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EFFECT OF DIAPHRAGM DISCONTINUITY IN THE SEISMIC RESPONSE OF MULTI-STOREY BUILDING

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***ABSTRACT*:**

Many buildings in the present scenario have irregular configurations both in elevation and plan. These in future may be subjected to devastating earthquakes. It is necessary to identify the performance of the structures to withstand against disaster for both new and existing buildings. Now a day's opening in the floors is common for many reasons like stair cases, lighting architectural etc., These openings in diaphragms cause stresses at discontinuous joints with building elements. Discontinuous diaphragms are designed without stress calculations and are thought-about to be adequate ignoring any gap effects. In this paper an attempt is made to try to know the difference between a building with diaphragm discontinuity and a building without diaphragm discontinuity.

This present paper makes a humble effort to portrait the behavior of the five different multi storied buildings with diaphragm openings under response spectrum analysis using ETABS v 9.7.4 To achieve this objective, various models with varying diaphragm openings were analyzed and compared for seismic parameters like maximum dead load, base shear, maximum storey drifts, and response spectrum results.

Key Words: Diaphragm Discontinuity, Response spectrum Analysis, Maximum Dead Load, Base Shear, Maximum Storey Drifts.

1. INTRODUCTION

1.1 GENERAL

In multi-storied framed building, damages from earthquake generally initiate at locations of structural weaknesses present in the lateral load resisting frames. This behavior of multi-storey framed buildings during strong earthquake motions depends on the distribution of mass, stiffness, strength in both the horizontal and vertical planes of buildings. In few cases, these weaknesses may be created by discontinuities in stiffness, strength or mass along the diaphragm. Such discontinuities between diaphragms are often associated with sudden variations in the frame geometry along the length of the building. Structural engineers have developed confidence in the design of buildings in which the distributions of mass, stiffness and strength are more or less uniform. There is a less confidence about the design of structures having irregular geometrical configurations and diaphragm discontinuities.

The recent earthquake including the last Nepal earthquake (2015) in which many reinforced concrete structures have been severely damaged or collapsed, have indicated the need for evaluating the seismic adequacy of existing buildings. In multi-storied framed building, damages from earthquake generally initiate at locations of structural weaknesses present in the lateral load resisting frames. This behavior of multi-storied framed buildings during strong earthquake motions depends on the distribution of mass, stiffness, strength in both horizontal and vertical planes of buildings. In few cases, these weaknesses may be created by discontinuities in stiffness, strength or mass along the diaphragm.

1.2 CONCEPT OF DIAPHRAGM DISCONTINUITY

According to IS-1893:2002: Diaphragms with abrupt discontinuities or variations in stiffness, which include those having cut-out or open areas greater than 50 percent of the gross enclosed diaphragm area, or changes in effective diaphragm stiffness of more than 50 percent from one storey to the next. In structural engineering, a diaphragm is a structural system used to transfer lateral loads to shear walls or frames primarily through in-plane shear stress. Lateral loads are usually wind and earthquake loads.

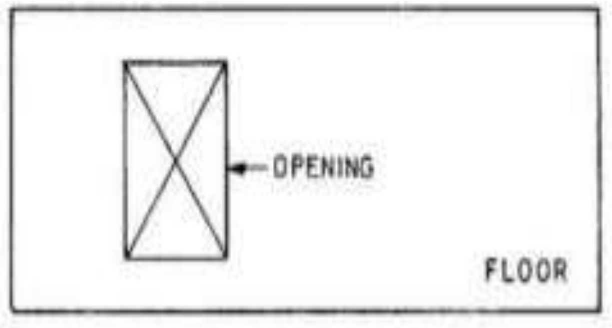


Fig.1 Diaphragm Discontinuity

Two primary types of diaphragms are rigid and flexible. Flexible diaphragms resist lateral forces depending on the area, irrespective of the flexibility of the members that they are transferring force to. Rigid diaphragms transfer load to frames or shear walls depending on their flexibility and their location in the structure. Flexibility of a diaphragm affects the distribution of lateral forces to the vertical components of the lateral force resisting elements in a structure

1.3 OBJECTIVE OF THE STUDY

A detailed literature review is carried out and the major findings of the review are

i) International Building Code (IBC) suggests that for buildings with diaphragm separation, the code prescribes arise of twenty five percent within the design forces found for connections of diaphragms.
ii) American Concrete Institute Building Code, I 318-08 doesn't address the result of a gap on the floor.
iii) ASCE 7-05, Section 12.3.1.2, permits diaphragms of RCC slabs or concrete crammed metal decks with span-to-depth ratios of 3:1 or less.

Based on the literature review, the salient objectives of the present paper identified as follows:

1. To investigate the seismic performance of a multi-story building with different diaphragms i.e., model-1 and model-2 , model-3, model-4, and model-5, through a detailed case study.
2. To evaluate the effect of diaphragm discontinuity on these five models.

1.3 SCOPE OF THE PAPER

In the present paper, a typical multi storey building is analyzed using commercial software ETABS V9.7.4 by response spectrum analysis. The analyses have been carried out considering and ignoring the diaphragm discontinuity and the results so obtained have been compared. This study is done for RC framed multistory building with fixed support conditions. The results of this report is based on one case-study.

1.4 METHODOLOGY

a) A thorough literature review to understand the seismic evaluation of building structures and application of response spectrum analysis has been carried out.
b) Select an existing building with diaphragm discontinuity.
c) Design the building as per prevailing Indian Standard code for dead load, live load, and earthquake load.
d) Analyze the results and arrive at conclusions.

2. LITERATURE REVIEW

Swartz and Rosebraugh (1974), Aghayere and Macgregor (1971), and Park and Kim (1992) addressed buckling of concrete plates beneath combined in-plane and transverse loads. Since concrete diaphragms is thought-about as concrete plates with beams as web stiffeners, this buckling approach doesn't address openings.

Button et. al. (1984) Studied the influence of floor diaphragm flexibility on 3 totally different buildings, massive arrange aspect ratio, three-winged (Y-shaped) and separate towered. Notwithstanding the insight given into however lateral force distribution differs from rigid to flexible diaphragms, openings weren't thought-about.

Basu (2004), Jain (1984) and Tao (2008) have analyzed differing kinds of structures starting from formed, Y-shaped to long and slender buildings. Although these studies proved to be contributing to understanding the dynamics of such style of structures, they didn't address the effects of diaphragm openings.

Kunnath et. al. (1991) has developed a modeling theme for the inelastic response of floor diaphragms, and Reinhorn et. al. (1992) and Panahshahi et. al. (1988) verified it, using shake table testing for single-story RC, 1:6 scaled model structures, gap effects weren't incorporated within the model and also the projected model's ability to account for in-plane diaphragm deformations, confirmed the chance of building collapse, as a results of diaphragm yielding for low rise (one-, two-, and three-story) rectangular buildings with finish shear walls and building plan aspect ratio bigger than 3:1.

3. RESEARCH METHODOLOGY

Table-1 : Modeling Parameters

No of floors	G +10
Zone Factor	II
Plan Size	21 m x 27 m
Beam Size	450 mm × 450 mm
Column size	450 mm × 600 mm
Storey Height	3.0 m
Bottom storey	3.5 m
Slab Thickness	125mm
Concrete Grade	M30
Steel Grade	Fe415
Floor finish	1.5 kN/m2
Imposed load	3.5 kN/m2
Unit weight of concrete	24 kN/m3

Configuration is critical to good seismic performance of buildings. The important aspects affecting seismic configuration of buildings are overall geometry, structural systems, and load paths. Various issues related to seismic configuration are discussed in this section.

Buildings oscillate during earthquake shaking and inertia forces are mobilized in them. Then, these forces travel along different paths, called *load paths*, through different structural elements, until they are finally transferred to the soil through the foundation. The generation of forces based on basic oscillatory motion and final transfer of force through the foundation are significantly influenced by overall geometry of the building, which includes:

(a) plan shape,
(b) plan aspect ratio, and
(c) slenderness ratio of the building.

3.1 a) Plan Shape

The influence of plan geometry of the building on its seismic performance is best understood from the basic geometries of *convex*- and *concave*-type lenses . Buildings with former plan shape have direct load paths for transferring seismic inertia forces to its base, while those with latter plan shape necessitate indirect load paths that result in stress concentrations at points where load paths bend. Buildings with convex and simple plan geometries are preferred, because they demonstrate superior seismic performance than those with concave and complex plan geometries.

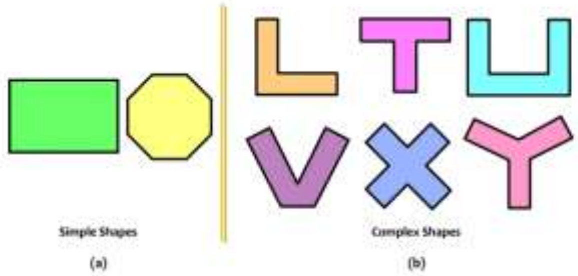


Fig 2.Plan shapes of buildings (a) simple shapes undergo simple acceptable structural seismic behaviour, while (b) those with complex shapes undergo complex unacceptable structural seismic behaviour.

(1) Buildings with different shapes, but same Plan Area Rectangular (or square) columns are good in resisting shear and bending moment about axes parallel to their sides. Thus, it is important to have buildings oscillating primarily along their sides – *translation along diagonals* or *torsional* motions are NOT good for seismic performance of columns, and hence, of buildings Further, in regular buildings, the overall motion is controlled by the first few modes of oscillation; the fundamental mode (corresponding to largest natural period) usually contributes maximum, followed by the 2nd mode, 3rd mode, etc. Thus, it is desirable to have pure translation modes as the lower modes of oscillation and push torsional and diagonal translational modes to the higher ranks. Primarily, these undesirable (diagonal translation and torsional) modes arise when there is lack of symmetry in the plan shape of buildings along the sides. It is important to have regular plan shape of buildings.

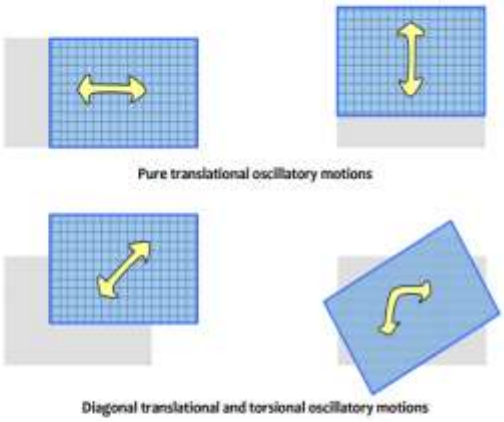


Fig 3 : Oscillatory motions of buildings during earthquake shaking: Diagonal translational and torsional oscillations are not preferred

4. Modeling in ETABS

The following models are taken for the analysis. The model 1 is a simple model without any diaphragm discontinuity in the plan . The remaining models (model2, model3, model4, and model5) have discontinuity either externally or internally in the plan. The necessary details are as per the modeling parameters mentioned in table 1.

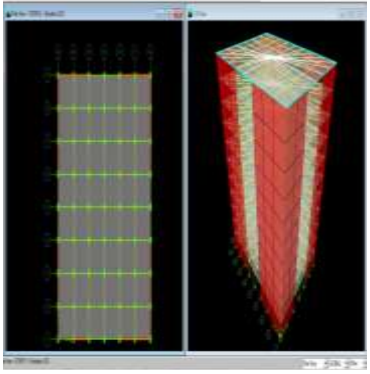


Fig 4 . Model 1

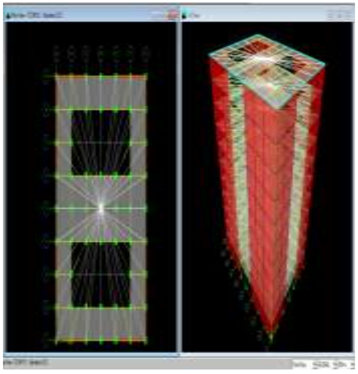


Fig 5 . Model 2

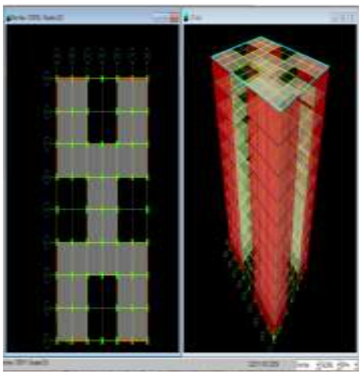


Fig 6 . Model 3

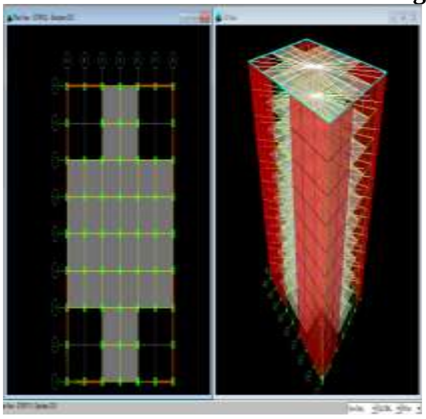


Fig 7 . Model 4

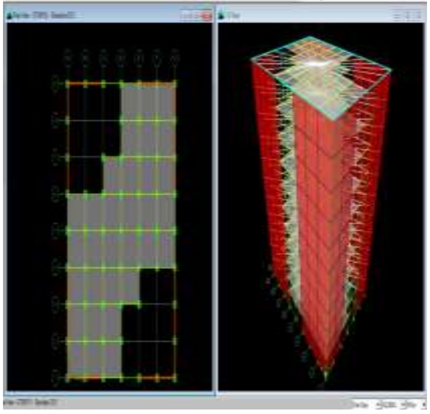


Fig 8 . Model 5

5. RESULTS AND ANALYSIS

5.1 STOREY DRIFT

Drift is defined as the lateral displacement. Story drift is the drift of a multistory building relative to the level below. Inter story drift is the difference between the roof and floor displacements of any given story as the buildings ways during the earthquake, normalized by the story height. For example, for a 10 foot high story, an inter story drift of 0.10 indicates that the roof is displaced one foot in relation to the floor below.

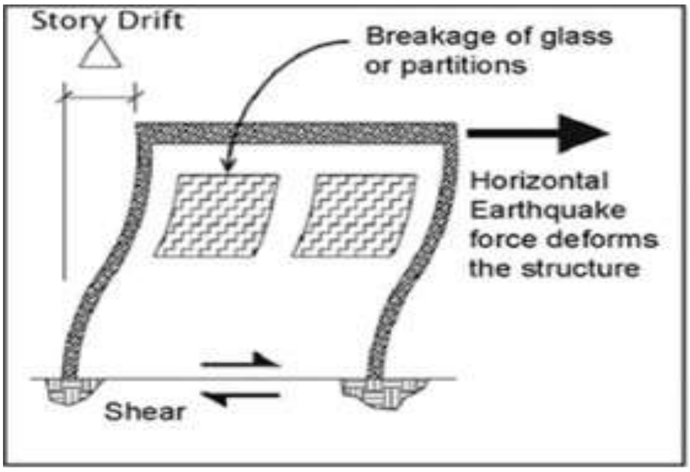


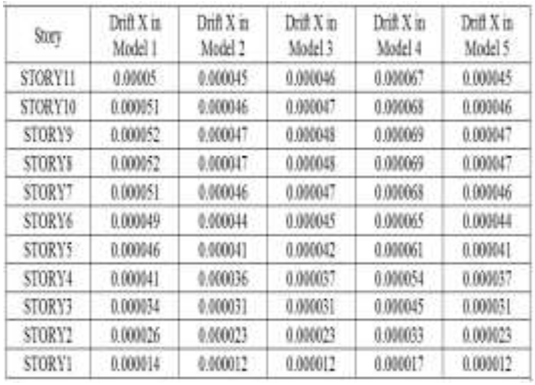
Figure 9. Story drift in a building

The greater the drift, the greater the likelihood of damage. Peak inter story drift values larger than 0.06 indicate sever damage, while values larger than 0.025 indicate that the damage could be serious enough to pose a serious threat to human safety. Values in excess of 0.10 indicate probable building collapse.

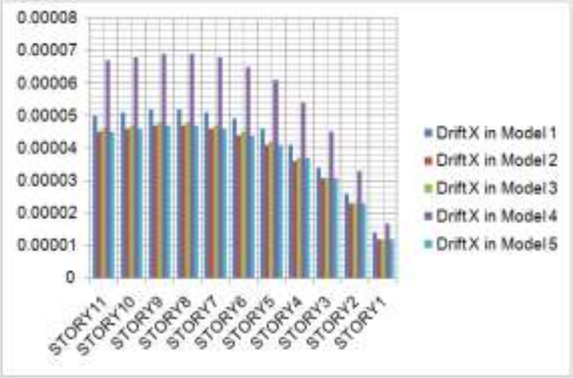
The results of the analysis are presented in tables and graphs below.

5.1.1 DRIFT IN X DIRECTION

Table 2 . Drift values(meters) in x direction



Story	Drift X in Model 1	Drift X in Model 2	Drift X in Model 3	Drift X in Model 4	Drift X in Model 5
STORY11	0.00005	0.000045	0.000046	0.000067	0.000045
STORY10	0.000051	0.000046	0.000047	0.000068	0.000046
STORY9	0.000052	0.000047	0.000048	0.000069	0.000047
STORY8	0.000052	0.000047	0.000048	0.000069	0.000047
STORY7	0.000051	0.000046	0.000047	0.000068	0.000046
STORY6	0.000049	0.000044	0.000045	0.000065	0.000044
STORY5	0.000046	0.000041	0.000042	0.000061	0.000041
STORY4	0.000041	0.000036	0.000037	0.000054	0.000037
STORY3	0.000034	0.000031	0.000031	0.000045	0.000031
STORY2	0.000026	0.000023	0.000023	0.000033	0.000023
STORY1	0.000014	0.000012	0.000012	0.000017	0.000012

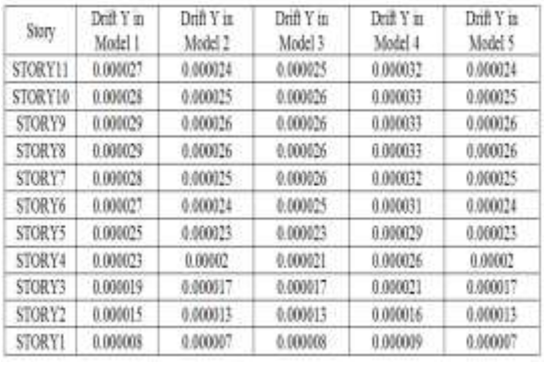


Graph 1: Graph for Storey drift in X direction

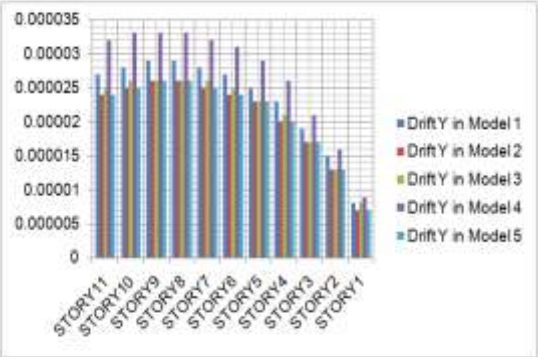
From the above graph ,the drift value increases from bottom to top as we go from storey 1 to storey 10. It is concluded that drift in x direction is more in model 4 as compared to other models, the model 2 is having least drift in x direction compared to the other models and model 5 is also best after the model.

5.1.2 DRIFT IN Y DIRECTION

Table 3 . Drift values(meters) in y direction



Story	Drift Y in Model 1	Drift Y in Model 2	Drift Y in Model 3	Drift Y in Model 4	Drift Y in Model 5
STORY11	0.000027	0.000024	0.000025	0.000032	0.000024
STORY10	0.000028	0.000025	0.000026	0.000033	0.000025
STORY9	0.000029	0.000026	0.000026	0.000033	0.000026
STORY8	0.000029	0.000026	0.000026	0.000033	0.000026
STORY7	0.000028	0.000025	0.000026	0.000032	0.000025
STORY6	0.000027	0.000024	0.000025	0.000031	0.000024
STORY5	0.000025	0.000023	0.000023	0.000029	0.000023
STORY4	0.000023	0.00002	0.000021	0.000026	0.00002
STORY3	0.000019	0.000017	0.000017	0.000021	0.000017
STORY2	0.000015	0.000013	0.000013	0.000016	0.000013
STORY1	0.000008	0.000007	0.000008	0.000009	0.000007



Graph 2: Graph for of Storey Drift in y direction

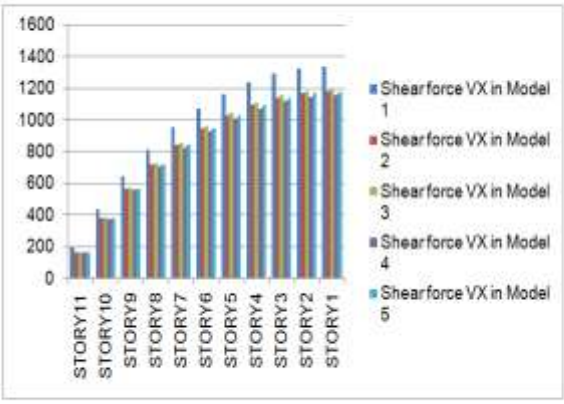
From the above graph , the drift value increases from bottom to top as we go from storey 1 to storey 10. It is concluded that drift in y direction is more in model 4 as compared to other models, the model 2 is having least drift in y direction compared to the other models and model 5 and model 2 has less compared to the other models. In story 9 and 8 the drift values are same for the models 2,3,5 having almost same values.

5.2 SHEAR FORCE

5.2.1. SHEAR IN X DIRECTION

Table 4 . Shear values(kN) in x direction

Story	Shear force VX in Model 1	Shear force VX in Model 2	Shear force VX in Model 3	Shear force VX in Model 4	Shear force VX in Model 5
STORY11	195.35	166.11	168.89	164.89	166.17
STORY10	439.85	383.94	389.69	378.21	383.97
STORY9	645.25	567.23	575.36	556.94	567.13
STORY8	815.37	719.2	729.21	704.65	718.91
STORY7	955.47	844.31	855.82	826.2	843.8
STORY6	1070.63	946.91	959.65	926.24	946.2
STORY5	1164.19	1029.95	1043.72	1007.76	1029.08
STORY4	1237.25	1094.48	1109.08	1071.61	1093.48
STORY3	1289.39	1140.32	1155.55	1117.25	1139.24
STORY2	1320.63	1167.66	1183.27	1144.52	1166.52
STORY1	1334.08	1179.44	1195.22	1156.15	1178.28



Graph 3: Graph for Shear in x direction

From the above graph, the shear value decreases from bottom to top as we go from storey 1 to storey 10.It is concluded that, the shear force in x direction , model 4 is having least values that of compared to other models. The shear force in model 2 is also less compared to other models but the model 4 having least , the shear force in model1 is having great values than all other models .

5.2.2 IN Y DIRECTION

Table 5 . Shear values(kN) in y direction

Story	Shear force VY in Model 1	Shear force VY in Model 2	Shear force VY in Model 3	Shear force Vy in Model 4	Shear force VY in Model 5
STORY11	191.03	162.6	165.23	160.62	162.48
STORY10	433.97	379.11	384.67	372.27	378.93
STORY9	641.26	564.01	572.03	552.73	563.84
STORY8	815.05	719.12	729.17	703.89	719.02
STORY7	958.84	847.43	859.14	828.82	847.41
STORY6	1076.39	952.19	965.27	930.76	952.27
STORY5	1170.67	1036	1050.19	1012.32	1036.17
STORY4	1243.29	1100.36	1115.42	1074.92	1100.61
STORY3	1294.9	1145.95	1161.64	1119.23	1146.25
STORY2	1326.29	1173.57	1189.67	1146.05	1173.91
STORY1	1340.55	1186.14	1202.42	1158.2	1186.5

Graph 4: Graph for Shear in y direction

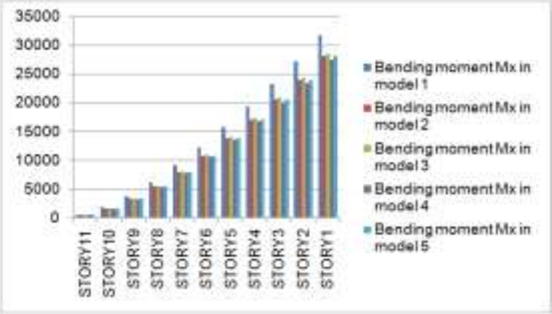
From the above graph, shear value decreases from bottom to top as we go from storey 1 to storey 10. It is concluded that, the shear force in y direction , model 4 is having least values that of compared to other models. The shear force in model 2 is also less compared to other models but the model 4 having least model, the shear force in model 1 is having great values than all other models .

5.3 BENDING MOMENT

5.3.1. IN X DIRECTION

Table 6 . Bending Moment (kN-m) in x direction

Story	Bending moment Mx in model 1	Bending moment Mx in model 2	Bending moment Mx in model 3	Bending moment Mx in model 4	Bending moment Mx in model 5
STORY11	573.086	487.797	495.687	481.865	487.434
STORY10	1874.51	1624.698	1649.26	1598.243	1623.796
STORY9	3795.948	3314.76	3363.343	3254.414	3313.362
STORY8	6234.095	5466.233	5544.857	5360.124	5464.537
STORY7	9094.903	7995.275	8108.794	7833.213	7993.578
STORY6	12295.53	10827.72	10980.01	10601.26	10826.35
STORY5	15763.74	13898.66	14092.79	13601.06	13897.93
STORY4	19435.63	17150.6	17388.94	16776.71	17150.76
STORY3	23253.26	20531.51	20815.81	20077.66	20532.75
STORY2	27164.02	23994.38	24325.82	23458.25	23996.81
STORY1	31785.98	28086.37	28473.6	27452.84	28090.25

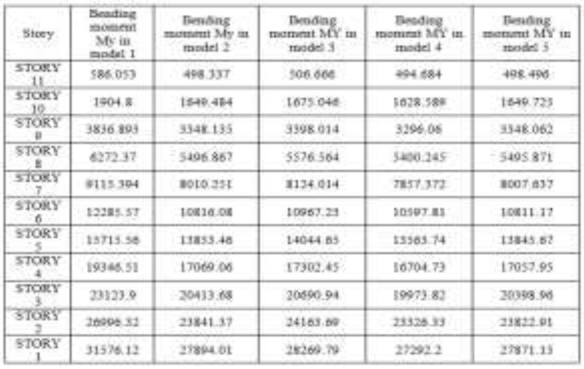


Graph 5: Graph for Bending Moment in x direction

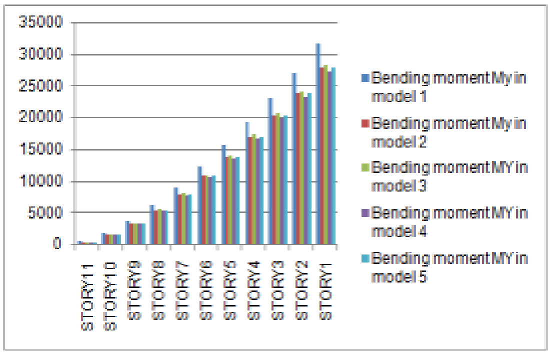
From the graph , it made a conclusion that, the bending moment in x direction , model 4 is having least bending moment compared to other models, the bending moment in story11 are very less compared to other story in every model ,and next to model 2 is having less values compared with other models .

5.3.2 IN Y DIRECTION

Table 4 . Bending Moment (kN-m) in y direction



Story	Bending moment My in model 1	Bending moment My in model 2	Bending moment MY in model 3	Bending moment MY in model 4	Bending moment MY in model 5
STORY 11	586.053	498.337	506.666	494.684	498.496
STORY 10	1904.8	1649.484	1675.046	1628.589	1649.725
STORY 9	3836.893	3348.135	3398.014	3296.06	3348.062
STORY 8	6272.37	5496.867	5576.564	5400.245	5495.871
STORY 7	8115.394	8010.251	8134.014	7857.372	8007.637
STORY 6	12285.57	10816.08	10967.23	10597.81	10811.17
STORY 5	15715.58	13853.48	14044.85	13565.74	13845.82
STORY 4	19346.51	17069.06	17302.45	16704.73	17057.95
STORY 3	23123.9	20413.68	20690.94	19973.82	20398.96
STORY 2	26996.32	23841.37	24163.69	23326.33	23822.91
STORY 1	31576.12	27894.01	28269.79	27292.2	27871.13



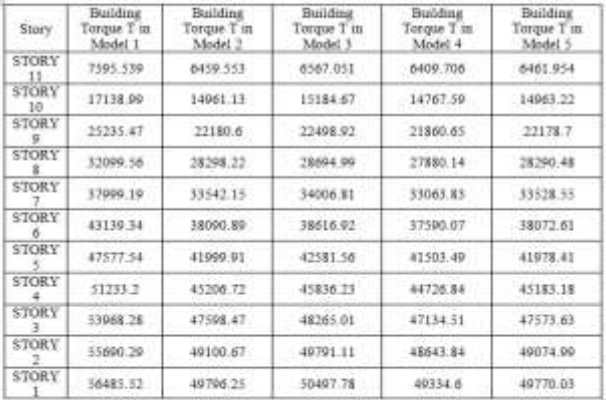
Graph 6: Graph for Bending Moment in y direction

From the graph , it made a conclusion that, the bending moment in y direction , model 4 is having least bending moment compared to other models, the bending moment in story11 are very less compared to other story in every model ,and next model 2 is having less values compared with other models

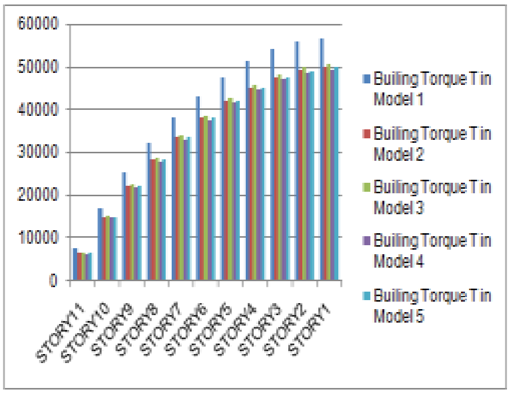
5.4 BUILDING TORQUE

Torque is a twisting or turning force that tends to cause rotation around an axis, which might be a center of mass or a fixed point. Torque can also be thought of as the ability of something that is rotating, such as a gear or a shaft, to overcome turning resistance. The results of the analysis are presented in tables and graphs below.

Table 4 . Building Torque



Story	Building Torque T in Model 1	Building Torque T in Model 2	Building Torque T in Model 3	Building Torque T in Model 4	Building Torque T in Model 5
STORY 11	7595.539	6459.553	6567.051	6409.706	6461.954
STORY 10	17138.99	14961.13	15184.67	14767.59	14963.22
STORY 9	25235.47	22180.6	22498.92	21860.65	22178.7
STORY 8	32099.56	28298.22	28694.99	27880.14	28290.48
STORY 7	37999.19	33542.15	34006.81	33063.83	33528.55
STORY 6	43139.34	38090.89	38616.92	37590.07	38072.61
STORY 5	47577.54	41999.91	42581.56	41503.49	41978.41
STORY 4	51233.2	45206.72	45836.23	44726.84	45183.18
STORY 3	53968.28	47598.47	48265.01	47134.51	47573.63
STORY 2	55690.29	49100.67	49791.11	48643.84	49074.99
STORY 1	56485.52	49796.25	50497.78	49334.6	49770.03



Graph 7: Graph Building Torque

The above graph shows as building torque , the least building torque is absorbed in model 4 than that of the other models , the story 11 having less torque values that compared to the other storey with different models . Next to model 4 , model 2 is also having less values compared to other values

CONCLUSIONS

From the above research the following conclusions were made

1. The values of storey drifts are found to be less in Model 2 and model 5 than all remaining models (model 1,model 3, model 4,) in both X-Direction and Y-Direction. The higher value of Drift value is obtained in model 4. The value of story Drift decreases from top story (11th story) to bottom story (1st story)
2. The maximum value of Shear force is observed in model 1 than all remaining models ((model 2, model 3, model 4, model 5) in both X-Direction and Y-Direction. The minimum value of Shear force value is observed in model 4.
3. The maximum value of Building torque (T) is observed in model 1 than all remaining models ((model 2, model 3, model 4, model 5) in both X-Direction and Y-Direction. The minimum value of Building torque (T) is observed in model 4.
4. The maximum value of Bending moment is observed in model 1 than all remaining models ((model 2, model 3, model 4, model 5) in both X-Direction and Y-Direction. The minimum value of bending moment value is observed in model 4.

5. Form the above comparison it is concluded that the model 2 and model 4 have similar values of Drift and the value of shear force, bending moment and torque has less in model 2, so this model is better than other models (model 1, model 3, model 4, model 5)

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