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Seismic Behaviour of RCC Structure with Different Substructures

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ABSTRACT

Foundation is the first element of any structure that encounters seismic forces. The various types of seismic waves, reaches and affects the foundations first and then the superstructure. Instead, this is the underprivileged component of the structure, when it comes to seismic forces consideration, compared with super structure. Different types of foundations respond differently to seismic forces. The type of soil, its characteristics, and bearing capacity, affects the design and capacity of foundations severely. Average response acceleration coefficient, as specified in IS 1893-2002 (Part 1), which takes into account the type of soil, also plays a vital role in determining the seismic forces on structure. Therefore, in this research work, RCC structure will be analyzed for the seismic behavior for different types of foundations. Various types of foundations like isolated footings, raft foundations, combined footings, pile foundations, etc. will be analyzed. Seismic analysis will be done in STAAD Pro to compare values of nodal displacement, drift, story and base shear, moment development and fundamental time period. Comments will be made considering safety and stability aspects of the structure.

Introduction

The waves from an earthquake are experienced firstly by the substructure and then they produce motions in the structure. These waves are firstly encountered in soil strata, on which the structure rests. These depend on the structure's vibrational characteristics, layout of structure and the soil on which it rests. For the structure to react to the motion, it needs to overcome its own inertia force, which results in an interaction between the structure and the soil.

Various types of substructures respond differently to the earthquake waves. Various types of substructures can be provided for various types of structures depending on layout and purpose of structure, loading on structure and soil conditions.

So in this paper behavior of different types of substructures is studied for same structural, loading and soil conditions.

Literature Review

Shamsher Prakash & Vijay K Puri in their paper *Foundations under Seismic Loads* concluded that analytical solutions need validation on model, full scale and/or centrifuge tests. Again, the codal provisions permitting 33% increase in static bearing capacity for the seismic case need to be re-examined in view of the test results cited in paper and the settlement and tilt that may be experienced by the footings due to earthquake loading.

R. M. Jenifer Priyanka, N. Anand, Dr. S. Justin in their paper *Studies on Soil Structure Interaction of Multi Storeyed Buildings with Rigid and Flexible Foundation* studied and compared the seismic response of the building frames such as Lateral deflection, Storey drift, Base shear and Moment values building frames with flexible and fixed base. Lateral deflection, Storey drift, Base shear and Moment values increases when the type of soil changes from hard to medium and medium to soft for fixed and flexible base buildings. Lateral deflection, Storey drift, Base shear and Moment values of fixed base building was found to be lower as compared to flexible base building.

Aslan S. Hokmabadi & Behzad Fatahi in their paper *Influence of Foundation Type on Seismic Performance of Buildings Considering Soil–Structure Interaction* in their paper describes how a 3D numerical simulation was used to conduct a series of parametric studies on a 15-storey full-scale (prototype) structure with different types of foundations including a fixed base, a shallow foundation, a floating pile foundation, and a pile-raft foundation. Material (soil and superstructure) and geometric (uplifting, gapping and P-Δ effects) nonlinearities have been considered in the 3D numerical simulation. The results of this study indicated that the structure supported by the pile-raft foundation and the floating pile foundation experienced more base shear than the structure supported by the shallow foundation and structure supported by the shallow foundation experienced the most severe rocking compared to the floating pile and pile-raft foundations because the pile elements in both foundations reduced the maximum uplift and the rocking experienced by the structure. Moreover, the structure supported by the pile-raft foundation experienced on average 20% less rocking than the structure supported by the floating pile foundation because the compressive stresses generated in one side of the floating pile foundation meant that the piles experienced more settlement here than in the pile raft foundation where the compressive stresses were distributed over a larger area, which in turn, reduced the settlement. So, the types of foundations that experienced a considerable amount of rocking during an earthquake, dissipated much more earthquake energy than other types of foundations and demonstrated that rocking-dissipation directed less shear forces to the superstructure and reduced the structural demand of the superstructure.

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Samridhi Singh, Faizan Ahmad, Bandita Paikaray in their *paper Effects of Earthquake on Foundations* studied that the effect of earthquake on the foundation of different architectural structures are influenced in a number of ways by the nature and the behavior of the soils in the affected area. The solution to prevent the damage is either the super structure should be tied to the foundation so that the entire structure acts as a single unit or the building can be floated above its foundation which is known as base isolation. Resulting to which, lateral acceleration is decreased and the structure experiences far less deformity and damage. However, the structure still can receive fixed amount of vibrational energy during seismic loading even with base isolation system in place. The building itself can drench this energy to some level, however its capability to do so is proportionate with the ductile nature of the material used during construction

Methodology

Multi storeyed building with same superstructure subjected to seismic forces was analyzed for different types of substructures namely isolated footings, strap footings and raft foundation. The structures were analyzed using static method using software STAAD Pro. The floor plan is as shown in *fig.a* for all floors of the analyzed building.

Seismic analysis was carried out by following IS 1893:2002 - Part I. Results were found for nodal displacement, drift, story and base shear, moment development and reactions at base.

A] Input Data

Size of the building – 25.00 x 14.65 m, Type of structure - RCC Multi storeyed framed structure, Seismic zone - IV, Response reduction factor - 3, Importance factor – 1.0, Height of the building - 33 m, No. of Storey - 11 (G+10), Height of floor - 3 m, Imposed load – 1.5 kN/m^2, Materials – M 30 (beams & columns), Fe 415, Depth of the slab – 125 mm, Unit weight of RCC - 25 kN/m^3, Type of soil - Medium, Static Method - IS 1893 (Part I) 2002, Damping - 5%, Depth of foundation - 2.00 m, Wall thickness - External 230 mm & Internal 115 mm, Period in X-direction – 0.61 sec, Period in Z-direction – 0.79 sec.

B] Description of Structural Models

Three models of G+10 RCC framed structure were created in STAAD Pro as described above in input data. Isolated footings, Strap footings and Raft foundation are provided to the models respectively.

Case I - Isolated Footings

For the first structure *(fig.b)*, isolated footings are provided in the form of fixed supports at the bottom nodes of columns.

Case II - Strap Footings

For the second structure *(fig.d)*, strap footings are provided in the form of fixed supports at the bottom nodes of columns which are interconnected by beams. The strap beams carry an overlying load of 7.02 kN/m of the soil above.

Case III - Raft Foundation

For the third structure *(fig.f)*, raft foundation is provided in the form of plates connected to column bottom end. Fixed supports are provided at the bottom nodes of columns and the nodes on the plate periphery created because of meshing.

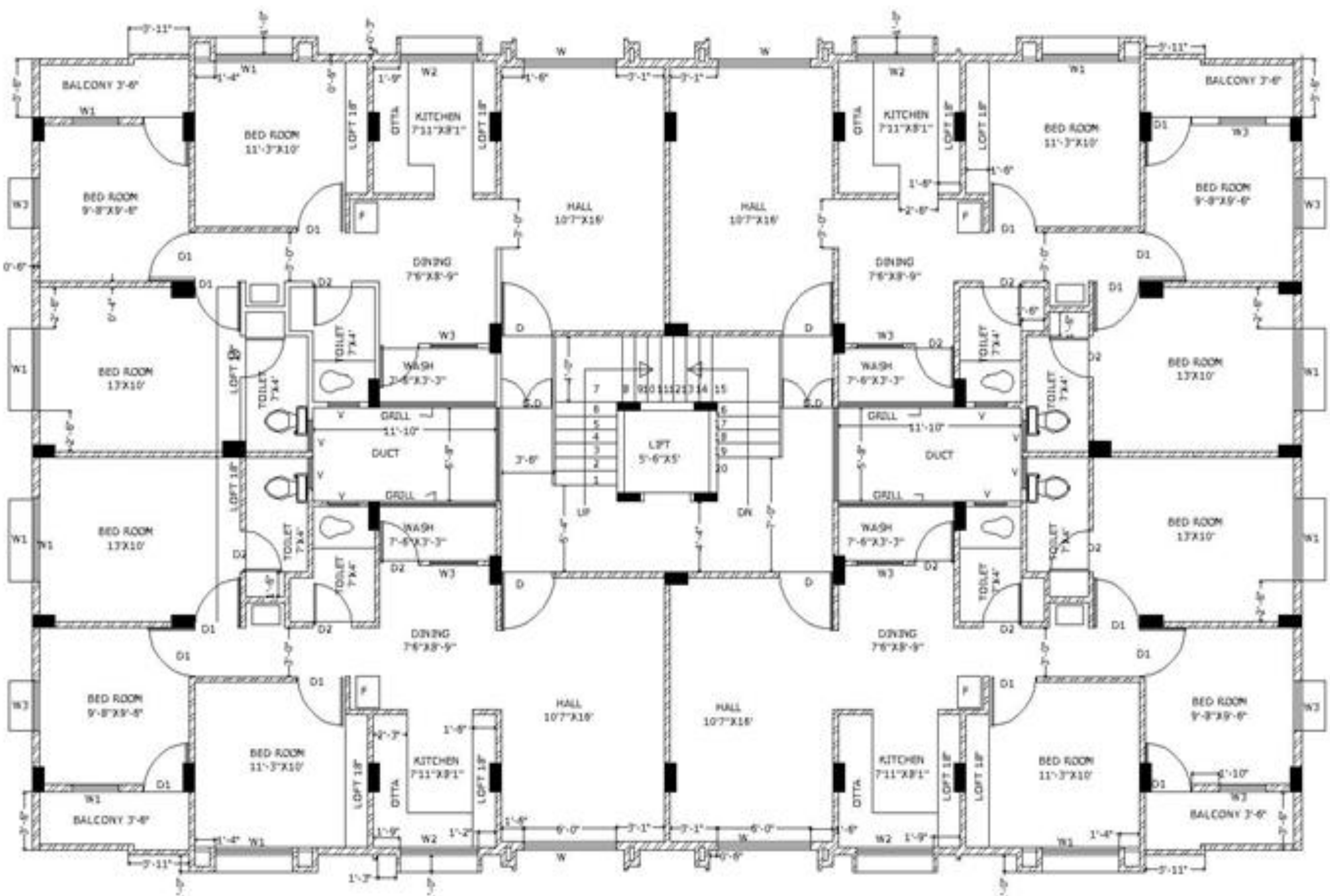

Fig. a. Typical Floor Plan of Building.

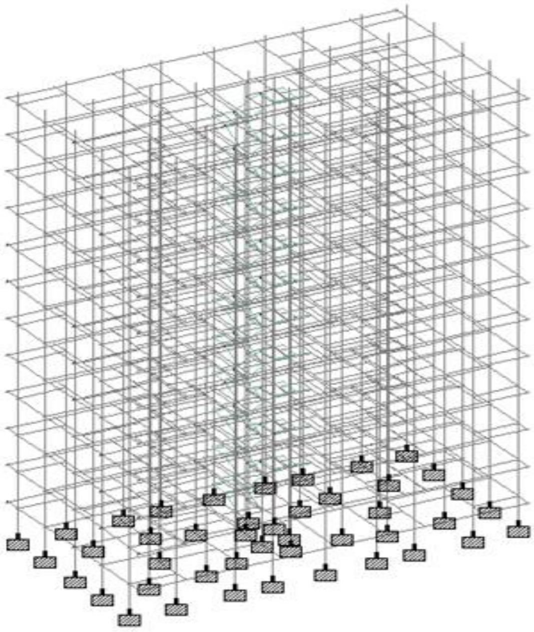

Fig. b. Structure with Isolated Footings Modelled in STAAD Pro.

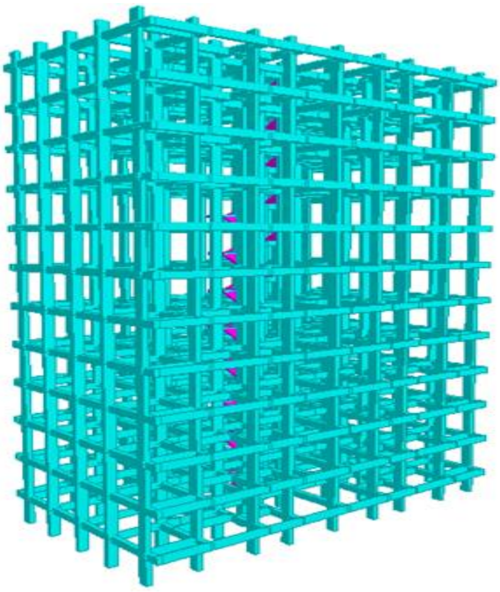

Fig. c. 3D Rendered View of Structure with Isolated Footings Modelled in STAAD Pro.

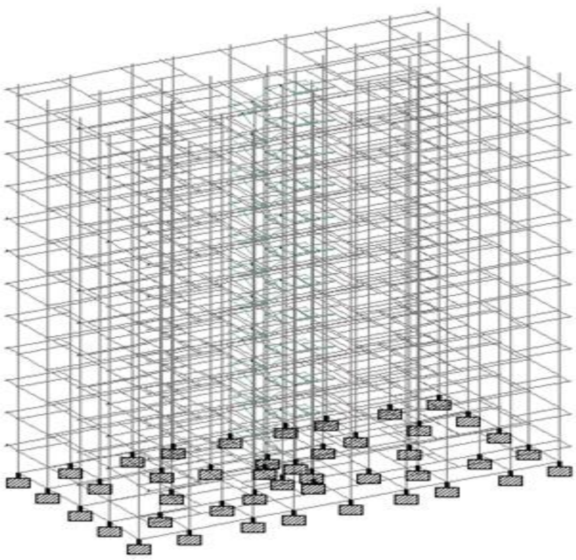

Fig. d. Structure with Strap Footings Modelled in STAAD Pro.

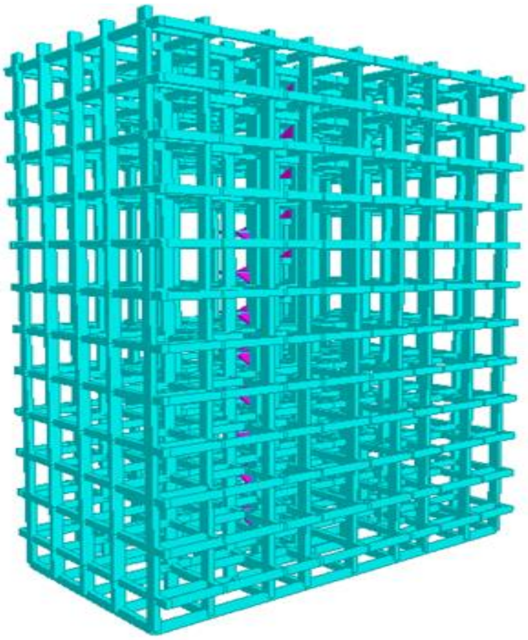

Fig. e. 3D Rendered View of Structure with Strap Footings Modelled in STAAD Pro.

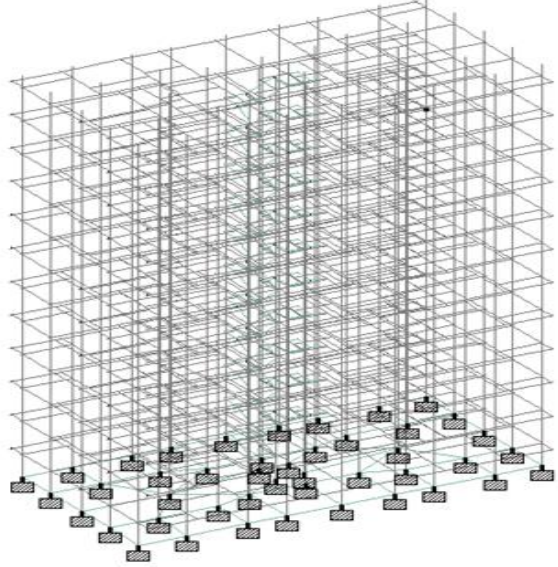

Fig. f . Structure with Raft Footings Modelled in STAAD Pro.

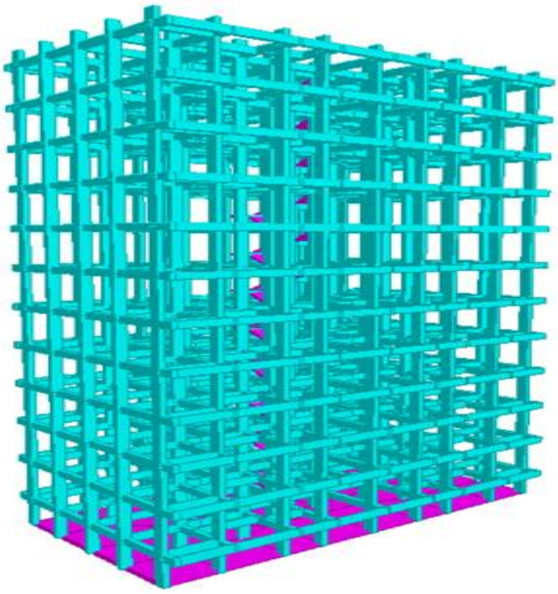

Fig. g. 3D Rendered View of Structure with Raft Footings Modelled in STAAD Pro.

Observations

On the basis of analysis results for various loading combinations as specifies in IS 1893:2002 and static coefficient method, the observations related to translational displacement, rotational displacement, drift values, shear force and bending moment in the member and the base shear values are marked for the nodes along the outer edge as well as for the probable crushing junction i.e. staircase landing. The following observations as specified below in Table No. 1 to 6 reflects nodal translational and rotational values and corresponding drift values whereas Table No. 7 to 9 reflects moment and shear values for vertical members along the outer corner edge and staircase junction.

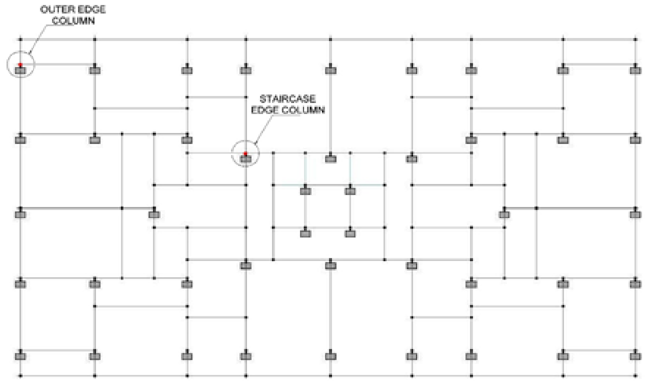

Fig. h. Drawing Showing Location of Outer Edge and Staircase Edge Nodes.

Table No.10 to 12 are related to storey shear development values considering nodes again at outer corner and staircase junction. The Table No. 13 to 15 tabulates the reaction development for one quadrant as the structure is symmetrical along both X and Y axes.

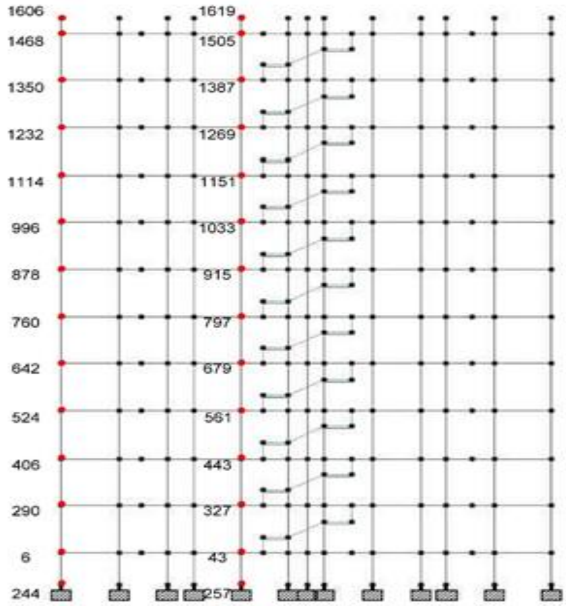

Fig. i. Drawing Showing Location and Number of Outer Edge and Staircase Edge Nodes.

Table No. 1. Max. Translational Displacement, Rotational Displacement of Outer Edge Columns for Structure with Isolated Footing.

Outer Edge Column Nodes							
Node	**Max Trans. Disp.**	**Drift Values**	**Load Combination**	**rX**	**Load Combination**	**rZ**	**Load Combination**
1606	396.470	-	10 1.5(DL+EQ X)	-0.005	13 1.5(DL-EQ Z)	-0.006	10 1.5(DL+EQ X)
1468	390.689	5.781	10 1.5(DL+EQ X)	-0.005	13 1.5(DL-EQ Z)	-0.006	10 1.5(DL+EQ X)
1350	373.972	16.717	10 1.5(DL+EQ X)	-0.005	13 1.5(DL-EQ Z)	-0.006	10 1.5(DL+EQ X)
1232	351.052	22.920	10 1.5(DL+EQ X)	-0.007	13 1.5(DL-EQ Z)	-0.008	10 1.5(DL+EQ X)
1114	322.083	28.969	10 1.5(DL+EQ X)	-0.008	13 1.5(DL-EQ Z)	-0.009	10 1.5(DL+EQ X)
996	288.241	33.842	10 1.5(DL+EQ X)	-0.009	13 1.5(DL-EQ Z)	-0.009	10 1.5(DL+EQ X)
878	250.737	37.504	10 1.5(DL+EQ X)	-0.009	13 1.5(DL-EQ Z)	-0.010	10 1.5(DL+EQ X)
760	210.691	40.046	10 1.5(DL+EQ X)	-0.010	13 1.5(DL-EQ Z)	-0.010	10 1.5(DL+EQ X)
642	169.181	41.510	11 1.5(DL-EQ X)	-0.010	13 1.5(DL-EQ Z)	-0.010	10 1.5(DL+EQ X)
524	127.085	42.096	11 1.5(DL-EQ X)	-0.010	13 1.5(DL-EQ Z)	-0.010	10 1.5(DL+EQ X)
406	85.274	41.811	11 1.5(DL-EQ X)	-0.009	13 1.5(DL-EQ Z)	-0.009	10 1.5(DL+EQ X)
290	45.049	40.225	11 1.5(DL-EQ X)	-0.009	13 1.5(DL-EQ Z)	-0.008	10 1.5(DL+EQ X)
6	10.280	34.769	11 1.5(DL-EQ X)	-0.006	13 1.5(DL-EQ Z)	-0.006	10 1.5(DL+EQ X)
244	0.000	10.280	-	0.000	-	0.000	-

Table No. 2. Max. Translational Displacement, Rotational Displacement of Staircase Edge Columns for Structure with Isolated Footing.

Staircase Edge Column Nodes							
Node	Max Trans. Disp.	Drift Values	Load Combination	rX	Load Combination	rZ	Load Combination
1619	389.244	-	11 1.5(DL-EQ X)	0.004	12 1.5(DL+EQ Z)	0.002	11 1.5(DL-EQ X)
1505	387.482	1.762	11 1.5(DL-EQ X)	0.004	12 1.5(DL+EQ Z)	0.002	11 1.5(DL-EQ X)
1387	372.492	14.990	10 1.5(DL+EQ X)	0.005	12 1.5(DL+EQ Z)	0.003	11 1.5(DL-EQ X)
1269	350.058	22.434	10 1.5(DL+EQ X)	0.006	12 1.5(DL+EQ Z)	0.004	11 1.5(DL-EQ X)
1151	321.478	28.580	10 1.5(DL+EQ X)	0.007	12 1.5(DL+EQ Z)	0.004	11 1.5(DL-EQ X)
1033	287.965	33.513	10 1.5(DL+EQ X)	0.007	12 1.5(DL+EQ Z)	0.005	11 1.5(DL-EQ X)
915	250.727	37.238	10 1.5(DL+EQ X)	0.008	12 1.5(DL+EQ Z)	0.005	11 1.5(DL-EQ X)
797	210.868	39.859	10 1.5(DL+EQ X)	0.008	12 1.5(DL+EQ Z)	0.005	11 1.5(DL-EQ X)
679	169.391	41.477	10 1.5(DL+EQ X)	0.008	12 1.5(DL+EQ Z)	0.005	11 1.5(DL-EQ X)
561	127.213	42.178	10 1.5(DL+EQ X)	0.008	12 1.5(DL+EQ Z)	0.005	11 1.5(DL-EQ X)
443	85.225	41.988	10 1.5(DL+EQ X)	0.008	12 1.5(DL+EQ Z)	0.005	11 1.5(DL-EQ X)
327	44.815	40.410	10 1.5(DL+EQ X)	0.007	12 1.5(DL+EQ Z)	0.005	11 1.5(DL-EQ X)
43	10.150	34.665	10 1.5(DL+EQ X)	0.005	12 1.5(DL+EQ Z)	0.003	11 1.5(DL-EQ X)
257	0.000	10.150	-	0.000	-	0.000	-

Table No. 3. Max. Translational Displacement, Rotational Displacement of Outer Edge Columns for Structure with Strap Footing.

Outer Edge Column Nodes							
Node	**Max Trans. Disp.**	**Drift Values**	**Load Combination**	**rX**	**Load Combination**	**rZ**	**Load Combination**
1606	406.587	-	10 1.5(DL+EQ X)	-0.005	13 1.5(DL-EQ Z)	-0.006	10 1.5(DL+EQ X)
1468	400.685	5.902	10 1.5(DL+EQ X)	-0.005	13 1.5(DL-EQ Z)	-0.006	10 1.5(DL+EQ X)
1350	383.551	17.134	10 1.5(DL+EQ X)	-0.005	13 1.5(DL-EQ Z)	-0.006	10 1.5(DL+EQ X)
1232	360.043	23.508	10 1.5(DL+EQ X)	-0.007	13 1.5(DL-EQ Z)	-0.008	10 1.5(DL+EQ X)
1114	330.331	29.712	10 1.5(DL+EQ X)	-0.008	13 1.5(DL-EQ Z)	-0.009	10 1.5(DL+EQ X)
996	295.621	34.710	10 1.5(DL+EQ X)	-0.009	13 1.5(DL-EQ Z)	-0.010	10 1.5(DL+EQ X)
878	257.156	38.465	10 1.5(DL+EQ X)	-0.010	13 1.5(DL-EQ Z)	-0.010	10 1.5(DL+EQ X)
760	216.084	41.072	10 1.5(DL+EQ X)	-0.010	13 1.5(DL-EQ Z)	-0.010	10 1.5(DL+EQ X)
642	173.509	42.575	11 1.5(DL-EQ X)	-0.010	13 1.5(DL-EQ Z)	-0.010	10 1.5(DL+EQ X)
524	130.333	43.176	11 1.5(DL-EQ X)	-0.010	13 1.5(DL-EQ Z)	-0.010	10 1.5(DL+EQ X)
406	87.450	42.883	11 1.5(DL-EQ X)	-0.010	13 1.5(DL-EQ Z)	-0.010	10 1.5(DL+EQ X)
290	46.193	41.257	11 1.5(DL-EQ X)	-0.009	13 1.5(DL-EQ Z)	-0.009	10 1.5(DL+EQ X)
6	10.532	35.661	11 1.5(DL-EQ X)	-0.006	13 1.5(DL-EQ Z)	-0.006	10 1.5(DL+EQ X)
244	0.000	10.532	-	0.000	-	0.000	-

Table No. 4. Max. Translational Displacement, Rotational Displacement of Staircase Edge Columns for Structure with Strap Footing.

Staircase Edge Column Nodes							
Node	**Max Trans. Disp.**	**Drift Values**	**Load Combination**	**rX**	**Load Combination**	**rZ**	**Load Combination**
1619	399.170	-	11 1.5(DL-EQ X)	0.004	12 1.5(DL+EQ Z)	0.002	11 1.5(DL-EQ X)
1505	397.398	1.772	11 1.5(DL-EQ X)	0.004	12 1.5(DL+EQ Z)	0.002	11 1.5(DL-EQ X)
1387	382.025	15.373	10 1.5(DL+EQ X)	0.005	12 1.5(DL+EQ Z)	0.003	11 1.5(DL-EQ X)
1269	359.014	23.011	10 1.5(DL+EQ X)	0.006	12 1.5(DL+EQ Z)	0.004	11 1.5(DL-EQ X)
1151	329.700	29.314	10 1.5(DL+EQ X)	0.007	12 1.5(DL+EQ Z)	0.004	11 1.5(DL-EQ X)
1033	295.326	34.374	10 1.5(DL+EQ X)	0.008	12 1.5(DL+EQ Z)	0.005	11 1.5(DL-EQ X)
915	257.133	38.193	10 1.5(DL+EQ X)	0.008	12 1.5(DL+EQ Z)	0.005	11 1.5(DL-EQ X)
797	216.251	40.882	10 1.5(DL+EQ X)	0.008	12 1.5(DL+EQ Z)	0.005	11 1.5(DL-EQ X)
679	173.711	42.540	10 1.5(DL+EQ X)	0.008	12 1.5(DL+EQ Z)	0.005	11 1.5(DL-EQ X)
561	130.454	43.257	10 1.5(DL+EQ X)	0.008	12 1.5(DL+EQ Z)	0.005	11 1.5(DL-EQ X)
443	87.392	43.062	10 1.5(DL+EQ X)	0.008	12 1.5(DL+EQ Z)	0.005	11 1.5(DL-EQ X)
327	45.950	41.442	10 1.5(DL+EQ X)	0.007	12 1.5(DL+EQ Z)	0.005	11 1.5(DL-EQ X)
43	10.400	35.550	10 1.5(DL+EQ X)	0.005	12 1.5(DL+EQ Z)	0.004	11 1.5(DL-EQ X)
257	0.000	10.400	-	0.000	-	0.000	-

Table No. 5. Max. Translational Displacement, Rotational Displacement of Outer Edge Columns for Structure with Raft Footing.

Outer Edge Column Nodes							
Node	**Max T. D.**	**Drift Values**	**Load Combination**	**rX**	**Load Combination**	**rZ**	**Load Combination**
1606	405.027	-	10 1.5(DL+EQ X)	-0.005	13 1.5(DL-EQ Z)	-0.006	10 1.5(DL+EQ X)
1468	399.144	5.883	10 1.5(DL+EQ X)	-0.005	13 1.5(DL-EQ Z)	-0.006	10 1.5(DL+EQ X)
1350	382.073	17.071	10 1.5(DL+EQ X)	-0.005	13 1.5(DL-EQ Z)	-0.006	10 1.5(DL+EQ X)
1232	358.656	23.417	10 1.5(DL+EQ X)	-0.007	13 1.5(DL-EQ Z)	-0.008	10 1.5(DL+EQ X)
1114	329.059	29.597	10 1.5(DL+EQ X)	-0.008	13 1.5(DL-EQ Z)	-0.009	10 1.5(DL+EQ X)
996	294.483	34.576	10 1.5(DL+EQ X)	-0.009	13 1.5(DL-EQ Z)	-0.010	10 1.5(DL+EQ X)
878	256.166	38.317	10 1.5(DL+EQ X)	-0.009	13 1.5(DL-EQ Z)	-0.010	10 1.5(DL+EQ X)
760	215.252	40.914	10 1.5(DL+EQ X)	-0.010	13 1.5(DL-EQ Z)	-0.010	10 1.5(DL+EQ X)
642	172.842	42.410	10 1.5(DL+EQ X)	-0.010	13 1.5(DL-EQ Z)	-0.010	10 1.5(DL+EQ X)
524	129.832	43.010	10 1.5(DL+EQ X)	-0.010	13 1.5(DL-EQ Z)	-0.010	10 1.5(DL+EQ X)
406	87.114	42.718	10 1.5(DL+EQ X)	-0.010	13 1.5(DL-EQ Z)	-0.010	10 1.5(DL+EQ X)
290	46.016	41.098	10 1.5(DL+EQ X)	-0.009	13 1.5(DL-EQ Z)	-0.009	10 1.5(DL+EQ X)
6	10.493	35.523	10 1.5(DL+EQ X)	-0.006	13 1.5(DL-EQ Z)	-0.006	10 1.5(DL+EQ X)
244	0.000	10.493	-	0.000	-	0.000	-

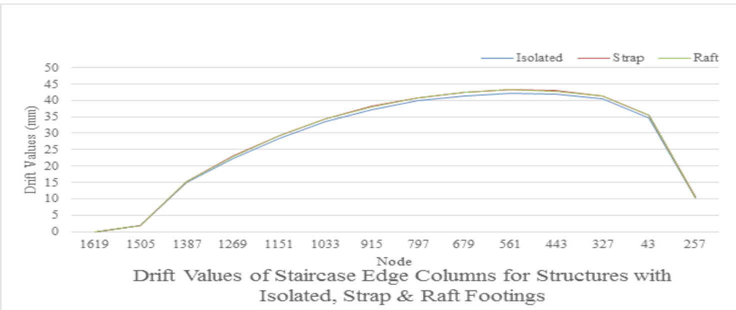

Fig. j. Graph Showing Comparison between Drift Values of Outer Edge Columns for Structures with Isolated, Strap & Raft Footings.

Table No. 6. Max. Translational Displacement, Rotational Displacement of Staircase Edge Columns for Structure with Raft Footing.

Staircase Edge Column Nodes							
Node	**Max T. D.**	**Drift Values**	**Load Combination**	**rX**	**Load Combination**	**rZ**	**Load Combination**
1619	397.639	-	11 1.5(DL-EQ X)	0.004	12 1.5(DL+EQ Z)	0.002	11 1.5(DL-EQ X)
1505	395.869	1.770	11 1.5(DL-EQ X)	0.004	12 1.5(DL+EQ Z)	0.002	11 1.5(DL-EQ X)
1387	380.555	15.314	10 1.5(DL+EQ X)	0.005	12 1.5(DL+EQ Z)	0.003	11 1.5(DL-EQ X)
1269	357.633	22.922	10 1.5(DL+EQ X)	0.006	12 1.5(DL+EQ Z)	0.004	11 1.5(DL-EQ X)
1151	328.432	29.201	10 1.5(DL+EQ X)	0.007	12 1.5(DL+EQ Z)	0.004	11 1.5(DL-EQ X)
1033	294.191	34.241	10 1.5(DL+EQ X)	0.008	12 1.5(DL+EQ Z)	0.005	11 1.5(DL-EQ X)
915	256.145	38.046	10 1.5(DL+EQ X)	0.008	12 1.5(DL+EQ Z)	0.005	11 1.5(DL-EQ X)
797	215.421	40.724	10 1.5(DL+EQ X)	0.008	12 1.5(DL+EQ Z)	0.005	11 1.5(DL-EQ X)
679	173.045	42.376	10 1.5(DL+EQ X)	0.008	12 1.5(DL+EQ Z)	0.005	11 1.5(DL-EQ X)
561	129.854	43.191	10 1.5(DL+EQ X)	0.008	12 1.5(DL+EQ Z)	0.005	11 1.5(DL-EQ X)
443	87.057	42.797	10 1.5(DL+EQ X)	0.008	12 1.5(DL+EQ Z)	0.005	11 1.5(DL-EQ X)
327	45.775	41.282	10 1.5(DL+EQ X)	0.007	12 1.5(DL+EQ Z)	0.005	11 1.5(DL-EQ X)
43	10.362	35.413	10 1.5(DL+EQ X)	0.005	12 1.5(DL+EQ Z)	0.004	11 1.5(DL-EQ X)
257	0.000	10.362	-	0.000	-	0.000	-

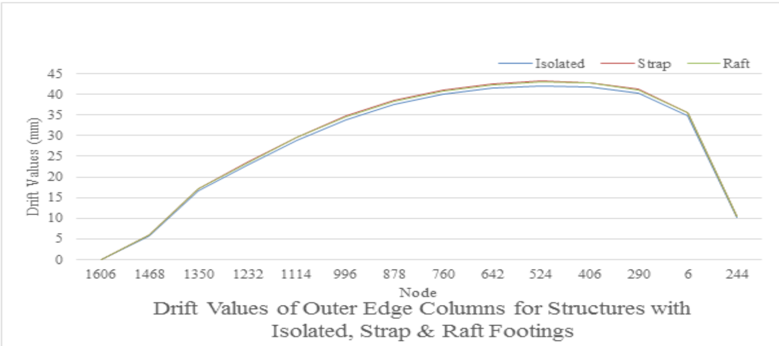

Fig. k. Graph Showing Comparison between Drift Values of Staircase Edge Columns for Structures with Isolated, Strap & Raft Footings.

Table No. 7. Max. Bending Moment and Shear Force of Outer Edge and Staircase Edge Columns for Structure with Isolated Footing.

Outer Edge Column Nodes					Staircase Edge Column Nodes				
Member No.	**Mz +**	**Mz -**	**Fy**	**Fx**	**Member No.**	**Mz +**	**Mz -**	**Fy**	**Fx**
2888	0.00	0.00	0.00	0	2901	0.00	0.00	0.00	0.00
2770	29.50	-18.50	16.00	-2.09	2783	53.20	-44.40	32.50	10.30
2556	17.00	-15.30	10.80	-45	2569	34.40	-36.50	23.70	14.10
2342	17.00	-14.70	10.60	-137	2355	47.30	-45.10	30.80	18.80
2128	16.10	-14.00	10.00	-270	2141	52.50	-51.60	34.70	21.10
1914	15.20	-13.40	9.54	-436	1927	55.20	-55.10	36.80	19.70
1700	14.20	-12.50	8.91	-629	1713	56.00	-55.90	37.30	14.20
1486	12.70	-11.20	7.99	-843	1499	55.70	-54.70	36.80	4.97
1272	10.60	-9.35	6.66	-1074	1285	55.00	-52.30	35.70	-7.38
1058	7.71	6.72	4.81	-1317	1071	54.10	-49.50	34.50	-21.60
844	3.98	-3.31	2.43	-1570	857	51.90	-48.10	33.30	-35.80
630	0.15	-3.47	1.21	-1818	643	39.40	-43.60	27.70	-48.10
416	-6.60	-9.02	1.21	-2005	429	1.54	9.94	-4.20	-68.70

Table No. 8. Max. Bending Moment and Shear Force of Outer Edge and Staircase Edge Columns for Structure with Strap Footing.

Outer Edge Column Nodes					Staircase Edge Column Nodes				
Member No.	**Mz +**	**Mz -**	**Fy**	**Fx**	**Member No.**	**Mz +**	**Mz -**	**Fy**	**Fx**
2888	0.00	0.00	0.00	0	2901	0.00	0.00	0.00	0.00
2770	30.20	-19.00	16.40	-2.15	2783	54.50	-45.50	33.30	10.60
2556	17.40	-15.70	11.00	-46.2	2569	35.30	-37.50	24.30	14.50
2342	17.40	-15.10	10.80	-140	2355	48.50	-46.30	31.60	19.30
2128	16.50	-14.40	10.30	-277	2141	53.90	-53.00	35.60	21.70
1914	15.60	-13.70	9.78	-447	1927	56.60	-56.50	37.70	20.20
1700	14.60	-12.80	9.13	-645	1713	57.50	-57.40	38.30	14.60
1486	13.10	-11.50	8.20	-865	1499	57.20	-56.10	37.80	5.10
1272	10.90	-9.59	6.83	-1101	1285	56.40	-53.60	36.70	-7.57
1058	7.91	-6.89	4.93	-1351	1071	55.50	-50.70	35.40	-22.20
844	4.08	-3.39	2.49	-1610	857	53.20	-49.30	34.20	-36.80
630	0.15	-3.56	1.24	-1865	643	40.40	-44.80	28.40	-49.30
416	-6.77	-9.25	1.24	-2056	429	1.58	10.20	-4.31	-70.40

Table No. 9. Max. Bending Moment and Shear Force of Outer Edge and Staircase Edge Columns for Structure with Raft Footing.

Outer Edge Column Nodes					Staircase Edge Column Nodes				
Member No.	**Mz +**	**Mz -**	**Fy**	**Fx**	**Member No.**	**Mz +**	**Mz -**	**Fy**	**Fx**
2888	0.00	0.00	0.00	0	2901	0.00	0.00	0.00	0.00
2770	30.10	-18.90	16.40	-2.14	2783	54.30	-45.40	33.20	10.50
2556	17.30	-15.70	11.00	-46	2569	35.20	-37.30	24.20	14.40
2342	17.30	-15.00	10.80	-140	2355	48.30	-46.10	31.50	19.20
2128	16.40	-14.30	10.30	-276	2141	53.70	-52.80	35.50	21.60
1914	15.60	-13.70	9.74	-445	1927	56.40	-56.30	37.60	20.10
1700	14.50	-12.80	9.10	-643	1713	57.20	-57.10	38.10	14.50
1486	13.00	-11.50	8.17	-861	1499	57.00	-55.90	37.60	5.08
1272	10.90	-9.55	6.80	-1097	1285	56.20	-53.40	36.50	-7.54
1058	7.88	-6.87	4.92	-1346	1071	55.30	-50.60	35.30	-22.10
844	4.07	-3.38	2.48	-1604	857	53.00	-49.10	34.00	-36.60
630	0.15	-3.54	1.23	-1858	643	40.20	-44.60	28.30	-49.10
416	-6.75	-9.21	1.23	-2048	429	1.58	10.20	-4.29	-70.10

Table No. 10. Storey Shear Development Values of Outer Edge and Staircase Edge Columns for Structure with Isolated Footing.

Outer Edge Column Nodes			Staircase Edge Column Nodes		
Node	**X - Direction**	**Z - Direction**	**Node**	**X - Direction**	**Z - Direction**
1606	0.529	0.408	1619	0.529	0.408
1468	22.755	17.571	1505	24.728	19.094
1350	19.857	15.332	1387	21.506	16.606
1232	16.308	12.592	1269	17.662	13.638
1114	13.109	10.122	1151	14.197	10.962
996	10.258	7.921	1033	11.110	8.579
878	7.757	5.989	915	8.401	6.487
760	5.604	4.327	797	6.069	4.687
642	3.801	2.935	679	4.116	3.178
524	2.346	1.812	561	2.541	1.962
406	1.241	0.958	443	1.344	1.038
290	0.485	0.374	327	0.525	0.405
6	0.076	0.059	43	0.082	0.064

Table No. 11. Storey Shear Development Values of Outer Edge and Staircase Edge Columns for Structure with Strap Footing.

Outer Edge Column Nodes			Staircase Edge Column Nodes		
Node	**X - Direction**	**Z - Direction**	**Node**	**X - Direction**	**Z - Direction**
1606	0.542	0.419	1619	0.542	0.419
1468	23.339	18.021	1505	25.362	19.584
1350	20.366	15.726	1387	22.058	17.032
1232	16.727	12.915	1269	18.116	13.988
1114	13.445	10.382	1151	14.561	11.244
996	10.521	8.124	1033	11.395	8.799
878	7.956	6.143	915	8.616	6.653
760	5.748	4.438	797	6.225	4.807
642	3.898	3.010	679	4.222	3.260
524	2.407	9.515	561	2.606	2.013
406	1.273	0.983	443	1.379	1.064
290	0.497	0.384	327	0.539	0.416
6	0.078	0.060	43	0.084	0.065

Table No. 12. Storey Shear Development Values of Outer Edge and Staircase Edge Columns for Structure with Raft Footing.

Outer Edge Column Nodes			Staircase Edge Column Nodes		
Node	**X - Direction**	**Z - Direction**	**Node**	**X - Direction**	**Z - Direction**
1606	0.540	0.417	1619	0.542	0.417
1468	23.249	17.952	1505	25.265	19.508
1350	20.288	15.665	1387	21.972	16.966
1232	16.662	12.866	1269	18.046	13.934
1114	13.393	10.341	1151	14.505	11.200
996	10.481	8.093	1033	11.351	8.765
878	7.925	6.119	915	8.583	6.627
760	5.726	4.421	797	6.201	4.788
642	3.883	2.998	679	4.206	3.247
524	2.397	1.851	561	2.596	2.005
406	1.268	0.979	443	1.373	1.060
290	0.495	0.382	327	0.536	0.414
6	0.078	0.060	43	0.084	0.065

Table No. 13. Reaction Development for One Quadrant for Structure with Isolated Footing.

Nodes	Fx	Fy	Fz	Mx	My	Mz
244	190.990	5903.540	-273.575	-594.804	0.761	-267.421
248	-211.070	6265.168	-269.387	-579.667	0.868	280.753
254	-113.950	5835.603	-253.578	-571.498	0.819	216.759
255	-112.264	5608.685	-266.728	-583.555	0.650	216.030
262	-92.118	5198.755	-249.082	-544.380	0.550	202.837
245	349.600	6048.814	-203.672	-240.654	-0.759	-779.537
249	546.946	5032.971	-166.860	-213.584	0.865	-896.758
252	-450.311	5254.269	201.544	235.746	-1.289	841.121
257	-285.574	4442.543	389.954	654.115	6.659	330.465
264	-246.104	3949.993	-259.479	-551.555	-6.710	305.009
259	421.127	6711.348	-210.149	-255.059	-17.775	-902.775
241	302.868	5093.590	-200.126	-238.487	0.331	-739.833
250	-417.529	5570.808	-186.672	-227.576	1.643	809.115

Table No. 14. Reaction Development for One Quadrant for Structure with Strap Footing.

Nodes	Fx	Fy	Fz	Mx	My	Mz
244	195.62	6029.774	-280.009	-621.942	0.777	273.141
248	-216.376	6410.492	-275.621	-606.382	0.886	294.262
254	-116.828	5974.078	-259.871	-598.281	0.836	-230.006
255	-115.135	5749.976	-273.256	-619.619	0.661	229.383
262	-94.462	5345.237	-254.836	-577.597	0.562	207.088
245	358.256	6210.881	-208.893	.248.495	0.778	796.753
249	560.349	5148.647	-170.936	219.57	0.884	-907.347
252	-461.175	5373	206.53	254.015	-1.314	847.881
257	-292.672	4580.616	399.454	-671.958	6.825	352.222
264	-252.388	4074.08	-265.775	565.857	-6.874	312.402
259	431.655	6928.314	-215.486	261.475	-18.18	-948.37
241	309.738	5248.632	-205.214	-242.878	0.337	755.74
250	-427.343	5730.665	-191.382	-231.307	1.682	825.056

Table No. 15. Reaction Development for One Quadrant for Structure with Raft Footing.

Nodes	Fx	Fy	Fz	Mx	My	Mz
244	194.906	5992.62	-279.017	-607.376	0.774	-273.081
248	-215.558	6374.085	-274.66	-591.881	0.883	286.782
254	-116.384	5939.513	-258.901	-583.769	0.833	221.429
255	-114.692	5717.928	-272.25	-596.011	0.66	220.705
262	-94.101	5317.544	-253.949	-555.825	0.56	207.217
245	356.921	6176.552	-208.088	-245.862	0.761	-796.292
249	558.283	5172.039	-170.307	-218.099	0.881	-915.902
252	-459.5	5342.109	205.761	240.768	-1.31	859.029
257	-291.578	4557.082	397.989	668.115	6.799	337.502
264	-251.419	4073.052	-264.804	-563.292	-6.849	311.602
259	430.032	6890.932	-214.663	-260.541	-18.118	-921.951
241	308.679	5223.144	-204.43	-243.626	0.336	-755.428
250	-425.83	5791.45	-190.656	-232.459	1.676	826.24

When comparison is made for translational displacement of case 1, 2 and 3, it is observed that in all the three cases, the drift values for top storey is comparatively very less as compared to next nodal values. For example, the drift value for node 1606 and 1468 is 5.781 mm whereas for node 1468 and 1350 it is 16.717 mm for structure with isolated footing. The drift value is increasing with decreasing storey level up to second floor and then again starts decreasing. The drift value is maximum at fourth floor level i.e. difference between node 642 and 524 which is 42.096 mm for structure with isolated footing and this is seen similar for the analysis of raft and strap footings also.

When comparison is made for drift values of nodes of outer edge and near staircase junction, it is found that the values are less for nodes near staircase junction. For example, the drift value for 1619 and 1505 is 1.762 mm as in Table No. 2, however in Table No.1, the value is 5.781 mm.

When comparison is made among various cases, it is seen that nodal displacement value and corresponding drift value is greater for structure with strap footing followed by structure with raft foundation and then for the structure with isolated footing. However, the difference between the nodal displacement values of structure with strap and raft footing is in decimals and is negligible as in Table No. 3 and 5. For example drift value for node 1606 and 1468 for structure with strap footing is 5.902 mm and that for structure with raft foundation is 5.883 mm. Similarly other values are also with negligible difference.

When the comparison is made for the column moment and shear force values, it is seen that for columns along the outer edge, maximum moment development is for node 2770 i.e. top second floor location. While for columns along the edge of staircase, maximum moment is developing at the mid of the structure i.e. for node 1713 as in Table No. 7, 8 and 9. The values of moment as well as shear force is higher for structure with strap footing followed by raft foundation and then for isolated footing. The values of Fy in all the 3 tables i.e. from 7 to 9 are different with little difference where Fy is the vertical or gravitational force.

The storey shear calculations for both directions X and Z as in Table No. 10 to 12 shows that storey shear values at top node is very less as that of the nodes just below it.

For example, for node 1606 it is 0.529 and for node 1468 it is 22.755 for structure with isolated footing. The storey shear development values are almost same in all 3 cases with minute decimal difference. The values are greater for structure with strap footing followed by structure with raft foundation and then for structure with isolated footing.

The reaction values for nodes shows that Fx values are almost same however there is a considerable difference in Fz and Fy when comparison is made between various cases.

Conclusion

On the basis of observations, various conclusions can be drawn as specified below.

- The Drift value at top is minimum whereas increases successively up to fourth floor. Similarly, drift values of inner nodes are less as compared to outer nodes. The comparative drift values of all three cases shows negligible difference in decimals and thus reflects equivalent auxilatory behavior.
- Again the bending moment and shear force is greater for columns at top as compared to successive lower columns. There is a rapid growth in bending moment and shear force values for a building with strap footing as that compared to raft and isolated footing. The values of Fy i.e. vertical force is greater for structure with strap footing.
- Base shear and storey shear calculations table shows that as the analysis counts, the total weight of structure 'W' which is multiplied by horizontal seismic coefficient so as to get the base shear and further storey shear values.
- The extra amount of mass contributed due to the provision of strap beams or raft, is increasing the overall weight of structure and when multiplied by the constant parameter A_h (horizontal seismic coefficient for considered location) gives higher base shear values and thus more storey shear distribution.
- For maintaining the stability, the reactions contracts the moments and forces acting and thus the building with more weight is showing greater reaction values.

It can be seen clearly that the behavior of RC structure highly depends upon the mass or inertia even though the provision of bands or plates are provided in the form of strap beams or raft foundation.

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