Analysis of horizontal deviation values on shearwalls in building structure according to earthquake load design

E Walujodjati*, R Roestaman, I Farida and M A Agesti

Department of Civil Engineering, Sekolah Tinggi Teknologi Garut, Jalan Mayor Syamsu 1, Garut 44151, Indonesia

*eko.walujodjati@sttgarut.ac.id

Abstract. Technoplex Living Apartment Bandung is one of the buildings using a shear wall that is built in earthquake-prone areas. This study analyzes the CW3 shear wall Type which aims to determine the seismic load design using spectrum response analysis that is applied and analyzed on the structure of the building so that the horizontal deviation value that will be compared against the value of horizontal deviation that is permitted under SNI 1726 of 2012 is obtained. The results of this study can be concluded that the CW3 shear wall produces the highest horizontal deviation value in the direction of X of 0.032 m greater than the highest horizontal deviation value in the direction Y of 0.0042 m. Because it was analyzed in one direction, namely the X direction with the percentage of earthquake loads received using orthogonal systems where the X direction building structure received an earthquake load of 100% while Y direction was 30% of the earthquake load as a result of the spectrum response analysis method and the resulting horizontal deviation value was below the allowable safety margin, the percentage of X direction is 56.7% while Y direction is 92.3%.

1. Introduction
The Indonesian archipelago is the meeting point between three plates, namely the Indo-Australian plate in the south, the Eurasian plate in the north and the Pacific plate in the east [1]. Earthquakes are vibrations or shocks caused by the sudden movement of the Earth's plates that occur on the earth's surface [2]. Technoplex Living Apartment is one of the apartments located on the Jalan Telekomunikasi, Terusan Buah Batu, Bandung, and a building that was built using shearwall to respond to earthquake loads [3]. Based on this, this study aims to determine the horizontal deviation values that occur on the CW3 type shear wall [4] on the Technoplex Living Apartment building based on SNI 1726 in 2012 and compare the safety of inter-floor deviations that are permitted under the regulation.

Shear wall is a type of wall structure in the form of reinforced concrete which is usually designed to withstand the shear forces caused by earthquakes. With the shear wall made at each vulnerable point, the lateral force of the earthquake can be muted by the shear wall [5,6]. The finite element model has been carried out to analyze vertical and horizontal wood diaphragms, on masonry walls, including reinforced concrete shear walls [7-10]. The results of transferring the load from the diaphragm tested experimentally and predicting the model were found in good agreement. Parametric studies with models show that diaphragmatic stiffness is significantly affected by stiffness, distance, and blocking use [7].
1.1. Inter-floor deviation is permitted (\(\Delta a\))
For design level intersections (\(\Delta\)), the allowance should not exceed the floor level deviation shown in table 1 below:

| Struktur, apart from the structure of 4-level or less brick shear walls with interior walls, partitions, ceilings, and exterior wall systems that have been designed to accommodate intersection between level floor section | Risk Category |
|---|---|---|---|
| | I/II | III | IV |
| structure, apart from the 4-level or less brick shear walls with interior walls, partitions, ceilings, and exterior wall systems that have been designed to accommodate intersection between level floor section | 0.025 h | 0.020 h | 0.015 h |
| structure and shearwalls cantilever bricks | 0.010 h | 0.010 h | 0.010 h |
| structure and shearwalls masonry/bricks | 0.007 h | 0.007 h | 0.007 h |

2. Methods

2.1. Research sites
The location used as a case study in this study is in the Tecknoplex Living Apartment building. This project is located on Jl. Telekomunikasi, Terusan Buah Batu, Kab. Bandung West Java.

2.2. Research data
The research data needed is as follows:
- Shop Drawing
- Data on soil testing results
- Technical specifications of structural planner consultants (PT Anugerah Multi Cipta Karya)
- SNI 1726 of 2012 concerning Procedures for planning earthquake resistance for buildings and non-building structures
- Indonesian Earthquake and Source Map of 2017
- SNI 1727 1989 Guidelines for Loading Planning for Houses and Buildings.

Whereas, for the method used in supporting this research is the finite element.

2.3. Research data sources
Data sources for research were obtained from the field directly, and the contractor namely PT Pembangunan Perumahan (Persero) Tbk and the internet to obtain data on supporting regulations and material for compiling literature.

2.4. Research methods
The location used as a case study in this study is in the Tecknoplex Living Apartment building. This project is located on Jl. Telekomunikasi, Terusan Buah Batu, Kab. Bandung West Java.

In analyzing the structure of the building in which there is a shearwall, there needs to be a research stage. Following are the stages of research to be carried out:
- Collect Technoplex Living Apartment data for research such as shop drawings, technical specifications, results, soil testing, SNI regulations (seismic load planning and building loading), and other supporting data.
- Determine and calculate the load on the building structure in the form of dead loads, live loads, and earthquake loads based on SNI 1727 of 1989 and SNI 1726 of 2012.
- Designing 3D structure modeling with the installation of shear walls in accordance with the structure plan (shop drawing) and analyzing using finite elements to determine the magnitude of horizontal deviation especially in CW3 shearwall type
- Controlling the safety of building structures in response to earthquakes based on horizontal deviation values that occur with those permitted under SNI 1726 of 2012.
- Take conclusions and suggestions based on the results of research that has been done.
3. Results and discussion

3.1. Load analysis
Loading on the calculated structure of the Technoplex Living Apartment Bandung includes:

3.1.1. Life load. Based on SNI 1727 of 1989 article 2.1.2, the living load on the floor of a hotel/apartment building is taken at 250 kg / m, and the roof load is taken at 100 kg / m. As for the parking floor of 400 kg / m.

3.1.2. Dead load. The dead load used in this study is the load due to the building's own weight. These loads include beam, column, floor plate, and shear wall. This load is automatically calculated on the finite element method.

3.1.3. Earthquake load. Following is the calculation to determine the earthquake load plan based on SNI 1726 of 2012.
- Building structure risk categories: Based on SNI 1726 of 2012 article 4.1.2, the Technoplex Living project is used as an apartment so that it is in the risk category II.
- The primacy of the earthquake, Ic: Based on SNI with risk category II, the priority factor of the earthquake (Ic) is 1.0.
- Site classification: Based on one parameter, that is, from soil data, the results of SPT testing are obtained between 15 to 50 values (can be seen in Table 2). Therefore, the classification of sites in the construction of Technoplex Living Apartment is medium land (SD).
- Parameter of earthquake acceleration: Technoplex Living Apartment was built in the Bandung area so that based on the "2017 Indonesian Earthquake Map" in the manner as shown in Figure 1, the value of Ss (acceleration of bedrock in a short period of 0.2 seconds) is obtained between 1.0 - 1.2 g and the average value is taken from that range.

\[
S_s = \frac{(1.0 + 1.2)}{2} = 1.1 \text{ g} \\
S_1 = \frac{(0.4 + 0.5)}{2} = 0.45 \text{ g}
\]

Figure 1. Map of acceleration of the response spectrum of 0.2 seconds with 5% attenuation in base rocks (SB) for exceeded probabilities of 2% in 50 years.
After obtaining the Ss and S1 scores, calculated the Maximum Earthquake Acceleration Considered Risk-Targeted (MCER) with the Response Parameters to obtain the Fv and Fa values carried out by the interpolation method to obtain:

The vibration amplification factor is related to acceleration in short period vibrations \( (F_a) = 1.06 \)

The vibration amplification factor is related to the acceleration of the vibration period of 1 second \( (F_v) = 1.55 \)

The parameters of the acceleration spectrum in the short period (Sms) and period of 1 second (SM1) which are adjusted to the effect of site classification, must be determined by the following formula.

\[
\text{Sms} = F_a \times S_s = 1.06 \times 1.1 = 1.166 \text{ g}
\]
\[
\text{SM1} = F_v \times S_1 = 1.55 \times 0.45 = 0.6975 \text{ g}
\]

The spectral acceleration parameters for the short period, SDS and in the period of 1 second, SD1 are specified in the equation as follows.

\[
\text{SDS} = \frac{2}{3} \times \text{Sms} = \frac{2}{3} \times 1.166 = 0.777 \text{ g}
\]
\[
\text{SD1} = \frac{2}{3} \times \text{SM1} = \frac{2}{3} \times 0.6975 = 0.465 \text{ g}
\]

- Seismic design category: Determining the category of seismic design uses the SDS value (Parameters of acceleration response in short periods) and for the Response of Acceleration in the Period of 1 Second (SD1), SDS = 0.777 g ≥ 0.50 g => 0.50 g DS SDS. Based on the risk categories of building structures, namely II and SDS ¬ values. Hence, the building structure of Technoplex Living Apartment is in the category of "D" seismic design.

\[
\text{SD1} = 0.465 \text{ g} \geq 0.20 \text{ g} \Rightarrow 0.20 \text{ g} DS SDS
\]

Based on the building structure risk category, namely II and SD1 ¬ values. Hence, the building structure of Technoplex Living Apartment is in the category of "D" seismic design.

- Combination of loading: The loading combinations that will be used are as follows:

1.4D
1.2D + 1.6L
1.3554D + 1.3 Rx + 0.39 Ry + L
0.7446D + 1.3 Rx + 0.39 Ry

Where:
Rx, Ry: earthquake load design X and Y direction, D: Dead load L: Live load

- Design response spectrum: The spectrum of design responses is in the form of curves, for the required data, namely the value of acceleration parameters in short periods (SDS) and Response of Acceleration at 1 Secondary Period (SD1) and the fundamental vibrational periods of structures namely to and TS which can be calculated based on the equation below.

\[
T_0 = 0.2 \frac{\text{SD1}}{\text{SDS}} = 0.2 \times 0.465 / 0.777 = 0.12; \quad \text{TS} = \text{SD1} / \text{SDS} = 0.465 / 0.777 = 0.60
\]

For data to be included in the finite element method are as spectrum response.

- Allowable inter-floor intersection (\( \Delta a \)): Based on SNI 1726 of 2012, for design-level intersections, (\( \Delta \)) may not exceed the level of permits deviation between floors (\( \Delta a \)). Technoplex Living Apartment Bandung uses a structure of reinforced concrete shear walls and a momentary frame bearing system. With the risk category II, the intersection of the permit is obtained (\( \Delta A \)) of 0.020–hx. (where height hx is between floors). Because it is in the seismic design category D, the inter-floor deviation of the permit (\( \Delta A \)) must be divided by a reduction factor of 1.3.

3.2. Output of horizontal deviation value on type CW3

After analysis in stages using the finite element method. Then the results obtained in the form of horizontal deviation values as follows:
Table 2. Horizontal direction X deviation against intersection between floors allowed (ΔA) on shear wall type CW3.

| Floor   | Floor height (m) | Direction X (mm) | Direction Y (mm) | Deviation of the Permit ΔA (m) | Explanation |
|---------|------------------|------------------|------------------|-------------------------------|-------------|
| Ground Floor | 0                | 0,0000           | 0,0000           | 0,0000                        | Safe        |
| P1      | 4,5              | 0,0840           | 0,0001           | 0,0692                        | Safe        |
| P2      | 3,8              | 0,2437           | 0,0002           | 0,0585                        | Safe        |
| 2       | 4                | 0,6626           | 0,0007           | 0,0615                        | Safe        |
| 3       | 2,9              | 1,1750           | 0,0012           | 0,0446                        | Safe        |
| 4       | 2,9              | 1,8148           | 0,0018           | 0,0446                        | Safe        |
| 5       | 2,9              | 2,5664           | 0,0026           | 0,0446                        | Safe        |
| 6       | 2,9              | 3,4021           | 0,0034           | 0,0446                        | Safe        |
| 7       | 2,9              | 4,3155           | 0,0043           | 0,0446                        | Safe        |
| 8       | 2,9              | 5,2971           | 0,0053           | 0,0446                        | Safe        |
| 9       | 2,9              | 6,3469           | 0,0063           | 0,0446                        | Safe        |
| 10      | 2,9              | 7,4665           | 0,0075           | 0,0446                        | Safe        |
| 11      | 2,9              | 8,6510           | 0,0087           | 0,0446                        | Safe        |
| 12      | 2,9              | 9,8953           | 0,0099           | 0,0446                        | Safe        |
| 13      | 2,9              | 11,1939          | 0,0112           | 0,0446                        | Safe        |
| 14      | 2,9              | 12,5415          | 0,0125           | 0,0446                        | Safe        |
| 15      | 2,9              | 13,9352          | 0,0139           | 0,0446                        | Safe        |
| 16      | 2,9              | 15,3733          | 0,0154           | 0,0446                        | Safe        |
| 17      | 2,9              | 16,8475          | 0,0168           | 0,0446                        | Safe        |
| 18      | 2,9              | 18,3481          | 0,0183           | 0,0446                        | Safe        |
| 19      | 2,9              | 19,8715          | 0,0199           | 0,0446                        | Safe        |
| 20      | 2,9              | 21,4167          | 0,0214           | 0,0446                        | Safe        |
| Roof    | 3,5              | 23,3067          | 0,0233           | 0,0538                        | Safe        |

Based on these data, the highest horizontal deviation value obtained on the 22nd floor in the direction of X is 0.0233 m which is still below the allowable safety margin of 0.0538 m with the percentage difference in deviation in the direction of X by 56.7%. This is due to the influence of the CW3 shearwall type, which can reduce the horizontal deviation value that occurs due to the earthquake based on SNI 1726 of 2012 in the spectrum response analysis.

4. Conclusion

Based on the results of research on the structure of Technoplex Living Apartment Bandung with reference based on SNI 1726 of 2012 and analyzed using the finite element method. Then it can be concluded that:

- The output produced wherein the CW3 type wall shear produces the highest horizontal deviation value in the X direction with a value of 0.032 m greater than in the direction Y with a value of 0.0042 m. Because this analysis was carried out in one direction, namely the X direction with the percentage of earthquake loads received using orthogonal systems where the X direction building structure received an earthquake load of 100% while the Y direction of 30% of the earthquake load was the result of calculation of spectral response analysis methods.
- The value of horizontal deviation generated is below the allowable safety margin based on SNI 1726 of 2012 with the percentage of X-direction being 56.7% while the Y direction is 92.3%.

Acknowledgments

Authors wishing to acknowledge encouragement from colleagues, special work by technical staff or financial support from Sekolah Tinggi Teknologi Garut (STTG).

References

[1] Daly M C, Cooper M A, Wilson I, Smith D G and Hooper B G D 1991 Cenozoic plate tectonics and basin evolution in Indonesia Mar. Pet. Geol. 8 2–21

[2] Bolt B A 2001 The Nature of Earthquake Ground Motion The Seismic Design Handbook (Boston, MA: Springer US) pp 1–45
[3] Lee T-H and Mosalam K M 2005 Seismic demand sensitivity of reinforced concrete shear-wall building using FOSM method Earthq. Eng. Struct. Dyn. 34 1719–36

[4] Hemsas M, Elachachi S M and Breysse D 2010 Evaluation of the seismic vulnerability of quasi symmetrical reinforced concrete structures with shear walls Eur. J. Environ. Civ. Eng. 14 617–36

[5] Arslan M H and Korkmaz H H 2007 What is to be learned from damage and failure of reinforced concrete structures during recent earthquakes in Turkey? Eng. Fail. Anal. 14 1–22

[6] Mullapudi R Evaluation of Behavior of Reinforced Concrete Shear Walls through Finite Element Analysis ACI Spec. Publ.

[7] Falk R H and Itani R Y 1989 Finite Element Modeling of Wood Diaphragms J. Struct.Eng. 115 543–59

[8] Andreasson S, Yasumura M and Daudeville L 2002 Sensitivity study of the finite element model for wood-framed shear walls J. Wood Sci. 48 171–8

[9] Benedetti D and Benzoni G M 1984 A numerical model for seismic analysis of masonry buildings: Experimental correlations Earthq. Eng. Struct. Dyn. 12 817–31

[10] Betti M, Galano L and Vignoli A 2014 Comparative analysis on the seismic behaviour of unreinforced masonry buildings with flexible diaphragms Eng. Struct. 61 195–208