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AN ANALYTICAL STUDY OF THE SEISMIC PERFORMANCE OF FLAT SLAB STRUCTURES WITH DIFFERENT SHAPES OF DROP PANELS

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ABSTRACT

Flat slabs are best suited for layouts of asymmetrical columns such as ramps and floors that have curved shapes, among many other construction works (George, & Tian, 2012). There are numerous advantages of utilising flat slabs, such as offering a solution for depth, flat soffit and design layouts flexibility, to mention but a few. However, flat slab structures do not perform very well under seismic loading when it comes to structural efficiency (Burak, 2005). It is an undesirable characteristic caused by a lack of sufficient horizontal resistance since flat slabs structures do not have shear walls or deep beams. This work studies the seismic behaviour of multistory buildings for flat slab structures with drop panels of different shapes. Slabs with rectangular and square drop panels are analysed under earthquake loads using dynamic analysis method. Square flat slab buildings with a plan area of 28m X 28m both in web and flange are modelled, and then all these models are analysed using ETABs software for earthquake zone III and IV. Parameters used to evaluate the seismic behaviour are; storey drift, displacement and base shear. From observations, flat slab buildings with square shaped drop panels are more flexible for earthquake loads.

Keywords: Seismic, Storey Drift, Base Shear, Modes, Storey Displacement, Stiffness, Flat Slab.

I. INTRODUCTION

Of all the modern building materials used in the construction industry, Reinforced Concrete (RC) is one of the most utilized (O'Rourke & Liu, 1999). After Poland cement was invented in the 19th century, concrete became so popular, but those in the industry did not widely use it in construction because it has limited tensile resistance. A composite material, widely known as reinforced concrete (RC), formed by embedding steel bars in the concrete, was introduced to overcome this less tensile strength issue. However, the construction using concrete needs a certain level of expertise (Erberik & Elnashai, 2004), quality, and technology, especially during the construction process at the site. Despite the need for this professional contribution, numerous low-rise buildings and single houses worldwide have been, and they are still being put up without any input from engineers. Some of the reasons why RC structures fail under earthquake loading include:

1. Due to Soft and Weak Mechanism of the Storey. The soft-story failure mechanism in many mid-rise RC buildings occurs mostly at the first story. Weak-story failure can occur in any story with no partition walls or fewer column cross-sectional areas to withstand changes in lateral strength that occur suddenly from adjacent buildings. Therefore, in an earthquake, collapse may occur partially or totally on such stories.
2. Insufficient Transverse Reinforcement in Columns and Beams.
3. Due to Short Column. If an earthquake occurs, lateral loads caused should be borne by shear walls and columns (Farhey et al, 1995). Shorter columns are stiffer and more brittle than the others, attracting more shear forces. The high shear loads lead to a critical failure, shear failure, damaging these columns.
4. Because of Short Gaps between Adjacent Buildings. Building structures without sufficient gaps from each other collide in the event of an earthquake. The danger is more when the floors of the two different buildings are not exactly at the same height level. Figure 1 below shows an occurrence of such damage during the Bingöl earthquake in the year 2003.

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Fig 1: Adjacent buildings fail during the Bingöl earthquake (source: Ahmet Topçu).

5. When there is a Strong Beam but a Weak Column

6. Due to Failures of Gable Walls. Gable wall failures are not structural damages, but they may result in property loss or even claim lives.

7. Because of Poor Quality of Concrete and Corrosion.

8. Due to In-Plane Effect or Out-Of-Plane Effect

Some few principles for health construction if followed, can achieve the resistance required against earthquake loads. They may not prevent all damage but can reduce the life-threatening damages to some extent. They include: Building structures should not be brittle but rather tough with room to deform and deflect.

- Design engineers should evenly provide shear walls, bracings, and other resistant elements on the entire building in the two directions and from top to bottom.
- All building elements, such as roofs and walls, should be tied so that in the event of an earthquake shaking, they will behave as a unit, and the forces will be transferred across the connections without separation.
- A good foundation that is properly connected to the earth should also be connected to the building structure. The foundation itself should be tied together and to the wall, while designers should avoid soft and wet soils unless special means of strengthening are provided.
- Good quality material must be used and protected from all factors that compromise their strength, such as insects, sun, rain, and other weakening actions.
- Designers should generally reinforce earth and masonry with either steel or wood as the unreinforced cannot be relied on against tensional forces. In compression, they are also brittle.

A flat slab is an RC slab that directly rests on concrete columns and with the absence of beams. Therefore, it can be defined as a "one or two-sided support system whose slab's shear load is exacted directly on concrete columns" (Agrawal & Sen, 2020). There are four types of flat slabs. One is a typical flat slab supported directly on columns and is mostly used for office buildings, warehouses, and public halls. Another one is a flat slab with a column head. The column head is when the part of the column in contact with the slab is widened to mitigate the punching shear. Another type of flat slab is the one with a drop panel where the slab close to the column is slightly thickened. Normally the height of the drop is double the height of the slab. The last type of flat slab is with both column head and drop. Figure 2 below shows the different types of flat slabs. .

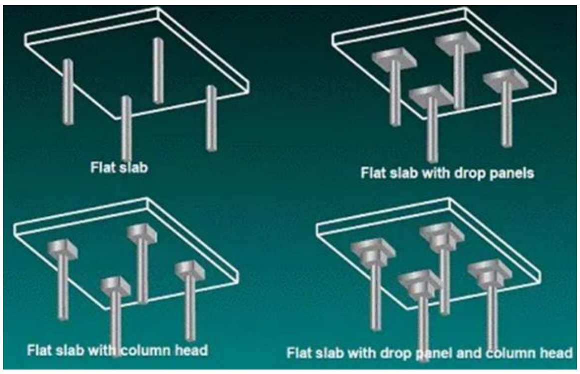

Fig 2: Types of flat slabs (https://images.app.goo.gl/HY8Pm49ggqeYRuL29).

When subjected to vertical loading, the flat slab structure's behavior is well understood. However, little is known regarding the behavior of flat slab structures subjected to lateral loading (Kayastha & Debbarma, 2019). Some structures have considered wind as the lateral load during design, but this is insufficient in the event of an earthquake. Research shows that flat slabs do not perform well under seismic loading. Therefore, it has been difficult to predict how these structures can behave in an event seismic forces are applied; however, they can still be modeled so that they will be easy to understand (Murty et al, 2016). This gap of knowledge on ways to model flat slab structures to predict how they behave under seismic loading is the main motivation in this research. This paper studied the seismic behavior of flat slab structures with rectangular and square shapes drop panels.Four flat slab buildings with five stories in Etabs 18 software were modeled to achieve this. Dynamic analysis was carried out for story drift, displacement, and base shear. All the buildings had a square plan area of 28m X 28m. One building having a square shaped drop panels was modeled for zone III, and IV, while another one having a rectangular shaped dropped panels was modeled for the same zones.

II. METHODOLOGY

For this work, the response spectrum linear method of dynamic analysis was used. The results obtained were used to study and compare the seismic behavior of these structures. In modal analysis, modes shapes are normally obtained by the general normalized form, and therefore the Response spectrum results ought to be appropriately scaled. For this study, the scaling was done according to the IS 1893:2002 code guidelines.

III. MODELLING AND ANALYSIS

The following models were used for analysis:

- Model 1 – Flat slab building with square drop panel at zone III
- Model 2 - Flat slab building with rectangular drop panel at zone III
- Model 3 - Flat slab building with square drop panel at zone IV
- Model 4 - Flat slab building with rectangular drop panel at zone IV

The Structural Elements for Model-1, and Model-3 were:

- Column: 600 mm x 600 mm.
- Drop: 2450 mm x 2450 mm.
- Slab thickness: 200 mm.
- Drop thickness: 200 mm.
- Number of stories: 5=(G+4)
- The storey height: 3000 mm
- The bottom storey height: 3500 mm
- The support condition is fixed.

The Structural Elements for Model-2, and Model-4 were:

- Column: 600 mm x 600 mm.
- Drop: 2000 mm x 3000 mm.
- Slab thickness: 200 mm.
- Drop thickness: 200 mm.
- Number of stories: 5=(G+4)
- The storey height: 3000 mm
- The bottom storey height: 3500 mm
- The support condition is fixed.

The Properties of the Material that were used:

- The unit weight of concrete: 25 kN/m .
- The characteristic strength of concrete: 30 N/mm.
- Characteristic strength of steel: 500 N/mm^2.

The Data of Seismic Design:

- Seismic zones IV, and III with zone factors 0.24 and 0.16 respectively.

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- Soil type is: medium.
- Damping ration of concrete: 5%
- Response reduction factor: 5
- Importance factor is: III

The loads Considered:

- Dead loads of columns and slabs.
- Live load of 5 kN/m^2 and 2 kN/m^2 at the terrace.
- Additional dead load of 2 kN/m^2.

The following are the some of the images of the model used.

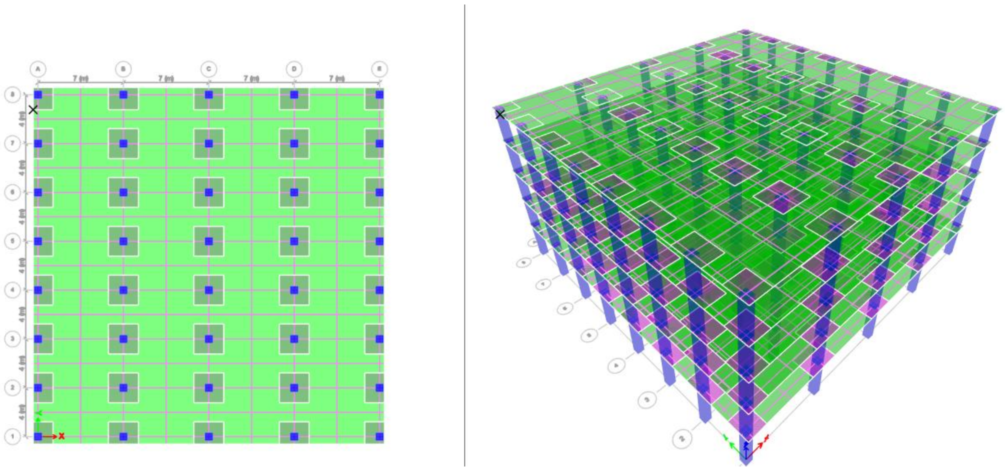

Fig 3: The plan and isometric view of the flat slab with square drop panels.

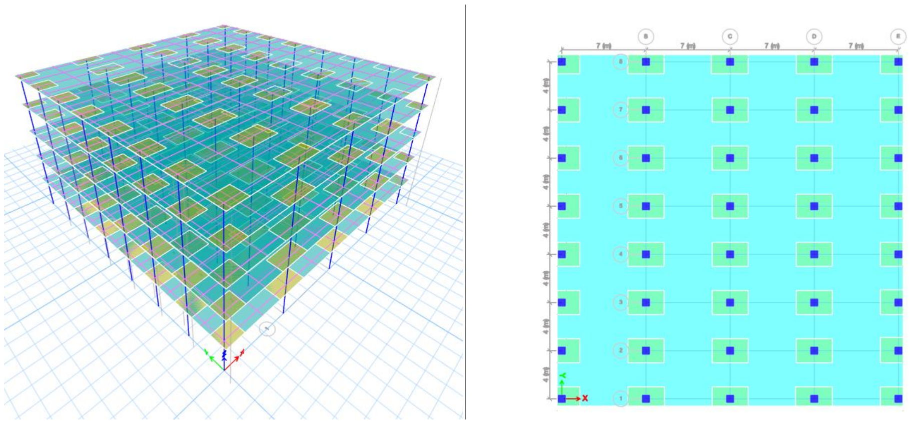

Fig 4: The plan and isometric view of the flat slab with rectangular drop panels

IV. RESULTS AND DISCUSSION

The parameters of results that were used in this study are; story stiffness, base shear, story displacement, storey drift, and mode periods. Response spectrum method of linear dynamic analysis was employed. This is a method that is utilized to estimate the response of a structure to dynamic events that are transient, short and dynamic in nature.

Storey Displacement.

The following table show the story response values for both the Model-1 and Model-2 in zone III.

Table 1: Storey displacement for flat slab Model-1 and Model-2

	Model-1		Model-2	
Story	X-Dir	Y-Dir	X-Dir	Y-Dir
	mm	mm	mm	Mm

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Story5	46.664	34.71	193.643	193.708
Story4	41.683	31.489	140.798	140.847
Story3	33.41	25.771	91.126	91.158
Story2	22.307	17.895	47.99	48.008
Story1	9.936	8.693	15.715	15.721

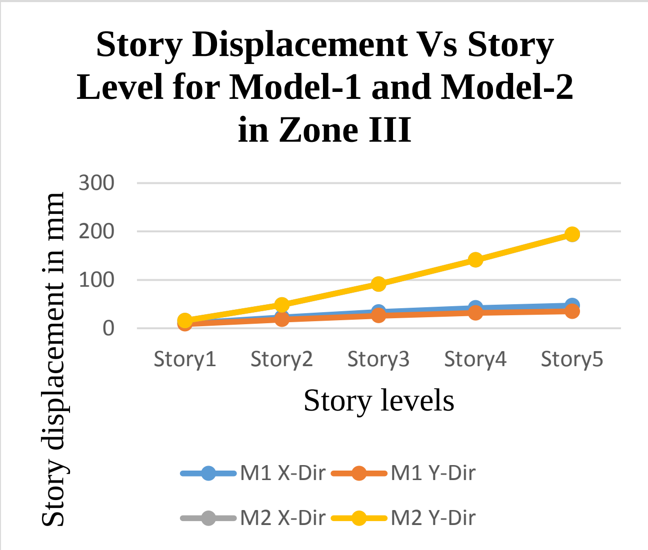

Fig 5: Story Displacement Vs Story Level for Model-1 and Model-2 in Zone III

Table 1 shows the storey displacement in RSA along X and Y-direction for Model-1 and Model-2 in zone-III. Model-2 shows the maximum storey displacement of about 193.70mm along Y-direction. As per the analysis it is confirmed that the structure with rectangular panel shows more displacement when compared with square panel structure. The storey displacement got decreased by 76.94% and 82.1% along X and Y-direction in Model-1 when compared to Model-2. Whereas the storey displacement along X-direction is almost same as that of Y-direction in Model-2.

Table 2: Storey displacement for flat slab building Model -1 and Model-2

	Model-3		**Model-4**	
Story	**X-Dir**	**Y-Dir**	**X-Dir**	**Y-Dir**
	mm	**mm**	**mm**	**Mm**
Story5	69.996	52.065	290.464	290.562
Story4	62.525	47.233	211.198	211.27
Story3	50.114	38.657	136.688	136.737
Story2	33.46	26.843	71.985	72.012
Story1	14.904	13.04	23.572	23.582

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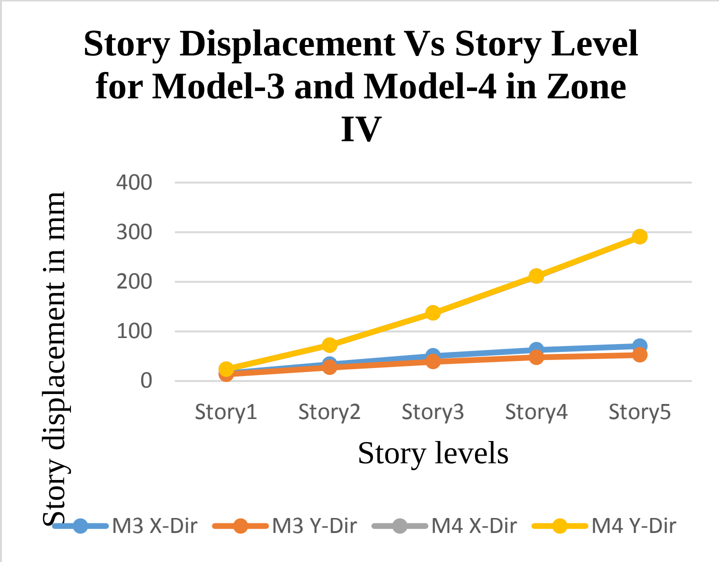

Fig 6: Story Displacement Vs Story Level for Model-3 and Model-4 in Zone IV

Table 2 shows the storey displacement values in RSA along X and Y-direction for Model-3 and Model-4 in seismic zone IV. The maximum displacement of 290.56 mm is shown by Model-4 along the Y-direction. In this zone too, the analysis confirms that the storey displacement for the structure with the rectangular drop panel is more compared to that of the structure with the square drop panel.

The storey displacement decreased by 75.9 % and 80.7 % along the X and Y- direction respectively from comparing Model-3 with Model-4. Like Model-2 in zone III, the story displacement along X and Y displacement for Model-4 in zone IV is almost the same. For seismic zone IV, the displacement was generally higher for both the flat slab structures with the square and the rectangular-shaped drop panels compared to zone III due to more severe seismic activity in zone IV compared to zone III.

Storey Drift

Story drift can be defined as the lateral displacement of a floor in relation to the floor below it. The storey drift for the flat slab buildings with both the square and the rectangular drop panels in zone III are as shown in the following tables:

Table 3: Story response values in for the flat slab model -1 and Model-2

	Model -1		Model-2	
Story	**X-Dir**	**Y-Dir**	**X-Dir**	**Y-Dir**
Story5	0.00171	0.0011	0.01794	0.01794
Story4	0.0028	0.00194	0.01687	0.01687
Story3	0.00372	0.00264	0.01455	0.01455
Story2	0.00413	0.00307	0.0108	0.0108
Story1	0.00284	0.00248	0.00449	0.00449

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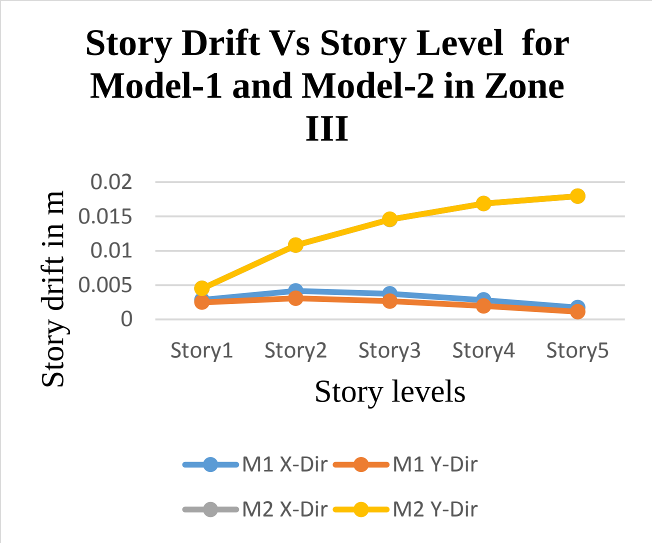

Fig 7: Story Drift Vs Story Level for Model-1 and Model-2 in Zone III

Table 3 shows the story drift for in RSA along X and Y-direction for Model-1 and Model-2 in seismic zone III. Model-2 shows the maximum story drift of 0.001794 m along Y-direction. According to the analysis, the structure with the rectangle drop panels has more storey drift than that with the square drop panels.

There was a decrease of story drift by 90.5 % and 93.9 % along X and Y-direction respectively for Model-1 in comparison to Model-2. The story drift for Model 2 along the X and Y-direction were the same.

The story drift for both the models in zone IV are as shown in the table below:

Table 4: Story response values for the flat slab model-3 and Model-4

	Model-3		Model-4	
Story	**X-Dir**	**Y-Dir**	**X-Dir**	**Y-Dir**
Story5	0.00257	0.00166	0.02691	0.02691
Story4	0.00421	0.0029	0.0253	0.02531
Story3	0.00559	0.00396	0.02182	0.02183
Story2	0.00619	0.00461	0.0162	0.01621
Story1	0.00426	0.00373	0.00674	0.00674

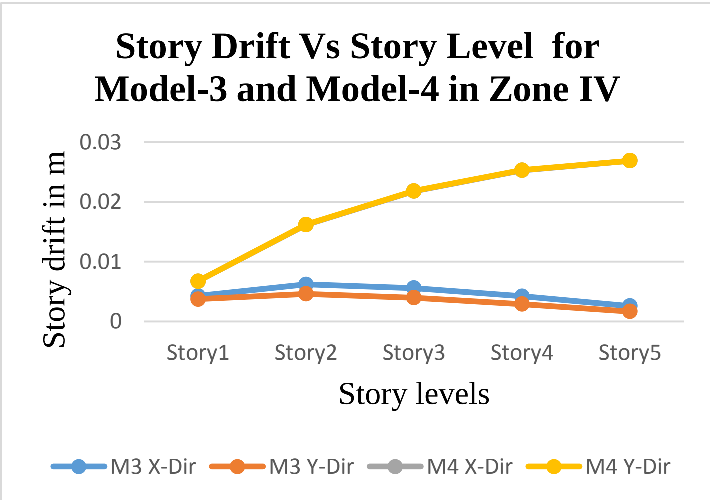

Fig 8: Story Drift Vs Story Level for Model-3 and Model-4 in Zone IV

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Table 4 shows the story drift values in RSA for Model-3 and Model-4 along the X and Y-direction. The analysis results have revealed that the story drift was more the flat slab structure with rectangular drop panel compared to that with the square drop panel.

There was a decrease of story drift by 83.36 % and 88.54 % along the X and Y-direction respectively. However the story drift for Model-4 was almost the same in both X and Y direction in seismic zone IV. Generally, for seismic zone IV, as observed in the tables above, the story drift values were higher in comparison to those in seismic zone III for the flat slab models. This is because the earthquake in zone IV is more severe than that in zone III.

Base Shear and Storey Forces:

Base shear can be defined as an estimate for the maximum force in the lateral direction expected on the base of a structure as a result of a seismic activity. In zone III, the story forces and base shear for the flat slabs with both the square and rectangular drop panels shown below:

Table 4: Base and Story shear values for Model-1 and Model-2 in zone III

Story forces and base shear	Model-1		Model-2	
Story	**X-Dir**	**Y-Dir**	**X-Dir**	**Y-Dir**
	kN	**kN**	**kN**	**kN**
Story5	2802.7	3074.0	1544.0	1544.0
Story4	5255.7	5918.4	1615.2	1615.2
Story3	7180.5	8194.4	1772.9	1772.9
Story2	8528.8	9821.5	2594.2	2594.2
Story1	9225.3	10694.1	3294.2	3294.2

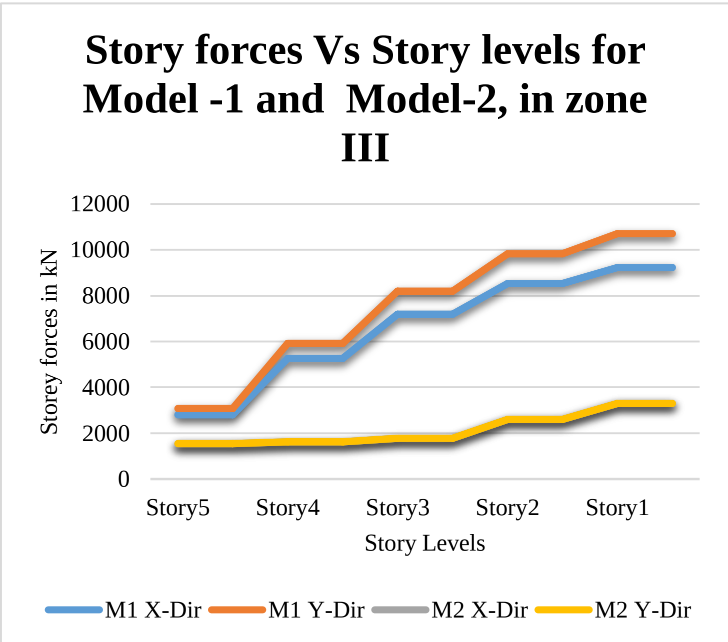

Fig 9: Story forces Vs Story levels for Model-1, and Model-2, in zone III

Table 5 shows the story and base shear values in RSA for Model-1 and Model-2 along X and Y direction in zone III. Model-1 shows the maximum base shear of 10694.1798 kN along the Y-direction. The analysis results show that there is more storey and base shear for the flat slab structure with square drop panel than that with the rectangular drop panel. The base shear by 64.29 % and 69.20% along the X and Y-direction respectively for Model-1 in comparison to Model-2 in seismic zone III. In Model the story shear and base shear values were the same in both the X and Y-direction.

In zone IV, the results for story shears and base shear for both the models are as shown below:

Table 5: Base and Story shear values for Model-3, and Model-4, in zone IV

Story forces and base shear	Model-3		Model-4	
Story	X-Dir	Y-Dir	X-Dir	Y-Dir
	kN	kN	kN	kN
Story5	4204.1814	4611.0582	2316.0883	2316.0863
Story4	7883.5965	8877.6774	2422.8342	2422.8326
Story3	10770.8744	12291.6946	2659.4873	2659.4855
Story2	12793.294	14732.2781	3891.4363	3891.4331
Story1	13838.0212	16041.2696	4941.3591	4941.3547

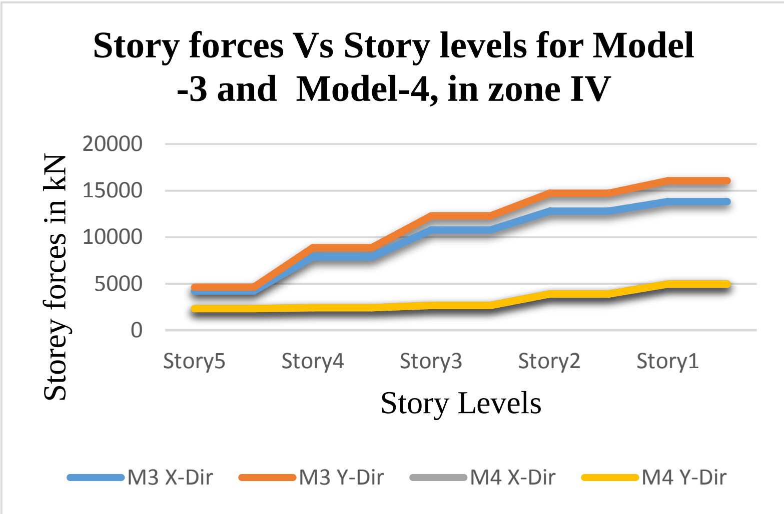

Fig 10: Story forces Vs Story levels for Model -3 and Model-4, in zone IV

Table 6 shows the story and base shear value in RSA for Model-3 and Model-4 in both X and Y-direction at seismic zone IV. The maximum base share of 16041.2696 kN was observed in Model-3 along the Y-direction. Also in this zone, the analysis results confirms that the flat slab structure with the square drop panel has more base and storey shears than that with the rectangular drop panel.

The base shear decreased by 64.29 % and 69.20 % along the X and Y-direction respectively for Model-3 in comparison to Model-4 in seismic zone IV just like in seismic zone III. The values of story shears in model 4 were the same in both X and Y-direction. The values for the base shear and story shears are higher in zone IV compared to zone III.

Storey Stiffness.

Story stiffness can be defined as "lateral force producing unit translational lateral deformation in the specified storey when it has its lateral displacement restrained." The following are the results for the story stiffness in response spectrum dynamic analysis for both the flat slab structure with square and rectangular shaped drop panels in seismic zone III:

Table 6: Story stiffness values for flat slab Model -1 and Model-2

	Model -1		Model-2	
Story	X-Dir	Y-Dir	X-Dir	Y-Dir
	kN/m	kN/m	kN/m	kN/m
Story5	545319.49	928059.104	28701.643	28701.637

Story4	624988.81	1019582.67	31925.863	31925.861
Story3	642891.33	1034477.95	40637.18	40637.178
Story2	688659.45	1066112.89	80096.619	80096.608
Story1	928482.62	1230170.79	209683.24	209683.21

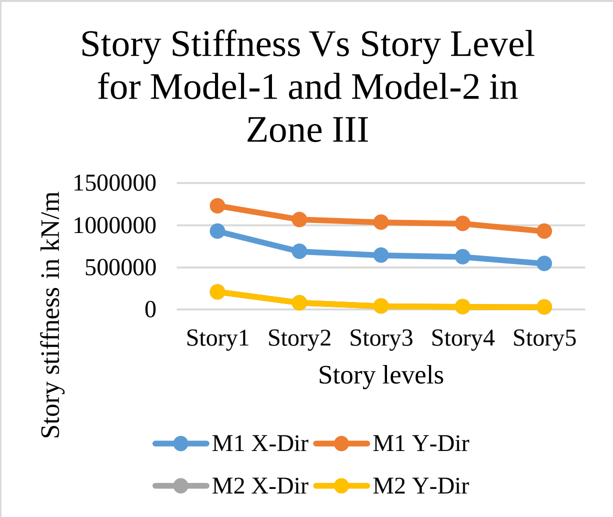

Fig 11: Story Stiffness Vs Story Level for Model-1 and Model-2 in Zone III

Table 7 shows the story stiffness in RSA for Model-1 and Model-2 along the X and Y-direction in seismic zone III. The maximum story stiffness was observed in Model-1 along the Y- direction of 1230170.79 kN/m. As per the analysis results, the flat structure with the square drop panel has higher story stiffness compared to that with the rectangular shaped drop panels in seismic zone III.

There was an increment of story stiffness by 77.42 % and 82.96 % along the X and Y-direction respectively after comparing Model-1 with model-2 in this seismic zone. The story stiffness value for Model-2 was almost the same for both X and Y-direction. The values of story stiffness were almost the same in both seismic zone III and seismic zone IV.

Mode Periods.

The following are the result values for the mode periods and frequencies for the flat slab structures in both seismic zones.

Table 8: Mode period of all the models in 'Sec'

Mode period of all the models in 'Sec'				
Mode	**Model-1**	**Model-2**	**Model-3**	**Model-4**
Mode-1	0.644	2.537	0.644	2.537
Mode-2	0.534	2.537	0.534	2.537
Mode-3	0.524	1.874	0.524	1.874

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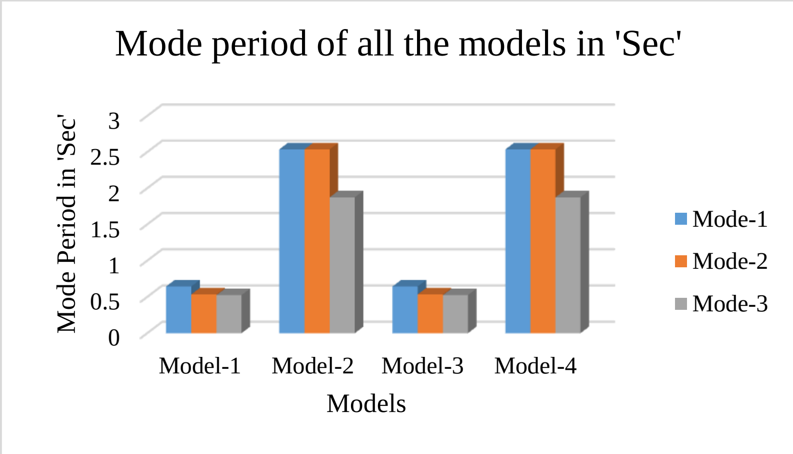

Fig 12: Mode Periods for Model-1, 2, 3 and 4.

Table 8 shows the mode periods in RSA for Model-1 and Model-2 in seismic zone III and Model-3 and Model-4 in seismic zone IV. As per the results from the analysis, the model with the square drop panel shows higher values of period compared to that with the rectangular drop panel. The highest value of period is observed for Model-1 and it is 0.644 seconds. In both seismic zones the values for period are almost the same for both the models.

V. CONCLUSION

This paper studied and compared two flat slab building structures one with rectangular drop panels and the other square drop panels in seismic zones III and IV using the Response spectrum linear dynamic analysis method. The same difference was found in seismic zone IV but the values for seismic zone IV were higher than those in seismic zone III as shown in tables above.

Maximum story displacement, maximum story drift, and base shear and story forces were more in zone IV compared to zone III. This is because there is much severity in seismic activity in zone IV than in seismic zone III. The story stiffness and, mode periods and frequencies parameters did not show a significant difference when in zone III and when in zone IV. The paper has revealed an advantage of using square drop panels overusing rectangular drop panels in earthquake zones III and IV. All the parameters used have indicated a lesser effect of the earthquake on the flat slab building structure with square drop panels than that with the rectangular drop panels. The analysis of this project has also shown that the flat slab structure's behavior in both seismic zone III and zone IV is almost the same however in zone IV there's slightly more severe seismic activity.

The displacement in the flat slab with a rectangular drop panel structure was more than that of the structure with square shaped drop panel by 69.61% at the top story and 28.78% at the bottom story for seismic zone III. In seismic zone IV the displacement of the structure with rectangular drop panel was more than that of the structure with square drop panel with the same percentage however the values for this zone were higher. The story drift for the structure with rectangular drop panels was more than that of the structure with square drop panels by 88.40% at the top story but and 28.78% at the bottom story. The base shear and story shears are more for the building with square drop panels than that with rectangular drop panels. Also, the story stiffness values for the flat slab structure with square drop panels are more than that of the structure with rectangular shaped drop panels. The values for mode periods were higher for the structure with rectangular shaped drop panels but lesser frequencies hence the Eigen value for the structure with rectangular drop panel was lesser.

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