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Earthquake Resistance Design-Impact On Cost Of Reinforced Concrete Builidings

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Abstract: *Earthquakes strike suddenly, violently and without warning at any time of the day or night.It is highly impossible to prevent an earthquake from occuring, but the damage to the builiding can be controlled through proper design and detailing. Hence it is mandatory to do the sesmic analysis and design to structure against collapse. This study addresses the performance and variation of precentage steel and concrete quantity of R.C framed structure in different seismic zones and influence on overall cost of construction. This study mainly focuses on the comparision of percentage steel and concrete quantities when the builiding is designed for gravity loads as per IS 456:2000 and when the builiding is designed for earthquake forces in different seismic zones as per IS 1893:2002. A five storied R.C.C framed structure has been analyse and designed using STAAD ProV8i. Ductile detailing has been done in conformation with IS:13920*

Keywords: *Earthquake, seismic analysis, seismic zones, overall cost.*

I. Introduction

Vibrations of the earth‟ s surface caused by waves coming from a source ofdisturbances inside the earth are described as earthquake. By far the most important earthquake from an engineering standpoint is of tectonic origin, that is,those associated with large scale strains in the crust of the earth. Almost any building can be designed it be earthquake resistant provided its site is suitable.Buildings suffer during an earthquake primarily because horizontal forces are exerted on a structure that often meant to contend only with vertical stresses. The important point to be highlighted is that accurate prediction will help save lives,but structures have to be engineered to withstand appropriate forces depending on the seismiczone where they are located.If the building material is week in tension such as brick or stone masonry cracking occurs which reduces the effective area for resisting bending moment. It follows that the strength in tension and shear is importantfor earthquake resistance.

The extent of damage to a building depend much on the strength, ductility, and integrity of a building and the stiffness of ground beneath it in a given intensity of the earthquakes motions. The following properties and parameters are most important from the point of view of
the seismic design.
(i) Building material properties
Strength in compression, tension and shear, including dynamic effects
Unit weight
Modulus of elasticity
(ii) Dynamic characteristics of building components.

II. Analysis Significance

Seismic analysis or earthquake analysis is a subset of structural analysis and is the calculation of the response of a structure to the earthquakes. A structure has the potential to waveback and forth during an earthquake this is called the fundamental mode and is the lowes tfrequency of the structure response. However, buildings also have higher modes of response,which are uniquely activated during an earthquake.

The analysis process can be categorized on the basis of three factors, the type of externally applied loads, the behaviour of the structure or the structural material and the type of structural modal selected.
Importance of seismic analysis:

1. Resist minor level of earthquake ground motion without damage
2. Resist moderate level of earthquake motion without structural damage, possible experience non-structural damage.
3. Resist severe earthquake ground motion having intensity equal to the strongest shaking experienced at the site, without collapse of structure as well known as non-structural damage.

III. OBJECTIVE OF THE STUDY

1. To prevent loos of life, serious injury and to prevent buildings from collapse and dangerous damage under maximum intensity earthquakes.
2. To ensure buildings against irreparable damage under moderate to heavy earthquake. The strength built into the structure alone cannot create and earthquake resistant design, it also requires absorption, which means that structure should have predictable ductility as wellas strength.
3. The damping characteristics of a structure have a major effect on its response to ground motion because small amount of damping significantly reduces the maximum deflection to resonant response of the structure.

IV. METHODOLOGY

Seismic analysis of the structures is carried out on the basis of lateral force assumed to act along with the gravity loads. In this study, a five (G+4) storied RC building has been analyzed using the equivalent static method in STAAD-Pro V8i.In the earthquake analysis along with earthquake loads, vert ical loads are also applied. For the earthquake analysis, IS 1893-2002 code was used.

***4.1 Preliminary Data for the problem taken*:**

Type of the structure : RCC Framed structure
Number of stories : G+4
floor to floor height : 3.6 m
Plinth height : 0.6 m
Walls thickness : 230 mm
Grade of concrete : M 25
Grade of steel : Fe 415
Earthquake load : As per IS1893 (Part 1) : 2002
Size of the columns : 0.4mx0.4m and 0.45mx0.45m
Size of the beams : 0.23mx0.4m
Slab thickness : 0.13m
SBC of soil taken : 200kN/m²
Live load : 3kN/m²
Floor finishes : 1kN/m²
Seismic zones considered : II,III,IV,V

4.2 Loading Data:

Dead Load (DL)
1. Self weight of slab = 0.13x25 = 3.25kN/m2
2. Floor finishes = 1.00kN/m2
Total DL = 4.25kN/m2
(Assume 130mm total depth of slab)
3. Weight of walls = 0.23x19x 3.6 = 15.73kN/m
Live Load (LL)
Live Load on each slab = 3.00kN/m2
Earthquake Load (EL)
As per IS-1893 (Part 1): 2002.

4.3 Loading combinations:

The following load combinations are used in the seismic analysis, as mentioned in the code IS 1893(Part-1): 2002.

1. 1.5(DL+LL)
2. 1.2(DL+LL+EQX)
3. 1.2(DL+LL- EQX)
4. 1.2(DL+LL+ EQZ)
5. 1.2(DL+LL- EQZ)
6. 1.5(DL+ EQX)
7. 1.5(DL- EQX)
8. 1.5(DL+ EQZ)
9. 1.5(DL-EQZ)
10. 0.9DL+ 1.5EQX
11. 0.9DL- 1.5EQX
12. 0.9DL+ 1.5EQZ
13. 0.9DL-1.5EQZ

Earthquake load was considered in +X,-X, +Z and –Z directions. Thus a total of 13 load combinations are taken for analysis. Since large amount of data is difficult to handle manually all the load combinations are analyzed using software STAAD Pro. All the load combinations are mentioned above.

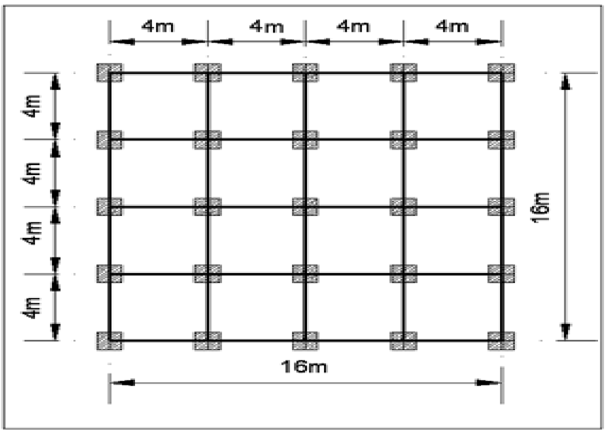

Fig.1 Plan of the building

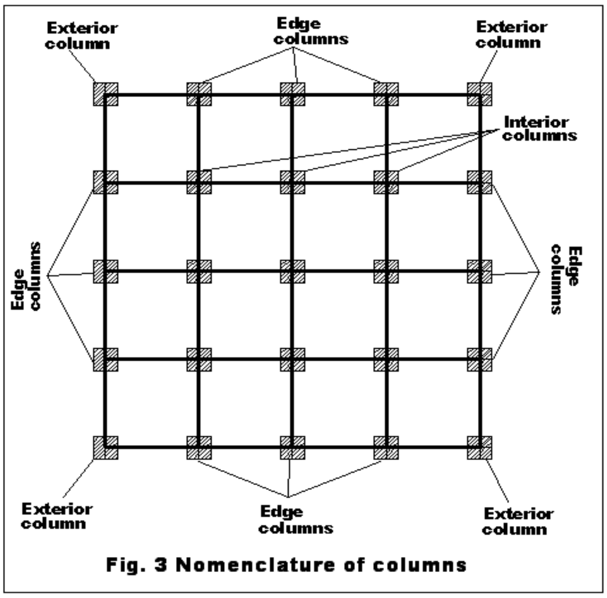

Fig.2: Nomenclature of columns

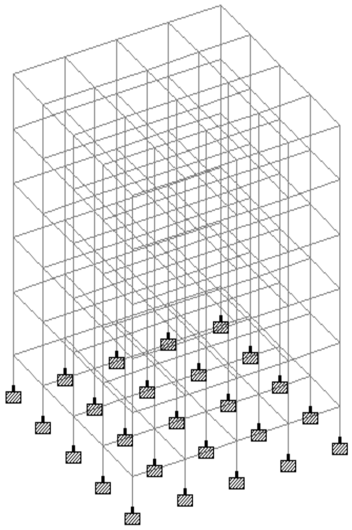

Fig.3 3-D view of the whole structure

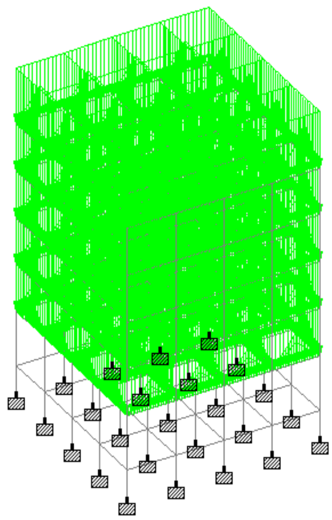

Fig.4 Whole structure subjected to vertical loading

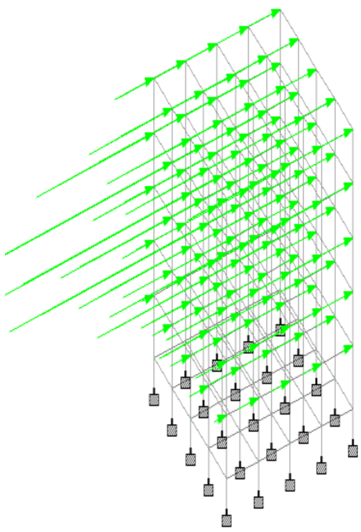

Fig.5 Structure subjected to Earthquake in +X direction

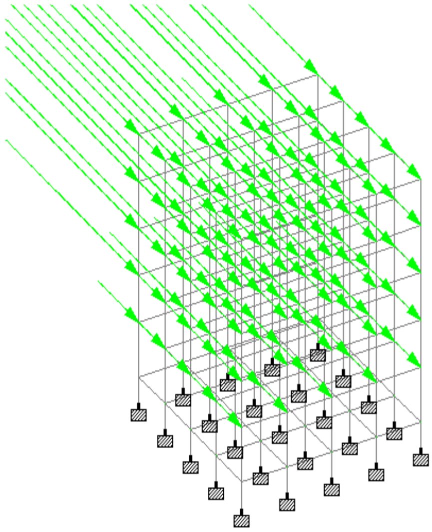

Fig.6 Structure subjected to Earthquake in +Z direction

V. Results And Discussions

5.1comparison of Support Reactions in Different Seismic Zones

The variation of support reactions at each location of the columns and the percentage difference in different seismic zones with respect to gravity loads is represented in the in Table I and Fig.7. It is observed that in edge columns, variations are 17.72, 28.35, 42.53, and 63.7% between gravity load to seismic zones II, III, IV and V respectively. In exterior columns, the variations are 11.59, 18.54, 27.81, and 41.71% between gravity load to seismic zones II, III, IV and V respectively. The variation is very small in interior columns.

Table: I Comparison of support reactions in different seismic zones

	Support Reaction (ken)					Percentage difference between Gravity load Vs Seismic zones			
	DL+LL	DL+LL+EL							
Location of the columns	GL	II	III	IV	V	II	III	IV	V
Edge columns	544	640	699	775	891	17.72	28.35	42.53	63.7
Exterior columns	868	969	1029	1109	1130	11.59	18.54	27.81	41.71
Interior columns	1296	1310	1319	1330	1347	1.10	1.76	2.64	3.95

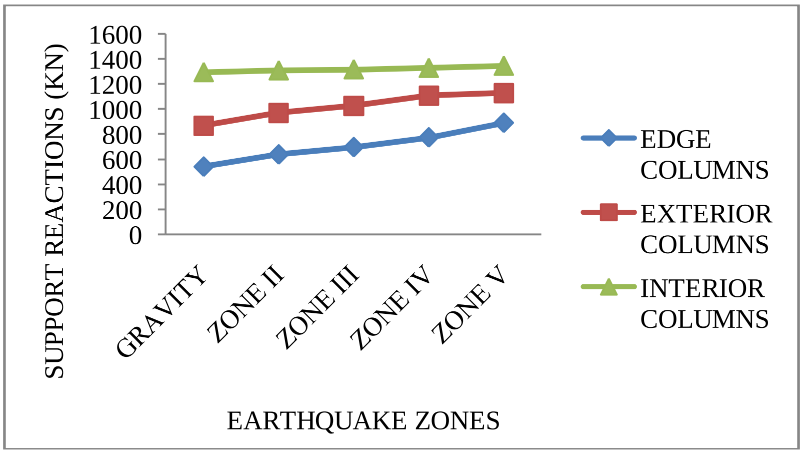

Fig.7 Variation of support reactions in different seismic zones

5.2 Comparison of Volume of Concrete in Footings in Different Seismic Zones

The variation of volume of concrete at each location of the column footing and the increase in percentage difference in different seismic zones with respect to gravity loads is represented in the in Table II and Fig.8. It is observed that in edge column footings, variations are 17.75, 17.75, 27.17 and 42.0% between gravity load to seismic zones II, III, IV and V respectively. In exterior column footings, the variations are 21.51, 21.51, 45.15 and 57.77% between gravity load to seismic zones II, III, IV and V respectively. Therefore, the volume of concrete in footings is increasing in seismic zones III, IV and V due to increase of support reactions due to lateral forces. However the variation is very small in interior column footings.

Table II Comparison of volume of concrete in footings in different seismic zones

	Volume of concrete in footings (cu m)					Percentage difference between Gravity load Vs Seismic zones			
	DL+LL	DL+LL+EL							
Location of the columns footings	GL	II	III	IV	V	II	III	IV	V
Edge	2.18	2.57	2.57	2.78	3.10	17.75	17.75	27.17	42.0
Exterior	1.50	1.83	1.83	2.186	2.376	21.51	21.51	45.15	57.77
Interior	3.29	3.29	3.29	3.40	3.40	0.0	0.0	3.51	3.51

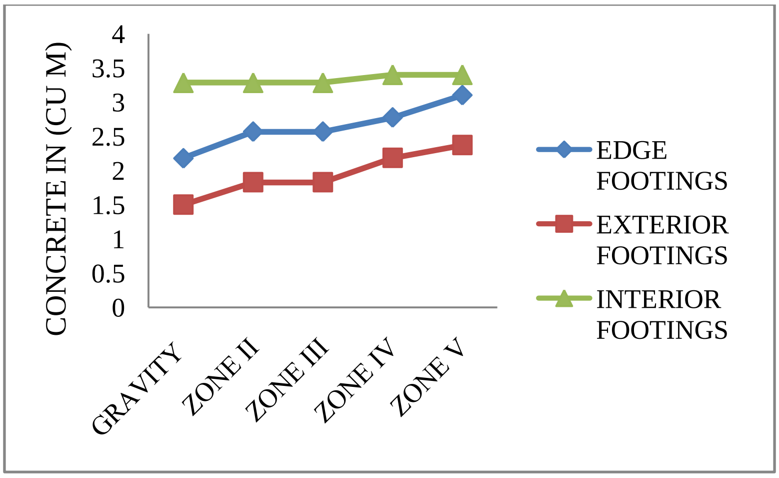

Fig.8 Variation of volume of concrete in footings in different seismic zones

5.3 Comparison of Weight of the Steel in Footings in Different Seismic Zones

The variation of weight of steel at each location of the column footing and the percentage difference in different seismic zones with respect to gravity loads is represented in the in Table III and Fig.9. It is observed that in edge column footings, variations are 0.0, 23.61, 47.92, and 98.96% between gravity load to seismic zones II, III, IV and V respectively. In exterior column footings, the variations are 38.17, 54.88, 70.79 and 91.04% between gravity loads to seismic zones II, III, IV and V respectively. In the interior columns footings, the variations are 22.07, 42.44, 56.03 and 67.91% between gravity loads to seismic zones II, III, IV and V respectively

Table III Comparison of weight of the steel in footings in different seismic zones

	Weight of the steel in footings (kg)					Percentage difference between Gravity load Vs Seismic zones			
	DL+LL	DL+LL+EL							
Location of the column footings	GL	II	III	IV	V	II	III	IV	V
Edge	28.80	28.80	35.60	42.60	57.30	0.00	23.61	47.92	98.96
Exterior	46.90	64.8	72.64	80.10	89.60	38.17	54.88	70.79	91.04
Interior	58.90	71.9	83.9	91.9	98.9	22.07	42.44	56.03	67.91

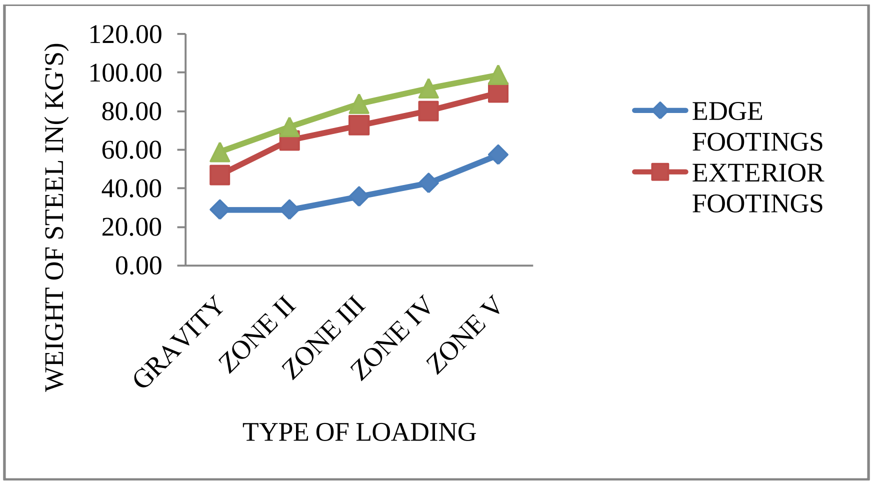

Fig. 9 Variation of weight of steel in footings in different seismic zones

5.4 Comparison of Percentage of the Steel in Columns in Different Seismic Zones

The variation of percentage of steel at each location of the column in different seismic zones with respect to gravity loads is represented in the in Table IV and Fig 10. The variation of percentage of steel in edge columns vary from 0.8% to 3%, exterior columns varying from 0.8% to 3.9% and interior columns varying from 1.1% to 3.7% between gravity loads to zone V. For the comparison purpose at each location, the cross sectional dimension of column was kept same in all the zones.

Table IV Comparison of percentage of the steel in columns in different seismic zones

	Percentage of the steel reinforcement in the columns				
	DL+LL	DL+LL+EL			
Location of the columns	GL	II	III	IV	V
Edge	0.8	0.9	1	1.5	3
Exterior	0.8	0.9	1.5	2.3	3.9
Interior	1.1	1.3	1.8	2.4	3.7
Note: for the comparison purpose at each location , the cross section of columns was kept in all the zones					

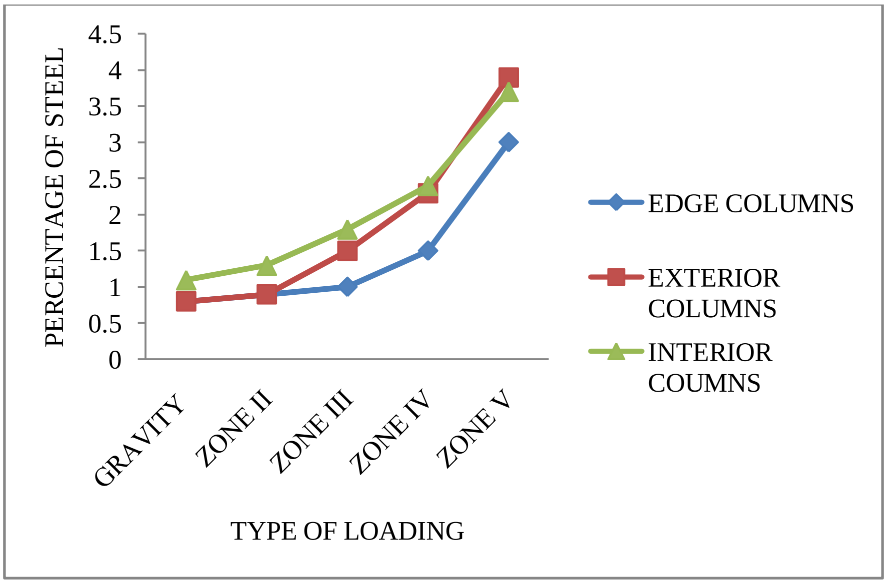

Fig. 10 Variation of percentage of steel in columns in different seismic zones

5.5 Comparison of Percentage of the Steel in Beams in Different Seismic Zones

The variation of percentage of steel in beams in different seismic zones with respect to gravity loads is represented in the in Table V and Fig.11. The variation of percentage of steel at supports, in external beams 0.54% to 1.23% and in internal beams 0.78% to 1.4% varying from gravity loads to zone V. At mid span locations of external and internal beams, the percentage of reinforcement is same in all the zones.

Table V Comparison of percentage of the steel in beams in different seismic zones

		Percentage of the steel reinforcement in the beams				
		DL+LL	DL+LL+EL			
Location of the columns	Beams	GL	II	III	IV	V
At supports	External	0.54	0.64	0.75	0.93	1.23
	Internal	0.78	0.83	0.97	1.18	1.4
At mid span	External	0.32	0.32	0.32	0.32	0.32
	Internal	0.42	0.42	0.42	0.42	0.42
Note: for the comparison purpose at each location , the cross section of beams was kept in all the zones						

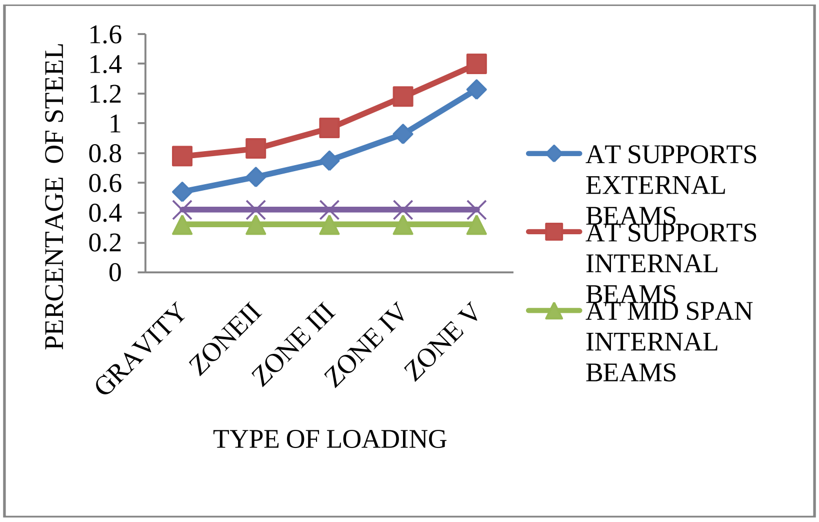

Fig11 Percentage of steel in beams in different seismic zones

5.6 Comparison of Weight of the Steel in Beams in Different Seismic Zones:

The variation of weight of steel at each location of the beams and the percentage difference in different seismic zones with respect to gravity loads is represented in the in Table VI and Fig.12. It is observed that in external beams, variations are 4.38, 13.8, 31.3, and 49.6% between gravity loads to seismic zones II, III, IV and V respectively. In the internal beams, the variations are 3.07, 15.3, 20.2 and 53.3% between gravity loads to seismic zones II, III, IV and V respectively.

Table VI Comparison of weight of the steel in beams in different seismic zones

	Weight of the steel (kg)					Percentage difference between Gravity load Vs Seismic zones			
	DL+LL	DL+LL+EL							
Beams	GL	II	III	IV	V	II	III	IV	V
External	137	143	156	180	205	4.38	13.8	31.3	49.6
Internal	163	168	188	196	250	3.07	15.3	20.2	53.3
Note: For the comparison purpose at each location, the cross sectional dimension of beams was kept same in all the zones.									

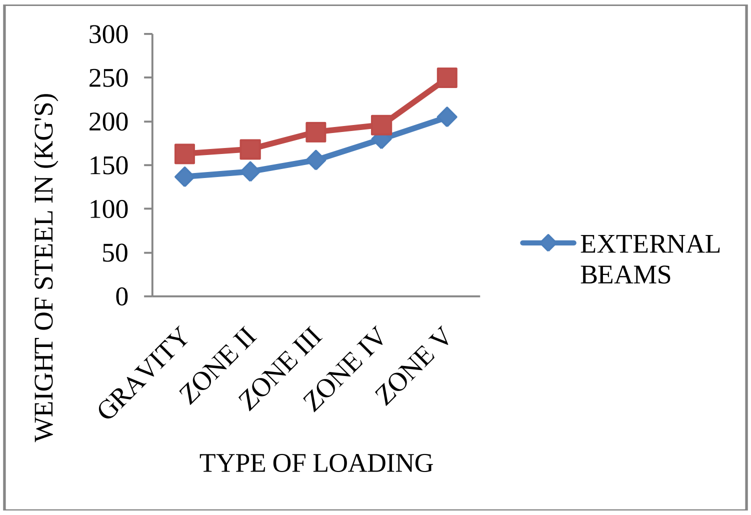

Fig. 12 Variation of weight of steel in beams in different seismic zones

5.7 Volume of Concrete for the Total Building and Percentage Variation of Concrete Non Earthquake Design Vs Earthquake Design

The total quantity of the concrete for the building has shown in table VII, for the entire earthquake and non earthquake zone and the percentage variation of the concrete for earthquake vs. non earthquake zones shown in table 8.

Table VII Volume of concrete for the total building

Type of loading	Volume of concrete (Culm)
Gravity loads [DL+LL]	406.8
Zone II [DL+LL+EL]	412.82
Zone III [DL+LL+EL]	414.7
Zone IV [DL+LL+EL]	417.75
Zone V [DL+LL+EL]	422.36

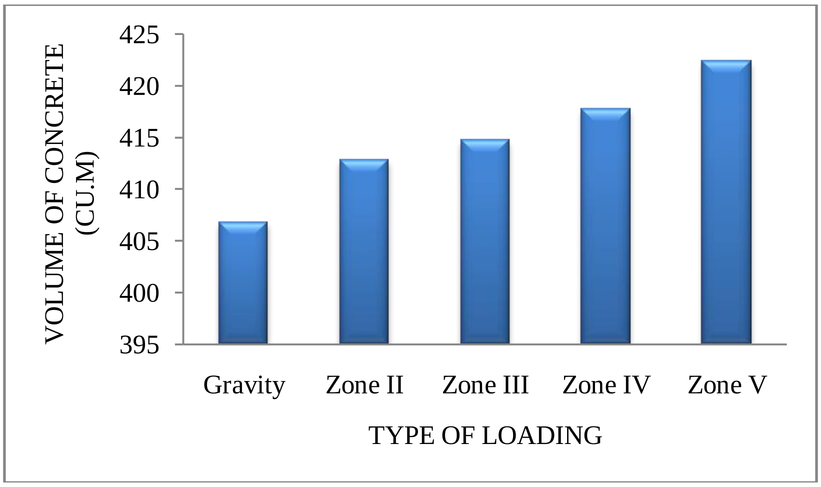

Fig. 13 Volume of concrete in all the earthquake and non earthquake zones

Table VIII Percentage variation the volume of concrete for earthquake design Vs non earthquake design

Type of loading	Percentage difference
Gravity loads Vs Zone II	1.479
Gravity loads Vs Zone III	1.94
Gravity loads Vs Zone IV	2.69
Gravity loads Vs Zone V	3.824

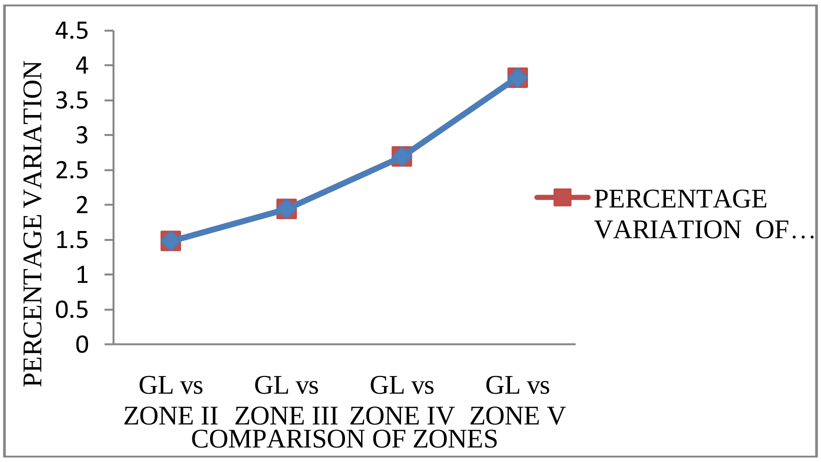

Fig. 13.1 Percentage variation of the concrete quantity in different zones

5.8 Quantity of Steel for the Total Building and Percentage Variation of Steel Non-Earthquake Design Vs Earthquake Design:

The total quantity of the steel for the building has shown in Table IX, for the entire earthquake and non earthquake zones, and the percentage variation of the weight of the steel for earthquake vs. non- earthquake designs shown in Table 10.

Table IX Weight of the steel for the total building in different seismic zones

Type of loading	Weight of steel (Tonnes)
Gravity loads [DL+LL]	20.92
Zone II [DL+LL+EL]	23.62
Zone III [DL+LL+EL]	24.76
Zone IV [DL+LL+EL]	29.58
Zone V [DL+LL+EL]	39.55

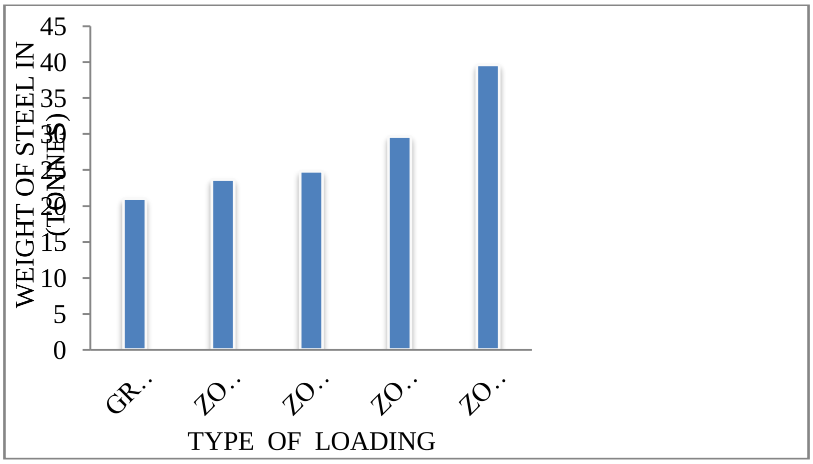

Fig. 14 Quantity of the steel in all the earthquake and non earthquake zones

Table X Percentage variation of the quantity of steel for earthquake and non earthquake designs

Type of loading	Percentage difference
Gravity loads Vs Zone II	12.96
Gravity loads Vs Zone III	18.35
Gravity loads Vs Zone IV	41.395
Gravity loads Vs Zone V	89.10

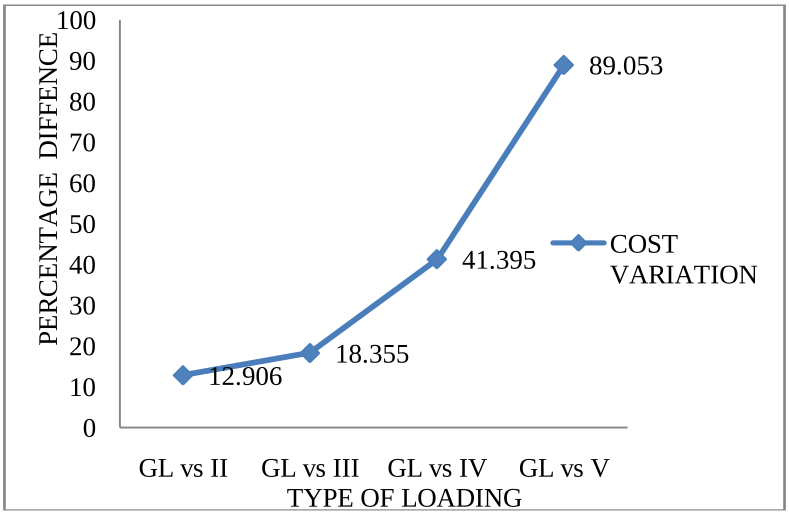

Fig14.1 Percentage variation of the steel quantity in different zones

5.9 Total Cost of the Building for All the Seismic Zones:

The total cost of the building for the design with respect to gravity loads and all the seismic zones as shown Table XI, and the variation of percentage of cost for non-earthquake vs. earthquake designs shown in Table 12.

Table XI Cost of the building for all the earthquake and non earthquake zones

Type of the loading	Cost of the building	Cost of the building Per (sft)	Cost of the building Per (sq m)
Gravity loads [DL+LL]	1,16,68,472	834/-	9115.99/-
Zone II [DL+LL+EL]	1,19,64,319	854/-	9347.12/-
Zone III [DL+LL+EL]	1,20,57,329	862/-	9419.78/-
Zone IV [DL+LL+EL]	1,25,00,188	892/-	9765.77/-
Zone V [DL+LL+EL]	1,33,71,609	995/-	10446.56/-

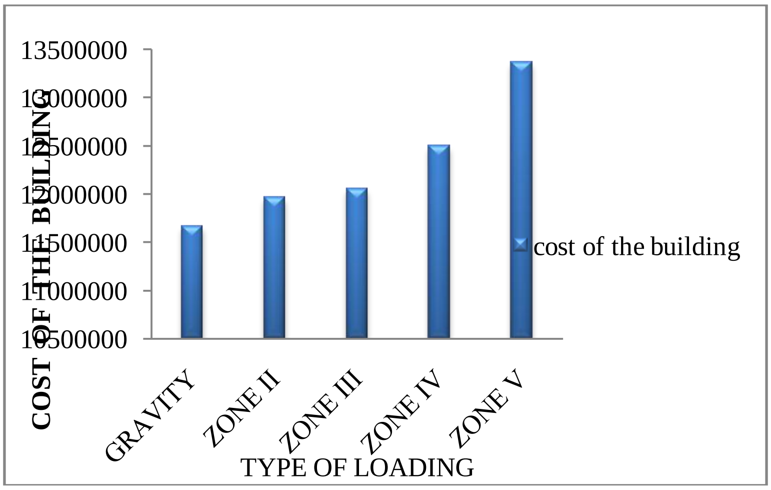

Fig. 15 Cost of the building in all the zones

Table XII Comparison of percentage variation of the cost for the building in earthquake and non earthquake designs

Type of the loading	% difference
Gravity loads Vs Zone II	2.53
Gravity loads Vs Zone III	3.33
Gravity loads Vs Zone IV	7.12
Gravity loads Vs Zone V	14.59

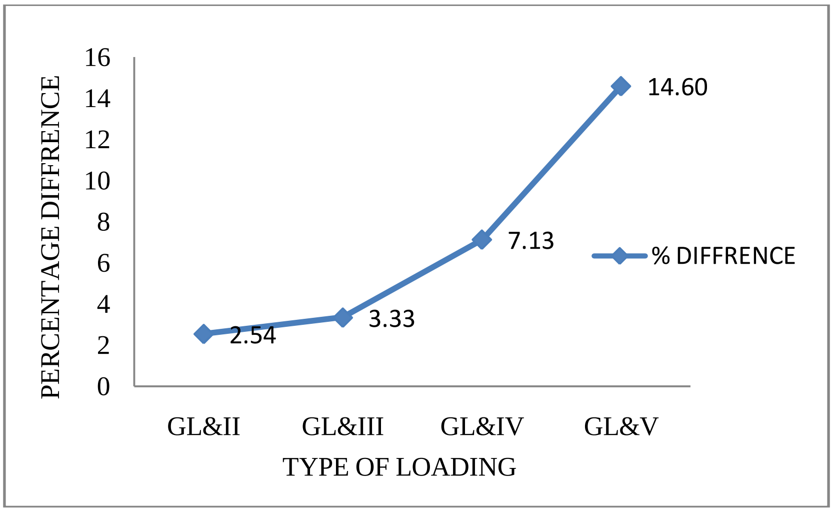

Fig. 15.1 Percentage of the cost variation for the building with earthquake and without earthquake

5.10 Cost Comparison Of Ductile Detailing Vs Non Ductile Detailng Of The Building:

The cost comparison for the ductile detailing and non ductile detailing as shown in the Table 13. Hear the cost variation only due to the increasing of steel in ductile detailing. The variation of cost in ductile detailing vs. non ductile detailing is nearly 4 percent.

Table XIII Steel quantity and cost difference for the building with ductile and without ductile detailing

	Ductile	Non ductile	% difference
Weight of steel	46.2 T	39.6 T	16.66
Cost of the building	1,39,15,086.14/-	1,33,71,608.81/-	4.06

VI. Conclusions

1. The variation of support reactions in exterior columns increasing from 11.59% to 41.71% and in edge columns increasing from 17.72% to 63.7% in seismic Zones II to V. However the variations of support reactions are very small in interior columns.
2. The volume of concrete in exterior and edge column footings is increasing in seismic zones III, IV and V due to increase of support reactions with the effect of lateral forces. However the variation is very small in interior column footings.
3. It is observed that the weight of steel in edge column footings between gravity loads to zone II, III, IV and V varies as 0, 23.6, 47.9 and 98.9 % respectively.
4. It is observed that the weight of steel in exterior column footings between gravity loads to zone II, III, IV and V varies as 38.1, 54.8, 70.7 and 91.04 % respectively.
5. It is observed that the weight of steel in interior column footings between gravity loads to zone II, III, IV and V varies as 22.07, 42.4, 56.03, and 67.9% respectively.
6. The percentage variation of steel in edge, exterior and interior columns varies from 0.8-3%, 0.8-3.9% and 1.1-3.7% between gravity loads to seismic zone V respectively.
7. The variation of percentage of steel at support sections in external beams is 0.54% to 1.23% and in internal beams is 0.78% to 1.4%.
8. In the external and internal beams, the percentage of bottom middle reinforcement is almost same for both earthquake and non earthquake designs.
9. Percentage variation of total concrete quantity for the whole structure, between gravity load and seismic zones II, III, IV and V varies as 1.4, 1.94, 2.69 and 3.8 respectively.
10. Percentage variation of total steel quantity for the whole structure, between gravity load and seismic zones II, III, IV and V varies as 12.96, 18.35, 41.39 and 89.05 respectively.
11. It is observed that the percentage variation of cost for the whole structure, between gravity load and seismic zones II, III, IV and V varies as 2.53, 3.33, 7.17 and 14.59 respectively.
12. It is observed that the cost of the building per SFT with the design for
13. Gravity loads -----------834 /-
14. Zone II-------------------854 /-
15. Zone III------------------862/-
16. Zone IV-----------------892/-

17. Zone V------------------995/-
18. It is observed that the cost of the building per Sq m with the design for
19. Gravity loads ------------9115.9/-
20. Zone II-------------------9347.12 /-
21. Zone III------------------9419.78/-
22. Zone IV------------------9765.77/-
23. Zone V------------------10446.56/-
24. The percentage increase of steel for the whole structure with ductile detailing compared to non ductile detailing is 16%.
25. The percentage increase in cost for the whole structure with ductile detailing compared to non ductile detailing is 4.06%

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