

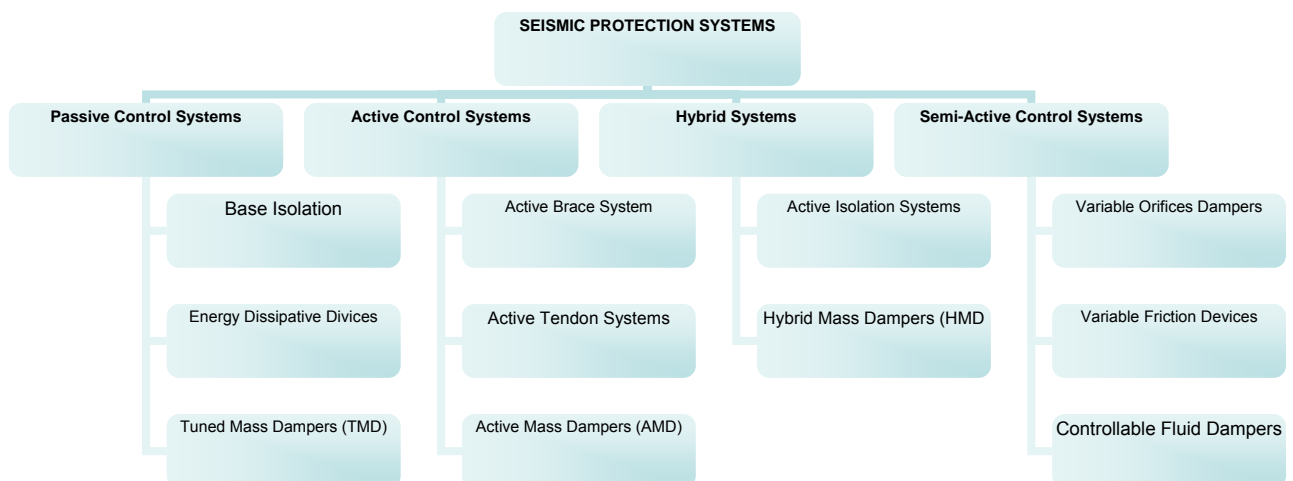
1. STATE-OF-THE-ART: SEISMIC PROTECTION SYSTEMS

This summary presents a comparative study of the current state-of-the-art seismic protection systems. It aims to show the contributions of the new system EGEOMOL-AV.

A description is made of the main seismic protection systems and the devices they use, giving a short outline of their most outstanding applications. Each system is evaluated from the perspective of how effective it is.

The seismic protection systems currently in use range from simple passive control systems to advanced active control systems. Passive systems are probably better known and they include the base isolation systems and the mechanical systems of energy dissipation.

According to J.M.Kelly, systems can be classified into four categories: Passive, Active, Semi-Active and Hybrid



2. PASSIVE CONTROL SYSTEMS

Passive control systems make use of devices that reduce dynamic response through wholly mechanical means. The most usual passive control systems are base isolation, energy dissipative devices and Tuned Mass Dampers (TMD's). Each of the systems employs different approaches to control the structural response and their effectiveness varies with the type of structure.

2.1. BASE ISOLATION SYSTEMS

They isolate buildings from ground motion. They work by considerably increasing the fundamental period of the Building-System set, to prevent it from going into resonance.

ELASTOMERIC BEARINGS.

They make use of natural rubber or neoprene elastomeric bearings reinforced with thin sheet steel. The significant lateral flexibility on the elastomer enables the lateral

displacement of the edges of the insulating material, whereas the reinforcing sheet prevents elastomer enlargement and affords it a considerable vertical rigidity.

There are three basic types:

Natural Rubber Bearings (**NRB**)

Lead - Rubber Bearings (**LRB**)

High-Damping natural Rubber isolators (**HDR**)

SLIDING.

Sliding devices dissipates energy by means of the friction forces present due to the relative displacement between two plates in contact. One of the most innovative devices is the friction pendulum system, which combines the sliding action with the generation of a restituting force due to the geometry of the damper

2.2. ENERGY DISSIPATIVE DEVICES.

They are designed to absorb the majority of the seismic energy, preventing dissipation caused by an excessive deformation of the structure.

HYSTERETIC DAMPERS.

They include metallic dampers as well as frictional dampers. In essence, they depend on the displacements of the structure.

A) Metallic dampers are based on the creep of metals due to bending, cutting, torsion or extrusion. One of the best-known metallic devices is the **ADAS**, made up of steel plates with an X-shaped transversal section, fixed in parallel on the stays.

B) Friction dampers are devices that dissipate energy by means of the friction forces present due to the relative displacement between two plates in contact. They are designed to slide a predetermined load, and they remain inactive until there is an important seismic strain on the building.

VISCOELASTIC DAMPERS

Among this group:

A) Solid visco-elastic dampers, made up of a layer of visco-elastic material placed between two steel plates.

B) Fluid viscous dampers are devices that dissipate energy by forcing the flow of a fluid through a hole (similar to shock-absorbers in a vehicle)

2.3. TUNED MASS DAMPER (TMD)

The tuned mass damper is such an energy absorber consisting of a mass, a spring, and a viscous damper. The motion of its mass is activated when the natural frequency of the TMD is tuned to be in or near resonance with the predominant frequency of the main structure. Resonant oscillators are quite effective in reducing vibrations produced by wind in tall buildings. They can also be used to reduce the seismic response.

3. APPLICATION OF SEISMIC PROTECTION SYSTEMS

The perspectives for the application of seismic protection systems in countries with a considerable seismic risk focus mainly on passive control systems such as seismic isolation and fluid-viscous dampers. These systems are compatible with the structural typology of contemporary buildings.



The main effect of seismic isolation in the dynamic performance of the structure is the considerable increase in the fundamental vibration period. This increase is a consequence of the flexibility imposed by isolating materials on the structural system.

Regardless of the remarkable difference between the fundamental vibration periods corresponding to each direction of the building with a fixed **foundation plate**, there is no significant difference between the periods corresponding to the building with seismic isolation.

The performance of the structure with seismic isolation is mainly controlled not by the structural configuration of the building but by the isolators. Even though the seismic displacement of the isolated building is quite large, the majority of this displacement is concentrated on the isolation system, through the lateral buckling in the isolators.

Seismic isolation is an efficient and innovative technology that should be used to afford structures seismic protection against severe stress.

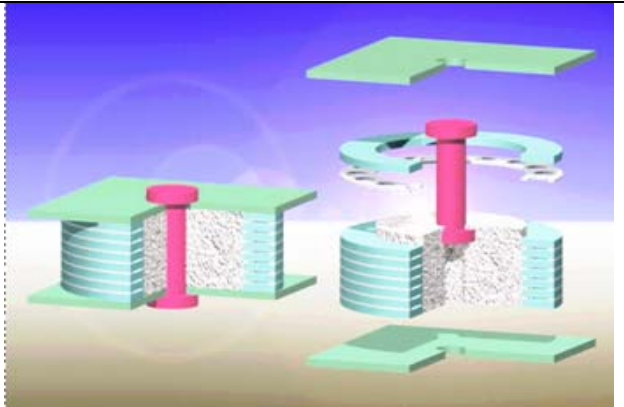
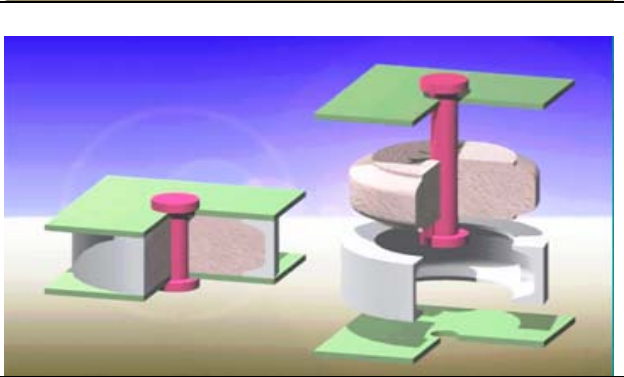
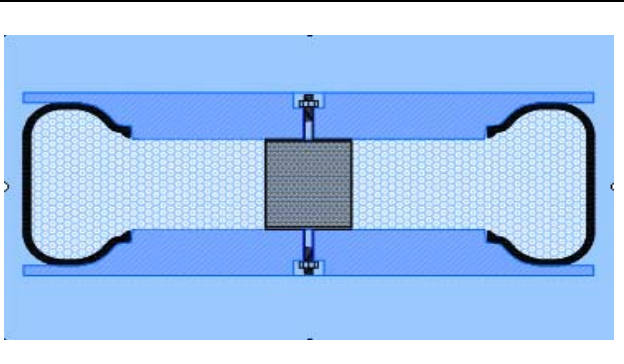
The isolating system reduces the stress and relative displacements in the structure to less than half of the effects corresponding to the structure with a fixed **foundation plate**. These results are particularly encouraging and they improve the perspectives in the application of seismic protection systems in those countries that face seismic hazard, in the near future.

4. DESCRIPTION OF THE EGEOMOL SYSTEM

The EGEOMOL-AV system unit is made up of two plastic plates joined by a central silentblock. They hold an elastic brace filled with a solid material having hydraulic properties.

This solid granular material has the property of transmitting pressure to the elastic brace (pneumatic) without losing its leak-tightness.

Aimed at optimizing its performance, different models have been developed that are based on the same concept as the patented EGEOMOL-AV:

<p>Elastic brace made up of RINGS with different elasticity.</p> <p>Filled with solid material having hydraulic properties.</p> <p>With a central silentblock.</p> <p>Parts are made of PVC</p>	
<p>Elastic brace made up of a RING with medium elasticity.</p> <p>Filled with a solid material having hydraulic properties.</p> <p>With a central silentblock.</p> <p>Parts are made of PVC.</p>	
<p>Elastic brace made from a used TYRE</p> <p>Filled with solid plastic material with hydraulic properties.</p> <p>With a central silentblock.</p>	

In the EGEOMOL-AV system, two hydraulic models have been adopted depending on the type of particle used, ranging from the characterization of the **liquid performance to that of the gas performance.**

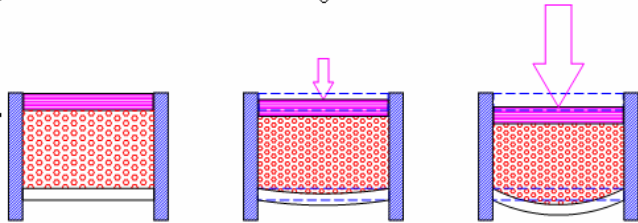
- Characteristic behaviour of a LIQUID: **Rigid** particles with moderate internal friction

(medium viscosity).

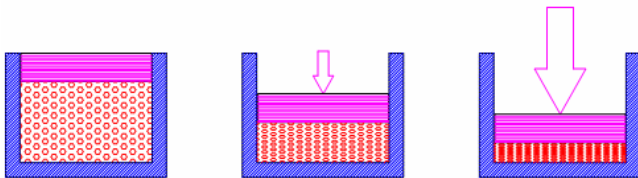
- Characteristic behaviour of a GAS: **Elastic** particles with low internal friction (low viscosity).

Hence, the EGEOMOL-AV system can achieve hydraulic performance setting out from solid components, which avoids losses in imperviousness and implies zero maintenance.

Behaviour resembling the Liquid state: Rigid Particles.

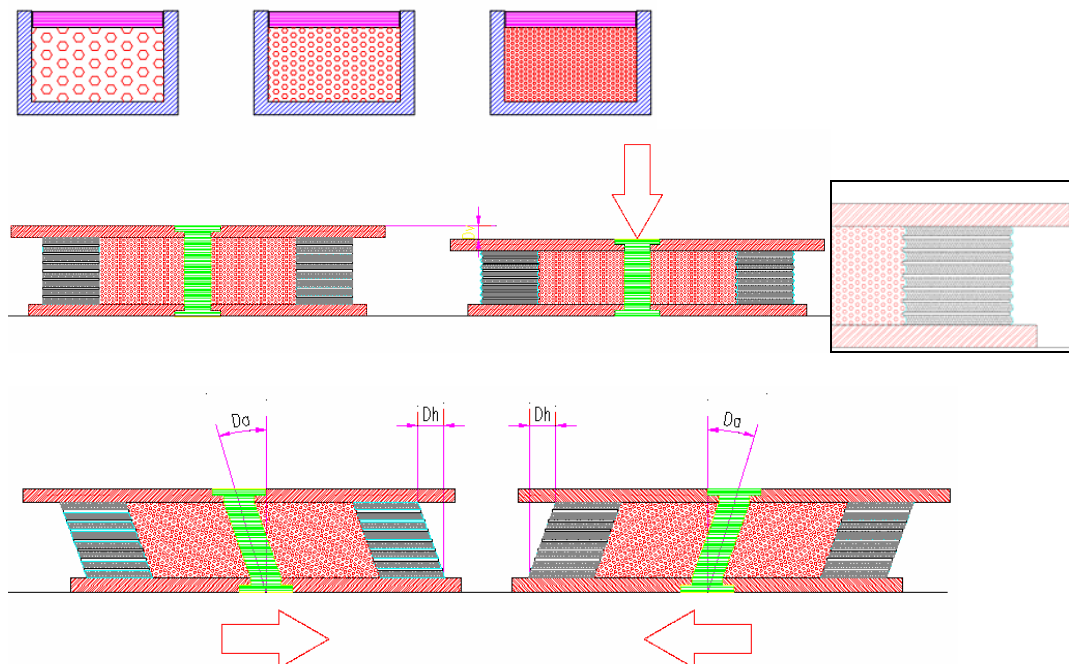


Behaviour resembling the Gaseous state: Elastic Particles.



To sum up, we can conclude that the system can achieve hydraulic performance that is similar to that of a liquid or gaseous state depending on the characteristics of the granular material used:

- SIZE and SHAPE; spherical, lentil-shaped, cylindrical (internal friction, viscosity)
- TEXTURE: smooth, rough (internal friction – viscosity)
- ELASTICITY OF THE PARTICLE: Elastic, Rigid (compressibility)



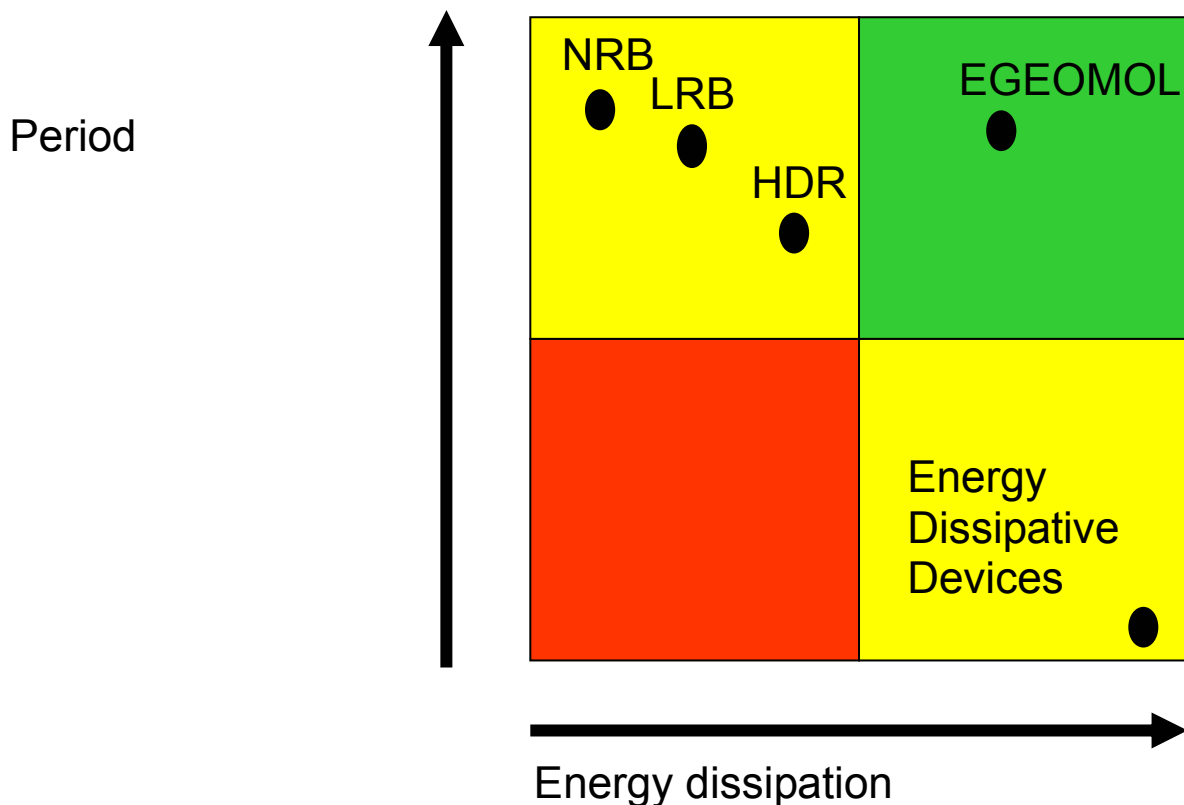
5. LIMITATIONS OF THE CURRENT SYSTEMS AND ADVANTAGES OF EGEOMOL

To get an optimal response, a seismic protection system should be able to:

- Isolate the building from the ground by means of systems with low resistance to horizontal displacement, so that it increases the natural period of the building-system set.
- Absorb part of the earthquake energy, avoiding excessive accelerations and displacements that could cause non-structural damage.

It has been customary to use combinations of Natural Rubber Bearings (NRB) and Energy Dissipative Devices to obtain adequate seismic protection systems.

The disadvantage of the Dissipative Devices is their high cost and maintenance. Therefore, there is a tendency nowadays, especially in Japan, to use Lead-Rubber Bearings (LRB) and High-Damping natural Rubber isolators (HDR), which have a greater capacity to dissipate energy than elastomeric supports. However, their damping capacity is not enough to avoid the use of additional dampers. Therefore, currently there is no system that satisfactorily fulfils the requirements mentioned above.



SEAOC Blue Book¹ set up “General Requirements for the Design and Construction of Seismic-Isolated Structures”. In general, acceptable systems will: (1) remain stable for required design displacements, (2) provide increasing resistance with increasing displacement, (3) not degrade

under repeated cyclic load, and (4) have quantifiable engineering parameters (such as force-deflection characteristics and damping)².

If we apply high horizontal loads to Lead-Rubber Bearings (LRB), the lead nucleus will be irreversibly deformed, so their functioning cannot be guaranteed in future earthquakes.

Conceptually, there are four basic types of isolation system force-deflection relationships.

These idealized relationships are shown in Figure with each idealized curve having the same design displacement, DD , for the design earthquake.

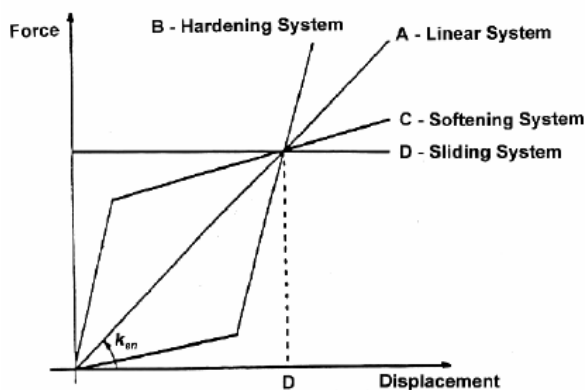


Figure C13.1-1 Idealized force-deflection relationships for isolation systems (stiffness effects of sacrificial wind-restraint systems not shown for clarity).

A linear isolation system is represented by Curve A and has the same isolated period for all earthquake load levels. In addition, the force generated in the superstructure is directly proportional to the displacement across the isolation system.

A hardening isolation system is represented by Curve B. This system is soft initially (long effective period) and then stiffens (effective period shortens) as the earthquake load level increases. When the earthquake load level induces displacements in excess of the design displacement in a hardening system, the superstructure is subjected to higher forces and the isolation system to lower displacements than a comparable linear system.

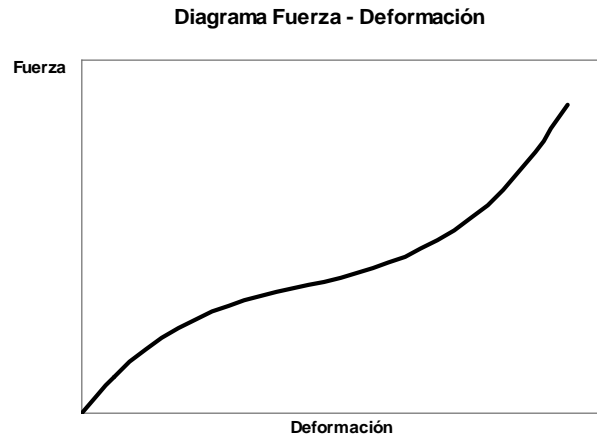
A softening isolation system is represented by Curve C. This system is stiff initially (short effective period) and softens (effective period lengthens) as the earthquake load level increases.

A sliding isolation system is represented by Curve D. This system is governed by the friction force of the isolation system.

Like the softening system, the effective period lengthens as the earthquake load level increases and loads on the superstructure remain constant.

A consideration in the design of isolated structures is the need to minimize building response under wind load. To accomplish this, the isolation system must have a relatively high initial stiffness. However, the combination of a high stiffness with a high effective yield force can lead to an isolation system that does not respond well in frequent, minor earthquakes. To be effective in such events, the effective yield force should generally be chosen to be of the same order as the largest wind-induced base shear³.

The ideal system should have a high initial stiffness, should reduce its stiffness for moderate displacements to respond adequately to low and medium intensity earthquakes and should have a high stiffness for large displacements, to achieve a better response to strong earthquakes. To achieve this, the system should present a force-deflection diagram, as shown in the figure.



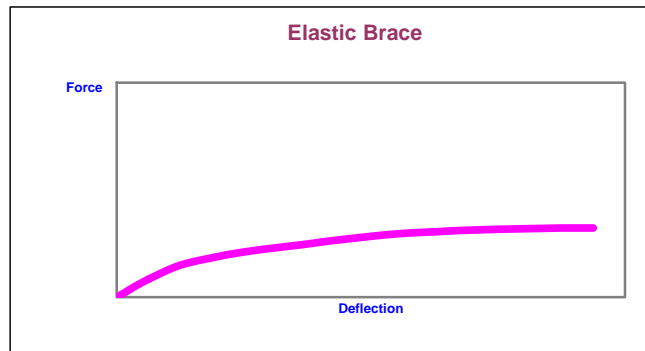
High-Damping natural Rubber isolators (HDR) are currently under development, with force-deflection diagrams approaching the ideal performance, as shown in the previous figure. To achieve this, it is necessary to work on the composition (formulation) of the neoprene.

The EGEOMOL-AV system gives better results, as it comprises three basic components (elastic brace, solid granular material with hydraulic properties and central silentblock), each of them with different mechanical properties (different force-deflection diagrams). Consequently, the system has multiple design parameters that enable it to optimize the force-deflection diagrams. It is then possible to act on the whole system as well as on its components.

- Elastic Brace:
 - Composition of the material comprising the rings.
 - Dimensions
 - Design and combination of the different types of ring
- Granulated Filling:
 - Material composition
 - Grading
 - Filling shape
- Central Silentblock:
 - Material composition
 - Shape
 - Dimension

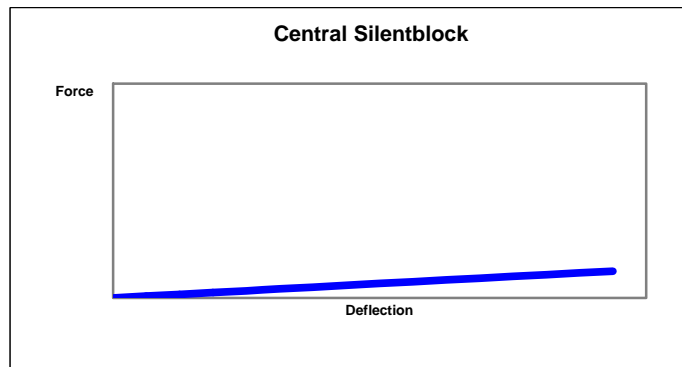
Therefore, the EGEOMOL-AV system has three different force-deflection diagrams corresponding to its basic components, so that by combining them in the proper way we get the optimal response from the system.

$$K_1 \times F_1$$



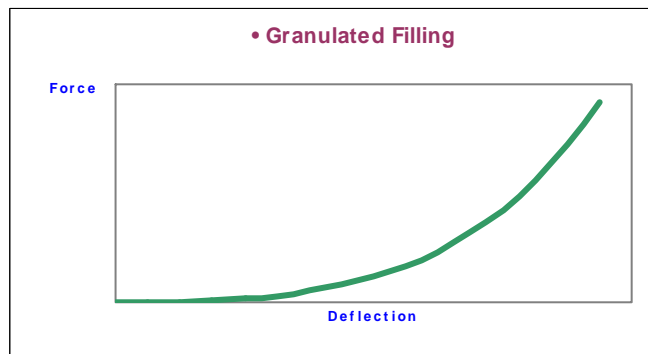
+

$$K_2 \times F_2$$



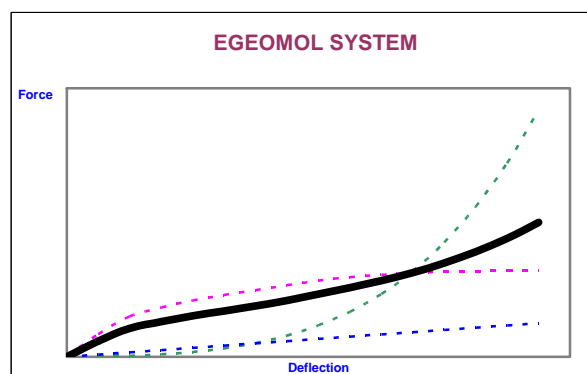
+

$$K_3 \times F_3$$



=

$$F_{EGEOMOL} = \sum K_i \times F_i$$



EGEOMOL is a versatile seismic protection system of passive control, which means it complies with the requirements of design regulations for seismic-isolated buildings.

6. COMPARATIVE STUDY: PASSIVE CONTROL SYSTEMS

The following chart summarizes the advantages and disadvantages of the passive control seismic protection systems currently used, in comparison with the EGEOMOL system.

System	Reduction in fundamental period	Level of energy dissipation	Design variables	Maintenance	Other Complementary systems required	Functionality after an earthquake	Cost
EGEOMOL	High	High	High	Nil	No	High	Low
NBR	High	Low	Low	Nil	Dissipators	High	Medium
LRB	High	Medium	Medium	Nil	Dissipators (1)	Medium	Medium
HDR	Medium	High	Medium	Nil	No	High	Medium
Metallic dampers	Medium	High	High	Medium	Isolators	Medium	Medium
Fiction damper	Medium	High	High	Medium	Isolators	High	High
Fluid viscous dampers	Medium	High	High	High	Isolators	High	High

(1) To a lesser extent than NBR

7. CONTRIBUTIONS OF THE PATENT

Patent number 6,581,340 / title: MODULAR ANTI-SEISMIC PROTECTION DEVICE TO BE USED IN BUILDINGS AND SIMILAR CONSTRUCTIONS” from the company named INNOVACIÓN Y DISEÑO OROVAY, S.L. provides new concepts in the field of isolation and damping systems.

Within the Passive control systems, the EGEOMOL-AV system is a simple and innovating device, which can work at the same time as:

- **Seismic isolation system**
- **Energy dissipation system**

Obtaining:

- a. Improvement to the performance of the building work with respect to the effects of wind, due to the control of the vertical compression of the system by means of the incorporated compression chamber.
- b. Reduction in building oscillations and resonance produced by the seism through energy dissipation, which is achieved when the particles inside the chamber enter into friction.
- c. Calibration of the damping factor as a function of the different types of granular material.
- d. Reduction of system maintenance, by eliminating the deficiency in leak-tightness of liquid and gas inside the circuit.
- e. Increase in the load range, as a consequence of the pre-tensioned and strapping effect of the pneumatic brace, which increases the system’s resistance to compression.

La innovaciones más destacables de la patente, las podemos resumir:
The most remarkable innovations of the patent could be summarized as follows:

- A) Use of a solid granular material with hydraulic effect.
- B) The pre-tensioned and strapping effect of the pneumatic brace.
- C) The inclusion of new materials in the field of seismic protection.

1- Use of a solid element with hydraulic effect.

This innovation consists of the substitution of a **fluid element** for a **solid element with hydraulic properties**; that is to say, achievement of the intrinsic property of the material (hydraulic) irrespective of its state (solid, liquid or gaseous)

2- Pre-tensioned and strapping effect of the pneumatic brace.

This mechanism affords the system a higher resistance to vertical loads and deformations that are compatible with the structure, implying enough displacement to absorb the horizontal drive of the earthquake and minimal vertical deformations. The compression chamber generates a restituting force with a favourable effect on seismic protection.

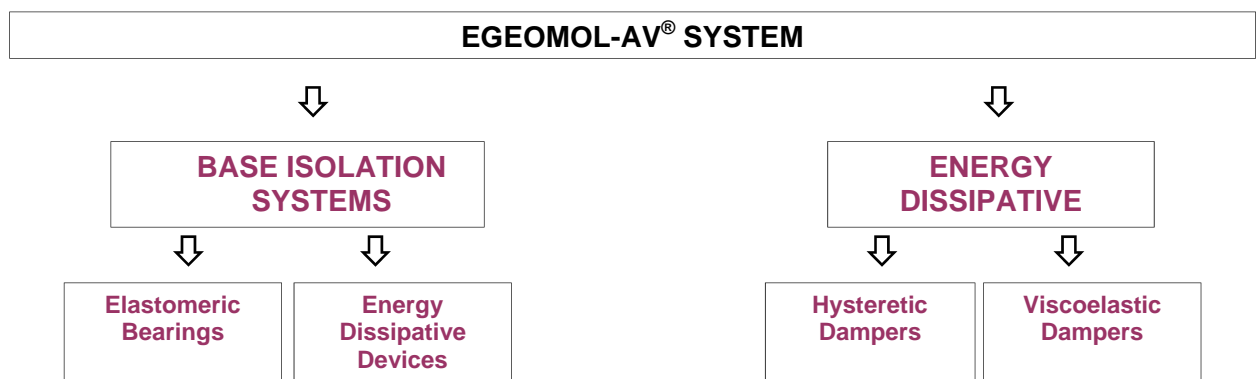
3- Introduction of new materials in the field of seismic protection.

The use of plastic materials that have not been used before in seismic protection, enables cost reduction.

8. IMPACT OF THE INNOVATION

The elements of the system (the solid granular material with hydraulic effects, the elastic brace, and the central silentblock) make the system behave as an ideal combination of the current Passive control seismic protection systems.

The performance of the system is protected by the patent.



1- Performance of the System as a Rubber bearing.

The system incorporates a brace made up of layers of elastic material, reinforced with intercalated laminas of another, harder plastic material. The significant flexibility enables the lateral displacement of the isolator edges, whereas the reinforcing laminas prevent the material with elastomeric properties from bulging and provide it with considerable vertical stiffness.

2- Performance of the system as a Sliding Bearing.

The upper and lower plates of the system have a sliding surface, which allows energy dissipation by means of the friction of the plates with the granular material and of the granular material itself.



3- Performance of the system as a Hysteretic Damper.

The central nucleus that holds the two plates enclosing the compression chamber, acts as a “metallic hysteretic damper”, as it depends on the displacement of the structure. This mode of dissipation is based on the ability plastic has to be deformed when subjected to flexion, cutting or torsion loading.

4- Performance of the system as a Viscoelastic damper.

The solid granular material with hydraulic effect, behaves as a layer of visco-elastic material situated within the compression chamber of the system. The deformations of the granular material caused by compression are similar to the performance of a liquid visco-elastic device.

9. CONCLUSION

The new EGEOMOL-AV System affords advantages to the BASE ISOLATION SYSTEMS and the VISCOELASTIC DAMPERS, with optimal cost of application due to the incorporation of economical PVC materials and the use of a solid granular material with hydraulic effect.

We can state that with the new and economical EGEOMOL-AV System we enter a new stage in the application of seismic protection systems, moving from a selective and almost unaffordable application of these systems, to the general implementation in all types of buildings ranging from single-family to collective housing, buildings, hospitals, schools ...and so on.

¹ “General Requirements for the Design and Construction of Seismic-Isolated Structures.” “Appendix to Chapter 2” of SEAOC Blue Book. Structural Engineers Association of California (SEAOC) State Seismology Committee.

² Chapter 13 Commentary. SEISMICALLY ISOLATED STRUCTURE DESIGN REQUIREMENTS

³ PERFORMANCE CONSIDERATIONS FOR ISOLATIONS SYSTEMES IN REGIONS OF HIGH SEISMICITY