A Comparative Study of Different Positioning of Reinforced Concrete Shear Walls in Soft Storey Building Subjected to Acheh Earthquake Event

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Abstract. The system of shear wall as an additive in retrofitting of soft storey structure has been investigated in previous and present research to improve the strength of structures due to seismic load. The aim of this research is to conduct comparative study on Equivalent Static Analysis (ESA), Response Spectrum Analysis (RSA) and Time History Analysis (THA) of structure between reference sample and shear wall systems was performed in order to determine the strength and stiffness of soft storey structure. The locations and shapes of shear wall system were used as retrofitting method. The retrofitting of soft storey structure was done for fives (5) models consist of one (1) model without shear wall as reference sample and the other four (4) models of different location and shape of shear wall systems. The models were tested by using SAP200 computer software to performed strength of structure. The models had been checking by value of lateral displacement and base shear resistance. Based on the collected data, the additional of shear wall was found to increase the strength and stiffness of soft storey structure. The swastika shape of shear wall and provide at centre experienced the maximum base shear resistance in all X, Y and Z direction and the least displacement compared to other model. Through this study had shown the improvement of strength of soft storey structure by applying shear wall system as an additive strength and stiffness of structure due earthquake event.

1. Introduction

Earthquake can cause damage to the structures. The lateral forces from the earthquake event can produce the critical stresses in a structure that cause lateral sway. These days, developed country has built many high-rise buildings to accommodate high population and it cause the adopted of parking problem for many vehicles. As a result, a soft storey is one of the ways to cater the parking problems. A soft storey also known as open ground storey, weak storey or stilt floor which are generally used in the urban environment nowadays since they provide parking area of vehicles, reception lobbies, office or for any other purpose such as intercourse hall. These buildings have no walls at the ground floor and brick infill wall panel are at the upper stories.

First floor stiffness is less strong or more flexible compare to the walls of upper floor makes the total building deflects higher. Due to this basis, the whole structure lateral displacement is ruled...
mostly by the deformation at the lower stories [1]. Load from earthquake can easily damage and cause cracks to the structures that have soft storey due to lack of stiffness and substantially less resistance. This natural disaster has taken many life and destroyed many possessions. This building must be strengthened to increase its seismic performance by through retrofitting such as shear wall, dampers, isolators and bracings. Lateral forces such as earthquake, winds and uneven settlement loads can create powerful twisting or torsional forces cause failure to the building with soft storey [2].

Earthquake can be define as movements of earth crusts that cause stress to build up at the rocks. The rock store the energy and release it once the stresses is exceed its strength. Earthquake happened unexpected with rapid shaking of earth caused by the breaking and shifting of rocks underneath the earth surface. Nowadays earthquake is one of big issue where the building can experiences big damage and collapse at the end [3]. It becomes a main concern of structural engineering and the performance of structural due earthquake load is extensively studied in the last decade. [4-6]. The damage and collapse of building not only depend on the earthquake magnitude, but also on local geology and on building techniques. Type of soil or grounds conditions, building design and construction effect these all can contribute to the building collapse. At the earthquake area, the building need for design based on seismic response by suitable method to certainly strength and stability of structure [7].

One way to increase the strength of the building and reach public safety is by seismic retrofitting. The existing structure will be modified to improve the performance during the earthquake. Seismic retrofitting is the process to increase the weak connection in roof to wall connections, continuity ties, shear wall and the roof diaphragm. Seismic retrofitting is done for several reasons including to make employees, machinery and inventory in the building is safe and secure. Bracing, shear wall, stiffer columns and lateral loads resisting system are the methods to control the building soft storey drift[8], [9]. The most effective retrofitting system is shear wall, which increase stiffness of the first storey and reduced displacement around 80% compare to other methods [10].

Moinuddin et. al. [11] conducted study on 12 difference models of 21 storey building model by using SAP2000 and ETABS software to analyze time period. They also used SAP2000 and ETABS to calculate base shear resistance by using both equivalent static analysis and response spectrum analysis. Meshram et.al [12] carried out analytical investigation to study the feasibility of implementing water tank as passive tuned mass damper using SAP2000. Seven and 12 storey RCC structure were considered during the study. Rani et.al. [13] used SAP2000 to conducted a nonlinear time history analysis of two symmetrical 5 and 10 storey buildings subjected to three real earthquake records namely EL Centro earthquake data, N.Palm earthquake data and Uttarkashi earthquake data to determine roof displacements, base shear, storey drifts and member.

2. Methodology

The research focus is to study the behavior of shear wall systems on the soft storey building. Five different model of seven-storey reinforced concrete structure was analyzed using SAP 2000 software. The buildings designed column size is 600 x 600 mm, beam size 300 x 500 mm and also slab thickness 150mm with grade concrete C25. By using 3D model of soft storey with bottom storey height is 4.2m, beside that second to six storey is 3.5m and upper storey is 3.5m. In this study, strengthening shear wall system on building was determine by analysis of maximum displacement and base shear resistance.

The significance of research is to analyze the structural performance of building with soft storey when subjected to earthquake load or seismic forces. This research has been defined whether shear wall system on the soft storey building can increase structural strength and stiffness of building for vulnerable to collapse due to earthquake load. This study also to determined which one of positioning shear wall system on soft storey building have a highest vulnerable when lateral force added.

2.1. Building Description

The research was carried out on reinforced concrete moment resisting frame buildings. The plan layout of building was same for all models as shown in Figure 1 and Figure 2. This study has been done on five (5) different models of seven (7) storey building and have height of bottom storey is 4.2 m, 2nd to 6th is 3.5 m, and top storey also 3.5 m. The building has plan dimensions 12.6 m x 27.7 m as shown
in Figure 1 and Figure 2. Other relevant data of building description was given as below in Table 1.

![Figure 1. Plan view of building](image1)

![Figure 2. Elevation view of building](image2)

**Table 1. Analysis data of building**

| Description                       | Value                        |
|-----------------------------------|------------------------------|
| Size of Building                  | 12.6 m X 27.7 m              |
| Grade of concrete                 |                              |
| -Beam and column                  | C 35/45                      |
| -slab                             | C 25/30                      |
| Grade of steel                    | Fe 415                       |
| Slab thickness                    | 0.15 m                       |
| Wall thickness                    | 0.23 m                       |
| Size of columns                   | 600 mm x 600 mm              |
| Size of beam                      | 300 mm x 500 mm              |
| Poisson’s ratio of concrete       | 0.2                          |
| Live load on floor                | 4 kN/m²                      |
| Floor finishes                    | 1.5 kN/m²                    |
| Roof treatment                    | 1.5 kN/m²                    |
| Seismic zone                      | V                            |
| Zone factor, Z (Table 2 of IS 1893-2002) | 0.36                        |
| Importance factor, I (Table 6 of IS 1893-2002) | 1.0                         |
| Response reduce factor, R (Table 7 of IS 1893-2002) | 5.0                         |
| Soil condition/type (Figure 2 of IS 1893-2002) | Type II (Medium soil)      |
| Importance factor                 | 1                            |
| Density of concrete               | 25 kN/m³                     |
| Modulus of elasticity of brick mansory | 4.66 x 10⁶ kN/m²         |
| Density of masonry                | 20 kN/m³                     |

2.2 Seismic Response of Soft Storey

Following four models with one of them frame model, fully in filled full brick masonry infill frame (only outer face) with top and bottom soft storey without otherwise another three models with different positioning of shear wall as shown in Table 2. All of models are analysed by using SAP 2000 software as special moment resisting frame by using Equivalent static analysis (ESA), Response spectrum analysis (RSA), Time history analysis (THA).

![Figure 3. 3D view and plan view of model 1.](image3)

![Figure 4. 3D view and plan view of model 2](image4)
Table 2. Description of models

| Model name | Description |
|------------|-------------|
| Model 1    | Building model has no brick masonry infill in ground and top storey, but has full brick masonry infill in rest of all storeys as shown in Figure 3 |
| Model 2    | Building model is same as model 1, further T shape shear wall is provided at center of building as shown in Figure 4. |
| Model 3    | Building model is same as model 1, further swastika shape shear wall is provided at center of building as shown in Figure 5. |
| Model 4    | Building model is same as model 1, further I section shear wall is provided at center of building as shown in Figure 6. |
| Model 5    | Building model is same as model 1, further plane shear wall is provided at center of outer face building as shown in Figure 7. |

2.3. Modelling of structure

The physical and functional characteristics of places can be determined by generation and management of digital representations. SAP2000 is a general purpose element program which performs the static and dynamic analysis of structural systems. It is also powerful design tool to design structures following AISC building codes and other standards. The modelling, analyzing, designing, and displaying the structure geometry, properties and results analysis can be done using SAP2000 graphic user interface.

Seismic load using response spectrum analysis (RSA) was based on IS 1893-2002 time history analysis (THA) was recorded at Ipoh, Perak, Malaysia due to Aceh, Indonesia earthquake event. All of load of structure define each one in detailed and must consider nonlinear analysis load such as earthquake load. The highest amplitude is 0.020247 for function graph Earthquake 0.05, but the lowest amplitude is -0.023824. Meanwhile for function graph Earthquake 0.15, the highest amplitude recorded 0.082648 but the lowest amplitude is -0.077367. Both function graphs Earthquake data give different impact on the soft storey building including lateral displacement.

3. Results
Three analyses had been conducted in this study which is Equivalent Static Analysis (ESA), Response Spectrum Analysis (RSA) and Time History Analysis (THA). Five models of seven-storey buildings of soft storey as mentioned before have been used for comparison purpose with control models. For the control model, the addition of shear wall system with different positions has been applied.

3.1. Lateral Displacement

Table 3 shows the value of lateral displacement conducted for each model by three methods of analysis. There were Equivalent Static Analysis (ESA), Response Spectrum Analysis (RSA) and Time History Analysis (THA). The value was based on each direction, there are x-axis (longitudinal direction), y-axis (transverse direction) and z-axis.

| MODEL | ESA | RSA | THA |
|-------|-----|-----|-----|
|       | X   | Y   | Z   | X   | Y   | Z   | X   | Y   | Z   |
| 1     | 7.87| 15.58| 15.72| 11.93| 24.57| 27.27| 25.67| 33.23| 25.11|
| 2     | 5.52| 13.23| 13.37| 9.58 | 22.22| 24.92| 23.32| 30.88| 22.76|
| 3     | 1.24| 8.95 | 9.09 | 5.3  | 17.94| 20.64| 19.04| 26.6 | 18.48|
| 4     | 2.28| 9.99 | 10.13| 6.34 | 18.98| 21.68| 20.08| 27.64| 19.52|
| 5     | 5.21| 12.92| 13.06| 9.27 | 21.91| 24.61| 23.01| 30.57| 22.45|

Graph was plotted as the ordinate for different models in x-axis, y-axis and z-axis as shown in Figure 8, Figure 9 and Figure 10 respectively. Conclusion can be made that displacement was higher for model 1, structure without shear wall system compared to other models.

![Figure 8. Displacement profile in longitudinal direction for ESA, RSA and THA (X-axis)](image)

![Figure 9. Displacement profile in transverse direction for ESA, RSA and THA (Y-axis)](image)

![Figure 10. Displacement profile in z-axis direction for ESA, RSA and THA.](image)
Based on results in all directions, the displacement value is higher in THA analysis. The different building models (2, 3, 4, and 5) with different location installed of shear wall is considerably reducing the storey displacement for ESA. In case RSA and THA also similar variation is observed. From the results in Table 3, it can see the maximum displacement overall in the Z direction compared in the X and Y direction in ESA and RHA analysis. Otherwise, in THA analysis, maximum displacement were obtained in direction of Y compared in direction of X and Z.

Besides that, from Figure 8 and Figure 9, it is clear that majority of displacement in the THA analysis is more than majority displacement in the ESA and RSA analysis in both direction of X and Y. However in the direction of Z from Figure 10, shown RSA analysis are the higher value of displacement compared three of them. All the value of displacement either from X direction or Y direction or Z direction are varies linearly from ESA to THA. From chart also can analyze that the value of maximum displacement for all of three directions is higher when THA analysis.

From the tabulated data for Figure 8, Figure 9 and Figure 10 also can show that, among all 5 models, model 3 which is shape of swastika in positioning of shear wall has the lowest value of maximum displacement compare to others for all directions and all of three analyses. Even if the value of maximum displacement of RSA analysis in Z direction for all model is higher than ESA and THA analysis, the value of maximum displacement of Y direction is contradict.

3.2 Base Shear Resistance
Base shear resistance is the maximum expected lateral force that will occur due to earthquake ground motion at the base of the structure. Table 4 compares the base shear resistance value of the model in x, y and z directions respectively using ESA, RSA, and THA. Based on chart on Figure 11 (x direction), Figure 12 (y direction), Figure 13 (z direction) shown that models have a shear wall can increase of the base shear wall depend on location and type of shear wall along x-direction. Similar percentage variation is observed in y and z direction.

| MODEL | ESA X | ESA Y | ESA Z | RSA X | RSA Y | RSA Z | THA X | THA Y | THA Z |
|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| 1     | 459.01| 446.83| 451.15| 206.32| 207.93| 209.29| 308.06| 313.23| 318.2 |
| 2     | 691.13| 678.61| 682.93| 496.38| 458   | 499.35| 977.12| 733.9 | 738.87|
| 3     | 766.34| 753.33| 770.66| 603.62| 551.04| 543.91| 1328.26| 972.53| 1320.34|
| 4     | 691.16| 678.64| 682.96| 466.91| 478.45| 469.88| 1000.46| 940.65| 1005.62|
| 5     | 575.93| 563.55| 567.87| 363.65| 374.73| 366.62| 863.79 | 827.47 | 832.44|

Table 4. The value of base shear resistance for each model (kN)
The maximum base shear resistance for all three analyses along x, y and z direction found that for model 3, with THA having maximum base shear resistance. Therefore, it also found that, seismic load will lead under estimation of base shear resistance by considering building by ordinary frame. Base shear resistance has shown in Table 4, the largest value were obtained in X direction for the all analyses, there are ESA, RSA, and THA compared between other direction. Chart from Figure 11, Figure 12 and Figure 13, shown in all direction of X, Y and Z, the higher base shear resistance are in THA analysis. The highest value of base shear resistance is model 3 which is 1328.26kN for X direction and in THA analysis.

Thus, is have been all five different models have different value for both maximum displacement and base shear resistance during analysis. From the result and discussion, it was observed that the value of displacement are decrease and the value of base shear resistance increase when model 1 (without shear wall) compared model 2, 3, 4, and 5 (structure retrofit with shear wall system added). It is has been shown that when swastika shape of positioning shear wall (model 3) the value of maximum displacement are reduce and base shear resistance are increase compare to model 1.

4. Conclusion
From the results obtained, it showed that the maximum displacement value for soft storey with swastika shape shear wall provided at centre of building were the lowest value in all three analysis ESA, RSA, THA and the lowest displacement in all direction, there are longitudinal, transverse and z-axis compared with another models. The swastika shape of positioning shear wall system on soft storey structure also showed the largest value of maximum base shear resistance compared with another models in all of three analyses ESA, RHA, THA.

Besides that, this model also the highest value of maximum base shear resistance in all direction,
there are in x-axis, y-axis and z-axis. So, it will conclude that the swastika shape is the best positioning of shear wall system on the soft storey building. It also will give more strengthening of building due to earth quake load and not easy to collapse.

This study has identified that the use of swastika shape of positioning shear wall system as an additive in soft storey buildings give the positive effect of strength characteristic compared to another position in term of displacement and shear wall parameter. The increased in strengths is mainly due to earthquake load, so it will conclude that the swastika shape is the best positioning of shear wall system on the soft storey building. It also will give more strength to the building due to earthquake load and not easy to collapse.

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