# CHAPTER II

# LITERATURE REVIEW

## 2.1 Passive Control System

To remove the effect of vibration in a building, passive control system is used. Passive control system is characterized by the absence of an an external source of energy in the system. The dissipation of energy is activated by the structure itself when vibration motion happens. Passive control system has advantages over active control system due to the fact that it is usually simple and inexpensive to be implemented. There are several mechanisms of passive control system such as tuned mass damper (TMD), tuned liquid damper (TLD), bracing, shear wall, viscoelastic damper, damping system and base isolation system. (Arfiadi.2000). The basic equation of motions for structure using passive control system can be written as:

$$(m + m_d)\ddot{u} + (c + c_d)\dot{u} + (k + k_d)u = e_d a_g \tag{2.1}$$

Where $m =$ the mass of the structure itself, $m_d$ = mass of the passive control system, $c =$ the damping of the structure, $c_d$ = the damping of the passive control system, $k =$ the stiffness of the structure, and $k_d$ = the stiffness of the passive control system. While $u =$ the displacement vector, $e_d$ = vector representing the influence of earthquake on passive control system, and $a_g$ = the acceleration of the earthquake.

### 2.2 Principle of Base Isolation System

In general, base isolation techniques follow this basic approaches. The isolation system introduces a layer of low lateral stiffness between the structure and the foundation underneath (Chopra et al., 2007). This isolation layer provides the structure with a natural period which is much longer than its fixed-base natural period.

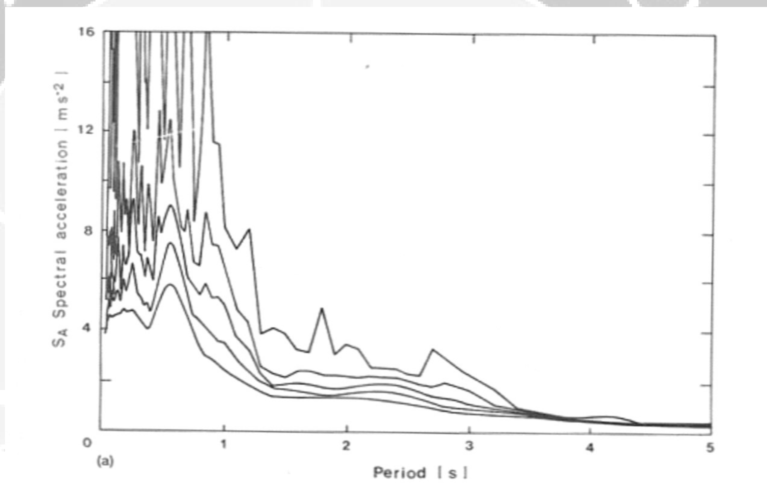


Fig.2.1 Acceleration response spectrum for 'El Centro' NS 1940 with damping of 0, 2, 5, 10, and 20% (Skinner et al.,1993)

Figure 2.1 show the acceleration spectra for typical design earthquakes. It is seen that these maximum accelerations are more severe on the first vibrational period of the structure is in the range of 1.1-0.6 s and the structural damping is low. This range is typical for buildings which have from 1 to 10 stories.

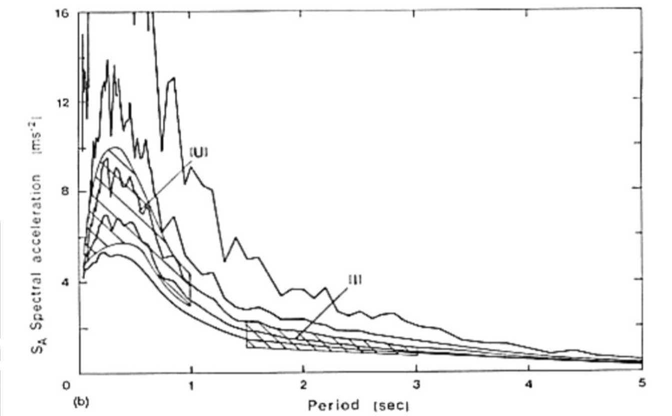


Fig.2.2 Acceleration response spectrum for average of four accelerograms (El Centro 1934, El Centro 1940, Olympia 1949, Taft 1952) with damping of 0, 2, 5, 10, and 20% (Skinner et al.,1993)

The shaded area marked (U) in Figure 2.2 show the acceleration spectra for first natural periods (up to 1 s) which the main candidate for base isolation. The shaded area marked (I) in Figure 2.2 show the acceleration spectra for first natural periods and damping of the structure using base isolation. A comparison of the shaded areas for un-isolated and isolated structures in

figure 2.2 shows that the acceleration spectral responses, and hence the primary inertia loads, may well be reduced by a factor of 5 to 10 or more by introducing isolation. (Skinner et al.,1993)

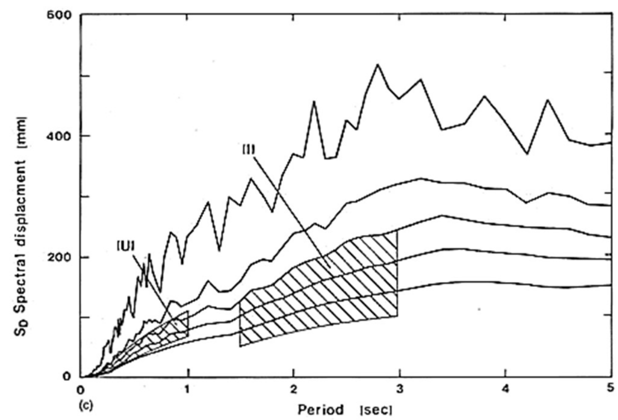


Fig.2.3 Displacement response spectrum for average of eight accelerograms (El Centro 1934, El Centro 1940, Olympia 1949, Taft 1952) with damping of 0, 2, 5, 10, and 20% (Skinner et al.,1993)

Figure 2.3 shows that displacement can be quite large. The larger displacements may contribute substantially to the costs of the isolators and to the costs of accommodating the displacements of the structures, and therefore isolator displacements are usually an important design consideration. (Skinner et al.,1993)

### 2.2.1 Linear Theory of Seismic Isolation

The linear theory of seismic isolation has been given by Naeim and Kelly (1999). The basic concepts of base isolation can be shown with a simple 2-degree-of-freedom system with concentrated masses, as shown in Figure 2.4

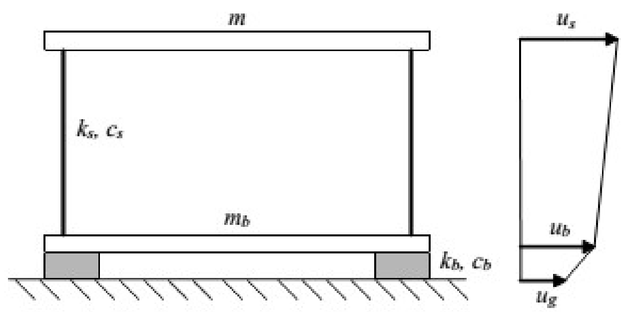


Fig.2.4 Parameter of 2-degree of freedom isolated system (Naeim and Kelly,1999)

The mass m is intended to represent the superstructure of the building and $m_b$ the mass of the base floor above the isolation system. The structure damping and stiffness are represented by $c_s$ , $k_s$ and the damping and stiffness of the isolation by $c_b$, $k_b$. Absolute displacement of the two masses are $u_s$ and $u_b$ , but more convenient is to relate all with relative displacements:

$$v_b = u_b - u_g \tag{2.2}$$

$$v_s = u_s - u_b \tag{2.3}$$

Where $u_g$ is the ground displacement. This choice with relative displacement appears to be efficient because Eq. (2.2) represent the isolation system displacement and Eq. (3.3) is the inter-stories drift.

The equation of motion can be easily expressed by applying d'Alambert's principle:

$$(m + m_b)\ddot{v}_b + m\dot{v}_s + c_b\dot{v}_b + k_b v_b = -(m + m_b)u_g \tag{2.4}$$

$$m\ddot{v}_b + m\ddot{v}_s + c_b\dot{v}_b + k_b v_b = -m\ddot{u}_g \tag{2.5}$$

If we introduce the total mass

$$M = m + m_b \tag{2.6}$$

the mass ratio

$$\gamma = \frac{m}{m + m_b} = \frac{m}{M} \tag{2.7}$$

the nominal frequencies

$$\omega_b^{\ 2} = \frac{k_b}{M} \qquad \omega_s^{\ 2} = \frac{k_s}{m} \tag{2.8}$$

the frequency ratio

$$\varepsilon = \frac{\omega_b^{\ 2}}{\omega_s^{\ 2}} = O(10^{-2}) \tag{2.9}$$

the damping factor

$$\xi_b = \frac{c_b}{\omega_b M} \qquad \xi_s = \frac{c_s}{\omega_s m} \tag{2.10}$$

the basic equations of motion become, in a matrix notation,

$$\begin{bmatrix} 1 & \gamma \\ 1 & 1 \end{bmatrix} \begin{Bmatrix} \ddot{v}_b \\ \ddot{v}_s \end{Bmatrix} + \begin{bmatrix} 2\xi_b\omega_b & 0 \\ 0 & 2\xi_s\omega_s \end{bmatrix} \begin{Bmatrix} \dot{v}_b \\ \dot{v}_s \end{Bmatrix} + \begin{bmatrix} \omega_b^{\ 2} & 0 \\ 0 & \omega_s^{\ 2} \end{bmatrix} \begin{Bmatrix} v_b \\ v_s \end{Bmatrix} = -\begin{Bmatrix} 1 \\ 1 \end{Bmatrix} \omega \ddot{u}_g \tag{2.11}$$

The characteristic equation of the frequency is

$$(1-\gamma)\omega^4 - (\omega_b^{\ 2} + \omega_s^{\ 2})\omega^2 + \omega_b^{\ 2}\omega_s^{\ 2} = 0 \tag{2.12}$$

The solution of which, to first order in ε, are given by

$$\omega_1^{\ 2} = \omega_b^{\ 2}(1-\gamma\varepsilon) \qquad \omega_2^{\ 2} = \frac{\omega_s^{\ 2}}{1-\gamma}(1+\gamma\varepsilon) \tag{2.13}$$

And the mode shapes are

$$\phi_1 = \begin{Bmatrix} 1 \\ \varepsilon \end{Bmatrix} \qquad \phi_2 = \begin{Bmatrix} 1 \\ -\frac{1}{\gamma}[1-(1-\gamma)\varepsilon] \end{Bmatrix} \tag{2.14}$$

The modal analysis of this system yields with the expressing the participation factors as

$$L_1 = 1-\gamma\varepsilon \qquad L_2 = \gamma\varepsilon \tag{2.15}$$

And the damping ratio

$$\xi_1 = \xi_b\left(1-\frac{3}{2}\gamma\varepsilon\right) \qquad \xi_2 = \frac{\xi_s + \gamma\xi_b\sqrt{\varepsilon}}{\sqrt{1-\gamma}}\left(1-\frac{3}{2}\gamma\varepsilon\right) \tag{2.16}$$

If $S_d(\omega,\xi)$ and $S_a(\omega,\xi)$ are the pseudo-displacement and the pseudo-acceleration spectra, the maximum modal displacement can be calculated and combined using the SRSS rule to get:

$$v_{b,\max} = \sqrt{L_1^{\ 2}\left[S_b(\omega_1,\xi_1)\right]^2 + L_2^{\ 2}\left[S_b(\omega_2,\xi_2)\right]^2} \tag{2.16}$$

$$v_{s,\max} = \varepsilon\sqrt{(1-\gamma\varepsilon)^2\left[S_b(\omega_1,\xi_1)\right]^2 + [1-2(1-\gamma)\varepsilon]^2\left[S_b(\omega_2,\xi_2)\right]^2} \tag{2.17}$$

The shear coefficient can be defined as:

$$C_s = \sqrt{\left[S_a(\omega_1,\xi_1)\right]^2 + \left[S_a(\omega_2,\xi_2)\right]^2} \tag{2.18}$$

Taking into account that, usually, for isolated systems, we have $\varepsilon \cong 1$ and $S_d(\omega_2, \xi_2) \cong S_d(\omega_1, \xi_1)$, consequently, $\omega_1 \cong \omega_b$, $L_1 \cong 1$ and $\xi_1 \cong \xi_b$:

$$v_{s,\max} = S_d(\omega_b, \xi_b) \quad (2.19)$$

$$v_{b,\max} = \varepsilon \cdot S_d(\omega_b, \xi_b) \quad (2.20)$$

$$C_s = S_a(\omega_b, \xi_b) \quad (2.21)$$

Indicating that for small ε and typical design spectrum, the isolation base can be designed, at least at initial phase, for relative base displacement of $S_b(\omega_b, \xi_b)$ and the building for base shear coefficient of $S_a(\omega_b, \xi_b)$. The reduction in base shear as compared to fixed structure where $C_s = S_a(\omega_s, \xi_s)$ is given by $C_s = S_a(\omega_b, \xi_b)$, which constant velocity spectrum is $\frac{\omega_b}{\omega_s}$ , or roughly order of $\sqrt{\varepsilon}$.

## 2.3 Effect of Base Isolation System

As one of the leaders in base isolation use, there are hundreds of building implementing this technology. One of the examples is 3-chome apartment, in Tokyo. The building is 12 stories above ground, with total height 37.75m. The isolator installed on building are 12 units of Lead Rubber Isolator and 4 units of Natural Rubber Bearing. The analysis of the structure conducted by analyzing the acceleration report recorded from several parts of the building during 2011 The Great East Japan Earthquake. (Yamamoto, 2013)

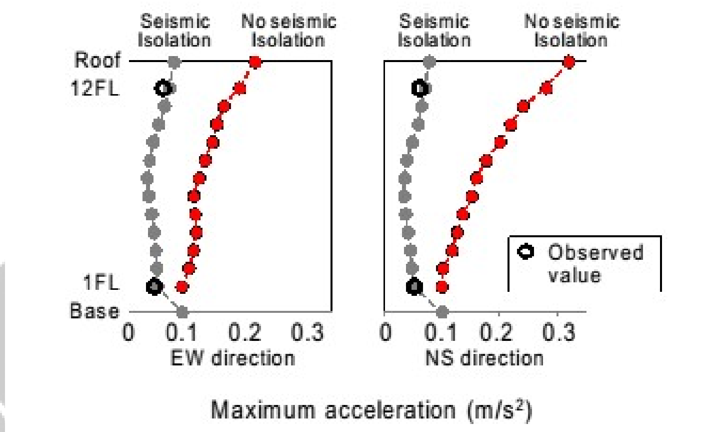


Fig.2.5 Comparison of story maximum acceleration (Yamamoto, 2013)

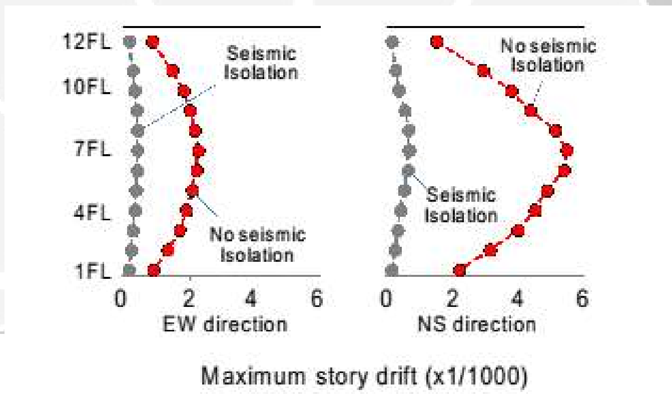


Fig.2.6 Comparison of maximum story drifts angle (Yamamoto, 2013)

From these two figure, we can see that the base isolation able to reduce the acceleration from 1/2 at its lowest part to 1/4 at the top. In addition, the story drifts angle of each story able to reduce to 1/5 to 1/10.

As the use of base isolation is still limited in Indonesia. There are not many study case that can be observed. One of the building in Indonesia that implemented base isolation system is gudang garam tower in Jakarta. The building consists of 22 stories and 2 level of basement. The bedrock response spectra for the case of 500 and 2500 years' return are used for this project, with peak ground acceleration of 0.211g and 0.366g. The building using the High Damping Rubber (HDR) from Bridgestone manufacturer. 16 of the isolator are 1.3m in diameter and 24 of the isolator are 1.5m in diameter. The model is analyzed using ETABS with a linear method for the upper structure and non-linear method for the base isolation. (Hussain et al., 2012)

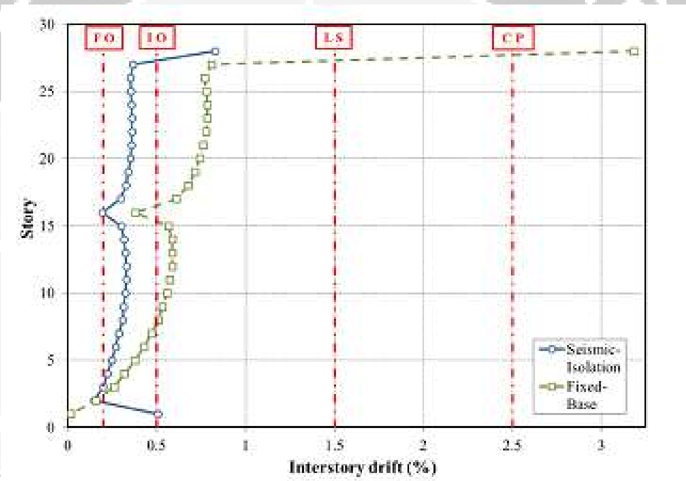


Fig.2.7 Comparison of story drifts ratio (Hussain et al., 2012)

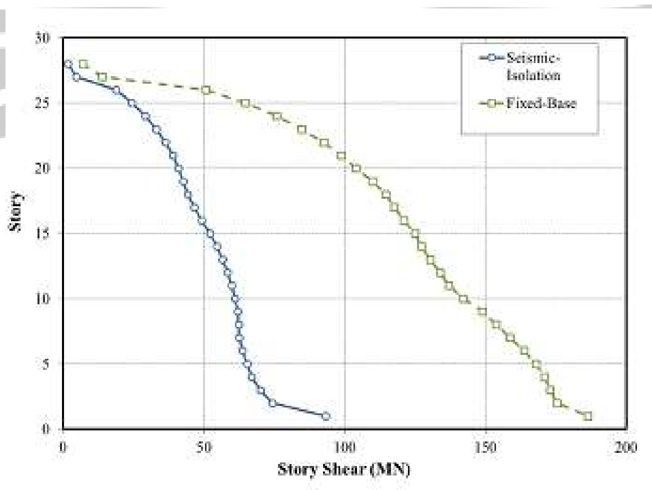


Fig.2.8 Comparison of story shear (Hussain et al., 2012)

From these two figure, we can see that the base isolation able to reduce story shear and drift by 50%.

Other examples of base isolation use in Indonesia are the analysis of IBIS hotel in Padang. Similarly, the analysis is using isolator from Bridgestone manufacturer and the building analyzed using ETABS. From the analysis, it is found that the inner force of the structure can be reduced from 60% to 80% and the story drift can be reduced up to 30% compared to fix base structure (Ismail, 2012).