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290 – 297

Performance Assessment and Design of Multistoreyed Reinforced Concrete Special Moment Resisting Frames

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Abstract—Reinforced Concrete Special Moment Resisting Frames are used as part of seismic force resisting systems in buildings that are designed to resist earthquakes. Special proportioning and detailing requirements result in a frame capable of resisting strong earthquake shaking without significant loss of stiffness or strength. These moment resisting frames are called Special Moment Resisting Frames. The main objective of the study is the study of comparative performance of SMRF and OMRF frames, designed as per IS codes, using pushover analysis and software SAP-2002. The more realistic performance of the OMRF and SMRF building requires modeling the stiffness and strength. In this paper performance assessment of buildings designed as Special Moment Resisting Frame (SMRF) and Ordinary Moment Resisting Frame (OMRF) is studied for 4 storeyed, 8 storeyed,12 storeyed and 16 storeyed buildings with fixed support condition. The buildings are designed and modeled using SAP 2000 software. Pushover analysis is performed on these buildings and the response is monitored. A pushover curve comprising of Base Shear versus Roof Displacement is plotted for each frame using the analysis data.

Keywords- *pushover analysis, moment curvature relation, capacity curve, special moment resisting frames, ductility, stiffness*.

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I. Introduction *(General)*

The Buildings, which appeared to be strong enough, may crumble like houses of cards during earthquake and deficiencies may be exposed. Due to wrong construction practices and ignorance for earthquake resistant design of buildings in our country, most of the existing buildings are vulnerable to future earthquakes. In the simplest case, seismic design can be viewed as a row-step process. The first, and usually most important one, is the conception of an effective structural system that needs to be configured with due regards to all important seismic performance objectives, ranging from serviceability consideration to life safety and collapse prevention. Suitable capacity parameters and their acceptable values, as well as suitable methods for demands prediction will depend on the performance level to be evaluated. In light of these facts, it is imperative to seismically evaluate the existing building with the Present day knowledge to avoid the major destruction in the future earthquakes. The Buildings found to be seismically deficient should be retrofitted or strengthened.

A. Moment Curvature Relation

Earthquake is a global phenomenon. It causes significant damage every year in different part of the world. It has been a field of interest for the researchers to minimize the loss of life and property due to such catastrophe. Static Nonlinear performance based analysis is the result of such researches. It is a vast tool that is applied to simulate structural performance during an earthquake. In recent times, Guner & Vecchio (2010), D'Ambrisi et al. (2009), Pereira et al. (2009), Guo et al. (2011) –all have used nonlinear pushover analysis in their research. In this method, status of damage is indicated by hinges formed in the frame elements. Therefore, nonlinear moment-curvature behaviour are assigned to discrete locations along the length of frame (line) elements. However, moment curvature relation is dependent on various parameters and hence it is essential to know the effect of these parameters on M-φ curves before applying them in pushover analysis. Research have been conducted to find out these effect on steel (Ricart & Plumier, 2008).

The need to perform some form of inelastic analysis is already incorporated in many building codes. Theoretical moment-curvature analysis for reinforced concrete columns, indicating the available flexural strength and ductility, can be conducted providing the stress-strain relation for the concrete and steel are known. The moments and curvatures associated with increasing flexural deformations of the column may be computed for various column axial loads by incrementing the curvature and satisfying the requirements of strain compatibility and equilibrium of forces.

B. Sress Strain Model For Concrete

Mander's model is highly popular model since it is simple and effective in considering the effects of confinement. It considers increase in both the strength and ductility of RC members with confined concrete. The model is popularly used to evaluate the effective strength of the columns confined by stirrups, steel jacket and even by FRP wrapping as accomplished in Figure 1.1

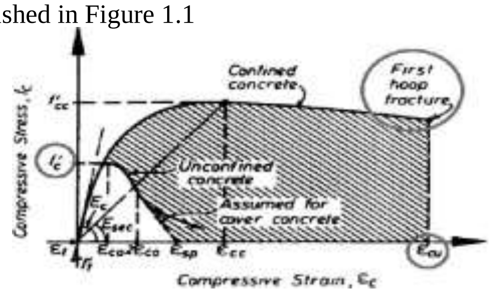

Figure 1.1 –Mander's Model for Stress-Strain Relationship For Confined Concrete.

 ISSN: 2454-4248
290 – 297

Moment Curvature For Beam

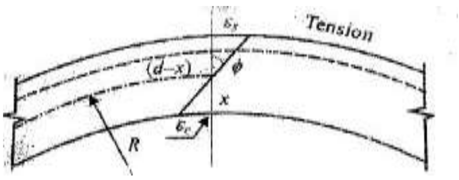

Figure 1.2 –Beam members in bending

The most fundamental requirement in predicting the Moment Curvature behaviour of a flexural member is the knowledge of the behaviour of its constituents. With the increasing use of higher-grade concretes, the ductility of which is significantly less than normal concrete, it is essential to confine the concrete. In a flexure member the shear reinforcement also confines the concrete in the compression zone. The relationship for the bending member as depicted in Figure 1.2 .

C. Necessity Of PushOver Analysis

The existing building can become seismically deficient since seismic design code requirements are constantly upgraded and advancement in engineering knowledge. Further, Indian buildings built over past two decades are seismically deficient because of lack of awareness regarding seismic behavior of structures. The widespread damage especially to RC buildings during earthquakes exposed the construction practices being adopted around the world, and generated a great demand for seismic evaluation and retrofitting of existing building stocks.

E. PushOver Analysis

The pushover analysis of a structure is a static non-linear analysis under permanent vertical loads and gradually increasing lateral loads. The equivalent static lateral loads approximately represent earthquake induced forces. A plot of the total base shear versus top displacement in a structure is obtained by this analysis that would indicate any premature failure or weakness. The analysis is carried out up to failure, thus it enables determination of collapse load and ductility capacity. On a building frame, and plastic rotation is monitored, and lateral inelastic forces versus displacement response for the complete structure is analytically computed. This type of analysis enables weakness in the structure to be identified.

F. Puspose of Non Linear Static Pushover Analysis

The purpose of pushover analysis is to evaluate the expected performance of structural systems by estimating performance of a structural system by estimating its strength and deformation demands in design earthquakes by means of static inelastic analysis, and comparing these demands to available capacities at the performance levels of interest. The pushover is expected to provide information on many response characteristics that cannot be obtained from an elastic static or dynamic analysis. The following are the examples of such response characteristics: The realistic force demands on potentially brittle elements, such as axial force demands on columns, force demands on brace connections, moment demands on

- Beam to column connections, shear force demands in deep reinforced concrete spandrel beams, shear force demands in unreinforced masonry wall piers, etc.
- Estimates of the deformations demands for elements that have to form in elastically in order to dissipate the energy imparted to the structure.
- Consequences of the strength deterioration of individual elements on behavior of structural system.
- Consequences of the strength determination of the individual elements on the behavior of the structural system.
- Identification of the critical regions in which the deformation demands are expected to be high and that have to become the focus through detailing.
- Identification of the strength discontinuities in plan elevation that will lead to changes in the dynamic characteristics in elastic range.
- Estimates of the understory drifts that account for strength or stiffness discontinuities and that may be used to control the damages and to evaluate P-Delta effects.

II. SPECIAL MOMENT RESISTING FRAMES

Reinforced concrete special moment frames are used as part of seismic force-resisting systems in buildings that are designed to resist earthquakes. Beams, columns, and beam-column joints in moment frames are proportioned and detailed to resist flexural, axial,and shearing actions that result as a building sways through multiple displacement cycles during strong earthquake ground shaking. Special proportioning and detailing requirements result in a frame capable of resisting strong earthquake shaking without significant loss of stiffness or strength. These moment-resisting frames are called “Special Moment Frames” because of these additional requirements, which improve the seismic resistance in comparison with less stringently detailed Intermediate and Ordinary Moment Frames.

Most special moment frames use cast-in-place, normal-weight concrete having rectilinear cross sections without prestressing.

A. Use Of Special Moment Frames (Historic Development)

Reinforced concrete special moment frame concepts were introduced in the U.S. starting around 1960 (Blume, Newmark, and Corning 1961). Their use at that time was essentially at the discretion of the designer, as it was not until 1973 that the Uniform Building Code (ICBO 1973) first required use of the special frame details in regions of highest seismicity. The earliest detailing requirements are remarkably similar to those in place today. In India the use of special moment resisting frames was started by around 1993. The proportioning and detailing of SMRF in India is according to IS-13920(1993) which is reaffirmed in the year 2002.

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Volume: 4 Issue: 1 290 – 297

B. When To Use SMRF

Moment frames are generally selected as the seismic force-resisting system when architectural space planning flexibility is desired. When concrete moment frames are selected for buildings assigned to Seismic Design Categories III, IV, or V, they are required to be detailed as special reinforced concrete moment frames. Special moment frames may be used in Seismic Design Categories I,and II though this may not lead to the most economical design. If special moment frames are selected as the seismic force-resisting system, All requirements for the frames must be satisfied to help ensure ductile behavior. According to IS 13920(2002), special moment frames are allowed to be designed for a force reduction factor of R=5. That is, they are allowed to be designed for a base shear equal to one-fifth of the value obtained from an elastic response analysis.

C. Principle for Design Of SMRF

The proportioning and detailing requirements for special moment frames are intended to ensure that inelastic response is ductile. Three main goals are: (1) to achieve a strong-column/ weak-beam design that spreads inelastic response over several stories; (2) to avoid shear failure; and (3) to provide details that enable ductile flexural response in yielding regions.

D. Design A Strong Column / Weak Beam Frame

When a building sways during an earthquake, the distribution of damage over height depends on the distribution of lateral drift. If the building has weak columns, drift tends to concentrate in one or a few stories (Figure 2.1 a), and may exceed the drift capacity of the columns. On the other hand, if columns provide a stiff and strong spine over the building height, drift will be more uniformly distributed (Figure 2.1 c), and localized damage will be reduced. Additionally, it is important to recognize that the columns in a given story support the weight of the entire building above those columns, whereas the beams only support the gravity loads of the floor of which they form a part; therefore, failure of a column is of greater consequence than failure of a beam. Recognizing this behavior, building codes specify that columns be stronger than the beams that frame into them. This strong-column/weak-beam principle is fundamental to achieving safe behavior of frames during strong earthquake ground shaking. ACI 318 adopts the strong-column/weak-beam principle by requiring that the sum of column strengths exceed the sum of beam strengths at each beam-column connection of a special moment frame. Studies (e.g. Kuntz and Browning 2003) have shown that the full structural mechanism of Figure 2.1c can only be achieved if the column-to-beam strength ratio is relatively large (on the order of four). As this is impractical in most cases, a lower strength ratio of 1.2 is adopted. Thus, some column yielding associated with an intermediate mechanism (Figure 2.1 b) is to be expected, and columns must be detailed accordingly. Section 5.4 of this guide summarizes the column hoop and lap splice requirements of ACI 318.

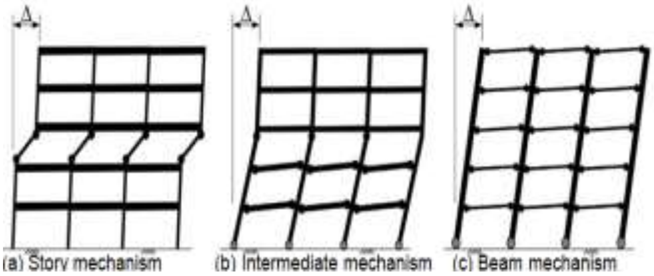

Figure 2.1 – Design of Special Moment Frames aims to avoid a) Story Mechanism and instead achieve either an b) Intermediate Mechanism or c) Beam Mechanism.

E. Avoid Shear Failure

Ductile response requires that members yield in flexure, and that shear failure be avoided. Shear failure, especially in columns, is relatively brittle and can lead to rapid loss of lateral strength and axial load-carrying capacity. Column shear failure is the most frequently cited cause of concrete building failure and collapse in earthquakes. Shear failure is avoided through use of a capacity-design approach. The general approach is to identify flexural yielding regions, design those regions for code-required moment strengths, and then calculate design shears based on equilibrium assuming the flexural yielding regions develop probable moment strengths. The probable moment strength is calculated using procedures that produce a high estimate of the moment strength of the as-designed cross section

III. DETAIL FOR DUCTILE BEHAVIOUR

Ductile behavior of reinforced concrete members is based on the following principles.

A. Confinement For Heavily Loaded Sections

Plain concrete has relatively small usable compressive strain capacity (around 0.003), and this might limit the deformability of beams and columns of special moment frames. Strain capacity can be increased ten-fold by confining the concrete with reinforcing spirals or closed hoops. The hoops act to restrain dilation of the core concrete as it is loaded in compression, and this confining action leads to increased strength and strain capacity.

Hoops typically are provided at the ends of columns, as well as through beam-column joints, and at the ends of beams. Figure 3.1 shows a column hoop configuration using rectilinear hoops. Circular hoops and spirals, which can be very efficient for column confinement, are not covered in this guide.

ISSN: 2454-4248
290 – 297

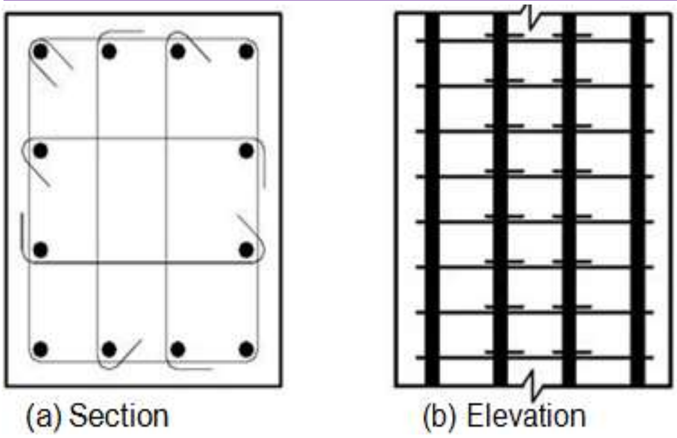

Figure 3.1 –Hoops confined heavily stressed cross section of columns and beams, with a) hoops surrounding the core and supplementary bars, all of which are b) closely spaced along the member length.

B. Ample Shear Reinforcement

Shear strength degrades in members subjected to multiple inelastic deformation reversals, especially if axial loads are low. In such members it requires that the contribution of concrete to shear resistance be ignored, that is, $V_c = 0$. Therefore, shear reinforcement is required to resist the entire shear force.

C. Avoidance Of Anchorage Or Splice Failure

Severe seismic loading can result in loss of concrete cover, which will reduce development and lap-splice strength of longitudinal reinforcement. Lap splices, if used, must be located away from sections of maximum moment (that is, away from ends of beams and columns) and must have closed hoops to confine the splice in the event of cover spalling. Bars passing through a beam-column joint can create severe bond stress demands on the joint for this reason, code restricts beam bar sizes. Bars anchored in exterior joints must develop yield strength (fy) using hooks located at the far side of the joint. Finally, mechanical splices located where yielding is likely must be splices capable of developing at least the specified tensile strength of the bar.

IV. PROBLEM STATEMENT

The buildings to be designed and analyzed by pushover analysis are as follows-

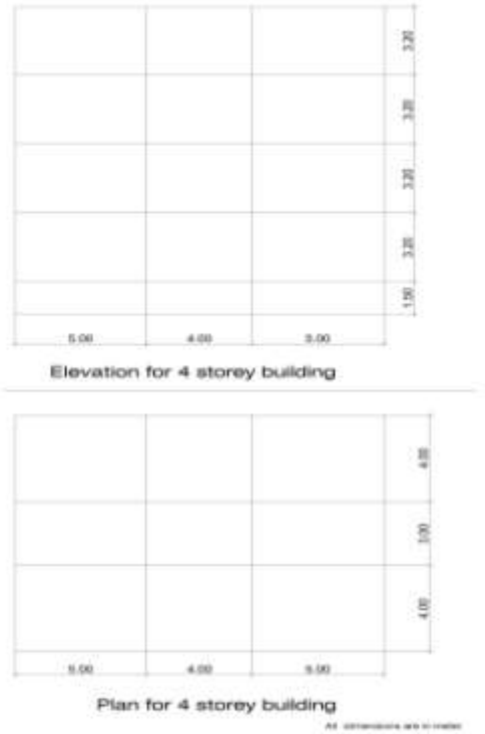

Figure 4.1 –Plan and elevation for 4 storyed building

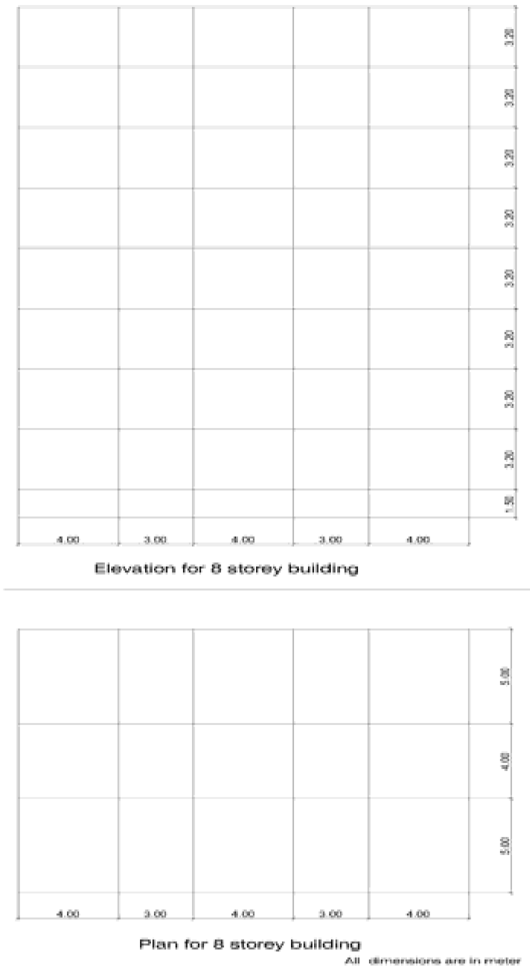

Figure 4.2 –Plan and elevation for 8 storyed building

ISSN: 2454-4248
290 – 297

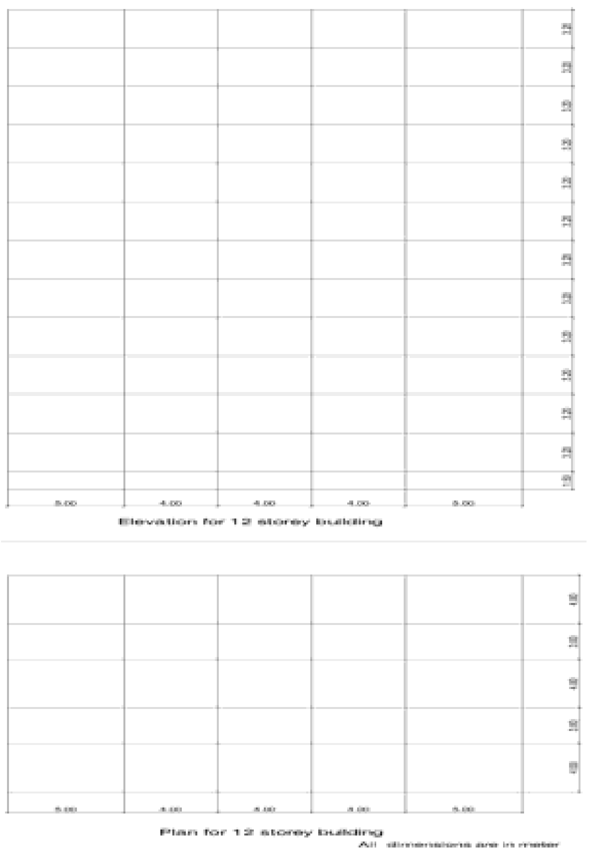

Figure 4.3 –Plan and elevation for 12 storyed building

Figure 4.4 –Plan and elevation for 16 storyed building

TABLE NO 4.1: MATERIAL PROPERTIES AND GEOMETRIC PARAMETERS ASSUMED

Sr. No	DESIGN PARAMETERS	VALUES
1	Characteristic strength of concrete	25 N/mm2
2	Characteristic strength of steel	415N/mm2
3	Unit weight of concrete	25KN/m3
4	Modulus of elasticity of steel	200GPa
5	Damping ratio	5%
6	Slab thickness	150mm
7	External wall thickness	230mm
8	Internal wall thickness	150mm

TABLE NO 4.2: SEISMIC DESIGN DATA ASSUMED FOR SMRF:

Sr.No	DESIGN PARAMETERS	VALUES
1	Seismic Zone	V
2	Zone factor (Z)	0.36
3	Response Reduction Factor (R)	5
4	Importance Factor (I)	1
5	Soil Type	Medium soil
6	Damping Ratio	5%
7	Frame Type	SMRF

TABLE NO 4.3: SEISMIC DESIGN DATA ASSUMED FOR OMRF:

Sr.No	DESIGN PARAMETERS	VALUES
1	Seismic Zone	V
2	Zone factor (Z)	0.36
3	Response Reduction Factor (R)	3
4	Importance Factor (I)	1
5	Soil Type	Medium soil
6	Damping Ratio	5%
7	Frame Type	OMRF

TABLE NO 4.4: SEISMIC DESIGN DATA ASSUMED FOR OMRF:

Sr.No	LOAD TYPE	VALUES
1	Live load	3 KN/m2
2	Dead load (Self weight of element)	As per size of member
3	Floor finish	1 KN/m2
4	Parapet wall load	6.9 KN/m
5	Wall load	11.96 KN/m
6	Roof live load	1.5KN/m2

ISSN: 2454-4248
290 – 297

V. RESULTS

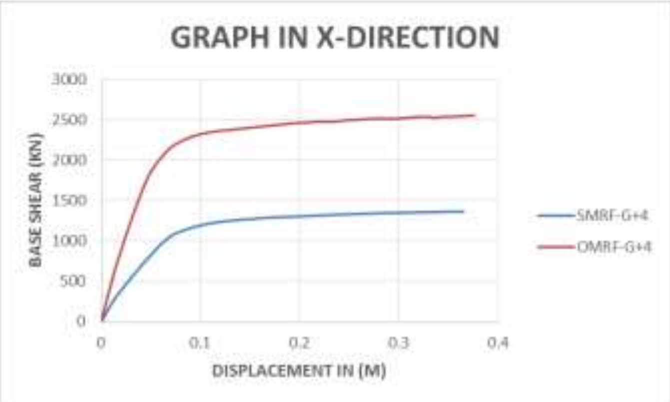

Fig No 4.5a- Combined Pushover curve for G+4 buildings in X-Direction

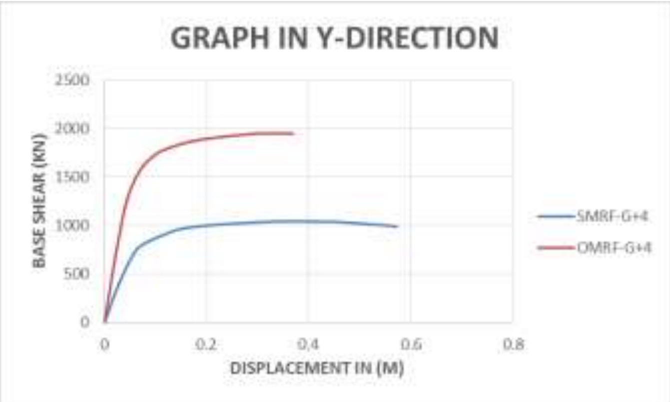

Fig No 4.5 b- Combined Pushover curve for G+4 buildings in Y-Direction

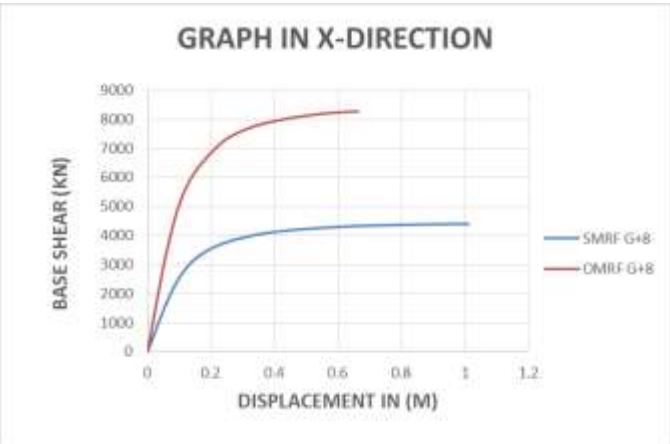

Fig No 4.6a- Combined Pushover curve for G+8 buildings in X-Direction

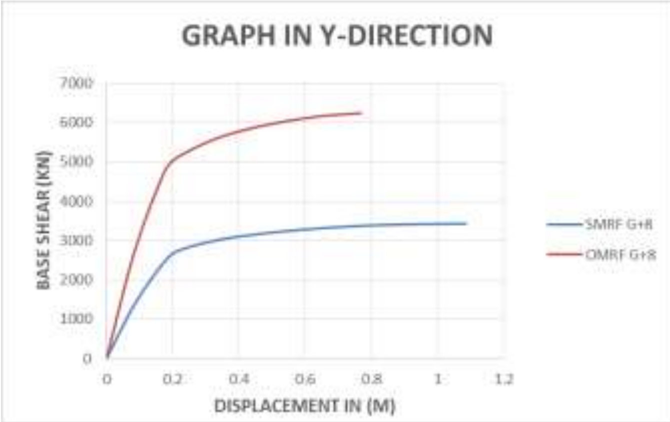

Fig No 4.6b- Combined Pushover curve for G+8 buildings in Y-Direction

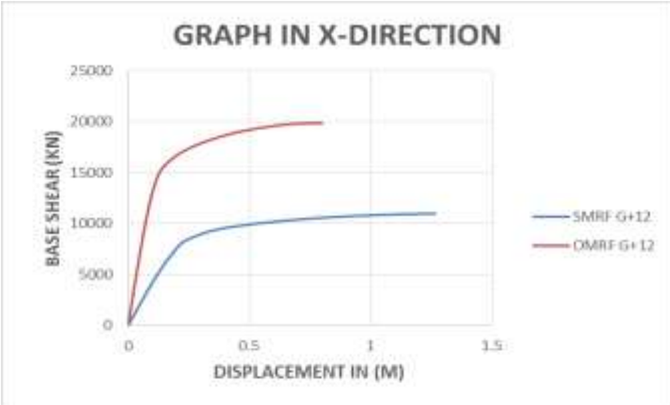

Fig No 4.7a- Combined Pushover curve for G+12 buildings in X-Direction

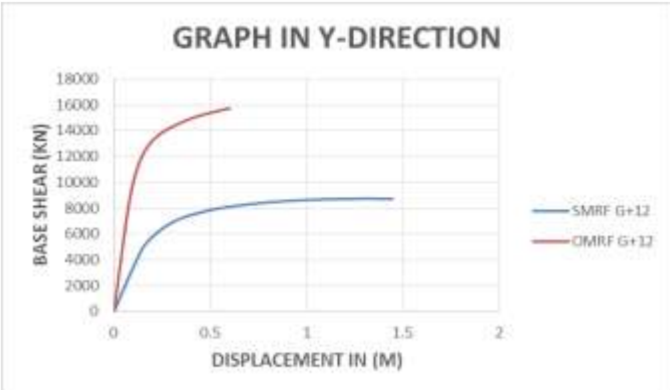

Fig No 4.7b- Combined Pushover curve for G+12 buildings in Y-Direction

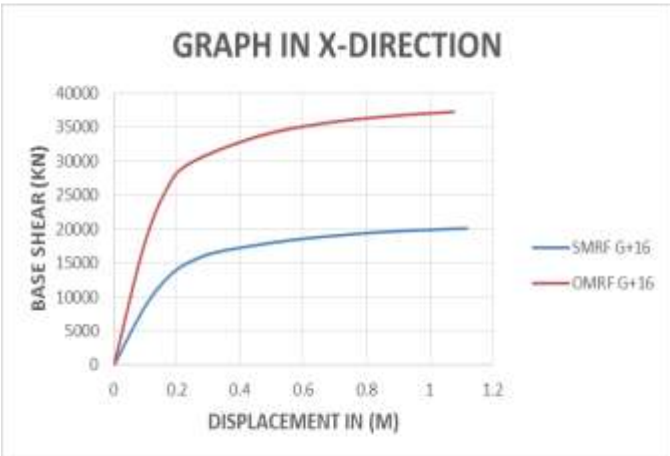

Fig No 4.8a- Combined Pushover curve for G+12 buildings in X-Direction

ISSN: 2454-4248
290 – 297

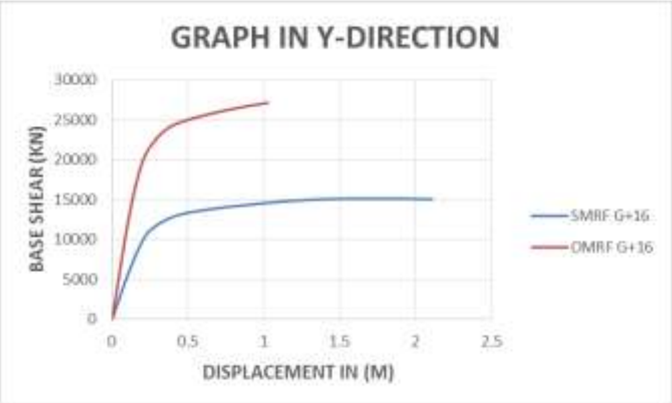

Fig No 4.8b- Combined Pushover curve for G+12 buildings in Y-Direction

TABLE NO 5.1:PERFORMANCE COMPARISON OF OMRF AND SMRF BUILDINGS WITH FIXED SUPPORT.

Building Configuration	BASE SHEAR (KN)		% Increase in Base Shear for OMRF	ROOF DISPLACEMENT (mm)		% Increase in Displacement for SMRF
	OMRF	SMRF		OMRF	SMRF	
G+4 3B X-DIRCT	2554	1363	87.83%	365	375	2.73%
G+4 3B Y-DIRCT	1949	991	96.67%	369	570	54.47%
G+8 5B X-DIRCT	8271	4398	88.06%	662	1011	52.71%
G+8 3B Y-DIRCT	6243	3460	80.43%	768	1084	41.14%
G+12 5B X-DIRCT	19853	10975	80.89%	799	1264	58.19%
G+12 5B Y-DIRCT	15725	8718	80.37%	600	1445	140%
G+16 6B X-DIRCT	37289	20119	85.34%	1076	1117	3.81%
G+16 5B Y-DIRCT	27126	15048	80.26%	1026	2108	105%

V. CONCLUSIONS

The performance assessment of buildings designed as Special Moment Resisting Frame (SMRF) and Ordinary Moment Resisting Frame (OMRF) is studied for 4 storeyed, 8 storeyed,12 storeyed and 16 storeyed buildings with fixed support condition. The buildings are designed and modelled using SAP 2000 software. Pushover analysis is performed on these buildings and the response is monitored. A pushover curve comprising of Base Shear versus Roof Displacement is plotted for each frame using the analysis data. The comparative observations are as follows.

- The behaviour of SMRF and OMRF buildings with fixed support is compared. It is found that SMRF buildings perform much better compared to OMRF buildings.
- The ductility of SMRF buildings is almost 40% to 140% more than OMRF buildings. The reason is the heavy confinement of concrete due to splicing and use of more number of stirrups as ductile reinforcement.
- It is also found that the base shear capacity capacity of OMRF buildings is 80% to 97% more than that of SMRF buildings.
- The pushover curve plotted is found that the ductility and the magnitude of base shear that can be resisted increases with increase in the number of storeys.
- It is observed that all the SMRF buildings considered has almost the same value of initial slope in the pushover curve.
- Comparative study for the number of bays is also carried out for both SMRF and OMRF buildings and it is observed that the magnitude of base shear that can be resisted increases with increase in number of bays.
- Though pushover analyses give an insight about nonlinear behavior imposed on structure by seismic action, the design and seismic evaluation process should be performed by keeping in mind that some amount of variation always exists in seismic demand prediction of pushover analysis.
- Finally, more systematic and complete parametric studies, strength ratios and earthquake ground motions will be required to establish definite criteria for efficient design of Reinforced Concrete Special Moment Resisting Frames.

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290 – 297

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