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Toward Effective Distribution of Shear Walls in Reinforced Concrete Buildings Subjected to Earthquake Loading

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Abstract: The current paper presents the results of investigations of the effect of shear walls locations in reinforced concrete buildings on general structural performance when being subjected to lateral forces caused by earthquakes. The use of shear walls as a part of structural system to resists earthquakes is very common worldwide. However, they are usually located in buildings taking into consideration architectural constraints which results in bad structural performance. In this paper, the effects of different shear wall locations on lateral displacements and base shear are thoroughly examined to give recommendations on the best location of shear walls. It was found that shear walls are more effective when being placed at all sides of the periphery of a building while using a core wall at the center. The analysis results clearly show that the use of core shear wall at the center, the U-shaped shear walls would result in torsional mode of vibration which is not desirable.
Keywords: Shear walls, Reinforced concrete, Equivalent lateral method, Base shear, drift.

I. INTRODUCTION

The construction of tall building has become much more popular worldwide due to the scarcity of the land. Tall buildings are so often characterized by large lateral drifts due to lateral loads like seismic loadings. The use of ductile moment resisting frames (MRFs) as a structural system to resist earthquake forces is not always enough. To meet the demand of limiting drifts to acceptable values recommended by codes, shear walls are used. The use of such structural walls would not only decrease drifts but also reduce internal forces i.e. shear and moments caused by lateral loads inside columns and beams of MRFs [1].

Shear walls, if properly located inside a building, can greatly enhance the structural performance during earthquakes. Unfortunately, in most daily design, the distribution of shear walls in buildings is governed mainly by architectural constraints. Shear walls are placed arbitrarily around stair cases and elevators as shown in Figure 1, which results in bad structural behaviour during earthquakes. Such distribution would usually increase the distance between center of mass and center of rigidity which leads to negative torsional effects on the building.

Limited number of research papers available on the investigation of the effect of shear wall locations on structural performance of buildings. M. Ashraf and others [1] have studied the effect of shear wall locations on the internal bending forces inside beams and columns. They have drawn some remarkable conclusions on the on the effect of changing shear walls locations on the internal forces in beams and columns. However, only four cases of shear walls locations have been studied. The effect of flat slab with different shear walls locations on the lateral displacements and fundamental period of vibrations have been studied by K. G. Patwari1 and L. G. Kalurkar [2]. On the other hand, S. Tuppad and R. J. Fernandes [3] have suggested the use of core shear wall at the center the building as the best location in multi-storey buildings. However, the use of such core at center would make the building more vulnerable to torsion. The need for more comprehensive study on the effect of shear walls locations on lateral displacements, fundamental period of vibration and base shear is inevitable. So, the primary objective of this paper is to comprehensively examine the effect of different locations of shear walls on building structural performance and to suggest an effective location of shear wall to get most favorable behaviour.

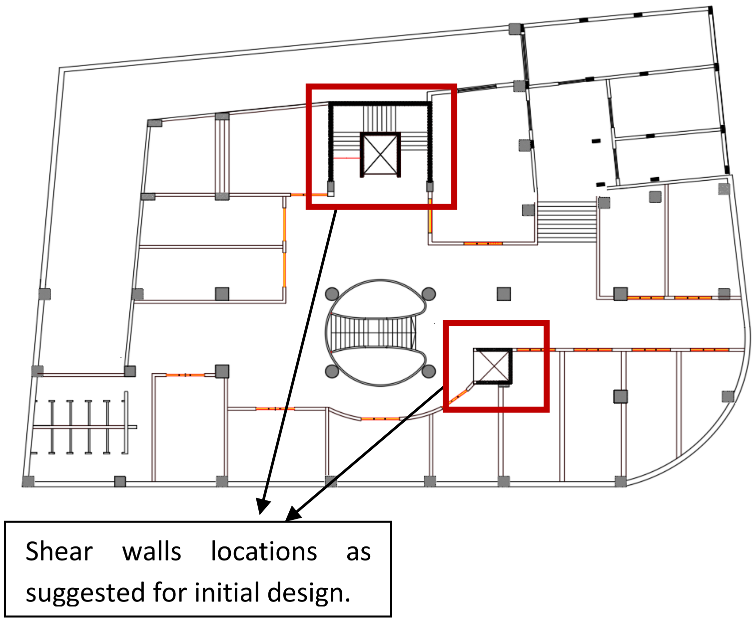

Figure 1. Example of a building where shear walls are located around the elevator and the stair case to satisfy architectural constraints.

II. METHODOLOGY OF THE WORK

A seven-storey regular building is considered for making the comparison. The effect of changing the location of shear walls is considered by building fourteen structural models on Etabs [4] with different configurations for the shear walls to reflect the different choices that could be considered by a designer. The total area of shear walls is kept the same in all model as increasing or decreasing that area would increase or decrease the lateral stiffness. So, this way the effect resulted from changing the shear walls areas has been excluded and the focus is on the location of the walls. Equivalent lateral method is used for seismic analysis of the building. Finally, the results are compared and presented.

III. DESCRIPTION OF THE MODELS

Figure 2 shows the regular seven storeys building which consists of 5 bays of 5m each in x and y directions. The height of each storey is 3 m and solid slab of 25 cm with square beams of 50 cm in two directions are used. The columns are square with 50 cm dimensions. The live load and superimposed dead load are 3 kN/m2 and 4 kN/m2 respectively. The contribution of the live load to seismic mass is taken to be 30% The building is checked against gravity loading and found to be satisfactory. The figures below present all models with all shear walls locations used in this study.

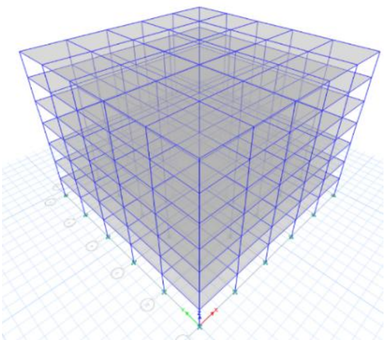

Figure 2. Model 1 - moment resisting frames (no shear walls).

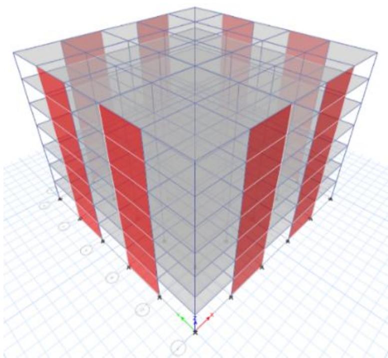

Figure 3. Model 2 - shear walls at periphery

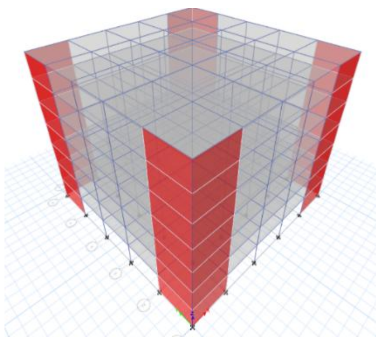

Figure 4. Model 3 - L-shaped shear walls at exterior corners

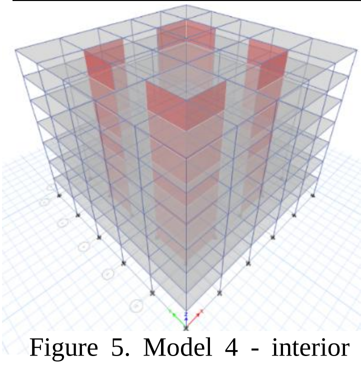

Figure 5. Model 4 - interior L-shaped shear walls at interior

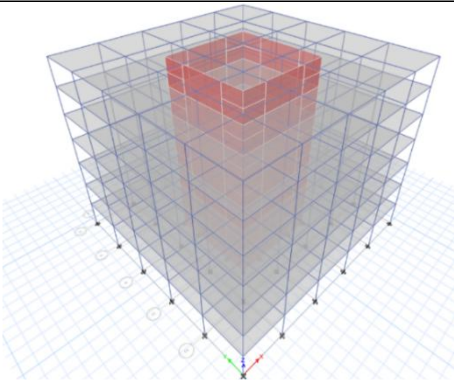

Figure 6. Model 5 - interior core at center

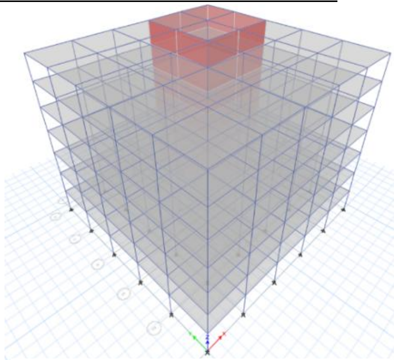

Figure 7. Model 6 - core at one of the building corners

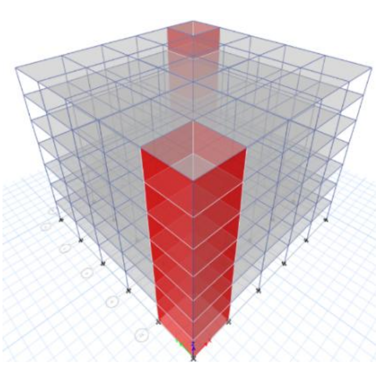

Figure 8. Model 7 - two shear wall cores at opposite corners

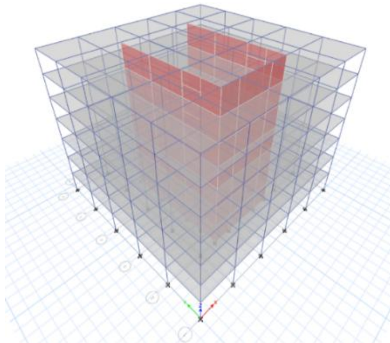

Figure 9. Model 8 - U-shaped shear walls at the center.

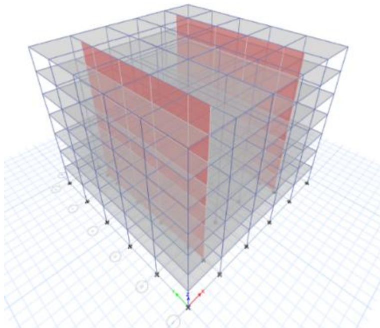

Figure 10. Model 9 - too long shear walls in one direction

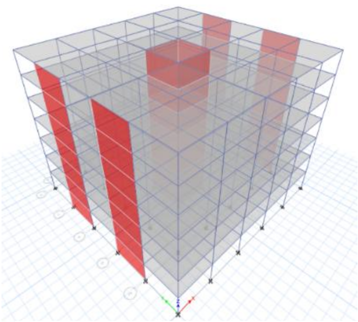

Figure 11. Model 10 - core shear wall at center with walls at periphery in one direction

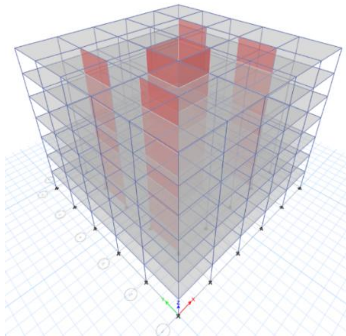

Figure 12. Model 11 - core shear wall at center with walls at the inside in one direction

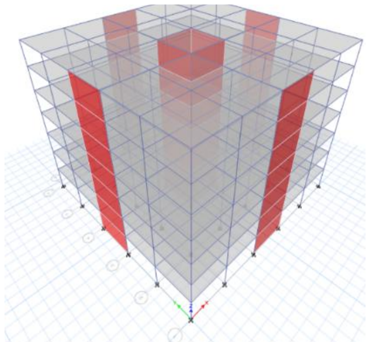

Figure 13. Model 12 - core shear wall at center with walls at periphery in two directions

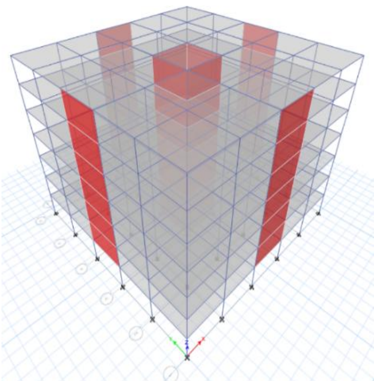

Figure 14. Model 13 - core shear wall at center with wall at periphery in two directions

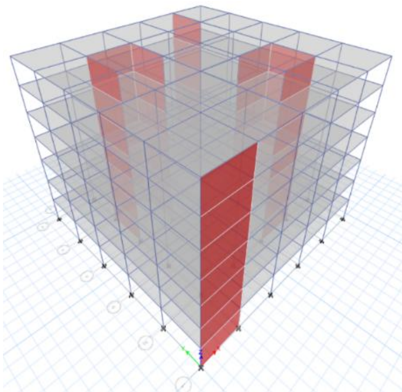

Figure 15. Model 14 - random distribution of shear walls

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IV. METHOD OF ANALYSIS

IBC code [5] does not give all required details about the calculations of earthquake-induced forces. However, it requires that forces must be calculated according to ASCE standards [6]. The ASCE outlines three methods to calculate the seismic forces; equivalent lateral force procedure, modal response spectrum analysis and time-history analysis. The latter is a dynamic method used for analysis of special structures like nuclear plants and it will not be used in this study. Response spectrum is a dynamic method where the distribution of the seismic forces depends largely on the natural modes of vibration of a structure. The earthquake behaviour of regular structure is dominated by it first or fundamental mode of vibration and the dynamic analysis could be essentially simplified to static one [7]. This represents the essence of the equivalent lateral approach where an equivalent static lateral force is applied at each floor level. Since the structure considered in this study is regular, equivalent lateral method is used for earthquake analysis. The following parameters are used to define earthquake load using equivalent lateral method based on ASCE standards.

V. RESULTS AND DISCUSSION

Following the application of equivalent lateral method, all structural models built in Etabs are compared in term of fundamental period of vibration, base shear and drift in each model. Firstly, the base shear of model 1 is less than that of other models. This clearly indicate that the use of shear walls increases the stiffness of the structures and hence attract more seismic forces. Secondly, changing the shear walls locations has no effect on the total base shear since the mass of the building and total area of shear walls in each model are the same. However, the drift of each model has been seriously affected by locations of shear walls.

The discussion starts with model 1 (where no shear walls used in the building). The drift is the maximum in model 1 compared to all other models. Adding shear walls would greatly decrease drifts caused by lateral loads. Model 6 (where interior core only is used) has least drift among all models. However, its fundamental model of vibration is torsion which is not preferable. The use of L-shaped shear walls at the four corners of the building would prevent torsional behaviour. However, it results with drifts larger than that of model 6. On the other hand, the use of core open U-shape core (model 5) would result in small drifts, but the building will experience torsional mode of vibration. Figure 16 summarizes the drift in each model for earthquake in X-direction.

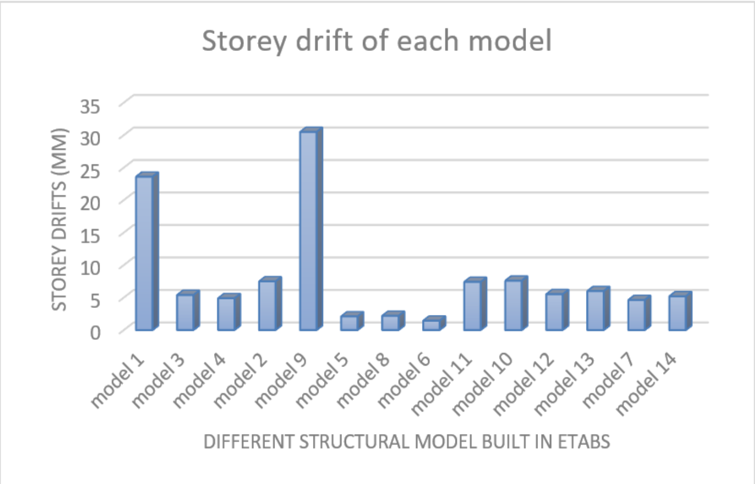

Figure 16. Storey drift for each model

Based on the results obtained and examining carefully the fundamental mode of vibrations of all models, the following distribution of shear walls would result in torsional behaviour of the building.

1. Closed core shear wall.
2. Closed shear wall at one of the corners.
3. Interior open concrete shear wall.
4. Core shear wall with interior walls in one direction.

It is clear from model 6 that locating very long symmetrical shear walls in one direction would greatly reduce the drift in that direction. However, the drift in the other direction would be large. Comparing the fundamental period of vibration of all models, adding shear walls increases the stiffness of a structure and deceases its period. However, the period of model 5 is very large in comparison to other models where shear walls are used. This is primarily because very long shear walls are used in Y-direction which make the structure stiff compared the X-direction. So, too long walls in only one direction should not be used.

Model 13 represents a case where two closed shear walls are used at opposite corners. The center of mass coincides with the center of rigidity and no eccentricity exists in any direction. However, the fundamental model of vibration in this model was a combination of x and y translation. So, the use of such configuration is not recommended. Model 14 represents a case where a designer might locate shear walls randomly in a building. Such distribution, which is unfortunately common as a first draft among inexperienced engineers and architects, could lead to too bad and unfavorable torsional behaviour.

VI. CONCLUSIONS

Effect of locations of shear walls on the general structural behaviour of buildings during earthquakes has been carefullystudied in this current paper. The equivalent lateral method is used as method of analysis since the structure considered in this study is regular. The followings are the main conclusions drawn from this study:

- It was found that the presence of shear walls in a building would attract more seismic forces due to increased stiffness but will reduce drifts caused by earthquakes.
- The random distribution of shear walls in a plan should be strictly prevented as it causes eccentricity between center of mass and center of rigidity. An example of random distribution is the allocation of shear walls around elevators and stair cases which are usually located at the off-center of the building.
- The use of interior closed core shear wall, open interior U-shaped shear walls, core at corner, core and shear walls in one direction, core and interior shear walls in two direction and the inclusion of soft storey is not recommended at all. Each case will result in the first mode of vibration to be torsion which is considered as bad behaviour.
- Based on drifts observed in different configurations of shear walls, the use of core wall at center with shear walls distributed at periphery is highly recommended.
- The inclusion of soft storey caused by removal of shear walls at the ground floor must be prevented.
- The use of core central shear walls would result in small drifts. However, the structure would be subjected to torsional mode of vibration.
- It is more effective to place shear walls at the periphery of the building rather than placing them at the interior of the building
- The use of core at center would enhance the stiffness of the building compared to separate straight walls. However, stress concentrations at edges of core or L-shaped occur and need to be designed for.

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