PILLOW-SHAPE BASE ISOLATION SYSTEM AND ITS SEISMIC BEHAVIOR

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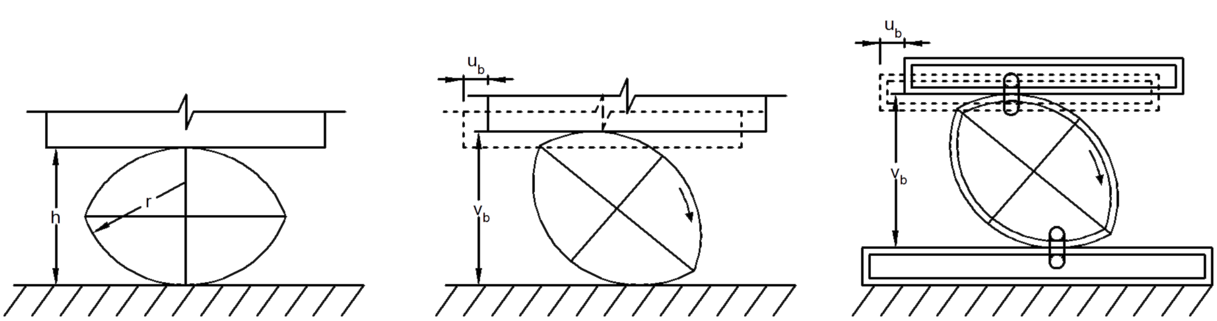
Base isolation is one of the well-known techniques for advanced seismic design of building systems. However, most of the existing isolators are expensive and their manufacturing needs high technology, and these are discouraging factors in implementation of base isolation technique. Among various isolating devices those which are based on using rollers, either of circular or non-circular section are less expensive and easier to manufacture. Therefore, some researchers have worked on developing this type of isolators in recent decades. One of the shortcomings of rollers with circular section is the lack of restoring or re-centering force, thus the use of rollers with noncircular sections have dragged more attention. The use of elliptical rollers (Jangid et al., 1998) and rocking isolators (Lu et al., 2012) or concave bed (Hosseini and Soroor, 2011) are solutions for creating the re-centering capability. However, there are still some shortcomings in these types of isolating systems such as stress concentration between rollers and their bed and weakness against uplift, which causes separation of the rollers from their bed. In this paper a somehow new isolator, which can be called Pillow-Shape Base Isolation System (PSBIS), is introduced, by which the two mentioned shortcoming can be removed. In the following paragraphs first the features of the proposed isolating system are briefly explained and then its effect in seismic response reduction is presented. PSBIS consists of two orthogonal pairs of pillow-shape, each pair resting in parallel on their bed. Figure 1 shows one of the pillow-shape rollers of the PSBIS at rest and also in its moved state without and with uplift restrainers.



a) at rest b) moved state without uplift restrains c) moved state with uplift restrains

Figure 1. Pillow-Shape Base Isolation System (PSBIS)

Looking at Figures 1-a and 1-b, it is apparent that the system has an inherent restoring capability due to the pillow shape of the rollers. In fact, at rest the top and bottom contact points of the roller with its top and bottom surfaces both locate on one vertical lie, while when the roller moves laterally, these contact points are not on the same vertical line any more, and the existing vertical forces acting at these two points tend to turn the roller back to its initial position. Furthermore, as it can be seen in Figure 1-c, the uplift forces tend to help the roller to roll more, rather than to separate from its bed, and therefore, separation of rollers from their bed cannot easily happen. PSBIS can also greatly alleviate problems of previous proposed isolators, including low damping, and high stress concentration due to the small contact area between the ball or small diameter rollers and their beds.

Regarding the geometric nonlinearity of the system and the action of rolling resistance at two levels, beneath the rollers as well as at their top, the Newton law cannot be used for derivation of equation of motion, and instead, the Lagrange equation of motion is used. Based on the derived equation of motion in free vibration state, the following equation can be developed:

$$\ddot{\theta} = \left(\frac{-1}{m_b\left(h^2+4(2r^2-rh)(1-\cos\theta)\right)}\right)\Big\{4m_b\dot{\theta}^2(2r^2-rh)\sin\theta - 2m_b\dot{\theta}^2(2r^2-rh)\sin\theta + 2k\Big[2r^2\theta + \left(r-\frac{h}{2}\right)^2\sin 2\theta - 2r\left(r-\frac{h}{2}\right)\sin\theta - 2r\theta\left(r-\frac{h}{2}\right)\cos\theta\Big] + 2m_b g\left(r-\frac{h}{2}\right)\sin\theta - \left[sign(\dot{\theta})\frac{m_b g\, b}{r} + c\left(2r\dot{\theta} - 2\left(r-\frac{h}{2}\right)\dot{\theta}\cos\theta\right)\right]\left(r-\left(r-\frac{h}{2}\right)\cos\theta\right)\Big\} \qquad (1)$$

where $\theta=\theta(t)$ is the rotation angle of the roller with respect to its initial position, m_b is the mass resting on the isolator, h and r are as shown in Figure 1, and k and c are stiffness and damping coefficients of the spring-damper connected to the mass center. Equation 1 is suitable for using the Runge-Kutta technique, by which $\theta(t)$ can be calculated, and also the variation of natural period of the system with respect to the geometric features of rollers can be obtained as shown in Figures 2 and 3.

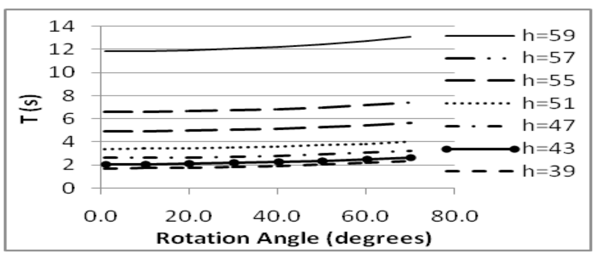


Figure 2. Variation of PSBIS oscillation period with the height of roller for r = 30 cm

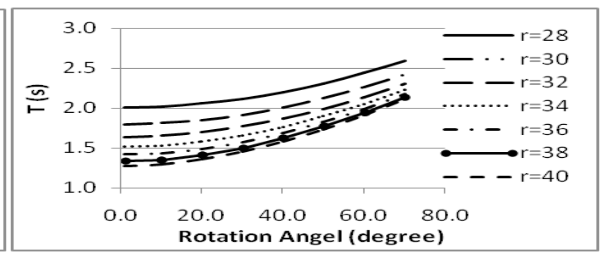


Figure 3. Variation of PSBIS oscillation period with the radius of roller for h = 40 cm

In developing Figures 2 and 3 it has been assumed that no slippage happens between rollers and their beds. It can be seen in these two figures that for rotation angles less than 15 degrees, the oscillation period of the system is almost constant, and can be considered to be only dependent on the values of r. Figures 4 and 5 show the resonance displacement response of the PSBIS subjected to sinusoidal excitation as well as its acceleration time histories subjected to an earthquake record.

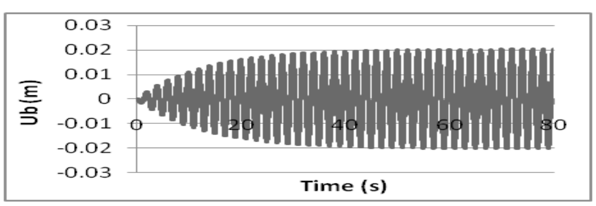


Figure 4. Displacement response of a mass resting on the PSBIS at resonance

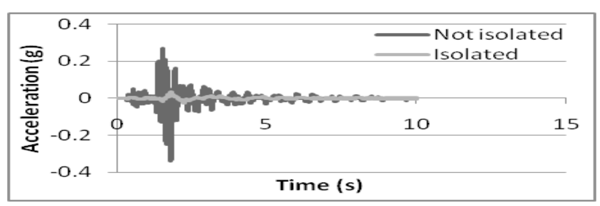


Figure 5. Acceleration time histories beneath and at the top of PSBIS subjected to Coyote Lake record (1979)

Based on the numerical results and the advantages of the proposed isolating system, PSBIS, its application in essential buildings and other types of vital structures can be strongly recommended.

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