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A Cost Optimization Study of Multi Story Building under Different Indian Zones

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Abstract: Even after designing structures for different level of seismic forces, those may or may not perform to the level that they were designed for. It is very important to have practice of earthquake-resistant design, in order to adequately predict the behavior of a real building during a severe seismic motion that it will have to withstand without collapse, at least once during its service life. Civil engineering tends to achieve acceptable performance of structures during seismic excitation, with the robust design. For example, if a building is designed for Design Basis Earthquake (DBE) according to Bureau of Indian Standards, the building may not perform even for DBE. It is due to the safety provided by existing codes based on engineer's judgment and their past experience, which incorporate the randomness in data. It is the responsibility of engineer to deal with such uncertain information. Consequences can be severe for the upcoming events, since performance of the structure cannot be predicted from experience.

In the present study seismic behavior of 12 storied RC framed building with typical plan has been studied. A twelve storey RC framed building designed for earthquake resistant design located in various zones, soils and with different response reduction factor. The designed building performance is compared, in terms of structural economy, fundamental period of vibration, pattern of displacements variation and hinge formation pattern. The seismic performance of building is investigated using linear static analysis and non-linear time history analysis.

In the present work, these issues were studied in detail by evaluating the performance of chosen typical building configuration using nonlinear time history analysis. Even though this kind of studies existed in literature, till date no study concentrate on the comparison of variation of cost due to different design levels and their performance. Objective of seismic design of buildings is to ensure the following multilevel performance criteria: Safety of the life of users and general public in the event of Maximum Considered Earthquake (MCE), Building suffers minor nonstructural damage and no structural damage under less severe but more frequent earthquake, and buildings shall remain operational without any structural and nonstructural damage for frequent earthquake.

I. INTRODUCTION

Civil engineering tends to achieve acceptable performance of structures during seismic excitation, with the robust design. Even after designing structures for different level of seismic forces, those may or may not perform to the level that they were designed for. For example, if a building is designed for DBE according to Bureau of Indian Standards, the building may not perform even for DBE. It is due to the safety provided by existing codes based on engineer's judgment and their past experience, which incorporate the randomness in data. It is the responsibility of engineer to deal with such uncertain information.

During an earthquake, the ground accelerations cause structures to vibrate and induce inertial forces in them. Earthquakes in the past have shown the consequences of neglecting the seismic forces in design of structures. Hence, structures need to be suitably designed and detailed to ensure stability, strength and serviceability with acceptable levels of safety to resist seismic forces. The resultant inertial force at any level depends on the mass at the floor level and also on the height above the foundation. The distribution of the inertial force along the building height is parabolic with maximum value at the top floor. In regions of high seismic intensity, it is desirable to minimize the weights at the various floor levels, especially at the roof and upper storey. In order to study the seismic performance of buildings which are designed for various zones for different soil type conditions with different ductile detailing are designed for bi-directional earthquake using Response Spectrum Analysis and Modal Analysis. The Fundamental Period and Base Shear are basic factors according to Indian code.

The concept of earthquake- resistant design is that the structure should be designed to resist the forces, which may occur at least once during the life of a structure due to moderate earthquake that will cause minor damage. Such an earthquake is characterized as DBE. The chances of exceedance of this earthquake are 10% in 50 years. In case of severe earthquake that may occur once in lifetime of the structure, a controlled structural damage is accepted but total collapse is avoided. Such an earthquake is characterized

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as MCE with a return period of 2500 years and 2% as the probability of occurrence. In the present work, these issues were studied in detail by evaluating the performance of chosen typical building configuration using nonlinear time history analysis. Even though this kind of studies existed in literature, till date no study concentrate on the comparison of variation of cost due to different design levels and their performance. Objective of seismic design of building is to ensure the following multilevel performance criteria: Safety of the life of users and general public in the event of MCE, building suffers minor nonstructural damage and no structural damage under less severe but more frequent earthquake, and buildings shall remain operational without any structural and nonstructural damage for frequent earthquake.

A. Scope of Present Work

The present study concentrates on the analytical study of performance evaluation of R.C. multistory building. In this study seismic behavior of 12 storied RC framed building with typical plan has been studied. A 12 storey RC framed building designed for earthquake- resistant design located in various zones, soils and with different response reduction factor. The designed building performance is compared, in terms of structural economy, fundamental period of vibration, pattern of displacements variation and hinge formation pattern. The seismic performance of building is investigated using linear static analysis and non-linear time history analysis in order to investigate and characterize performance levels of building (e.g. IO-Immediate occupancy, LS-Life safety, CP-Collapse prevention) in terms of energy dissipation.

II. LITERATURE REVIEW

Geeta Mehta, Bidhan Sharma and Anuj Kumar,Optimization of structural cost can be achieved by optimizing the size of structural components as the cost of the material required in structural system for a multi-storeyed building makes 40-50 % of the overall cost of a typical RCC structure. Material required for construction varies with change in size of members. In the present study optimizing the size of structural components using ETABS has been achieved. The analysis and design has been done for G+9, G+11, G+13 and G+15 RCC structure for seismic zone V. The loading and all other relevant considerations are made for office building. For the analysis and design of a RCC structure, there are much software available in the market such as STAAD-Pro, ETABS, SAP, ANSYS etc. Among all the available software, ETABS has many advantages over its counterparts such as accurate analysis result, optimized design output, better user interface and availability of more number of Indian and International codes. Based on the output obtained from the detailed analysis, the optimized size of structural components for G+9, G+11, G+13 and G+15 RCC structure for seismic zone V are obtained. After getting the optimized size of structural components the cost of materials has been calculated and quantity wise cost of various structures has been given. It can help to forecast the project cost of RCC structures for various storeys to be designed in zone V with optimized size of structural components.

Renavikar Aniket V, The project involves Analysis of a residential building with steel-concrete composite and R.C.C. construction. The proposed structure is a four multistoried buildings of G+9, G+12, G+15, G+18, with 3.0m as the height of each floor. The overall plan dimension of the building is 15m x 9m. The analysis and involves the load calculation, analyzing it by 2D modeling using software STAAD-Pro 2007. Analysis has been done for various load combinations as per the Indian Standard Code of Practice. The project also involves analysis of an equivalent R.C.C. structure so that a cost comparison can be made between a steel-concrete composite structure and an equivalent R.C.C. structure.

Sangeetha k, Vinod Shavare, G H Basavaraj, Nowadays tall building development is rapidly increasing. In the present study an attempt is made to evaluate deflection control of 30 story commercial building using E-tabs software. Different structural framing systems are applied to know the building performances in Zone III. Response spectrum method is used due to its innate simplicity of computation. Models are prepared with bare frame having central core, braced frame, shear wall frame system in order to get effective lateral load resisting system. Though the structural cost of tall building is around 20 to 25% of total cost, optimizing the design by repetitive design process, considerable savings could be achieved. Results includes time period, maximum story deflection, maximum story drift, base shear absorption, Stability against overturning moment, for different framing system in zone III and are presented in tabular form.

M. S. Aainawala , Dr. P. S. Pajgade From the past records of earthquake, there is increase in the demand of earthquake resisting building which can be fulfilled by providing the shear wall systems in the buildings. Static Analysis is performed for regular buildings up to 90m height in zone II and III, Dynamic Analysis should be performed for regular buildings in zone IV and V above 40 m. Reinforced cement concrete (RCC) framed structures combined with shear walls has been widely used to resist lateral forces during earthquakes in tall buildings. Shear walls are generally provided for full height of the frame. Shear wall systems are one of the most commonly used lateral-load resisting systems in high-rise buildings. Shear walls have very high in-plane stiffness and strength, which can be used to simultaneously resist large horizontal loads and support gravity loads, making them quite advantageous in many structural engineering applications. An earthquake load is applied to a building for G+12, G+25, G+38 located in zone II, zone III, zone IV and zone V for different cases of shear wall position. An analysis is performed using ETAB v 9.0.7 software. Lateral displacement and story drift are calculated in all the cases. It was observed that Multistoried R.C.C. Buildings with shear wall is economical as compared to without shear wall.

Shubham R. Kasat From the past records of earthquake, there is increase in the demand of earthquake resisting building which can be fulfilled by providing the shear wall systems in the buildings. For achieving economy in reinforced concrete building structures, design of critical section is carefully done to get reasonable concrete sizes and optimum steel consumption in members. In the present study, an attempt has been made to model 18 storey building with and without shear walls by static analysis method for earthquake zone III. E-TAB v9.2.0 software is used for the analysis. The objective of this study is to assess the comparative seismic performance of buildings in terms of displacement, storey drift, and base shear. Buildings with shear wall are economical as compared to without shear wall.

III. METHODOLOGY

In the present study a 12 storey RC framed building with a typical plan described below has been considered. To compare the seismic performance and structural economy, the building is analysed and considered for various different situations.

A. General points are worth noting regarding the building

The Length of the building is 25 m and Width of the building is 14 m. Floor to floor height considered is 3.1 m. The height of 12 storey RC frame building measured from the ground level is 37.2 m. The depth of the foundation below the ground level is 1.2 m.

All external walls are 250 mm thick and internal walls are 150 mm thick.

All floor diaphragms are considered to be rigid.

Centre to centre dimension is followed for analysis and design, and the effect of finite size joint width is not considered.

Seismic loads are considered to act in the horizontal direction (along either of the two principle directions) and not in the vertical direction.

Stiffness of infill walls is not considered in the seismic analysis of the building.

Deductions for opening is not done while calculating the seismic weight of building.

g) Wind load is not considered.

Building is considered to be fixed at the base level in all the cases.

B. Buildings Considered in the parametric study

The Building is analysed for different varying parameters such as type of soil, ductility factor, Response Reduction Factor, Zone factor. With the combination of the above various parameters the building is analysed for following situations.

Building situated in Zone 4, Hard Soil (Type 1) and designed for Ductility

Building situated in Zone 4, Medium Soil (Type 2) and designed for Ductility

Building situated in Zone 4, Soft Soil (Type 3) and designed for Ductility

Building situated in Zone 4, Hard Soil (Type 1) and not designed for Ductility

Building situated in Zone 4, Medium Soil (Type 2) and not designed for Ductility

Building situated in Zone 4, Soft Soil (Type 3) and not designed for Ductility

Building situated in Zone 5, Hard Soil (Type 1) and designed for Ductility

Building situated in Zone 5, Medium Soil (Type 2) and designed for Ductility

Building situated in Zone 5, Soft Soil (Type 3) and designed for Ductility

Building situated in Zone 5, Hard Soil (Type 1) and not designed for Ductility

Building situated in Zone 5, Medium Soil (Type 2) and not designed for Ductility

Building situated in Zone 5, Soft Soil (Type 3) and not designed for Ductility

Buildings plan and elevation are shown in Fig. 3.1-3.3. The plan is same for all the buildings.

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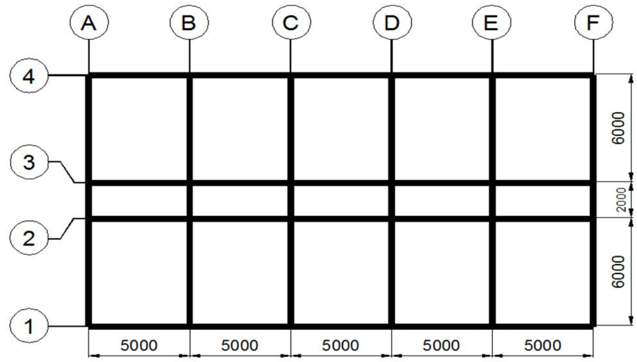

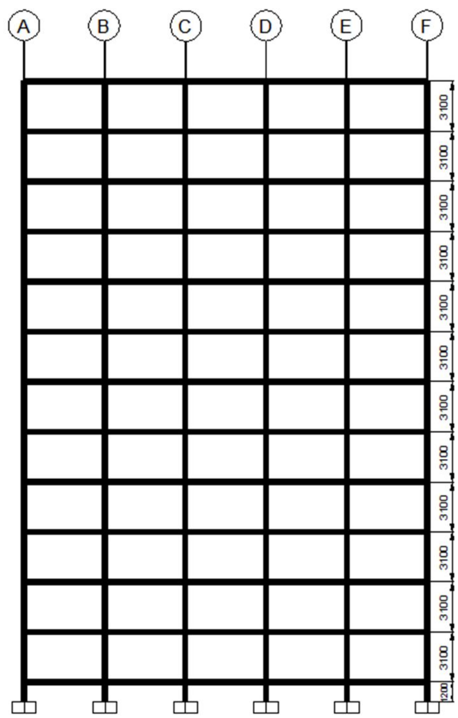

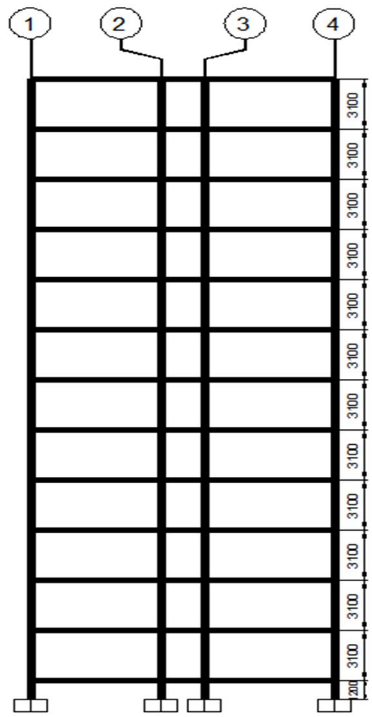

Fig:1 Elevation in longitudenal Plane

Fig:2 Elevation in lateral Plane

C. Material Properties

Grade of Concrete	M30
Characteristic Compressive strength of Concrete	30 *N/mm*^{2}
Modulus of Elasticity of concrete	2.5E10 *N/mm*^{2}
Grade of Steel	Fe 415
Yield Strength of steel	415 *N/mm*^{2}
Minimum Tensile Stress of steel	415 *N/mm*^{2}

D. Computer Modeling of Buildings

The buildings are modelled as 3D space frame as shown in figure using software SAP 2000 V14.0.0. For simulation of behaviour under gravity and seismic loading the beams and columns have been modelled using frame elements with six degree of freedom at

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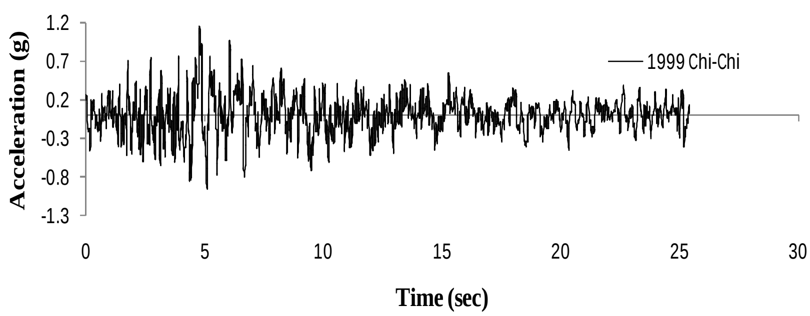
each node. To consider the effect of slab rigid diaphragm constraint has been provided. The joints are considered as rigid. For this purpose rigidity body constraint has been provided at each node. The foundation of building has been considered as fixed support. The loads of the slab have been distributed according to yield line pattern of distribution as specified in BIS-2002. Analysis of model has done based on cracked sections as described in (ASCE-41 2006). The floor diaphragms are assumed to be rigid and centre-line dimensions are followed for analysis and design. The beams are assumed to be rectangular so as to distribute larger moments in columns. By Rayleigh Damping method, damping considered as 5% for first two modes in corresponding direction. Auto P-M-M hinges to each end of the moment frame columns. Auto M3 hinges to each end of the moment frame beams were assigned as described in (ASCE-41 2006) for non-linear modelling of frame members.

E. Ground motion data considered in study

For numerical analysis, earthquake record listed in Table 3.1 was taken from the Strong Motion Database of PEERC (Pacific Earthquake Engineering Research Centre. The earthquake has peak ground acceleration greater than 0.36g and its acceleration time history details have been shown in Table 3.1 and the plotted graph of Earthquake have been shown in Figure

Table:1 Earthquake record used in the analysis

Event	Magnitude	PGA [g]	PGV	PGD [cm]
1999 Chi-	7.6	0.372	38.331	38.331



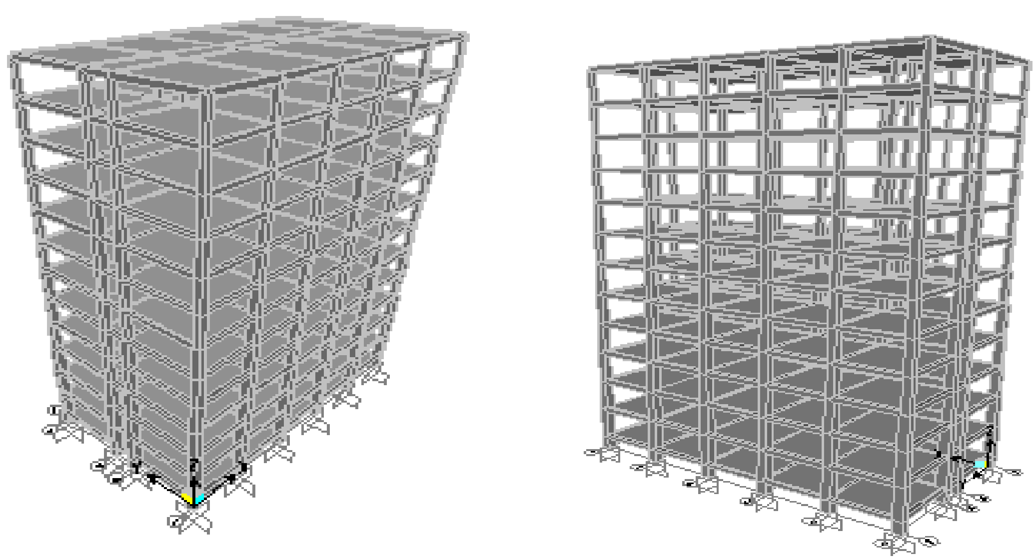


Fig:3 3D-Modelling of 12 storey RCC Building

F. Loadings considered in the parametric study

Primary loads acting on the building have been considered as dead load, Live load and earthquake load. The dead load and live load has been applied in Gravity direction and earthquake load has been applied in lateral direction.

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G. Dead loads & live loads

Dead loads are basically due to self weight of structure, as well the weight of floor slab, beams, columns, walls, floor finish and live loads.

G. Loading Data

Weight of floor finish	1 kN/m^2
Weight of roof treatment	1.5 kN/m^2
Live load on floors	3 kN/m^2
Live load on roof	1.5 kN/m^2
Unit weight of RCC	25 kN/m^3
Unit weight of masonry infill	20 kN/m^3

IV. RESULTS AND DISCUSSION

A. Performance Evaluation and Structural Economy

Building is analyzed for different varying parameters such as Type of soil, Ductility factors, Response Reduction Factor, Zone factor. With the Combination of the above various parameters, the building is analyzed and designed. To compare the seismic performance of buildings and structural economy evaluation of buildings the structural column, beams sizes are kept uniformity for DBE and MCE. To compare the structural economy reinforcement in columns is maintained in the range of 1-2% and for beams reinforcement is maintained in the range of 1-1.5%.

B. Linear Dynamic response of RC Buildings

To compare the linear dynamic response the buildings are analyzed and designed for linear static analysis. Step by step procedure to perform linear static analysis is as follows:

A three dimensional computer model must be created in which all significant structural elements are modeled. This can be used for static and dynamic loads.

The three dimensional mode shapes should repeatedly be evaluated during the design of the structure.

The direction of the base reaction of the mode shape associated with the first fundamental frequency of the system is used to define the principal directions of the three dimensional structure.

Using SQRS method, the "dynamic base shears" are calculated in each principal direction.

The "design base shear" is obtained from the analysis model after applying base shear corrections. The lateral loads at various floor levels are computed from the design base shear.

Dynamic displacements and member forces are calculated.

Structural cost is estimated for optimized member sizes.

C. Discussion of results

In present study a 12 storied RC framed building was designed and analyzed for various parameters such as type of soil, zone factor, ductility factors relating response reduction factor and so 24 different types of buildings are developed accordingly. From achieved 24 buildings, 12 are designed for DBE and other 12 are designed for MCE. The results are discussed based on Fundamental Time period, linear static displacements, structural economy, base shear and Performance point for all the 24 types of buildings.

Table:2 One of the Fundamental Modal Time Period in Principal Directions for DBE

S N	TYPE OF BUILDING	TIME PERIOD											
		MO DE	MO DE	MO DE	MO DE	MO DE	MO DE	MO DE	MO DE	MO DE	MO DE	MO DE	MO DE
1	DBE Z 4 S 1	1.81	1.77	1.73	0.65	0.64	0.64	0.40	0.39	0.39	0.29	0.29	0.29
2	DBE Z 4 S 2	1.81	1.77	1.73	0.65	0.64	0.64	0.40	0.39	0.39	0.29	0.29	0.29
3	DBE Z 4 S 3	1.81	1.77	1.73	0.65	0.64	0.64	0.40	0.39	0.39	0.29	0.29	0.29
4	DBE Z 5 S 1	1.81	1.77	1.73	0.65	0.64	0.64	0.40	0.39	0.39	0.29	0.29	0.29
5	DBE Z 5 S 2	1.81	1.77	1.73	0.65	0.64	0.64	0.40	0.39	0.39	0.29	0.29	0.29
6	DBE Z 5 S 3	1.81	1.77	1.73	0.65	0.64	0.64	0.40	0.39	0.39	0.29	0.29	0.29
7	DBE Z 4 S 1	1.90	1.85	1.82	0.74	0.73	0.73	0.45	0.44	0.44	0.31	0.31	0.31

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8	DBE Z 4 S 2	1.90	1.85	1.82	0.74	0.73	0.73	0.45	0.44	0.44	0.31	0.31	0.31
9	DBE Z 4 S 3	1.90	1.85	1.82	0.74	0.73	0.73	0.45	0.44	0.44	0.31	0.31	0.31
10	DBE Z 5 S 1	1.90	1.85	1.82	0.74	0.73	0.73	0.45	0.44	0.44	0.31	0.31	0.31
11	DBE Z 5 S 2	1.90	1.85	1.82	0.74	0.73	0.73	0.45	0.44	0.44	0.31	0.31	0.31
12	DBE Z 5 S 3	1.90	1.85	1.82	0.74	0.73	0.73	0.45	0.44	0.44	0.31	0.31	0.31

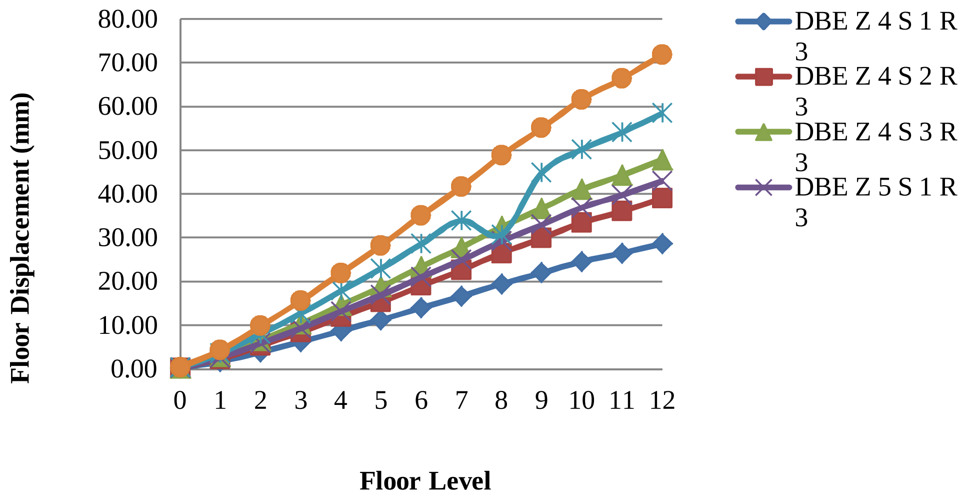

Fig: 4 Floor Displacements of OMRF building for design basis earthquake excitation along X-Direction

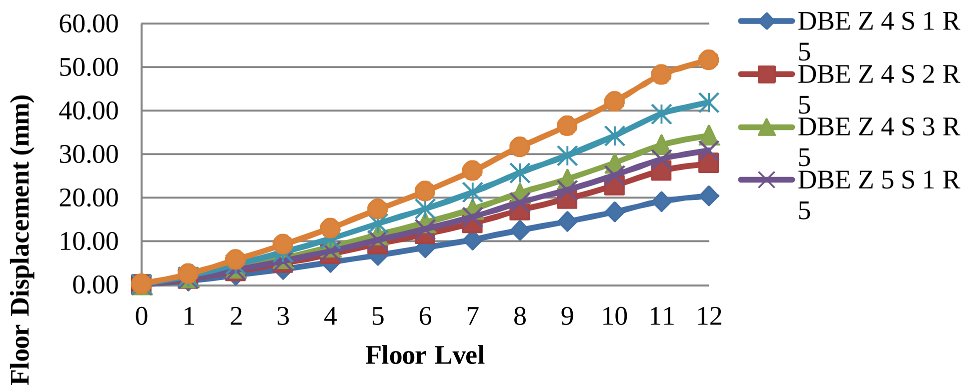

Fig:5 Floor Displacements of SMRF building for design basis earthquake excitation along X-Direction

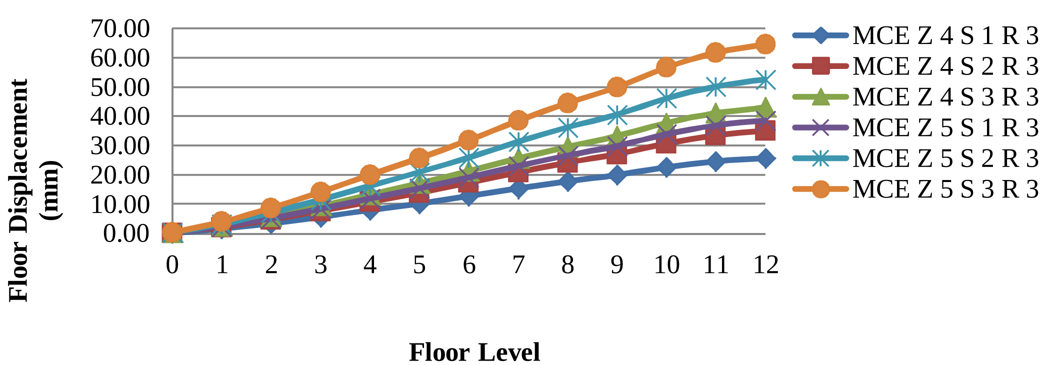

Fig:6 Floor Displacements of OMRF building for maximum considered earthquake excitation along X-Direction

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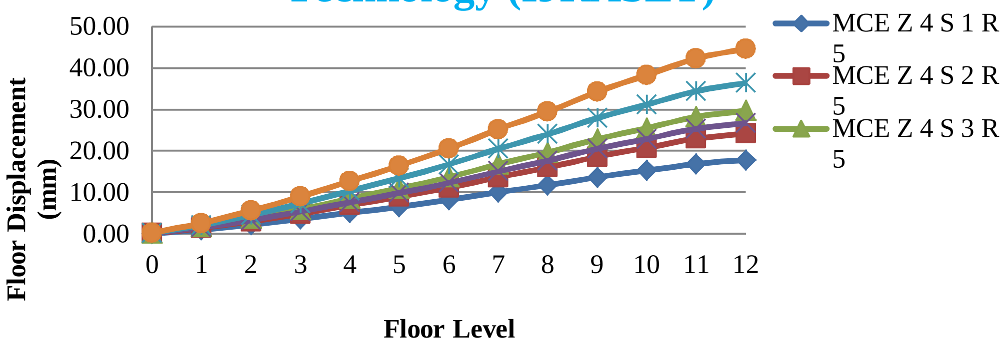

Fig:7 Floor Displacements of SMRF building for maximum considered earthquake excitation along X-Direction

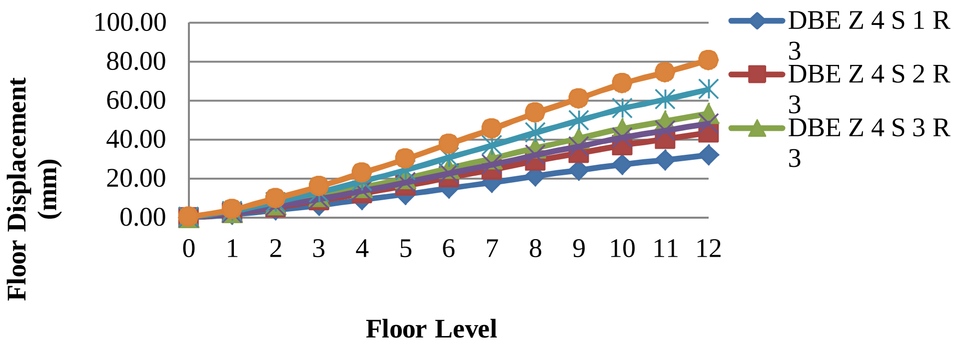

Fig:8 Floor Displacements of OMRF building for design basis earthquake excitation along Y-Direction

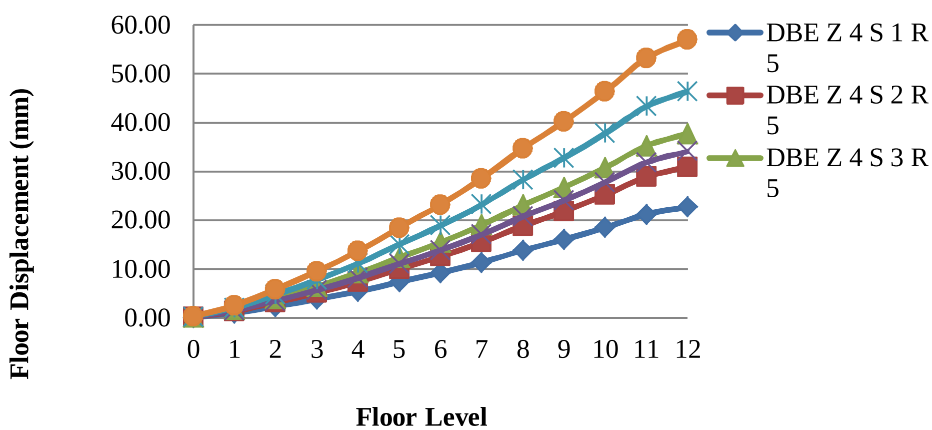

Fig:9 Floor Displacements of SMRF building for design basis earthquake excitation along Y-Direction

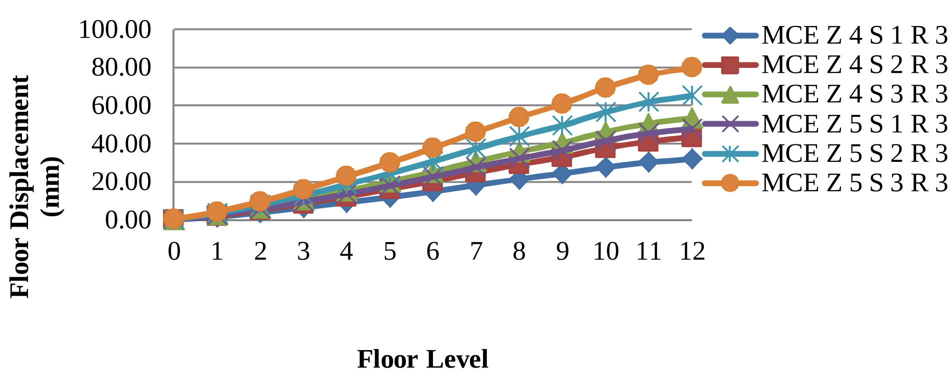

Fig:10 Floor Displacements of OMRF building for maximum considered earthquake excitation along Y-Direction

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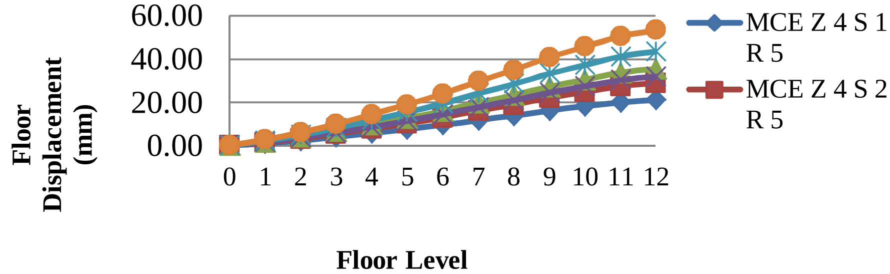

Fig:11 Floor Displacements of SMRF building for maximum considered earthquake excitation along Y-Direction

Table:3 Structural Cost comparison of RC frame buildings for DBE

S NO	TYPE OF BUILDING	COLUMNS				COLUMNS COST IN RS /-	BEAMS COST IN RS /-	COLUMNS SHEAR IN RS /-	BEAMS SHEAR IN RS /-	TOTAL BUILDING COST IN RS /-
		FRAME Y = 0	FRAME Y = 6	FRAME Y = 8	FRAME Y = 14					
1	DBE Z 4 S 1 R 3	573695.00	567526.00	567526.00	573695.00	2282444.00	2413434.00	205333.00	390167.00	5291379.00
2	DBE Z 4 S 2 R 3	579716.00	571416.00	571416.00	579716.00	2302265.00	2453665.00	205712.00	398843.00	5360487.00
3	DBE Z 4 S 3 R 3	593761.00	582079.00	582071.00	593761.00	2351675.00	2481709.00	206031.00	410175.00	5449592.00
4	DBE Z 5 S 1 R 3	598902.00	574785.00	574443.00	598681.00	2346812.00	2466316.00	205860.00	403776.00	5422766.00
5	DBE Z 5 S 2 R 3	633770.00	618892.00	618892.00	633770.00	2505326.00	2514284.00	205819.00	425831.00	5651262.00
6	DBE Z 5 S 3 R 3	700705.00	697858.00	697858.00	700705.00	2797128.00	2559234.00	204627.00	448486.00	6009475.00
7	DBE Z 4 S 1 R 5	564700.00	553853.00	554083.00	564584.00	2237221.00	2368358.00	193372.00	386263.00	5185216.00
8	DBE Z 4 S 2 R 5	568966.00	558712.00	559121.00	585362.00	2272163.00	2386895.00	193586.00	388387.00	5241032.00
9	DBE Z 4 S 3 R 5	576523.00	567755.00	567755.00	576426.00	2288460.00	2407161.00	193775.00	390567.00	5279965.00
10	DBE Z 5 S 1 R 5	569691.00	562379.00	562379.00	570089.00	2264540.00	2396040.00	193668.00	389295.00	5243545.00
11	DBE Z 5 S 2 R 5	590705.00	572992.00	582511.00	590705.00	2336916.00	2429778.00	194007.00	394620.00	5355321.00
12	DBE Z 5 S 3 R 5	613172.00	605988.00	605988.00	613172.00	2438323.00	2458161.00	194296.00	402677.00	5493459.00

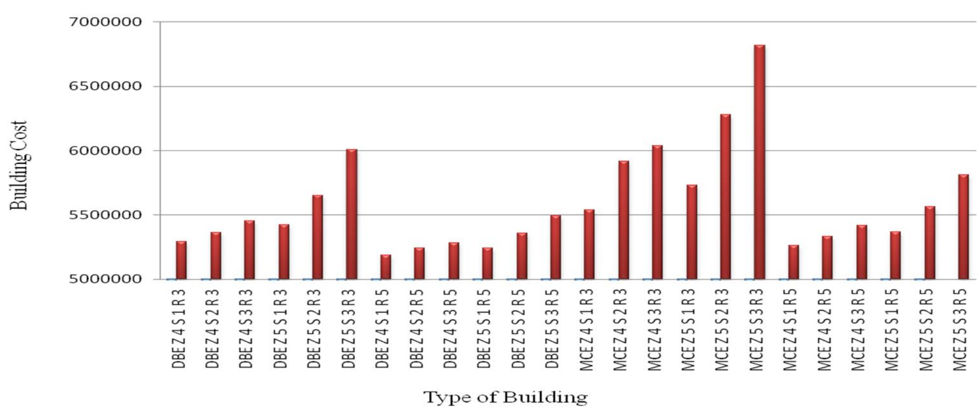

Fig: 12 Structural Cost comparison of RC frame buildings

V. CONCLUSIONS

Behaviour and seismic response of RC buildings designed for different varying parameters such as Type of soil, Ductility factors, Response Reduction Factor, Zone factor are compared. Seismic performnace of RC buildings is evaluated using Non-linear Dynamic Analysis. Following are the major conclusions of the study:

Floor displacemnets for all the buildings analysed in the study are varying linearly as variation of floor base shear.The variation of structural cost is very minimal (0-4%) for OMRF & SMRF RC framed building designed for DBE resting on different soil conditions, even for which the base shear varies from 36-67%.The variation of structural cost very minimal (0-4%) for OMRF & SMRF RC framed buildings designed for MCE resting on different soil conditions, for which base shear varies from 36-67%.The variation of structural cost is 10% for OMRF RC framed building designed for DBE and OMRF RC framed building designed for MCE of base shear variation is 50%.The variation of structural cost is 4% for SMRF RC framed building designed for DBE and MCE eventhough base shear variation is 50%. The variation of structural cost is 1% for OMRF RC framed building designed for DBE and SMRF RC framed building designed for DCE. The variation of structural cost is 5% for OMRF RC framed building designed for MCE and SMRF RC framed building designed for MCE. Hinges are developed in columns and beams of most of the stories, and the hinges are in collapse level for OMRF building designed for DBE condition with various soil conditions. Hinges are developed in columns and beams of most of the storeys, and the hinges are in collapse prevention level for SMRF building designed for DBE condition with various soil condition. Hinges are developed in columns and beams of most of the storeys, and the hinges are in collapse level for OMRF building designed for MCE condition with various soil conditions. Hinges are developed in columns and beams of most of the storeys, and hinges are in immediate occupancy level for SMRF building designed for MCE condition with various soil conditions. SMRF gives a better performance interms of stabilty and structural cost compared to the OMRF building for DBE and MCE condition. Building deigned for MCE condition with SMRF gives the better performance (immedeiate occupancy) compared to the building designed for DBE condition with SMRF.

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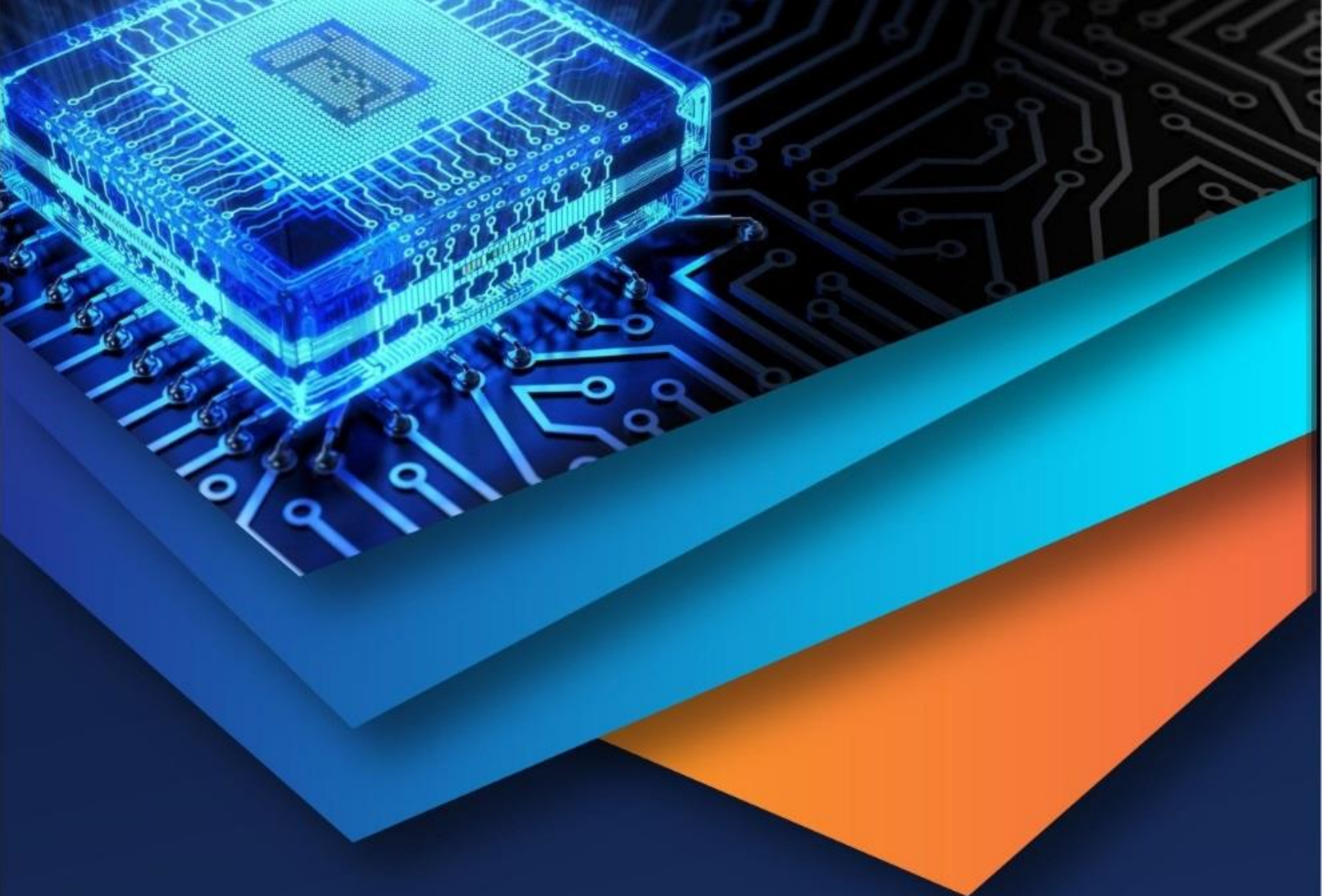

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