Analysis of vibration response from high damping rubber bearing and lead rubber bearing for using in high rise building foundations subjected to earthquake

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Abstract. Vibration due to earthquakes that occur in a high rise building like hospital building can disrupt the comfort, as well as operation of the hospital, and can cause casualties because usually, the building response to the earthquake is of a cantilever movement. The solution from a mechanical vibration point of view is to change the response of buildings to earthquakes so that hospital buildings are not destroyed by earthquakes by controlling the response of vibrations that produce lateral movement responses. One technology that is used to increase the resilience of buildings that subjected to earthquake, as well as control vibration response is the application of rubber bearing base isolation on the building foundations. High damping and lead rubber bearings base isolation are used on high rise building foundations which are designed to give lateral motion due to the base isolation construction. The results of computer simulation using ANSYS® software have shown that the rubber bearing base isolation gave vibration response in lateral motion.

1. Introduction
The impact of a strong earthquake response on a hospital building which is full of patients, medical personnel and medical care facilities, as well as many modern sophisticated types of equipment, is very dangerous. This can happen since the hospital building is rigid so the vibration response to the earthquake will be in cantilever motion. The solution to controlling such a vibration response is applying the principle of mechanical vibration that will respond in a lateral movement. One of the earthquake-resistant structural building is by using rubber bearing base isolation on the foundation. The types of high damping rubber bearing and lead rubber bearing base isolation. However, it is not yet known how the real vibration response of rubber bearing base isolation types will be when an earthquake occurs. So, therefore, virtual reality simulation using ANSYS® software was conducted to determine the vibration response of the high damping and lead rubber bearing base isolation due to the earthquake.

2. Analysis model
2.1. Specifications of high damping rubber bearing
The base isolation type high damping rubber bearing used in the hospital building studied is made of natural rubber sheets affixed to steel plates alternately which has no lead core in the center with the damping ratio (ζ) on the base isolation type high damping rubber bearing is 0.240 [1] and has the
following specifications presented in Table 1. High damping rubber bearing is modeled as in Figure 1. With the red layer being the rubbers and the black layers being steel plates. [2]

| Table 1. Design characteristics of high damping rubber bearing [1] |
|---------------------------------------------------------------|
| **Component** | **Value** |
| Outer diameter | $d_0$ mm | 800 |
| Number of rubber layers | $n$ - | 37 |
| Thickness of rubber layers | $t_r$ mm | 5.4 |
| Height | H mm | 422.2 |
| Shear modulus | $G_{eq}$ N/mm$^2$ | 0.620 |
| Spring constant | K $10^3$ kN/m | 1.56 |

2.2. Specifications of lead rubber bearing
The base isolation type lead damping rubber bearing used in the hospital building studied is made of natural rubber sheets affixed to steel plates alternately which lead core in the center with the damping ratio ($\xi$) on the base isolation type lead damping rubber bearing is 0.300 [1] and has the following specifications presented in Table 2. Lead rubber bearing is modeled as in Figure 2. With the red layer being the rubbers, the black layers being steel plates and the green being lead. [3]

| Table 2. Design characteristics of lead damping rubber bearing [1] |
|---------------------------------------------------------------|
| **Component** | **Value** |
| Outer diameter | $d_0$ mm | 800 |
| Number of rubber layers | $n$ - | 37 |
| Thickness of rubber layers | $t_r$ mm | 5.4 |
| Height | H mm | 422.2 |
| Outer diameter of lead plug | $d_l$ mm | 180 |
| Shear modulus | $G_{eq}$ N/mm$^2$ | 0.385 |
| Spring constant | K $10^3$ kN/m | 2.01 |

3. Simulation parameters
Base isolation used in hospital building totaled 161, but in this study, only one base isolation was simulated and analyzed, so the mass of hospital building used in calculations and simulation was the mass of hospital building for one base isolation. It is calculated that the mass of the hospital building is
259,989.666 kg with the maximum earthquake acceleration based on Figure 3 is 0.554 g during the earthquake period (T) of 0.57 seconds, so the earthquake frequency \((f_p)\) is 1.75 Hz.

**Figure 3.** The earthquake excitation (http://puskim.pu.go.id/) [4]

To determine the earthquake excitation force using the following the Eq. (1).

\[
F(t) = F \cos \omega t
\]  \hspace{1cm} (1)

The desired earthquake excitation is at the time of the maximum earthquake, so the value of \(\cos \omega t\) is 1. To determine the maximum earthquake excitation using the following Eq. (2). The result of the maximum earthquake excitation force \((F(t))\) is 1,412,976.237 N.

\[
F = m \cdot a
\]  \hspace{1cm} (2)

To analyze the vibration response of the base isolation type high damping rubber bearing and lead rubber bearing are with a frequency ratio using the following Eq. (3). The result of the frequency ratio at the time of earthquake frequency \((f_p)\) is 1.75 Hz at base isolation type of high damping rubber bearing is 4.6 while the type of lead rubber bearing is 4.16.

\[
\beta = \frac{\omega_f}{\omega_n} = \frac{f_p}{f_n}
\]  \hspace{1cm} (3)

Based on the magnification factor vs frequency ratio graph in Figure 4, the vibration response on the base isolation type of high damping rubber bearing and lead rubber bearing that occurs when the earthquake frequency \((f_p)\) is 1.75 Hz is very small, which means the vibration amplitude is very small. The magnification factor value produced is very small due to the small value \(\omega_n\). The cause of the small value \(\omega_n\) is due to base isolation that is not rigid.

**Figure 4.** Magnification factor vs frequency ratio [5]
4. Simulation preparations
To find out the vibration response of the base isolation type high damping rubber bearing and lead rubber bearing, simplified modeling using FEA in ANSYS®. In this study, two types of simulation are run using the harmonic response analysis tools. The first is high damping rubber bearing simulations and the second is lead rubber bearing simulations. Simulations using models and specifications of high damping rubber bearings and lead rubber bearings are presented in Table 1 and Table 2 and the calculated harmonic response parameters inputted.

For a clearer visualization, a base is added at the top and bottom of the base isolation model. The top base is assumed as the building and the bottom base as the ground. A distributed mass of 259,989.666 kg is applied vertically to the top base and an excitation force of 1,412,976.237 N is applied horizontally at the bottom base. The pre-simulated model is shown in Figure 5.

5. Result and discussion
The simulation is done using FEA in ANSYS® software using the harmonic response analysis tools. The base isolation type high damping rubber bearing is modeled with 37 layers of rubber that affixed to steel plates alternately. The vibration response that occurs in the results of the simulation base isolation type of high damping rubber bearing in Figure 6 is the lateral movement. The lateral movement response that occurs in high damping rubber bearing in the face of earthquake exposure allows the hospital building to withstand the seismic impact which has the potential to destroy [6]. The results obtained from the simulation of the vibration response of high damping rubber bearing are displacement in the horizontal direction is 51.08 mm in Figure 6 and the vertical direction is 18.38 mm in Figure 7.
The base isolation type of lead rubber bearing is modeled with 37 layers of rubber that are affixed to the steel plates alternately and there is lead inside. The vibration response that occurs in the results of the simulation base isolation type of lead rubber bearing in Figure 8 is the response that approaches the cantilever movement. The response that approaches the cantilever movement that occurs can potentially damage the structure and contents of the hospital building. A response that approaches the cantilever movement can occur due to the addition of leads which makes the base isolation rigid. However, if seen from the simulation results of the vibration response of the base isolation type lead rubber bearing response that approaches the cantilever movement there is a relative motion between the layers of rubber and steel plate which allows a slight lateral movement, so that the response that approaches the cantilever movement on the base isolation type lead rubber bearing lead does not cause severe damage. The results obtained from the simulation of vibration responses of base isolation type lead rubber bearing are displacement in the horizontal direction is 33.27 mm in Figure 8 and the vertical direction is 30.57 mm in Figure 9.
Figure 9. Lead rubber bearing simulation results at 1.75 Hz frequency in the vertical direction.

The results of the vibration response simulation of the base isolation type high damping rubber bearing produce lateral movement response and the base isolation type lead rubber bearing produces a response that approaches the cantilever movement. Base isolation type high damping rubber bearing is better than base isolation type lead rubber bearing in the face of earthquake exposure [7]. However, if the use of base isolation type lead rubber bearing combined with base isolation type high damping rubber bearing will make the base isolation type lead rubber bearings function as a displacement barrier, which means the displacement that occurs is smaller than the displacement on the base isolation type high damping rubber bearing.

6. Summary
By using base isolation type high damping rubber bearing, the vibration response during the earthquake period (T) 0.57 seconds is merely lateral movement. Displacement in the horizontal direction is 51.08 mm and in the vertical direction is 18.38 mm which is insignificant compared to horizontal displacement. Meanwhile, by using base isolation type lead rubber bearing, the vibration response during the earthquake period (T) 0.57 seconds is relatively still lateral movement since the total displacement is smaller. Displacement in the horizontal direction is 33.27 mm and the vertical direction is 30.57 mm. The base isolation is stiffer that makes the lateral movement shorter due to the addition of lead which makes the base isolation more solid.

If the use of base isolation is combined between types of high damping rubber bearing and lead rubber bearing, it is recommended that the lead rubber bearings are located in the outer circumference so it will function as a displacement barrier. Therefore total displacement is smaller than the displacement of all high damping rubber bearings only usage.

7. References
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