Performance evaluation of shear wall shapes using pushover analysis (case study: green sedayu tower 1 apartment, Cengkareng, West Jakarta)

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Abstract. Shearwall plays an important role in resisting shear force generated from earthquake loads. The lay out of the shear wall is very influential on the performance of the shear wall in receiving lateral forces. To investigate how the shear wall layout affecting the performance of the structure to lateral load, pushover analysis on 27 storey structure with three different shear wall shape is conducted. The three shapes of shear wall layout considered are shear wall with C shape layout, shear wall with I shape lay-out and shear wall with L shape lay-out. The shear capacities of the structure with different shear wall shapes were checked against the design requirement in SNI 1726-2012. ETABS software were used for push over analysis. Their ductility and structural performance level based on the ATC-40 method were compared for both in x direction and y direction. From the results of the pushover over analysis it was found that shear wall with C shape layout is the most favorable since it has the highest structural stiffness and smaller drift.

Keywords: Shear Wall, Earthquake Load, Pushover Analysis, Capacity Curve, Ductility

1. Introduction

ATC 40 (1997) indicates that one of the newest concepts for earthquake resistant building planning is Performance Based Design. The concept of Performance Based Design is used in new buildings with an understanding of reducing property losses, occupant safety, and readiness for use. One analytical approach that can be used is non-linear dynamic analysis or pushover analysis.

Push over analysis is a nonlinear static analysis in which lateral loads are increased, to maintain a predetermined distribution pattern along the height of the building, until the collapse mechanism increases. Pushover analysis is a nonlinear static method for observing the successive state of damage to a building. The effect of a planned earthquake on the structure of a building is considered as a static load given to the center of mass of each floor, the value of which is gradually increased until it exceeds their capacity causing yielding (plastic joints) in the structure of buildings, then with an increase in the burden of further experiencing a large post-elastic shape changes until reaching elastic conditions. Then followed by yielding (plastic joints) at the other location of the structure.
To do a pushover analysis, a lateral load of the deformation curve for the component is required. The results of the pushover analysis will provide a load curve for deformation. The actual performance of a building may differ from the calculated performance, because the load curve for deformation and earthquake level used in the analysis is based on estimates.

Technological developments help civil engineers in planning and analyzing the performance of a building structure. The development of advance structural analysis programs such as ETABS and SAP2000, can overcome problems in the form of 3D modeling and analysis which was previously very complex if done conventionally. One of the advance application of complex structural analysis is in determining the seismic performance of buildings by using pushover analysis.

2. Study Literature

2.1. Structural Ductility

Ductility describes the extent to which a material (or structure) can undergo large deformations without failing. The term is used in earthquake engineering to designate how well a building will endure large lateral displacements imposed by ground shaking. The pushover curve is obtained from the structure modeling based on the parameters used, and ultimate points on the displacement, to obtain the displacement ductility value. Several procedures has been develop to determine the structural ductility. One of the method is FEMA 440 Displacement Modification procedures which has been used in this research where the ductility value of the structure calculate using the following equation:

\[ \mu = \frac{\delta_u}{\delta_y} \]

Where:
- \( \mu \) = displacement ductility
- \( \delta_u \) = displacement at ultimate
- \( \delta_y \) = displacement at yield

2.2. Response Modification Factors (R)

The R factor was first introduced through ATC-3-06 (1978). The magnitude of the R factor contained in the regulation is often only based on empirical experience and only provides a qualitative understanding of the structural response expected by the regulation. Since the mid-90s until now, researchers have continued to conduct studies on the feasibility and verification of the R values contained in the regulations as well as several key parameters that affect and shape the R value.

According to ATC-19 (1995a) and ATC-34 (1995b) the value of R is the result of multiplication of 3 factors, that is:

\[ R = R_s R_m R_R \]

The Rs factor is similar to the structural over strength factor (\( \Omega_0 \)) as in ASCE 7-10. A factor of Rs greater than 1 indicates that the structure is able to absorb earthquake loads until all elements of the structure yielding (\( V_{max} \)) and exceed the design earthquake load (\( V_d \)).
\[ R_s = \frac{V_{\text{max}}}{V_d} \]

ATC-19 (1995a, 1995b) provides several equations to determine the value of \( R_s \). The equation given uses the assumption that the building structure can be modeled as a single degree of freedom system (SDOF). The following equation can be used to obtain the value of \( R_s \) by considering the condition of the soil at the location of the structure (Miranda dan Bertero, 1994),:

\[ R_s = \frac{\mu - 1}{\phi} + 1 \]

The value of \( \phi \) depends on the type of soil conditions at the location of the structure. The value of \( \phi \) can be determined using the following formula:

\[ \phi = 1 + \frac{1}{12T - \pi T} - \frac{2}{5T} e^{-2(\ln(7) - 0.2)^2} \]

Where \( T = \) natural period of the structure

The redundancy factor \((R_R)\) is influenced by the number of earthquake load-bearing systems used in each direction. Whittaker, et al. (1999) recommend that the minimum redundancy in buildings can be achieved if there were at least 4 earthquake bearing systems in each direction (ATC-19, 1995a; ATC-34, 1995b; Whittaker, et al., 1999). All earthquake retaining frames in a structure have an almost similar contribution in resisting the earthquake (strength and deformation compatible) that makes all the earthquake retaining frames contribute to the degree of structural redundancy (Whittaker, et al., 1999).

| Number of Earthquake Retaining Frames | Proposed Value \( R_R \) |
|---------------------------------------|---------------------------|
| 2                                     | 0.71                      |
| 3                                     | 0.86                      |
| > 4                                   | 1                         |

2.3. Level of structural performance

Building performance is an indicator of how well a structure supports the defined needs of its users. Acceptable performance indicates acceptable (or tolerable) levels of damage or condition that allow uninterrupted facility operations. Consequently, performance-based design is the process or methodology used by design professionals to create buildings that protect functionality and the continued availability of services. In this study, Performance levels of the buildings are specified according to ATC-40 based on the maximum drift ratio values with the classification table listed in 2, with the following equation:

| Parameter | Performance Level |
|-----------|-------------------|
| Damage Control | IO | 0.01 - 0.02 |
| Structural Stability | LS | 0.33 |
Maximum Total Inelastic Drift | 0.005 | 0.005 - 0.015 | No Limit | No Limit

Where $D_t$ is the maximum value of displacement that occurs on the roof and the value of H is the height of the building structure.

Maximum drift $\frac{D_t}{H}$

Maximum Inelastic Drift $\frac{(D_t-D_1)}{H}$

3. Methodology

This research was conducted using 27-storey building structure objects with various shear wall layout. The three shapes of shear wall layout considered are shear wall with C shape layout, shear wall with I shape lay-out and shear wall with L shape lay-out. The life load reduction during earthquake is 30 %.

The structures were design based on the requirement in SNI 1726-2012. The requirement of 90 % mass participating factor has been fulfilled in accordance with SNI 1726-2012 Article 7.9.1. The earthquake load distributed to each floor in accordance with SNI 1726-2012 article 7.8.3.

ETABS structural analysis software is used for push over analysis to calculate the maximum lateral force can be resist by structure. The plastic connection limit used in columns and beams is based on ASCE 41-13. The push over analysis result is presented in peal displacement – shear force graph

FEMA 440 Displacement Modification procedures is used to determine the ductility value of the structure. Performance levels of the buildings are specified according ATC-40 based on the maximum drift ratio value

![Figure 1 Building Plan](image)
Figure 2 Shear wall with C shape layout

Figure 3 Shear wall with L shape layout

Figure 4 Shear Wall with I shaped layout
4. Results and Discussion

4.1 Structural ductility

The ductility value in X direction and Y directions are determined based on push over analysis using ETABS computer software. The target transition value (δ_t) is used as the ultimate switching parameter (δ_u) for structure ductility calculation. The first yield point (δ_y) is determined using the equivalent area method or the idealization curve (bilinear) which is the same as the capacity curve. The result of analysis is presented in Table 3, Table 4, Table 5 and Figure 6.

Table 3 Ductility structure of positive x direction

| No | Structure  | δ_y (mm) | V_y (ton) | δ_u (mm) | V_t (ton) | Ductility (μδ) |
|----|------------|----------|-----------|----------|-----------|----------------|
| 1  | Shearwall C | 116      | 278       | 401      | 556       | 3.46           |
| 2  | Shearwall I | 121      | 220       | 479      | 524       | 3.97           |
| 3  | Shearwall L | 192      | 322       | 675      | 585       | 3.51           |

Table 4 Ductility structure of negative x direction

| No | Structure  | δ_y (mm) | V_y (ton) | δ_u (mm) | V_t (ton) | Ductility (μδ) |
|----|------------|----------|-----------|----------|-----------|----------------|
| 1  | Shearwall C | 119      | 301       | 387      | 568       | 3.21           |
| 2  | Shearwall I | 121      | 220       | 479      | 524       | 3.97           |
| 3  | Shearwall L | 198      | 341       | 596      | 648       | 3.27           |
Table 5 Ductility structure of positive negative Y direction

| No | Structure  | $\delta_y$ (mm) | $V_y$ (ton) | $\delta_u$ (mm) | $V_t$ (ton) | Ductility ($\mu_d$) |
|----|------------|----------------|-------------|----------------|-------------|-------------------|
| 1  | Shearwall C | 122            | 299         | 348            | 733         | 2.85              |
| 2  | Shearwall I | 240            | 343         | 755            | 999         | 3.15              |
| 3  | Shearwall L | 102            | 180         | 305            | 488         | 2.99              |

From above table, it can be seen that the value of the structure ductility Shear Wall with C shaped layout direction x has a smaller value compared to the Shear Wall with I and L shaped layout. This is due more rigid which is indicated by the value of the natural of the structure. The higher the structural stiffness, the ductility value will be decrease.

Figure 6 Ductility structure in the positive X direction, negative X and negative Y positive

4.2 Response modification factors (R)

The response modification factor using the ATC-19 and SNI 03-1726-2002 based on the ductility value are presented in Table 6, Table 7, and Table 8.
Table 6 *Response modification factors in positive x direction*

| No | Structure  | Ductility ($\mu_d$) | $R_{ATC-19}$ | $R_{SNI 1726-2002}$ |
|----|------------|---------------------|--------------|---------------------|
| 1  | Shearwall C | 3.46                | 7.89         | 5.54                |
| 2  | Shearwall I | 3.97                | 9.94         | 6.35                |
| 3  | Shearwall L | 3.51                | 9.00         | 5.62                |

Table 7 *Response modification factors of negative x direction*

| No | Structure  | Ductility ($\mu_d$) | $R_{ATC-19}$ | $R_{SNI 1726-2002}$ |
|----|------------|---------------------|--------------|---------------------|
| 1  | Shearwall C | 3.21                | 7.32         | 5.14                |
| 2  | Shearwall I | 3.97                | 9.94         | 6.35                |
| 3  | Shearwall L | 3.27                | 8.38         | 5.23                |

Table 8 *Response modification factors of positive negative Y direction*

| No | Structure  | Ductility ($\mu_d$) | $R_{ATC-19}$ | $R_{SNI 1726-2002}$ |
|----|------------|---------------------|--------------|---------------------|
| 1  | Shearwall C | 2.85                | 6.71         | 4.56                |
| 2  | Shearwall I | 3.15                | 8.25         | 5.05                |
| 3  | Shearwall L | 2.99                | 7.84         | 4.78                |

4.3 Level of structural performance

Performance levels of the buildings are specified according ATC-40 based on the maximum drift ratio value and based on maximum inelastic drift. The result of analysis is presented in Figure 7 and Figure 8:
Figure 7 Maximum drift in positive X direction, negative X and positive and negative Y

Figure 7 shows that the performance of the structure with different shear wall lay-out area based on maximum drift is categorized as Immediate Occupancy where when a structural earthquake does not experience significant damage based on ATC-40.
Figure 7 shows that the performance of the structure with shaped and L shaped shear wall lay-out based on maximum in elastic drift is categorized as Damage Control where when a structural earthquake does not experience significant damage based on ATC-40.

5. Conclusion

Based on the results of the analysis of the research conducted it can be concluded that:

- The structural ductility of The Shear Wall with C shaped layout is smaller compared with I shape and L shape.
- The structural stiffness of The Shear Wall with C shaped layout is higher compared with I shape and L shape and therefore has smaller drift value due to earthquake load.
- All shear wall layout has Immediate Occupancy structure level if analyzed using maximum drift value.
- Structural with Shear Wall with C shaped layout has Immediate Occupancy structure level if analyzed using maximum inelastic drift value, but Structural with Shear Wall with I and L shaped layout has Damage Control performance level if analyzed using maximum inelastic drift value.
- The Shear Wall with C shaped layout has better performance compared with I shape and L shape.

**Figure 8** *Maximum inelastic drift in positive X direction, negative X and positive and negative Y*

| Performance Level | Shearwall C | Shearwall I | Shearwall L |
|-------------------|------------|-------------|-------------|
| positive X Direction | 0.004 | 0.0048 | 0.00676 |
| Negative X Direction | 0.00393 | 0.0048 | 0.00601 |
| Positive negative Y Direction | 0.00351 | 0.00743 | 0.00303 |
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