RESPONSE OF EXISTING RUBBER BEARING AND DESIGNED BASE ISOLATOR FOR MALAYSIAN HIGHWAY BRIDGES

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ABSTRACT: In structural earthquake engineering, natural rubber and steel are used as base isolators for energy dissipation systems to reduce earthquake effect on structures. With laminated natural rubber and steel, the bearing can provide high vertical stiffness and flexibility in horizontal direction to ensure the mounts can support the loading from the structure and prevent excessive sideways from any horizontal loading especially when earthquake occur. This research performs the study of performance of Public Works Department (PWD) standard bridges under low intensity earthquake effect. The finite element modelling technique was used in this study to learn the behaviour of rubber bearing with various dimensions and directions of loading (vertical and horizontal). Performances of the rubber bearing were examined based on their stiffness factors. Seismic isolator is designed and it is found that the usage of designed seismic isolator increases the overall performance of the PWD Bridge. In general, this research indicates that the seismic risks should be considered in design the bridge for Malaysian.

Keywords- natural rubber, steel, base isolator, stiffness, earthquake, finite element

1. Introduction

In Malaysia, bridge rubber bearings are commonly used to absorb vertical vibrations produced by movement of traffics. The bearings are generally placed between bridge decks and tops of columns to ensure the loading does not affect the overall bridge structural elements. To make it more effective of rubber bearings, some improvements are needed in our bridge bearing design practices and consideration of seismic factor needs to prevent the bridges under earthquake loading.

In structural earthquake engineering, base isolator is one of the earthquake hazard reduction system that is used widely to provide earthquake resistant in structures such as buildings and bridges.

Base isolation as the seismic control technique is a strategy to reduce the inertia force of seismic as well as to reduce the form of inelastic deformation and damage to the sub-structure. The seismic isolation system that is widely used consists of laminated rubber bearings that are made of layers of rubber with steel shims. With this combination, the bearing can provide a very high vertical stiffness and is very flexible in the horizontal direction. These characteristics are important to ensure the mounts can support the loading from the structure and prevent excessive sides ways from any horizontal loading especially during earthquake.

2. Methodology

The method and theory that were practised to obtain successful results in this research will be briefly explained.

a) The bridge and existing rubber bearing properties are examined. Than the seismic isolator is designed. The vertical and horizontal stiffness of rubber bearing and seismic isolator are calculated. The equations used to obtain these stiffness values are given in equations below:

(i) Vertical Stiffness, $$K_C = \frac{3AG}{h}\left[1 + 2S2\right]$$

Shape factor for a square shape: $$S = \frac{r}{2h}$$

(ii) Horizontal Stiffness, $$K_S = \frac{AG}{h}$$

b) The Finite element software is used to create a model of a bridge structure that will be studied. Response spectrum analysis (RSA) is done on the bridge model using the finite element software. From this analysis we are able to obtain the moment, shear force, axial force and displacement of each element. The truckload analyses are also done and the results are used for comparison purposed.

c) Comparisons are done for the bridge with existing rubber bearing and bridge with seismic isolator on displacement, shear and moment for various earthquake intensity.

3. Description of Bridge

A simple span and simply supported bridge, representative of typical PWD bridges, are evaluated under this study. BRIDGE F0094, Kulai-Kota Tinggi highway is selected in this study. For these bridges the number of spans are equal to three and consist of concrete slab on prestress girder decks and reinforce concrete pier bents and abutments. The pier are all circular, and the geometry and boundary condition of these bridge models are shown in Fig 1a and 1b.

3.1 Decks and Pier Bents

The bridge decks are composite concrete slab on prestress concrete girders and pier bents consist of reinforced concrete circular columns. The cross section of deck prestress girders varies along the length. In these studies the simplified modelled are used by using the mid-span cross section girders (Fig 2). The girder dimensions properties in the mid-span and adjacent to the end-span segment are presented in Table 1

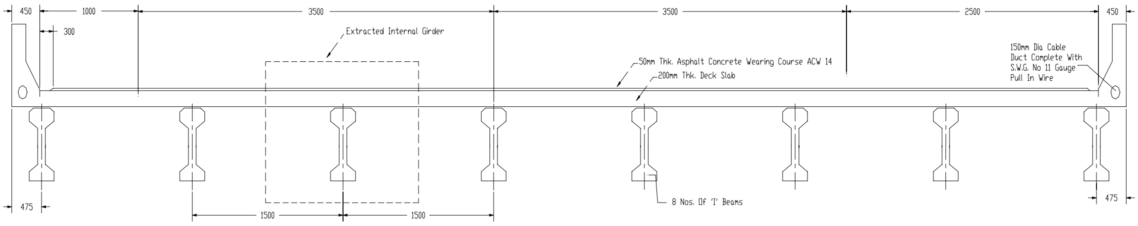

Fig 1a. Bridge Cross Section

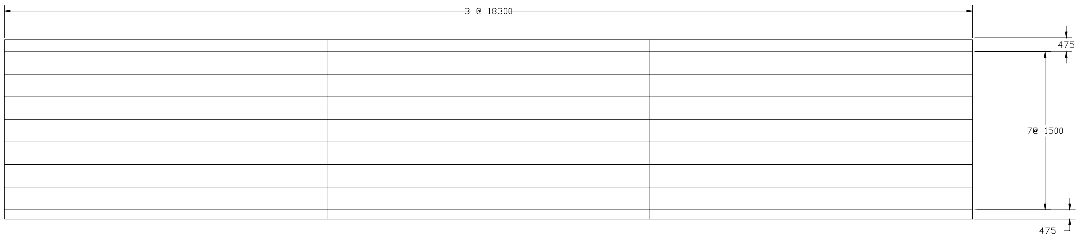

Fig 1b. Bridge Plan View

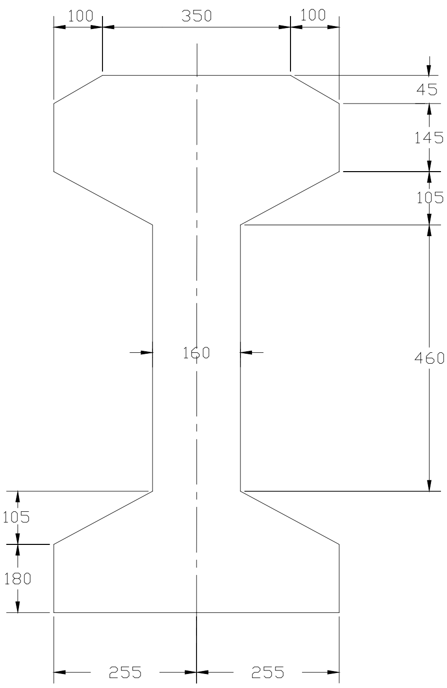

Fig 2. Mid span cross-section prestress girder

3.2 Column

The bridges, which are selected, have all circular columns with reinforcements. Fig 3 shows the geometric properties of the column and for detailed, Table 1 shows the cross-sectional properties and properties of the columns as an input data in the finite element modelling.

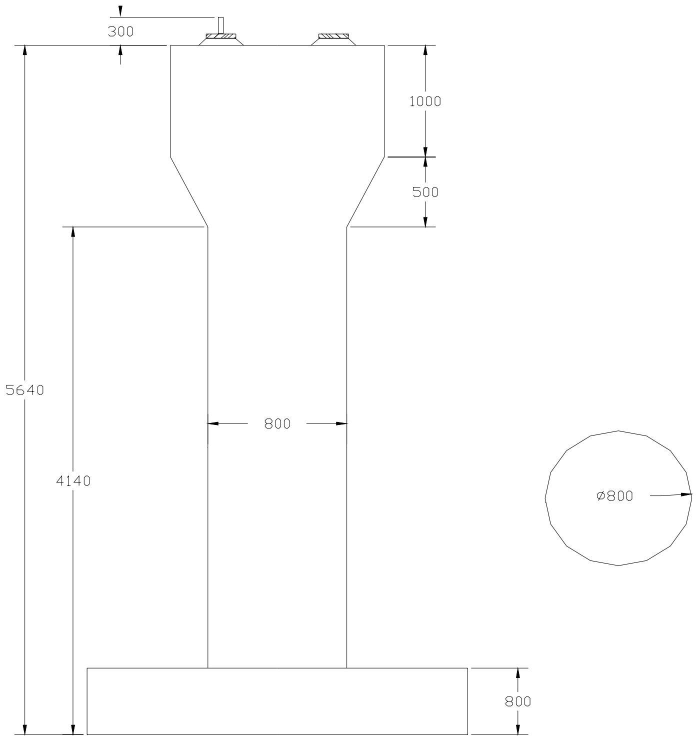

Fig 3. Bridge column for 3 span bridges

3.3 Existing Bearings

A typical fixed bearing is shown in Fig 4, which consists of rubber and steel layer with each part welded to the top and bottom steel plates. Connecting bolts connects the top steel plates to the deck prestress girder and the bottom steel plate is connected to the concrete support by anchor bolts. Rubber and steel layer bearing are used to transfer the vertical and horizontal forces from the superstructure to the substructure. Table 2 shows the bearing properties used in this study (ELB 400).

Table 1: Beam and column element dimension and materials properties

	Beam	**Column**
Composite Equivalent sec. Area (m^2)	0.3322	0.5027
Moment of Inertia on X direction (m^4)	3.740E-2	3.260E-2
Moment of Inertia on Y direction (m^4)	5.857E-3	3.260E-2
Modulus Of Elasticity (kN/m^2)	33.7E6	25.0E6
Weight (kN/m^3)	23.5616	23.5616
Mass	2.402	2.402

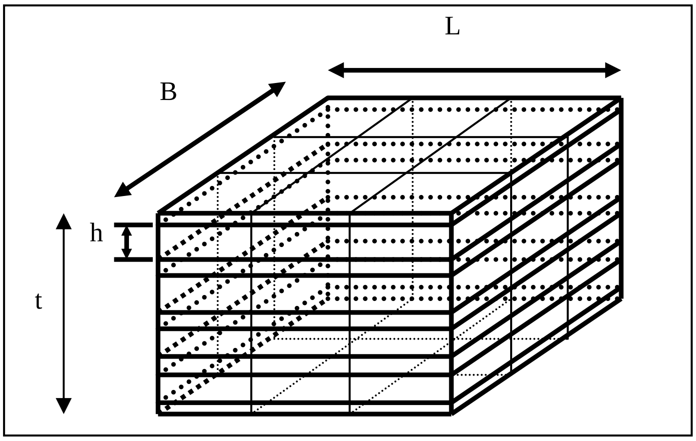

Fig 4. Typical dimension of rubber bearing

Table 2: Elastomeric laminated Bearings properties

Type	Dimension L x B x t (mm)	Compressive Stiffness (kN/mm)	Shear Stiffness (kN/mm)	Natural Rubber Thickness For		Steel Plate		Shape factor, S
				Inner Slab t1 (mm)	Outer Slab t0 (mm)	Nos.	Thickness ts (mm)	
ELB 400	250x280x39	457	2.1	9	6	3	3	7.34

3.4 Design of Base Isolator

The design example provided in this section is based on design to 1997 UBC requirements. The material definitions are contained in Table 3. The IHD 55 is adopted for into this study and the properties of the rubber used are also listed. In this design procedure, the three-span bridge is redesigned in term of loading to compute the actual loadings imposed for each rubber bearing. In the proposed design, the total loading is taken into consideration as the input data in design procedure.

Using the 1997 UBC, several assumptions are made to get the seismic parameter in this study. The site condition is taken to be Zone 1 with S_E soil type, and it is assumed that the site is more than 15kM from a known active fault. The parameter associated with the location are Z=0.075, S=S_E, N_A=1 and M_M=2.67. The full parameters for seismic design are listed in Table 4.

Table 3: Material properties used in design

Elastomer Properties	KN, mm
Shear Modulus	0.00064
Ultimate Elongation	6.5
Material Constant, k	0.73
Elastic Modulus, E	0.0022
Bulk Modulus	2.0
Damping	0.10
Gravity	9810

Table 4: Seismic Design Parameters

Seismic zone factor, Z	0.075
Soil Profile type	S_E
Seismic Coefficient, C_A	0.18
Seismic Coefficient, C_V	0.25
Near-Source Factor, N_a	1.0
Near-Source Factor, N_v	1.0
MCE Shaking intensity $M_M Z N_a$	0.2
MCE Shaking intensity $M_M Z N_v$	0.2
Seismic Source type	C
Distance to Known Source (km)	> 15 km
MCE response Coefficient, M_M	2.67
Lateral Force Coefficient, R_l	2.5
Fixed Base Lateral Force Coefficient, R	
Important Factor, I	
Seismic Coefficient, C_{AM}	0.35
Seismic Coefficient, C_{vm}	0.65

In this study, the stiffness values are the interested factors to be analyses and are taken as the parameter in the finite element modelling. Fig 5 shows the geometric dimensions for the designed base isolator. The bearing consists of five layers of internal rubber layers which 10.4mm thickness. The final dimension of the bearing is 250mm width, 260mm length and 76mm total height. The full properties for the design base isolator are proposed in Table 5 with the 67kN/mm for the vertical stiffness and 0.8kN/m for the horizontal stiffness. Every rubber layer is laminated with 2mm steel shims and 5mm cover layer.

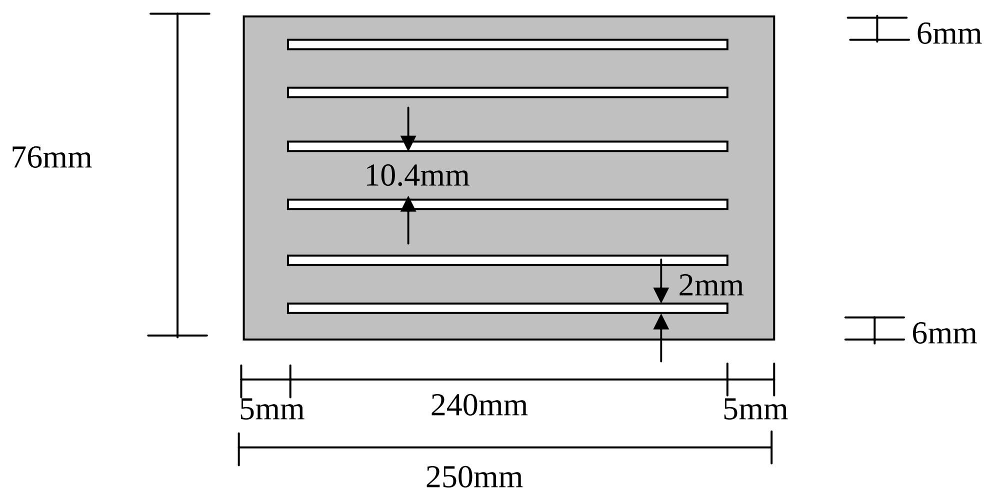

Fig 5. Detail design of isolator (not to scale)

Table 5: Elastomeric laminated Bearings properties

Type	Dimension L x B x t (mm)	Compressive Stiffness (kN/mm)	Shear Stiffness (kN/mm)	Natural Rubber Thickness For		Steel Plate		Shape factor, S
				Inner Slab t1 (mm)	Outer Slab t0 (mm)	Nos.	Thickness ts (mm)	
Design Base Isolator	250x260x76	67	0.8	10.4	6	6	2	6.07

4. Computer Models

The bridges are analyses using SAP2000 computer programs, where beam-column elements are used to model the columns and simple connection elements are employ in modelling bearings. In this study 5% damping is considered in the bridge models. This is consistent with AASHTO's response spectra and it is commonly used value for others analyses. This level of analysis can be looked upon as radiation damping at the foundations. The three-dimensional analysis is done to get the clear behaviour of bridge with conversional rubber bearing and bridge base isolation under earthquake ground motion.

SAP2000 are used in this study, Fig 6 show the analytical 3-D models for 3 Span PWD Bridge. For major mode shapes in the tree translational directions (i.e., longitudinal, transverse and vertical) corresponding mass proportional damping was assigned to the bridge modelled.

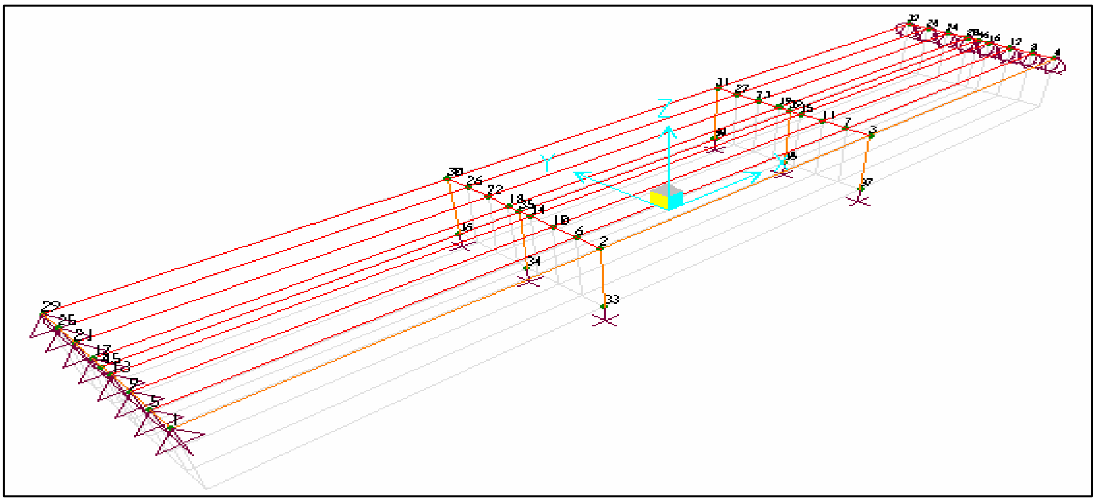

Fig 6. Joint Number for 3D analysis

4.1 Input Ground Motion

Ground motion records of the S16E component recorded at the Pacoima Dam during the February 9, 1971 San Fernando Earthquake were obtained and used in the study. The actual ground acceleration for this earthquake is 1.17g and its classify under most strongly earthquake with 65 are deaths. The horizontal components of the original ground acceleration were linearly scaled so that their peak ground acceleration (PGAs) are 1.17g accordance with the maximum PGA for San Fernando Earthquake.

4.2 Earthquake Intensity scaling factor

The 5% damping are taken for both earthquake ground motion. With the actual ground acceleration, the scaling factors are used to get the uniform intensities for comparison between both ground motions. The intensities vary from 1.17g to 0.02g.

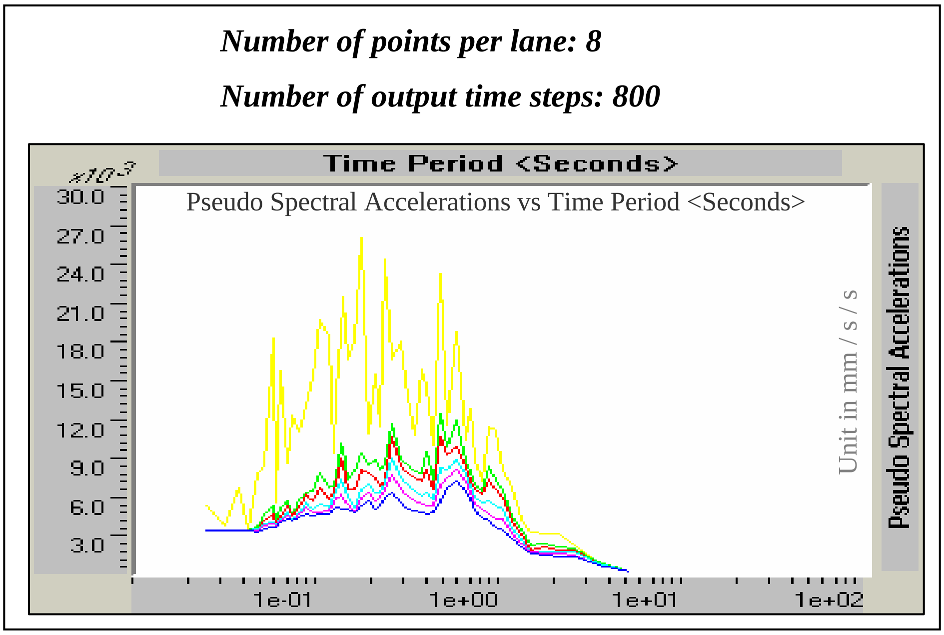

Fig 6. Response Spectrum Curves of San Fernando Earthquake

5. Result and Analysis

5.1 Level of Safety Design Base Isolator

The finite elements models are developed based on the properties of the designed base isolator and than the comparison are made between this isolator and the existing bridge rubber bearing. The response spectrum of San Fernando Earthquake signal is scaled from 0.02g to 1.17g. Fig 7 gives the example on how the analysis is done for maximum axial forces for beam with base isolation system. In the same systems, two types of analysis are performed; there are truckload analysis and response spectrum analysis (San Fernando Earthquake).

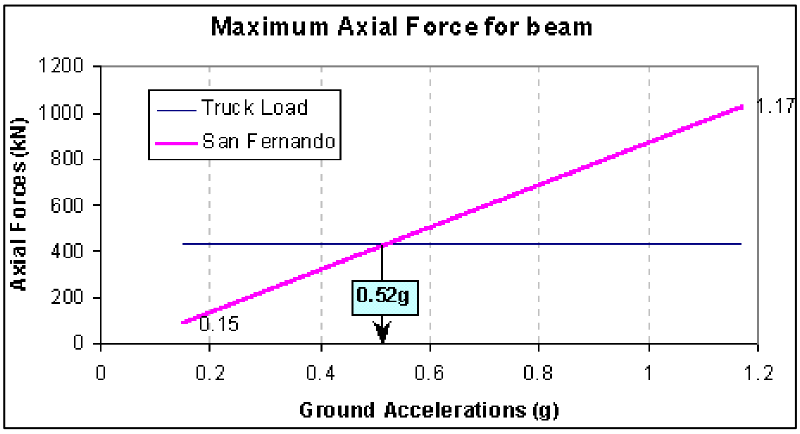

Fig 7: Maximum axial force for beam (base isolation)

The result from truckload analysis is made as the guide to get the maximum sustainable axial forces for beam. For the response spectrum analysis, several analyses were done with increased earthquake intensity from 0.02g to 1.17g. Than, the maximum axial forces for beam are recoded for every intensity and the graph are plotted. The ground acceleration at the transaction point between truckload analysis and response spectrum analysis is the maximum ground acceleration (g) can be supported by the beam element. Another several graphs are plotted such maximum shear force, maximum bending moment for beam element and also for column element. The comprehensive result for the designed base isolator and the existing PWD rubber bearing are shown in Table 6.

Table 6: The comprehensive result for the designed base isolator and the existing JKR rubber bearing

	Maximum internal forces for Column			Maximum internal forces for Beam		
	Axial	Shear	Moment	Axial	Shear	Moment
Design Base Isolator	0.66g	0.43g	0.57g	0.52g	Lower than design capacity	Lower than design capacity
Actual rubber Bearing (ELB400)	0.23g	0.31g	0.38g	0.37g	Lower than design capacity	Lower than design capacity
Conventional Analysis	0.42g	0.22g	0.27g	0.085g	Lower than design capacity	Lower than design capacity

From the result, it is clearly shown that, the analysis with design base isolator increase the overall performance of the bridge (between 28% and 65%) compare than the analysis with the actual rubber bearing. With design base isolator, the selected bridge are also can sustained the selected seismic loading up to 0.43g compare than just up to 0.23g when the analysis is done with the actual bearing.

6. Conclusion

In structural earthquake engineering and bridge study, basic study on rubber bearing design is needed to define the characteristic of the bearing. The considerations of the horizontal stiffness are important to design the rubber bearing under earthquake ground motion. These studies are also important to begin the finite element modelling technique. From the analysis, several conclusions can be made regarding the stiffness behaviour of the rubber bearing such as listed below;

i. The flexibility of the bearing is important to the structures under earthquake ground motion;
ii. The large vertical stiffness produces very large displacement in vertical direction and not suitable under earthquake ground motion;
iii. Designed base isolators provide higher internal forces under the San Fernando Earthquake such as shear force and bending moment for column element;
iv. The selected bridge can sustain earthquake loading up to 0.23g with existing bridge bearing and it is still acceptable in our condition with expected maximum ground acceleration is 0.15g for Peninsular Malaysia; and
v. The selected bridge can sustain earthquake loading up to 0.43g with designed base isolator and it is increase the overall bridge performance up to 47% compare than existing bridge bearing.

The response spectrum analyses are useful to study the structural performance of bridges especially in seismic analysis. The stiffness ratio is important to determine the shape factor of the rubber layer. The rubber bearing made of combination of natural rubber and steel have very large vertical stiffness to support the weight of the structure and very low horizontal stiffness (large horizontal flexibility) to prevent the movement of the ground from being transmitted into the structure during an earthquake. The shear stiffness was found to be the most important factor in bearing design.

In term of design of the seismic isolator purposed, the trial and error process are needed to get the most suitable bearing. Malaysian designers do not only need to study the seismic isolation system but also to look into the seismic design guidelines and codes suitable to our country, which is located in the low intensity seismic region.

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