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Seismic Performance Evaluation of Multistoried RC framed buildings with Shear wall

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Abstract: The dual structural system consisting of special moment resisting frame (SMRF) and concrete shear wall has better seismic performance due to improved lateral stiffness and lateral strength. A well designed system of shear walls in a building frame improves its seismic performance significantly. The configurations of RC moment resisting framed building structure with different arrangements of shear walls are considered for evaluation of seismic performance, so as to arrive at the suitable arrangement of shear wall in the structural framing system for better seismic resistance. A comparison of structural behaviour in terms of strength, stiffness and damping characteristics is done by arranging shear walls at different locations/configurations in the structural framing system. The elastic (response spectrum analysis) as well as in-elastic (nonlinear static pushover analysis) analyses are carried out for the evaluation of seismic performance. The results of the study indicate that the provision of shear walls symmetrically in the outermost moment resisting frames of the building and preferably interconnected in mutually perpendicular directions forming a core will lead to better seismic performance.

Index Terms - Seismic performance , Shear walls , Base shear , Lateral displacements , Lateral stiffness.

1 INTRODUCTION

Reinforced concrete (RC) structural walls, conventionally known as shear walls are effective in resisting lateral loads imposed by wind or earthquakes. They provide substantial strength and stiffness as well as the deformation capacity (capacity to dissipate energy) needed for tall structures to meet seismic demand. It has become increasingly common to combine the moment resisting framed structure for resisting gravity loads and the RC shear walls for resisting lateral loads in tall building structures.

Generally few shear walls are located symmetrically in the building plan as per the architectural requirements of the buildings or concentrated centrally as core wall to provide the lateral load resistance and lateral stiffness required to limit the lateral deformations to acceptable levels.

Many choices exist with multiple shear walls or shear wall cores (shear walls arranged in box type structure) in a tall building with regard to their location in plan, shape, number, and arrangement.

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Wallace, 2007 , Panjan et.al., 2010 , Bozdogan, 2011

and Kubin et.al., 2008[5]] has been carried out to study the behaviour of reinforced concrete shear walls and frame-shear wall dual systems, the need is felt to study the behaviour of frame – shear wall structural system with different arrangements of shear walls in a frame – shear wall dual system for better lateral strength and stiffness.

Dolsek developed a computing environment for the seismic performance assessment of reinforced concrete frames in Matlab in combination with OpenSees. Seismic performance assessment of an eight-storey frame is performed using incremental dynamic analysis with consideration of the modeling uncertainties [Dolsek, 2010][1].

Mohan and Prabha studied the behaviour of shear walls of different shape and compared the results of the "Time History analysis", "Response Spectrum Analysis" and the "Equivalent Static Analysis", [Mohan R. and Prabha C.,2011][6].

An approximate method which is based on the continuum approach and one dimensional finite element method to be used for lateral static and dynamic analyses of wall-frame buildings is presented by [Bozdogan Bozdogan K.B.,2011][4]. [Deierlein et.al.,2010][7] discussed in detail the modeling issues, nonlinear behavior and analysis of the frame – shear wall structural system.

2. Numerical Example Considered:

The numerical examples namely, six storied, twelve storied, twenty four storied and thirty six storied moment resisting RC framed building, having the plan dimensions of 30m x 20m with bay length of 5m in both directions and floor height of 3m are considered in the study. The structural configurations considered, indicating the arrangement of shear walls are presented in fig.1.a. and fig.1.b. The total length of shear walls is 40m for models 2, 3 and 4 and 80m for the models 5, 6, 7 and 8 in both directions for all the models as described in table 1.

Properties of the Concrete : Modulus of Elasticity = 28500MPa, Poisson's ratio = 0.2, thickness of slab is 0.125m and. Properties of the Reinforcement Steel : Modulus of Elasticity = 210000MPa, Poisson's ratio = 0.3. Properties of the Masonry : Modulus of Elasticity = 3500 MPa, Poisson's ratio = 0.2, thickness of wall is 0.23m. Properties of shear wall: thickness of reinforced concrete shear wall is 0.23m.

The structures are modeled as 3D frame. The eight models of each of six storied, twelve storied, twenty four storied and thirty six storied RC framed building structures are prepared.

3. Modelling and analysis of building structure:

The frame elements are modelled as beam elements. The masonry infill is modelled as quadrilateral shell element (with in-plane stiffness) of uniform thickness of 0.23mm. The nonlinear properties for columns are assumed to be a plastic P-M-M hinge and for the beams as plastic moment hinge. The plastic hinges are defined according FEMA 356 with the designed rebar distribution. The shear walls are modelled with Mid-Pier frame elements with P-M-M Interaction hinge. The results of different models are compared in terms of overall behaviour of the structural systems. The slab is modelled as rigid (in-plane) diaphragm.

The load deformation responses of the numerical models were followed through to collapse by means of the capacity curve. The nonlinear static Pushover analysis is performed for RC frame building with masonry infill and shear walls. The software, ETABS [CSI, 2004][8] was used for the elastic analysis using response spectrum approach . and to perform pushover analysis.

4. Results and Discussion:

The structure is analyzed for the seismic loads and load combinations as per the Indian standards, IS-1893(Part-1)-2002, for Seismic zone = Zone V, Importance factor = 1, Soil type = II, Live load = 3.5KN/m^2 and designed as per IS-456-2000. Full dead load (self weight) and 50% of live (Imposed) load constitute the seismic weight.

The "Seismic Analysis" using "Response Spectrum Method" and "Nonlinear Static Pushover Analysis" are performed on all the thirty two models namely, the eight models of 6 stories, eight models of 12 stories, eight models of 24 stories and eight models of 36. The results of the elastic analysis using "Response Spectrum Method", namely the lateral displacements in mm ,are presented in figs.2-5. The natural period and the base shear are presented in the Tables 2. The results of the in-elastic analysis using the "Nonlinear Static Pushover Analysis" namely, the displacement ratio (d_i/d_1= top displacement of model-i / top displacement of model-1), the base shear ratio (V_{Bi} / V_{B1} = base shear of model-i / base shear of model-1), the effective damping and effective period at performance point are presented in the Figures 6-9.

Table 1 Details of numerical models

Model No.	Structural details
1	RC moment resisting frame with full masonry infill without shear walls
2	RC moment resisting frame with replacement of masonry infill by shear walls at all corners with the total length of shear wall as 40m in the plan.
3	RC moment resisting frame with replacement of masonry infill by shear walls symmetrically placed on all sides with the total length of shear wall as 40m in the plan.

4	RC moment resisting frame with replacement of masonry infill by shear walls symmetrically placed in the central core with the total length of shear wall as 40m in the plan.
5	RC moment resisting frame with replacement of masonry infill by shear walls symmetrically placed at all corners and central core with the total length of shear wall as 80m in the plan.
6	RC moment resisting frame with replacement of masonry infill by shear walls symmetrically placed on all sides and central core with the total length of shear wall as 80m in the plan.
7	RC moment resisting frame with replacement of masonry infill by shear walls symmetrically placed on all sides with the total length of shear wall as 80m in the plan.
8	RC moment resisting frame with replacement of masonry infill by shear walls symmetrically placed in the form of a core with the total length of shear wall as 80m in the plan.

Table 2. Results of **"Response Spectrum Analysis"** for 6, 12, 24 & 36 models

Model No.	**Natural Period In, sec**			
	6	12	24	36
1.	0.242	0.513	1.08	1.69
2.	0.195	0.446	0.957	1.54
3.	0.182	0.423	0.911	1.49
4.	0.175	0.419	0.923	1.48
5.	0.155	0.378	0.828	1.36
6.	0.151	0.372	0.832	1.37
7.	0.141	0.344	0.744	1.24
8.	0.136	0.342	0.745	1.24

Model No.	**Base Shear in kN**			
	6	12	24	36
1.	7026	14707	15393	18609
2.	7013	14638	17585	20538
3.	7082	14685	18376	21521
4.	7148	14629	18081	21776
5.	7295	14763	20492	23276
6.	7306	14706	20278	23397
7.	7455	14934	23063	25177
8.	7525	14913	22877	25528

4.1 Observations on the results of elastic analysis using "Response spectrum" procedure :

1. It is observed from the storey displacement graphs (fig. 2-5), the 6 and 12 storied buildings behave like shear building since the height of the building being less than or nearly equal to the lateral dimension of the building.

The 24 and 36 storied buildings exhibit flexural behavior since the height of the building being much greater than the lateral dimension.

2. The top lateral displacement in x-direction, for the model-3(side shear wall) and model-4(core + side shear wall) are nearly the same, for the model-5(core + corner shear wall) and model-6(core + side shear wall) are nearly the same and model-7(side shear wall), model-8(core shear wall) are nearly the same. This is true for both 12 and 24 storied structures studied. Although similar trends are observed in y direction, the top displacements, in general are greater in the y-direction compared to the top displacements in x-direction. This is because of lesser lateral stiffness due to lesser plan dimension in the y direction

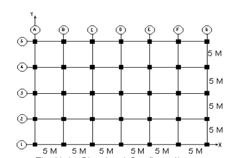

Fig.1(a) Structural Configuration of the Frame (Plan)

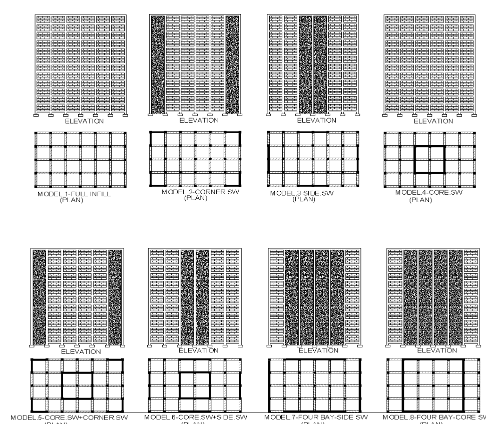

Fig.1(b) . Structural Configuration of the Frame and Shear walls (Plan & elevation)

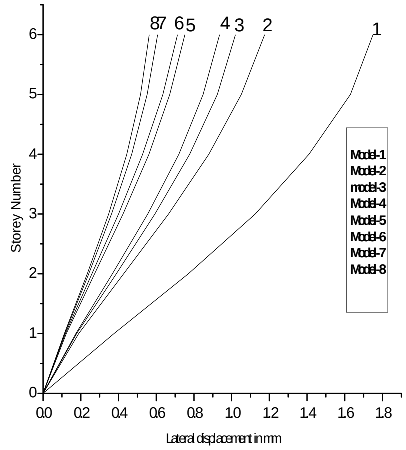

Fig.2 Lateral displacement in x-direction

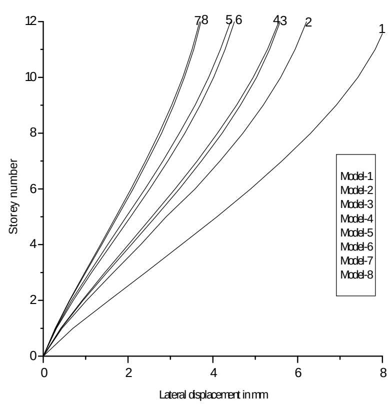

Fig.3 Lateral displacement in x-direction

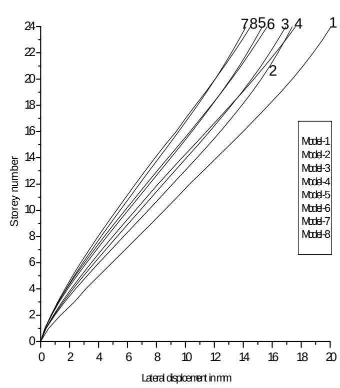

Fig.4 Lateral displacement in x-direction

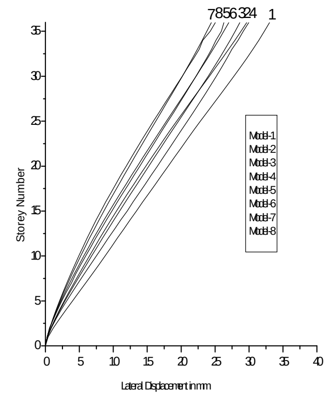

Fig.5 Lateral displacement in x-direction

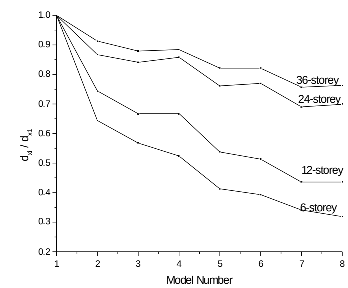

Fig.6 Displacement ratio in x-direction

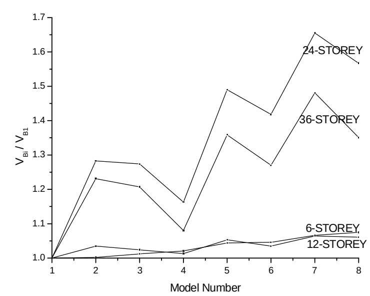

Fig.7 Base shear ratio in x-direction

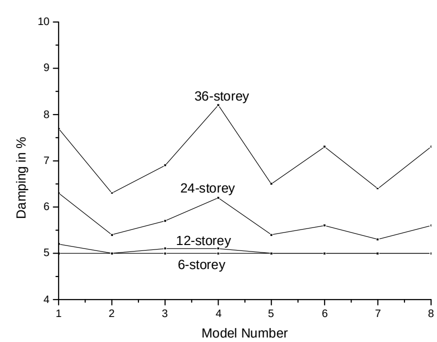

Fig.8 Damping in x-direction

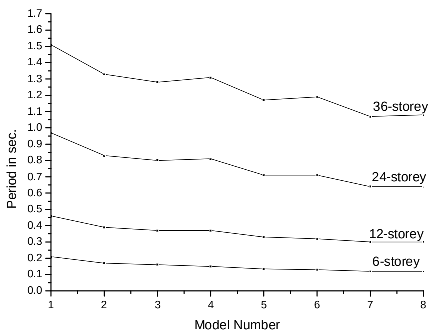

Fig.9 Period in x-direction

3. Amongst the models 1,2,3 and 4, the top lateral displacement of model 4 is the least for 6 and 12 storied buildings while the top lateral displacement of model 3 is the least for 24 and 36 storied buildings. It is to be noted that the moment of inertia is greater for model-3. Therefore the increased moment of inertia has influence only in the taller structures since the tall structures exhibit predominantly the flexural behavior. It is also worth noting that the top displacement of model-3 is 87% of that of model-1 (without shear wall) for 36 storied building where as it is 58% for 6 storied building .

4 Amongst the models 5,6,7 and 8, the top lateral displacement in x-direction of model 8 is the least for 6 storied building while the top lateral displacement of model 7 is equal to that for 12 storied building and the least for 24 and 36 storied buildings. It is to be noted that the moment of inertia of the model-7 is greatest about y-axis. This behviour indicates that the increased moment of inertia has influence only in the taller structures since the tall structures exhibit predominantly the flexural behavior. It is also worth noting that the top displacement of model-7 is 74% of that of model-1 (without shear wall) for 36 storied building where as it is 35% for 6 storied building.

4.2 Observations on the results of in-elastic analysis using "Nonlinear Static Pushover Analysis" procedure :

1. The lateral stiffness is known to be inversely proportional to the lateral displacement. It is inferred from fig. 6 that the model-1 (without shear wall) has the least stiffness and the models 7 and 8 have comparatively very large stiffness, as the displacement ratios, d_{xi}/d_{x1} and d_{yi}/d_{y1} are the very small for the models 7 and 8 at performance point. Again for these models namely, models 7 and 8 at performance point, the displacement ratios, d_{xi}/d_{x1} and d_{yi}/d_{y1} are the very small (around 0.3) for 6 storied building while the displacement ratios, d_{xi}/d_{x1} and d_{yi}/d_{y1} are the large (around 0.8) for 36 storied building indicating that the influence of shear wall is quite large for shorter buildings than for taller buildings. Among the frames with the shear wall, it is observed that the model 8 (Four-Bay Core shear wall) has the least lateral displacement at the roof level at performance point among the frames with shear walls. This indicates that the placing of shear walls symmetrically in the outermost frames (models 7 and 8) and preferably interconnected in mutually perpendicular direction forming the core (model-8) will have least lateral displacement at the roof level at performance point and hence such a configuration will have greater lateral stiffness.

2. The lateral load resistance capacity (base shear at performance point) of the masonry infill frame is very much less than the frames with shear walls for the tall buildings which is evident from the fig. 7 The base shear ratio at performance point is closer to 1, for shorter buildings and the same is much greater for tall buildings. This indicates that the provision of shear walls has significant influence on strength in taller buildings.

Among the frames with the shear wall, it is observed that the model 8 (Four-Bay Core shear wall) has The lateral load resistance capacity (lateral load resistance at performance point) greatest among the frames with shear walls, models 5,6,7 and 8. However the lateral load resisting capacity (base shear) of model-8 is marginally greater than that for model-7 in the y-direction. This indicates that the placing of shear walls symmetrically in the outermost frames (models 7 and 8) and preferably interconnected in mutually perpendicular direction forming the core (model-8) will have greater lateral load resistance.

On the study of stiffness and strength parameters, it is observed that the lateral displacement is more and the lateral load resistance capacity (base shear) is less in the Y-direction in comparison to these parameters in the X-direction. This is so because the lateral dimension and hence the lateral stiffness of the frame is comparatively less in the Y-direction.

3. The influence of shear walls is significant in terms of the damping characteristics at the performance point only for tall buildings as indicated in the fig. 8.

4. It is obvious that the taller buildings have longer periods. Amongst the building models of the same height, the influence of shear walls is significant in tall buildings whereas the periods at the performance point of all the models are nearly the same for short buildings as seen from the fig. 9 . The periods at the performance point of the models 7 and 8 are the shortest among all the models of the building of any given height indicating the comparatively higher lateral stiffness of models 7 and 8.

5. Conclusions :

In general, the provision of shear wall has significant influence on lateral strength in taller buildings while it has less influence on lateral stiffness in taller buildings. The provision of shear wall has significant influence on lateral stiffness in buildings of shorter height while it has less influence on lateral strength. The influence of shear walls is significant in terms of the damping characteristics and period at the performance point for tall buildings. The structural configuration of model-8 has exhibited superior structural performance in terms of both the stiffness and strength in the elastic as well as in the nonlinear range up to performance point. The model-7, however also has closer structural performance to the model-7, in terms of both the stiffness and strength in the elastic as well as in the nonlinear range up to performance point. Hence the structural configurations of models 7and 8 not only provided the improvement in lateral load resistance capacity but also the increase in lateral stiffness. The frame without the shear walls but with masonry infill exhibited inferior structural performance in terms of both the stiffness and strength. Provision of shear walls symmetrically in the outermost moment-resisting frames and preferably interconnected in mutually perpendicular direction forming the core will have better seismic performance in terms of strength and stiffness.

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