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Innovative Superelastic Isolation Device

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The objective of the present work is to propose a new seismic isolation device based on superelastic material components manufactured using shape memory alloys. Seismic isolation is one of the most effective options for the passive protection of structures. Shape memory alloys (SMAs) are characterized by unique mechanical properties due to a solid-solid transformation. An isolation bearing system based on a SMA superelastic effect is intended to provide nonlinear flag-shaped lateral displacement-shear force hysteresis, additional damping, and recentering properties to reduce or eliminate the residual deformations.

The device concept is based on two separate systems, one to transmit the vertical load and another to act as a lateral restrainer. This article presents in detail the mechanical components of the innovative device focusing on its main properties.

The system theoretical response is computed, resulting very attractive from the earthquake engineering point of view, because of its capability in reaching the design goals, i.e., modification of the structural response, ability to undergo large displacement demands without loss of strength, energy dissipation, and recentering after the seismic event.

Keywords Seismic Isolation; Shape Memory Alloys; Superelastic Effect; Flat Slider Device; Superelastic Spring; Recentering Isolator

1. Introduction

The present work proposes the idea of an innovative base isolation device. Suitability and advantages of a theoretical superelastic base isolation device have been investigated and reported in Attanasi et al. [2009a,b]. In this context, the design process is aimed to develop a real device configuration providing good isolation properties with no residual displacements.

In general, as presented in Skinner et al. [1993], Naeim and Kelly [1999], Christopoulos and Filiatrault [2006], and Priestley et al. [2007], a good device should be able to: transmit the vertical load both during seismic and most demanding non seismic conditions; provide an appropriate lateral stiffness under the design seismic event affecting the effective period of the structure; limit the base shear transmissible to the superstructure; accommodate most of the displacement demand of the isolated structure without loss of strength; reduce the residual displacements at the end of the design seismic event; provide a relevant initial stiffness and strength to make the isolation system rigid under service loads, like wind; and provide the chance of easily replace any components.

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To meet the previous requirements, the new system conception is based on two different contributions: (1) a device intended to carry and to transmit the vertical load; (2) a device working horizontally as a lateral restrainer.

Hence, the idea is to decouple the system lateral and vertical load transmission elements to improve performance. The proposed solution consists of a flat sliding bearing and a superelastic material lateral restraining system manufactured using shape memory alloy (SMA) helical spring components. Shape memory alloys are a novel functional material with increasing applications in many areas, recently also in response control of civil structures [Song et al., 2006]. SMAs have energy dissipation capabilities, large elastic strain capacity, hysteretic damping, good high- and low-cycle fatigue resistance, recentering capabilities, and excellent corrosion resistance [DesRoches and Smith, 2003].

The horizontal slider is supposed to carry the vertical load and to provide lateral displacement capability to the structure. The superelastic spring system is then designed to act as a recentering lateral restrainer system. The choice of the spring shape and of its horizontal orientation in the direction of the motion results from an optimization-aimed design process. Numerical and experimental investigations on superelastic springs are reported in Atanasi et al. [2011a,b,c] and demonstrate that such a lateral restrainer system is characterized by an attractive response. It shows large displacement capability without loss of strength due to the high deformability of the springs, limitation of the maximum transmittable shear due to the nonlinearity of the constitutive relation of the material, and theoretical recentering action given by the superelastic behavior of the springs.

2. Flat Slider Device

A flat slider device is a bearing transmitting the vertical load in a structure consisting of a steel interface in contact with a polymeric material interface. The most common type of sliding bearing is characterized by the use of steel and teflon, or polytetrafluoroethylene (PTFE), interfaces. An example of this bearing device is shown in Fig. 1.

Flat slider devices have been traditionally used to accommodate thermal movements and effects of pre-stressing, creep and shrinkage in bridges or long structures, but have also been proposed as a part of seismic isolation systems (see Kelly, 1986). In the present work, this latter concept is considered. Several investigations have been performed to identify

![FIGURE 1 Flat slider device.](image-url)
slider behavior in seismic conditions. An overview on some of the most interesting contributions is reported in Mokha et al. [1990], Constantinou et al. [1990], Makris and Chang [2000], Jangid [2000], Higashino et al. [2003], and Dolce et al. [2005]. Proposals of isolation systems based on sliding bearing together with other lateral restraining elements were presented in Constantinou et al. [1991], Bondonet and Filiatrault [1997], Cardone et al. [2003], and Dolce et al. [2007a,b].

In general, a sliding system is able to limit the force transmitted to the superstructure to a predefined level as function of the coefficient of friction which is almost independent from the intensity and the spectral content of the earthquake. Important drawbacks in seismic isolation applications are the large dispersion in the peak displacements and the occurrence of residual displacements. A detailed description of advantages and disadvantages of flat sliding bearing systems in seismic isolation has been presented in Dolce et al. [2005].

In the context of this paper, sliding bearings are intended to carry the vertical structural load supporting the weight of the superstructure and the force induced by the overturning moment. As already reported in Dolce et al. [2005], large freedom in designing sliders with different friction coefficients is possible, by changing either the friction material and adding lubrication. Therefore, in the present work an ideal slider is considered, characterized by a negligible shear capability, a negligible influence on the system lateral stiffness and negligible energy dissipation contribution. Additional lateral restrainers shall mitigate the magnitude of the residual displacement. A possible type of restrainers is discussed in the following section.

3. Coil Spring Lateral Restrainer

In the present work, the possibility of using a single coil spring system as a lateral restrainer is investigated. Results from theoretical and experimental studies on the mechanical behavior of superelastic SMA springs are reported in Attanasi et al. [2011a,b,c], after Toi et al. [2004].

The design conception of the device is based on the possibility to let the spring wire work in torsion during compression or tension loading, and to ensure a uniform yielding along all the coils. In this framework, it is important to note that the stress distribution is not uniform in the wire section and it is given by the sum of the torque and shear stresses as reported in Fig. 2 (see also Attanasi et al., 2011b, for more details).

![Schematic stress distribution](image)

**FIGURE 2** Schematic stress distribution in the helical spring wire section due to torque and shear generated by a compressive load.
Few test snapshots from the experimental campaign on SMA springs described in detail in Attanasi et al. [2011a] are reported in Fig. 3. The springs resulted in a very good and stable response during elongation (see Fig. 3a) and in buckling response in compression due to side deformation (as shown in Fig. 3b).

The complexity of the internal stress-strain distribution leads to the need of using a finite element model to study the global device response. This model has been implemented and validated with respect to experimental data in Attanasi et al. [2011b] and it is characterized by a very simple modelling approach. The spring geometry is described using several straight two-nodes beam elements and the analysis is characterized by material and geometrical nonlinearity. Material properties are taken into account using a SMA constitutive relation (as described in detail in Attanasi et al., 2011b, and shortly recalled in Sec. 4). An example of force-displacement relation comparison between finite element model and experimental test result is reported in Fig. 3c. Of course, due to its simplicity, the model does not take into account coil contact and other complex phenomena, but it results very useful to describe the overall system behavior. The same numerical model is used in the present work to predict the system response.
The main conclusions of previous investigations were that coil spring systems made of superelastic material can be designed to be used as lateral restrainers. They provide stable flag-shaped force-displacement response, large displacement capability with limited overall dimensions, and they are characterized by large freedom in design to ensure the target displacement capability and strength. Obviously, it is impossible to obtain the force-displacement relationship needed for a base isolation restraining system using only one spring. Hence, the design process aim is to obtain a spring configuration characterized by a stable and symmetrical response, regardless of the direction of the seismic motion in plan.

To reach this goal, different investigation steps are presented. The response of a single degree of freedom system restrained using two springs in parallel is reported in Sec. 4. Then, the analyses are repeated using eight springs in a radial configuration as reported in Sec. 5.

A main concern in the present investigation is the design of the spring-end boundary condition. In fact, the superelastic spring system is the lateral link between the superstructure and the fixed base and, in function of the mechanical solution adopted to connect the spring ends to the other elements, different device responses are obtained. Two conditions have been considered, one in which the spring-end is hinged and another one in which it is fixed. To provide a hinge-type connection the solution presented in Fig. 4 was proposed. It consists of a mechanical hinge which allows the device to rotate around the vertical axis (as shown in Fig. 4) which is the vertical axis of the isolated building. In the fixed-end case, the dead coil is simply welded to the end plate and rotations are constrained in all directions.

In the present analyses, the spring-end connected to the superstructure is fixed in all the cases, while, as just said, the other spring-end (connected to the fixed base) was considered in one case as fixed and in another case as hinged.

4. Response of Two Springs in Parallel

The system investigated in this section is shown in Fig. 5 and consists of two springs restraining a single degree of freedom system, with one spring acting in compression and the other in tension at any given time. The two springs are set in series but their effect on the restrained mass is the effect of two springs in parallel.

The spring is assumed to be made of a superelastic shape memory alloy characterized by a flag-shaped stress-strain relation model, like the one shown in Fig. 6. To reproduce the superelastic material response, an ABAQUS [2003] implementation of the superelastic model, originally proposed by Auricchio and Taylor [1996, 1997] and based on the concept of generalized plasticity [Lubliner and Auricchio, 1996] was used.
Innovative Superelastic Isolation Device

![Schematic of the double spring system.](image)

**FIGURE 5** Schematic of the double spring system.

![Superelastic flag-shaped stress-strain model.](image)

**FIGURE 6** Superelastic flag-shaped stress-strain model.

The material properties used in the analysis are compatible with actual manufactured high-dissipation superelastic shape memory alloys and they are summarized in Table 1. It has been assumed in all the numerical tests involving SMAs that the temperature does not affect the response of the material, which responds consequently with the same stress-strain relation.

A coil spring geometry is chosen: the coil radius is 50 mm, the height of the spring axis is 200 mm, the height of one single coil is 108 mm, the number of coils is 1.85, and the wire section is circular, with diameter 30 mm. In this investigation, large freedom in design

<table>
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<tr>
<th>Table 1: Superelastic SMA material properties (flag-shaped model as defined in Fig. 6) used in the FB modeling</th>
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<tr>
<td><strong>SMA material properties (flag-shaped model)</strong></td>
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<tr>
<td>1&quot; transf. stress</td>
</tr>
<tr>
<td>2nd transf. stress</td>
</tr>
<tr>
<td>3rd transf. stress</td>
</tr>
<tr>
<td>4th transf. stress</td>
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<tr>
<td>Rupture stress</td>
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<td>Initial Young modulus</td>
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<tr>
<td>Final Young modulus</td>
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<tr>
<td>Poisson ratio</td>
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is assumed. In fact, these geometrical dimensions are not usual in the actual SMA manufacture production, which is mainly focused on small diameter bars and wires (usually smaller than 1 mm, for biomedical applications or similar). Nonetheless, there are theoretically no concerns about the mechanical possibility of manufacturing bigger elements. The impossibility to find bars or wires of such dimensions is an actual application-market issue, not a manufacturing-technical one. Moreover, the response of "big" devices should be as stable as the one of "small" devices.

Due to the motivations reported in the previous section two boundary conditions are checked: the fixed-fixed one and the fixed-hinged one, as defined in the investigation summarized in Attanasi et al. [2011b].

Results are shown in Fig. 7 for the fixed-hinged analysis and in Fig. 8 for the fixed-fixed case. Obviously, the resulting force-displacement relations are given by the sum of the tensile and compressive spring contributions. The comparison of the maximum amplitude cycles is shown in Fig. 9.

Differences in boundary conditions play a key role in the definition of the spring yielding limit and of the second stiffness of the device. Figure 9 clearly shows that the yielding force capacity of the fixed-fixed system is almost 40% higher than the fixed-hinged one. However, the shape of the unloading curve is similar for both systems. Regarding the system stiffness after yielding, the fixed-hinged second stiffness is very low, due to the buckling of the spring in compression, while in the fixed-fixed case the second stiffness is not a negligible percentage of the initial one.

A hardening response is shown at large displacements by the device. As acknowledged in Attanasi et al. [2011b], this effect is due both to material hardening and to the reduction of the diameter of the tensile spring coil (which produces a stiffness increase in the spring). In the global isolation system response, this point can be very important for the effects induced on the superstructure, mainly in terms of accelerations and shear force. Therefore, the device has to be designed to reach a lateral displacement in which the hardening effect is taken into account and does not produce any critical effect on the system.

Globally, the system response for the double spring configuration is very good. The compressive and tensile components summed together provide a final hysteresis that is
regular and smooth, because the large deflection local problems affecting compressive buckling (which is evident both from the deformed shape of the finite element model and from experimental tests) and tensile hardening compensate themselves. Theoretically, the superelastic material constitutive law is working properly both in tension and in compression. Nonetheless, the use of two elements, one elongated and the other compressed at the same time, helps the recentering of the system after buckling.

The two boundary conditions are characterized by a different displacement capability before reaching the rupture stress and different yielding and maximum force levels. From the performed analyses the flat plateau provided by the fixed-hinged solution can be an
attractive property for a lateral restrain which is intended to work in the non-linear range limiting also the transmittable force.

5. Response of Eight Springs in Radial Position

The double spring configuration shown in Fig. 5 works properly if it is supposed to act as a restrainer in the direction of the two springs. On the contrary, its response is not suitable if the direction of the motion can be arbitrary. The latter is typically the case of the earthquake input motion which is totally unknown, also with respect to the direction of motion. Hence, for seismic applications, a first requirement for a restrainer is to provide the same shear force-lateral response in any direction.

Considering a system based on coil springs, the multiple directionality can be provided designing a system made up of several springs located all around the device which is to be restrained. In this context, the possibility of using eight springs in a radial configuration is considered, as shown in Fig. 10, assuming that the response is constant regardless to the direction of motion.

The use of eight springs instead of just two is a simple way of providing symmetrical response in plan, however this more complex system produces a response different with respect to the double spring configuration due to the non negligible contribution of the other six elements. Assuming that no torsion occurs in the device and that the displacement occurs along two spring axis direction, for each displacement history one spring is compressed, two are laterally displaced and compressed, one is in tension, two are laterally displaced and in tension, and the other two, whose axis is perpendicular to the displacement direction, contributes only with their lateral stiffness and strength.

If torsion occurs, the response is more complex and differences between the fixed-fixed and fixed-hinged configurations are larger. In the fixed condition, due to the device rotation, the shear is applied perpendicularly to the spring height and this obviously leads to a not optimized device response. The hinged system is characterized by a more favorable response and even if there are rotational effects the shear is mainly carried along the direction of the spring axis. Nevertheless, a smart placing of the isolation devices within

FIGURE 10 Schematic of the eight spring system.
FIGURE 11 Superelastic fixed-hinged eight spring system tension-compression test.

the structure (e.g., arranging the devices along the building perimeter, quite far from the centre of stiffness of the isolation system) would be effective in mitigating torsion effects on the single device, leading every isolator to work mainly for lateral displacement even if the building experiences torsion.

An exhaustive description of the device response has been provided through finite element analysis. The same material properties and spring dimensions described in Sec. 4 are used also in the present simulation.

Results of fixed-hinged condition are shown in Fig. 11 while those of the fixed-fixed condition in Fig. 12. The force-displacement relationship is a flag-shaped hysteresis stable and smooth. In Fig. 13, the comparison of the maximum displacement cycle response is presented for the two boundary conditions. The fixed-fixed system is much stiffer before yielding and presents a higher stiffness hardening afterwards. Hence, the yielding force is much larger in the fixed-fixed case with respect to the fixed-hinged one. At yielding, the force in the fixed-fixed configuration is almost 60% higher than in the fixed-hinged configuration. Response differences are even larger as the displacement is increased. However, at maximum displacement the difference between the two systems reduces, due to the material final hardening.

Figure 13 also reports the response of the double spring configuration (system in Fig. 5) for the fixed-hinged case. This comparison provides a roughly measure of the efficiency of the eight radial spring position with respect to the two spring device (obviously, in the direction of motion). It is evident that the eight spring system is characterized by the not so efficient contribution of six of the eight springs, hence to obtain a system which is effective along different directions some material optimization has to be sacrificed. In terms of maximum yielding force, the 8 radial springs configuration response is about 2.75 times larger than the 2 spring one in the case of the hinged-fixed case and about 4.50 times larger in the case of the fixed-fixed 8 spring system.

As a general conclusion, the use of several superelastic springs to reach a symmetrical plane restraining response provides a very interesting force-displacement relationship. It has been verified through numerical analyses that the system gives a nonlinear relation which limits the maximum transmissible force and dissipate energy, and it avoids residual
FIGURE 12 Superelastic fixed-fixed eight spring system tension-compression test.

FIGURE 13 Two-parallel fixed-hinged spring system response compared with fixed-hinged and fixed-fixed eight-radial spring system.

displacements. As identified previously, the fixed-hinged condition is preferable because of the ability of undergoing larger displacement capacity without exceeding the maximum material strength.

6. Design Example of a Superelastic Technology Isolation Bearing

The result of a simulated design process for a superelastic technology-based isolation system is presented in this section. The design process goal is to obtain an optimized superelastic isolation device configuration equivalent to a real existing isolation bearing
as a possible alternative to it. The equivalence is intended to be achieved with respect to the design yielding and maximum shear force and the same design displacement capability, obviously with a different force-displacement relationship.

6.1. Reference Lead Rubber Isolation Device

To define the main features, underline the drawbacks, and eventually to be able to examine the advantages of an isolation system characterized by a flag-shaped lateral force-lateral displacement relationship, a response comparison is performed with respect to an equivalent lead-rubber bearing system.

The isolator considered as a reference is an actual lead rubber bearing, which has been fully characterized experimentally. It is produced by AGOM International srl and the manufacturer provides parameters for the design in terms of elastoplastic hysteresis, as listed in Table 2. The theoretical force-displacement relationship of the model and the comparison with experimental test results is shown in Fig. 14.

The elastoplastic model is clearly an approximation of the real behavior of the isolator. In particular, the comparison with the experimental results shows that the elastoplastic model does not estimate the initial stiffness nor the degradation very well. However, for the

<table>
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<tr>
<th>TABLE 2 Nominal design properties of reference lead rubber bearing diameter 500 mm (courtesy of AGOM International srl)</th>
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<tr>
<td>LRB 500 (elastoplastic model)</td>
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<tr>
<td>yielding shear</td>
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<tr>
<td>design shear</td>
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<tr>
<td>yielding displacement</td>
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<td>design displacement</td>
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<td>initial stiffness</td>
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<td>second stiffness</td>
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<td>secant stiffness</td>
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<tr>
<td>seismic vertical load</td>
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FIGURE 14 Comparison of the theoretical and experimental force-displacement relationships of the Isolator LRB 500 (from Attanasi et al., 2009b, experimental data and model parameters have been provided by AGOM International srl).
FIGURE 15 Superelastic isolator device: 3D view.

representation of the general characteristics of the devices, the adopted model is acceptable, being exact in terms of secant stiffness at the design displacement and providing a good estimation of the hysteretic energy dissipated and of residual displacements.

The lead core contribution provides a large and highly dissipating hysteresis, characterized by an equivalent hysteretic damping equal to 28% according to the hysteresis area based approach (see Chopra, 2006). The isolator device is compatible with a seismic demand represented by Eurocode 8 (CEN, 2004) Type 1 spectra relative to a PGA = 0.25 g and a soil type C.

6.2. Superelastic Isolator Device Design

The superelastic isolator device design has been performed considering as a target the properties reported in Table 2 in terms of shear and maximum displacement capability. The superelastic material properties assumed to be used are the ones reported in Table 1.

6.3. Flat Slider

In this example, we assume to use a low friction slider device, for example a lubricificated device (see Dolce et al., 2005), whose friction coefficient is about 0.25%. Being based on the seismic weight reported in Table 2 and using this friction coefficient, the slider friction force is about 3% of the yielding shear. Hence, its contribution for the base shear is negligible. As such, the slider has just to be designed to be able to accommodate the maximum design displacement, and considering an acceptable upper bound on the pressure value in the device which has been estimated at 30 MPa. The final configuration is characterized by a circular section of diameter 270 mm, as shown in Fig. 16.

6.4. Lateral Restraining Superelastic Springs

The optimum spring configuration for a lateral restraining system having the needed displacement capability and providing the same yielding and maximum force with respect to the reference device has been investigated. The eight radial spring configuration has been used considering fixed-hinged springs. The spring wire section is a pipe section with a 30 mm external diameter and a 20 mm internal diameter. The coil radius is 50 mm and the height of the spring axis is 200 mm. The number of coils is 1.85. The springs are clamped...
7. Issues with the Geometrical Configuration

The final device configuration is shown in a tri-dimensional view in Fig. 15 and in a bi-dimensional scheme in Fig. 16.

The outer dimensions of the final device configuration are more than a factor of two larger than the dimensions of the rubber bearing isolator, whose diameter is 500 mm. This could be an important drawback for this system, because it is more difficult to accommodate such a large device within a structure. Anyway, a smart structural design could be characterized by some bearings with the lateral superelastic restrainers and other being composed only by the slider bearing system, carrying the vertical load without recentering restrainers. Therefore, the problem related to the dimensions of the device could affect
only some devices, not all the bearings. Moreover, other spring positioning systems could be designed, again decoupled from the sliding bearing system, for example around a rigid first level slab and fixed to a foundation wall, or to other locations.

The hinge is supposed to be rotating only around the vertical axis and this guarantees the spring deformation occurring mainly in the horizontal plane, leading to the need for just a relatively small vertical space to accommodate the springs. The height of the device is therefore similar to the one of the actual LRB. The possibility of replacement of the spring restrainer device has been taken into account in the geometrical configuration. As shown in the top view in Fig. 16, there is space enough to replace the coils from the lateral bounds clamped to the base using bolted connection. Looking at the lateral view in Fig. 16, it can be noticed that the slider surfaces are easily replaceable as well, because enough space is available to position the needed jacks.

8. Superelastic Isolator Device Response

The superelastic isolator device response has been numerically predicted using the finite element model experimentally validated as reported in Attanasi et al. [2011a]. The numerical prediction has been computed using the finite element analysis program ABAQUS [2003]. Only the contribution of the spring lateral restrainer has been considered for carrying the shear force, the friction force provided by the slider being negligible. The superelastic device system response is shown in Fig. 17, together with the plot of the experimental test results on the actual LRB.

The results show that the superelastic device system provides the same yielding force and maximum force than the LRB, therefore the secant stiffness to the design displacement is the same. The spring system is characterized by a lower initial stiffness. The maximum displacement ductility for which no critical hardening effects are expected to occur is about $\mu = 3$. The proposed system is characterized by a theoretical hysteretic damping which is about 9% of the critical damping for the same displacement ductility (neglecting the friction contribution). Anyway, as acknowledged in previous investigations [Attanasi et al., 2009a,b], the dynamic response of a flag-shaped recentering system is not directly comparable in terms of hysteretic damping to an elasto-plastic system.

The system numerical response shows that the superelastic device is perfectly recentering. On the contrary a LRB system is characterized by large residual displacements.

![Graph showing force-displacement relationship for LRB and superelastic spring](image)

**FIGURE 17** LRB500 and superelastic isolator bearing force-displacement relationships comparison.
This is a main advantage of the superelastic bearing, because it implies that at the end of the seismic event the isolation system would recover the original position. Possibility of avoiding expensive and time consuming reparations is quite attractive and this is the main advantage in using this superelastic devices with respect to traditional high dissipating but not recentering devices.

9. Comparison of the Proposed Device with Other Superelastic Isolators

In this section, the device configuration as introduced in the present research is compared with respect to the solutions already presented in previous works.

Several configurations have been proposed based on SMA wires. Among others, the devices presented in Dolce et al. [2000], Choi et al. [2006], and Liu et al. [2008] use this technology. Of course, an important advantage of this class of devices consists in the fact that the production of wires is significantly easier compared to the production of complex devices, like, e.g., springs. However, the limitation of maximum deformation in tension of SMA wires implies the use of long wires in which uniform deformation along all their length has to be guaranteed. To ensure an elongation of 200 mm, which is the design displacement of the device proposed in the present work, and assuming to limit the available strain in the wire to 7%, a total wire length of 2,857 mm is needed. To provide a uniform wire deformation seems not trivial, as well. A solution like the one in Choi et al. [2006] which is based on SMA wires wrapped around the bearing perimeter seems not suitable to avoid stress and strain concentrations in the wire corners. The proposal in Liu et al. [2008], which consists of SMA wires wrapped diagonally around rubber bearing (hence it is very similar to the previous one), seems applicable only for small displacements. Both solutions are anyway not efficient, because the SMA force resultant acts diagonally increasing the axial load while carrying the shear force. The solution presented in Dolce et al. [2000] is probably the most efficient application based on SMA wires and it has been demonstrated to work properly, however in this case the concern is on the device manufacturing complexity. A different implementation based on flexural SMA bar response is reported in Casciati et al. [2007]. Even if the device configuration motivation is not very clear from the paper, the proposal is close to the SMA bending bar approach, as presented in Bondolot and Filiatrault [1997]. The response obtained from this device conception is not recentering, hence not meeting an important goal set within this study.

Regarding the device proposed in the present work, the large number of spring geometrical free parameters makes it possible to find suitable device configurations to meet the needed requirements. Moreover, an important advantage consists of the spring capability in reaching very large elongations with respect to its axis length. In Dolce and Cardone [2001], it was recognized that because of the material transformation occurring slowly, the torsional response of the superelastic material is very interesting. Nevertheless, the complexity in manufacturing devices with the SMA intended to respond in torsion is an important limitation to their application is seismic engineering. The spring shape is considered an optimized compromise from this point of view. Firstly, because it works in torsion, leading to a favourable material utilization. Then because it is relatively easy to be manufactured needing only a SMA bar to be coiled around another large diameter bar.

10. Conclusions

The design of an innovative superelastic isolation bearing has been investigated. The design result is a very flexible innovative device which is composed by an independent element for
the transmission of the vertical load and by another system working as a lateral restrainer. The first element is a flat sliding bearing, a traditional device well known for civil engineering applications. The lateral restrainer is a superelastic device system composed by SMA coil springs. The restraining system carries the design shear force being while able to accommodate the design displacement.

A design example is provided, where a superelastic device characterized by the same response in terms of period elongation than an actual lead rubber bearing is designed. The design goals were reached and the final device results to be very attractive. The global isolation device is theoretically able to satisfy all the design requirements, carrying the vertical load, accommodating the design displacement avoiding residuals, limiting the transmittable base shear to the superstructure, providing suitable initial and lateral stiffness affecting the system period elongation, and allowing the replacement of components which need to be substituted. According to the author point of view, it is more suitable for base isolation applications that the other previously proposed solutions based on shape memory alloy devices.

References


Innovative Superelastic Isolation Device


