Bulletin of the *Transilvania* University of Braşov
Series I: Engineering Sciences • Vol. 5 (54) No. 1 - 2012

A BRIEF HISTORY UPON SEISMIC ISOLATING SYSTEMS

M. BOTIŞ[1] **C. HARBIC**[1]

Abstract: *This paper presents a summarization of base isolation solutions. Engineering history has given modern seismic engineering valuable lessons, constituting a support for present-day earthquake-proof solutions in civil engineering. The main goal of seismic isolation is to shift the fundamental frequency of a structure away from the dominant frequencies of the ground motions.*

Key words: *friction pendulum isolators, triple friction pendulum isolators.*

1. Introduction

The field of seismic design is a subject that deals primarily with life safety and uncertainty. For several years now, it has been a quest for structural engineers to design earthquake-proof buildings and bridges.

Initially, it has been generally thought that building a massive and stiff construction would make it earthquake resistant. But this stiffness or rigidity of the structural elements would lead eventually to a fragile and sudden failure, all in all not complying with the life safety performance criteria and letting inhabitants no time to react in case of an earthquake.

Next, the increase of damping, redundancy of buildings, ductility and seismic energy dissipation were taken into consideration and well implemented throughout the years in seismic building codes.

Furthermore, a new alternative approach was implemented in earthquake protective systems, Figure 1, and base isolation being one of the most common systems nowadays.

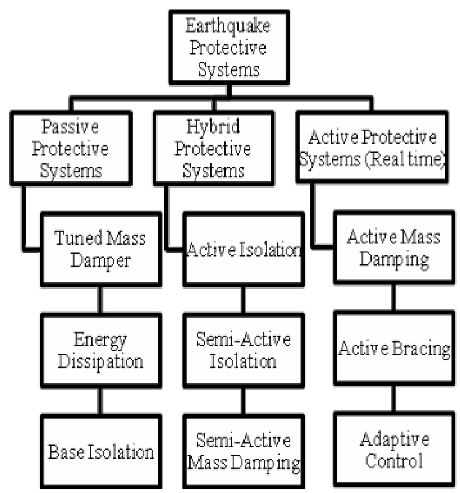

Fig. 1. *Earthquake protective systems*

2. The Concept of Base Isolation

Seismic isolation is a relatively new approach in building design and is based on the idea that it's more efficient to reduce the seismic demand on a building rather than increasing its earthquake resistance capacity.

[1] Dept. of Civil Engineering, *Transilvania* University of Braşov.

The principle in base isolation, as suggested in its name - isolation = *the state of being separated*, and base = *a part that supports from beneath or serves as a foundation for an object or structure* (definition according to Concise Oxford Dictionary), is that of decoupling a structure from its foundation, or in the case of bridges, separating the superstructure from the infrastructure columns or piers.

More accurately, it is a simple but effective idea: detach the building from the ground, in order for the ground to move in the case of an earthquake, but not transmitting this horizontal motion caused by the seismic waves, to the building.

According to FEMA (Federal Emergency Management Agency) design guidelines [3], a base isolated structure would have the following layout, Figure 2.

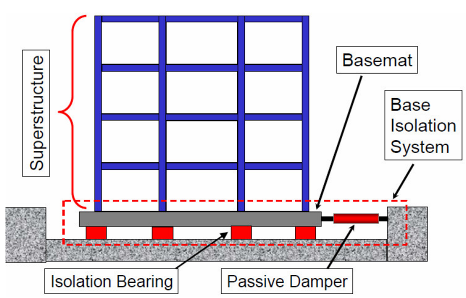

Fig. 2. *Overview of a base isolated structure* [3]

Basically and theoretically, there would be no distribution and no amplification of seismic forces, and therefore no inter-story drifts, this leading to almost zero structural and non structural damage.

A parallel between a usual building and a base isolated one can be seen in Figure 3 and Figure 4.

As an analogy, one could think of a tablecloth pulled of from a table. If it is done correctly, the dishes would remain in place and glasses would not overturn. That is because the cloth forms a sliding surface, and its motion is not transmitted to the dishes.

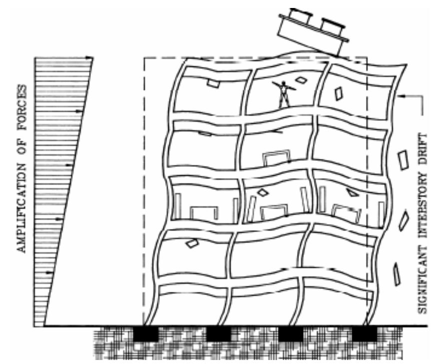

Fig. 3. *Conventional structure*

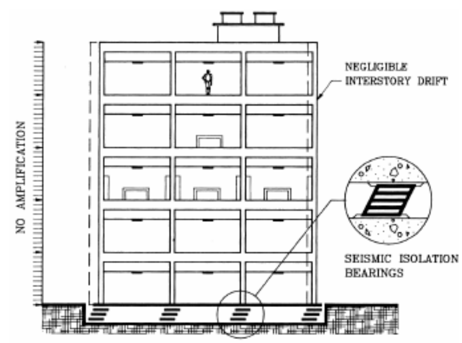

Fig. 4. *Base isolated structure*

In theory, it sounds quite simple. But the isolator materials, the buffer zone, all in all, the applicability range takes the problem, which initially was a solution, to a whole different level.

The basic idea applies clearly: increase the period of vibration of a structure (by increasing damping), in order to reduce base shear [3]. These characteristics provide a reduction of the considered seismic design forces, therefore inter story drifts are limited and the risk of damage in structural and non structural building elements is minimized.

3. Beginnings and Evolution

3.1. Mausoleum of Cyrus the Great

The Tomb of Cyrus the Great is considered to be the world's first base isolated structure, Figure 5.

Fig. 5. *Tomb of Cyrus the Great*

According to historians and archaeologists, it was build around 550 B.C., in Pasargadae, Iran and it still exists today.

The tomb, made of limestone, has basically two foundations.

A lower one, made of stones cemented together using Sāroj mortar (which is a mixture of plaster of lime and ashes or sand), after that polished, resulting in a smooth surface.

The upper next foundation level, which is not tied or mortared to the base, it was laid out of wide blocks of polished stones, fastened together with metal bars and clips in order to create a large plate.

And so in the case of an earthquake, when the earth moves, the base foundation moves, and the upper part glides freely on its base.

Today's presence and integrity of the monument confirms the fact that engineers constructed the monument to withstand a severe earthquake (around 7.0 on the Richter magnitude scale).

Their base isolation solution contributed to the mausoleum durability in time, taken into consideration that Iran is one of the most seismically active countries in the world, as more than 90% of the country falls within an active seismic zone, the Alpine-Himalayan belt.

3.2. J.A. Calantarients

In 1909, an English doctor, J.A. Calantarients, sent a letter to the Director of the Seismological Service of Chile, drawing attention to his invention, the so called "lubricated free joint" [2].

He proposed that each building to be build on his free joint and a fine layer of sand, mica or talc, the thick black line as seen in Figure 6, that would allow the building to slide in case of an earthquake.

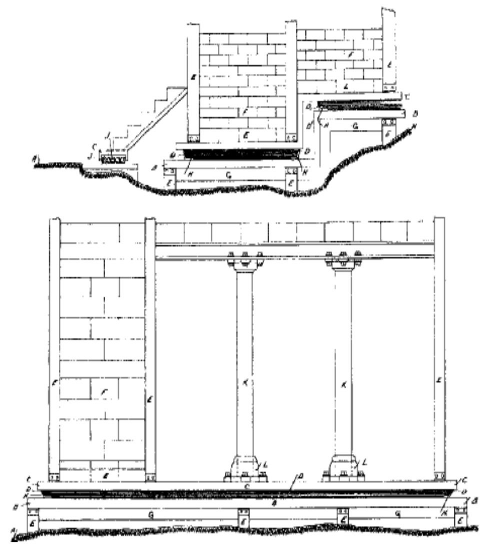

Fig. 6. *Base isolation system proposed by Calantarients* [2]

Furthermore, he also took into consideration a way to allow gas and water pipes, sewage, to enlarge safely with the base of the isolated structure, [2].

Nowadays, base isolation has become a practical reality over the last 30 years.

3.3. Elastomeric bearings

Elastomeric bearings include low-damping natural rubber bearings and lead-rubber bearings.

The first modern base isolated structure is known as being Pestalozzi School in Skopje, Macedonia, in 1969. The isolation system consisted of 16 rubber pack bearings, each made of 7 layers of unreinforced rubber, glued together with a type of adhesive. These had as a disadvantage the fact that under a horizontal movement, vertical movements of the structure were recorded, as the vertical stiffness being only few times larger than their horizontal one [2].

Later on, rubber bearings and lead rubber bearings (LRB) have been developed and especially used in bridges, and also in buildings, C-1 building (Tokyo) being the largest building in the world that is protected by these type of devices.

Elastomeric lead bearings are composed of vulcanized rubber layers (Japan) or neoprene (France), alternating with steel plates to form a flexible structural support. In the middle of the bearing a solid lead core is inserted, which ensures the stiffness in vertical direction, Figure 7 and Figure 8. In the case of a seismic activity, the core acts as a damper, converting kinetic energy into heat.

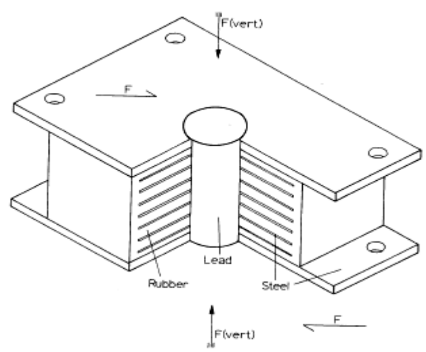

Fig. 7. *Scheme of a LRB isolator*

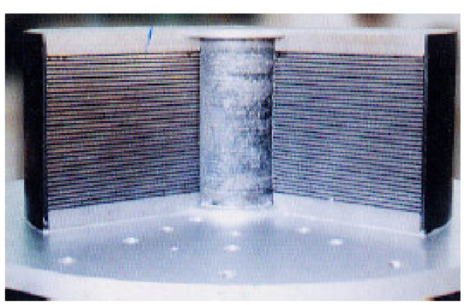

Fig. 8. *Section of a LRB isolator*

The top and the bottom of the bearing are fitted with mounting steel plates, which are used to attach the bearing to building through its foundation.

These lead rubber bearings are designed in the way that the bearing is very stiff and strong in its vertical direction, but flexible in a horizontal direction. This large flexibility to horizontal movement can be observed in testing the isolators, Figure 9.

Fig. 9. *LRB testing*

LRB's have been widely used, and seismic records showed that LRB isolated buildings behaved as expected during the Northbridge earthquake (1994) and Kobe (1995), [2].

Among disadvantages, rubber fatigue subjected to cyclical motions can be mentioned, and one main disadvantage of this system would be that it introduces moment of order 2 (P-Δ effect) at the top and bottom of the bearing, and thus these moments would have to be taken into consideration when designing the foundation and the superstructure.

High Damping Rubber Bearings (HDRB) is large laminated elastomeric bearings which provide elastic restoring force and a required amount of damping up to a maximum of 10-15% of critical.

The rubber for this type was developed by Malaysian Rubber Producers Association, and it has extra fine carbon blacks, oils and resins, and other similar additives. At large strains, a crystallization process takes place in the rubber, together with an increase in energy dissipation [2].

Mechanical properties of elastomeric bearings depend on temperature, rate of loading, loading and strain history.

Disadvantages of this system would be that it also introduces P-Δ moments, its stiffness and damping is strain dependent, and it requires a complex analysis.

3.4. Sliding isolation systems

Sliding isolation bearings use friction in order to limit the transmission of the base shear force across the isolation interface and dissipate seismic energy.

The simplest frictional base isolation device is pure-friction without any restoring force. The Coulomb friction is a simplified quantification of the friction force that exists between two dry surfaces in contact with each other, and could only be used theoretically.

In reality, materials used for sliding isolation systems are Teflon or stainless steel, and their frictional characteristics depend on temperature, velocity of motion, surface wear and tear, fatigue etc.

Commonly known isolation systems with restoring force include the resilient-friction base isolator (R-FBI) system, which is composed of a set of flat rings with a central rubber core and other minor rubber cores, the role of the rubber core being as to distribute sliding displacement and velocity along the height of the R-FBI.

Newest and large-scale used isolation system is the friction pendulum system (FPS). Friction pendulum bearings use the characteristics of a pendulum to lengthen the natural period of an isolated structure, a requirement in base isolation.

The principle is consisted of a sliding movement of an articulated slider on a spherical/concave surface, and generating a restoring force (gravity force), caused by its geometry, Figure 10.

In case of an earthquake movement, the articulated slider glides on the concave surface, having a horizontal movement, but also an insignificant vertical movement due to the nature of the concavity.

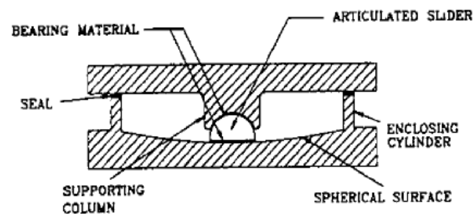

Fig. 10. *Scheme of an FPS isolator*

The effective stiffness of the isolator and the isolated building period are determined and controlled by the curvature radius of the concrete surface [2].

A series of advantages of a frictional type system over a conventional rubber bearing could be mentioned, one that the frictional forces developed at the base are proportional to the mass supported by the bearing, therefore there is no eccentricity between the centre of mass of the superstructure and the centre of stiffness (leading to minimal or none accidental/ additional torsion), and as well that frictional isolators have no unique natural frequency being able to dissipate the seismic energy over a wide range of frequency input without the risk of resonance with the ground motion. Also, the components of the bearings sliding interface are constructed from materials that have a demonstrated longevity and resistance to environmental deterioration and aging.

Possible sticking of the articulated slider is a disadvantage which is taken into consideration, and by any means, controlled.

4. Implementation of Base Isolation in Romania

Chapter 11 of the Romanian Seismic Code P 100-1/2006 evaluates the base isolation concept, reproducing the chapter with the same name as in Eurocode 8.

In Romania, base isolation has been implemented in the project named "Consolidation and Modernization of the Victor Slăvescu building", located in Bucharest. The principle considered was to increase the period of the future isolated structure, in order to go beyond the predominant period of earthquake ground motion, which at the site was known to be $T_c = 1.4 \div 1.6$ seconds. The determined period of the isolated structure is now around $T_{\text{isolated}} = 2.8 \div 3$ seconds [1].

The site works consisted of mounting 37 elastomeric bearings as well as 18 seismic dampers, Figure 11, between an upper foundation beam and a lower foundation beam supported on a slab, that were cast on site [1].

Fig. 11. *Installed viscous damper* [1]

The relative floor displacement diagram now reflects a rigid body motion of the structure.

The adopted base isolation solution was convenient and had as advantage the fact that the daily activities carried on undisturbed inside the building, during the site works. Also, the facade and general view of the building remained intact, as an architectural request imposed by its historical monument condition.

5. Conclusions

Triple FPS, developed by EPS, Inc., is the latest isolation system used in the seismic design of the Sabiha Gökçen International Airport (SGIA) Terminal Building in Istanbul, Turkey, the largest base isolated structure.

It consists in three pendulums in one bearing, an inner one which has the property to reduce peak accelerations, and also the shear forces that occur during the service level earthquake. The second pendulum minimizes shear forces for the design basis earthquake, reducing the costs, and the third one is designed to work in case of the maximum probable earthquake.

As base isolation concept has a limited effectiveness, future trends go beyond, implementing Active Control Systems for earthquake protection design.

References

1. Kelly, J.M.: *Earthquake - Resistant Design with Rubber.* New-York. Springer-Verlag 1997.
2. Naeim, F., Kelly, J.M.: *Design of Seismic Isolated Structures: From Theory to Practice*. Chichester. John Wiley & Sons, 1999.
3. Skinner, R.I., Robinson, W.H., McVerry, G.H.: *An Introduction to Seismic Isolation.* Chichester. John Wiley & Sons, 1993.