Impact of fault line on behaviour of flat slab under vertical motion of earthquake

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Abstract - *The effects of vertical acceleration of the ground on flat slab building are presented in this paper. In the current environment, most design standards, including IS 1893-2016, recommend that the vertical acceleration element of an earthquake be designed as 2/3 of the horizontal. During recent quakes, the vertical element of ground motion was discovered to be greater than the horizontal element. It is consequently vital to investigate structural reaction in this sort of earthquake, where the vertical element's peak ground acceleration (PGA) may reach two-thirds of the horizontal element. Time history analysis was done in this study utilising 5 unscaled seismic data. To account for the influence of vertical ground vibrations, 5 various structural systems were investigated, including a drop panel, shear walls, and three flat plates of varying thickness. Variations in several parameters such as axial force for column at several locations in building, punching shear at the junction of slab & column, and deflection of slab have been examined. The results of the calculations demonstrate that vertical ground movement has a significant impact on the flat slab structure in regards to axial force variations, punching shear, and deflection of slab.*

Key Words: **flat slab, flat plate, vertical ground motion, vertical earthquake motion, vertical PGA, response of flat slab, time history analysis**

1.INTRODUCTION

The reinforced concrete flat slab technique is being used extensively for residential and commercial development in various regions, including high seismic zones. Flat slab is fashionable and easy to construct. It also helps to maximise the height between the ceiling and the floor.

Below are the types of flat slabs:

1. Flat Slabs without drop and column head.
2. Flat Slabs with column head.
3. Flat Slabs with drop
4. Flat Slabs with drop and column head

Due to its low lateral stiffness, flat slabs wobble significantly during seismic events, and the most dangerous failure in flat slabs is punching shear failure. If this occurs, the surrounding connections must be able to handle and redistributed pressures else it might cause a progressive failure of the structure.

Due to the belief that vertical acceleration is often smaller than horizontal acceleration, vertical ground motion has received less study. The vertical component of the ground motion was found to be greater than the horizontal component during the most recent earthquakes. Most design codes, including IS-1893 (2016), accept **Newmark and Hall's (1982)** recommendation that the design vertical spectrum should be 2/3 of the design horizontal spectrum.

Within 30 km of the source, the V/H ratio is crucial, according to **Papazoglou and Elnashai (1996) (1),** and the 2/3 rule is found to be on the cautious side for events that occur close to the source.

Nipan Bhandar Kayastha and Rama Debbarma (2016) (2) performed analysis on G+3 building by SAP 2000. They considered seismic zone V with soft soil strata. They chose 5 different structural configurations consist of conventional RC frame structure, flat slab with dropped, column head & shear wall. Flat slab with shear wall at periphery performs batter that general RC frame. It also gives maximum base shear compare to other models. Story displacement, Story drift are minimum in flat slab with shear walls. Natural period is also very less.

Further, a study on vertical ground motion and its impact on engineered structures by **Bipin Shrestha (2009) (3)** found that the current design process could have catastrophic results. It is advised that sites located within 20 km of the main active fault be designed to account for the combined effect of horizontal and vertical ground motion. The V/H ratios for near-source seismic events can be higher than 2/3. The primary impact of the vertical ground motion on the structure is to put more axial strain on the vertical load bearing element. When a vertical motion with similar amplitude to a horizontal motion occurs, it is seen that the axial force is typically greater than the equivalent transverse loading. It is also noted that variation of axial force is more on upper floor rather than lower floor.

Researchers **Siyun Kim, Sung Jig Kim, and Chunho Chang (4)** The effect of vertical ground movement on the 13 reinforced concrete structures with various geometric shapes was studied analytically. Horizontal ground motion has a greater impact on lateral displacement than vertical movement of the ground. Vertical ground movement caused by earthquakes is incorporated, the axial force fluctuation on the Reinforced concrete columns in the 1st story increases significantly, up to roughly 240%. This significant axial force fluctuation reduces shear capacity and raises the possibility for shear failure as the Vertical to horizontal ratio and length ratio rise.

The seismic reaction of Reinforced Concrete structure subjected to both ground movements observed during the 2009 L'Aquila (Italy) quake was researched by **L Di Sarno, A.S. Elnashai, and G. Manfredi (5)**. Four documented ground accelerated movements were used in a nonlinear dynamic analysis. According to the findings of the inelastic dynamic studies, an average rise in column compression load varies between 175%. They used time history analysis to examine the influence of vertical seismic vibrations on a 7-story frame building. When the V/H ratio is 1.31, the axial force of the internal columns decreases 1.3 times compared to the gravity load, indicating that tension force developed. Furthermore, when just lateral ground motion was applied, the plastic hinges were mostly found near the frame's beam ends. However, when combined horizontal and vertical ground movement were applied, the column hinges significantly increased, particularly the plastic hinges at the intermediate floor columns.

2. METHODOLOGY

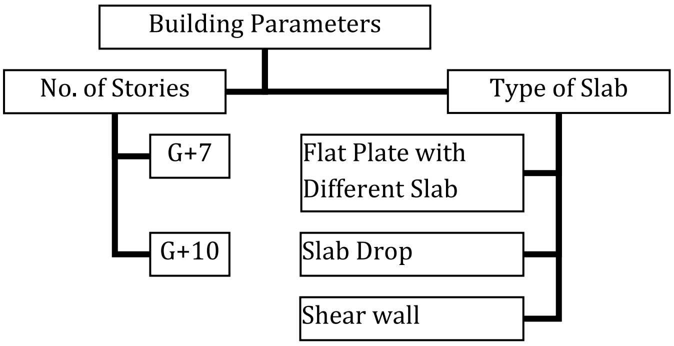

Chart -1: building parameters

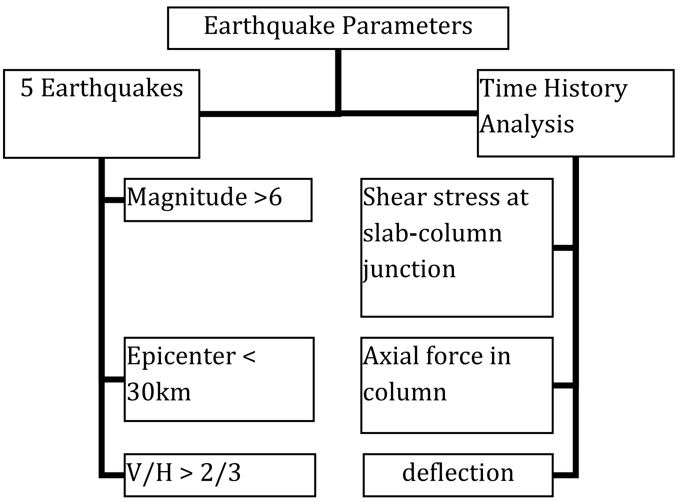

Chart -2 earthquake parameters

In this study, three possible structural configurations—flat plate, flat slab with drop, and flat slab drop with shear wall were taken into consideration for each of the two buildings, G+7, G+10. Three alternative Length to Depth ratios 15, 20, and 25 are taken into consideration for the flat plate structural system for determining the impact of slab thickness on punching shear and vertical acceleration. All models includes beams at perimeter to reduce the amount of punching shear stress at slab-column intersections. For all structures, the storey height is maintained to 3 metres.

The following factors were evaluated while selecting ground movement records: (1) Seismic magnitude greater than 6 (2) Epicentre distance less than 30kM, (3) Vertical to Horizontal ratio should be greater than 2/3 (4) non-pulse ground movement data. We investigated 5 unscaled seismic ground movements after screening out earthquake recordings from the strongmotioncenter & NGA-West2 database using these criteria, as indicated. As a result, we examined around 50 models for various vertical ground movements. The linear time history approach and ETABS v17 were used to analyse all buildings subjected to both vertical and horizontal ground motion acceleration.

Table -1: structural member sizes

Structural member sizes in (mm)	
Column size	530 x 530
Peripheral beam size	230 x 450
Shear wall size	2750 (L) x 230 (T)
Flat slab thickness (L/D)	
15	365
20	375
25	225
Drop thickness	100
Drop panel size	2750 x 2750
Storey height	3000
Bay spacing in both	5500

Table -2: gravity loads and material grade

Gravity loads and material grade	
Self-weight	Per ETABS software
Floor finish	1.5 KN/m^2
Floor live load	3 KN/m^2
Terrace lice load	1.5 KN/m^2
Concrete grade	M30
Steel grade	Fe- 415

Table -3: ground motion records

GROUND MOTION RECORDS									
REF. NO	**EVENT**	**YEAR**	**STATION**	**M**	**EP**	**Hor1**	**Hor2**	**Ver**	**V/H RATIO**
L1	Kozani, Greece	1995	Kozani	6.4	19.5	0.21	0.13	0.09	0.69
L2	Chamoli, India	1999	Gopeshwar	6.6	17.3	1.95	3.53	1.54	0.79
L3	Uttarkashi, India	1991	Bhatwari	7	21.7	2.48	2.42	2.89	1.19
L4	Northridge California	1994	Northridge	6.7	12.9	0.2	0.18	0.12	0.67
L5	Chi-chi, Taiwan	1999	Taichung	6.3	10.2	0.47	0.54	0.48	1.02

*EP= epicenter distance, M= Magnitude of earthquake, Hor1= Long. PGA, Hor2= Trans. PGA, Ver= Vertical PGA

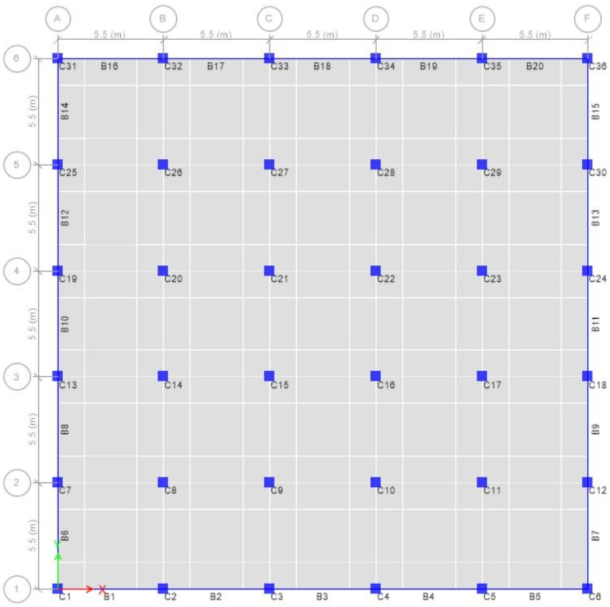

Fig -1: Flat Slab Building Plan

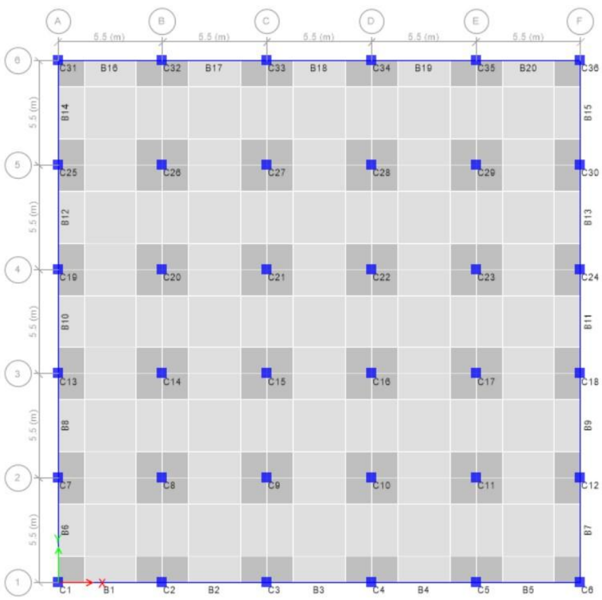

Fig -2: Flat Slab with Drop Building Plan

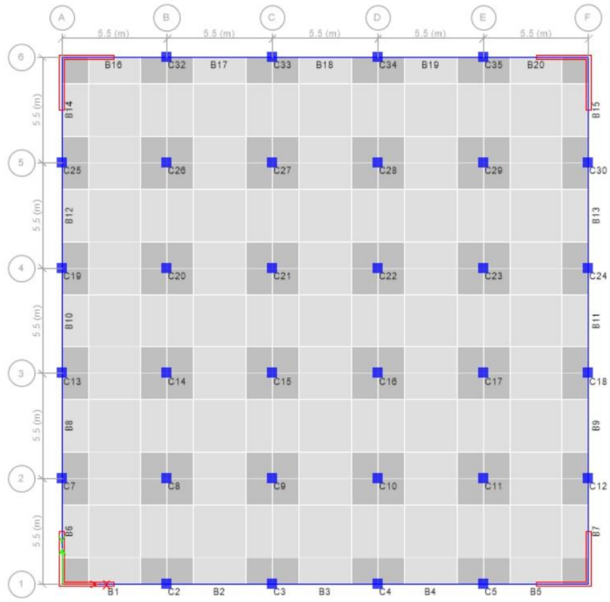

Fig -3: Flat Slab with Drop & Shear wall Building Plan

3. EXPLORATION FINDINGS DISCUSSION

For 5 chosen ground motion records, a linear time history analysis is carried out and applied to (5+5) various buildings. G+7 and G+10 will be used to denote building height in the study, while D, SW, LD15, LD20, and LD25 will denote structural system drop and shear wall, respectively.

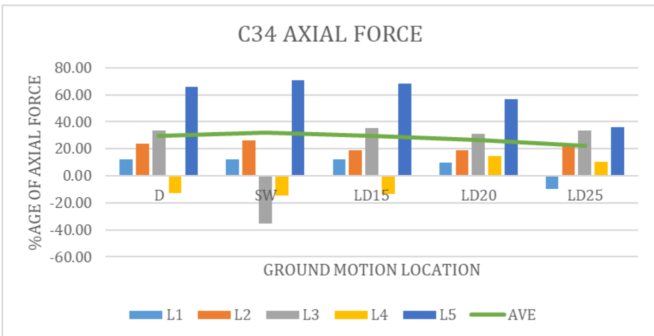

Chart -3 axial force in column C34 in G+7

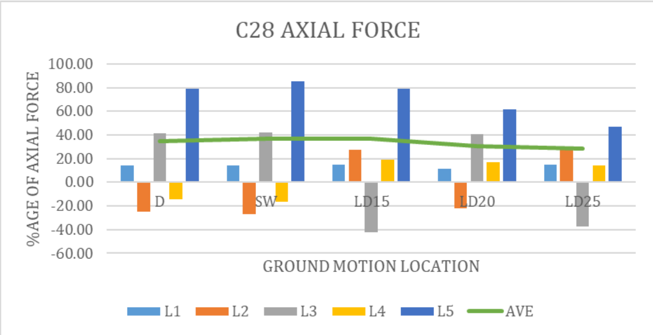

Chart -4 axial force in column C28 in G+7

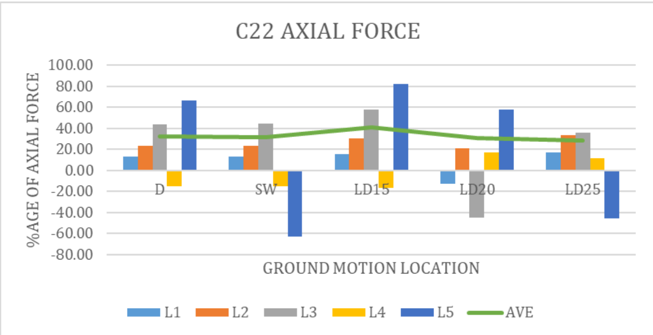

Chart -5 axial force in column C22 in G+7

Above are charts 3 to 5 for G+7 building. We chose three columns to illustrate the consequence of axial force in a column caused by vertical acceleration compare to gravity load. C34 is situated at outer perimeter, C28 is the middle column, and C22 is the interior column. In all models, the highest axial force is recorded in the lowest story; however, certain columns encountered axial tension loads greater than axial compression. Similarly, below charts 6 to 8 are for G+10 building.

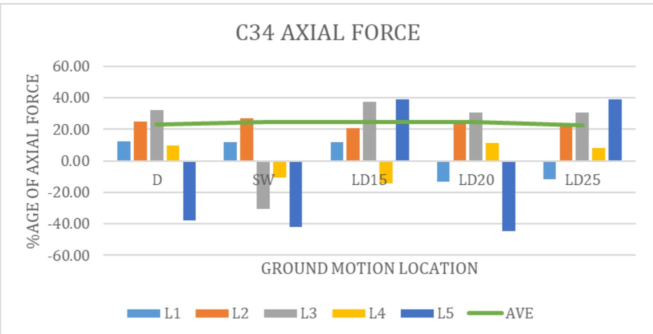

Chart -6 axial force in column C34 in G+10

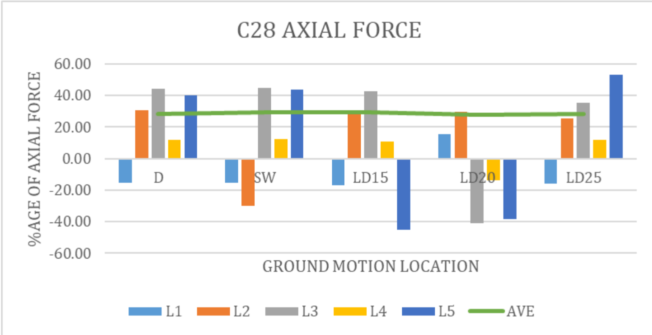

Chart -7 axial force in column C28 in G+10

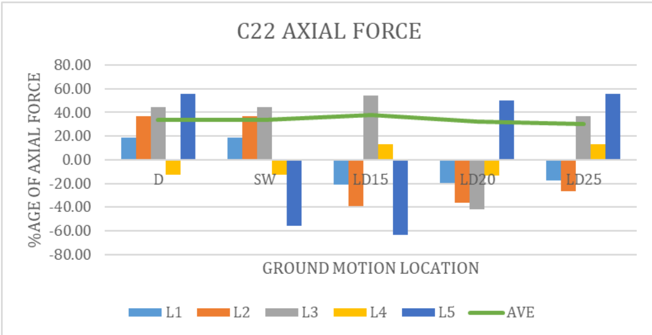

Chart -8 axial force in column C22 in G+10

Maximum axial force due to gravity is 3441KN & 4780KN respectively in G+7 & G+10 building. Whereas Maximum axial force due to vertical acceleration 2827KN compression & 1721KN as tension in G+7 building where as 2600KN as compression & 3028KN as tension in G+10 building. Maximum fluctuation is occurred in G10_LD15_L5. L5 indicated CHI-CHI Taiwan location. It has V/H ratio of 1.02. L3 indicated UTTARKASHI India location. it has V/H ration of 1.19 though L5 has more fluctuation in column axial force than L3.

The seismic impact on a flat slab building is shown by slab deflection. The slab deflection appears greatest near the centre of the slab for all earthquake records and model. Due to the column's axial compressing/Tensioning effect, the overall deflection of the slab is deeper on the top floor and progressively decreasing in the story below. As a consequence, the top most slab result is shown in figures below for various structural systems. Below chart indicate absolute value of deflection ignoring hogging or sagging. In below charts deflection due to vertical component is shown as bars where deflection due to gravity load is shown as dotted line.

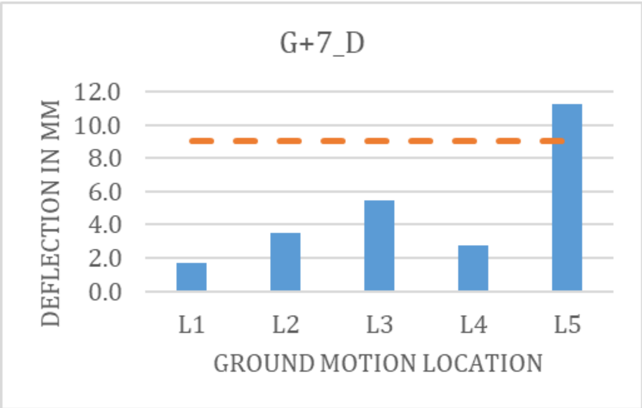

Chart -9 Slab Deflection in G+7_D

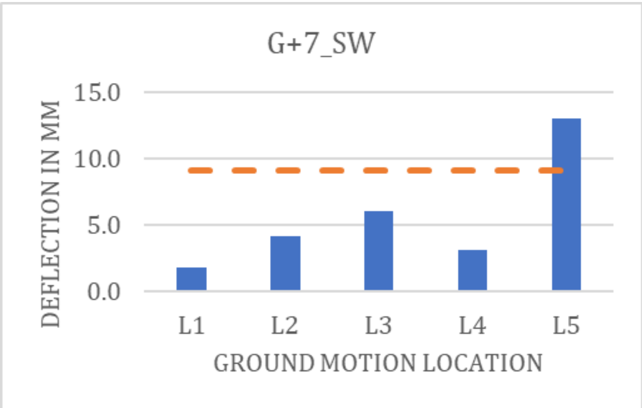

Chart -10 Slab Deflection in G+7_SW

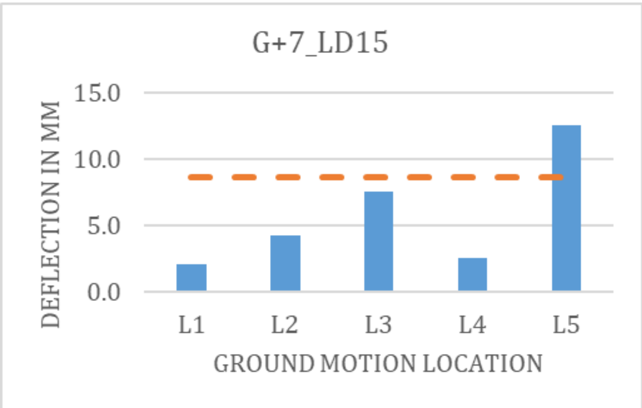

Chart -11 Slab Deflection in G+7_LD15

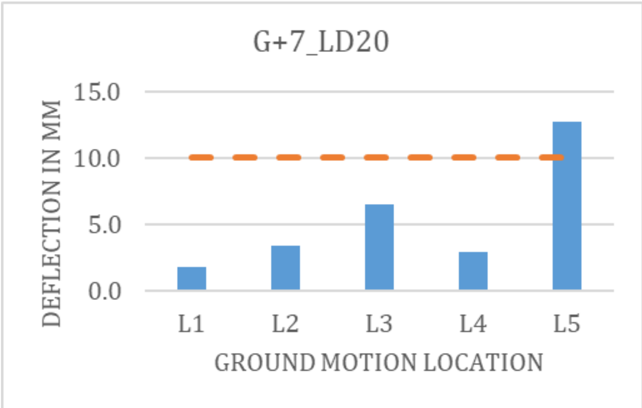

Chart -12 Slab Deflection in G+7_LD20

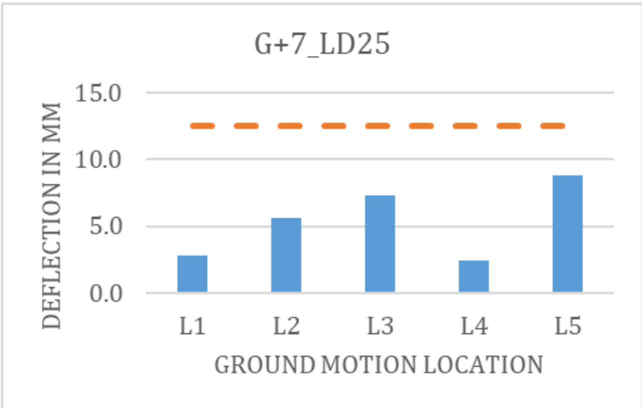

Chart -13 Slab Deflection in G+7_LD25

As can be seen in the figures, in one case, the deflection of the slab owing to vertical ground motion is greater than the deflection caused by gravity loads. The maximum slab deflection caused by vertical acceleration in G7_SW is 13mm, whereas the maximum deflection generated by gravity load is 9.1mm in G7_SW & 12.5mm in G7_LD25. As a result, the overall deflection will be 22.1mm, which is substantially greater than the limit prescribed (L/250) in IS 456. This displacement may cause non-structural parts to be damaged and slab stiffness to deteriorate. When drops are compared to with & without shear walls, deflection increases in drop with shear wall. It is showing that shear walls won't be able to regulate deflection due to vertical motion. In comparison to slab thickness, the maximum deflection of LD15, LD20, and LD25 is 11.1mm, 12.6mm, and 12.9mm, respectively, when using L5, suggesting that deflection due to vertical component would rise as slab thickness decreases. Same as G+7 see below chart for slab deflection for G+10 building.

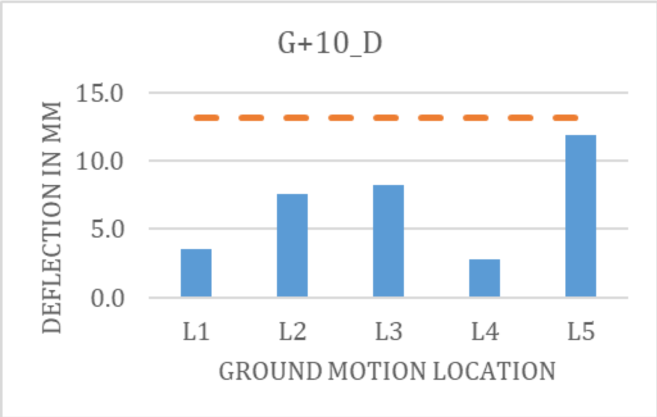

Chart -14 Slab Deflection in G+10_D

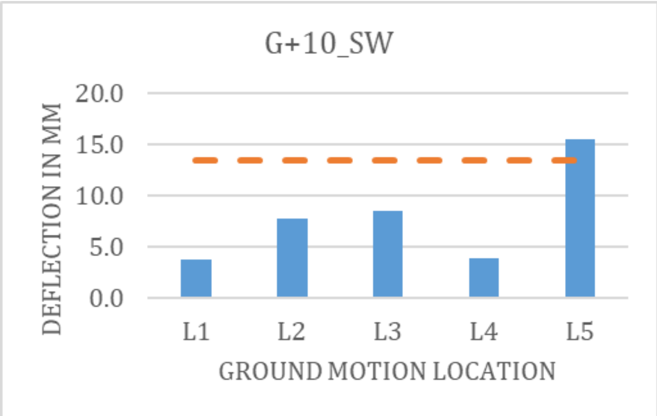

Chart -15 Slab Deflection in G+10_SW

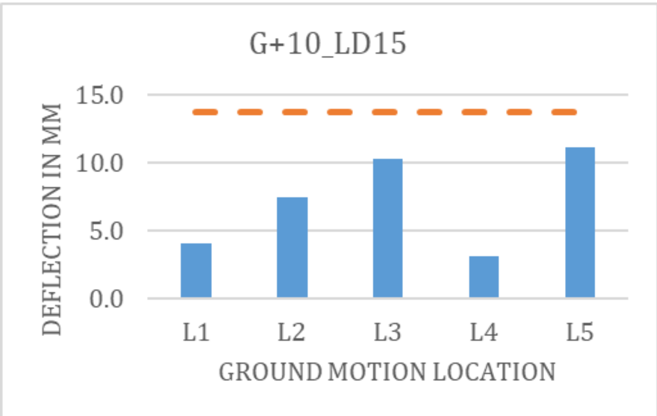

Chart -16 Slab Deflection in G+10_LD15

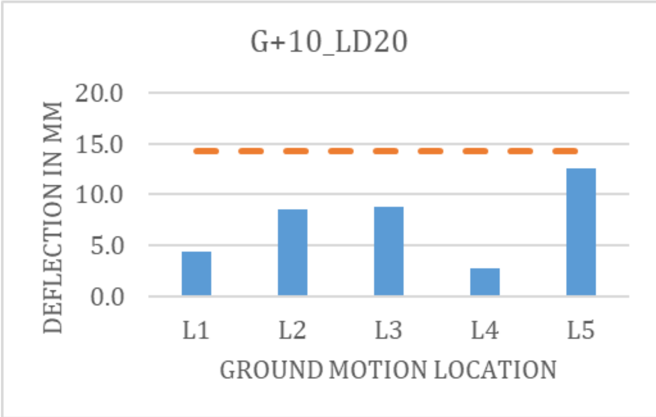

Chart -17 Slab Deflection in G+10_LD20

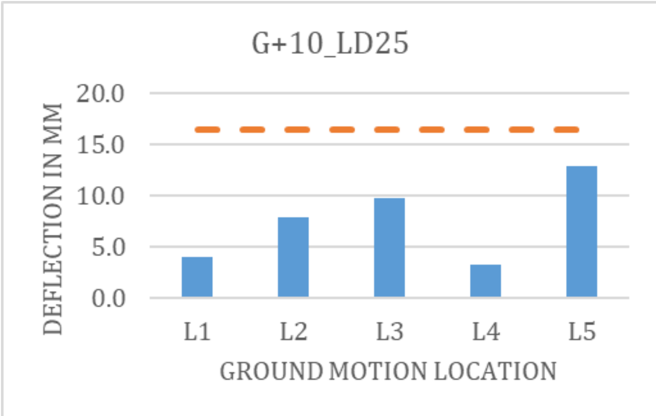

Chart -18 Slab Deflection in G+10_LD25

Failure due to Punching shear is the most catastrophic form of failure in flat slabs; it is harmful since there are no obvious symptoms of failure prior to breakdown. Vertical earthquake acceleration can greatly enhance both the vertical shear and slab rotation conveyed by a slab-column junction. As we have shown, the largest effect of vertical motion is found in the interior column, and the maximum effect of punching shear is found at C22 column. The hidden line in charts represents punching shear caused by gravity loads. Punching shear failure produces comparable results to slab deflections. The maximum shear stress ratio caused by vertical earthquake component is 0.45 & 0.52 in the G+10 & G+7 SW building where as due to gravity it is 0.25. Flat slab with drop & drop with shear wall have almost same value in gravity but flat slab with shear wall have more punching shear value. Out of 5 ground motion location, 2 location have values more than gravity loads. In G+7_SW & G+7_D building have 207% & 101% more punching shear value compare to gravity. Where as in G+10_SW & G+10_D have 180% & 100% respectively. Below are the charts for punching sear values.

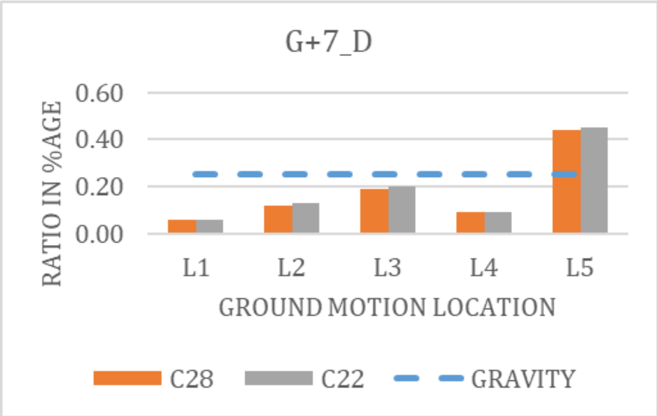

Chart -19 Punching Shear in G+7_D

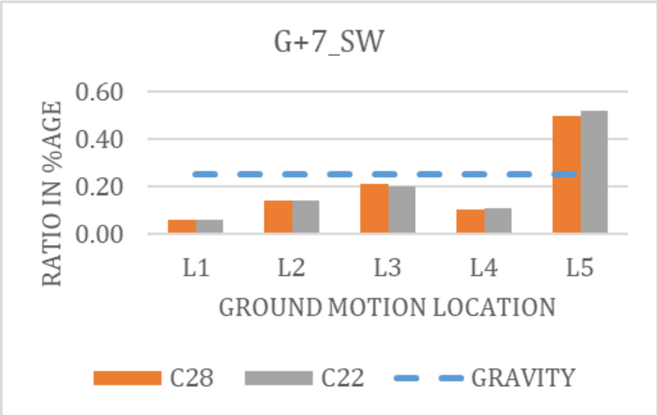

Chart -20 Punching Shear in G+7_SW

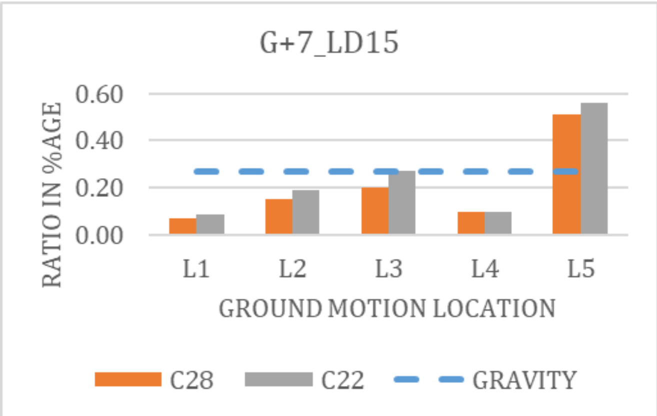

Chart -21 Punching Shear in G+7_LD15

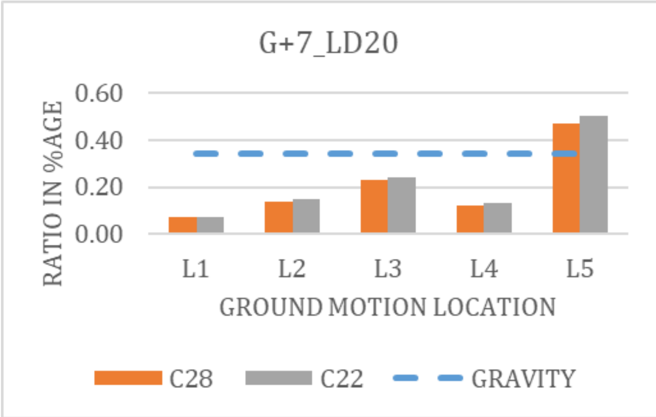

Chart -22 Punching Shear in G+7_LD20

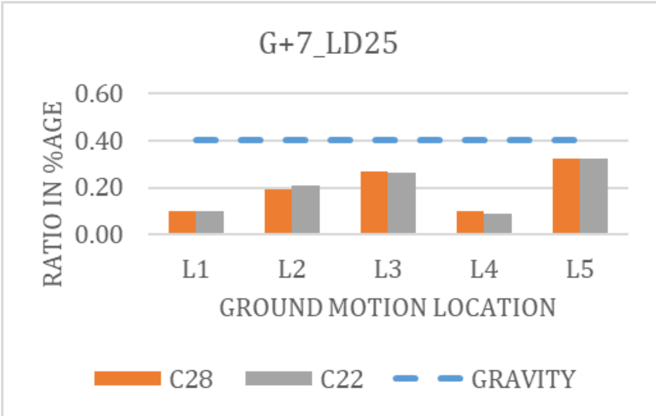

Chart -22 Punching Shear in G+7_LD25

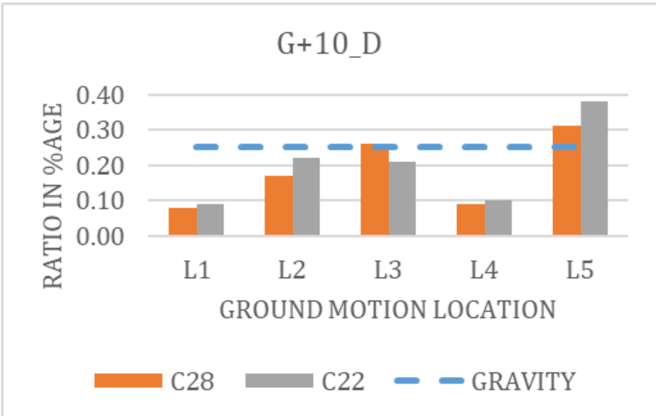

Chart -23 Punching Shear in G+10_D

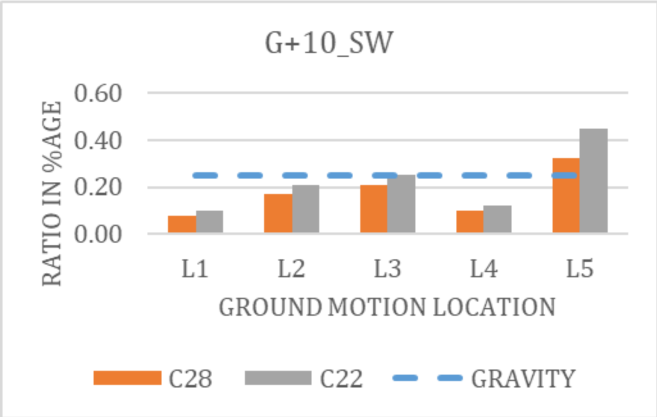

Chart -24 Punching Shear in G+10_SW

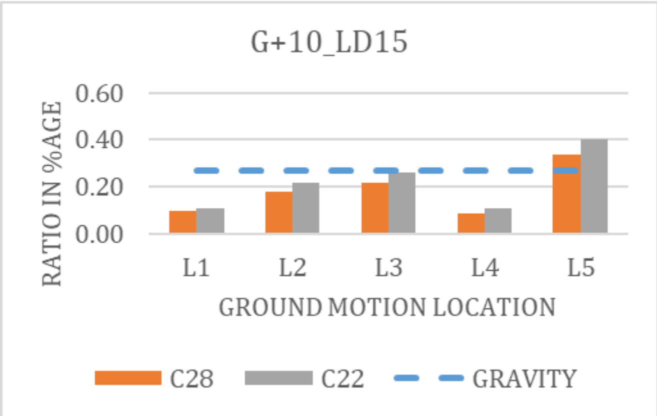

Chart -25 Punching Shear in G+10_LD15

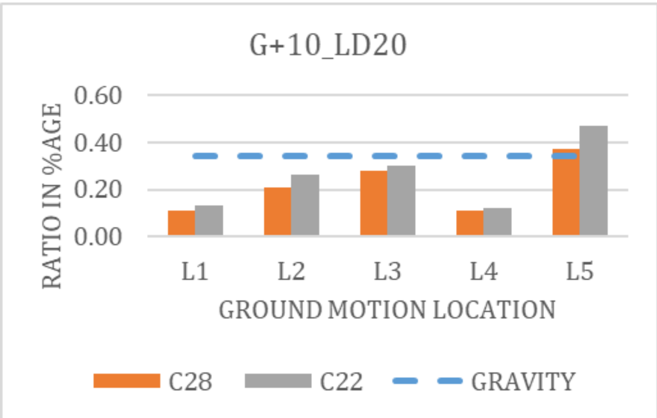

Chart -26 Punching Shear in G+10_LD20

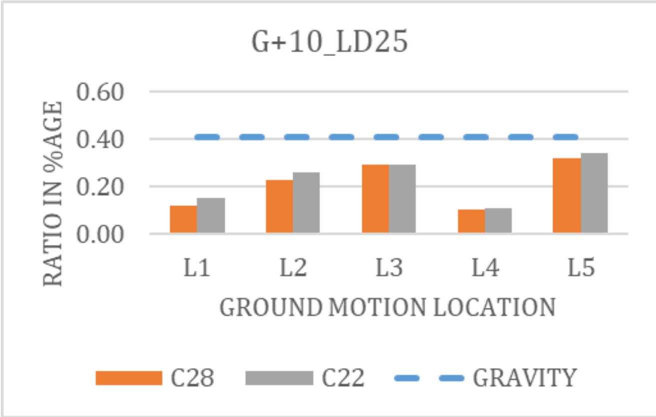

Chart -27 Punching Shear in G+10_LD25

3. CONCLUSIONS

Below is the list of observations are drawn from linear time history studies by using ETABS models:

• We discovered that vertical earthquake ground movements had a considerable influence on the response over a flat slab building.

• It is worth noting that the majority of the maximum outputs in the form of axial force in column, deflection of slabs, and punching shear at slab column junctions are almost identical to the Peek Ground Acceleration in specific applied ground movements.

• We discovered a maximum of 85.1% of axial force in column owing to vertical motion when compared to gravity loads, which is sufficient to cause column failure by splitting when considered as combination.

• It's also worth noting that the influence of vertical earthquake forces on axial loads in columns rises in interior columns while decreasing equally in outer perimeter columns.

• We discovered a max rise of 146.3% in deflection of slab due to vertical acceleration as compared to gravity loads.

• Slab deflections caused only by vertical motions do not exceed the permitted limit set by IS 456-2000, but in 60% of cases, they surpass 50% of the limit.

• We also show that introducing a shear wall does not reduce vertical deflection or displacement as much as it does lateral displacement. even though we only installed shear walls at all corners, their efficiency against vertical motion should be tested by providing at other areas too.

• It is noticed that the most damaging effects of vertical motion are on punching shear at the junction of column & flat slab, and this varies depending on thickness of slab & dropped panels.

• Only vertical earthquake force resulted in a maximum of 0.52 punching shear ratio. Maximum of 208% of punching stress is raised in percentage terms, which is sufficient to cause gradual collapse of any flat plate building.

• Punching shear stresses caused by vertical motion surpass punching shear stresses caused by gravity loads in 40% of the records.

• In a flat slab building, lateral earthquake force is often totally controlled by shear wall or partly controlled by special moment resisting frame while interior columns are intended to behave as gravity columns, although this is hazardous under vertical earthquake motion.

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