Comparison of Conventional Two-Way & Flat Slab Structure by Lateral Loading

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Abstract— Flat slab structural systems are widely used in urban India. The slabs which are directly rest on columns without beams are known as flat slabs. Even though the performance of flat slab structures is dominating to conventional beam-slab-column systems, it has some limitations to resist the punching shear failure and flexural failure under seismic loading conditions. The objective of study is to observe the behavior under various lateral loading conditions. This paper presents the analysis on parameters like storey displacement, storey drift, base shear, time period, axial force, shear force and bending moment on the behavior of both flat slab and conventional two-way slab structures subjected to seismic as well as wind loading. Analysis is done using ETABS software.

Keywords— ETABS, Flat Slab Structures, Seismic Analysis, Wind Analysis

I. INTRODUCTION

Due to rapid urbanization in India, flat slabs are being trendier than conventional slab structures. The slabs which are directly rest on columns without beams are known as flat slabs. Flat slab system has less self-weight as beams are absent. This structural system provides large clear floor to floor height as well. It is proving convenient in construction practices as it is beneficial directly and indirectly in achieving economy, convenience in formwork design, providing compact construction period and satisfying architectural demands. Even though having several plus points in flat slab structural system, the structure fails because of punching shear and flexural failure. The severe effects are noted when lateral forces such as earthquake and wind forces are acted upon it. This paper presents the analysis of research carried out to check the behaviour of flat slab for different loading conditions and analysis parameters subjected to earthquake and wind forces.

Slab column connection does not possess the rigidity of the beam column joint. Shear concentration around column is very high due to the possibility of the column punching through the slab. Deflections tend to be very large due to lesser depth of slab

II. METHODOLOGY

A. Preliminary Remarks

Analysis of flat slab structures and conventional two-way slab structures is done using the specifications provided by the code of practice (IS 456:2000). For the analysis purpose, an actual existing structure is selected. The same structure is designed using conventional slabs and then for flat slabs. The architectural details for actual existing structure are described as follows:

- Location: Nashik Road, Nashik.
- Project Name: Suyojit One World
- No. of floors: Basement + Ground + 4

Floor Wise Occupancy of Structure:

Basement:	Parking
Ground floor:	Showrooms, shops
First floor:	Mezzanine floor for showroom, shops
Second floor:	Assembly halls, offices
Third floor:	Assembly halls, offices
Fourth floor:	Restaurant, terrace
Terrace:	Terrace

- Floor to floor height:
1. Basement: 3.45m
2. Ground floor & above: 3.6m
- Bottom of footing: 2m
- Height of building: IS 1893 (part 1): 2016, clause 4.10
1. Conventional Structure :19.85 m
2. Flat slab Structure :14.4 m

According to IS 1893 (part 1):2016, clause 7.7.1, if the structure locates in seismic zone 3 and it has height greater than 15m, then one must perform dynamic analysis along with equivalent static analysis. After the building model is constructed, the irregularity check has given according to IS 1893 (part 1):2016, clause 7.1, table 6. Therefore, the analysis has done by following methods:

1. Equivalent Static Method   IS 1893 (part 1): 2016,
2. Dynamic Analysis Method   IS 1893 (part 1): 2016,

The first step for the analysis is the modeling of a conventional slab structure in software. Proper loading conditions, soil conditions, earthquake zone etc; are to be considered in this model and are discussed further.

After clear analysis of conventional slab structure, the next step is to model the flat slab structure with drop using the of ETABS (version 2017) software. For this attempt, same loading conditions, soil conditions and earthquake zones are considered so that it will be easy for comparison.

B. Load Intensity Considerations

1) Dead load: IS 875 (part 1): 1987
- Self-weight of structure
- Floor Finish: Manglore tiles + Grit = 1 kN/m^2
- Brick Load: AAC (Autoclaved Aerated Concrete) blocks = 8 kN/m^3
- Water proofing load: 1 kN/m^2
- Ramp floor finish: 1 kN/m^2

2) Live load: IS 875 (part 2): 1987
- Parking: 5 kN/m^2
- Showroom: 6 kN/m^2
- Shop (retail shop): 4 kN/m^2
- Assembly Hall (without fixed seats): 5 kN/m^2
- Office: 3 kN/m^2
- Terrace: 3 kN/m^2
- Restaurant: 4 kN/m^2
- Impact allowance for lift= 25%
- Ramp: 5kN/m²

3) Loading on staircase
1. Going
- Referring to architectural drawing, riser is 150mm and trade is 280mm
- Floor finish = 1 kN/m^2
- Weight of steps per meter= ½ × trade × rise × unit weight of concrete × 1/trade = ½×0.28 × 0.15 × 25 × 1/0.28 =1.875kN/m
- Live load = 2 kN/m²
2. Mid-landing
- Floor finish = 1 kN/m^2
- Live load = 3 kN/m²

4) Loading on retaining wall provided in basement level
For the stability purpose, a retaining wall is provided at basement level. Consider separate load case 'Active Earth Pressure' (AEP) for this loading.

γ = Unit weight of soil = 15 kN/m^3
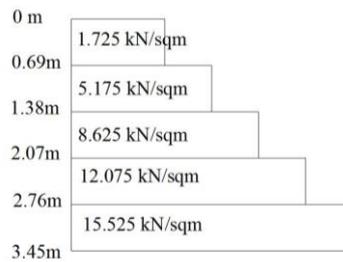
H= height of wall = 3.45m

Angle of repose = 30°

K_a = Coefficient of active earth pressure = $\frac{1-sin\phi}{1+sin\phi}$ = $\frac{1-sin\,30°}{1+sin\,30°}$ = 0.333

Lateral soil load on wall = $K_a \times \gamma \times H$ = 0.333 × 15 × 3.45 = 17.25 kN/m

Distribute this load on wall throughout its height. The distributed load is shown in figure below.

The wall is divided into 5 horizontal parts. Loads are calculated for each level and assigned separately to every divided part. The calculations are as follows:

```
0 m
        1.725 kN/sqm
0.69m
        5.175 kN/sqm
1.38m
        8.625 kN/sqm
2.07m
        12.075 kN/sqm
2.76m
        15.525 kN/sqm
3.45m
```

Figure 1: Loads on retaining wall at every level

Total height of wall = 3.45m. This wall is divided into 5 parts. Hence height of each level is $\frac{3.45}{5}$ = 0.69 m. Let us consider that the load is applied at the center of the level. Hence for first level, it will be applied at $\frac{0+0.69}{2}$ = 0.345 m.

The load applied at 0.345m = $K_a \times \gamma \times H$ = 0.333 × 15 × 0.345 = 1.725 kN/m²
Similarly, load applied at (0.345+0.69) = 1.035m = 0.333 × 15 × 1.035 = 5.175 kN/m²
The load applied at (1.035+0.69) = 1.035m = 0.333 × 15 × 1.725 = 8.625 kN/m²
The load applied at (1.725+0.69) = 2.415m = 0.333 × 15 × 2.415 = 12.075 kN/m²
The load applied at (2.415+0.69) = 3.105m = 0.333 × 15 × 3.105 = 15.525 kN/m²

5)   Loads due to vertical elevator
According to architectural drawings, the load considerations for vertical elevator is provided. The other details are provided in the same architectural drawings.
* Masses acting (weight of persons) = 1134 kg
* Travelling cable weight = 4 kg
* Car weight = 586 kg
* Counter weight = 856 kg
* Area of lift slab = 2.3m × 2.38m = 5.474 m² ≈ 5.5m²

Total load = 1134 + 4 + 586 + 856 = 2580kg = 25.30 kN
Total live load on lift area = 25.30/5.5 = 4.6 kN/m²
Assign 4.6 kN/m² as live load in load case 'Roof Live Load'

6)   Wind load: IS 875 (part 3): 2015
* Type of building: Flat roof building
* Basic wind speed V_B = 39 m/s
* Mean probable life of structure: 50 years
* Risk coefficient factor k_1 =1
* Terrain category = 3
* Height of building = 18m
* Terrain roughness and height factor k_2 =0.994
* Ground slope < 3° (flat ground)
* Topography Factor k_3 = 1
* Importance factor for cyclonic region k_4=1 (All other structures)
* Opening of wall: 5 %
* Internal wind pressure coefficient C_{pi} = ± 0.2

i.   Calculation of combined pressure coefficient (C_p)
Referring IS 875 (part 3): 2015,
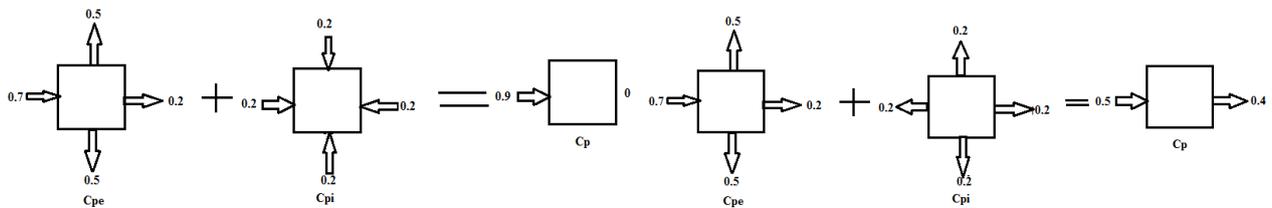h= Height of structure above mean ground level = 18m,
l = Length of member or larger horizontal dimension of a building =53.22 m,
w = lesser horizontal dimension of a building or structural member = 41.04m
$\frac{h}{w} = \frac{18}{41.04} = 0.4385$ <1/2. Therefore, refer case 1.
$\frac{l}{w} = \frac{53.22}{41.04} = 1.296$. (1 < 1.296 <3/2) therefore refer case 1.
a)   Calculation of wind at 0° and 90˚

Figure 2: a) Calculation of wind at 0°: External Pressure + Internal Suction, b) Calculation of wind at 0°: External Pressure + Internal Pressure

Combined Cp from of external pressure, internal pressure and internal suction for wind in 0° is 0.9.
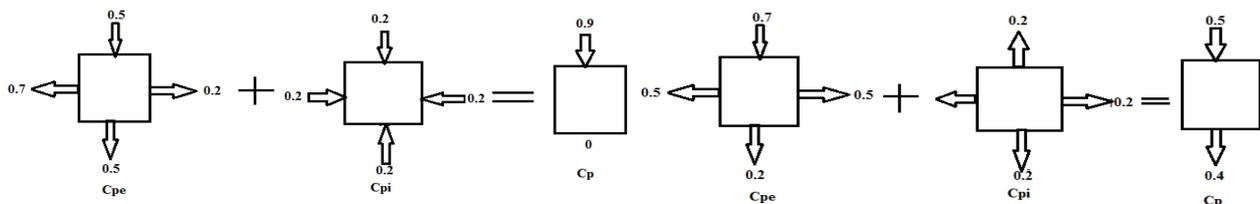
Figure 4: a) Calculation of wind at 90°: External Pressure + Internal Suction, b) Calculation of wind at 90°: External Pressure + Internal Pressure

Combined Cp from of external pressure, internal pressure and internal suction for wind in 90° is 0.9.

1.   Seismic load (Equivalent Static Analysis): IS 1893 (part 1): 2016
- Time Period:

T_{ax}: 0.315sec
T_{ay}: 0.276sec
- Importance factor I =1.5
- Type of soil: Rock and Hard Soil, Type A
- Seismic zone factor Z: 0.16, (Zone III)
- Response reduction factor: 5
- $(S_a/g)_x = (S_a/g)_y = 2.5$

2. Seismic load (Response Spectra Analysis): IS 1893 (part 1): 2016
- Modal case: Eigen value method
- Seismic zone factor = 0.16
- Soil type = I
- Function damping ratio = 0.5
- Modal combination method = CQC (Complete Quadratic Combinations)
- Scale factor $=\dfrac{I}{Z} \times \dfrac{G}{R} = \dfrac{1.5}{0.16} \times \dfrac{9.81}{5} = 1.4715$ m²/sec
- Number of initial modes considered = 150

B.A.1   Primary load cases

For the analysis and design purpose, the basic 8 load cases are considered. They are as follows:
1.   Dead load (DL)
2.   Live load (LL)
3.   Roof live load (RLL)
4.   Earthquake load in X direction (EQX)
5.   Earthquake load in Y direction (EQY)
6.   Wind load in X direction (WLX)
7.   Wind load in Y direction (WLY)
8.   Active Earth Pressure (AEP)

B.A.2   Load combinations for limit state of serviceability (Equivalent Static Analysis)

According to limit state of serviceability, the combinations of the above primary load cases are created. Referring to IS456(2000), the following load combinations for static earthquake and wind load analysis are considered.
101:DL + AEP + LL + RLL
102:DL + AEP + WL X+
103:DL + AEP + WL X-
104:DL + AEP + WL Y+
105:DL + AEP + WL Y-
106:DL + AEP + EQ X+

107:DL + AEP + EQ X-
108:DL + AEP + EQ Y+
109:DL + AEP + EQ Y-
110:DL + AEP + 0.8LL + 0.8RLL + 0.8WL X+
111:DL + AEP + 0.8LL + 0.8RLL + 0.8WL X-
112:DL + AEP + 0.8LL + 0.8RLL + 0.8WL Y+
113:DL + AEP + 0.8LL + 0.8RLL + 0.8WL Y-
114:DL + AEP + 0.8LL + 0.8RLL + 0.8EQ X+
115:DL + AEP + 0.8LL + 0.8RLL + 0.8EQ X-
116:DL + AEP + 0.8LL + 0.8RLL + 0.8EQ Y+

B.A.3   Load combinations for limit state of strength (Equivalent Static Analysis)

According to ultimate limit state, the combinations of the above primary load cases are created. Referring to IS456(2000), the following load combinations for static earthquake and wind load analysis are considered.

201:     1.5 (DL + AEP + LL + RLL)

202:     1.5 (DL + AEP + WL X+)
203:     1.5(DL + AEP + WL X-)
204:     1.5 (DL + AEP + WL Y+)
205:     1.5 (DL + AEP + WL Y-)
206:     1.5 (DL + AEP + EQ X+)
207:     1.5 (DL + AEP + EQ X-)
208:     1.5 (DL + AEP + EQ Y+)
209:     1.5 (DL + AEP + EQ Y-)
210:     0.9DL + 0.9AEP + 1.5WL X+
211:     0.9DL + 0.9AEP + 1.5WL X-
212:     0.9DL + 0.9AEP + 1.5WL Y+
213:     0.9DL + 0.9AEP + 1.5WL Y-
214:     0.9DL + 0.9AEP + 1.5EQ X+
215:     0.9DL + 0.9AEP + 1.5EQ X-
216:     0.9DL + 0.9AEP + 1.5EQ Y+
217:     0.9DL + 0.9AEP + 1.5EQ Y-
218:     1.2 (DL + AEP + LL + RLL + WL X+)
219:     1.2 (DL + AEP + LL + RLL + WL X-)
220:     1.2 (DL + AEP + LL + RLL + WL Y+)
221:     1.2 (DL + AEP + LL + RLL + WL Y-)
222:     1.2 (DL + AEP + LL + RLL + EQ X+)
223:     1.2 (DL + AEP + LL + RLL + EQ X-)
224:     1.2 (DL + AEP + LL + RLL + EQ Y+)
225:     1.2 (DL + AEP + LL + RLL + EQ Y-)

B.A.4   Load combinations for limit state of serviceability (Dynamic Response Spectra Analysis)

According to limit state of serviceability and referring to IS456(2000), the following load combinations for dynamic analysis are considered.

301:     DL + AEP + LL + RLL
302:     DL + AEP + RXX
303:     DL + AEP + RYY
304:     DL + AEP + 0.8LL + 0.8RLL + 0.8RXX
305:     DL + AEP + 0.8LL + 0.8RLL + 0.8RYY

B.A.5   Load combinations for limit state of collapse (Dynamic Response Spectra Analysis)

According to limit state of serviceability and referring to IS456(2000), the following load combinations for dynamic analysis are considered.

401: 1.5 (DL + AEP + LL + RLL)
402: 1.5 (DL + AEP + RXX)
403:1.5 (DL + AEP + RYY)
404: 0.9DL + 0.9AEP + 1.5RXX
405: 0.9DL + 0.9AEP + 1.5RYY
406: 1.2 (DL + AEP + LL + RLL + RXX)
407:1.2   (DL + AEP + LL + RLL + RYY)

B. **Parameters to be considered for analysis:**

i. storey displacement,
ii. storey drift,
iii. storey stiffness
iv. base shear,
v. modal time period,
vi. axial force,
vii. shear force,
viii. bending moment

III. RESULTS & DISCUSSION

As the analysis part is over in ETABS software, the results are extracted. For the representation of the results, two columns in the structure are selected. One of them is in the interior of structure and the other one is at the periphery. The columns are "C28" which is interior column and "C30" which is the exterior one. Shear force, axial force, bending moment are checked for C28 and C30. Other than these parameters, story displacement, storey drift, storey stiffness, modal time period and base shear are calculated and compared for both conventional and flat slab structure. The details of every results are discussed in detail below.

2.1 Storey displacement

Storey displacement is the lateral displacement of the storey relative to its base. Here the plot of storey level (abscissa) verses displacement in mm (ordinate) is presented for the results interpretation in graphical format. Along with that the displacement values in mm for both the structures for every level are presented in tabulated form. The difference as percentage increase relative to flat slab is calculated and added in the table.

2.1.1 Earthquake Analysis

The displacement by equivalent static analysis along X axis are as follows:
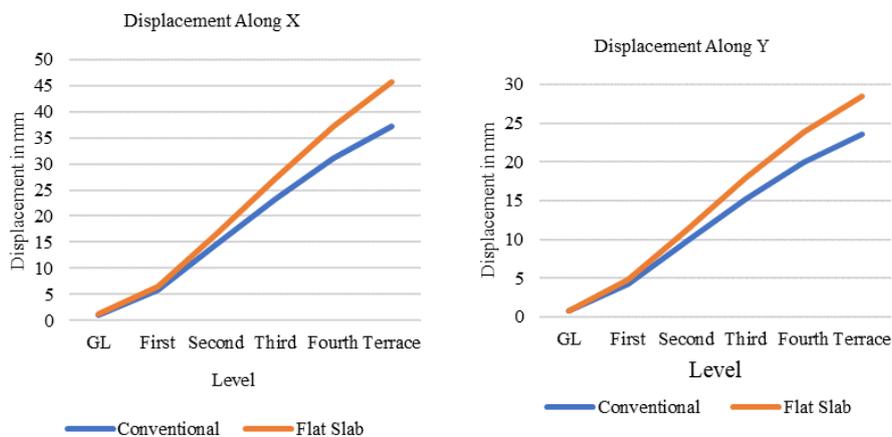
Figure 6: Storey Displacement: Equivalent static analysis: along X Axis and Y axis

As noted from graph, the storey displacement for flat slab structure is comparatively larger than conventional two-way flat slab structure. For the lower stories, the values of displacements for both structures are almost equal. The displacement in flat slab is 3.733% higher than conventional slab. But as the height of the building is increasing, the displacement if flat slab is increasing. At the terrace level, the difference is 22.66%. Same as the displacement in X axis, displacement in Y axis is higher for flat slab structure than conventional slab structure. But comparing to X axis, displacement in Y axis is lesser magnitude. Here, at the bottom storey, the displacement in flat slab is 1.01% higher than conventional two-way slab structure. At the terrace level, this difference increases by 1.2%.
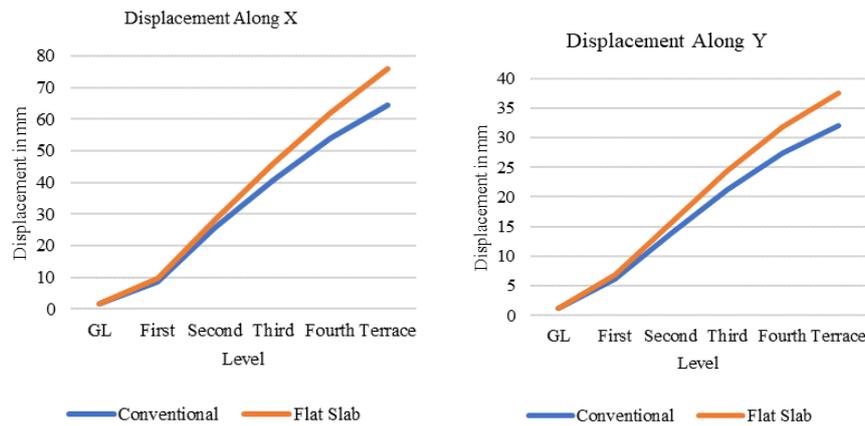
Figure 7: Storey Displacement: Dynamic Response Spectra Method: along X Axis and Y Axis

For the dynamic analysis with response spectra method, the values of displacement for flat slab structure is higher than conventional two-way slab structure. As we check the displacement results for the equivalent static analysis, the values of magnitudes of displacements by response spectra analysis are relatively higher. But at the ground level, the displacement in flat slab is 0.09% lesser. At the terrace level, this displacement increases by 1.176%. Same as in X direction, storey displacement along y axis is higher for flat slab structure than conventional two-way slab structure. At the ground level, the difference is 0.0075%. but at the terrace level, it becomes 1.171%.

2.1.2   Wind Analysis

Considering the combined effect of both internal suction and internal pressure for the external pressure, the wind load analysis is done. The storey displacements because of wind loading are discussed below.
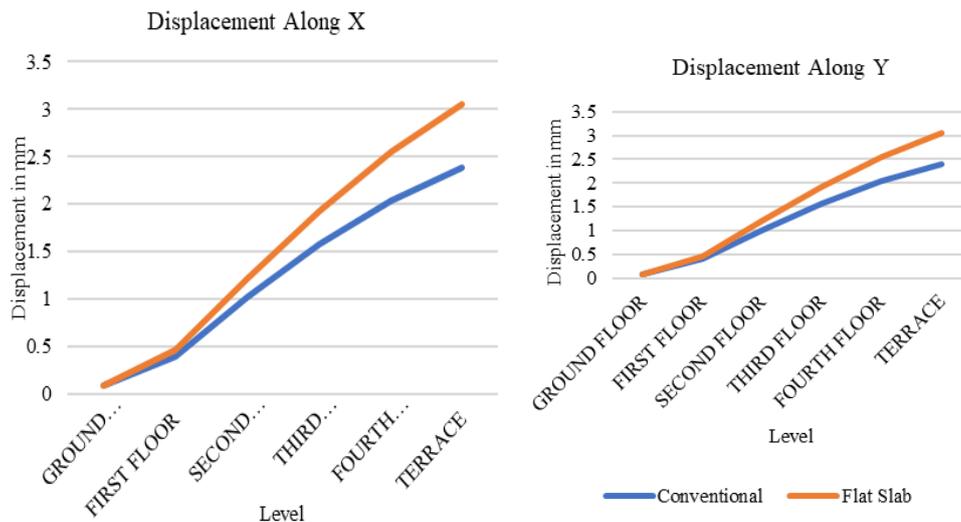
**Figure 10:** Storey Displacement: Wind Analysis: along X Axis and Y Axis

The storey displacement along X axis for wind loading is higher for flat slab than conventional two-way flat slab. Considering the earthquake forces with the wind forces, displacement because of wind is less than the earthquake force. The magnitude increases from 1.089% to 1.282% from ground level to terrace. Same as for X axis, the displacement in Y direction for wind analysis is higher for flat slab structures. The percentage increase in storey displacement is from 1.089% to 1.282%.

2.2   Storey Drift

Storey drift is the displacement of one level of a multi storey building relative to the level below. The plot of storey level (abscissa) verses drift in mm (ordinate) is presented for the results interpretation in graphical format. Along with that the drift values in mm for both the structures for every level are presented in tabulated form. The difference as percentage increase relative to flat slab is calculated and added in the table. According to IS 1893 (part 1): 2016, the storey drift in any storey shall not exceed 0.004 times the storey height, under the action of design base of shear V_B with no load factors, that is with partial safety factor for all loads taken as 1.0.

The permissible limit for drift in the models considered is as follows:

2.2.1   Earthquake Analysis
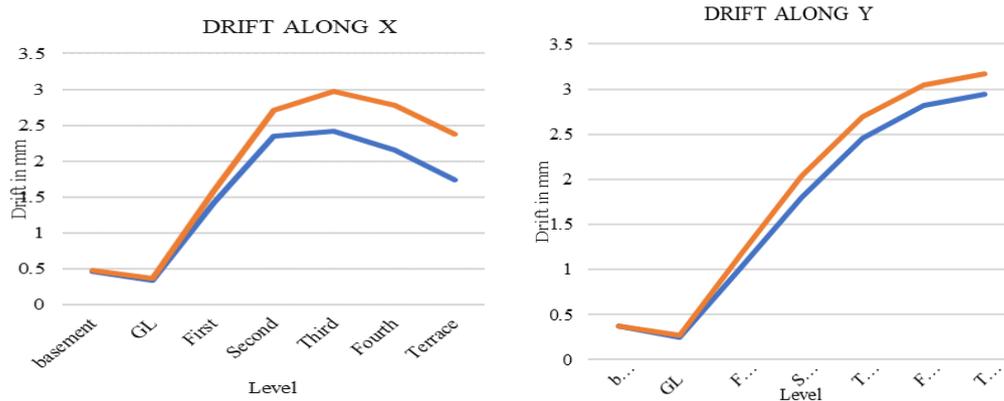
Figure 12: Storey Drift: Equivalent Static Analysis: along X Axis

The drift of flat slab is higher than the conventional slab structure. The drift increases from 1.035% to 1.371%. the peak increase is 1.293% at fourth level. If the drift is check according to its magnitude, the maximum value is 2.977, that is less than 3mm for both the structures. The drift of flat slab is higher than the conventional slab structure. The overall curve of graph decreases first then again drift increases. The maximum increase is 1.077%. the maximum drift of conventional slab is 2.945mm whereas drift in flat slab is 3.172mm.
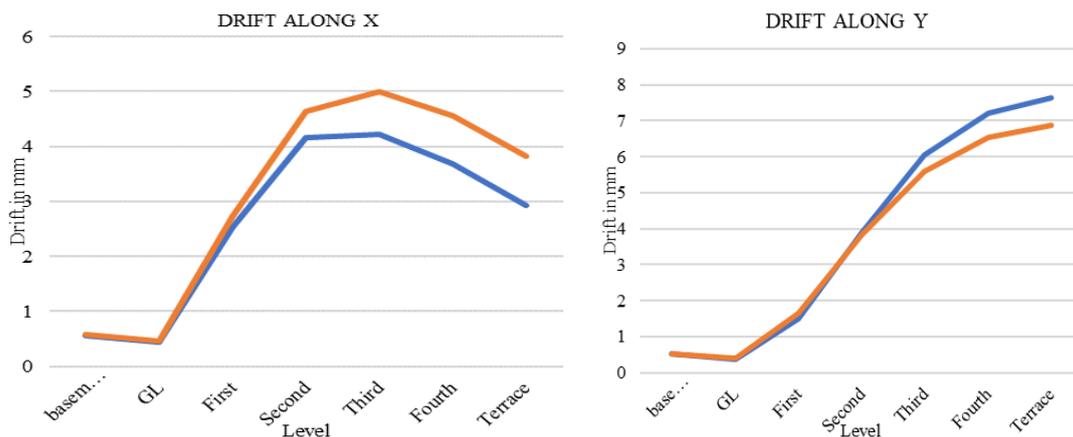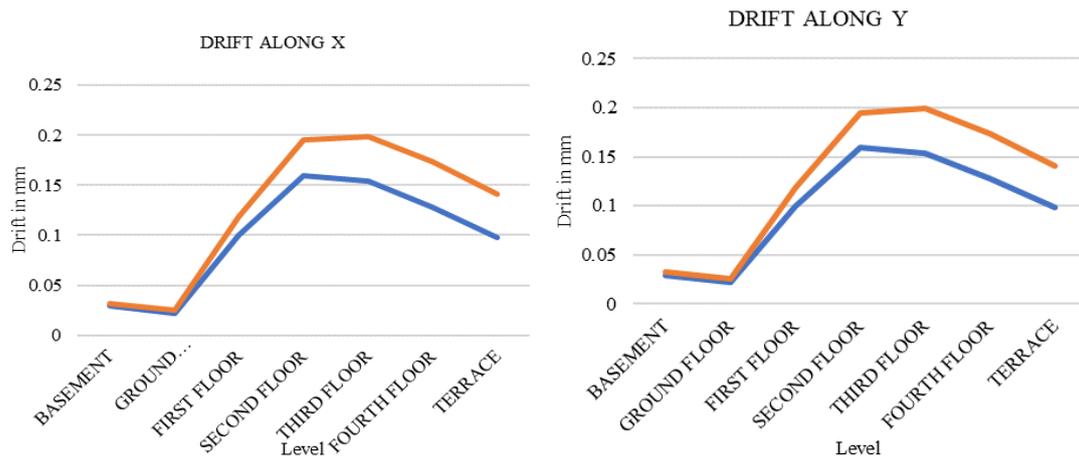

Figure 14: Storey Drift: Dynamic Response Spectra Analysis: along X Axis and Y Axis

The drift of flat slab is higher than the conventional slab structure. The drift in flat slab structure is 3.831mm and drift in conventional slab is 2.927mm. The percentage is 1.309. it is noted that, the drift calculated by dynamic response spectra method comes out larger in magnitude than equivalent static analysis. For the dynamic analysis of response spectra method, the drift along Y axis varies according to the floor level. Up to the third level, drift is almost equal for both flat slab structure and conventional two-way slab structure. As the storey level increases, the drift of conventional two-way slab structure increases than flat slab structure. The overall increase is from 0.972% to 0.901%.

2.2.2   Wind Analysis

The storey drift is calculated and compared for the wind loading along X and Y axes. The following table shows the storey drift of structures by wind loading along X axis.

Figure 16: Storey Drift: Wind Analysis: along X Axis and Y Axis

The drift of flat slab is higher than the conventional slab structure. The overall curve of graph decreases first then again drift increases and near the last floor (terrace), it again decreases. The maximum drift is 0.199 mm for flat slab and 0.154 mm for conventional slab structure. The maximum increase is found out to be 1.439% at terrace level. The drift of flat slab is higher than the conventional slab structure. The overall curve of graph decreases first then again drift increases and near the last floor (terrace), it again decreases. The maximum drift is 0.199 mm for flat slab and 0.154 mm for conventional slab structure. The maximum increase is found out to be 1.439% at terrace level.

For all the cases, the maximum storey drift is within permissible limit. Hence both the structures are safe.

2.3 Storey Stiffness

The word stiffness means the property of a material by which an object resists deformation in response to an applied force. The comparison of storey stiffness is done for the equivalent static method and response spectra method.

2.3.1 By Equivalent Static Analysis
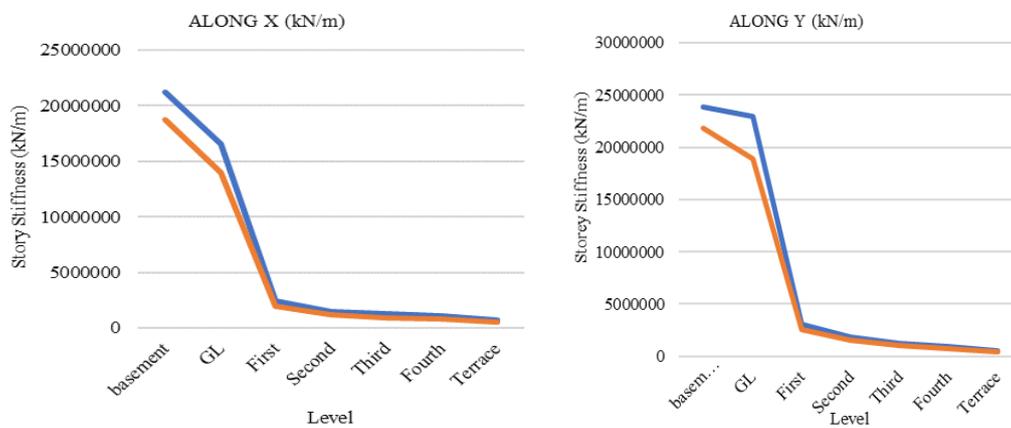
Figure 18: Storey Stiffness: Equivalent Static Analysis: along X Axis

The above table and graph show that the stiffness is maximum at basement level for both the structures. The conventional slab has more stiffness of 21187654.71 kN/m than flat slab which is 18771125.41kN/m. the difference is 0.886%. The pattern of variation of stiffness in both the directions is same. The maximum stiffness is found out to be in conventional slab structures at bottom level. The magnitude is 23895193.62 kN/m. the stiffness in flat slab structure at bottom 21851448.13 kN/m.

2.3.2 By Dynamic Analysis
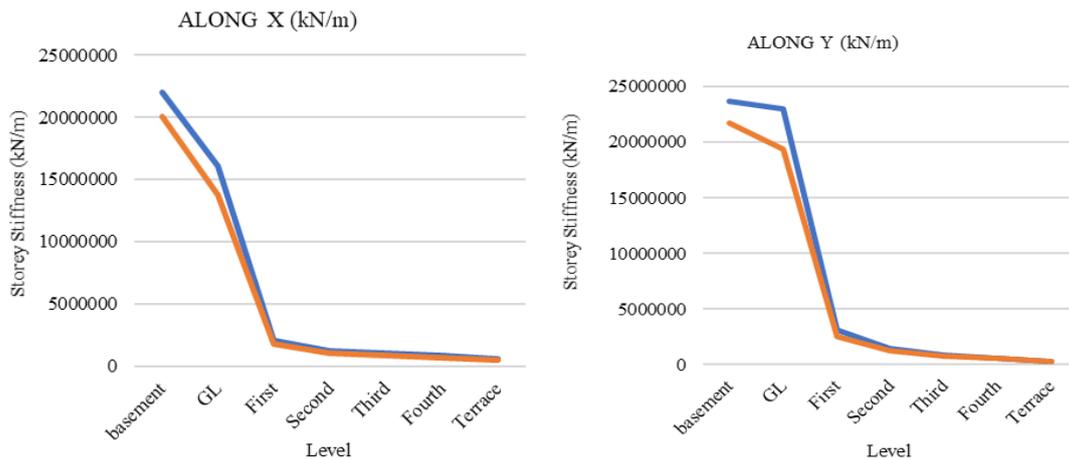
Figure 20: Storey Stiffness: Dynamic Analysis: along X Axis

The conventional slab structure has higher stiffness i.e. 22066022.27 kN/m than flat slab structures 20111626.3 kN/m at basement level. As the level increases, the stiffness goes on decreasing. On terrace level, the stiffness of conventional structure is 622031.635kN/m and for flat slab 472655.919kN/m. the maximum difference in stiffness is at bottom level is 0.911. As it can be seen from all the above four graphs, the storey stiffness for the conventional slab is higher in all the lateral directions. The intensity of storey stiffness reduces as the floor level increases. The conventional slab structure has higher stiffness i.e. 23725969.64kN/m than flat slab structures 21755952.46 kN/m at basement level. As the level increases, the stiffness goes on decreasing. On terrace level, the stiffness of conventional structure is 298435.579 kN/m and for flat slab 305199.603 kN/m. the maximum difference in stiffness is at bottom level is 1.023.

2.4   Modal Period

For the dynamic analysis, the response spectra method is considered. The time required for the undamped system to complete one cycle of free vibration is the natural period of vibration of the system in units of seconds. For the preliminary analysis 150 mode shapes are considered. For these modes, the time period in seconds is calculated as follows.
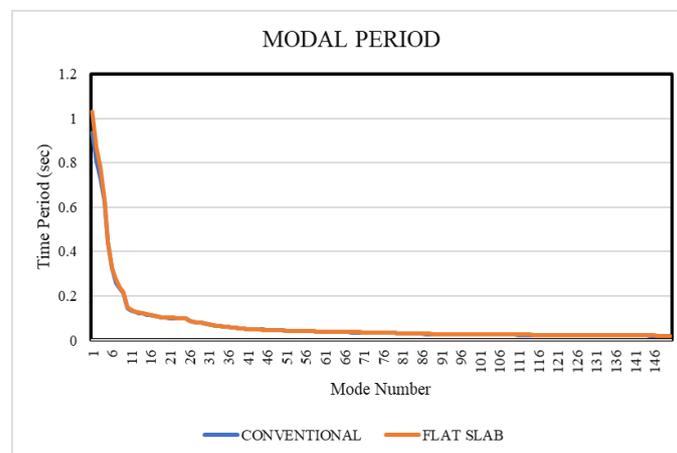

Figure 22: Modal Period in seconds

From the above graph, it is clear that modal period for both conventional and flat slab structure is almost equal. But for the first few modes, the value of time period for flat slab is higher than that of conventional slab structures. For conventional slab, the time period at first mode is 0.935 seconds and for flat slab it is 103 seconds.

2.5   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 a structure. The maximum value of base shear along X and Y directions is calculated for both the structures and compared.
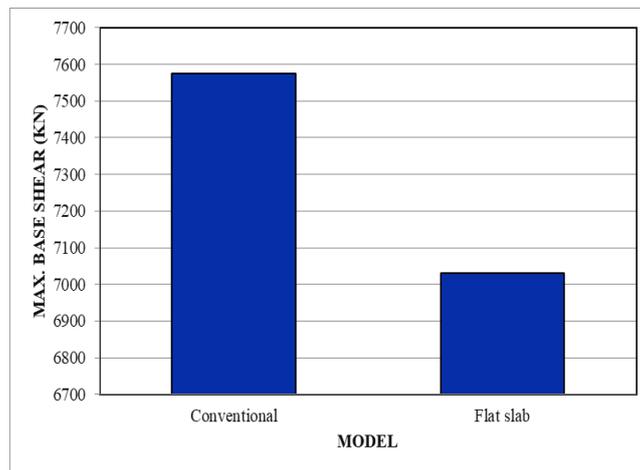
Figure 23: Base Shear (kN)

The base shear generating for the conventional slab structure is higher than flat slab structure. Calculated by equivalent static analysis, the magnitude of base shear along X and Y directions is same. For conventional slab structure, it is 7575.0401 kN. For flat slab structure the base shear is 7030.6772 kN.

2.6   Column Forces: Axial Force

If the load on a column is applied through the center of gravity of its cross section, it is called an axial load. Axial force is the compression or tension force acting in a member. If the axial force acts through the centroid of the member it is called concentric loading. If the force is not acting through the centroid it's called eccentric loading. Eccentric loading produces a moment in the beam as a result of the load being a distance away from the centroid.

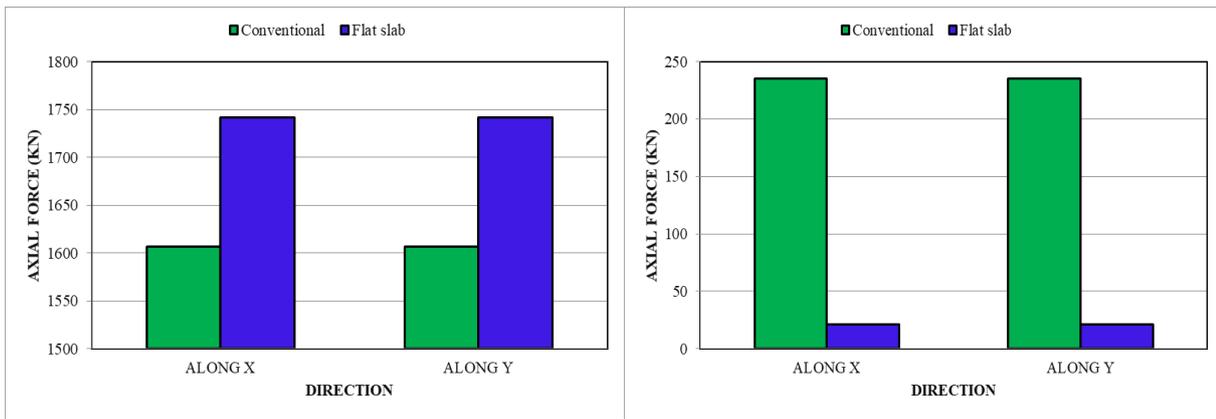**2.6.1   By Equivalent Static method**
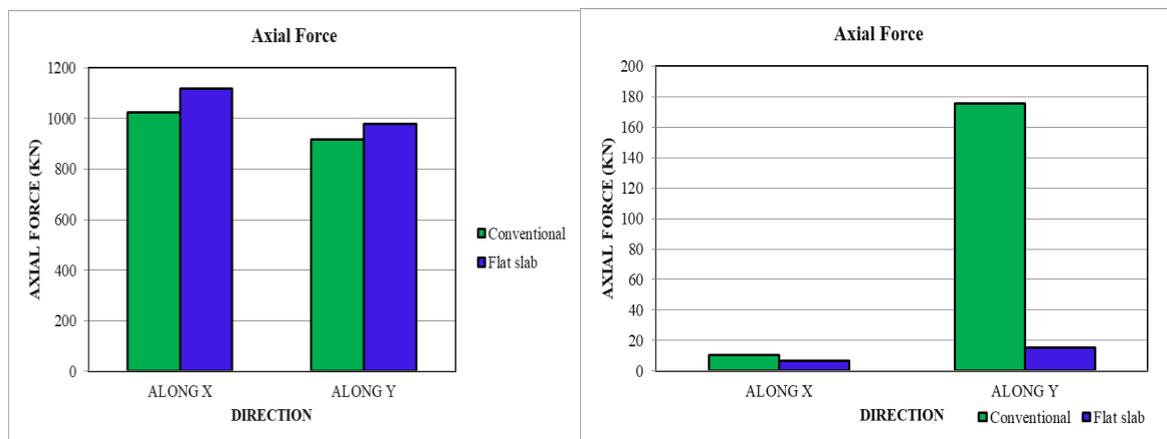
Figure 24: Axial Force (kN): Equivalent Static Method: C30 and C28

Here, axial force generating in flat slab is slightly higher than conventional two-way slab structure. Along X direction, the magnitude of conventional slab is 1024.4469 kN and of flat slab is 1117.68 kN. The axial force in flat slab is 1.09 % higher than conventional two-way slab structure. Along Y direction, the magnitude of conventional slab is 915.6172 kN and of flat slab is 978.81 kN. The axial force in flat slab is 1.07 % higher than conventional two-way slab structure. Axial force generating in flat slab is slightly higher than conventional two-way slab structure. Along X direction, the magnitude of conventional slab is 10.5554 kN and of flat slab is 6.8881 kN. The axial force in flat slab is 0.65 % higher than conventional two-way slab structure. Along Y direction, the magnitude of conventional slab is 175.3943 kN and of flat slab is 15.5646 kN. The axial force in flat slab is 0.09 % higher than conventional two-way slab structure.
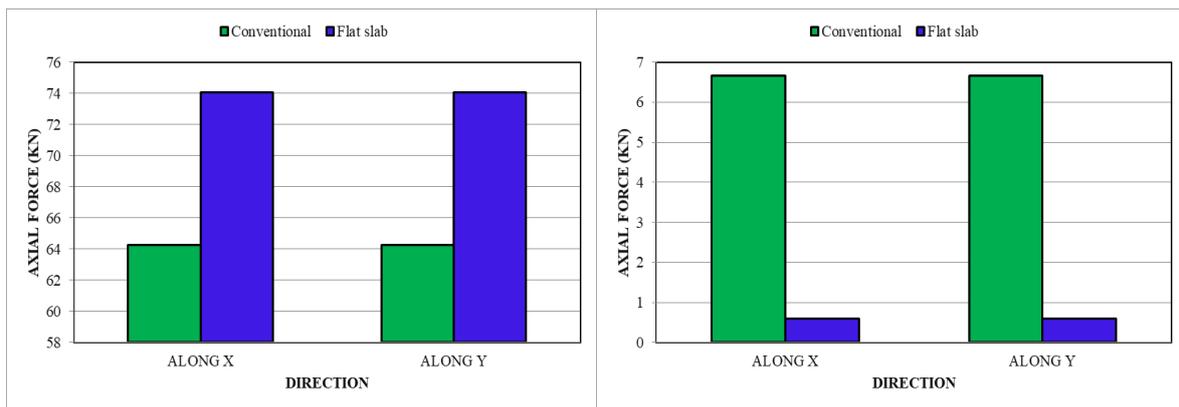
2.6.2   By Dynamic method

Figure 26: Axial Force (kN): Dynamic Method: C30 and C28

Here, axial force generating in flat slab is slightly higher than conventional two-way slab structure. Along X direction, the magnitude of conventional slab is 1607.117 kN and of flat slab is 1741.67 kN. The axial force in flat slab is 1.08 % higher than conventional two-way slab structure. Along Y direction, the magnitude of conventional slab is 1607.117 kN and of flat slab is 1741.67 kN. The axial force in flat slab is 1.08 % higher than conventional two-way slab structure. Here, axial force generating in flat slab is slightly higher than conventional two-way slab structure. Along X direction, the magnitude of conventional slab is 235.3105 kN and of flat slab is 20.9804 kN. The axial force in flat slab is 0.09% higher than conventional two-way slab structure. Along Y direction, the magnitude of conventional slab is 235.3105 kN and of flat slab is 20.9804 kN. The axial force in flat slab is 0.09 % higher than conventional two-way slab structure.

2.6.3 By Wind Loading

Figure 28: Axial Force (kN): Wind Loading: C30

Here, axial force generating in flat slab is higher than conventional two-way slab structure. Axial force generating in flat slab is slightly higher than conventional two-way slab structure. Along X direction, the magnitude of conventional slab is 64.2423 kN and of flat slab is 74.04 kN. The axial force in flat slab is 1.15 % higher than conventional two-way slab structure. Along Y direction, the magnitude of conventional slab is 64.2423 kN and of flat slab is 64.2423 kN. The axial force in flat slab is 1.15 % higher than conventional two-way slab structure. Here, axial force generating in flat slab is very less than conventional two-way slab structure. Along X direction, the magnitude of conventional slab is 6.6568 kN and of flat slab is 0.5977 kN. The axial force in flat slab is 0.09% higher than conventional two-way slab structure. Along Y direction, the magnitude of conventional slab is 6.6568 kN and of flat slab is 0.5977 kN. The axial force in flat slab is 0.09% higher than conventional two-way slab structure.

2.7 Column Forces: Shear Force

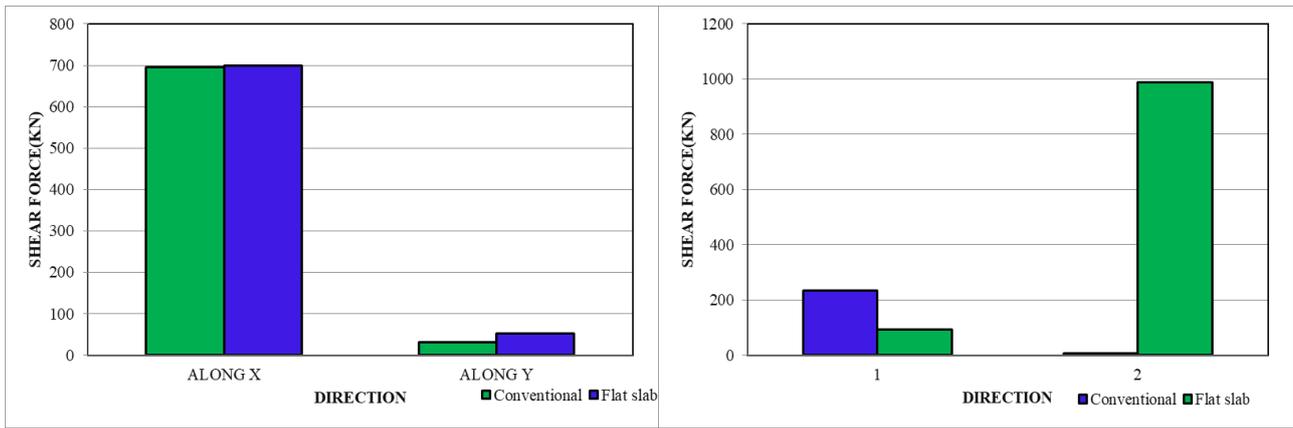### 2.7.1 By Equivalent Static method

Figure 30: Shear Force (kN): Equivalent Static Method: C30

The intensity of shear force along X direction for both the structures is much higher than along the Y direction. For the exterior column, the shear force is same in both the directions. Along X direction, the magnitude of conventional slab is 695.6621 kN and of flat slab is 699.1402 kN. The shear force in flat slab is 1% higher than conventional two-way slab structure. Along Y direction, the magnitude of conventional slab is 30.7021 kN and of flat slab is 51.5526 kN. The shear force in flat slab is 1.68% higher than conventional two-way slab structure. The intensity of shear force along X direction for both the structures is much higher than along the Y direction. For the exterior column, the shear force is same in both the directions. Along X direction, the magnitude of conventional slab is 232.9466 kN and of flat slab is 91.6025 kN. The shear force in flat slab is 0.39% higher than conventional two-way slab structure. Along Y direction, the magnitude of conventional slab is 5.5915 kN and of flat slab is 988.6508 kN. The shear force in flat slab is 176.81% higher than conventional two-way slab structure.
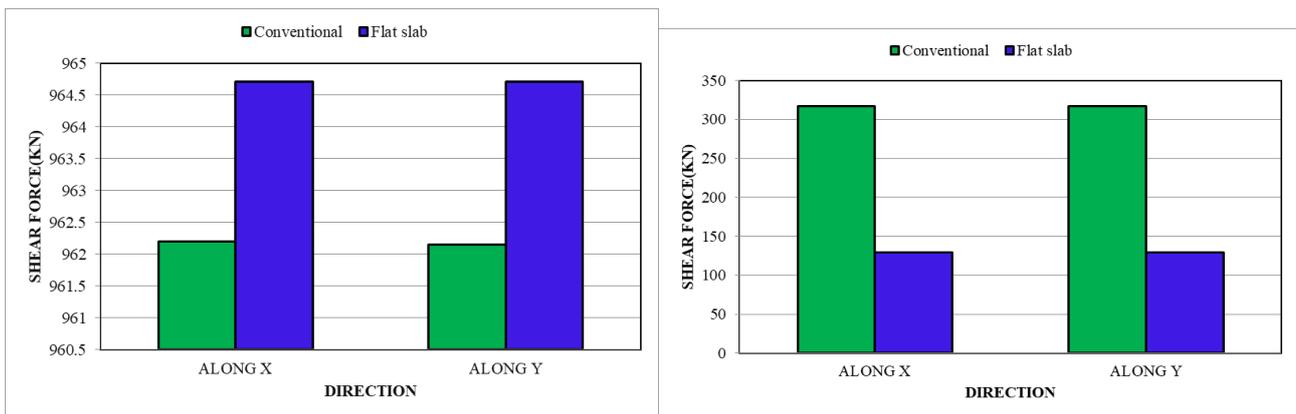
2.7.2   By Dynamic method

Figure 32: Shear Force (kN): Dynamic Method: C30

The calculated shear force for the flat slab is higher than the conventional two-way slab structures. The magnitude of shear force is same along both the directions for both the structures. Along X direction, the magnitude of conventional slab is 962.1951 kN and of flat slab is 964.7071 kN. The shear force in flat slab is 1.00% higher than conventional two-way slab structure. Along Y direction, the magnitude of conventional slab is 962.1951 kN and of flat slab is 964.7071 kN. The shear force in flat slab is 1.00% higher than conventional two-way slab structure. The calculated shear force for the flat slab is lower than the conventional two-way slab structures. The magnitude of shear force is same along both the directions for both the structures. Along X direction, the magnitude of conventional slab is 317.5214 kN and of flat slab is 129.088 kN. The shear force in flat slab is 0.41 % higher than conventional two-way slab structure. Along Y direction, the magnitude of conventional slab is 317.5214 kN and of flat slab is 129.088 kN. The shear force in flat slab is 0.41% higher than conventional two-way slab structure.
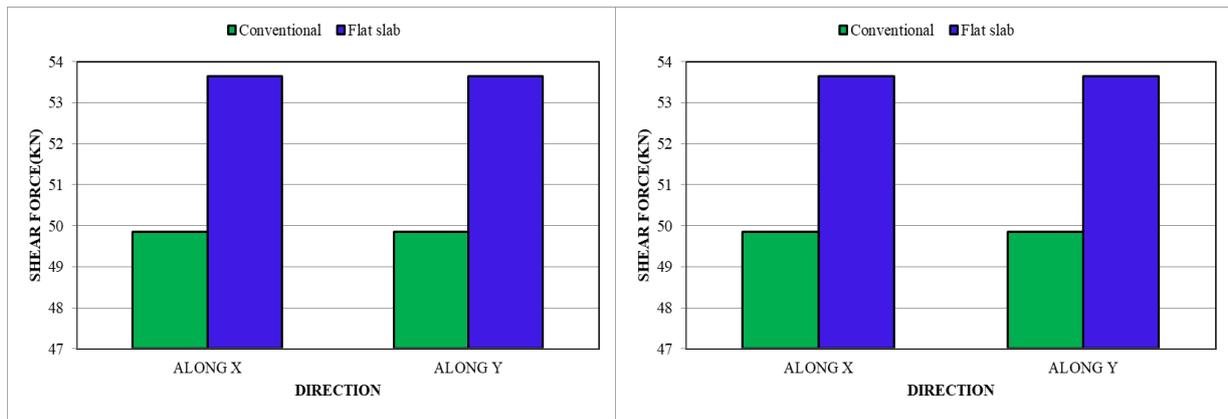
2.7.3   C30: By Wind Loading

Figure 34: Shear Force (kN): Wind Loading: C30

The calculated shear force for the wind loading for the flat slab is higher than the conventional two-way slab structures. The magnitude of shear force is same along both the directions for both the structures. Along X direction, the magnitude of conventional slab is 49.8517 kN and of flat slab is 53.6524 kN. The shear force in flat slab is 1.08% higher than conventional two-way slab structure. Along Y direction, the magnitude of conventional slab is 49.8517 kN and of flat slab is 53.6524 kN. The shear force in flat slab is 0.41% higher than conventional two-way slab structure. The shear force for the wind loading for the flat slab is higher than the conventional two-way slab structures. The magnitude of shear force is same along both the directions for both the structures. Along X direction, the magnitude of conventional slab is 13.7501 kN and of flat slab is 5.8923 kN. The shear force in flat slab is 0.43% higher than conventional two-way slab structure. Along Y direction, the magnitude of conventional slab is 13.7501 kN and of flat slab is 5.8923 kN. The shear force in flat slab is 0.43% higher than conventional two-way slab structure.

2.8 Column Forces: Bending Moment

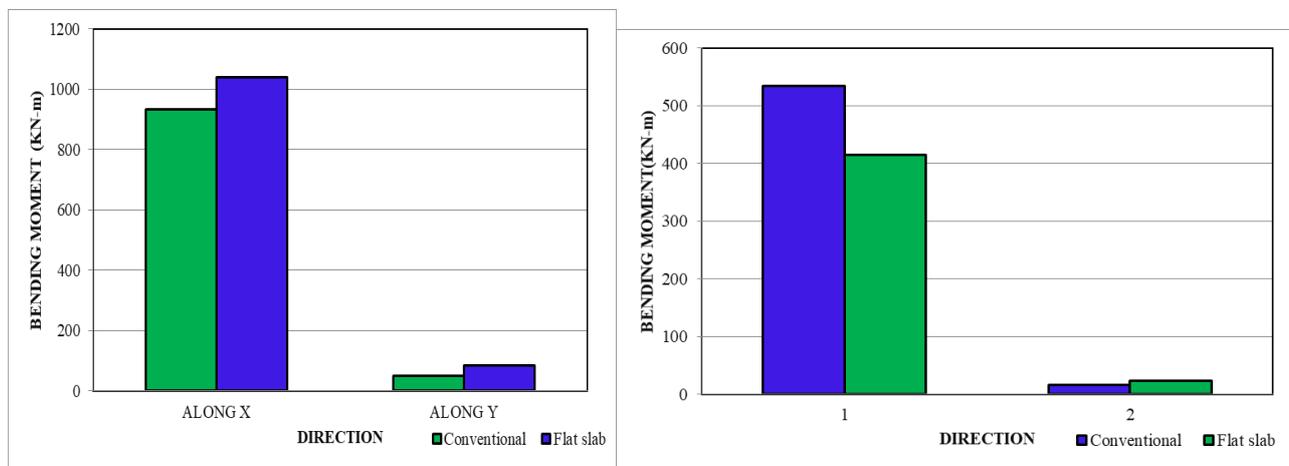### 2.8.1 By Equivalent Static method

Figure 36: Bending moment (kNm): Equivalent Static Method: C30

The bending moment along the X axis has the higher magnitude than the bending moment along Y direction. In both the directions the intensity of the conventional two-way slab structure is less than flat slab structure. Along X direction, the magnitude of conventional slab is 933.5263 kN and of flat slab is 1040.7527 kN. The bending moment in flat slab is 1.11% higher than conventional two-way slab structure. Along Y direction, the magnitude of conventional slab is 48.8438 kN and of flat slab is 83.4758 kN. The bending moment in flat slab is 1.71% higher than conventional two-way slab structure. Here, the bending moment along the X axis has the higher magnitude than the bending moment along Y direction. In X direction, the intensity of the conventional two-way slab structure is more than flat slab structure. In Y direction, the intensity of the conventional two-way slab structure is slightly less than flat slab structure. Along X direction, the magnitude of conventional slab is 534.9358 kN and of flat slab is 415.3392 kN. The bending moment in flat slab is 0.78% higher than conventional two-way slab structure. Along Y direction, the magnitude of conventional slab is 15.7939 kN and of flat slab is 23.6926 kN. The bending moment in flat slab is 1.5% higher than conventional two-way slab structure.
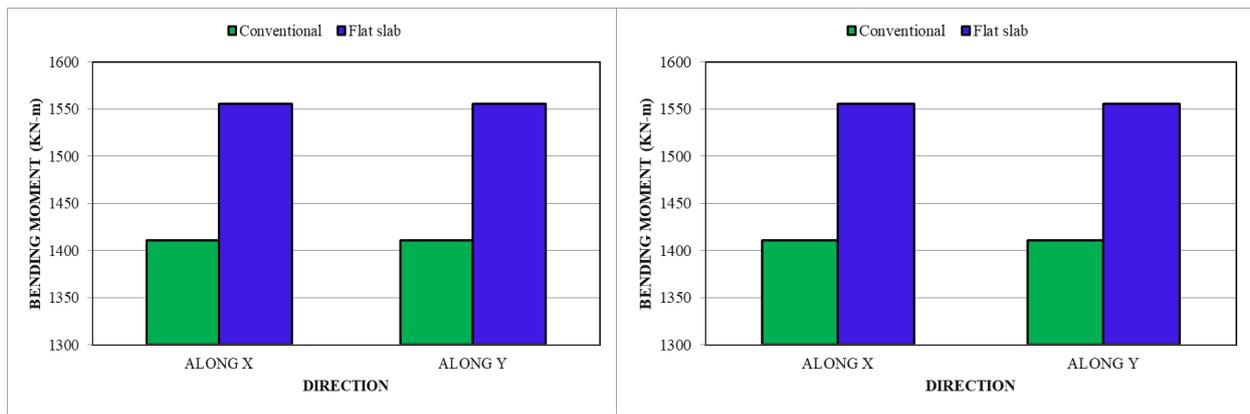
2.8.2 C30: By Dynamic method

Figure 38: Bending moment (kNm): Dynamic Method: C30

Along X direction, the magnitude of conventional slab is 1410.5659kN and of flat slab is 1555.7197kN. The bending moment in flat slab is 1.10 % higher than conventional two-way slab structure. Along Y direction, the magnitude of conventional slab is 1410.5659kN and of flat slab is 1555.7197 kN. The bending moment in flat slab is 1.10% higher than conventional two-way slab structure. For the dynamic loading, the bending moment tends to be higher for the flat slab structures. Along X direction, the magnitude of conventional slab is 733.433kN and of flat slab is 572.66kN. The bending moment in flat slab is 0.78% higher than conventional two-way slab structure. Along Y direction, the magnitude of conventional slab is 733.433kN and of flat slab is 572.66kN. The bending moment in flat slab is 0.78 % higher than conventional two-way slab structure.
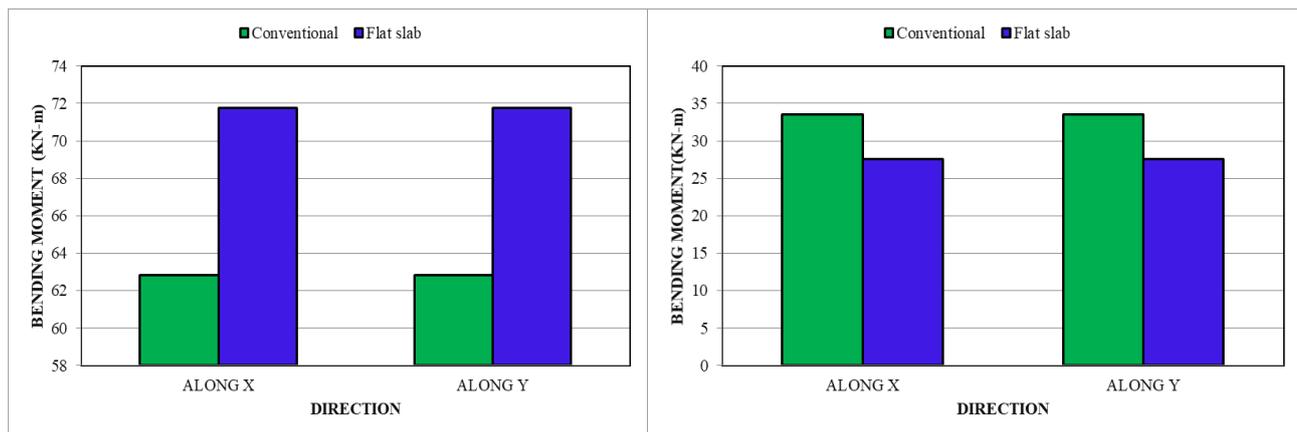
2.8.3 C30: By Wind Loading

Figure 40: Bending moment (kNm): Wind Loading: C30

Along X direction, the magnitude of conventional slab is 62.8295kN and of flat slab is 71.735kN. The bending moment in flat slab is 1.14 % higher than conventional two-way slab structure. Along Y direction, the magnitude of conventional slab is 62.8295kN and of flat slab is 71.735kN. The bending moment in flat slab is 1.14 % higher than conventional two-way slab structure. For the wind loading, the bending moment is higher in flat slab in exterior columns; whereas, it is lowered in interior column. Along X direction, the magnitude of conventional slab is 33.538kN and of flat slab is 27.5826kN. The bending moment in flat slab is 0.82% higher than conventional two-way slab structure. Along Y direction, the magnitude of conventional slab is 33.538kN and of flat slab is 27.5826kN. The bending moment in flat slab is 0.82% higher than conventional two-way slab structure.

IV. CONCLUSION

1. The structure is analysed for wind and earthquake loads. The storey displacement and storey drift are within permissible limit. Hence the structures are safe. The storey displacement in flat slabs is 1 to 1.8% higher than conventional two-way slab structures and story drift is 1.2 to 1.5% higher for the same.
2. The storey stiffness in conventional slab is 1% higher than flat slab structure. Here, the flat slab structure is getting dominated conventional two-way slabs.
3. The time period for conventional slab is 0.935 second whereas for flat slabs it is 1.03 second. The difference between both of them is not significant.
4. The base shear is higher for conventional two-way slab structure along both x and y directions than flat slab structure by 545 kN.
5. For the internal and external columns, axial force is 0.9 to 1% higher for the flat slab relative to conventional slab.
6. The shear force is 0.39 to 1.68% higher in conventional two-way slabs.
7. The bending moment is 0.78 to 1.14% higher in conventional two-way slabs than flat slab.

The difference between magnitudes of all comparing parameters for conventional two-way slab structures and flat slab structures is negligible. Therefore, it is suggested that flat slab structures are feasible and convenient to adopt instead of conventional two-way slab structures.

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