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Static Analysis of Multistoreyed RC Buildings By Using Pushover Methodology

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Abstract

Moment resisting frames are commonly used as the dominant mode of lateral resisting system in seismic regions for a long time. 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. Reinforced concrete special moment frames are used as part of seismic force-resisting systems in buildings that are designed to resist earthquakes. The poor performance of Ordinary Moment Resisting Frame (OMRF) in past earthquakes suggested special design and detailing to warrant a ductile behaviour in seismic zones of high earthquake (zone III, IV & V). Thus when a large earthquake occurs, Special Moment Resisting Frame (SMRF) which is specially detailed and is expected to have superior ductility. 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" because of these additional requirements, which improve the seismic resistance in comparison with less stringently detailed Intermediate and Ordinary Moment Resisting Frames.

Keywords: Moment Resisting Frames, SMRF, OMRF, Pushover Analysis, Static Non-Linear Analysis, Plastic Hinges, SAP2000, Ductility Factor, Earthquake Engineering, Response Reduction Factor.

I. INTRODUCTION

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 Resisting Frames" because of these additional requirements, which improve the seismic resistance in comparison with less stringently detailed Intermediate and Ordinary Moment Resisting Frames.

II. OBJECTIVE

In this project objective is to study *th*e base shear and ductility of frames with number of storeys 4,6, 8, and 10 all having 7 bays are designed and detailed as SMRF and OMRF as per IS 1893 (2002). In this study, the buildings are designed both as SMRF and OMRF, and their performance is compared. We also study the storey wise comparison of SMRF Buildings of storeys 4,6,8 and 10 all having 7 bays and also bay wise comparison of SMRF Buildings of bays 2,4 and 6 all having 6 storeys. For this, the buildings are modelled and Pushover Analysis is performed in SAP2000. The design criteria for SMRF buildings are given in IS 13920 (2002). The pushover curves are plotted from the analysis results and the behaviour of buildings is studied for fixed support conditions and infill conditions.

III. LITERATURE REVIEW

Rao *ET AL.* (1982) conducted theoretical and experimental studies on infill frames with opening strengthened by lintel beams. It was concluded that the lintel over the opening does not have any influence on the lateral stiffness of an infill frame.

Rutenberg (1992) pointed out that the research works considering single element models could not yield the ductility demand parameter properly, because they have considered distribution of strength in same proportion as their elastic stiffness distribution. Considering these drawbacks of the equivalent single element model, many investigations in this field adopted a generalized type of structural model which had a rigid deck supported by different numbers of lateral load-resisting elements representing frames or walls having strength and stiffness in their planes only.

The effect of different parameters such as plan aspect ratio, relative stiffness, and number of bays on the behaviour of infill frame was studied by Riddington and Smith (1997).

Deodhar and Patel (1998) pointed out that even though the brick masonry in infill frame are intended to be non-structural, they can have considerable influence on the lateral response of the building.

R. Hasan and D.E. Grierson (2002), conducted a simple computer-based push-over analysis technique for performance-based design of building frameworks subject to earthquake loading. And found that rigidity-factor for elastic analysis of semi-rigid frames, and the stiffness properties for semi-rigid analysis are directly adopted for push-over analysis.

B.Akbas. ***ET AL.,*** (2003), conducted a pushover analysis on steel frames to estimate the seismic demands at different performance levels, which requires the consideration of inelastic behaviour of the structure.

Das and Murthy (2004) concluded that infill walls, when present in a structure, generally bring down the damage suffered by the RC framed members of a fully infilled frame during earthquake shaking. The columns, beams and infill walls of lower stories are more vulnerable to damage than those in upper stories.

Asokan (2006) studied how the presence of masonry infill walls in the frames of a building changes the lateral stiffness and strength of the structure. This research proposed a plastic hinge model for infill wall to be used in nonlinear performance based analysis of a building and concludes that the ultimate load approach along with the proposed hinge property provides a better estimate of the inelastic drift of the building.

A. Shuraim ***ET AL.,*** (2007) the nonlinear static analytical procedure (Pushover) as introduced by ATC-40 has been utilized for the evaluation of existing design of a new reinforced concrete frame. Potential structural deficiencies in reinforced concrete frame, when subjected to a moderate seismic loading, were estimated by the pushover approaches. In this method the design was evaluated by redesigning under selected seismic combination in order to show which members would require additional reinforcement. Most columns required significant additional reinforcement, indicating their vulnerability when subjected to seismic forces. The nonlinear pushover procedure shows that the frame is capable of withstanding the presumed seismic force with some significant yielding at all beams and one column.

A.Kadid and A. Boumrkik (2008), proposed use of Pushover Analysis as a viable method to assess damage vulnerability of a building designed according to Algerian code. Pushover analysis was a Series of incremental static analysis carried out to develop a capacity curve for the building. Based on capacity curve, a target displacement which was an estimate of the displacement that the design earthquake would produce on the building was determined. The extent of damage Experienced by the structure at this target displacement is considered representative of the Damage experienced by the building when subjected to design level ground shaking. Since the Behaviour of reinforced concrete structures might be highly inelastic under seismic loads, the global inelastic performance of RC structures would be dominated by plastic yielding effects and consequently the accuracy of the pushover analysis would be influenced by the ability of the Analytical models to capture these effects

Taewan K ***ET AL.,*** (2009) designed a building as per IBC 2003 and showed that the building satisfied the inelastic behaviour intended in the code and satisfied the design drift limit.

Sattar and Abbie (2010) in their study concluded that the pushover analysis showed an increase in initial stiffness, strength, and energy dissipation of the infill frame, compared to the bare frame, despite the wall‟s brittle failure modes. Likewise, dynamic analysis results indicated that fully-infill frame has the lowest collapse risk and the bare frames were found to be the most vulnerable to earthquake-induced collapse. The better collapse performance of fully-infill frames was associated with the larger strength and energy dissipation of the system, associated with the added walls.

P.Poluraju and P.V.S.N.Rao (2011), has studied the behaviour of framed building by conducting Pushover Analysis, most of buildings collapsed were found deficient to meet out the requirements of the present day codes. Then G+3 building was modelled and analyzed, results obtained from the study shows that properly designed frame will perform well under seismic loads.

Mohammed.A ***ET AL.,*** (2012) investigated the seismic design factors for three RC-SMRF buildings with 4, 16 and 32 stories in Dubai, utilizing nonlinear analysis and found that a trend of poorer performance is detected as the building height increases.

IV. BUILDING DETAILS AND MODELLING FOR ANALYSIS

A total of 10 frames are selected by varying number of storeys, number of bays, infill wall configurations, and design methodology with regard to response reduction factors and confinement detailing. A detailed description of all the frames considered is presented in Table 4.1. The storey height is 3.5m and bay width is 3m, which is same for all frames. Each frame is designed as OMRF and SMRF considering response reduction factors such as 3 and 5. IS code suggests a response reduction factor of 3 for OMRF and 5 for SMRF.

Table - 4.1
Details of All The Fixed Support Bare Frames

Sl No	*Frame Name*	*Frame type*	*No. of storey*	*No. of bays*	*R*	*Frame Type*	*Support conditions*
1	*4S7B-SMRF-B-F*	*Bare*	*4*	*7*	*5*	*SMRF*	*Fixed*
2	*6S7B-SMRF-B-F*	*Bare*	*6*	*7*	*5*	*SMRF*	*Fixed*
3	*8S7B-SMRF-B-F*	*Bare*	*8*	*7*	*5*	*SMRF*	*Fixed*
4	*10S7B-SMRF-B-F*	*Bare*	*10*	*7*	*5*	*SMRF*	*Fixed*
5	*4S7B-OMRF-B-F*	*Bare*	*4*	*7*	*3*	*OMRF*	*Fixed*
6	*6S7B-OMRF-B-F*	*Bare*	*6*	*7*	*3*	*OMRF*	*Fixed*
7	*8S7B-OMRF-B-F*	*Bare*	*8*	*7*	*3*	*OMRF*	*Fixed*
8	*10S7B-OMRF-B-F*	*Bare*	*10*	*7*	*3*	*OMRF*	*Fixed*

Table - 4.2
Details of All The Fixed Support Frames With Strong Infill

Sl No	*Frame Name*	*Frame type*	*No. of storey*	*No. of bays*	*R*	*Infill Type*	*Frame Type*	*Support conditions*
1	*4S7B-SMRF-I-S-F*	*Infill*	*4*	*7*	*5*	*Strong*	*SMRF*	*Fixed*
2	*6S7B-SMRF-I-S-F*	*Infill*	*6*	*7*	*5*	*Strong*	*SMRF*	*Fixed*
3	*8S7B-SMRF-I-S-F*	*Infill*	*8*	*7*	*5*	*Strong*	*SMRF*	*Fixed*
4	*10S7B-SMRF-I-S-F*	*Infill*	*10*	*7*	*5*	*Strong*	*SMRF*	*Fixed*
5	*4S7B-OMRF-I-S-F*	*Infill*	*4*	*7*	*3*	*Strong*	*OMRF*	*Fixed*
6	*6S7B-SMRF-I-S-F*	*Infill*	*6*	*7*	*5*	*Strong*	*OMRF*	*Fixed*
7	*8S7B-OMRF-I-S-F*	*Infill*	*8*	*7*	*3*	*Strong*	*OMRF*	*Fixed*
8	*10S7B-OMRF-I-S-F*	*Infill*	*10*	*7*	*3*	*Strong*	*OMRF*	*Fixed*

Table - 4.3
Details of All The Fixed Support Frames With Weak Infill

Sl No	*Frame Name*	*Frame type*	*No. of storey*	*No. of bays*	*R*	*Infill Type*	*Frame Type*	*Support conditions*
1	*4S7B-SMRF-I-S-F*	*Infill*	*4*	*7*	*5*	*Weak*	*SMRF*	*Fixed*
2	*6S7B-SMRF-I-S-F*	*Infill*	*6*	*7*	*5*	*Weak*	*SMRF*	*Fixed*
3	*8S7B-SMRF-I-S-F*	*Infill*	*8*	*7*	*5*	*Weak*	*SMRF*	*Fixed*
4	*10S7B-SMRF-I-S-F*	*Infill*	*10*	*7*	*5*	*Weak*	*SMRF*	*Fixed*

5	*4S7B-OMRF-I-S-F*	*Infill*	*4*	*7*	*3*	*Weak*	*OMRF*	*Fixed*
6	*6S7B-SMRF-I-S-F*	*Infill*	*6*	*7*	*5*	*Weak*	*OMRF*	*Fixed*
7	*8S7B-OMRF-I-S-F*	*Infill*	*8*	*7*	*3*	*Weak*	*OMRF*	*Fixed*
8	*10S7B-OMRF-I-S-F*	*Infill*	*10*	*7*	*3*	*Weak*	*OMRF*	*Fixed*

Table - 4.4
Material Properties And Geometric Parameters Assumed

Sl No.	*Design Parameter*	*Value*
1	*Unit weight of concrete*	$25\ kN/m^3$
2	*Unit weight of Infill walls*	$18\ kN/m^3$
3	*Characteristic Strength of concrete*	*25 MPa*
4	*Characteristic Strength of steel*	*415 MPa*
5	*Compressive strength of strong masonry* (E_m)	*5000MPa*
6	*Compressive strength of weak masonry* (E_m)	*350MPa*
7	*Modulus of elasticity of Masonry Infill walls* (E_m)	$750f'_m$
8	*Damping ratio*	*5%*
9	*Modulus of elasticity of steel*	*2e5 MPa*
10	*Slab thickness*	*150 mm*
11	*Wall thickness*	*230 mm*

Table - 4.5
Seismic Design Data Assumed For Special Moment Resisting Frames

Sl No.	*Design Parameter*	*Value*
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*	*Ordinary Moment Resisting Frame*

Table - 4.6
Seismic Design Data Assumed For Ordinary Moment Resisting Frames

Sl No.	*Design Parameter*	*Value*
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*	*Ordinary Moment Resisting Frame*

Table - 4.7
Loads Considered For Designing Buildings

Sl No.	*Load Type*	*Value*
1	*Self-weight of beams and columns*	*As per dimensions*
2	*Weight of slab*	*11.25 KN/m*
3	*Infill weight*	*12 KN/m*
4	*Parapet weight*	*2.07 KN/m*
5	*Floor Finish*	*2.5 KN/m^2*
6	*Live load*	*3.0 KN/m^2*

A. PUSHOVER ANALYSIS

Performance assessment of the designed frames is carried out using nonlinear static pushover analysis. The modelling of the designed frames for nonlinear analysis is done in the Program SAP2000 Nonlinear.

Pushover analysis is a static, nonlinear procedure to analysis a building where loading is incrementally increased with a certain predefined pattern (i.e., inverted triangular or uniform). Local non-linear effects are modelled and the structure is pushed until a collapse mechanism is developed. With the increase in the magnitude of loads, weak links and failure modes of the building are found. At each step, structure is pushed until enough hinges form to develop a curve between base shear of the building and their corresponding roof displacement and this curve known as pushover curve.

All the buildings designed and their nomenclature is presented in a tabulated format. The seismic design data used while designing the buildings, as per the IS codes, has been discussed. A detailed discussion regarding Pushover analysis is discussed. The procedure for modelling structural elements and the equivalent struts for infill walls is also discussed in the chapter in a detailed manner.

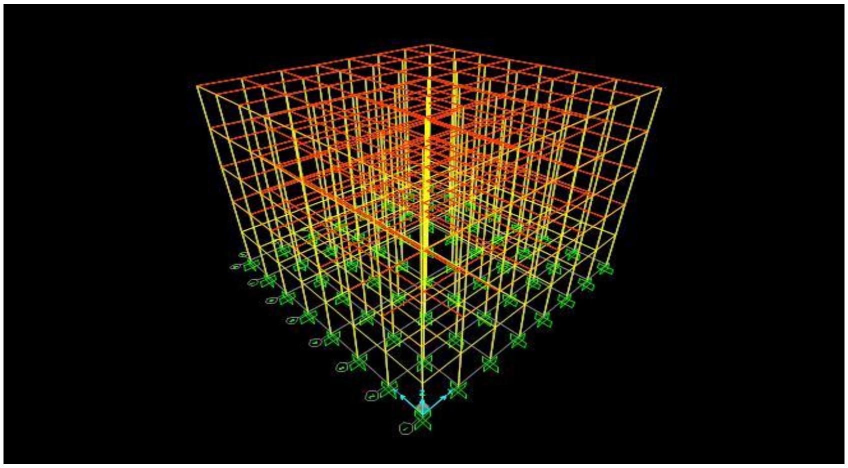

Fig. 4.1: Shows The Model of 4S7B

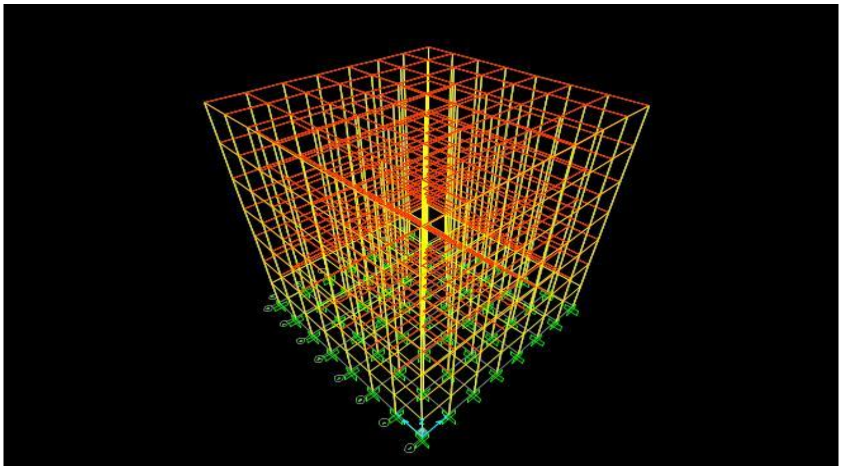

Fig. 4.2: Shows The Model of 6S7B

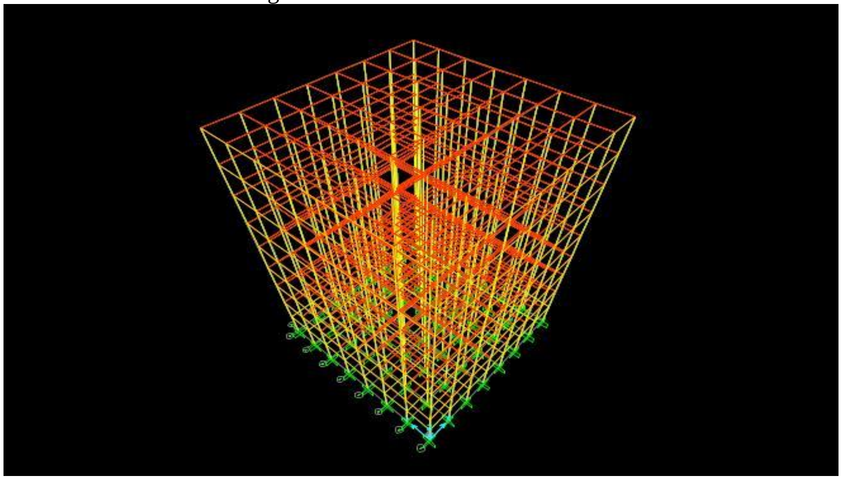

Fig. 4.3: Shows The Model of 8S7B

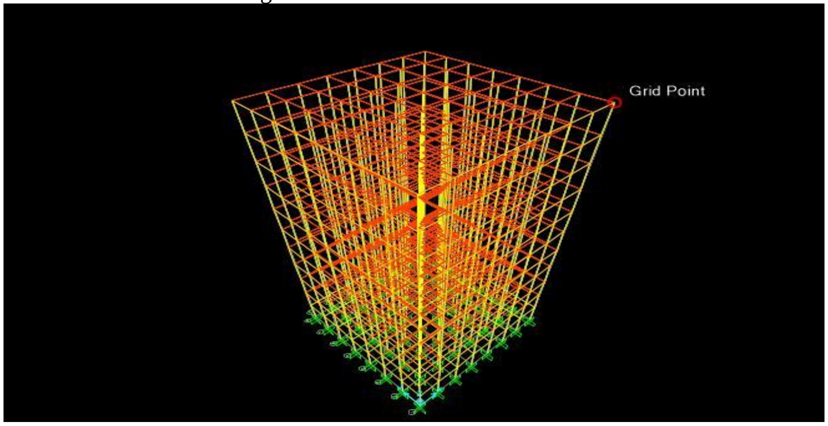

Fig. 4.4: Shows The Model of 10S7B

All the buildings are modelled in SAP2000 Nonlinear using the design data.

V. PERFORMANCE ASSESSMENT OF DESIGNED BUILDINGS

A. PERFORMANCE ASSESSMENT OF DESIGNED FRAMES

This chapter deals with the performance assessment of the designed buildings. The buildings are modelled in SAP2000 for nonlinear analysis. The pushover analyses of all the frames discussed in the previous sections is conducted. The base shear versus roof displacement at each analysis step is obtained. The pushover curves are presented in each case. A comparison study is carried out to observe the difference in behaviour of buildings.

B. COMPARISON OF SMRF AND OMRF: BARE FRAME, FIXED SUPPORT

In this comparison, the performance of ordinary moment resisting frames and special moment resisting frames with fixed support conditions are considered. The base shear versus roof displacement at each analysis step is obtained. The pushover curves are presented in each case.

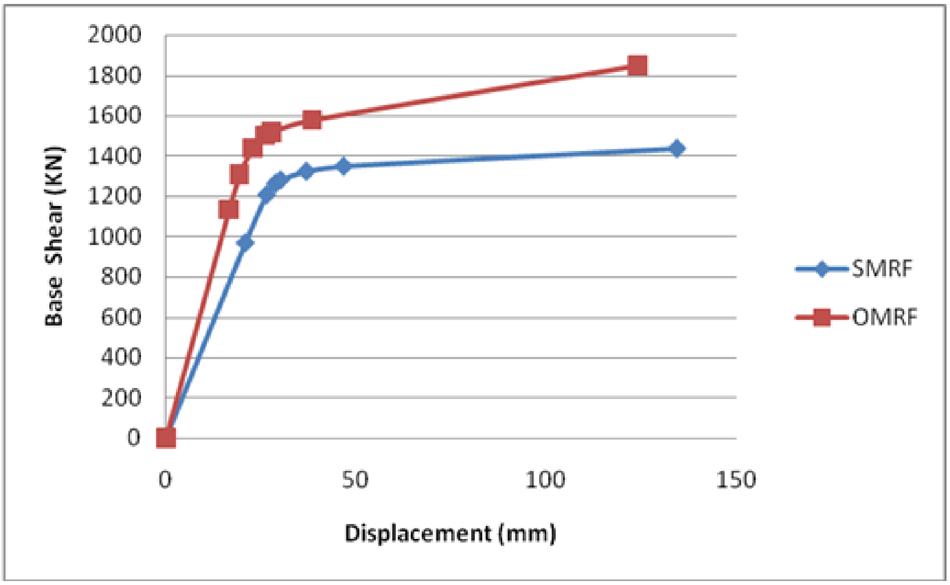

Fig. 5.1: Shows The Pushover Curves of 4S7B OMRF and 4S7B SMRF With Fixed Support Condition and No Infill.

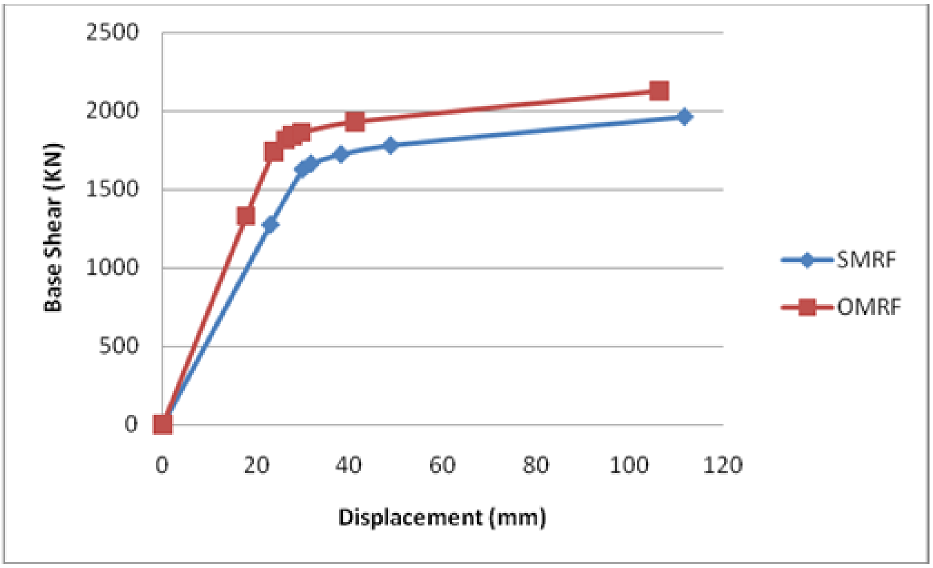

Fig. 5.2: Shows The Pushover Curves of 6S7B OMRF and 6S7B SMRF With Fixed Support Conditions and No Infill.

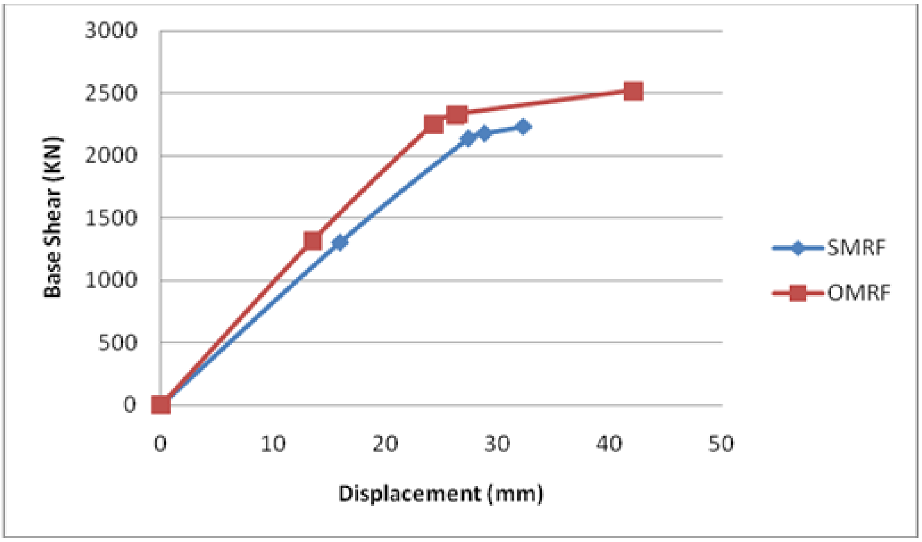

Fig. 5.3: Shows The Pushover Curves of 8S7B OMRF AND 8S7B SMRF With Fixed Support Condition And No Infill.

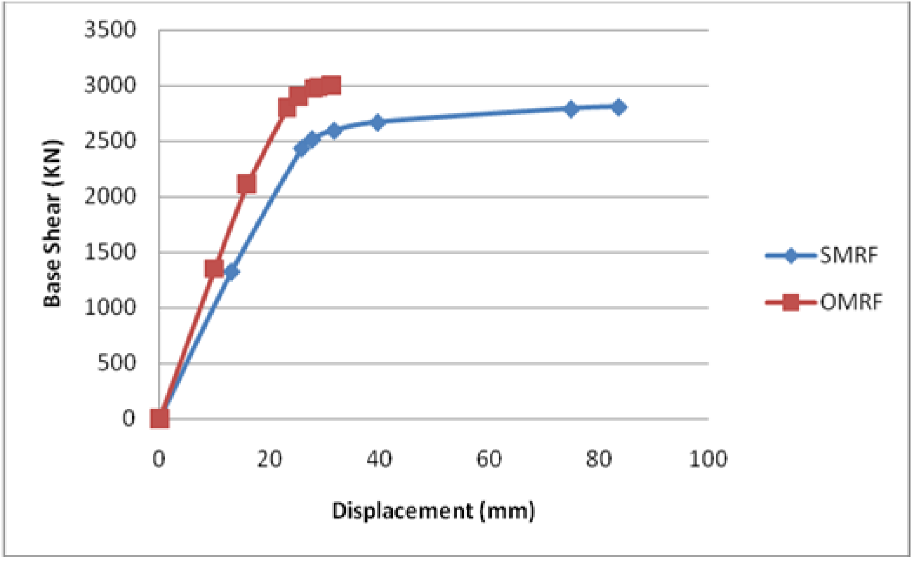

Fig. 5.4: Shows The Pushover Curves of 10S7B OMRF AND 10S7B SMRF With Fixed Support Condition and No Infill.

Table - 5.1
Performance Comparison of OMRF And SMRF Buildings With Fixed Support

Building Configuration	*BASE SHEAR (KN)*		*% Increase in Base Shearfor OMRF*	*ROOF DISPLACEMENT (mm)*		*% Increase in Displacement for SMRF*
	OMRF	*SMRF*		*OMRF*	*SMRF*	
4S7B	*1850*	*1437*	*28%*	*130*	*151*	*16%*
6S7B	*2131*	*1959*	*9%*	*148*	*166*	*12%*
8S7B	*2521*	*2230*	*13%*	*131*	*145*	*10%*
10S7B	*3004*	*2807*	*7%*	*140*	*186*	*33%*

It can be seen from Table 5.1 that OMRF buildings has about 7-28% more capacity to resist base shear, while SMRF buildings has about 10-33% more deflection than OMRF buildings.

C. STOREY WISE COMPARISON OF SMRF BUILDINGS

The buildings with the same number of bays are considered in this comparative study. The buildings considered are 4S7B SMRF, 6S7B SMRF, 8S7B SMRF AND 10S7B SMRF, all having 7 bays. The pushover curves are plotted.

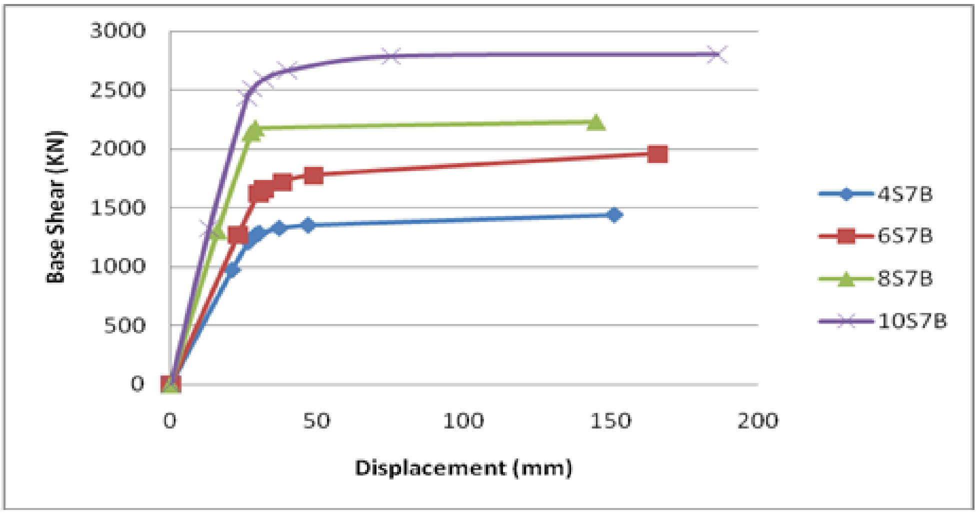

Fig. 5.5: Showing The Storey Wise Comparison of SMRF Buildings With Fixed Support Conditions And No Infill.

D. BAY WISE COMPARISON OF SMRF BUILDINGS

The buildings with the same number of storeys are considered in this comparative study. The buildings considered are 6S2B SMRF, 6S4B SMRF AND 6S6B SMRF, all having 6 storeys. The pushover analysis is performed and Base shear versus Displacement graphs are plotted.

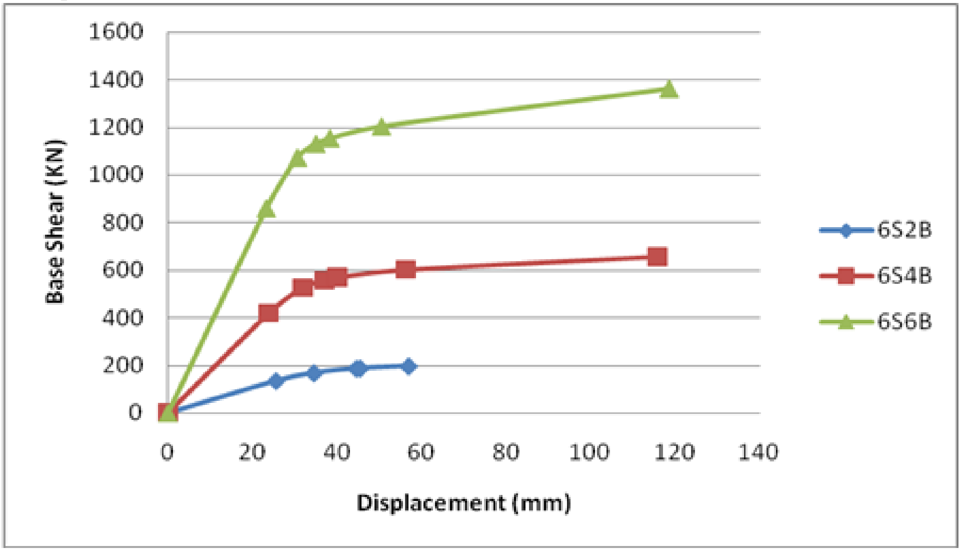

Fig. 5.6: Showing The Bay Wise Comparison of SMRF Buildings With Fixed Support Conditions and No Infill.

E. COMPARISON OF SMRF BUILDINGS WITH STRONG AND WEAK INFILL:

FIXED SUPPORT CONDITION.

In this study, the performance of SMRF buildings with strong and weak infill is compared. For strong infill condition the value of modulus of elasticity of brick is taken as 5000 MPa whereas for weak infill it is taken as 350 MPa.

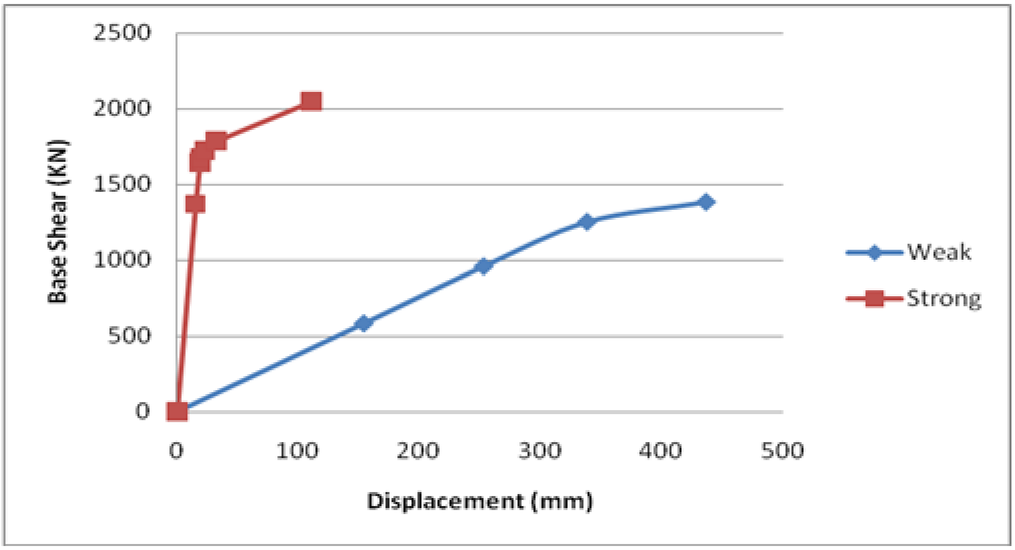

Fig. 5.7: Showing The Comparison of 4S7B SMRF Building With Strong And Weak Infill And Fixed Support Conditions.

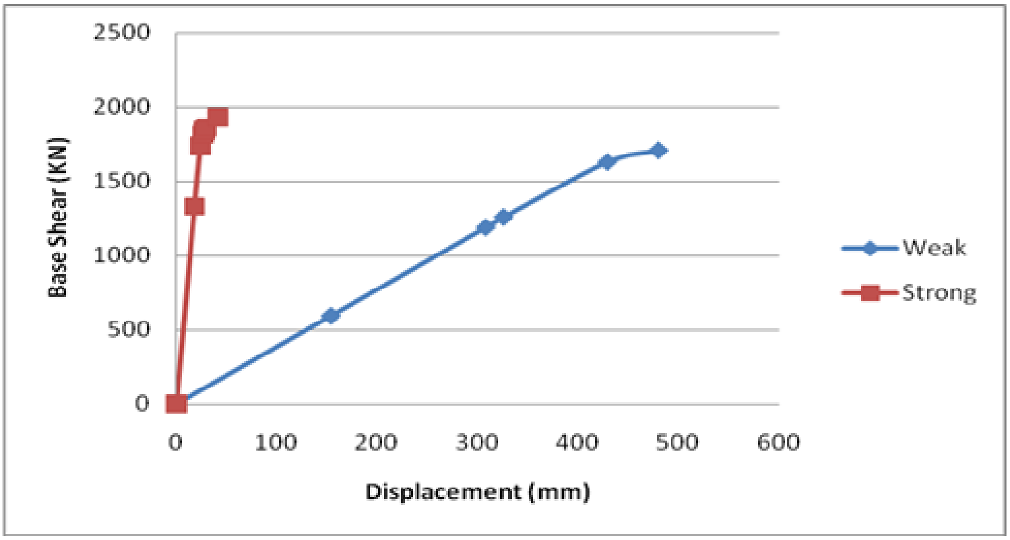

Fig. 5.8: Showing The Comparison of 6S7B SMRF Building With Strong And Weak Infill And Fixed Support Conditions.

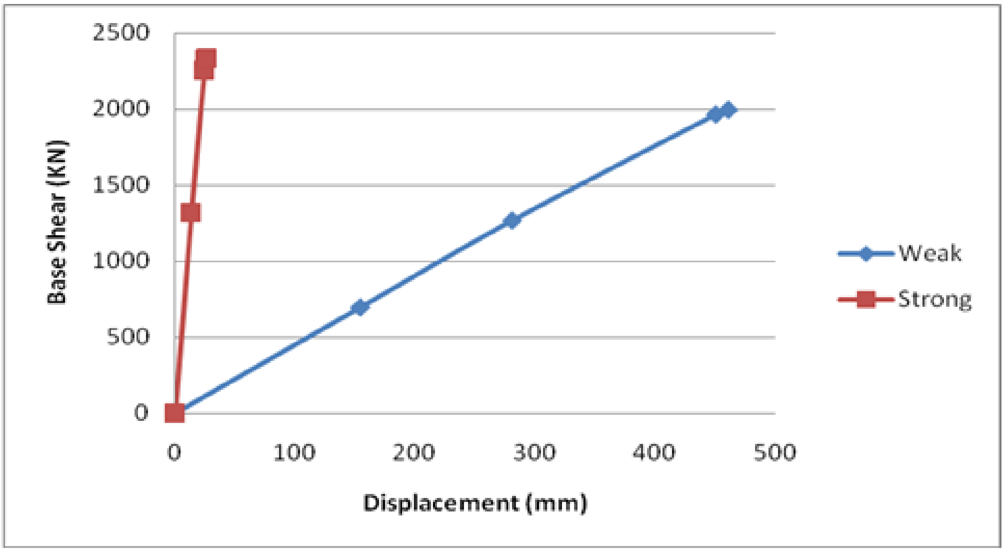

Fig. 5.9: Showing The Comparison of 8S7B SMRF Building With Strong And Weak Infill And Fixed Support Conditions.

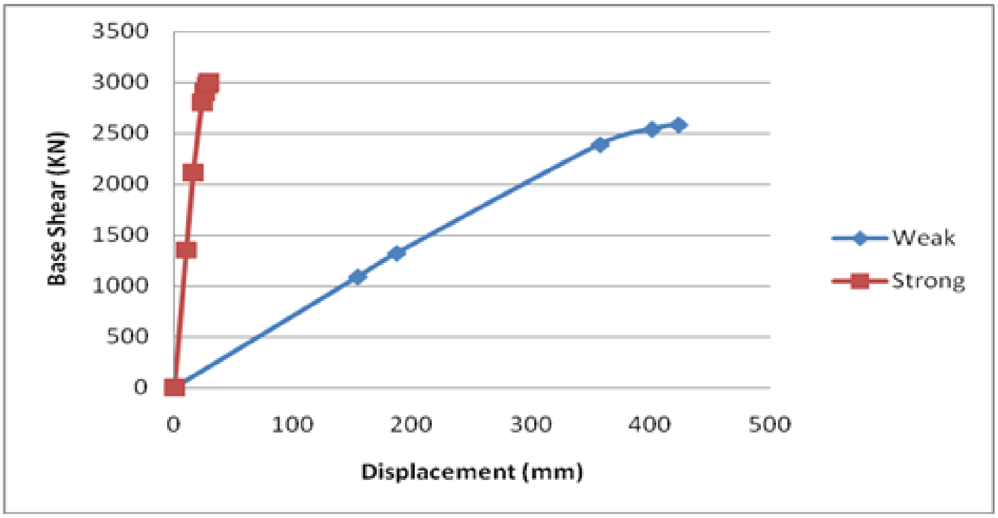

Fig. 5.10: Showing The Comparison of 10S7B SMRF Building With Strong And Weak Infill And Fixed Support Conditions.

VI. CONCLUSIONS

The performance assessment of buildings designed as Special Moment Resisting Frame (SMRF) and Ordinary Moment Resisting Frame (OMRF) is studied for different building configurations, infill conditions and support conditions. The buildings are designed and modelled using computational software. Nonlinear 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. Several comparative studies are carried out to study the behaviour of SMRF and OMRF.

- The behaviour of SMRF building and OMRF building with no infill and fixed support conditions are compared. It is found that the buildings designed as SMRF perform much better compared to the OMRF building. The ductility of SMRF buildings is almost 10 to 33% more than the OMRF buildings in all cases, the reason being the heavy confinement of concrete due to splicing and usage of more number of stirrups as ductile reinforcement. It is also found that the base shear capacity of OMRF buildings is 7 to 28% more than that of SMRF building.
- The SMRF buildings with same number of bays and different number of storeys are compared. The pushover curve is plotted and it 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 push over curve.
- The SMRF buildings with same number of storeys and different number of bays are compared. The pushover curve is plotted and it is found that the magnitude of base shear that can be resisted increases with increase in the number of bays. As the number of bays increases from 2 to 4, the base shear capacity will increase by 1.3 times. And when it increases from 4 bays to 6 bays, the magnitude of the base shear the building can withstand increase by 2 times It can be proposed that the number of bays play a major role in the stability of the buildings considered for the present study.
- The SMRF buildings with strong and weak infill are compared and it is found that the buildings with strong infill can withstand a higher magnitude of base shear when compared to those with weak infill. It can be concluded that the SMRF buildings with stronger infill have base shear capacity of about 1.16 to 1.5 times more than that of SMRF buildings with weak infill. Although, a precise conclusion cannot be drawn out for ductility, it can be suggested that weak infill are not preferred due to their linear nature in the pushover curve.

Although pushover analysis gives an insight about nonlinear behaviour imposed on structure by seismic action, pushover analysis were not able to reasonably capture neither the exact sequence of hinging nor their locations in some cases. Therefore, 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, considering different periods, strength ratios, and earthquake ground motions, however, will be required to establish definite criteria for efficient design of reinforced concrete special moment resisting frame system.

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