

Literturete Review & Survey of Spherical Bearing Patents

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Abstract— This study is intended to introduce the earthquake proof technology particularly in the area of base isolation systems that have been used to protect structures, from earthquake damage. This chapter presents the exists technologies, theoretical background, experimental studies, numerical analysis, and the applications of the advanced insulation systems consisting of rolling- and sliding-type isolation systems for structures.

Index Terms— elasormer isolator, spherical bearing, ball, concave, sesmic, sliding, rolling.

1. INTRODUCTION

ONE of the emerging tools for protecting buildings from the damaging effects of earthquakes is the use of isolation systems. Seismic isolation is achieved via inserting flexible isolator elements that shift the vibration period and increase energy dissipation. Seismic protective systems, herein assumed to include seismic (base) isolators and damping (energy dissipation) devices, were developed to mitigate the effects of earthquake shaking on bridges and buildings. Isolation shifts the response of the structure to a higher fundamental period and increases the damping, thus reducing the corresponding pseudo-acceleration in the design spectrum and attracting smaller earthquake-induced forces.

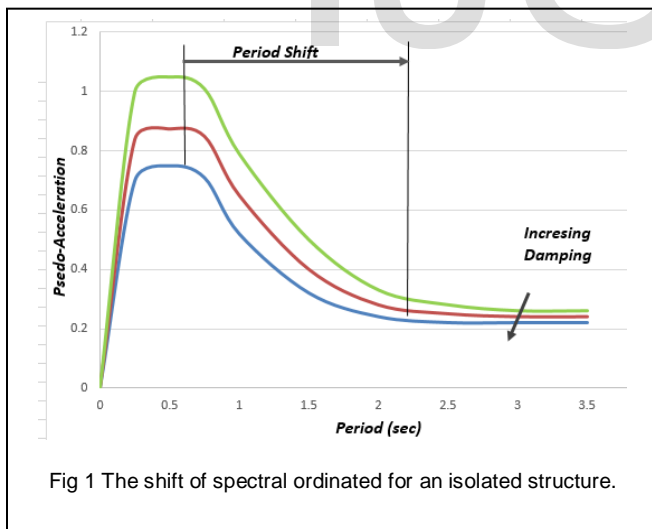


Fig 1 The shift of spectral ordinated for an isolated structure.

Damping is achieved through hysteretic energy dissipation. Energy dissipation devices (dampers) serve to protect structural components of a bridge from damage by reducing deformations and earthquake-induced damage. Energy is dissipated by either hysteretic or viscous damping in components

that are specifically designed for this function.

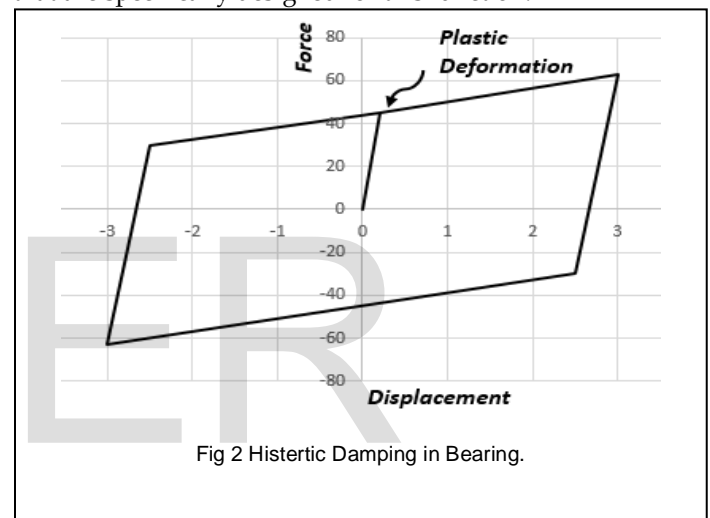


Fig 2 Histeric Damping in Bearing.

There are two common types of seismic isolation, namely, elastomeric bearings (low- and high-damping rubber; lead rubber) and sliding bearings (spherical sliding or Friction Pendulum bearings; flat sliding).

In aim to combine between this different system and provide a bearing which on the one hand releases the inertial movement of the bearings structure, with respect to the horizontal bearing plane, on the other hand ensures a return to the balance of the structure to its initial position, It is interesting to seek a lowest possible frequency, as long as the magnitude of the resultant displacement is compatible with the environment of the structure The bearing consists of a spherical ball rolling between two discs with spherical motion surfaces. This study summarize the existing similar technologies or have any referenc to research.

2. GENERAL BACKGROUND & PATENTS

In the past, there have been a lot of papers and reports concerning the use of rolling vibration isolation technology to increase the precision of machines by isolating vibration sources resulting from the environment .Recently, the isolation technology has been acknowledged as an effective technique

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to promote the earthquake resistibility of the structures by controlling structural responses during earthquakes on the basis of theoretical and experimental results and earthquake events (Naeim and Kelly, 1999)[[15]]. Several theoretical studies [[1]] have been made on the applications of the base isolation technology to critical equipment in seismic mitigation (Alhan and Gavin, 2005; Chung et al., 2008). Here is present the different rolling bearing patents that developed.

2.1.1. TOUAILLON PATENT

The isolation system with doubled spherical concave surfaces and a rolling ball located between these two concave surfaces was first patented by Touaillon in 1870[[6]], as shown in Fig 3.

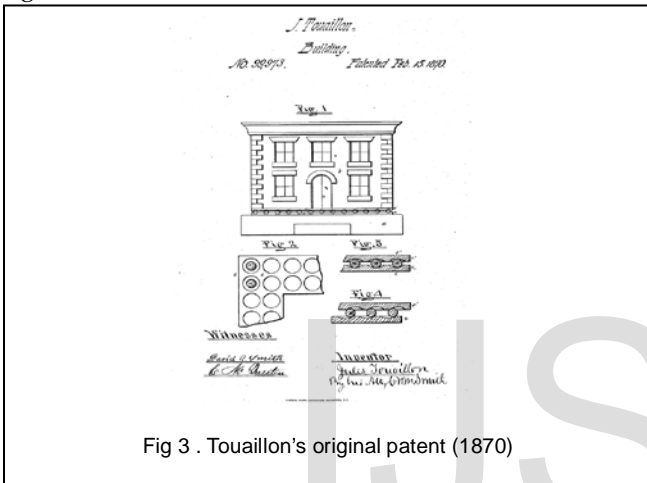


Fig 3 . Touaillon's original patent (1870)

2.1.2. SCHÄR PATENT

Several similar isolation systems with a ball located between two spherical concave surfaces were also proposed (Schär, 1910[[7]]; Cummings, 1930; Bakker [[8]], 1935; Wu, 1989), as shown in Fig 4 and Fig 5.

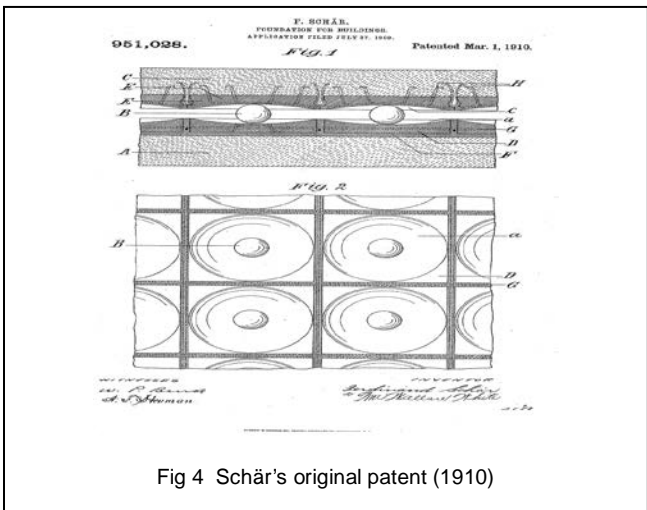


Fig 4 Schär's original patent (1910)

2.1.3. BAKKER PATENT

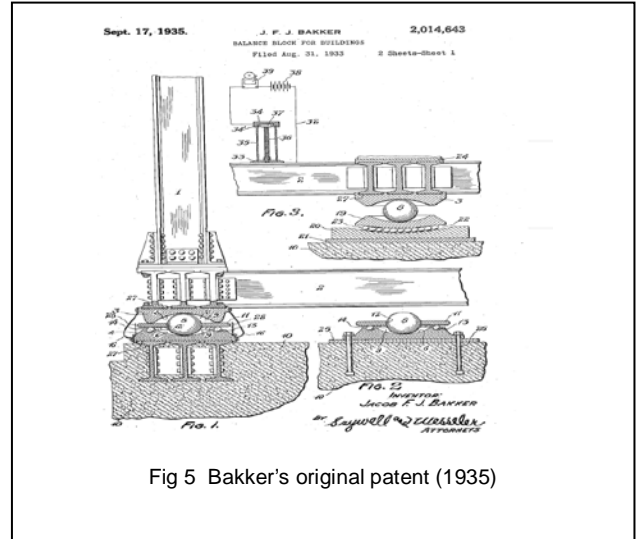


Fig 5 Bakker's original patent (1935)

2.1.4. WU PATENT

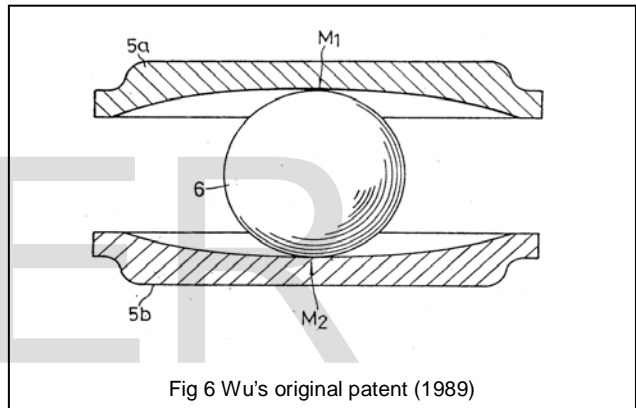


Fig 6 Wu's original patent (1989)

2.1.5. KEMENY PATENT

In 1997, Kemeny propounded a ball-income seismic isolation bearing that includes two conical concave surfaces and a ball seated between the conical surfaces, as shown in Fig 7.

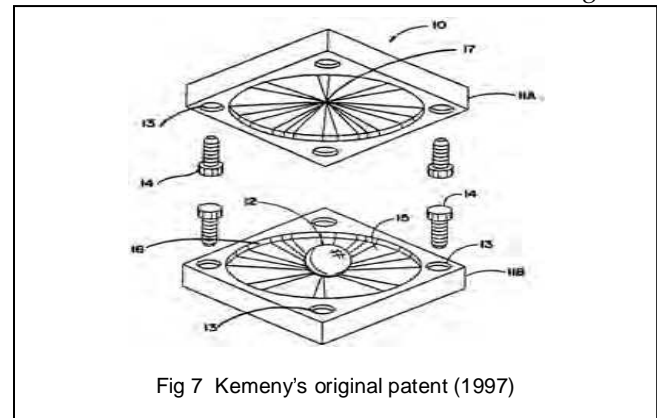
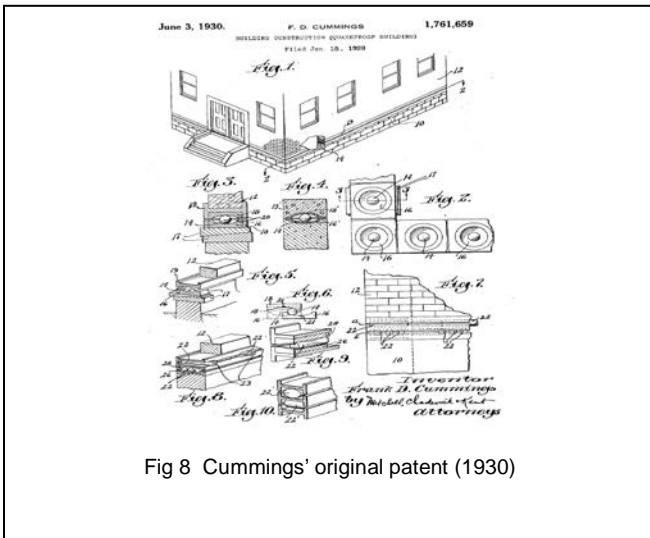


Fig 7 Kemeny's original patent (1997)

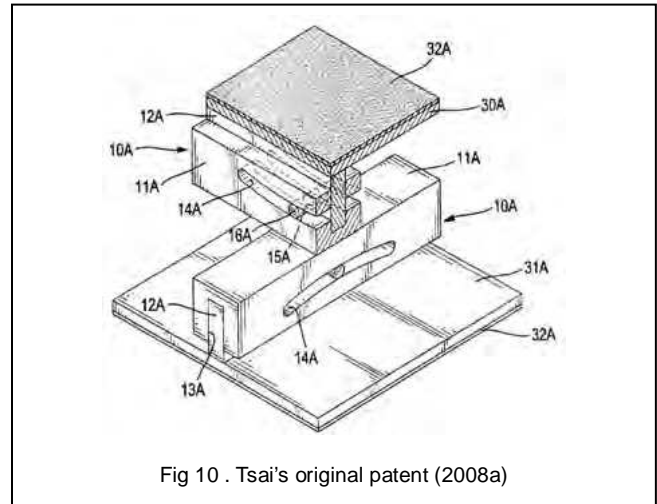
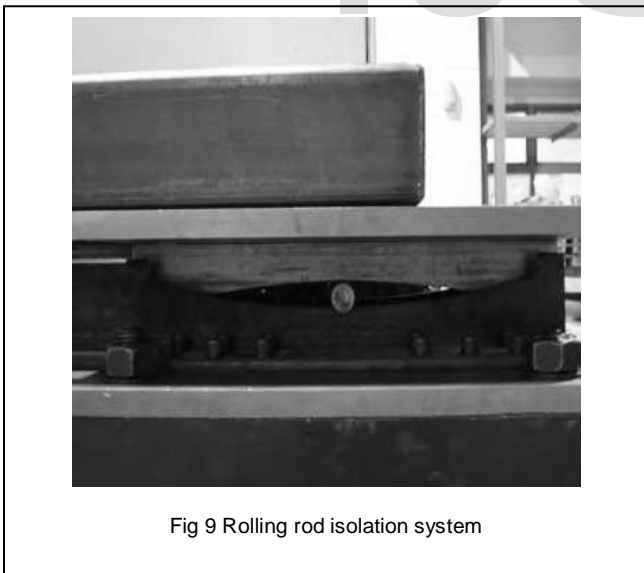
2.1.6. CUMMINGS' PATENT

The dynamic behavior of the ball-in-cone isolation system has been investigated (Kasalanati et al., 1997). In addition, Cummings (1930) also proposed a seismic isolation system with a rolling rod of a cylinder sandwiched between two concave surfaces, as shown in Fig 8.



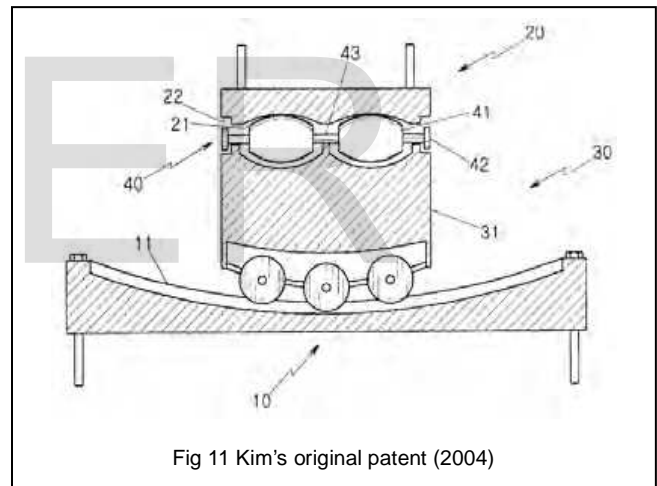
2.1.7. TSAI AND LIN PATENT

Lin and Hone (1993)[[12]], Tsai et al. (2006b)[[1]] and M. H. Tsai et al. (2007)[[3]] conducted research on the effectiveness of this type of base isolation system in seismic mitigation, as shown in Fig 9 and Fig 10.



2.1.8. KIM PATENT

Kim (2004) [[13]] proposed a seismic isolation system that has rollers of a bowling shape to roll in the friction channel, as shown in Fig 11.



These devices are capable of resisting the uplift while the vertical force in the isolator becomes negative under severe earthquakes.

2.1.9. TOUAILLON, WU, KEMENY PATENT

The isolation system with two concave surfaces and a rolling ball (Touaillon, 1870; Wu, 1989; Kemeny, 1997[[9]]) possesses some shortcomings even under small loadings like equipment and medical instruments, such as negligible damping provided by the system, a highly concentrated stress resulted from the weight of the equipment on the rolling ball and the concave surfaces due to the small contact area, and scratches and damage to the concave surfaces caused by the ball rolling motions during earthquakes. The rolling ball has a tendency to move even under environmental loadings such as human ac-

tivities during regular services. In addition, the bearing size is large because of the large bearing displacements under seismic loadings due to insufficient damping provided by the rolling motion of the ball on the concave surfaces in the system. To supply more damping to the isolation system and simultaneously reduce the bearing size as a consequence of smaller bearing displacements during earthquakes, Tsai et al. (2006a)[[11]] proposed a ball pendulum system (BPS). As shown in Fig 12 and Fig 13.



Fig 12 Open-up view of ball pendulum isolation system

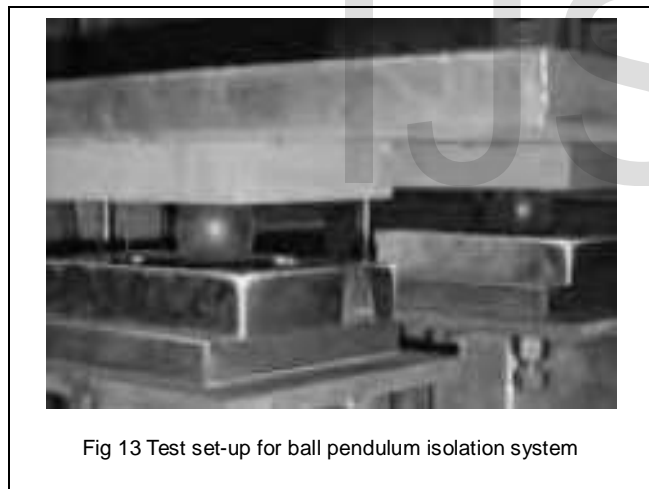


Fig 13 Test set-up for ball pendulum isolation system

This system comprises two spherical concave surfaces and a steel rolling ball covered with a special damping material to provide horizontal and vertical damping to tackle the problems mentioned above. A series of shaking table tests conducted by Tsai et al. (2006a) have proven that the BPS isolator can enhance the seismic resistibility of vibration sensitive equipment under severe earthquakes with smaller displacements compared to an isolation system with negligible damping. However, the special material covering the steel ball that supports the weight of the vibration sensitive equipment for a long period of time in its service life span might result in permanent deformation due to plastic deformation in the damping material. It may damage or flat the contacting surface of the special damping material after sustaining a certain period of service loadings and affect the isolation efficiency.

2.1.10. NY HAMBURGER PATENT

New-York Hamburger Gummi-Waaren Compagnie, published [[14]] on 1990a patent that An earthquake bearing with a spherical ball (26) located between two elastomer layers (18, 19) in the shape of half-shells. The elastomer layers each include a cylindrical elastomeric pad. The earthquake bearing further includes a spherical clearance (25) facing the ball (26), bearing musings halves (11, 12) being mutually braced by elastomer bearings (24) in order to achieve compliant, progressive damping. This system is capable of gently moving out of the way both vertically and horizontally. The bearing halves (11, 12) are prestressed by tension bars (23) which pass centrally through the bearings (24). The elastomer bearings (24) include of a plurality of columns defined by panes of elastomers and panes of Steel. Outwardly directed head bolts (15) are held on the base plates (13, 14) of the bearing housings (11, 12) and are anchored into the adjoining components.

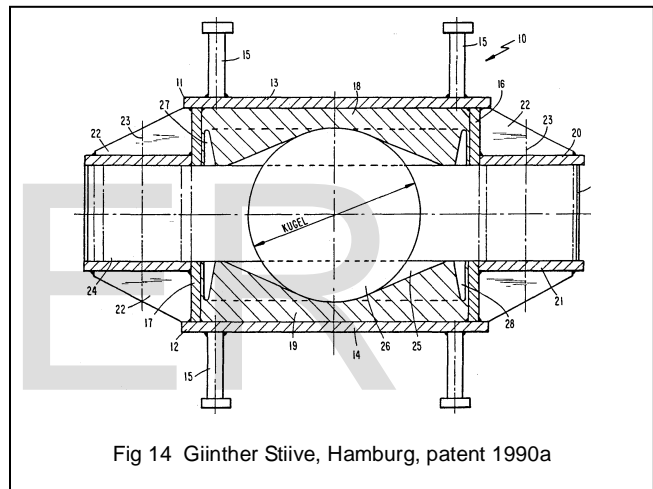


Fig 14 Giinther Stiive, Hamburg, patent 1990a

An object of the present invention is to create a compact earthquake bearing assuring compliant, progressive damping both in the vertical and in the horizontal directions. Progressive damping is provided by an earthquake bearing of the invention comprising a spherical core held between two elastomer layers shaped as half shells held within a housing. The elastomer layers comprise a cylindrical elastomeric pad with a spherical clearance facing the core. The radius of the clearance is at least twice that of the core, and the housing preferably includes plural bearing housings mutually braced to each other. By means of this design the system is able to gently move out of the way in the presence of earthquake shocks. The elastomeric core or ball support provides especially compliant, progressive damping along the horizontal. The damping compliance can be arbitrarily matched or adjusted. This is achieved by means of the shore hardness of the elastomer, the radius of curvature of the spherical clearances in the elastomer pads and the ball diameter.

2.1.11. FATHALI AND FILIATRAULT PATENT - SDI-BPS SYSTEM

An alternative approach for increasing damping and lessening the isolator displacement is, to add a damping device to the isolation system (Fan et al., 2008) [[5]]. Fathali and Filiatrault [[16]] (2007) presented a spring isolation system with restraint which is a rubber snubber to play a role of displacement restrainer to limit the isolator displacement. In general, the displacement restrainer will involve impact mechanisms as a result of contact made with isolated equipment, which lead to amplified acceleration responses and large dynamic forces. To increase damping for a rolling bearing and to prolong the service life of a bearing, an isolation system called the static dynamics interchangeable-ball pendulum system (SDI-BPS) was proposed by Tsai et al (2008a)[4], As shown in Fig 15.

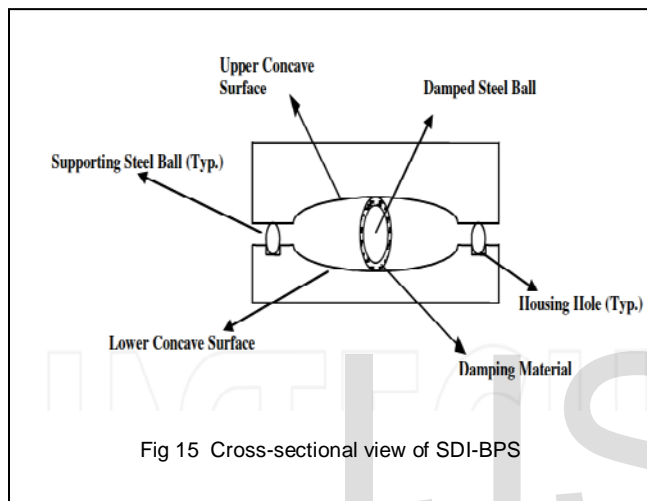


Fig 15 Cross-sectional view of SDI-BPS

The SDI-BPS system consists of not only two spherical concave surfaces and a steel rolling ball covered with a special damping material to provide supplemental damping and prevent any damage and scratches to the concave surfaces during the dynamic motions induced by earthquakes but also several small steel balls that are used to support the static weight to prevent any plastic deformation or damage to the damping material surrounding the steel rolling ball during the long term of service loadings. Because the concave surfaces are protected by the damping material covering the steel ball from damage and scratches, they may be designed as any desired shapes in geometry, which can be spherical, conical or concave surfaces with variable radii of curvature. The natural period of the SDI-BPS isolator depends only on the radii of curvature of the upper and lower concave surfaces, but not a function of the vertical loading (static weight). It can be designed as a function of the isolator displacement, and predictable and controllable for various purposes of engineering practice. The dynamics interchangeable-ball pendulum system (SDI-BPS) is schematized in Fig 15 consisting of one upper concave surface (not necessary a spherical shape), one lower concave surface, several supporting steel balls to provide supports for long terms of service loadings and the frictional damping effect to the isolator at small displacements (see Case 1 of Fig 16, several housing holes to lodge the supporting steel balls and one

damped steel ball covered by damping materials to uphold the vertical loads resulting from the static and seismic loadings at large displacements (see Case 3 of Fig 16) and supply additional damping to the bearing by deforming the damping material that could be a rubber material during earthquakes. As shown in Case 1 of Fig 16, almost all static loadings as a result of the weight of the equipment are sustained by the supporting steel balls and negligible loadings are taken by the damped steel ball while the system is under long terms of service loadings. In the event of an earthquake, the static loadings and the dynamic loadings induced by the ground or floor accelerations are still supported by the supporting steel balls while the horizontally mobilized force is less than the total frictional force from the supporting steel balls, and the damped steel ball remains inactivated, similar to Case 1 of Fig 16. The frictional force depends on the contact area and the coefficient of friction among the upper concave surface, the supporting steel balls and the housing holes located on the lower concave surface. This contact area and friction coefficient can be properly designed for the purpose of adjusting the frictional force and damping. When the horizontal force exceeds the frictional force, the damped steel ball is activated and starts rolling on the concave surfaces. The vertical force resulting from the static and dynamic loadings is shared by the damped steel ball and the supporting steel balls. Simultaneously, the damping effect is provided by the supporting steel balls due to the frictional force and the damped steel ball as a result of the deformation of the damping material enveloping the damped steel ball under the condition of small isolator displacement, as shown in Case 2 of Fig 16. The natural period of the isolated system is then dominated by the radii of curvature of the concave surfaces, which is equal to

$$2\pi\sqrt{(R_1 + R_2)/g} \quad (1)$$

Where R_1 and R_2 are the radii of curvature of the upper and lower spherical concave surfaces, respectively; and g is the gravity constant. If the system is subjected to a large isolator displacement during an earthquake, the supporting steel balls will be detached from the upper concave surface, and the total vertical and horizontal loads will be supported by the damped steel ball only to result in more damping effect due to the larger deformation of the damping material, and no damping effect results from the frictional force caused by the supporting steel balls, as depicted in Case 3 of Fig 16.

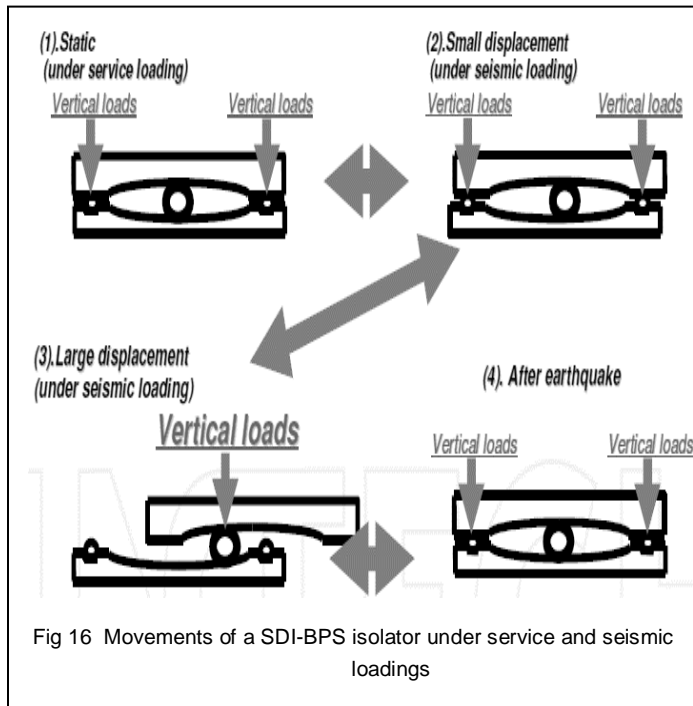


Fig 16 Movements of a SDI-BPS isolator under service and seismic loadings

Furthermore, the natural period of the isolated equipment is governed by the radii of curvature of the concave surfaces in this stage. The damping effect for the isolator is only provided by the deformation of the damping material covering the damped steel ball in the course of motions to reduce the size of the isolator as a result of smaller isolator displacements caused by earthquakes in comparison to a rolling isolation system with negligible damping. As shown in Case 4 of Fig 16 Because the component of the gravity force from the equipment weight tangential to the concave surface provides the restoring force, the isolator will be rolling back to the original position without a significant residual displacement after earthquakes. Therefore, the damped steel ball is subjected to temporary loadings induced by earthquakes only, and the static loadings in the life span of service won't cause any permanent deformation to the damping material enveloping the damped steel ball. In general, in the case of a service loading or a small earthquake, the static load is supported by the mechanism composed of the upper and lower concave surfaces and supporting steel balls with negligible supporting effect from the damped steel ball. On the other hand, in the events of medium and large earthquakes, the entire loads including static and dynamic loads are supported by the mechanism offered by the upper and lower concave surfaces and the damped steel ball while the isolation system is activated. These two mechanisms are interchangeable between the cases of static loading from the weight of equipment and seismic loading from the ground or floor acceleration. The isolators presented in this chapter, which provide damping as a result of the deformed material or the frictional force between the sliding interfaces, have rectified the drawbacks of the rolling ball isolation system, such as little damping provided by the system, highly concentrated stress produced by the rolling ball or cylindrical rod due to the small contact area between the rolling ball (or cylindrical rod)

and the concave surfaces, and scratches and damage to the concave surfaces caused by the ball or cylindrical rod motions during earthquakes. The presented isolators not only effectively lengthen the natural period of the vibration sensitive equipment but also provide significant damping to reduce the bearing displacement and size and the protection to the contact area between the damped steel ball and the concave surface to prevent any damage or scratch on the concave surfaces. Further, the advanced isolators possess a stable mechanical behavior during the life span of service. In addition, the isolators can isolate energy induced by earthquakes to ensure the safety and functionality of the vibration sensitive equipment located in a building. It can be concluded from these studies that the presented isolators in this chapter, including the rolling and sliding types of isolators, exhibit excellent features for preventing vibration sensitive equipment from earthquake damage.

2.1.11.1. TESTING AND CHARACTERISTIC OF THE SDI-BPS ISOLATOR

At test setup of the SDI-BPS isolator, the damped steel ball consisted of a steel rolling ball of 44.55mm in diameter covered with a thickness of 6.75mm damping material which was made of natural rubber material with hardness of 60 degrees in the IRHD standard (International Rubber Hardness Degree). The main purpose of this test was to investigate the mechanical behavior of the damped steel ball, therefore, supporting balls were removed during the component tests and all damping effect resulting from the system was provided by the damped steel ball. Fig 17 shows the relationship of the horizontal force to the horizontal displacement while the system was subjected to a vertical load of 4.56 kN and a harmonic

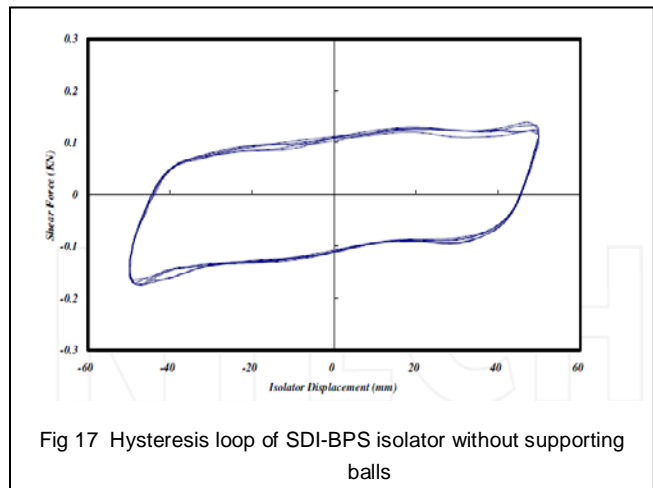


Fig 17 Hysteresis loop of SDI-BPS isolator without supporting balls

The enclosed area shown in the Fig 17 provides a damping effect into the isolation system. The test result demonstrates that the deformations of the rubber material led to significant damping effects in the system with negligible deformation occurring in the steel material.

3. CONCLUSION

There is many patent of rolling and sliding isolation most of them is at 2D. This study introduced the patents that exist at rolling isolation type that intend to reduce earthquake damage. This study presented the theoretical background, experimental studies, numerical analysis, and the applications of the advanced insulation systems consisting of rolling- and sliding-type isolation systems for structures. Till now these patents are not developed to commercial system.

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