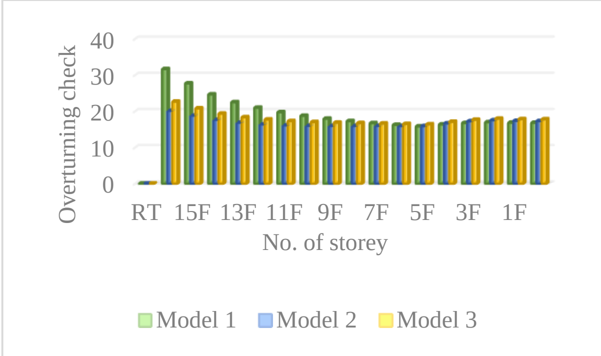


Figure 10. Overturning check in Y-Y direction

6.4 Sliding Check

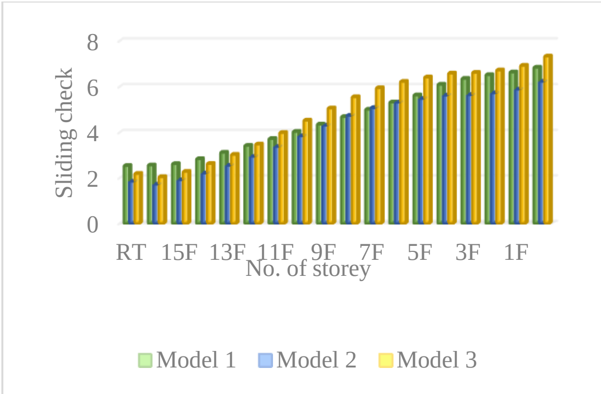


Figure 11. Sliding check in X-X direction

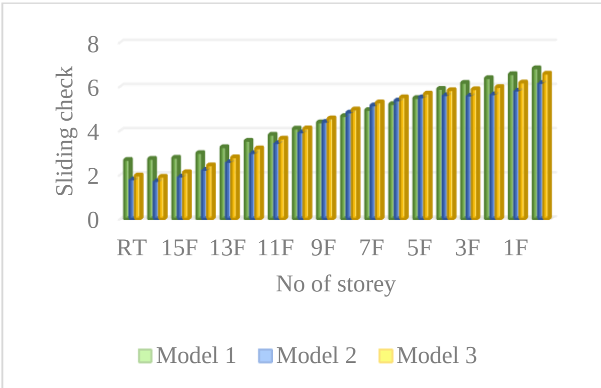


Figure 12. Sliding check in Y-Y direction

6.5 Base Shear

Base shear is an estimate of the maximum expected lateral force that will occur due to seismic ground motion at the base of the structure

Table 8. Base shear

Storey	Model 1	Model 2	Model 3
RT	4525.86477	4607.050573	4617.817
RB	3085.344054	3140.689528	3148.0291
15F	3085.344054	3140.689528	3148.0291
14F	3085.344054	3140.689528	3148.0291
13F	3085.344054	3140.689528	3148.0291
12F	3085.344054	3140.689528	3148.0291
11F	3085.344054	3140.689528	3148.0291
10F	3085.344054	3140.689528	3148.0291
9F	3085.344054	3140.689528	3148.0291
8F	3085.344054	3140.689528	3148.0291
7F	3085.344054	3140.689528	3148.0291
6F	3085.344054	3140.689528	3148.0291
5F	3085.344054	3140.689528	3148.0291
4F	2690.986069	2739.257477	2745.6589
3F	2690.986069	2739.257477	2745.6589
2F	2690.986069	2739.257477	2745.6589
1F	2690.986069	2739.257477	2745.6589
GF	2690.986069	2739.257477	2745.6589

6.6 Torsional Irregularities

Torsional irregularity is to be considered to exist when the maximum story drift, calculated with design eccentricity, at one corner of the structures transverse to an axis is greater than 1.2times the average of the story drifts at the two ends of the structure.

Table 9. Torsional Irregularities Check

Model	Max: Story drift	Average story drift	Δmax/Δavg <1.2	Structural Irregularity
Model 1	3.4181	3.14625	1.09	Does not exist
Model 2	2.2133	1.87165	1.18	Does not exist
Model 3	1.8097	1.58115	1.15	Does not exist

7. CONCLUSION

From the above study of comparison between three lateral load resisting systems, the following results has been obtained. Story drift values in X-direction and Y-direction were found comparatively lesser in dual system than beam-column system and frame with shear wall system. Beam-column system produces greater deflection and drift. Shear wall produce large effects of overturning. Torsional irregularity can be avoided in building by providing proper shape and symmetry in structure. It is found that structure with dual system gives better performance than other with same material consumption of lateral load resisting systems. It may conclude that dual system gives result than other as in the case of time period, displacement, story force and stiffness.

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