Design of Reinforced Concrete Shear Wall of Reactor Building, Experimental Power Reactor

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Abstract. Shear wall is a vertical structure in a high-level building that serves to withstand lateral loads such as seismic and wind forces. The addition of building height using portal frame structure to withstand lateral force becomes uneconomical because it causes the dimension of columns and beam structure to be large and the number of reinforcement needed more and more. To improve the stiffness and strength of the portal frame structure against the lateral force it is attempted to use a combination of portal frame structure and shear walls. The rigid relationship between columns, beams and shear walls forms the interaction between the portal frame structure and the shear wall thoroughly on the surface of the building. The objective of the research was to know the relation between the strength of the portal frame structure and the shear wall working together to withstand the loads that work both gravitational load and lateral load using SAP2000 withstand seismic force of up to 0.4 gal. The result shows that shear walls with a thickness of 20 cm is able to increase the rigidity of structure. The walls are consist of one layer reinforcements bar diameter is 13mm with spacing is 250 mm.

1. Introduction
Experimental Power Reactor (RDE) is a 10 MWe non-commercial reactor which will be built at Puspiptek Serpong Area. The construction of this reactor is expected for management project development, industrial heat application research experience in desalination process, production of hydrogen and coal liquefaction process, operational research reactor readiness and design development of reactor building structure independently in Indonesia [1]. The RDE is designed as a pebble bed reactor (PBR) which has high safety features. This reactor has been tested, can be developed further in order to meet the electricity demand [2]. In term of safety, the PBR design ensures a very minimum radiation release to the environment under any conditions including severe conditions such as Fukushima nuclear accidents which destroyed the cooling systems and leading to meltdown of reactor. Along with the construction technology, construction of building continues to increase, for instance high rise buildings and other special purpose buildings such as nuclear reactor building. Reinforced concrete is commonly used in the construction of nuclear reactor building [3]. Puspiptek area is classified as one of the areas that has a relatively high seismicity. Seismic load as lateral load must be taken into account in the design of this building based on Indonesian National Standard (SNI), so that the structure is able to sustain the load [4]. A shear wall is one of the most commonly used lateral...
loading resisting system. The addition of shear wall can dramatically increase the stiffness of the structure [5].

The program of RDE detailed design is expected to be completed on 2019, it will be considered as a pathway to reactor commercialization of PeLUIt[6]. The layout of the RDE is consist of several buildings such as turbine building, reactor building, emergency building and utility supply. It can be shown in Figure 1.

![Figure 1. RDE building layout [2]](image)

This program is the development of basic design, planning of building structure and analysis of reactor building structure, in order to study the strength of reactor building structure by using combination of frame structure and shear wall. The research considers national and international codes and standards [7]. The objective of the research is to obtain a complete shear wall design of the reactor building.

2. Shear Wall

Shear Wall is a vertical structure that functions to withstand lateral loads such as seismic and wind forces [8]. Based on the location and function, shear walls are classified into 3 types which are bearing walls, frame walls and core walls. Bearing walls are shear walls that support gravity loads. Frame walls are shear walls that resist to lateral loads, where the gravity load comes from reinforced concrete frames. Core walls are shear walls located within the central core area within a building typically filled with ladders or elevator shafts [9]. The walls located in the center have multiple functions and are considered to be the most economical choice. There have been several studies of shear walls [10]. The internal forces of frame structure with brasing and shear walls are smaller than the conventional frame structure [11]. Other analyzes are also carried out on the position of the shear wall, which can be modeled in an equation by considering the weight of the total structure and the base shear [12]. Variations of geometry and shear wall systems have also been tested on reinforced concrete structures.
The structural elements of shear wall include flexural walls, squat walls and couple shear walls, which have function to withstand lateral forces due to seismic loads. According to SNI 03-2847-2013 section 14.5.3.1, the minimum shear wall thickness shall not be less than 100 mm [13].

Column is structural component that accept bending combinations and axial loads of reinforced concrete, in accordance with SNI 03-2847-2013, section 21.6, this column is most widely used in structures to withstand axial force. Columns can be categorized into two types: short columns and long columns [14].

Beam is structural component which has function to withstand seismic loads and is primarily proportioned to withstand bending, based on SNI 03-2847-2013 [13].

3. Methodology

The research was conducted for a 47-meter reactor building which will be located in Puspiptek area, Serpong, South Tangerang City [1]. Firstly, modeling of structure was performed then entry for the structure is performed after the materials are defined. Next step was the input analysis using SAP2000 software [15]. The procedure of the research can be seen in Figure 2 while the data of structure presented in the Table 1.

![Procedure of the research](image-url)

**Figure 2.** Procedure of the research
Table 1. Data to be used in the analysis [24]

| Data of structure          | Description                                      |
|-----------------------------|--------------------------------------------------|
| Type of structure           | reinforced concrete                              |
| System structure            | ordinary moment resisting frame                  |
| Soil type                   | medium soil                                      |
| Location                    | Puspiptek area, Serpong, South Tangerang City   |
| Number of floors            | 14 floors                                        |
| Building length             | 42 m                                             |
| Building width              | 25 m                                             |
| The total height of the building | 47 m                           |
| Compressive strength of concrete ($f_{c}'$) | 35 MPa                                        |
| Yield strength of reinforcing bar ($f_y$) | 420 MPa                                    |

The floor plan of the reactor building at elevation -12.70 can be seen in Figure 3. It shows the relationship and function of each room. There are two big circular structures which contain the reactor pressure vessel and steam generator. The distance from center to center approximately 7.5 m. In order to simulate the stiffness of the structure, design is a shear wall was at cross section B-B, grid 4 number in the vertical axis direction.

![Figure 3. Floor plan of reactor building elevation -12.70 [2]](image_url)
The diagrammatic cross section of reactor building is shown in Figure 4. The lowest elevation of this building is -12.70m and the highest elevation of this building is +32.10m. The longest distance between columns is 10.20 m which can be seen at grid D to grid E. The patterned section of the wall indicates the shear wall that should be analyzed further but which one.

![Figure 4. Cross section of Reactor Building (B-B) [15]](image-url)
Figure 5 shows the two and three dimensional image of the reactor building using SAP2000. At the preliminary design phase, we calculate for 70 x 70 cm columns and 60 x 85 cm beams. The loading system includes a vertical loading system and a horizontal loading system [16]. Vertical loading system consists of dead loads and live loads. Dead loads (DL) are those loads which are considered to act permanently such as the weight of the structure and other related components while the live loads (LL) are usually unstable or moving loads. Horizontal loading system comprises of wind loads (WL) and seismic loads (EL) [17]. This research takes into account seismic loads only as horizontal loads [18]. The load combination as specified for COMB1 as 1.2DL + 1.6LL and COMB2 is 1.2DL + 0.5LL + 1.1 EL. Previous calculation shown the equivalent static shear load due to seismic load is 1,056 ton with seismic load distribution on each floor is as follows (Table 1) [19]:

**Table 2. Seismic load distribution of each floor of the reactor building**

| Number of Floor | Accumulation height $Z_i$ (m) | Load distribution Y-axis $F_{iy}$ (ton) |
|-----------------|-----------------------------|-------------------------------------|
| 14              | 44.80                       | 25                                  |
| 13              | 41.10                       | 23                                  |
| 12              | 38.10                       | 21                                  |
| 11              | 34.90                       | 19                                  |
| 10              | 31.75                       | 18                                  |
| 9               | 28.55                       | 16                                  |
| 8               | 25.40                       | 14                                  |
| 7               | 22.20                       | 12                                  |
| 6               | 19.05                       | 11                                  |
| 5               | 15.85                       | 11                                  |
| 4               | 12.70                       | 9                                   |
| 3               | 9.50                        | 7                                   |
| 2               | 6.35                        | 5                                   |
| 1               | 3.15                        | 3                                   |
4. Analysis and Discussion
Specific parameters are required before analysis stage. Those parameters are presented in Table 3. On the other hand Figure 6 shows the visualization of the wall. Blue color represents the columns while yellow color represents the walls.

Table 3. The design parameter of the shear wall

| Design Parameter                        | Symbols | Values | Units |
|-----------------------------------------|---------|--------|-------|
| shear force (from SAP2000 analysis)     | $V_u$   | 437.487| N     |
| reduction factor of shear force         | $\phi$ | 0.75   |       |
| thickness of the shear wall             | $t_w$  | 200    | Mm    |
| length of the shear wall                | $L_w$  | 10.2   | M     |
| height of the shear wall                | $h_w$  | 3.2    | M     |
| compressive strength of concrete        | $f'_c$ | 35     | MPa   |
| yield strength of reinforcing bar        | $f_y$  | 420    | MPa   |
| thickness of concrete cover             | $t$    | 40     | mm    |

Figure 6. Shear wall and the columns

4.1. Number of reinforcement

$A_{sv} = L_w \times t_w = 10.2 \times 10^3 \times 200 = 2.04 \times 10^6 \text{ mm}^2$

$V_u \text{ ada} = \frac{1}{6} \times A_{sv} \times \sqrt{f'_c} = \frac{1}{6} \times (2.04 \times 10^6) \times (\sqrt{35}) = 2.011.467 \text{ N}$

$V_u = 437,487 < V_u \text{ servicable} = 2.011.467 \text{ N} \text{ (one layer of reinforcement)}$

Maximum shear strength $V_u \text{ max} = 5 / 6 \times A_{sv} \times \sqrt{f'_c} = 5 / 6 \times (2.04 \times 10^6) \times (\sqrt{35}) = 10,057,336 \text{ N}$ so the shear force ($V_u$) is still below the upper limit of the shear strength ($V_u \text{ max}$). [20]

4.2. Designs the horizontal reinforcing bar.

Minimum reinforcement distribution ratio $\rho = 0.0025$ and maximum space 45 cm, [21]

Area of shear wall / meter length $A_{sw} = t_w \times 1 \text{ m} = 0.20 \times 1 = 0.20 \text{ m}^2$ at least every meter $A_{swt} = A_{sw} \times (0.0025) = 0.20 \times 0.0025 = 500 \text{ mm}^2$
If D13 reinforcing bar is utilized for vertical and horizontal, then for 1 layer is calculated as $A_{tul} = 1 \times \pi \times \left(\frac{D_{tul}}{4}\right)^2 = 1 \times \pi \times \left(\frac{132.67}{4}\right)^2 = 132.67 \text{ mm}^2$, then number of reinforcement bar become $N_{tul} = \frac{A_{swt}}{A_{tul}} = 3.77 = 4$

The space (S) is calculated as $S = \frac{1000}{4} = 250 \text{ mm}$ (as the minimum requirement), so we there for 250 mm spacing was used. [22]

4.3. **Designs the reinforcement in order to resist the shear force** [23]

Previous calculation is assumed by using one layer of reinforcement D13 - 250 mm. The shear strength of the wall is calculated as $V_n = A_{cv} \times (ac \times \sqrt{f'_c} + \rho_n \times f_y)$

\[
V_n = (200 \times 10200) \times (0.25 \times 35 + 0.0047 \times 420) = 7.873.286,05 \text{ N}
\]

$V_n = 437.487 \text{ N} < 7.873.286,05 \text{ N}$. So one layer reinforcement D13 - 250 mm was used.

Figure 7 shows the detail of reinforcement of the shear wall. The wall is 10.2 m in length and 3.2 m in height. It utilized a 13 mm diameter reinforcing bar with 250 mm spacing.

![Figure 7. Planning of crotch in the shear wall](image-url)

\[\text{Figure 7. Planning of crotch in the shear wall}\]
5. Conclusions and Suggestions
The result shows that shear walls with a thickness of 20 cm is able to increase the rigidity of structure. The shear walls are consist of one layer reinforcement bars with 13 mm diameter and 250 mm spacing.

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