Vibration Response Simulation on a High Risk Building with Laminated Rubber Bearing Base Isolation Subjected to Earthquake Excitation

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Abstract. In a high risk building like hospitals, laboratories, or school, the response of the building due to earthquake might be very dangerous. To reduce victims and damages in infrastructure, a type of base isolation is installed to the foundation of the building. The base isolation, in form of a laminated rubber bearing, produces a horizontal movement of the structure when subjected to earthquake forces in order to keep the people and equipment safe. Some calculations of the response vibration parameters are observed to determine the optimal characteristics of the base isolation. The Keq Value is 415,120,000 N/m and the total mass of the building is 739,534,249.7 kg as well as the highest vibration force is 4,015,079,348.47 N. The aim of this research is to simulate the lateral motion of the building with base isolation, due to earthquake forces and decide whether the response is as expected of the design.

1. Introduction
Indonesia is located in between three continental plates, as well as in the center of the ring of fire are where most of the planet’s active volcanoes are also located. With a long history of massive earthquakes and the risk of possible future earthquakes, a preventive action is used in the form of base isolations. Base isolation is an earthquake damage reduction method that is applied on the foundation of a building. The main function of base isolation is to reduce the response vibration excited by the earthquake to minimize victims and damages. One of the popular types of base isolation is the laminated rubber bearing, which consists of layers of steel and rubber plates. The laminated rubber bearings absorb the earthquake force without continuing it to the rest of the structure above [1], thus creating a lateral movement instead of a cantilever movement. The aim of this study is to simulate the response of a high risk building equipped with laminated rubber bearing base isolation to find out whether the base isolation can work to its designated function, as well as to compare the value of displacement based on two types of system simplification.

2. Analysis model
2.1. Specifications of base isolation
The actual laminated rubber bearings used in the building studied has the following specifications presented in Table 1. The data will be used for simplification on the simulation stage. There are 161 bearings divided in four types of different diameter sizes distributed on the foundation of the building. The types of rubber used are the high damping rubber bearing which has no lead core in the center.
Table 1. Design characteristics of base isolation

| Component                     | HH800 | HH1100 | HH1200 | HH1300 |
|-------------------------------|-------|--------|--------|--------|
| Outer Diameter \(d_0\) [mm]   | 800   | 1100   | 1200   | 1300   |
| Shear Modulus \(G_{eq}\) [N/mm²] | 0.620 | 0.620  | 0.620  | 0.620  |
| Thickness of rubber layer \(T_r\) [mm] | 5.4   | 7.4    | 8.0    | 8.7    |
| Number of rubber layer \(N\) | 37    | 27     | 25     | 23     |
| Height \(H\) [mm]             | 422.2 | 390.2  | 385.6  | 376.9  |
| Spring Constant \(kN/m\)      | 1.56  | 2.94   | 3.50   | 4.11   |

The base isolation is modeled as in Figure 1. With the green layer being the rubbers and the black layers being the steel plates.

Figure 1. Base isolation modeled in autodesk inventor.

3. Simulation parameters
To get higher accuracy in the simulation, some relevant data are needed. The building mass \((m)\) calculated from ANSYS mass calculation feature obtained the value of 739,534,249.7 kg. In addition to the mass, the earthquake excitation force value is also needed. The value of the force is obtained from the earthquake response spectrum graph shown in Figure 2 from which the building is located using the following Eq. 1.

\[
F = m \cdot a
\]  

(1)

The maximum acceleration value is chosen to get maximum response value, which is 0.554 times gravitational acceleration. Thus the value of excitation force is 4,015,079,348.47 N. Other parameter needed is the frequency of the earthquake and that is 1.75 Hz also taken from the earthquake response spectrum, due to the fact that it is the lowest frequency in the highest acceleration, therefore creating the highest response.

Figure 2. Earthquake response spectrum in which the building studied is located.
4. Simulation preparations
In this study, two types of simulation are ran. The first is the simple simulation that simplified the 161 base isolations in the building into just one with mean values for all the dimensions. The second simulation is the unified simulation that sum up the total diameter and created one base isolation in a larger scale using comparative equation. The simulations are done using ANSYS Mechanical with the Keq value of 415,120,000 N/m. The simulation type is using Harmonic Response function with the calculated parameters inputted [2]. The details of the dimensions are listed in Table 2.

| Specifications                           | Simple | Unified |
|------------------------------------------|--------|---------|
| Outer Diameter [mm]                      | 1.01   | 13.02   |
| Inner Diameter [mm]                      | 40.21  | 510     |
| Thickness of one steel plate [mm]        | 6.81   | 87      |
| Thickness of one rubber layer [mm]       | 6.79   | 82      |
| Number of steel plate                    | 30     | 30      |
| Number of rubber layer                   | 31     | 31      |
| Total height [mm]                        | 401.4  | 5160    |

For a clearer visualization, a structural steel base [3] is added at the top and bottom of the base isolation model with the dimension of 20,000 x 20,000 x 2,000 mm. The top base is assumed as the building and the bottom base as the ground, the dimensions are the same so the visualization can be focused on the rubber part of the model. A distributed mass of 739,534,249.7 kg is applied vertically to the top base and an excitation force of 4,015,079,348.47 N is applied horizontally at the bottom base. A fixed support was applied at the bottom of the model [4] and meshing was done [5]. The pre-simulated model is shown in Figure 3.

5. Result and discussion
The results of the simulations are the vertical and horizontal displacement value as well as the visualization of the motion of the building subjected to earthquake excitation. The results shown are from the model created using specifications in Table 2. The visualizations are shown in Figure 4 and Figure 5. From both simulations, the results show that the displacement in the horizontal direction is greater than the horizontal displacement up to three times. The exact value of the displacements are shown in Table 3.
Figure 4. The visuals of displacement on the simple.

Figure 5. The visuals of displacement on the unified simulation.

Table 3. Value of displacements from the simulations

| Simulation | Vertical Displacement [mm] | Horizontal Displacement [mm] |
|------------|----------------------------|-----------------------------|
| Simple     | 14                         | 47                          |
| Unified    | 19                         | 60                          |

To compare, the unified simulation creates a wavy surface on the top base that acts as the building, it can be seen that the value of displacement has very small difference, unlike the simple simulation that keeps the building in shape. This happens because the dimension of the unified simulation model is far bigger than the simple simulation, thus creating a smaller ratio of size to force. Therefore the base isolations resisted the force better at the bottom to middle part, creating a wavy pattern at the top [6].

A mechanical engineering approach is used to obtain the frequency ratio value using the magnification ratio vs frequency ratio graph shown in Figure 6. The natural frequency value of system is obtained using the modal analysis function in ANSYS and that it 0.112 Hz ($f_n$), and 1.75 Hz excitation frequency ($f$) value from earthquake response spectrum. Therefore the value of frequency ratio, calculated using Eq. 2 is 15.62 Hz. That value shows that both of the simulation results have very low magnification factor, creating a safe system for the people and equipment inside, also stating that the base isolations are functioning to its design [7].

$$\beta = \frac{f}{f_n}$$ (2)
6. Summary
Base isolation creates response that is hand in hand with the designed function, when an earthquake occur the response will be in a lateral horizontal motion. With a mass of 739,534,249.7 kg and excitation force of 4,015,079,348.47 N The simulations done have shown that the dominant response of the building is in the horizontal direction, with the value from the simple simulation and unified simulation are 47 and 60 mm respectively. The ratio of the horizontal and vertical displacements are also the same which is 1:3. The building in this study with all the base isolation system is considered safe due to the fact that the magnification factor of the system is very low. From this study, it can be concluded that the simplifications used are showing pretty similar results and can be used for future preventive simulation on base isolation.

7. References
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