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# Effective and economic combination of seismic isolation and vibration insulation within one innovative device

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## **ABSTRACT**

Seismic isolation is a well-known approach to reduce the risk of casualties as well as structural and content damage due to earthquakes. Vibration insulation on the other hand is increasingly a requirement in urban areas to ensure comfort and/or serviceability despite disturbing high frequency vibrations due to traffic, railway, or machinery. This is especially important for concert venues or scientific and research institutes with rather sensitive equipment. To combine earthquake, structure-borne sound and vibration protection in a very effective and economic way, a combined insulator-isolator was developed - the SIP<sup>®</sup>-V. The system cost is minimized by the fact that both functions are combined in one single compact device, thus avoiding two separate insulation or isolation layers respectively. The innovation is a PUR-based elastomer bearing integrated into the glider puck of a double curved surface slider (CSS), so that the vertical load for any displacement position is centrally transferred by the PUR-based elastomer pad. The noise insulation can be achieved for frequencies down to 8Hz, which is covering more than 98% of all projects requiring noise insulation. The seismic performance of the device is similar to regular CSS with respect to pendulum radius and dynamic friction coefficients resulting in the necessary damping effects. The SIP<sup>®</sup>-V devices were extensively tested at Eucentre in Italy to prove reliability and performance for dynamic service and seismic events. The successful implementation of the SIP<sup>®</sup>-V technology was demonstrated at the BioSense Institute – an agricultural research institute in Novi Sad/Serbia.

**KEYWORDS:** Seismic isolation, noise insulation, damage mitigation, serviceability

## 1 INTRODUCTION

Due to the increasingly dense construction in cities, expansion of transportation systems and increase in traffic, there is a growing demand to construct high-quality office/residential buildings, protect research facilities and mitigate vibration effects on auditoriums or similar structures. In the past, such properties often had limited usability due to the strong vibrations caused primarily by machines or traffic, especially rail traffic. These vibrations and secondary airborne noise due to structure-borne noise did not permit a high-quality use or even comfortable living inside these buildings.

However, it is now state of the art to insulate buildings from these vibrations using elastic bearings: either as full-surface bearings below the foundation or as point and strip bearings, usually below the ceiling above the basement floor.

Elastomer bearings based on PUR (polyurethane), rubber or, very occasionally, helical spring supports are used here. The relevant vibration excitations are usually in a frequency range between 15 Hz and 80 Hz with amplitudes often below or in the range of the perceptible limit. However, resonance excitation of ceilings and beams can result in perceptible vibrations in the range of the first natural frequency of the ceilings and beams or disturbing noise in the audible frequency range, which can be effectively reduced by the elastic suspension. The vertical tuning frequency of the elastic bearings is usually between 8 Hz and 12 Hz. In rare cases it is below 8Hz for rather sensitive equipment like electron microscopes. These rare cases below 8 Hz requirement were not considered in this paper.

In regions with strong earthquakes these buildings often must be constructed simultaneously with a seismic isolation system – devices like curved surface sliders (CSS) also called sliding pendulums or elastomeric bearings.

The earthquake isolation system is often designed for isolation periods of 2.8 to 6.0 seconds, which means that the structure represents a single degree of freedom system in the horizontal direction with an earthquake frequency in the range of 0.35 Hz to 0.17 Hz that the structure is effectively decoupled from the earthquake in the horizontal direction. The resulting horizontal relative displacements in the earthquake isolators can be up to 1 meter or even greater, depending on the earthquake intensity.

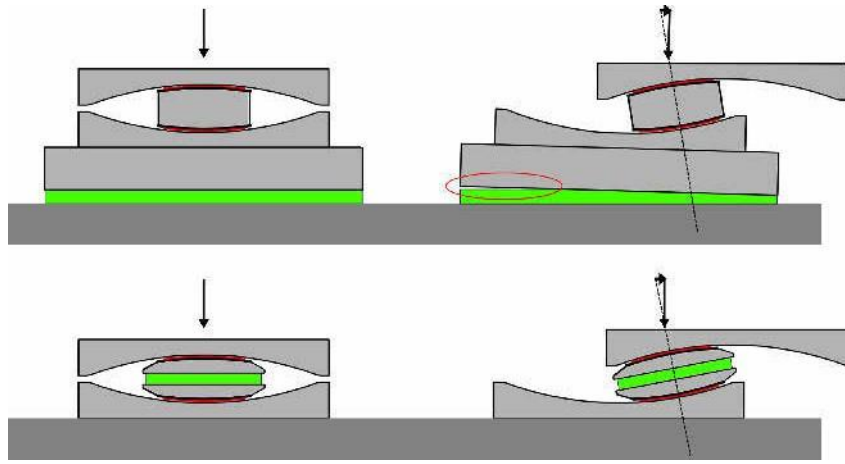
The requirements for vibration insulation in the vertical and seismic isolation in the horizontal direction are therefore fundamentally different and were previously not possible to be united in a combined single device. Expensive and separate bearing solutions were therefore often designed and applied.

## 2 TECHNICAL SOLUTION FOR A COMBINED ISOLATOR

There are various state of the art solutions for vibration insulation, such as the use of full-surface elastically supported concrete slabs in the cellar of buildings to isolate structure-borne noise.

For seismic isolation in contrast seismic isolators are placed at single positions – usually in the cellar – within a grid of 3-6 m.

To combine both ideas within one single device, it was decided to integrate the vibration insulation into the single support idea of seismic isolators. In below Figure 1 two possible approaches are shown.



*Figure 1: PUR insulation under seismic pendulum isolator (top) and integrated Syldyn® PUR pad into seismic bearing design (bottom) – graphic by Getzner*

When applying a vibration isolation layer, the performance depends on where and which elastomeric material is used, see detailed discussion in section 3. Here PUR (Polyurethane; green in Figure 1) was considered.

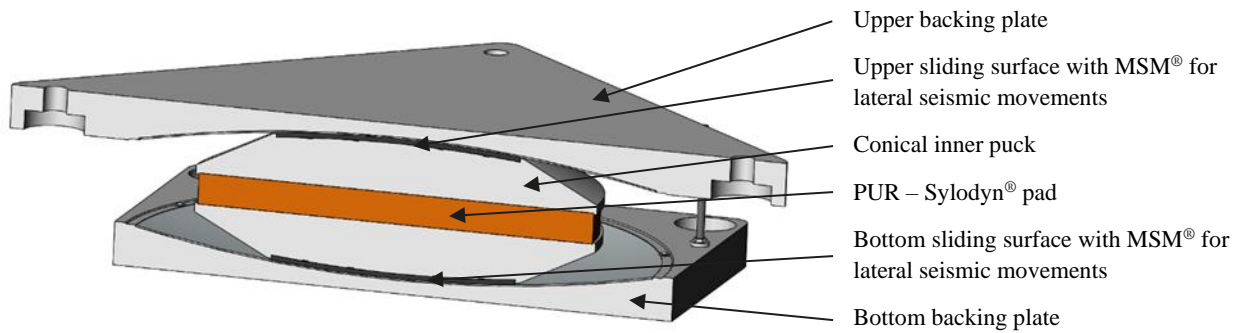
In a first design approach the PUR was set under the entire seismic pendulum isolator (Figure 1 two upper sketches). With such design, the soft elastomer PUR bearing pad would be subjected to strong eccentric loads in the event of large horizontal displacements of the seismic isolator during an earthquake (Figure 1 top on right). A correspondingly large bearing geometry and, as a result, a massive thick load distribution plate would be necessary to transfer the vertical loads without gapping joints at the bearing bottom. It would not be possible to optimally design the bearings stable or even save for large horizontal displacements in the earthquake isolator surfaces. Depending on the lateral seismic displacements, more or less gapping effects would occur (red cycle in Figure 1) resulting in damages of the PUR pad and severe bending within the bottom plates of the seismic isolator placed on top. A further regular and good operation of the isolator after a seismic event cannot be safeguarded then. Consequently, the bearing system would have to be exchanged, what cannot be accepted.

This problem was solved by integrating the PUR bearing directly into the heart of the inner slider lens (Figure 1 lower part). In normal use and centre position, the round PUR bearing pad acts as an insulator against structure-borne noise, just like a conventional elastomer point bearing. In the event of an earthquake with big lateral movements within the isolator, still the PUR bearing pad is subjected almost exclusively to compression without significant rocking effects within any components inside. Even at large seismic deflections the inner PUR pad is stable, not rocking and performs very well. Aside from very good performance, damage is avoided and continued functionality after an earthquake event can be granted.

### **3 DESIGN OF A COMBINED DEVICE**

The newly developed isolator is called SIP®-V – Sliding Isolation Pendulum with vibration insulation.

The challenge for the design is certainly to combine the different applied materials and the different physical requirements of totally different load cases, i.e. service noise insulation and ultimate extreme seismic horizontal isolation.



*Figure 2: Cut through SIP®-V device*

For frequency insulation, structure-born noise effects are active for service dead load conditions in centric horizontal isolator position. The vertical compression of the applied elastomeric rubber layer under dead load must be in a range of 6 mm to achieve approx. 8-12 Hz eigenfrequency within the isolator. Regular Chloroprene or Natural Rubber compounds specified in EN standards like EN1337 (Structural Bearings) and EN 15129 (Anti Seismic Devices) are not suitable, as they do not provide stable and safe compression behaviour for such low frequencies. These can only be applied for higher eigenfrequencies in the range of 15 Hz and above, while the corresponding vertical deflection will be 1-3mm then.

Therefore, the selected insulation material is on PUR basis, providing sufficient softness for proper low eigenfrequencies in the range of 8 Hz with 50-75 mm thickness. The material used is Sylodyn® HRB HS 12000 from Getzner with a comparatively high density and a German Type Approval. It is a well-tested, long-term stable and durable, closed-cell elastomer that does not absorb water. This material can withstand pressures of up to 30 N/mm<sup>2</sup> from quasi-permanent loads (G + 30 % Q according to EN 1990) and 2-3-fold higher seismic short-term loads. This PUR material is placed inside the bearing (Figure 2) with adaptation to required dead and maximum loads. When considering 4500 kN dead load the PUR pad diameter for 12 Hz eigenfrequency will be 650 mm and 50 mm thick.

For seismic isolation with lateral sliding displacements of 1 m and more, PE (Polyethylene) called MSM® sliding against polished stainless steel will be applied (Figure 2). This PE has got a European Technical Assessment with a long history and many applications of the field of seismic isolation, especially for sensitive structures like hospitals, museums, airports, etc. This 8 mm thick material is highly stress resistant beyond 300 N/mm<sup>2</sup> for short term seismic loads and can suffer 3-6 MCE (Maximum Credible Earthquake) events without damage, which was proven by excessive seismic dynamic testing campaigns showing no wearing and degradation of MSM® sliding liner material. The dynamic values of the coefficient of friction between 3-7 % together with the chosen pendulum radius adjust seismic isolation period and damping effect for final control of displacements and base shear within the isolated system. When considering 4500 kN dead load the MSM® pad diameter for 5 % dynamic friction will be 400 mm and 8 mm thick. Compared to any other type of sliding liner – such as PTFE-based or polyamide-based materials – the MSM® has superior performance regarding static friction, wearing, stable damping and stress resistance.

Due to the relatively low stress resistance and soft performance demand of the PUR pad compared to the high-level stress resistance of the sliding material, the inner lens geometry of the SIP®-V device had to be adjusted. Thus, the inner puck must be shaped conically to distribute loads through the PUR pad, while granting small sliding surface diameters at the MSM® for proper friction and damping conditions (Figure 2, Figure 3).

The design of the upper and lower sliding backing plates for accommodation of seismic displacements is considering the pendulum radius represented by the concave machined surface and the footprint necessary to allow a certain MSM<sup>®</sup>-pad diameter sliding laterally within a certain specified seismic movement.



Figure 3: Open prototype without upper sliding plate (left) with conical inner puck with white Sylodyn<sup>®</sup> pad inside and slider lens in black made of MSM<sup>®</sup>; assembled full device (right)

#### 4 TESTING OF THE COMBINED ISOLATOR

To provide sufficient evidence for proper function of the new isolator, excessive testing according to EN 15129 in November 2020 at Eucentre in Pavia/Italy was performed. Technical requirements as per Table 1.

Table 1: Design and test parameters

Prototype Specification	Value
Vertical load permanent	$N_{s,SLS} = 4500 \text{ kN}$
Vertical load maximum	$N_{ULS} = 9000 \text{ kN}$
Horizontal seismic period	$T_{iso} = 4.0 \text{ s}$
Effective pendulum radius	$R_{eff} = 3976 \text{ mm}$
Horizontal stiffness for $N_{s,SLS}$	$K_R = 1132 \text{ kN/m}$
Dynamic coefficient of friction for $N_{s,SLS}$	$\mu = 5 \%$
Maximum horizontal displacement	$d = \pm 400 \text{ mm}$
Vertical tuning frequency	$f_{vert} = 11.8 \text{ Hz}$
Diameter PUR	$D_{PUR} = 650 \text{ mm}$
Height PUR	$H_{PUR} = 50 \text{ mm}$

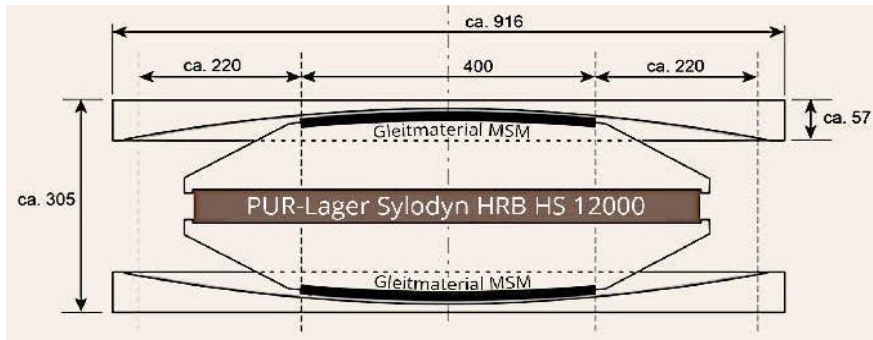


Figure 4: Dimensions of the prototype SIP®-V

Several test series were performed for vibration scenarios as well as for seismic impacts. The cross section through the bearing with rough dimensions is shown in Figure 4.

1. Vibration testing for vertical dynamic stiffness considering 4500 kN vertical load (Figure 5):

Overall system was tested at excitations of 2.5 Hz, 5.0 Hz and 10.0 Hz at 100 dBv. The deviations of the measured stiffnesses from the stiffnesses specified in the data sheet values are - 3.9 % to + 4.3 %. This shows a very good result for the vertical natural frequency for the load of 4500 kN (corresponding to a mass of 458.7 t) at 12.1 Hz, which is only slightly higher than the predicted value of 11.8 Hz. The effective damping was determined to be 5.0-6.5 % on average, irrespective of the amplitude and excitation frequency. This low damping ratio ensures excellent structure-borne noise behaviour, but still buffers more intense vibrations well.

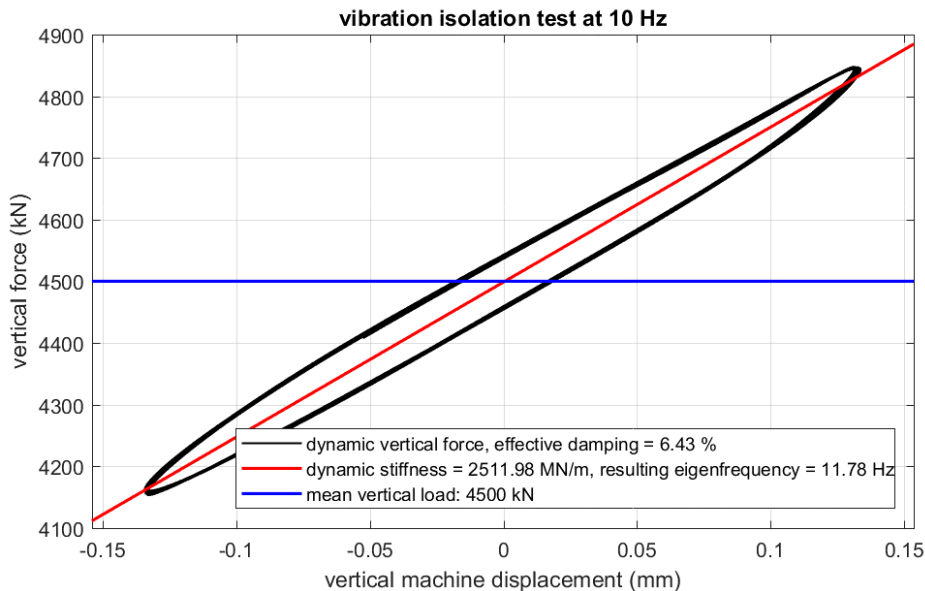


Figure 5: Test plot of hysteretic loop for vertical Force-Displacement loop at Eucentre

## 2. Seismic testing (Figure 6):

Testing was performed with +/-400 mm amplitude, 0.4 m/s velocity and 4500 kN vertically acting load. The promising test results show rather small deviations in the actual coefficient of friction  $\mu$  (+ 9 % to + 16 % from nominal value) and the actual horizontal stiffness  $K_R$  (+ 4.7 % to + 7.7 %) compared to their design values. As can be seen in Figure 6, the fit between theoretical plot (green) and real test plot (black) is very good.

It should be noted that the slight increase of friction coefficient at the end of the reversed cycles hysteric loop is resulting from static friction effects when changing the movement direction, also experienced in normal CSS. These effects are minor, are not influencing the overall structural performance and do not cause stick-slip effects.

After testing according to EN15129 no damages were observed and all tolerances of the standard were fulfilled. Thus, it can be concluded that for service and after seismic events the structure is able to operate and is also not suffering from any damages.

All this confirms the ability to design these pads easily and accurately for vibration insulation and seismic isolation in advance even for high load conditions.

The two function requirements of the seismic sliding pendulum bearing and the vertical vibration insulation bearing pad do not influence each other, which allows to dimension both independently from each other. The union within one device can be realized by adapting the inner steel components.

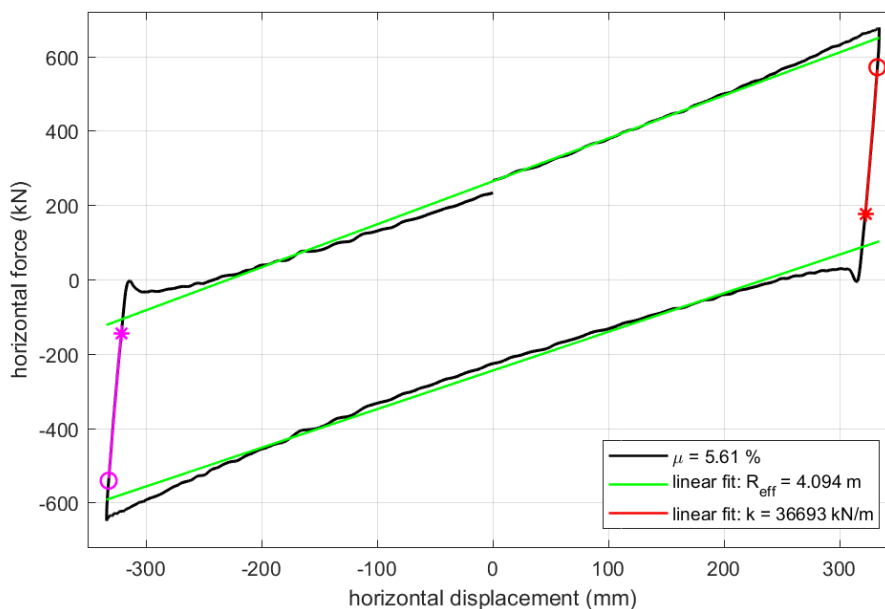


Figure 6: Test plot of hysteretic loop for horizontal Force-Displacement loop at Eucentre



*Figure 7: Test rig at Eucentre in Pavia, Italy showing prototype installation*

## **5 REFERENCE PROJECT BIOSENSE INSTITUTE BUILDING**

The unproblematic handling in planning and installation has already been confirmed by practical experience with the BioSense Institute building in Novi Sad, Serbia (Butenweg, Marinkovi und Michel 2022).

This institute was founded in Belgrade in 2015, and is part of the University of Novi Sad, where the new building has now been constructed. It is considered a pioneer in the field of digital and sustainable agriculture. Micro and nano electronics, sensor design, and cellular agriculture are some of its scientific fields. The laboratory area located in the institute's new building is accordingly sensitive. The requirements for the BioSense research building were clear: Inside, the new building is a small laboratory building core with a plan floor of 8 x 7 m and 4 floors with a height of approximately 17 m, which need high level of vibration protection (Figure 8; green part).

Specifically, this core accommodates complex and expensive laboratory instruments and microscopes. These must be protected against ground vibrations caused by traffic and earthquakes. The other parts of the institute building are less sensitive and therefore no protection was considered.



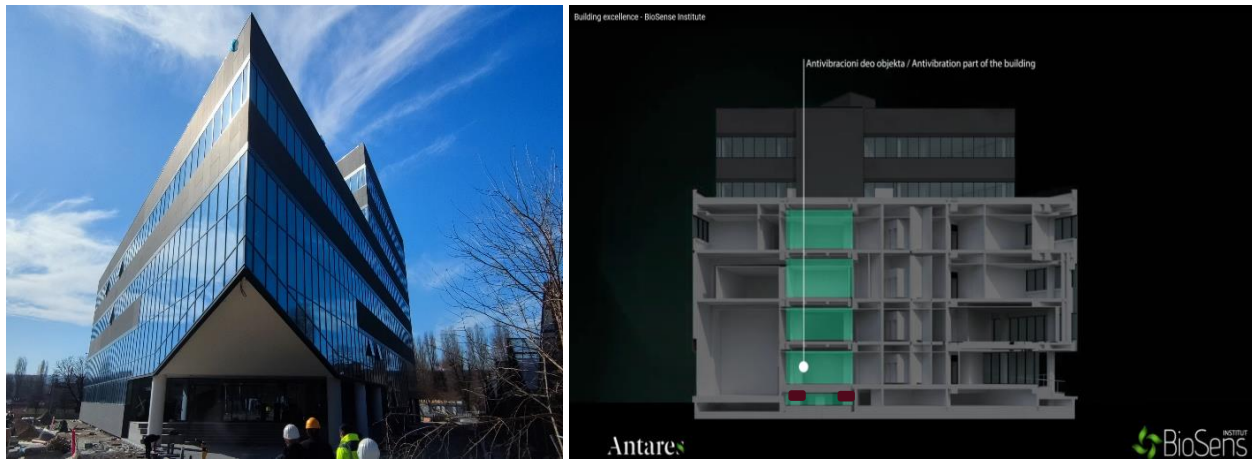


Figure 8: BioSense Research Institute in Novi Sad and inner protected green core area (right); reference “Building excellence - BioSense Institute (www.youtube.com)”

Below the sensitive laboratory building core 4 pcs SIP®-V units were placed with a footprint of only 650 x 650 mm to achieve the following:

- vertical load transmission for max. 400 t ultimate loads
- vibration eigenfrequency of 12 Hz within the devices
- less than +/-100 mm lateral seismic displacement
- less than 20 % lateral seismic base shear
- continued functionality under service and seismic conditions
- a very economical solution, with approx. 50-70 % savings compared to traditional solutions with helical steel springs or springs combined with additional separated seismic isolators.

The small isolator size allowed to design small and economic pedestals with footprint 1000 mm by 1000 mm.



Figure 9: SIP®-V devices within BioSense Research Institute; during installation (left) and installed (right)

## 6 CONCLUSIONS

The SIP<sup>®</sup>-V was presented to support building structures to achieve vibration insulation and seismic isolation within one single device.

- The cost for the combined solution in the SIP<sup>®</sup>-V is generally significantly lower than the sum of the costs of traditional separate pure earthquake isolation and pure vibration isolation systems.
- All requirements for vibration insulation (starting from 8Hz eigenfrequency in device) and seismic isolation (less than 20% base shear) can be meet.
- Continued functionality without damages to equipment, structure, and devices during regular service and even after MCE events.

## REFERENCES

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