A study of base isolation system at cyclotron building in Indonesia High Seismic Region

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Abstract. The study of earthquake resistance design on cyclotron bunkers using base isolators was introduced. With the increasing trend of detection and treatment of cancer using nuclear technology in Indonesia, the construction of nuclear medicine facilities which include the manufacture of radiopharmaceuticals using a cyclotron facility must be held immediately. With the many areas in Indonesia in earthquake-prone areas, a cyclotron bunker design is needed that can accommodate the effects of the earthquake. The cyclotron bunker must be able to withstand earthquake loads without damage because apart from being a building structure, concrete also acts as shielding radiation during cyclotron operations. Base isolators have become a reliable technology in overcoming earthquake loads and will be used in cyclotron buildings in earthquake areas. By using the spectrum response method in the cyclotron building, the results of the base isolator will be evaluated. It was found that building acceleration after adding base isolators decreased 37\% and base isolators also increased the vibration period of cyclotron bunkers away from the earthquake period.

Keywords. Cyclotron, base isolator, spectrum respond, lead rubber bearing

1. Introduction

According to a report released by the International Agency for Research on Cancer, the World Health Organization (WHO) estimates that there are 18.1 million new cancer cases and 9.6 million deaths that occurred in 2018. The increase in cancer patients makes WHO predict cancer will be the number one cause of death in the world. One solution for cancer treatment that has developed in the world today is using nuclear technology, namely radioisotope. In Indonesia, the demand for cancer detection using nuclear technology, namely radioisotopes (18F- Fluoro-Deoxy-Glucose) which is the result of cyclotron facilities is increasing. Because the half-life of radioisotopes is very short with an average of 2 hours, the cyclotron building facilities must be as close as possible to the area in need.

Cyclotron facilities include nuclear facilities which have strict requirements. Concrete building in a cyclotron bunker besides functioning as a building structure that protects high value and sensitive equipment also function as shielding against radiation rays generated when the cyclotron operates. Therefore, the cyclotron bunker must be able to withstand earthquake loads without any damage resulting in disrupted structural integrity and function as shielding radiation due to cracks. Base isolators that have been proven to reduce earthquake loads and become a trusted technology have been widely used in the world, and from there will be a feasibility study on the use of base isolators in cyclotron.
bunkers. The purpose of this study is to obtain a basic cyclotron bunker design that is resistant to earthquake loads using a base isolator.

2. Theoretical study
In principle, building resilience design for earthquake loads is based on the energy capacity that can be held by the building must be greater than the energy released by the earthquake regarding the building. One of the technologies used to increase building resilience against earthquake loads is to reduce the energy imposed on the building. One technology that has been trusted uses a base isolator system. There are several known base isolators, namely Natural Rubber Bearings (NRB), Lead Rubber Bearings (LRB), and High Damper Rubber Bearings (HRB). The difference from the various base isolators mentioned above is from the energy reduction capacity through lateral displacement. In this paper, we will focus on the use of the LDR in the study of the design of earthquake-resistant cyclotron bunkers.

For the feasibility study to be carried out is the use of LDR base isolators in the cyclotron bunkers in the area that has experienced one of the highest earthquakes in Indonesia, namely the Yogyakarta area in Central Java. The bunker design that will be used in the study is where the cyclotron bunker is a separate building not in the main building and has its own foundation. In the design of the cyclotron facility, there are two areas, namely cyclotron bunkers and PET buildings which are separated by a distance of 100 mm in order to stabilize the structure. Figure1 describes the layout of the cyclotron facility with a bunker that contains a cyclotron unit and a control room on the left and PET building on the right. The weight of the bunker building and the cyclotron equipment is around 1,055,599 kg.

For this study, the cyclotron bunker is assumed to be a solid model and a foundation with a bunker separated by a base isolator. The limitation in this design is that the shift from the cyclotron bunker must be less than 100 mm to avoid colliding with other buildings in this case PET Building.

Figure 1. Lay out view of cyclotron facility Bunker cyclotron and PET building on difference foundation.

The LRB specification that will be used in this study is obtained from the vendor base isolator and collected in table 1 [1]. The first step in our design evaluates the amount of LRB needed in a cyclotron building. Maximum stress on rubber bearings caused by dead loads must range from 5 N/mm² to 10 N/mm² [2]. This limit is the maximum limit so that the yield point on the rubber bearing is always stable.
Table 1. Specification lead rubber bearing.

| Specification                  | Value  |
|-------------------------------|--------|
| Isolator Diameter (D1)        | 405 mm |
| Yielded Stiffness (Kd)        | 0.5 kN/mm |
| Characteristic Strength (Qd)  | 110 kN |
| Compression Stiffness (Kv)    | 100 kN/mm |
| Maximum Displacement (D_max)  | 200 mm |
| Axial Load Capacity (P_max)   | 900 kN |

Based on the specifications obtained from table 1, the initial calculation of base isolator needed for bunkers is 15 pieces and 7 for control rooms. The LRB placement on the layout will be spread according to the center of gravity as illustrated in figure 2.

Figure 2. Arrangement of LBR bearing units at the seismic isolating layer for cyclotron bunker.

LRB modeling in this study is assumed to be a single degree of freedom lump mass model with each normal stiffness and tangential stiffness. The analytical model of a single degree of freedom oscillating system is shown in figure 3 below.

Figure 3. An analytical model of a single degree of freedom oscillating system.

3. Results and discussion
To see the base isolator's response to the seismic load imposed, spectrum analysis response will be used. The earthquake load input for this building design uses data for the Yogyakarta area figure 4 [3]. In the seismic response spectrum was obtained for rock types with dumping factor of 0.05% which contained
the Period vs. Acceleration linkages. For input from the analysis model, the seismic spectrum data is converted to frequency vs acceleration as shown in figure 4.

![Figure 4. Seismic excitation Acceleration vs T Period.](image)

The input will be included in two models, namely the fixed base and base isolator used in the cyclotron bunker. For fixed base cyclotron building, the rotations and translation of foundation node at the base is fixed. The fundamental natural frequency and mode shape of cyclotron building were obtained. For building using base isolators, base isolator placement is between the foundation and structure of the cyclotron building as shown in figure 5. The Modal analysis of fixed base and base isolator building was carried out to determining natural frequency.

![Figure 5. Seismic excitation Acceleration vs Frequency.](image)

The natural frequency based on simulation results for a fixed base building is 72.18 Hz and for base isolator building is 0.572 Hz as shown in figure 7 and figure 8. The addition of base isolator also resulted in the period of the cyclotron bunker structure changing from 0.01 s to 2.261 s as shown in figure 6.
This causes the period to stay away from the maximum design of the earthquake which is around the period T range from 0.1 to 0.6 second. Comparison of stress generated between fixed base and base building insulators in terms of one particular point in the building decreased by around 75%. This is because the excitation force has been reduced by the base isolator. The displacement that occurs in the bunker after being subjected to the excitation force is 56.412 mm. This displacement is still below the allowable displacement to avoid collisions with other buildings as shown in figure 7.

Another method that is carried out in this study is Time History Analysis. Time history is usually used also to find out the earthquake response with input acceleration vs time chart. In this simulation, data will be input from the earthquake El-Centro Data for North-South components up to 55 seconds as shown in figure 8 [4]. The time history simulation results, the displacement base isolator bunker cyclotron, and the time history for North-South Component, time vs acceleration, result time history analysis for cyclotron building can be seen as in figure 9, 10, 11 and 12 below.
Figure 8. First mode base isolator.

Figure 9. Increase period of vibration of bunker cyclotron.

Figure 10. Displacement base isolator bunker cyclotron.
Based on the simulation result, the use of LRB bearing has succeeded in reducing the peak ground acceleration by around 37% from 3.44 m/s$^2$ to 2.166 m/s$^2$. This shows that the use of basic insulators can reduce the amount of acceleration due to the earthquake that occurred. To ensure that earthquake frequency does not resonate with building structures, from a mechanical engineering perspective it can use a table of magnification ratio vs. frequency ratio where the frequency ratio as shown in table 2.

| $f_p$ (Seismic Frequency) | $f_n$ (building natural frequency) | $\beta$ |
|---------------------------|-----------------------------------|--------|
| 13.88 Hz                  | 0.572 Hz                          | 24.26  |
| 2.1 Hz                    | 0.572 Hz                          | 3.67   |

The result of the frequency ratio compared to figure 13 shows that the structure of the building will tend to be stable due to the value of the $\beta$ far from the frequency ratio $= 1$.
4. Conclusions
Based on a study of earthquake resistance design on cyclotron bunkers building, the following conclusions are obtained.

- Base Isolations are decoupled between the bunker structure from the earthquake load and make the lateral period longer than the fixed base bunker.
- Due to the presence of displacement in the cyclotron bunker that uses a base isolator, the stress and moment generated due to the earthquake load will be smaller than the fixed base.
- The use of base isolators reduces the risk of damage to structures and high-value components in the bunker by reducing the impact force due to the earthquake.

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