Earthquake lateral force analysis of reactor building, experimental power reactor

E R Iswanto¹, H Suntoko¹ and Fakhruddin²

¹National Nuclear Energy Agency, Jakarta, Indonesia
²Civil Engineering Department, Universitas Hasanuddin, Makassar, Indonesia

E-mail: ekorudi@batan.go.id

Abstract. Indonesia is considering to construct its first experimental power reactor. Similar to other conventional nuclear power plants, this type of reactor is designed and built to withstand external hazards such as an earthquake. The seismic resistance design standard for building (SNI 03-1726-2012) as basic guidance should be implemented and used for earthquake-resistant building design. In this paper, a reactor building is considered for earthquake lateral force analysis to determine the design base shear force. In general, this analysis performed statically and dynamically. For static analysis, the equivalent lateral force method were used, while for dynamic analysis, the response spectrum method is used. The results of this study have shown that the value of displacement by using static analysis is more significant than the value of displacement by using dynamic analysis. It can be concluded that although the dynamic analysis is more accurate, the static analysis would lead to a more conservative result.

1. Introduction

Geographically, Indonesia is located between two continental plates and two oceanic plates. Those continental plates are the Eurasian Plate and the Indian-Australian Plate, while those Oceanic Plates are the Philippine Sea Plate and Pacific Plate. Plates or tectonic plates are continually moving. On the other hand, Indonesia sits on the Pacific Ring of Fire so called the Circum-Pacific belt. It considers as an area with a high degree of tectonic activity. Being located on those plates and the belt, Indonesia has to deal with natural hazards such as volcanic eruptions, earthquakes, flood and tsunami. These hazards can harm not only human and animal lives, but also infrastructures such as buildings, roads, and bridges. In terms of buildings, Experimental Power Reactors (RDE) is a particular structure that requires high security and safety. It should be designed taking into account earthquake loads [1]. This study performed in Serpong site which is located at Serpong Nuclear Area Puspiptek, South Tangerang. The global positioning system coordinates of the location are at 6°21’28” S and 106°40’40” E. The site is planned to host the RDE as shown in figure 1.
2. Lateral force analysis
The lateral design force shall first be computed for the building as a whole. This lateral design force shall then be distributed to the various floor levels. The overall design seismic force thus obtained at each floor level shall then be distributed to individual lateral load resisting elements depending on the floor diaphragm action [3,4]. There are two commonly used procedures for specifying seismic design lateral forces which are equivalent static force analysis and dynamic analysis [5-7].

2.1. Equivalent static force analysis
The equivalent lateral force for an earthquake is a unique concept used in earthquake engineering. The concept is attractive because it converts a dynamic analysis into partly dynamic and partly static reports for finding the maximum displacement (or stresses) induced in the structure due to earthquake excitation. For the seismic-resistant design of structures, only these maximum stresses are of interest, not the time history of stresses. The equivalent lateral force for an earthquake is defined as a set of lateral static forces which will produce the same peak response of the structure as that obtained by the dynamic analysis of the structure under the corresponding earthquake. This equivalence is restricted only to a single mode of vibration of the structure.

2.2. The fundamental natural period (T)
The reactor building is a reinforced concrete structure equipped with a shear wall. In order to calculate the fundamental natural period (T), it should be used Eq. 1 [4].

$$ T = \frac{0.0062}{C_w} \times h_n $$

(1)

Where $h_n$ is the height of the structure and $C_w$ is a coefficient of the fundamental natural period as expressed in Eq. 2.

$$ C_w = \frac{100}{A_B} \sum_{i=1}^{x} \left( \frac{h_i}{h_n} \right)^2 \left[ 1 + 0.83 \left( \frac{h_i}{D_i} \right)^2 \right] $$

(2)

where $A_B$ is the area of the base structure, $A_i$ is the area of the shear wall, $D_i$ is the length of shear wall $h_i$ is the height of the shear wall, and $x$ is the number of a shear wall that has a function to counter the lateral load at the same axis effectively.
2.3. Base shear force
The applied of equivalent static force analysis on the building is generate base shear (V) which can be obtained by Eq. 3 [8].

\[ V = C_s \times W \] (3)

Where, \( C_s \) is a value of seismic response coefficient where could be found in SNI 1726 2012, and \( W \) is the effective seismic weight which considered as its full dead load plus the appropriate amount of imposed load as specified. While computing the seismic weight of each floor, the weight of columns and walls in any storey shall be equally distributed to the floors above and below the storey.

2.4. Seismic response coefficient
The seismic response coefficient (\( C_s \)) is used to determine base shear. It can be calculated by using Eq. (4).

\[ C_s = \frac{S_{DS}}{R I_e} \] (4)

where \( S_{DS} \) is the acceleration of short periods 0.2 second, \( R \) is response modifications factor or response reduction factor, depending on the perceived seismic damage performance of the structure, characterized by ductile or brittle deformations and \( I_e \) is an important parameter.

The value of \( C_s \) from Eq. 2 should not exceed the maximum seismic response coefficient (\( C_{s\ max} \)) which can be calculated by using Eq. 5.

\[ C_{s\ max} = \frac{S_{DS}}{T R I_e} \] (5)

Where \( T \) is the fundamental natural period of building. Meanwhile, the value of \( C_s \) from Eq. 2 should not less than the minimum of seismic response coefficient (\( C_{s\ min} \)) which can be calculated by using Eq. 6

\[ C_{s\ min} = 0.044 \times S_{DS} \times I_e \geq 0.01 \] (6)

An individual assessment for a structure that constructed on the area with the maximum response spectrum acceleration \( S_1 \) is equal or greater than 0.6g, the value of \( C_s \) should not less than \( C_s \ 0.6g \) as expressed in Eq. 7.

\[ C_{s\ 0.6g} = \frac{0.5 S_1}{R I_e} \] (7)

2.5. Vertical distribution of lateral force
The distribution of the lateral force vertically (\( F_x \)) along the height of the building can be calculated by using these equations as follow:

\[ F_x = C_{vx} \times V \] (8)

and

\[ C_{vx} = \frac{w_x \times h_x^k}{\sum_{i=1}^{n} w_i \times h_i^k} \] (9)

where \( C_{vx} \) is vertical distribution factor, \( w_x \) and \( w_i \) are a seismic weight on floor \( x \) or \( i \), \( h_x \) and \( h_i \) are the height of building from the base level up to level \( x \) or level \( i \) while \( k \) is exponent factor.

2.6. Horizontal distribution of lateral force
The distribution of the lateral force horizontally (\( V_x \)) is calculated using Eq. 10

\[ V_x = \sum_{i=x}^{n} F_i \] (10)
2.7. Dynamic force analysis

Dynamic analysis is classified into two types which are response spectrum method and time history method. Dynamic analysis shall be performed to obtain the seismic design force, and its distribution to different levels along with the height of the building. The response spectrum method will be discussed further.

Response spectrum is a curve plotted between the period of vibration of the structure and the maximum responses based on the damping ratio and specific input motion [9]. The maximum responses are describe as spectrum displacement, spectrum velocity and spectrum acceleration [9]. According to SNI 1726 2012, the response spectrum is determined by 2475 years return period with 2% probability of exceedance in 50 years. The parameters of response spectrum are calculated by these following equation.

\[
S_{DS} = \frac{2}{3} S_{MS}
\]

\[
S_{D1} = \frac{2}{3} S_{M1}
\]

\[
T_0 = 0.2 \times \frac{S_{D1}}{S_{DS}}
\]

\[
T_s = \frac{S_{D1}}{S_{DS}}
\]

\[S_{DS}\] is parameter of design acceleration spectrum response at short periods, \(S_{D1}\) is a parameter of design acceleration spectrum response at 1 second periods, \(S_{MS}\) is parameter of acceleration response spectrum at short periods, \(S_{M1}\) is parameter of acceleration response spectrum at 1 second periods, \(T_0\) is short natural periods and \(T_s\) is long natural periods.

These following steps should be followed to calculate the design acceleration response spectrum (\(S_a\)). The design response spectrum is shown in figure 2.

- For period (T) is less than \(T_0\)
  \[S_a = S_{DS} \times \left(0.4 + 0.6 \times \frac{T}{T_0}\right)\]

- T is greater or equal than \(T_0\), and T is less or equal than \(T_s\), \(S_a\) is equal to \(S_{DS}\)
- T is greater than \(T_s\)
  \[S_a = \frac{S_{D1}}{T}\]

**Figure 2.** Design of response spectrum in SNI 1726 - 2012 [4].
3. Methodology

In order to calculate lateral forces and its distribution to different level along with the height of building, two analysis are performed. Those are equivalent static force analysis and dynamic force analysis. The methodology of lateral forces analysis is shown in figure 3.

![Figure 3. Lateral forces analysis.](image)

Reactor building is a reinforced concrete building where the primary system, important auxiliary and supporting systems and the remote shutdown station take in place. It is designed to protect the reactor facility from external events. A general description of the reactor building is given in table 1.

| Data item          | Description           |
|--------------------|-----------------------|
| Type of structure  | reinforced concrete   |
| System structure   | ordinary moment resisting frame |
| Building types     | multistory            |
| Number of floors   | 14 floors             |
| Building length    | 42 m                  |
| Building width     | 25 m                  |

Table 1. Reactor building description [2].

Figure 4 (a) describes the floor plan of the reactor building with the 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. Meanwhile, the diagrammatic cross-section of reactor building is shown in figure 4 (b). 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.
4. Analysis and discussion

Loads are classified as either dead loads or live loads. Dead loads account for static forces that remain constant during the structure's life. In estimating dead loads, the actual weights of material and construction shall be used. In this study, the value of 1 t/m is considered as dead loads.

On the other hand, live loads account for moving loads. The implementation of live loads are based on what types of rooms are used in the building. The value of live loads at floor and roof is defined 0.5 t/m. Simple assumptions are made for the length of reactor building. For substructure, the length is approximately 42 m while the upper structure is approximately 34 m. Hence, the total seismic weight is 880 ton or equal to 8,768 KN as shown in table 2.

| Storey | Elevation | Live Loads LL (ton) | Dead Loads DL (ton) | Live Loads Reduction (ton) | Seismic Weight W = 1.2DL + 1.6LL (ton) | (KN) |
|--------|------------|---------------------|---------------------|--------------------------|----------------------------------------|------|
| Storey 15 (roof) | +32.10 | 17.00 | 34.00 | 8.50 | 54.40 | 542.04 |
| Storey 14 | +28.40 | 17.00 | 34.00 | 8.50 | 54.40 | 542.04 |
| Storey 13 | +25.40 | 17.00 | 34.00 | 8.50 | 54.40 | 542.04 |
| Storey 12 | +22.20 | 17.00 | 34.00 | 8.50 | 54.40 | 542.04 |
| Storey 11 | +19.05 | 17.00 | 34.00 | 8.50 | 54.40 | 542.04 |
| Storey 10 | +15.85 | 17.00 | 34.00 | 8.50 | 54.40 | 542.04 |
| Storey 9 | +12.70 | 17.00 | 34.00 | 8.50 | 54.40 | 542.04 |
| Storey 8 | +9.50 | 17.00 | 34.00 | 8.50 | 54.40 | 542.04 |
| Storey 7 | +6.35 | 17.00 | 34.00 | 8.50 | 54.40 | 542.04 |
| Storey 6 | +3.15 | 17.00 | 34.00 | 8.50 | 54.40 | 542.04 |
| Storey 5 | +0.00 | 21.00 | 42.00 | 10.50 | 67.20 | 669.58 |
| Storey 4 | -3.20 | 21.00 | 42.00 | 10.50 | 67.20 | 669.58 |
| Storey 3 | -6.35 | 21.00 | 42.00 | 10.50 | 67.20 | 669.58 |
| Storey 2 | -9.55 | 21.00 | 42.00 | 10.50 | 67.20 | 669.58 |
| Storey 1 | -12.70 | 21.00 | 42.00 | 10.50 | 67.20 | 669.58 |
| Grand Total | | | | | 880.00 | 8,768.33 |
4.1. Equivalent static force analysis

4.1.1. Fundamental period
The fundamental natural period (T<sub>a</sub>) of reactor building is calculated by using equation 1 as described in the following equation:

\[ T_a = \frac{0.0062}{\sqrt{C_w}} \times h_n = \frac{0.0062}{\sqrt{2,889.76}} \times 32.10 = 0.0037 \text{ s} \]

4.1.2. Base shear force
By utilized equation 3, effective seismic weight (W) is multiplied with the seismic response coefficient (C<sub>s</sub>) to calculate the base shear (V). The C<sub>s</sub> is determined by response modification coefficient and important factor. These values are available in SNI 1726 2012.

\[ V = C_s \times W = 0.18 \times 8,768.33 = 1.58 \text{ KN} \]

4.1.3. Lateral force distribution
According to SNI 1726 2012, the design base shear is to be distributed with height. The lateral force vertically (F<sub>x</sub>) are calculated and tabulated in Table 3. Lateral load at storey 15 or rooftop is approximately 19.14 KN.

| Storey   | Elevation | Wi (KN) | hi (m) | Wi hi<sup>k</sup> (KN) | C<sub>vx</sub> | F<sub>x</sub> (KN) |
|----------|-----------|---------|--------|------------------------|-------------|----------------|
| Storey 15 (roof) | +32.10    | 542.04  | 47.37  | 25,676.55              | 0.12        | 19.14          |
| Storey 14 | +28.40    | 542.04  | 44.80  | 24,283.50              | 0.11        | 18.10          |
| Storey 13 | +25.40    | 542.04  | 41.10  | 22,277.95              | 0.10        | 16.61          |
| Storey 12 | +22.20    | 542.04  | 38.10  | 20,651.82              | 0.10        | 15.40          |
| Storey 11 | +19.05    | 542.04  | 34.90  | 18,917.28              | 0.09        | 14.10          |
| Storey 10 | +15.85    | 542.04  | 31.75  | 17,209.85              | 0.08        | 12.83          |
| Storey 9  | +12.70    | 542.04  | 28.55  | 15,475.31              | 0.07        | 11.54          |
| Storey 8  | +9.50     | 542.04  | 25.40  | 13,767.88              | 0.06        | 10.26          |
| Storey 7  | +6.35     | 542.04  | 22.20  | 12,033.34              | 0.06        | 8.97           |
| Storey 6  | +3.15     | 542.04  | 19.05  | 10,325.91              | 0.05        | 7.70           |
| Storey 5  | +0.00     | 669.58  | 15.85  | 10,612.87              | 0.05        | 7.91           |
| Storey 4  | -3.20     | 669.58  | 12.70  | 8,503.69               | 0.04        | 6.34           |
| Storey 3  | -6.35     | 669.58  | 9.50   | 6,361.03               | 0.03        | 4.74           |
| Storey 2  | -9.55     | 669.58  | 6.35   | 4,251.85               | 0.02        | 3.17           |
| Storey 1  | -12.70    | 669.58  | 3.15   | 2,109.18               | 0.01        | 1.57           |

The lateral force distribution is illustrated in figure 5. These values are for the entire reactor building in X and Y direction.
4.2. Dynamic force analysis
In this study, dynamic force analysis is calculated based on SNI 1726 2012. In order to calculate the parameters of acceleration spectral response for $MCE_R$ seismic ($S_M$), it should be defined several parameters and factors as follows:

- $S_S = 0.75$
- $S_1 = 0.35$
- $F_a = 1.20$
- $F_v = 1.80$

then the design parameter of spectrum response acceleration can be calculated as follows:

- $S_{DS} = 2/3 (S_M S_S) = 2/3 (1.20 \times 0.75) = 0.60 \, g$
- $S_{D1} = 2/3 (S_M S_1) = 2/3 (1.80 \times 0.35) = 0.36 \, g$
- $T_S = S_{D1} / S_{DS} = 0.36 / 0.60 = 0.60 \, s$
- $T_0 = 0.2 (S_{D1} / S_{DS}) = 0.2 (0.60) = 0.12 \, s$

Figure 5. Seismic lateral force distribution of reactor building [2].
Figure 6. Design of response spectrum at Serpong site [2].

Figure 7. Displacement at each storey of reactor building for static analysis and dynamic analysis [2].
Further calculation is performed to estimate the displacement of each floor [10-12]. By using the model 2D of the reactor building and applying the load including all combinations. Figure 7 illustrates the displacement at each storey of the reactor building. It indicates the value of displacement by using static analysis is bigger than the value of displacement by using dynamic analysis [13, 14]. For instance at storey 15 (rooftop), the value of displacement by using static analysis is about 4.62 cm while the value of displacement by using dynamic analysis is approximately 3.68 cm. Those values are smaller than the required value based on a standard which has minimum displacement of high rise building is about 0.01 times the total height of the structure or equivalent to 28 cm.

5. Conclusions and suggestion
The earthquake lateral force analysis was performed by using static analysis and dynamic analysis. The static analysis approach defines a series of forces acting on a building to represent the effect of earthquake ground motion, typically defined by a seismic design response spectrum. The value of displacement by using static analysis is bigger than the value of displacement by using dynamic analysis. In terms of the design phase, the static analysis is more conservative than dynamic analysis although the dynamic analysis is more accurate and prone to the real situation.

6. Acknowledgments
This research is supported by the 2018 Research Fund of INSINAS Program from The Ministries of Research, Technology and Higher Education the Republic of Indonesia.

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