A comparative Study to Analyze the Effectiveness of Shear Walls in Controlling Lateral Drift for Medium to High Rise Structures (10 – 25 Storeys)

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Abstract. 2005 Earthquake brought vast destruction in Pakistan which resulted in revision of Building Code of Pakistan (BCP). Inclusion of shear walls adds stiffness to structure and aids in reducing lateral drift under seismic loads. Important aspects concerning design of shear walls are its placement in structure and the cross section (i.e. width to thickness ratio) keeping in view torsional stresses, economy and ductility of structure. A comparative study is carried out using ETABS software by varying location and cross section of shear wall for Stock Exchange Building, Islamabad. Maximum lateral drift, storey drift, base shear forces and time period of structure are important parameters considered. Response spectrum analysis has been carried out on 4 cases depending upon location of shear wall and best possible case is selected which is finally compared with actual building. It has been concluded that original location with 6in thick shear wall could have been more economical and ductile than existing 12in thick wall keeping in view the allowable lateral drift and base shear forces.

Keywords: Shear Walls, Structural Analysis, Seismicity of Pakistan, High Rise Buildings, Case study.

1. Introduction

A major earthquake struck Pakistan on Oct 8th, 2005 with recorded magnitude of 7.9 on Richter scale which caused major destruction in Northern parts of the country [1], [2]. Margalla Tower situated in Islamabad also collapsed due to structural failure as consequence to this earthquake. This earthquake resulted in 100,000 deaths, 138,000 injured and 3.5 million displaced. Incorporation of Shear wall along bracing is normally used technique in Pakistan to control lateral drift which adds stiffness to the structure and hence lateral drift can be controlled effectively.

Islamabad, the Capital of Pakistan, is situated in seismic zone 2B as per seismic map given in seismic provisions of Building Code of Pakistan (BCP 2007) [3]. The city has a good number of medium to high rise buildings and proper design and analysis is required especially when the building is subjected to lateral loads. Many high rise buildings are a part of future endeavours for the Capital of Pakistan.

2. Problem Statement

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Due to the seismic vulnerability and importance of life and structures, detailed analysis and design of shear walls is necessary. Shear walls have been in use for medium to high rise structures but generally the design is too conservative. This not only affects the economy but also the structural behavior under cyclic loads. Using thicker cross section induces large base shear forces, minimizes ductility and reduced time period of structure

3. Research Significance

Shear walls with varying thicknesses have been analyzed to understand the structural behaviour and also limiting lateral drift to permissible values. This can serve as a guideline to consider and analyse all possible cases during the design phase and finally selecting the best possible case on basis of analysis results.

4. Case Study: Stock Exchange Building, Islamabad

4.1. Introduction

Islamabad Stock Exchange building is located in Jinnah Avenue, Islamabad. This is a 16 storey building excluding 2 basements (Fig. 1). It has a dual structural system consisting intermediate moment resisting frame coupled with 12in thick shear wall. Building lies in seismic zone 2B (PGA range is 0.16g to 0.24g) with occupancy category of 3 i.e. Special occupancy structures [4]. Total height from natural ground level is 54 m (176 feet).

4.2. Modeling in ETABS

The building is modeled in ETABS (Fig. 1) with following assumptions,

- Floors and beams are modeled as rigid elements.
- Slabs are modeled as shell elements.
- Beam column joints are taken as rigid joints.
- All supports are modeled as fixed supports.
- The system was assumed to be linearly elastic.
- For mass source 100 % D.L and 25% L.L is used. The mass is lumped at each story level.
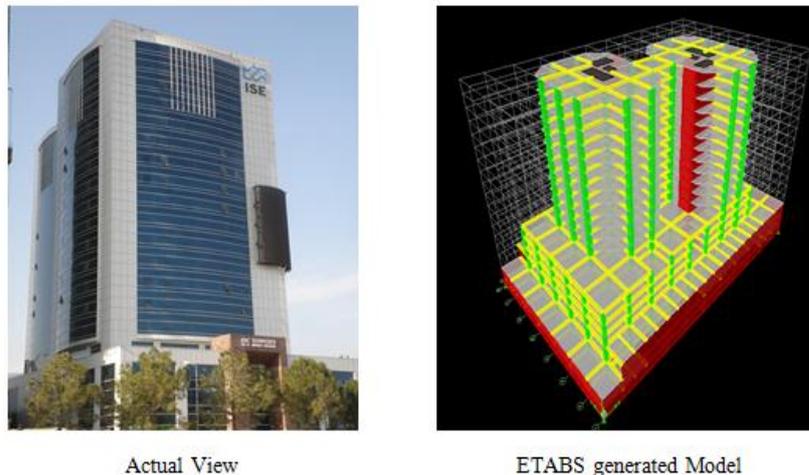

Actual View   ETABS generated Model

Fig. 1. Stock Exchange Islamabad Building View

4.3. Structural Irregularities

The building has Mass Irregularity, Vertical geometric Irregularity, Torsional and Stiffness Irregularity (Table 1). Mass Irregularity exists between 3rd and 4th floors. Vertical geometric and Stiffness Irregularity exist between ground and 1st floors where ground floor is acting as weak storey. Torsional irregularity exists when the difference between the center of mass and center of rigidity exceeds 20% of the plan width. All cases that are considered for analysis are subjected to torsional irregularity. P–Δ effects are considered when the ratio of secondary to primary moment is > 0.10 and our calculations show that P-Delta effects are not required in any case under consideration [4].

Table 1: Irregularity summary

Horizontal Irregularity	Check	Vertical Irregularity	Check
Torsional Irregularity	Yes	Stiffness Irregularity	Yes
Reentrant Corners	Nil	Weight Irregularity	Yes
Diaphragm Discontinuity	Nil	Vertical Geometric	Yes
Non Parallel structural irregularity	Nil	In Plane Discontinuity	Nil
Out of plane irregularity	Nil	Strength Irregularity	Not checked

4.4. Analysis Procedure

According to Section 5.29.8.4 of BCP 2007 Dynamic Analysis is preferred because,

- It is an irregular structure
- It lies in Seismic Zone 2B with Occupancy Category of 3.

Response spectrum analysis with Ritz vectors has been performed on 4 different cases. The spectrum cases in ETABS are defined according to UBC 97 [5], [6]. The allowable maximum drift value is calculated using H/500 expression while maximum storey drift is calculated using 0.02*H expression with reference to Section 5.30.10.2 of BCP 2007, where H is the height of building from ground surface [7] ,[8].

4.5. Analysis Results

Case 1: Original Building: Analysis is done considering actual location and configuration for 12in, 9in and 6in thick shear walls (Fig. 2a). Analysis results indicate an increasing trend in lateral drift values but well within permissible limits specified by building codes and higher time period for mode 1 against 153mm thick shear wall compared to 305mm thick wall (Table 2). Base shear forces are progressively decreasing because inclusion of thinner cross section reduces stiffness of structure. Among subcases of Case 1, Case 1c is selected for further evaluation based on economy and improved seismic performance.

Table 2: Result comparison for actual Stock Exchange building

Parameters	Case 1a: 305mm thick SW	Case 1b: 230mm thick SW	Case 1c: 153 mm thick SW	Allowable Value
Max. Lateral displacement (mm)	36	38.6	43.2	146
Max. story drift (mm)	14	13.7	18.3	64
Max. base shear (kN)	16660	15945	12250	----
Time period 1st mode	1.83	1.93	2.19	----

Case 2: Without shear wall: Case 2 is analyzed using frame structure only by removing shear walls. This is important because it will dictate the effectiveness of shear wall in controlling lateral drift in structure. Further it shall also serve as a guide to see if shear wall is necessary or not for medium rise structures. Maximum lateral displacement and storey drift has increased to 89.2mm and 38.1mm compared to 36mm and 14mm respectively for case 1a. Base shear forces are less than in Case 1a but greater than in Case 1c. Exclusion of shear wall has reduced stiffness of overall structure as dictated by time period for 1st mode (Table 3).

Table 3: Analysis results for frame structure

Parameters	Maximum Value	Allowable Value
Max. Lateral displacement (mm)	89.2	146
Max. story drift (mm)	38.1	64
Max. base shear (kN)	13329	----
Time period 1st mode	3.0	----

Case 3: Shear wall location change 01: For Case 3, the location of shear wall has been altered and is placed at the center of the building keeping in view the symmetry of structure. This acts as core shear wall (Fig. 2b). The base shear forces, lateral drift and time period for 1st mode are less compared to Case 1 (Table 4). **Case 3b** is selected for further consideration.

Table 4: Result comparison of Case 3 for Stock Exchange Building

| Cases	Case 3a: 305mm thick SW	Case 3b: 230mm thick SW	Case 3c: 153 mm thick SW	Allowable Value
Max. Lateral displacement (mm)	35.6	36.3	44.2	146
Max. story drift (mm)	12.7	14	16.3	64
Max. base shear (kN)	15291	14400	12569	----
Time period 1st mode	1.80	1.90	2.12	----

Case 4: Shear wall location change 2: In this case shear wall is moved to the periphery of the building (Fig. 2c). The configuration of wall is identical and shear wall is placed to maintain architectural aspects and structure's symmetry. Results are comparable to Case 1 and better structural behavior can be observed (Table 5). Case 4b is selected because lateral drift values are well controlled and shear forces are also on lower side.

Table 5: Result comparison of Case 4 for Stock Exchange Building

Cases	Case 4a: 305mm thick SW	Case 4b: 230mm thick SW	Case 4c: 153 thick mm SW	Allowable Value
Max. Lateral displacement (mm)	34.8	36.1	43.7	146
Max. story drift (mm)	13.7	13.7	16	64
Max. base shear (kN)	15229	14221	12663	----
Time period 1st mode	1.82	1.90	2.21	----
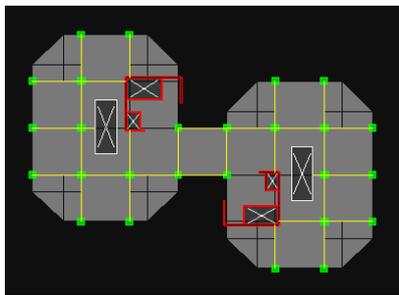
(a). Actual Location of Shear Wall for Stock Exchange Building
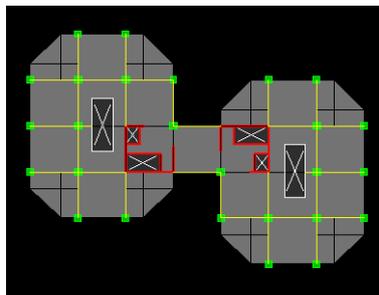
(b). Location Change 01 of Shear Wall for Stock Exchange Building
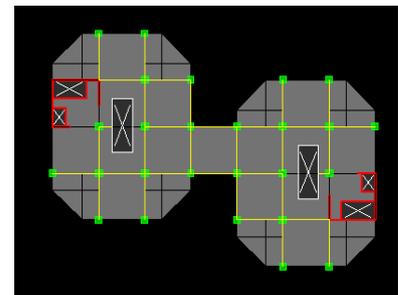
(c). Location Change 02 of Shear Wall for Stock Exchange Building

Fig. 2. Location of shear wall used for analysis

5. Comparison of Selected Cases

The 4 selected cases are now compared (Table 6) among which the most optimum and suitable case will be selected and compared with analysis results of existing structure. Comparison curves for maximum lateral displacement have been plotted in Fig. 3. Graph shows a non-linear behavior for first 4 floors, and then response curve becomes almost linear because from floor 4 onwards the building has similar floors. Effectiveness of dual system in controlling lateral drift is quiet obvious compared to frame structure (Fig. 3). Base shear forces are plotted in Fig 3 and is interesting to see that case 1c has lesser base shear values compared to frame structure. This corresponds to the importance of location of shear wall in structure. A well placed shear wall gives better seismic results and performance of structure than frame structure in terms of ductility, base shear forces and lateral drift values. Results indicate that lateral drift has increased by more than 100% for frame structure. Dual systems incorporating shear walls with frame are stiffer as compared to rigid frames based on results of time period of structure. For high rise structures where lateral drift is the governing criteria for design, dual systems must be used [9]. The most optimum case comes out to be Case 1c because of low base shear value and greater time period that impart more ductility in the structure [10]. It is also worth mentioning the economic benefits associated with thinner cross section of shear wall but in general the designer keeps the structure safe, maintaining a higher factor of safety. Hit and trial method based on several parameters like location, cross section etc. is a good practical approach to understand the behavior and performance of structure under seismic loads and design can be made more efficient.

Table 6: Selected Cases result comparison for Stock Exchange Building

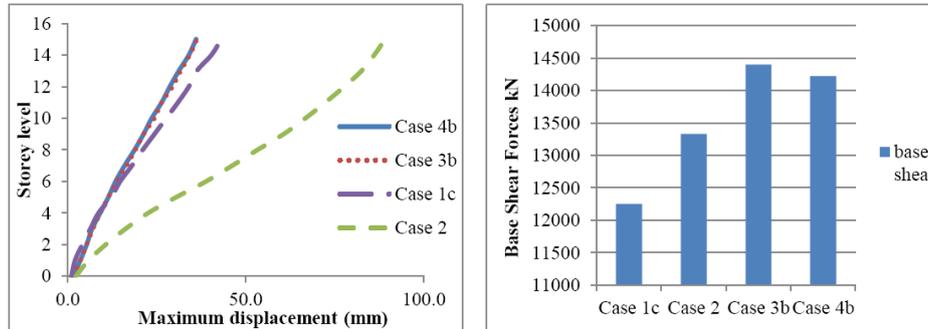| Parameters	Case 1c	Case 2	Case 3b	Case 4b
Max. Lateral displacement (mm)	43.2	89.2	36.3	36.1
Max. story drift (mm)	18.3	38.1	14	13.7
Max. base shear (kN)	12250	13329	14400	14221
Time period 1st mode	2.19	3.0	1.90	1.90

Fig. 3. Comparison graph for selected cases of Stock Exchange Building

6. Conclusion

The designer had designed the building according to case 1a but analysis results indicate that case 1c should have been a better option with respect to seismic performance and economy of structure (Table 7). Maximum storey drift has increased by 30.9% but is well below permissible limit and can be compromised. 19.6% increase in time period of structure and 26.4% decrease in base shear force are indication towards better seismic performance and efficient design of structure. The incorporation of 153mm thick shear wall in the structure will result in reduction in overall weight of structure. And as a result the structure is subjected to low base shear forces and cross sections of structural members can be reduced accordingly which will result in overall economy of structure. Frame structure can also be used for medium to high rise structures but dual systems are recommended in high intensity seismic zones to control lateral drifts.

BCP 2007 dictates building height limits for different building systems in zone 3 and 4. In Pakistan most important and high rise structures are located in Islamabad and Karachi that lie in seismic zone 2B. Hence, BCP 2007 must define the building height limits for building systems in seismic zone 2.

Table 7: Comparison of Selected case with actual Stock Exchange building

Parameters	Actual Building Case 1a	Selected Case Case 1c	%age difference
Max. Lateral displacement (mm)	36	43.2	20.0 % increase
Max. story drift (mm)	14	18.3	30.9 % increase
Max. base shear (kN)	16660	12250	26.4 % decrease
Time period 1st mode	1.83	2.19	19.6 % increase

7. Acknowledgements

8. References

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