Comparison of Seismic Performance of Buildings with Conventional Slab and Flat Slab in Different Zones of Bangladesh

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Abstract

As usable land is scarce in Bangladesh, the demand for high-rise buildings has risen over the past few decades. Conventionally, reinforced cement concrete (RCC) structures in Bangladesh have been used for residential, educational, institutional & commercial purposes. Bangladesh is located in a relatively earthquake-prone region on the fault plane; it is of utmost importance to assess seismic conditions while constructing a structure. Three types of slabs have been analyzed: conventional RCC slab, flat slab with drop panel, and flat slab with drop panel & shear wall. Typically, a conventional RCC slab contains a beam, column & slab with a large thickness of the beam. To avoid this, a flat slab with a drop panel may be used, but it has some limitations. As it has no lateral support, a flat slab with a shear wall can be replaced to gain more stability. According to BNBC 2006, Bangladesh was divided into three seismic zones. However, according to BNBC 2020, it is revised into four seismic zones. Seismic comparisons of three models in four seismic zones have been conducted. Maximum story displacement, maximum story drift, overturning moment and story shear have been found after analyzing three different types of models located in different seismic zones. The maximum story displacement and maximum story drift for flat slabs are greater than conventional slabs and flat slabs with shear walls. Moreover, the displacement between conventional and flat slabs with shear walls varies a little. Maximum overturning moment and story shear: it appears that for the traditional slab, the value is maximum, the flat slab is minimum, and the flat slab with the shear wall is between those two. The model for flat slab has been found to be more flexible than conventional RCC slab and flat slab with the shear wall.

Keywords: Site Co-efficient, Building Period, Maximum story displacement, Maximum story drift, Overturning moment and Story shear

1. Introduction

Developing countries demand shelter for their growing populations. Due to the scarcity of land, vertical construction in the form of low-rise, medium-rise, and high-rise buildings is taking over to provide for the ever-increasing inhabitants. To keep pace with people's demands, the construction technique is being modified from time to time. The widespread construction practice with conventional RCC slabs proves high strength and stiffness. In general, the slabs are constructed on beam and column supports. As a result, the depth of the beam decreases, thereby increasing the existing net clearance height. In some scenarios, slabs are directly supported on columns without the need for beams. This type of slab is classified as a flat slab. Flat slabs are visually appealing to the general public. However, the predominant problem faced by the designers in the vertical growth of the cities is efficiently handling the seismic forces, which need to be revised, and unpredictable. Flat slabs have a low resistance against lateral forces, so they need to be reinforced via different procedures, such as shear walls. Hence, earthquake modeling is to be executed carefully. Seismic forces cause different levels of vibration based on different regions and the variance in the damage rate. Factors such as the intensity of vibration and duration are crucial for understanding the effects of seismic force. Different types of slab construction systems deal with seismic forces in different ways.

Conventional RCC slabs are most commonly used in Bangladesh. They are supported on frames consisting of beams and columns. In this type of slab, the thickness tends to remain smaller, whereas the depth of the beam is usually large. It requires more formwork than most other slabs, such as flat slabs. Typically, there are two types: one-way and two-way slabs.

The conventional system tends to occupy a great deal of space. To overcome this problem, a special slab type, Flat Slab, is used. In general, a flat slab is a one-way or two-way system supported directly on columns or load-bearing walls.

Hence, this floor system is very popular nowadays. In our project, we have considered only these three types of slabs, i.e., conventional RCC slab, flat slab with drop, and flat slab with drop and shear wall.

No specific building code in Bangladesh was established before 1993. In 1993, the Bangladesh National Building Code (BNBC) was published by the Housing and Building Research Institute (HBRI), which is commonly known as BNBC. The seismic design provisions of BNBC were based on the UBC. Since then, BNBC has been widely used by engineers. BNBC has different provisions for earthquake load calculation and analysis procedures. For regular structures, the code defines a simple method to represent earthquake-induced inertia forces by equivalent static force for static analysis. As the codes were eventually developed throughout the decades, ETABS has removed the UBC 97 code, which is regarded as obsolete. So, the ASCE 7-05 code was utilized in this study instead of the UBC 97 to understand the phenomenon of seismic forces.

The wide availability of computer technology has made a more realistic simulation of structural behavior possible under seismic loading. The focus on seismic design in current building codes is of utmost importance. Economic losses due to recent earthquakes are estimated to be in the billions, and the numbers will be higher if the indirect losses are included. This fact lets code committees and decision-makers think beyond life safety, which is essential in design to alleviate economic losses. This trend creates an increased interest in performance-based design for structure.

In the study, **Spoorthy & Reddy (2018**) compared the seismic behaviour of conventional slabs and flat slabs. **Lande & Raut (2015**) definitively examined five different types of slab systems: flat slabs, flat slabs with perimeter beams, flat slabs with shear walls, flat slabs with drop panels, and conventional RCC slabs, utilising ETABS nonlinear version 9.7.3.

In a study by **Thakkar & Chandiwala (2016)**, various multistory buildings with different structural configurations were analysed using ETABS software. The analysis covered parameters such as story

displacement, shear, drift, axial force, and base shear for G+5, G+8, and G+11 structures with flat slabs containing drop walls, flat slabs without drop walls, and conventional RCC slabs.
In a separate study, **Bari & Das (2013)** compared seismic provisions in different building codes, providing valuable insights into the variations among the codes.
Suri & Jain (2018) carried out a comprehensive analysis of three different building models using ETABS. The study focused on conventional and flat slabs with perimeter beams in two distinct Indian seismic zones, III and IV, shedding light on the structural behaviour under seismic loading.
Bangladesh is prone to frequent earthquakes, and it is crucial to expedite the implementation of safety measures. Seismic activity significantly impacts buildings, necessitating thorough seismic analysis to understand their behaviour during earthquakes. While conventional RCC structures have high slab thickness and increased dead load, adopting flat slab structures offers a viable solution to reduce forces. However, it is important to note that flat slabs may experience higher displacement and drift, highlighting the necessity of incorporating shear walls for essential lateral support.
The study aims to develop three distinct models, namely the conventional RCC Slab, flat slab with drop wall, and flat slab with drop, and shear wall. These models will be meticulously analyzed using finite element software to obtain data on maximum story displacement, maximum story drift, overturning moment, and story shear. Subsequently, the results will be rigorously compared across different seismic zones to draw meaningful conclusions.

2. Methodology

The study aims to assess procedures using Finite Element software and analyze seismic behavior using the Equivalent Linear Static Analysis Method in ETABS. It evaluates the seismic performance of buildings with conventional slab and flat slab in a hypothetical structure of similar height (G+15). The models considered are conventional RCC slab, flat slab with drop panel, and flat slab with drop panel & shear wall, representing mass distribution, strength, stiffness, and deformability.
For three different types of models (conventional RCC slab, flat slab with drop and flat slab with shear wall), the plan views have shown in figure 1 to figure 3 -

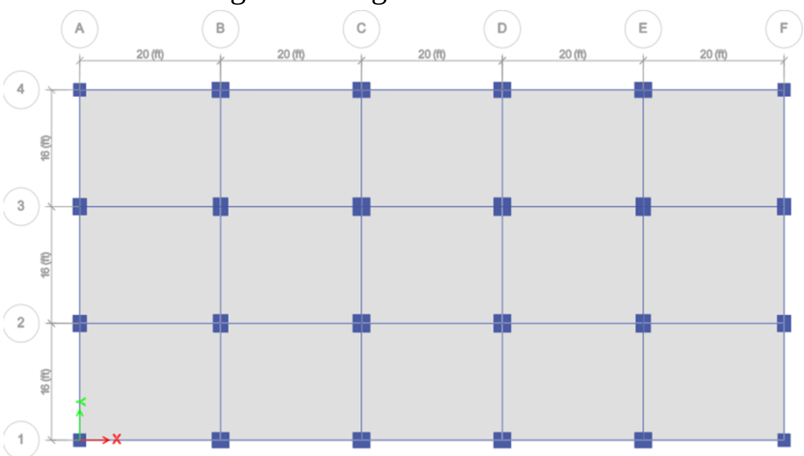

Figure-1: Plan view of conventional RCC slab (Model-1)

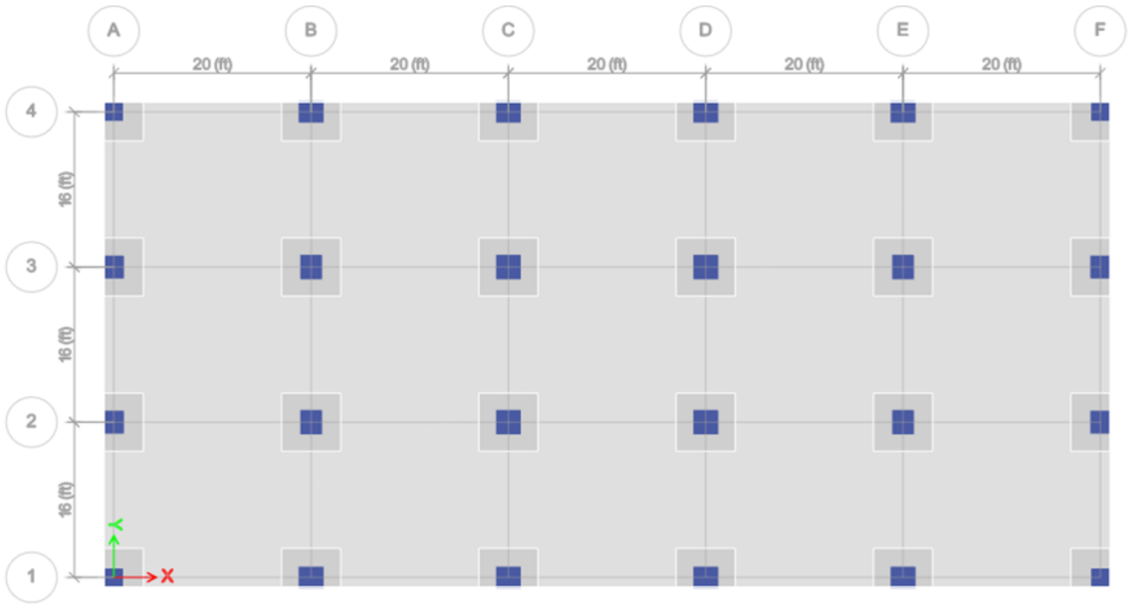

Figure-2: Plan view of flat slab with drop (Model-2)

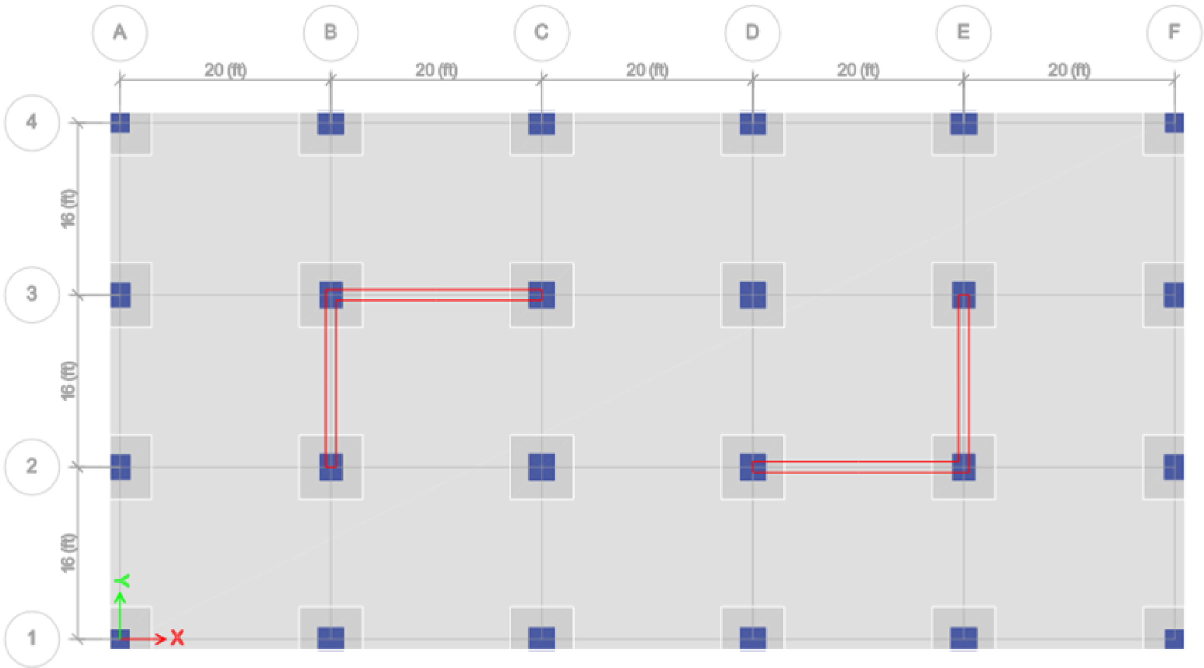

Figure-3: Plan view of flat slab with drop & shear wall (Model-3)

The Member size, slab, drop panel and shear wall thickness for models are given in table-1-

Table-1: Building model detailing

Design data of building		Dimensions	
Plan dimensions		100 ft X 48 ft	
No. Stories		16 (G+15)	
Column c/c distance in X direction		20 ft	
Column c/c distance in Y direction		16 ft	
Typical story height		10 ft	
Base story height		8 ft	
Types of material		Concrete	
Code standard		ACI 318-19	
Strength of concrete		4000 psi	
Grade of reinforcement		G60	
Section name	**Conventional RC Slab**	**Flat Slab**	**Flab slab with shear wall**
Column	C1= 22"X22"	C1= 22"X22"	C1= 22"X22"
	C2=24"X28"	C2=24"X28"	C2=24"X28"
	C3=26"X30"	C3=26"X30"	C3=26"X30"
	C4=30"X30"	C4=30"X30"	C4=30"X30"
Floor beam	B1=20"X24"		
	B2=22"X26"		
Grade beam	GB1=22"X26"	GB1=22"X26"	GB1=22"X26"
	GB2=22"X28"	GB2=22"X28"	GB2=22"X28"
Slab	Thickness=6"	Thickness=6"	Thickness=6"
Drop panel		Panel size=6'x6'	Panel size=6'x6'
		Thickness=12"	Thickness=12"
Shear wall			Thickness=12"

Here,

C1= Corner column
C2= Exterior column
C3= Exterior and interior column
C4= Interior column

B1=Exterior floor beam
B2=Interior floor beam
GB1=Exterior grade beam
GB2=Interior grade beam

For three different types of models (conventional RCC slab, flat slab with drop and flat slab with shear wall), the three dimensional views have shown figure 4 to figure 6 -

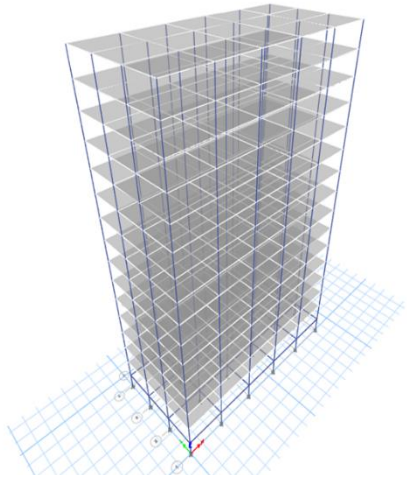

Figure-4: Conventional RCC slab (Model-1)

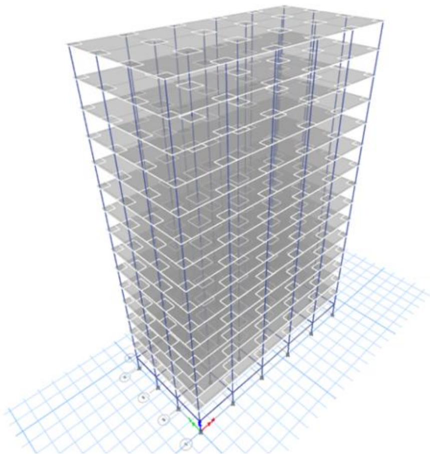

Figure-5: Flat slab with drop (Model-2)

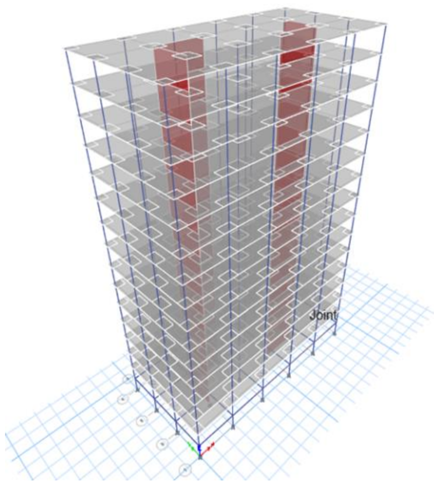

Figure-6: Flat slab with shear wall (Model-3)

According to BNBC 2020, Dead Load, Live Load and Seismic Load are given below in Table-2

Table-2: Dead Load, Live Load & Seismic Load

<table>
<tr><th>Dead Load and Live Load</th><th colspan="2">Loads</th><th colspan="2">Unit</th></tr>
<tr><td>Floor Slab Load</td><td colspan="2">16.4</td><td colspan="2">Psf</td></tr>
<tr><td>Roof Slab</td><td colspan="2">9.99</td><td colspan="2">Psf</td></tr>
<tr><td>Partition Wall Load</td><td colspan="2">44.7</td><td colspan="2">Psf</td></tr>
<tr><th>Seismic load</th><th>Zone-1</th><th>Zone-2</th><th>Zone-3</th><th>Zone-4</th></tr>
<tr><td>0.2 Sec Spectral acceleration (Ss)</td><td>0.3</td><td>0.5</td><td>0.7</td><td>0.9</td></tr>
<tr><td>1 Sec Spectral acceleration (S1)</td><td>0.12</td><td>0.2</td><td>0.28</td><td>0.36</td></tr>
<tr><td>Importance factor, I</td><td colspan="4">1</td></tr>
<tr><td>Site coefficient, Fa</td><td>1.15</td><td>1.15</td><td>1.15</td><td>1.15</td></tr>
<tr><td>Site coefficient, Fv</td><td>1.725</td><td>1.725</td><td>1.725</td><td>1.725</td></tr>
<tr><th>Structural type</th><th>Seismic force resisting system</th><th>Response modification, R</th><th>System over strength, Ω</th><th>Deflection amplification, Cd</th></tr>
<tr><td>Moment resisting frame system (no Shear wall)</td><td>Intermediate reinforced concrete moment frames</td><td>5</td><td>3</td><td>4.5</td></tr>
<tr><td>Building frame systems (with bracing or shear wall)</td><td>Ordinary reinforced concrete shear walls</td><td>5</td><td>2.5</td><td>4.25</td></tr>
<tr><td>Building Period</td><td colspan="3">1.524</td><td>Sec</td></tr>
<tr><td>Long Period Trans.</td><td colspan="3">2</td><td></td></tr>
</table>

3. Results and Discussion

3.1 Maximum Story Displacement

Zone-1: For earthquake in global X direction (EQX), story displacement of flat Slab is 4.74 times greater than Conventional RCC Slab, whereas Flat Slab with Shear Wall is 1.13 times greater than Conventional RCC Slab.

For earthquake in global Y direction (EQY), story displacement of flat slab is 3.38 times greater than conventional RCC slab, whereas flat slab with shear wall is 1.40 times greater than conventional RCC slab.

From Figure-7, it has been showed that story displacement of conventional RCC slab, flat slab and flat slab with shear wall in X and Y direction. Here, X axis represents the number of stories and Y axis represents the maximum story displacement.

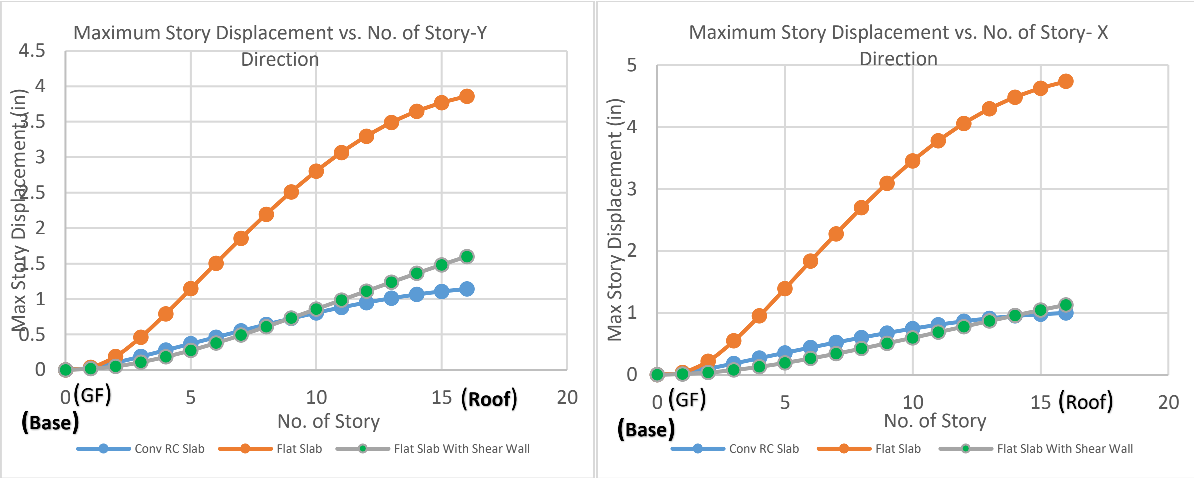

Figure-7: Max story displacement vs. No. of stories graph (Zone 1, X and Y-direction)

Zone-2: For earthquake in global X direction (EQX), story displacement of flat slab is 4.74 times greater than conventional RCC slab and flat slab with shear wall is 1.07 times greater than conventional RCC slab.

For earthquake in global Y direction (EQY), story displacement of flat slab is 3.38 times greater than conventional RCC slab and flat slab with shear wall is 1.30 times greater than conventional RCC slab.

From Figure-8, it has been showed that story displacement of conventional RCC slab, flat slab and flat slab with shear wall in X and Y direction. Here, X axis represents the number of stories and Y axis represents the maximum story displacement.

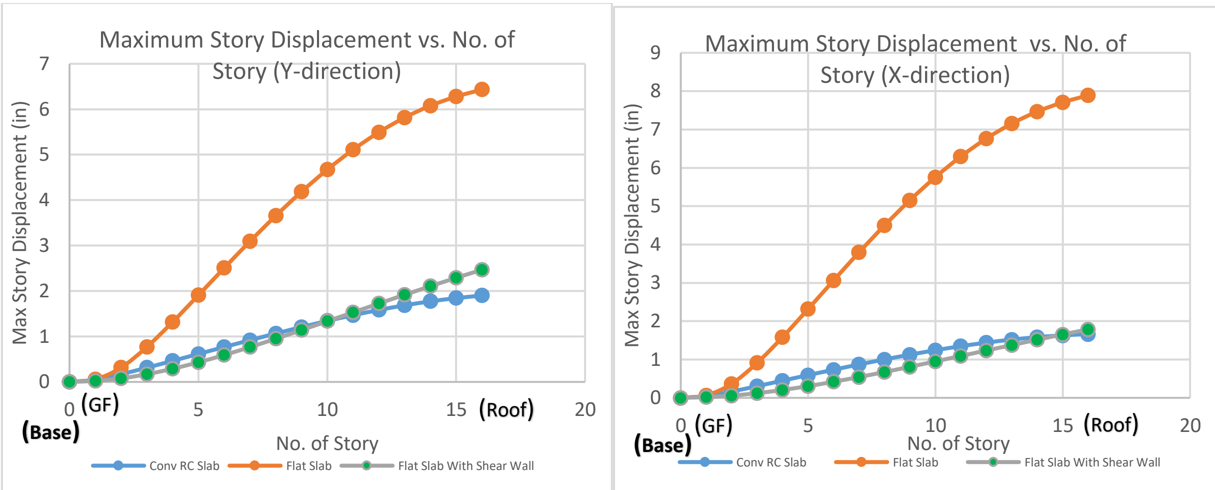

Figure-8: Max story displacement vs. No. of stories graph (Zone 2, X and Y-direction)

Zone-3: For earthquake in global X direction (EQX), story displacement of flat slab is 4.75 times greater than conventional RCC slab and flat slab with shear wall is 1.05 times greater than conventional RCC slab.

For earthquake in global Y direction (EQY), story displacement of flat slab is 3.39 times greater than conventional RCC slab and flat slab with shear wall is 1.25 times greater than conventional RCC slab.

From Figure-9, it has been showed that story displacement of conventional RCC slab, flat slab and flat slab with shear wall in X and Y direction. Here, X axis represents the number of stories and Y axis represents the maximum story displacement.

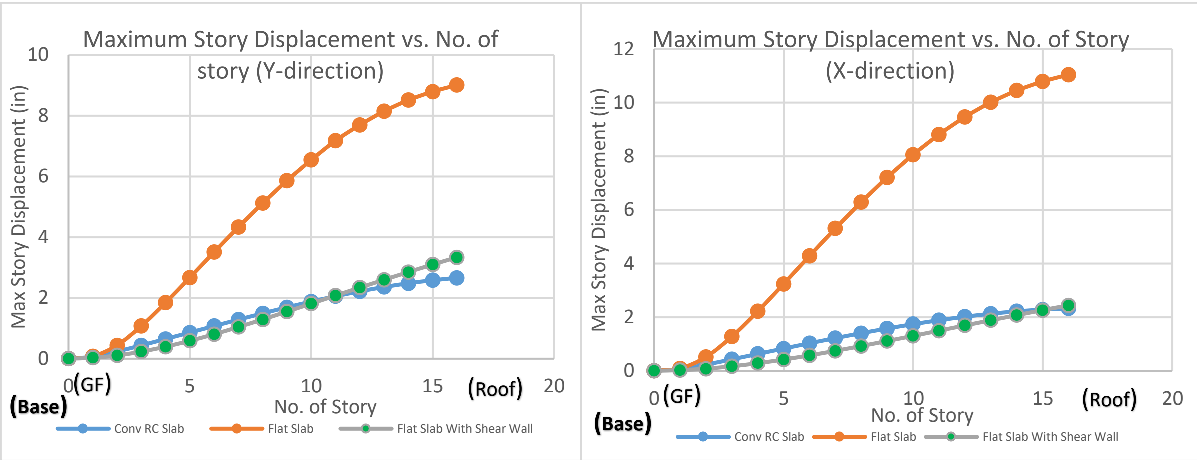

Figure-9: Max story displacement vs. No. of stories graph (Zone 3, X and Y-direction)

Zone-4: For earthquake in global X direction (EQX), story displacement of flat slab is 4.75 times greater than conventional RCC slab and flat slab with shear wall is 1.04 times greater than conventional RC slab. For earthquake in global Y direction (EQY), story displacement of flat slab is 3.39 times greater than conventional RCC slab and flat slab with shear wall is 1.23 times greater than conventional RCC slab.

From Figure-10, it has been showed that story displacement of conventional RCC slab, flat slab and flat slab with shear wall in X and Y direction. Here, X axis represents the number of stories and Y axis represents the maximum story displacement.

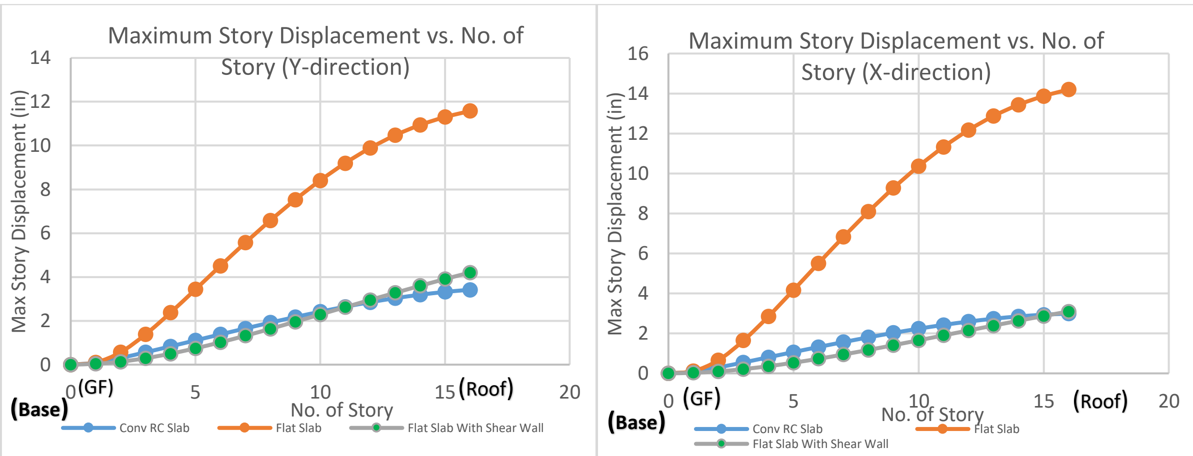

Figure-10: Max story displacement vs. No. of stories graph (Zone 4, X and Y-direction)

3.2 Maximum Story Drifts

Zone-1: For earthquake in global X direction (EQX), the maximum drifts for conventional RCC slab is 0.000721 at S3, flat slab is 0.003727 at S5 and flat slab with shear wall is 0.000753 at S11.

For earthquake in global X direction (EQX), the maximum drifts for conventional RCC slab is 0.000761 at S4 & S5 , flat slab is 0.002989 at S5 and flat slab with shear wall is 0.001059 at S10.

From Figure-11, it has been showed that maximum storey displacement of conventional RCC slab, flat slab and flat slab with shear wall in X and Y direction. Here, X axis represents the number of stories and Y axis represents the maximum story displacement.

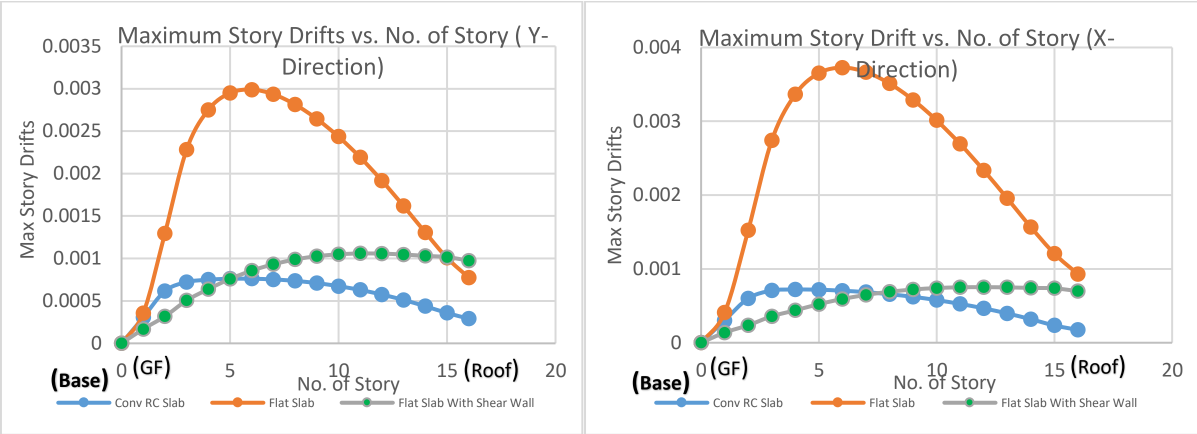

Figure-11: Max story drift vs. No. of stories graph (Zone 1, X and Y-direction)

Zone-2: For earthquake in global X direction (EQX), the maximum drifts for conventional RCC slab is 0.001201 at S3, flat slab is 0.006212 at S5 and flat slab with shear wall is 0.001187 at S11.

For earthquake in global Y direction (EQY), the maximum drifts for conventional RCC slab is 0.001268 at S4 & S5, flat slab is 0.004982 at S5 and flat slab with shear wall is 0.001629 at S10.

From Figure-12, it has been showed that maximum storey displacement of conventional RCC slab, flat slab and flat slab with shear wall in X and Y direction. Here, X axis represents the number of stories and Y axis represents the maximum story displacement.

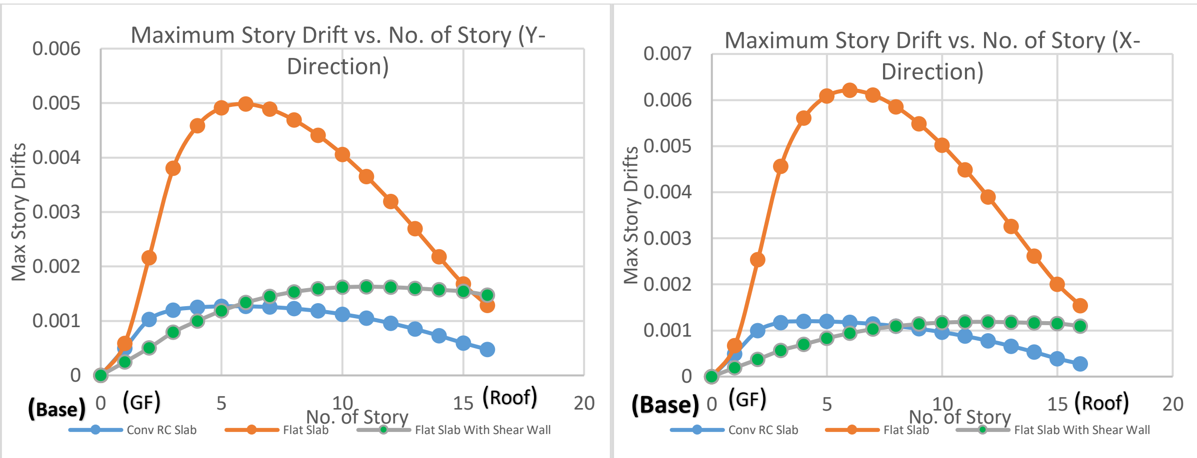

Figure-12: Max story drift vs. No. of stories graph (Zone 2, X and Y-direction)

Zone-3: For earthquake in global X direction (EQX), the maximum drifts for conventional RCC slab is 0.001682 at S3, flat slab is 0.008697 at S5 and flat slab with shear wall is 0.00162 at S11.

For earthquake in global Y direction (EQY), the maximum drifts for conventional RCC slab is 0.001776 at S5, flat slab is 0.006975 at S5 and flat slab with shear wall is 0.002199 at S10.

From Figure-13, it has been showed that maximum storey displacement of conventional RCC slab, flat slab and flat slab with shear wall in X and Y direction. Here, X axis represents the number of stories and Y axis represents the maximum story displacement.

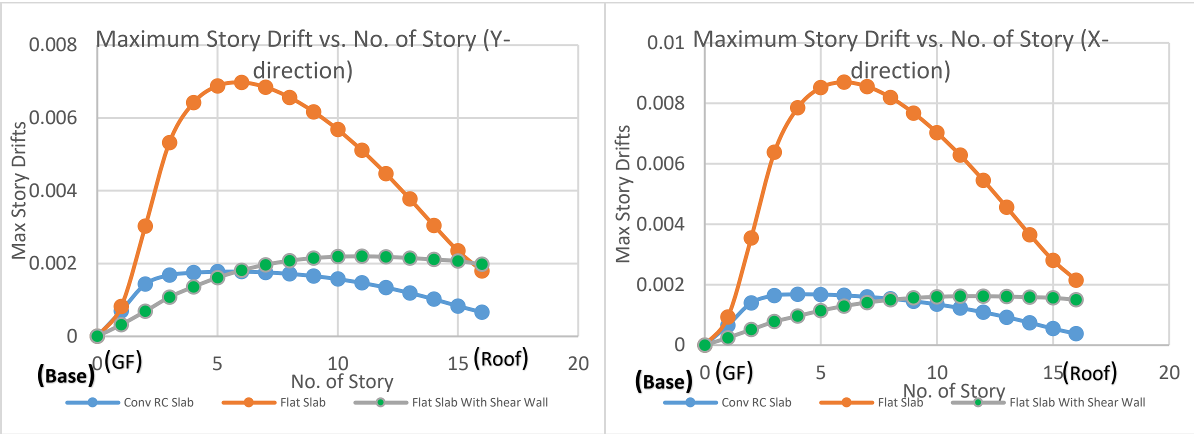

Figure-13: Max story drift vs. No. of stories graph (Zone 3, X and Y-direction)

Zone-4: For earthquake in global X direction (EQX), the maximum drifts for conventional RCC slab is 0.002162 at S3, flat slab is 0.011181 at S5 and flat slab with shear wall is 0.002053 at S10 & S11.

For earthquake in global Y direction (EQY), the maximum drifts for conventional RCC slab is 0.002283 at S5, flat slab is 0.008967 at S5 and flat slab with shear wall is 0.002769 at S10.

From Figure-14, it has been showed that maximum storey displacement of conventional RCC slab, flat slab and flat slab with shear wall in X and Y direction. Here, X axis represents the number of stories and Y axis represents the maximum story displacement.

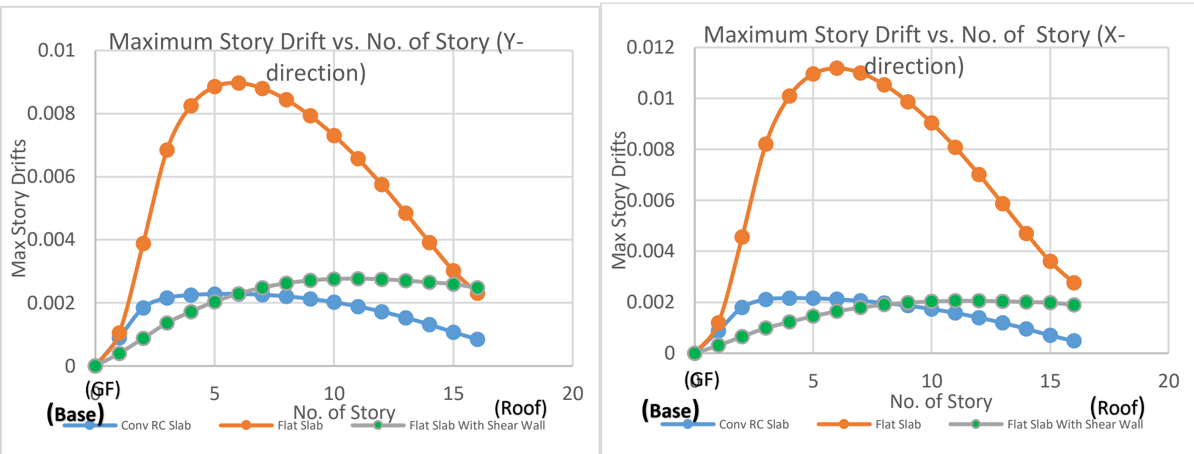

Figure-14: Max story drift vs. No. of stories graph (Zone 4, X and Y-direction)

3.3 Maximum Overturning Moment

Zone-1: For earthquake in global X direction (EQX), the maximum overturning moment of flat slab is less than conventional RCC slab by 22.93% and flat slab with shear wall is less than conventional RCC slab by 13.79%.

For earthquake in global Y direction (EQY), the maximum overturning moment of flat slab is less than conventional RCC slab by 23.49% and flat slab with shear wall is less than conventional RCC slab by 14.07%.

From Figure-15, it has been showed that maximum overturning moment of conventional RCC slab, flat slab and flat slab with shear wall in X and Y direction. Here, X axis represents the number of stories and Y axis represents the maximum story displacement.

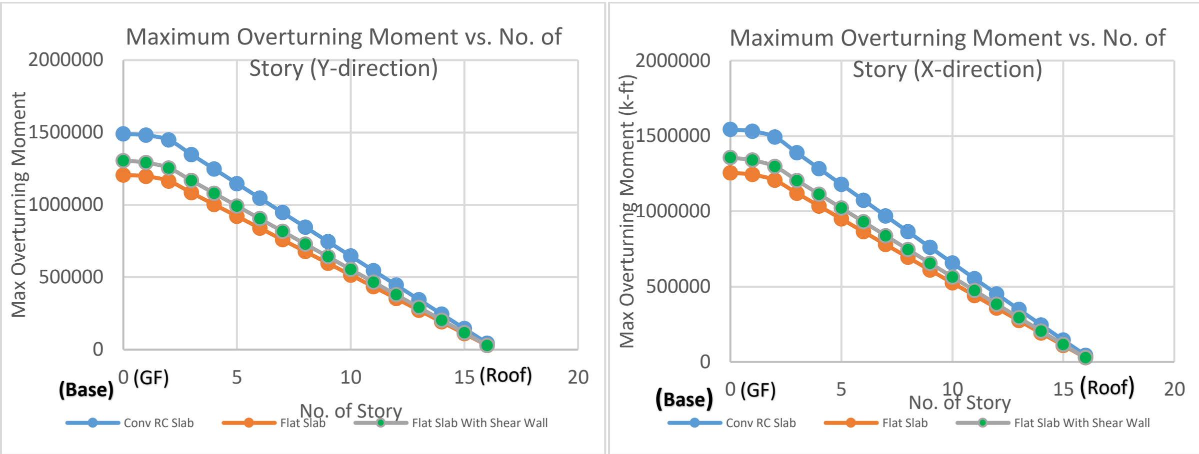

Figure-15: Max overturning moment vs. No. of stories graph (Zone 1, X and Y-direction)

Zone-2: For earthquake in global X direction (EQX), the overturning moment of flat slab is less than conventional RCC slab by 22.58% and flat with shear wall is less than conventional RCC slab by 13.63%. For earthquake in global Y direction (EQY), the overturning moment of flat slab is less than conventional RCC slab by 23.49% and flat with shear wall is less than conventional RCC slab by 14.16%.
From Figure-16, it has been showed that maximum overturning moment of conventional RCC slab, flat slab and flat slab with shear wall in X and Y direction. Here, X axis represents the number of stories and Y axis represents the maximum story displacement.

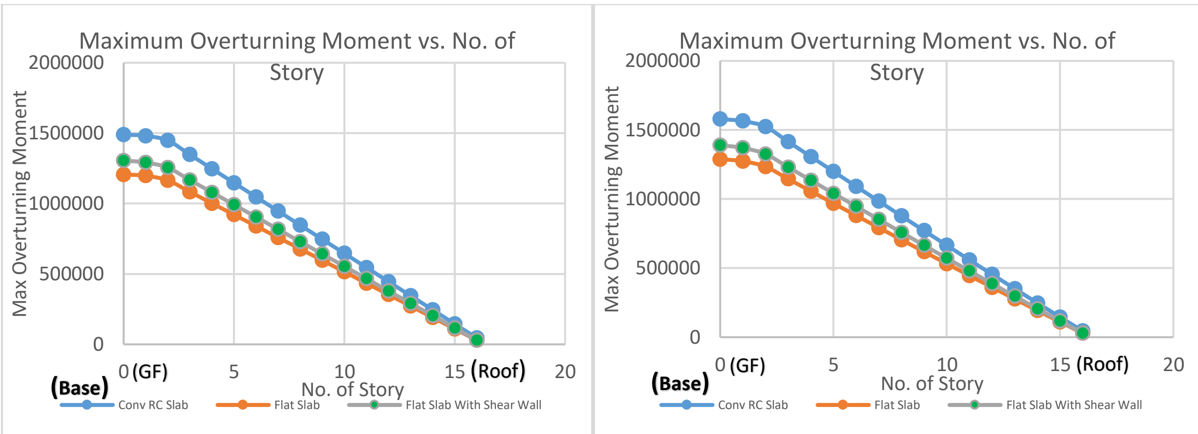

Figure-16: Max overturning moment vs. No. of stories graph (Zone 2, X and Y-direction)

Zone-3: For earthquake in global X direction (EQX), the overturning moment of flat slab is less than conventional RCC slab by 22.25% and flat with shear wall is less than conventional RCC slab by 13.47%. For earthquake in global Y direction (EQY), the overturning moment of flat slab is less than conventional RCC slab by 23.49% and flat with shear wall is less than conventional RCC slab by 14.10%.

From Figure-17, it has been showed that maximum overturning moment of conventional RCC slab, flat slab and flat slab with shear wall in X and Y direction. Here, X axis represents the number of stories and Y axis represents the maximum story displacement.

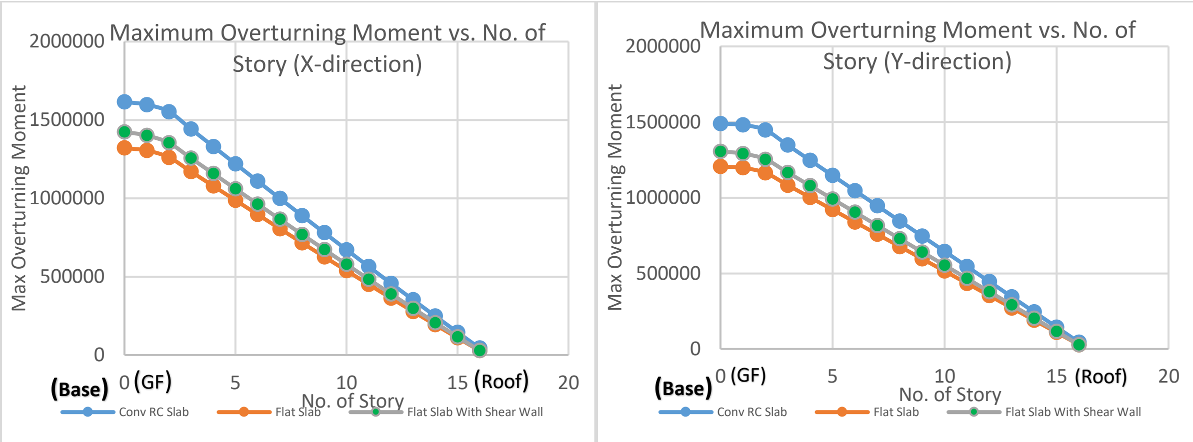

Figure-17: Max overturning moment vs. No. of stories graph (Zone 3, X and Y-direction)

Zone-4: For earthquake in global X direction (EQX), the overturning moment of flat slab is less than conventional RCC slab by 21.93% and flat with shear wall is less than conventional RCC slab by 13.33%. For earthquake in global Y direction (EQY), the overturning moment of flat slab is less than conventional RCC slab by 23.49% and flat with shear wall is less than conventional RCC slab by 14.12%.
From Figure-18, it has been showed that maximum overturning moment of conventional RCC slab, flat slab and flat slab with shear wall in X and Y direction. Here, X axis represents the number of stories and Y axis represents the maximum story displacement.

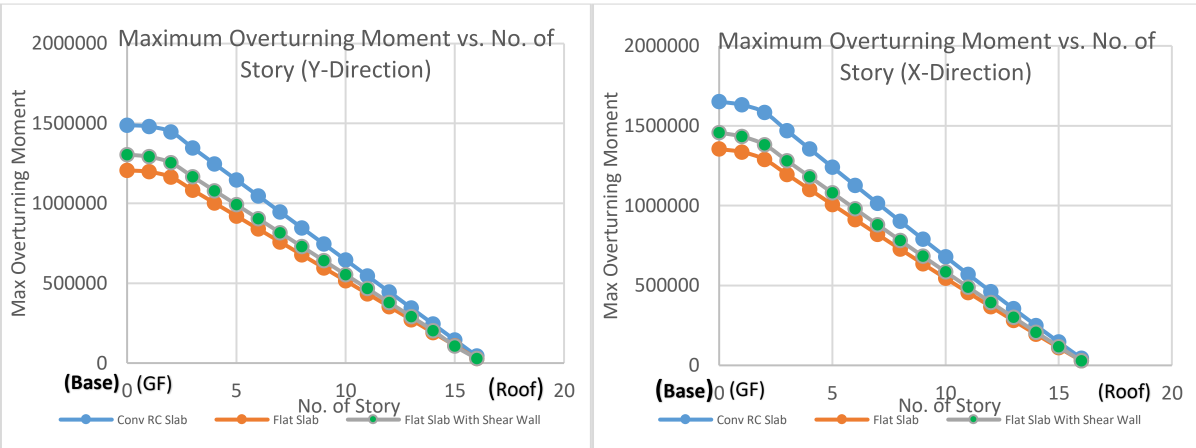

Figure-18: Max overturning moment vs. No. of stories graph (Zone 4, X & Y-direction)

3.4 Story Shear

Zone-1: For earthquake in global X direction (EQX), the story shear of flat slab is less than conventional RCC slab by 15.76% and flat with shear wall is less than conventional RCC slab by 5.97%.
For earthquake in global Y direction (EQY), the story shear of flat slab is less than conventional RCC slab by 25.83% and flat with shear wall is less than conventional RCC slab by 15.26%.

From Figure-19, it has been showed that Story Shear of conventional RCC slab, flat slab and flat slab with shear wall in X and Y direction. Here, X axis represents the number of stories and Y axis represents the maximum story displacement.

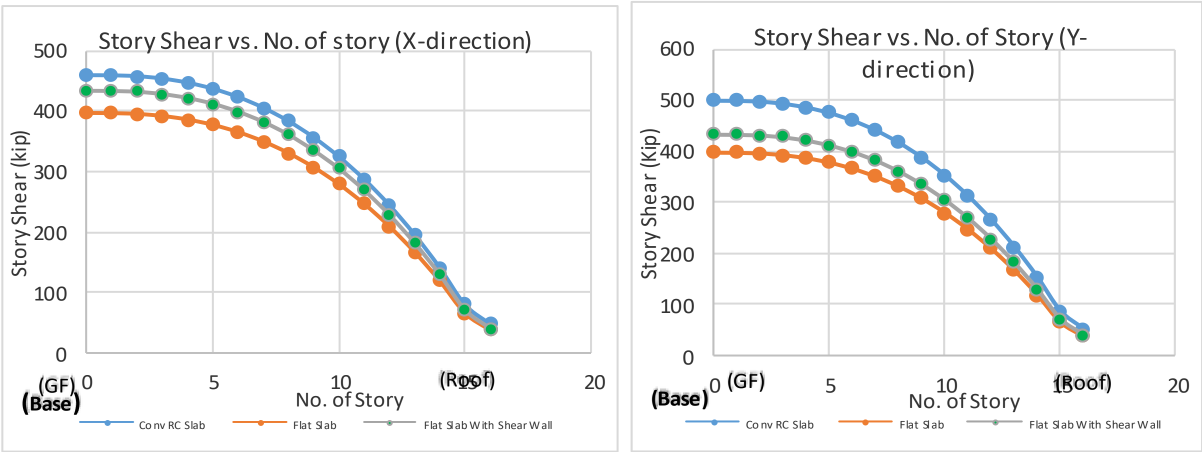

Figure-19: Story shear vs. No. of stories graph (Zone 1, X and Y-direction)

Zone-2: For earthquake in global X direction (EQX), the story shear of flat slab is less than conventional RCC slab by 15.76% and flat with shear wall is less than conventional RCC slab by 5.97%.
For earthquake in global Y direction (EQY), the story shear of flat slab is less than conventional RCC slab by 25.83% and flat with shear wall is less than conventional RCC slab by 15.26%.
From Figure-20, it has been showed that Story Shear of conventional RCC slab, flat slab and flat slab with shear wall in X and Y direction. Here, X axis represents the number of stories and Y axis represents the maximum story displacement.

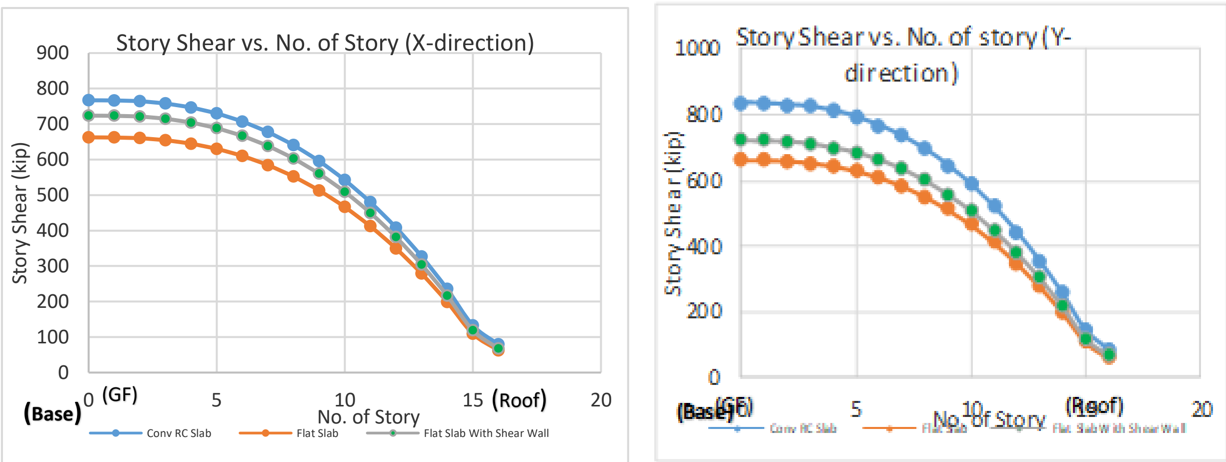

Figure-20: Story shear vs. No. of stories graph (Zone 2, X and Y-direction)

Zone-3: For earthquake in global X direction (EQX), the story shear of flat slab is less than conventional RCC slab by 15.76% and flat with shear wall is less than conventional RCC slab by 5.97%. For earthquake in global y direction (EQY), the story shear of flat slab is less than conventional RCC slab by 25.83% and flat with shear wall is less than conventional RCC slab by 15.26%.

From Figure-21, it has been showed that Story Shear of conventional RCC slab, flat slab and flat slab with shear wall in X and Y direction. Here, X axis represents the number of stories and Y axis represents the maximum story displacement.

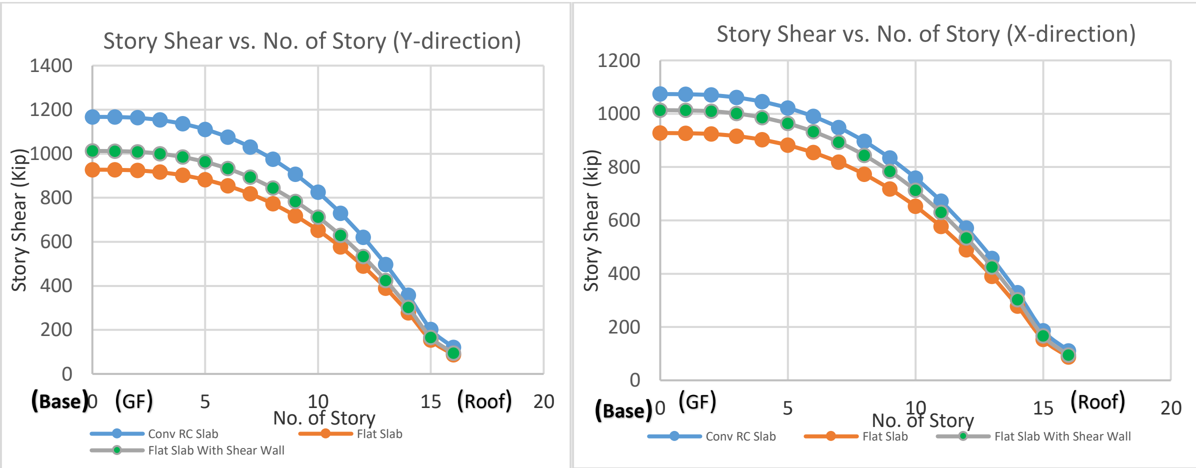

Figure-21: Story shear vs. No. of stories graph (Zone 3, X and Y-direction)

Zone-4: For earthquake in global X direction (EQX), the story shear of flat slab is less than conventional RC slab by 15.76% and flat with shear wall is less than conventional RCC slab by 5.97%.

For earthquake in global Y direction (EQY), the story shear of flat slab is less than conventional RC slab by 25.83% and flat with shear wall is less than conventional RCC slab by 15.25%.

From Figure-22, it has been showed that Story Shear of conventional RCC slab, flat slab and flat slab with shear wall in X and Y direction. Here, X axis represents the number of stories and Y axis represents the maximum story displacement.

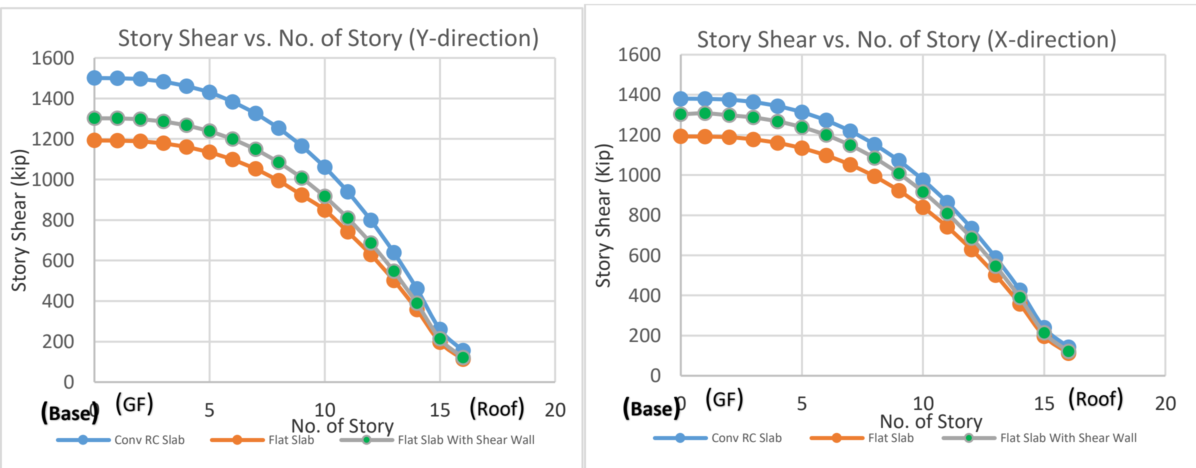

Figure-22: Story shear vs. No. of stories graph (Zone 4, X and Y-direction)

4. Conclusions

Equilibrium linear static analysis method is used for the simulation of a high rise commercial building under seismic condition with the help of ETABS 2019 and taking BNBC 2017 as a standard reference. The varieties of structures are analysed in this thesis work are conventional reinforcement concrete slab, flat slab with drop and flat slab with drop & shear wall. Maximum story displacement, maximum story

drift, overturning moment and story shear are estimated for every type of buildings, which are illustrated in the foregoing chapter and graphs are provided for the acknowledgement of the interrelation.
From maximum story displacement vs. story graph it is clearly acknowledged that the story displacement of flat slab is larger than rest of the others due to the absence of lateral load resisting system & the story displacement of conventional reinforcement concrete slab is greater than flat slab with shear wall but after a definite height an opposite case occurs.
From maximum story drift vs. story graph it is showed that there have highest points found at different stories for different types of structures in every specific seismic zones. For all the cases considered maximum story drift values follow a parabolic path along story height with maximum value lying somewhere near the middle story.
From overturning moment vs. story graph it is clear that the maximum value has found at the base for every structure and among conventional reinforcement concrete slab, flat slab and flat slab with shear wall, the values of conventional reinforcement concrete slab is greater, flat slab is smaller and flat slab with shear wall is between those two.
From story shear vs. story graph it is clear that the maximum value has found at the base for every structure and among conventional reinforcement concrete slab, flat slab and flat slab with shear wall, the values of conventional reinforcement concrete slab is greater, flat slab is smaller and flat slab with shear wall is between those two.
As the seismic level increases all parameters like maximum story displacement, maximum story drift, maximum overturning moment and story shear intensities are increases.
Four types of factors have been analyzed for three types of models, which are maximum story displacement, maximum story drift, maximum overturning moment and story shear. After analyzing those four types of factors it is clear that flat slab is more flexible than conventional RCC slab and flat slab with shear wall.
By comparing all above parameters it was found that conventional RCC slab has superior performance in earthquake against flat slab with drop and flat slab with drop & shear wall.

5. Referances

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