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"ANALYSIS OF THE SEISMIC RESPONSE OF A STEEL REINFORCED CONCRETE BUILDING USING THE BASE ISOLATION TECHNIQUE"

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ABSTRACT

Since there are more earthquake-prone regions in the world, structural engineers are expected to design our buildings to withstand the effects of earthquakes. We strive to satisfy a single fundamental equation, which states that capacity is larger than demand, for all possible load scenarios we may encounter during the design process, such as gravity and wind.

The widespread loss of lives and property as a result of severe earthquakes justifies the adoption of strategies to reduce the amount of ground motion that occurs during an earthquake in order to save lives and property in the aftermath. The main use of the foundation isolation technique is to shield any concrete building from the destructive effects of seismic attacks. It is one of the most successful strategies and has grown in popularity over the past three decades. This occurs as a result of the base isolation technique, a flexible base that largely decouples the structure from ground motion, and the fact that structure reaction accelerations are typically lower than ground acceleration. This project uses the Response Spectrum approach for dynamic analysis, adopting base isolation techniques and supplying base isolators like laminated neoprene pads with various diameters and a thickness of 160 mm.

Keyword*: Earthquake; base isolation; concrete structure; response spectrum method; foundation; laminated neoprene pads.*

I. INTRODUCTION

Earthquake is the sudden release of accumulated energy in the tectonic plates of the earth crust and resulting in propagation of seismic waves called P waves, S waves and surface waves. Earthquake occurs at the faults at boundaries the tectonic plates, causing colliding, separation, sliding, or sub ducting between the adjacent plates. A large proportion of world's population lives in regions of seismic hazards at risk from earthquakes of varying severity and frequency of occurrence earthquake causes significant loss of life and damage of property every year.

The modern seismic design primarily works upon the inelastic response of the structural members and systems to dissipate the energy imparted to a structure by an earthquake. In recent years, base isolation technique has been applied for structural design technique for buildings in highly seismic areas. The objective of seismic isolation system is to decouple the building structure from the damaging components of the earthquake input motion. The decoupling prevents the superstructure of the building from taking down the earthquake energy.

The basic concept of base isolation is to uncouple a structure from the ground by interposing a flexible element/bearing between structure and foundation. Seismic base isolation is a new technique that diminishes the effects of an earthquake by essentially isolating the structure and its contents from potentially dangerous ground motion especially in the high frequency range where the building is most affected.

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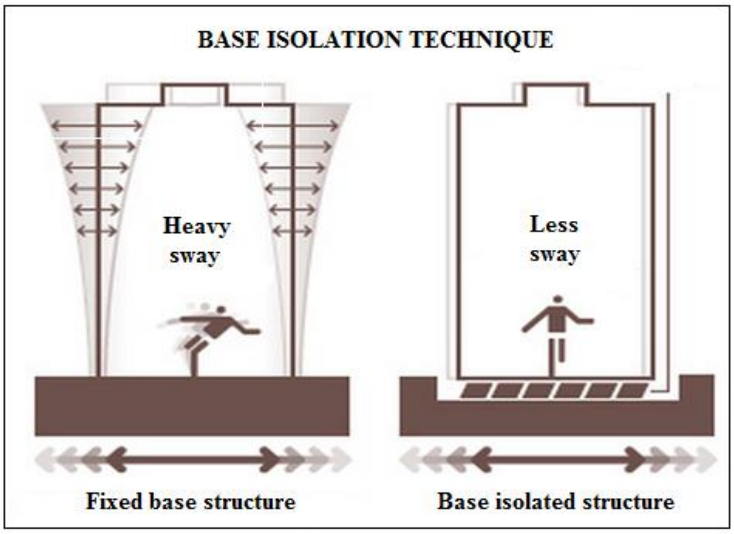

Figure 1: Base isolation in buildings

Base isolation consists of energy dissipation core (lead plug), vulcanized rubber layers, steel reinforcing plats, bottom mounting plate and over rubber. Energy dissipation core reduces earthquake forces and displacements by energy displacements by energy dissipation and also it provides wind resistance. Rubber layers provide lateral flexibility to the systems. Steel reinforcing provides vertical load capacity and also it confines lead core. A bottom mounting plate is incorporated with the isolator to be connected with the structure below and above isolator. Rubber is used to protect the steel plate.

In seismic isolation, the elementary aim is to reduce substantially the transmission of the earthquake forces and energy into the structure. This reduction in transmission is achieved by mounting the structure on an isolation system with considerable horizontal flexibility so that during an earthquake, when the ground vibrates strongly under the structure, only moderate motions are induced within the structure.

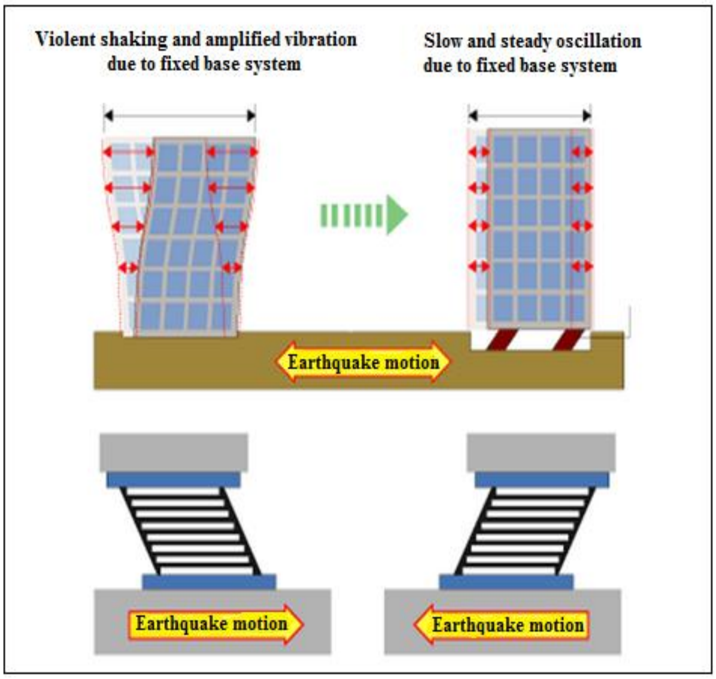

Figure 2: Response of buildings

II. LITERATURE REVIEW

Davis and Menon (2004) concluded that the presence of masonry infill panels modifies the structural force distribution

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significantly in an OGS building. The total storey shear force increases as the stiffness of the building increases in the presence of masonry infill at the upper floor of the building. Also, the bending moments in the ground floor columns increase (more than two fold), and the mode of failure is by soft storey mechanism (formation of hinges in ground floor columns).

Fumiaki Arima1 et al., (2000) they invented the new base-isolated system called Crossed Linear Bearings (CLB) which enables isolation application to lightweight houses or high-rise buildings or cylindrical structures. This system was developed to overcome the "restriction on application" which is caused by engineering problems such as buckling, or tensile failure when using conventional multi-rubber- bearing systems. Many experimental data or earthquake records have been examined in comparison with theory and analysis. The system demonstrated effective performance on response control, and it was verified that CLB has sufficient ground to be put into application. Based on this recognition, several buildings have already been constructed utilizing CLB systems.

Peng-Hsiang and Charng (1998) the benefits of implementing a seismic isolation system were investigated by comparing the performance of base isolated, segmental and fixed base multi-storey buildings. With the inclusion of seismic isolation devices, the base isolated and segmental buildings with elasto-plastic and bilinear isolation devices have; significantly reduced top floor deflections, accelerations, inter storey drifts and base shears when compared with the fixed base building.

Soong and Dargus et al., (1997) Using seismic isolation devices/systems to control earthquake induced vibration of bridges and buildings is considered to be a relatively matured technology and such devices have been installed in many structures world-wide in recent decades. Design guidelines have been established and they are periodically improved as new information based on research and or field observations become available during the past 20-30 years.

III. EXPERIMENTAL STUDY

3.1. Plan Dimension of the Structure

The structural plan of the multi-storey building taken for the purpose of this research will be of 15.25 m x 30.50 m. The different span of 4.9 m, 3.6m and 4.9 m has been taken for the analysis. The building will have 7bays in the longitudinal direction and 3 bays in the short direction. The height of the building has been taken a 28.0m and each storey of height 4.0m.

3.2. Objectives

- To study the behaviour of structural elements of a structure.
- To study response of the whole structure during earthquake combined with various loads such as gravity loads, live loads, wind loads, earthquake loads.
- To evaluate and compare the parameters like time period, base shear and displacement of the structure under various configuration of base isolation.

IV. RESEARCH METHODOLOGY

The methodology adopted for the study is to create four structural models varying the base configurations with typical structural members using standard structural analysis software STAAD. Pro to compute parameters like time period, displacement and base shear of the structure.

The base configuration of the structure is varying from fixed support condition to fully base isolated. For structural analysis gravity loads, live loads, wind loads and earthquake loads are considered. After carrying out analysis of these models, the time period, base shear, displacement, design of beam, column and foundation for various models are computed.

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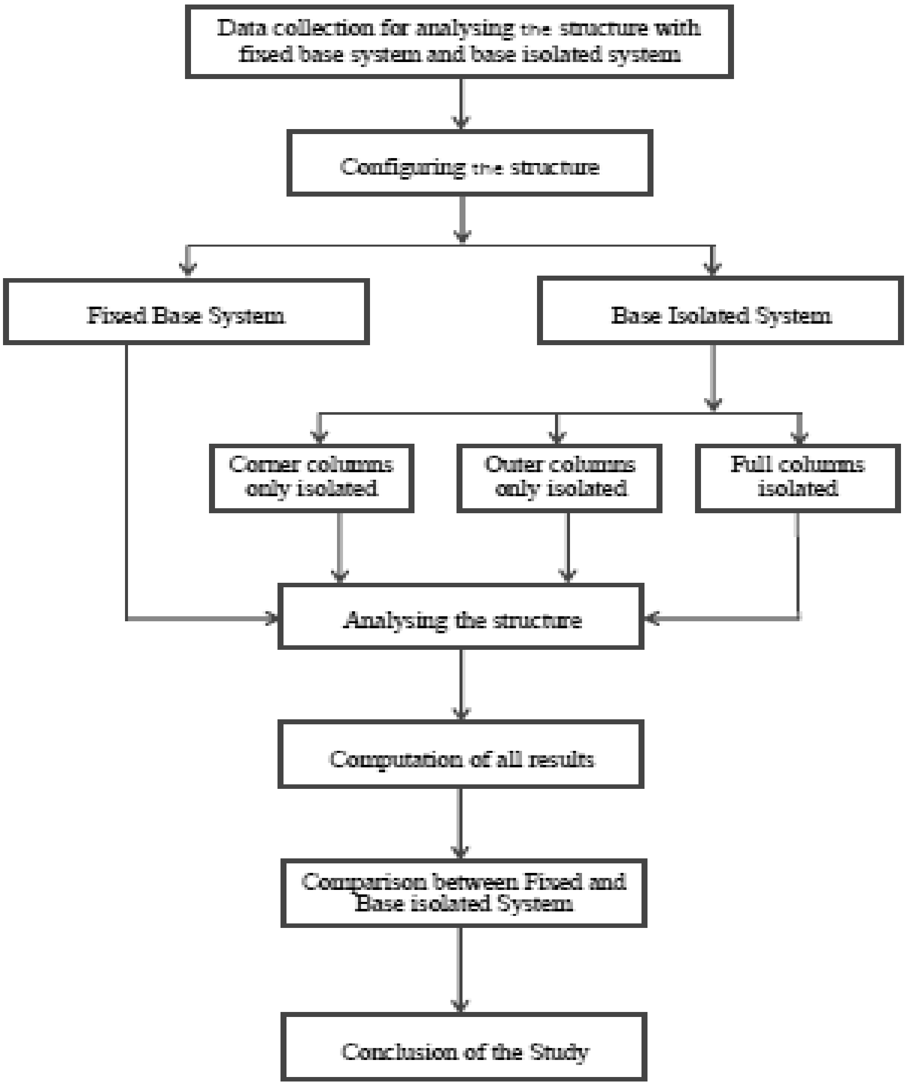

Figure 3: Flow chart of the methodology adopted

V. ANALYSIS AND DESIGN

5.1. Type of structure

The type of structure taken for this research is Hospital building and it is assumed to be located in Bhuj, since it is a high seismic intensity zone that is fall under category of zone V as per Indian code of practice IS1893 (Part 1) -2002.

5.2 Computation of loads

- ❖ The loads consist of gravity loads and dynamic loads. The gravity loads consist of dead load due to the self-weight of the structure, Reinforced concrete slabs, super-imposed dead loads, live load due to the usage of buildings.
- ❖ Loads such as primary loads (DL, LL, WL, EL) are taken and combinations as per IS 1893-Part: 2 – 2002.
- ❖ Self-weight of the slab = 6.0 kN/m2
- ❖ The live load = 5.0kN/ m2
- ❖ Seismic Weight due to Slab = 6.0 kN/m2
- ❖ Seismic weight due to floor LL = 50% x 6.0
  = 3.00 kN/m2

- ❖ Seismic weight due to terrace live load = 25% x 3.0 kN/m2 = 0.75 kN/m2
- ❖ The Design Wind Speed 'Vz' = Vb x k1 xk2x k3 = 51.5 m/s
- ❖ Design Wind Pressure 'pz'= 0.6 x Vz2 =1.59kN/m2

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5.3 Design of members

The structure being a R.C.C. building the size of columns and beams are initially adopted and designed as per IS 456-2000 assumed sizes are given in below

Table 1: Structural Members for All Stories

S. No.	Members	Sizes (mm)
1	Beam	230 x 460
2	Column	300 x 600

VI. ANALYSIS OF MULTI STOREY BUILDING WITH FIXED BASE

The models are analyzed using response spectrum method as per design procedures envisaged is code 1893 (part – 1): 2002 and the output parameters are time period, base shear in x and z direction, displacement in x and z direction are as follows.

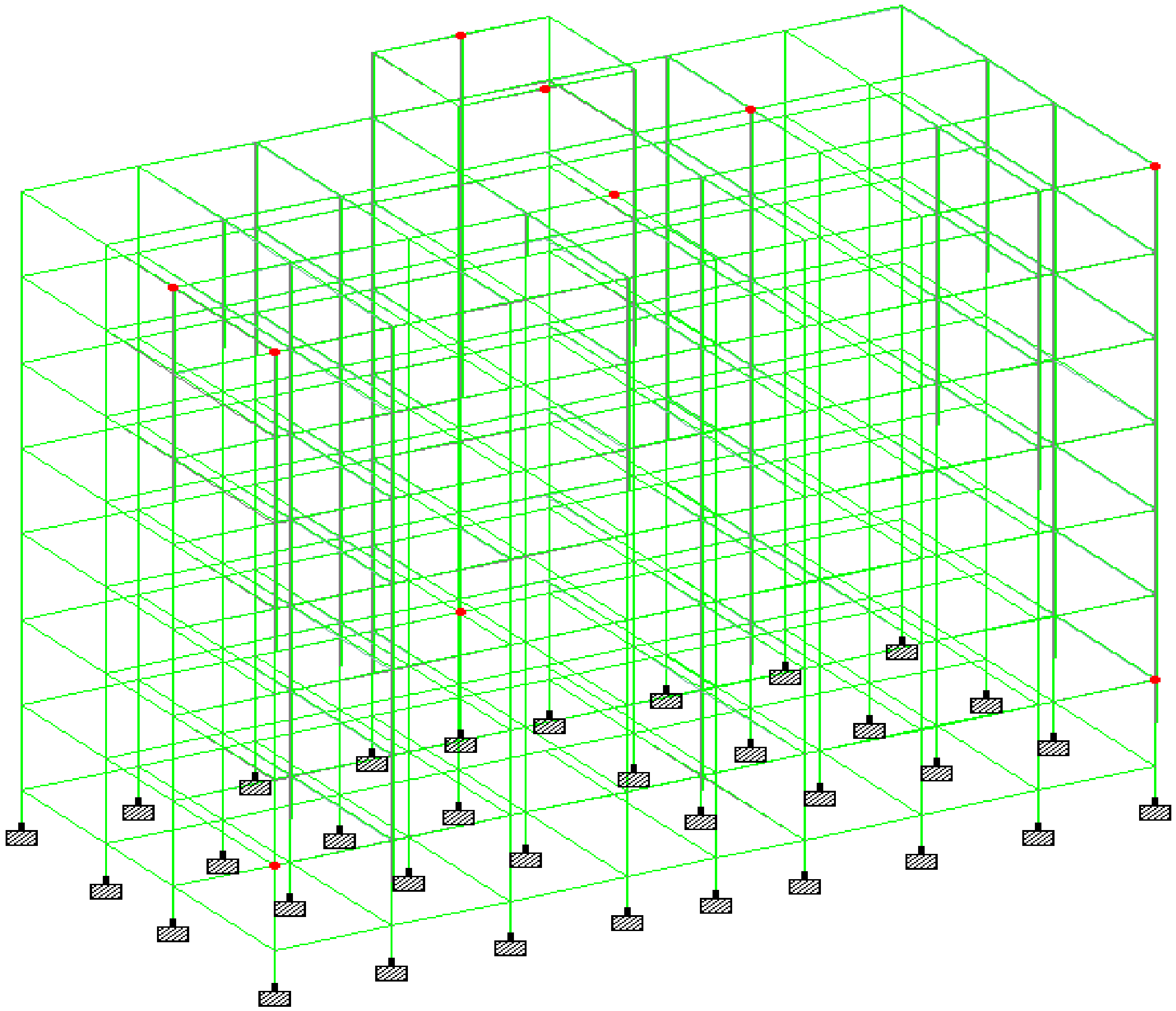

Figure 6: Frame of hospital building with fixed base system

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Table-2: Maximum Displacement for Fixed Base System

Description			Hor	Ver	Hor	Result	Rotational		
	Node	Load Combination	X mm	Y mm	Z mm	mm	rX rad	rY rad	rZ rad
MaxX	313	0.9DL + 1.5EX	**49.54**	-2.88	2.27	49.68	0.00	0.000	0.000
Min X	321	1.5(DL-EX)	**-49.74**	-8.00	-1.11	50.39	0.00	0.000	0.000
Max Y	109	SEISMIC Z-DIR	0.29	3.33	17.50	17.82	0.00	0.000	0.000
Min Y	328	1.5(DL+LL)	-0.08	-15.67	0.81	15.69	0.00	0.000	0.000
Max Z	313	1.5(DL+EZ)	1.26	-5.38	**110.0**	110.17	0.00	0.000	0.000
Min Z	340	0.9DL - 1.5EZ	-1.46	-5.66	**-108.8**	108.99	-0.00	0.000	0.000
Max rX	77	1.5(DL+EZ)	0.27	-1.70	24.94	25.00	0.00	0.000	0.000
Min rX	77	0.9DL - 1.5EZ	-0.35	-1.33	-24.75	24.78	-0.00	0.000	0.000
MaxrY	321	1.5(DL+EZ)	1.19	-5.39	105.73	105.88	0.00	0.000	0.001
Min rY	318	1.5(DL-EZ)	-1.46	-9.16	-105.94	106.35	0.00	0.000	-0.001
MaxrZ	81	1.5(DL+EX)	10.52	-1.69	0.38	10.66	0.00	0.000	0.002
Min rZ	73	1.5(DL-EX)	-10.63	-2.64	-0.37	10.96	0.00	0.000	-0.002
MaxRst	331	1.5(DL+EZ)	0.23	-10.67	110.02	110.54	0.00	0.000	-0.001

The time period of the building are generated and analysed for structure with fixed support for all columns. The time period for whole structure is calculated and the maximum time period are taken and tabulated as shown in below.

Table-3: Maximum time period for fixed base system

MODE	FREQUENCY (CYCLES /SEC)	PERIOD (SEC)	ACCURACY
1	0.416	**2.402**	0.000
2	0.496	2.014	0.000
3	0.622	1.608	3.494
4	1.25	0.800	2.305
5	1.501	0.666	0.000
6	1.907	0.524	9.901
7	2.093	0.477	4.928
8	2.538	0.394	6.708
9	2.907	0.344	0.000

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The displacement of the building are generated and analysed for the above geometrical configuration with fixed support for all columns and the maximum displacement are taken in account as shown.

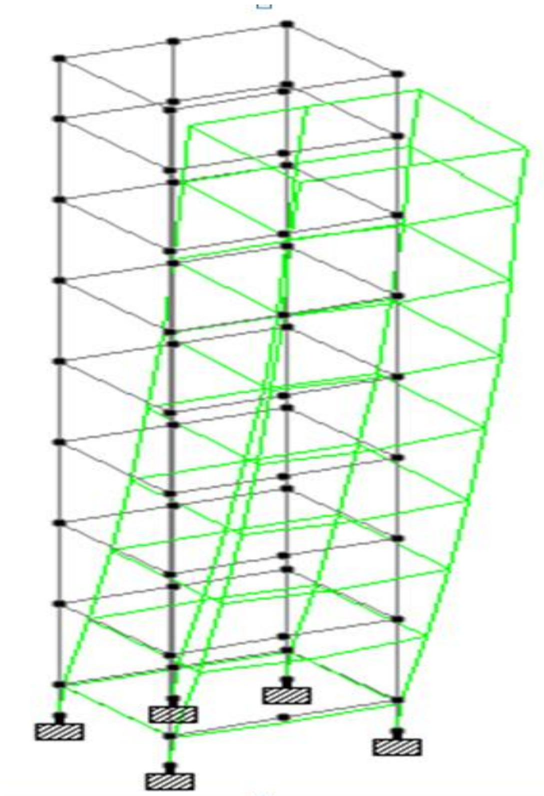

Figure 7: Maximum displacement for fixed base system

Table-4: Analysis results for fixed base system

S. No	Parameter	Units	Base isolated for corner columns
1	Time Period	sec	2.40
2	Base Shear In X Direction	kN	757.00
3	Base Shear In Z Direction	kN	529.01
4	Displacement In X Direction	mm	49.54
5	Displacement In Z Direction	mm	110.04

VII. ANALYSIS OF MULTI STOREY BUILDING WITH BASE ISOLATION

The models are analysed using Response Spectrum method as per design procedures envisaged IS code 1893 (Part – 1): 2002 and the output parameters are Time period, Base shear in X and Z direction, Displacement in X and Z direction are as follows.

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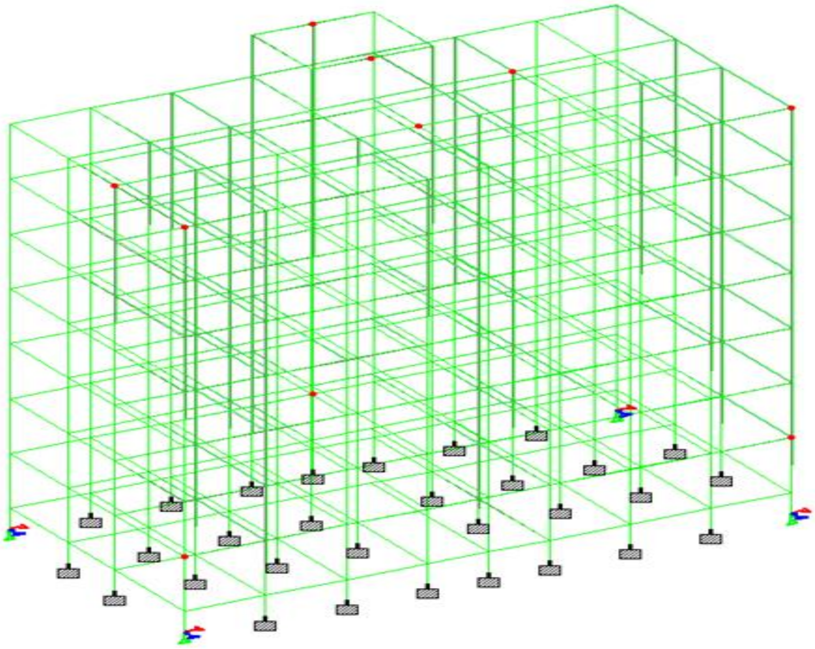

Figure 8: Frame of hospital building with base isolation for corner columns

Table-5: Maximum displacement with base isolation for corner columns

Description			Hor	Ver	Hor	Result	Rotational		
	Node	L/C	X mm	Y mm	Z mm	mm	rX rad	rY rad	rZ rad
Max X	340	1.5(DL+EX)	**57.74**	-6.53	13.77	59.72	-0.001	0.001	0.00
Min X	348	1.5(DL-EX)	**-57.69**	-9.37	-17.3	60.97	-0.002	-0.001	0.00
Max Y	331	SEIS X-DIR	35.58	1.28	10.29	37.06	0.000	0.001	0.00
Min Y	335	1.5(DL+LL)	0.13	-25.38	-2.08	25.46	0.000	0.000	0.00
Max Z	350	1.5(DL+EZ)	1.13	-6.49	118.0	**118.25**	0.004	0.000	0.00
Min Z	350	0.9DL - .5EZ	-1.07	-5.30	-115	**115.95**	-0.002	0.000	0.00
MaxrX	77	1.5(DL+EZ)	0.29	-1.88	25.33	25.40	0.006	0.000	0.00
Min rX	77	0.9DL - .5EZ	-0.29	-1.49	-25.9	25.99	-0.005	0.000	0.00
Max rY	353	0.9D +1.5EX	53.83	-8.82	1.09	54.56	0.000	0.002	0.00
Min rY	353	1.5(DL-EX)	-53.78	-14.87	1.14	55.81	0.001	-0.002	-0.00
MaxrZ	108	1.5(DL+EX)	12.50	-2.36	3.80	13.28	0.000	0.000	0.00
Min rZ	100	1.5(DL-EX)	-12.51	-3.78	-4.42	13.79	-0.001	0.000	-0.00
Max Rst	353	1.5(DL+EZ)	0.44	-14.21	117.9	118.8	0.002	0.000	0.00

The time period of the building are generated and analyzed for the above geometrical configuration and structure with base isolated for corner columns. The time period for whole structure is calculated and the maximum time period are taken and tabulated as shown in below.

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Table-6: Maximum time period with base isolation for corner columns

MODE	FREQUENCY (CYCLES /SEC)	PERIOD (SEC)	ACCURACY
1	0.382	2.614	0.000
2	0.484	2.067	0.000
3	0.562	1.778	0.000
4	1.143	0.874	0.000
5	1.463	0.683	0.000
6	1.717	0.582	0.000
7	1.868	0.535	0.000

Table-7: Analysis results with base isolation for corner columns

S. No	Parameter	Units	Base isolated for corner columns
1	Time Period	sec	**2.61**
2	Base Shear In X Direction	kN	**750.27**
3	Base Shear In Z Direction	kN	**527.13**
4	Displacement In X Direction	mm	**57.74**
5	Displacement In Z Direction	mm	**118.07**

7.2 Base Isolation for Outer Columns

The models are analysed using Response Spectrum method as per design procedures envisaged IS code 1893 (Part – 1): 2002 and the output parameters are Time period, Base shear in X and Z direction, Displacement in X and Z direction are as follows.

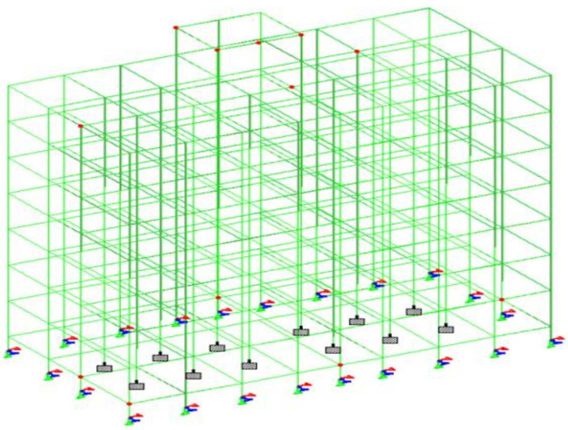

Figure 9: Frame of hospital building with base isolation for outer columns

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Table-8: Maximum displacement with base isolation for outer columns

Description			Hor	Ver	Hor	Result	Rotation		
			X	Y	Z				
	Node	L/C	mm	mm	mm	mm	rX rad	rY rad	rZ rad
Max X	353	0.9DL + 1.5EX	61.24	-8.933	0.855	61.901	0	0.001	0
Min X	354	1.5(DL-EX)	-61.47	-15.32	-2.115	63.387	0	-0.001	0
Max Y	331	SEIS X-DIR	39.55	1.39	3.701	39.752	0	0	0
Min Y	335	1.5(DL+LL)	-0.06	-25.6	-2.07	25.69	0	0	0
Max Z	349	1.5(DL+EZ)	2.35	-8.28	122.32	122.62	0.002	0	0
Min Z	352	0.9DL - 1.5EZ	-0.97	-9.2	-120.6	121.04	-0.001	0	0
Max rX	5	1.5(DL+EZ)	0.8	-1.21	6.17	6.34	0.006	0	0
Min rX	32	1.5(DL-EZ)	-0.92	-2.14	-5.85	6.3	-0.006	0	0
Max rY	28	0.9DL+1.5EZ	0.92	-0.62	19.22	19.25	0.002	0.002	0
Min rY	28	1.5(DL-EZ)	-1.06	-1.82	-19.38	19.49	-0.003	-0.002	0
Max rZ	27	1.5(DL+EX)	2.72	-1.55	2.77	4.18	0.001	0.001	0
Min rZ	19	1.5(DL-EX)	-2.78	-2.69	-3	4.89	0	-0.001	0

The time period of the building are generated and analysed for the above geometrical configuration and structure with base isolated for corner columns. The time period for whole structure is calculated and the maximum time period are taken and tabulated as shown in below.

Table-9: Maximum time period with base isolation for outer columns

MODE	FREQUENCY (CYCLES /SEC)	PERIOD (SEC)	ACCURACY
1	0.382	2.70	0.000
2	0.484	2.067	0.000
3	0.562	1.778	0.000
4	1.143	0.874	0.000

Table-10: Analysis results with base isolation for outer columns

S. No	Parameter	Units	Base isolated for outer columns
1	Time Period	sec	**2.70**
2	Base Shear In X Direction	kN	**734.90**
3	Base Shear In Z Direction	kN	**521.57**
4	Displacement In X Direction	mm	**61.25**
5	Displacement In Z Direction	mm	**122.32**

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7.3 Base Isolation for All Columns

The models are analysed using Response Spectrum method as per design procedures envisaged IS code 1893 (Part – 1): 2002 and the output parameters are Time period, Base shear in X and Z direction, Displacement in X and Z direction are as follows

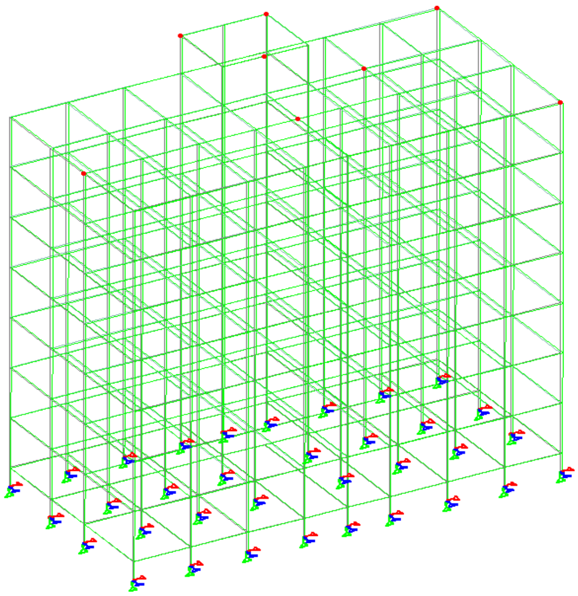

Figure 10: Frame of hospital building with base isolation for all columns

Table-11: Maximum displacement with base isolation for all columns

Description			Hor	Ver	Hor	Result	Rotational		
	Node	L/C	X mm	Y mm	Z mm	mm	rX rad	rY rad	rZ rad
Max X	351	1.5(DL+EX)	**151.47**	-9.84	49.38	159.6	0.002	0.014	0.000
Min X	349	0.9DL - 1.5EX	**-151.43**	-6.37	-37.75	156.1	0.001	-0.014	0.000
Max Y	331	SEIS X-DIR	99.26	1.16	140.28	171.8	0.000	0.010	0.000
Min Y	335	1.5(DL+LL)	0.13	-27.2	-2.04	27.37	0.000	0.000	0.000
Max Z	321	0.9DL +1.5EX	150.06	-3.39	**218.25**	264.8	0.001	0.014	0.001
Min Z	348	1.5(DL-EX)	-148.12	-9.48	**-220.9**	266.1	-0.002	-0.014	0.000
Max rX	41	1.5(DL+EZ)	2.82	-0.69	81.67	81.72	0.013	0.000	0.000
Min rX	41	0.9DL - 1.5EZ	-2.83	-0.53	-82.14	82.19	-0.013	0.000	0.000
Max rY	353	0.9DL + .5EX	151.41	-9.79	5.50	151.8	0.000	0.014	0.001
Min rY	353	1.5(DL-EX)	-151.37	-16.3	-2.93	152.2	0.001	-0.014	-0.00
Max rZ	63	1.5(DL+EX)	96.91	-0.92	115.12	150.4	0.007	0.009	0.004
Min rZ	46	1.5(DL-EX)	-96.55	-1.40	-112.3	148.1	-0.006	-0.009	-0.00
Max Rst	321	1.5(DL-EX)	-150.14	-8.98	-220.9	267.2	0.001	-0.014	0.000

The time period of the building are generated and analysed for the above geometrical configuration and structure with base isolated for corner columns. The time period for whole structure is calculated and the maximum time period are taken and tabulated as shown in below.

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Table-12: Maximum time period with base isolation for outer columns

MODE	FREQUENCY (CYCLES /SEC)	PERIOD (SEC)	ACCURACY
1	0.252	**3.973**	0.000
2	0.287	3.482	0.000
3	0.292	3.429	0.000
4	0.878	1.139	0.000
5	1.083	0.923	0.000
6	1.199	0.833	0.000

Table-13: Analysis results with base isolation for corner columns

S. No	Parameter	Units	Fully base isolated system
1	Time Period	sec	**3.97**
2	Base Shear In X Direction	kN	**332.52**
3	Base Shear In Z Direction	kN	**391.31**
4	Displacement In X Direction	mm	**151.47**
5	Displacement In Z Direction	mm	**218.25**

VIII. RESULTS AND DETAILING OF MEMBERS

8.1 Time Period of the Structure

It is observed from the chart time period is 2.4sec for fixed base system, 2.61sec for corners only isolated, 2.70sec for outer only isolated and 3.97sec for fully isolated columns. Hence it is quite apparent that base of the building has a major role, in time period the impact of ground motion absorbed significantly and time period extended from fixed base system to base isolation system as shown.

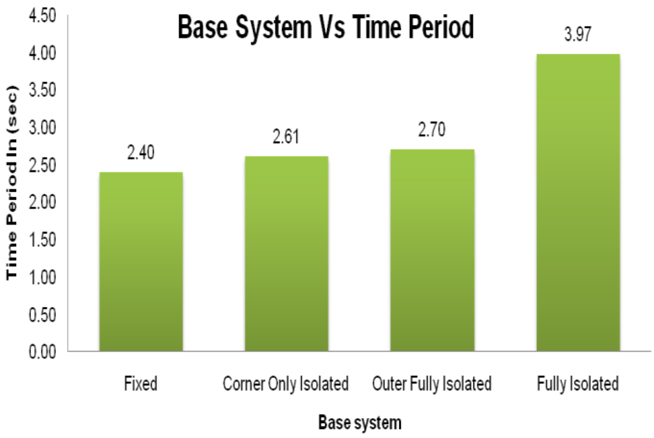

Figure 11 Base Time Vs Time Period

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8.2 Base Shear of the Structure

It is observed from the chart base shear is 751.68 kn for fixed base system, 750.27kn for corners only isolated, 734.90 kn for outer only isolated and 332.52 kn for fully isolated columns. Similarly for z direction 527.78kn for fixed base system, 527.13knfor corners only isolated, 521.57 kn for outer only isolated and 391.31 kn for fully isolated columns. From the observed results that the base shear get reduces from fixed system to base isolated system as shown.

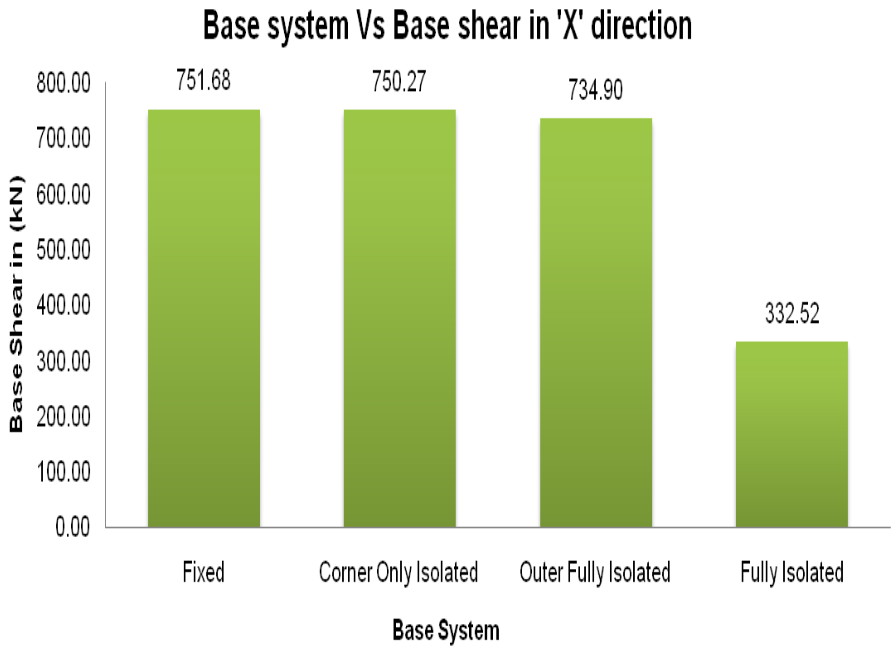

Figure 12 Base system Vs Base shear in 'X' direction

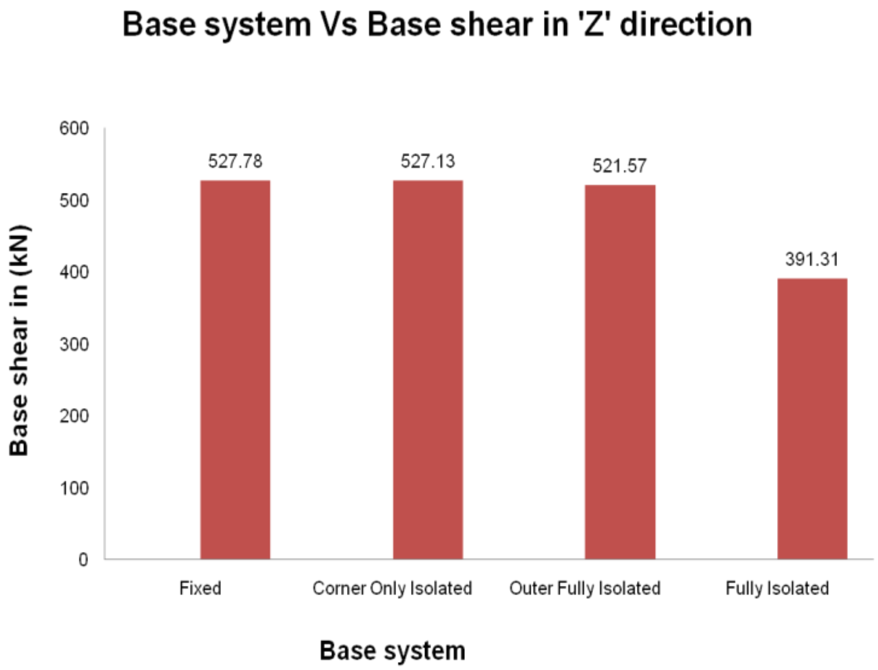

Figure 13 Base system Vs Base shear in 'Z' direction

8.3 Displacement of the Structure

It is observed from the chart displacement in 'X' directions are 49.54mm for fixed base system, 57.74mmfor corners

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only isolated, 61.24mm for outer only isolated and 151.47mmfor fully isolated columns. Similarly in 'Z' directions 110.04mm for fixed base system, 118.07mmfor corners only isolated, 122.32mm for outer only isolated and 218.25mmfor fully isolated columns.

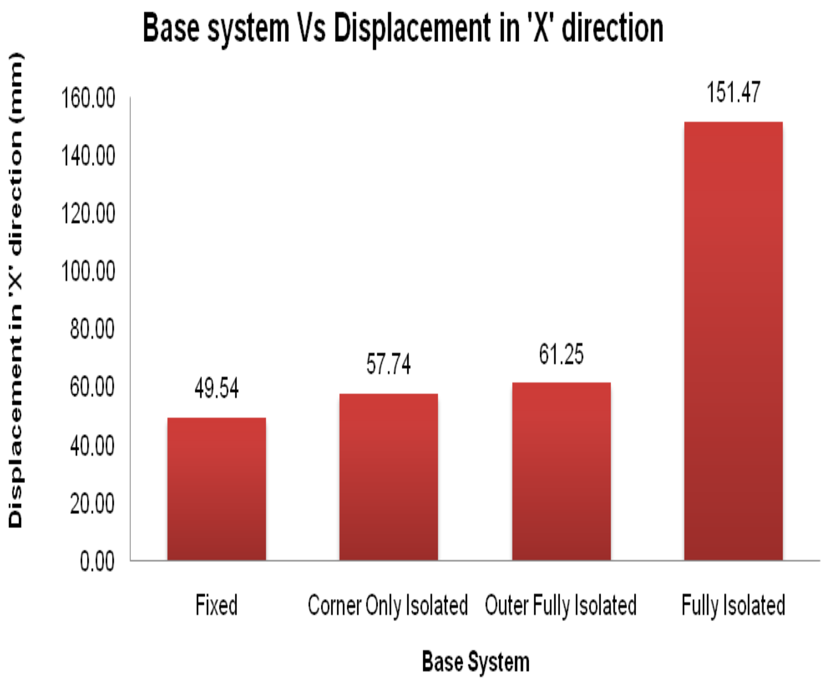

Figure 14 Base systems Vs Displacement in 'X' direction

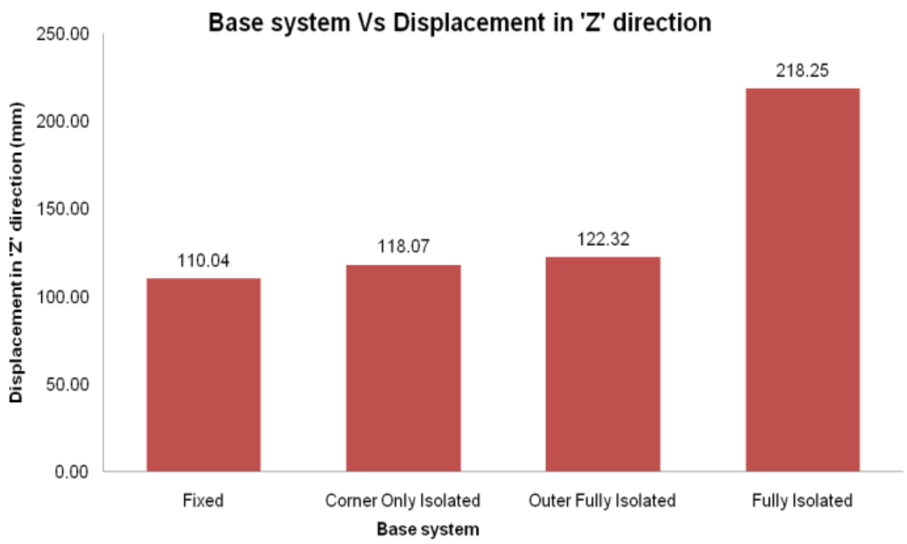

Figure 15 Base system Vs Displacement in 'Z' direction

8.4 Detailing of Structural Members

Detailing of the structural member has been done with results from the analysis and design of the structure created and with reference to ductility detailing code of IS 13920-1993.

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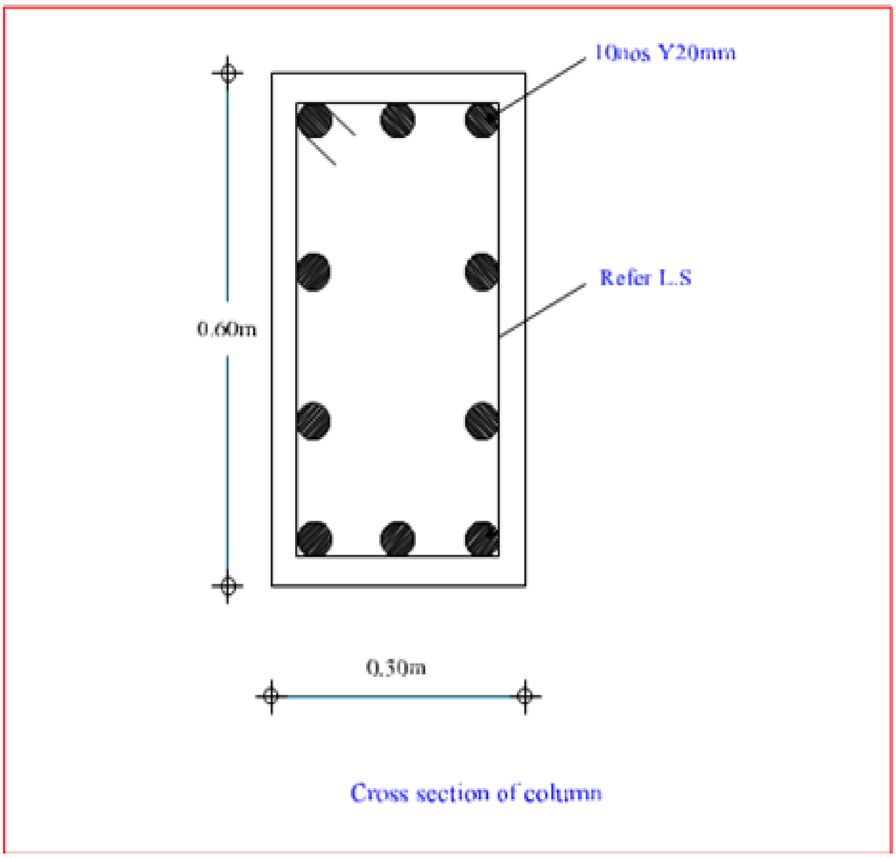

Figure 16 Cross section of column

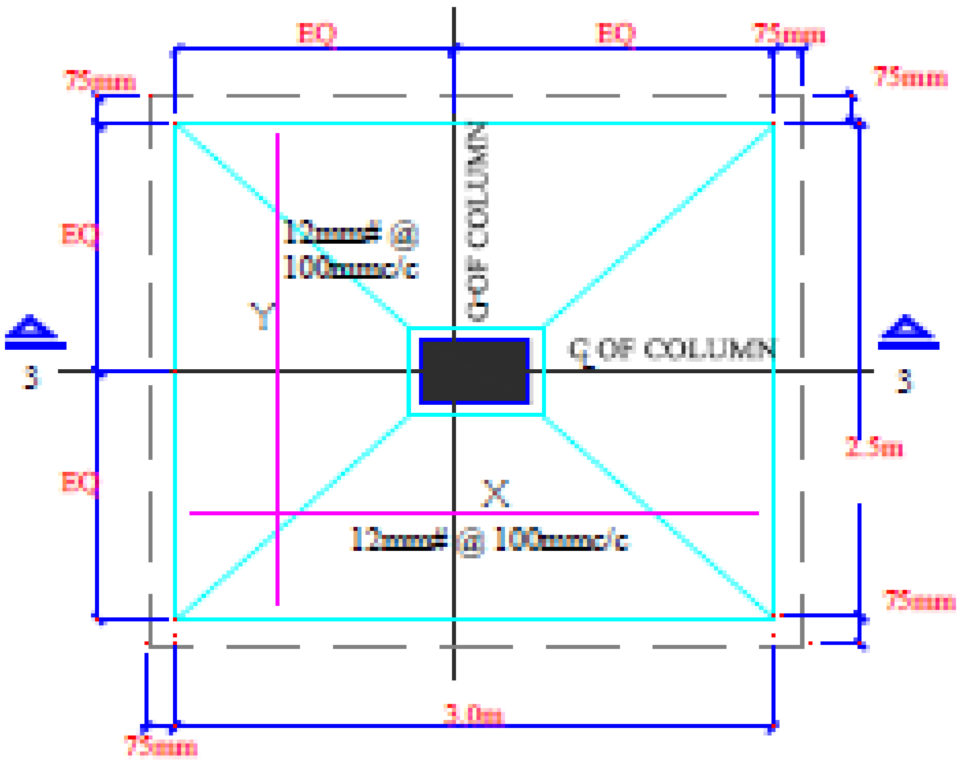

Figure 17 Plan of footing

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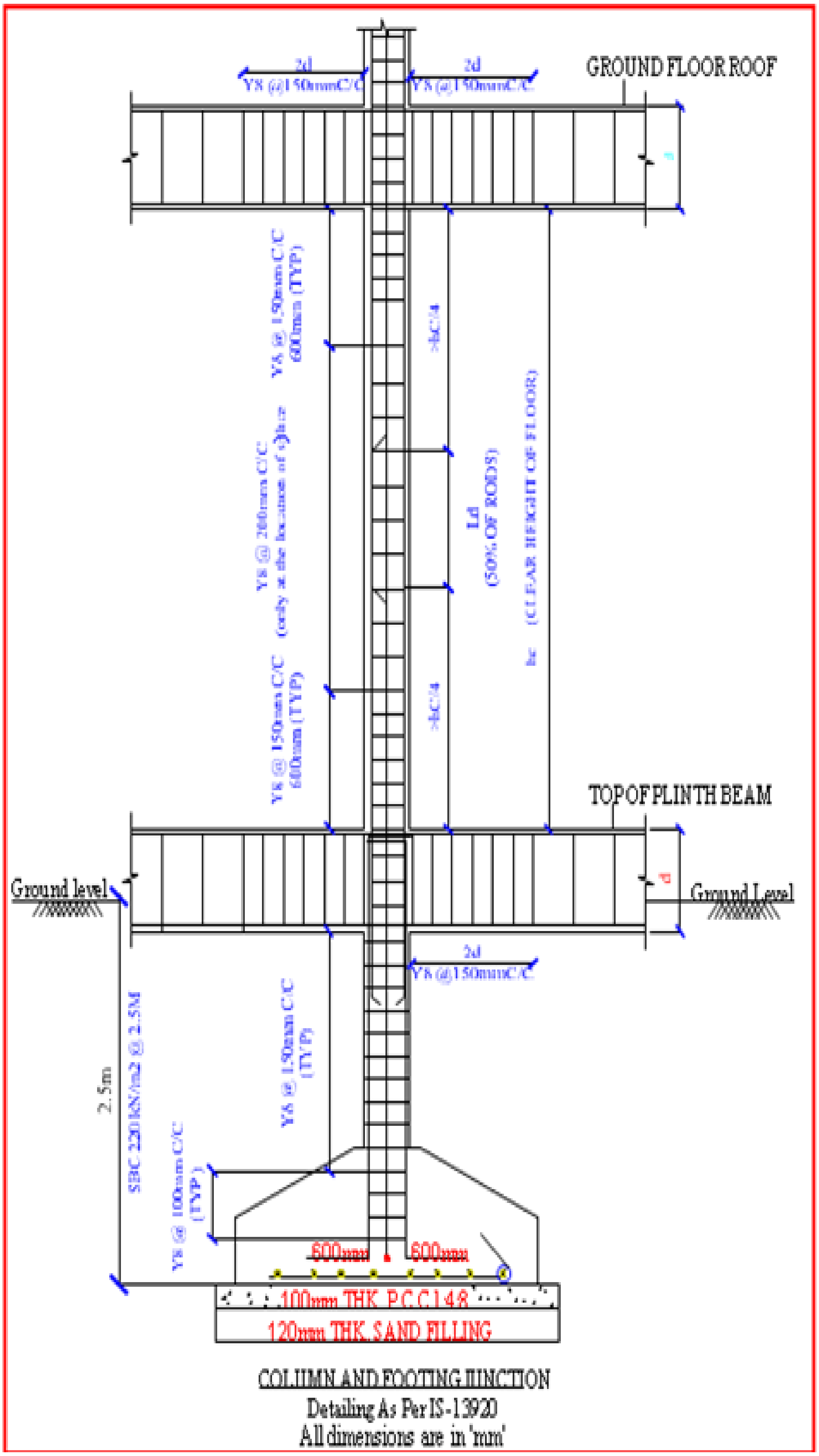

Figure 18 Longitudinal section of column

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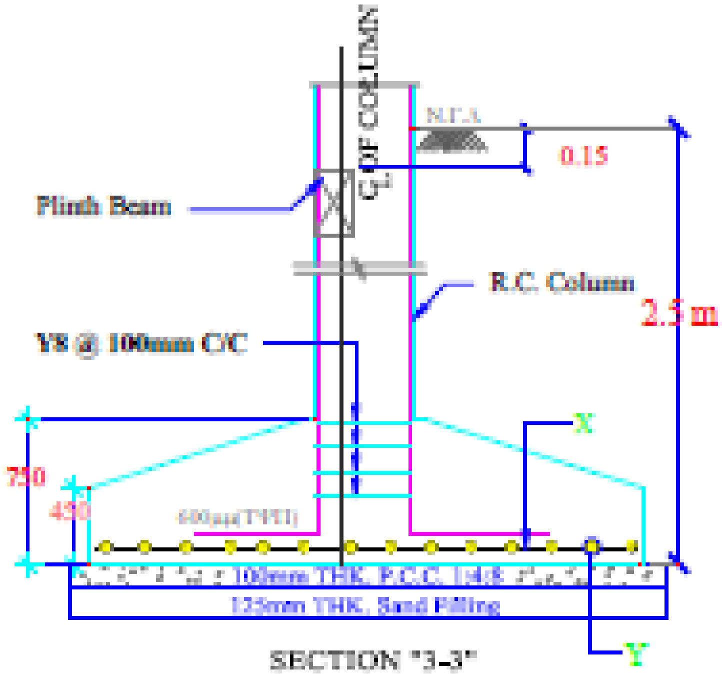

Figure 19 Cross section of footing

IX. CONCLUSIONS

In fixed base building time period increases when the storey height increases this implies that increased dead load and live load of multi storey building absorbs the considerable ground motion for the fixed base building. The base shear decreases non-linearly when the height of building increases. The displacement increases proportionately when the height of building increases.

In base isolated building the time period increases for base isolated building nearly two times has that of rigid base building of same height with all columns isolated and 1.5 times for outer columns isolated and 1.25 times for corner columns isolated.

The base shear decreases 30-50% for the base isolated buildings when compared with same size and height of fixed base building. The displacement for the base isolated building is 50% more than that of rigid base multi storey building.

It is suggested that building which has more importance are recommended to design structure with base isolation to reduce the effect of earth quake in the structure. Further research is required for preparation of draft code or design aid in the near future is indispensible, as there is neither design aid nor standard code for a seismic design of multi storey building using base isolators in India.

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