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EXPERIMENTAL TESTING OF INNOVATIVE, BIOMIMETIC SEISMIC METAISOLATORS

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Abstract

This work experimentally investigates the mechanical response of a bio-inspired seismic isolator that replicates the mechanics of the human body locomotion. Such a research moves from a recent work dealing with a novel sliding-stretching seismic isolator (SSI) combining a bio-inspired design of the internal architecture with stretching and sliding energy dissipation mechanisms. The unit cell of this device is composed of linkages mimicking human bones, and stretchable cables replicating muscle tendons. The vertical load transferred by the superstructure to the SSI is applied to the central post of the unit cell, which moves by sliding against the base of the system. The "metaisolators" analyzed in the present study adjust the nonlinear stiffness of their tendons so as that the motion of the device is not at resonance with the leading earthquake frequencies. Their fabrication does not require heavy industry or expensive materials, being partially or fully achievable with ordinary 3D printers. This work illustrates the experimental testing of such devices making use of a shake table setup that recently has been in-house built at the Laboratory of Structural Engineering of the University of Salerno. The given results lead us to conclude that SSI systems are classified as bio-inspired, tunable and cost-effective metaisolators. Their development permits to perform the protection of artworks, houses and essential equipment, in industrialized and developing countries, through a highly tunable and customizable approach.

Keywords: Seismic isolation, Shake table, Design strategy, Experimental validation

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1. INTRODUCTION

The characterization of the earthquake-resistance of structural models can be measured by shake table tests [1, 2], which can be used for different purposes such as, e.g., the analysis of soil-structure interaction problems [3, 4]; the identification of the dynamic properties of the structures under testing (say, for example, the natural vibration periods and damping coefficients) [5, 6]; as well as the experimental validation of novel prototypes of seismic isolators [7, 8] [9] and energy dissipation devices [10, 11].

Recently, a research group at the University of Salerno has started a challenging research project on the design, fabrication, and experimental validation of a novel sliding-stretching seismic isolator (SSI) combining a bio-inspired design of the unit's architecture cell with stretching-sliding energy dissipation mechanisms [7, 8].

It has been discovered that animals, during locomotion, aim to reach a state of resonance between the forces produced by contracting muscles and their natural vibration frequencies. An inverse function is played by the seismic "metaisolators" proposed in [7]: the resonance with earthquake frequencies is avoided using stretchable tendons that suitably tune the nonlinear stiffness of the system [7, 8].

The SSIs can be assembled using environmentally sustainable components, without heavy industry, which is partially or fully achievable with ordinary 3D printers and biobased and/or recycled materials.

This study illustrates the employment of an in-house built shake table setup, which is available at the Laboratory of Structural Engineering of the University of Salerno, to characterize the force vs. lateral displacement response of a SSI prototype. A good agreement between the results presented in this study and those given in [7] is observed. The main features of the employed shake-table setup are also analyzed: the possibility of applying large lateral displacements histories of various shapes; the application of considerably high vertical loads; and the achievement of high peak velocities of the horizontal motion.

2. Employed shake table setup

One of the goals of this work is to employ an in-house built shake table setup to apply a vertical force and a horizontal motion that simulates the action of an earthquake on a seismic isolation device. The employed shake-table setup is available at the Laboratory od Structural Engineering of the University of Salerno and makes use of the target properties shown in Table 1 (see Figure 1 for an illustration of such a setup). It is based on a main frame build up by Line BH Aluminum Profiles (https://aluminium-profiles.alusic.com/en/), which carries a vertical structure consisting of top and base plates, a servo-driven AC motor, a horizontal actuator and four vertical guideways and vertical actuators connected to the corners of the top table for vertical load application. The square base plate is made of the Anticorodal Al 6082 T6 (EN AW-6082) aluminum alloy with 20 *mm* thickness and 700 mm edge. It slides against linear guideways with a maximum stroke of 200 *mm* on both sides (allowing for extra safety margins of 100 mm), giving a total length of the guideways of 1200 mm. The maximum dimension of the base frame is 2570 *mm*, including the length of the horizontal actuator. The top plate slides on four linear guides with 25 mm circular section by means of ball bearings. The setup is closed on top by a vertical frame covered by a top plate (both made of A235 steel). The vertical frame is horizontally braced with four steel tie-rods (diameter 8 mm). The thickness of the square top plate is 20 mm and the edge length is 700 mm. It is reinforced with 100 mm x 10 mm perimeter and diagonal ribs. A uniform distribution of the forces applied by the vertical actuators on the top surface of the sample being tested is ensured by the presence of such a stiff plate.

Parameters	Values
Weight (kN)	2.94
Total Length L× Width W× Height H (mm)	2570 × 1200 × 1000
Base plate dimensions (mm)	700 x 700
Top plate dimensions (mm)	700 x 700
Vertical distance base-top plate (mm)	20 – 550
Maximum horizontal force (kN)	3
Maximum vertical load (kN)	30
Maximum displacement of the base plate (mm)	± 200
Maximum frequency (Hz)	20
Maximum velocity (m/s)	1
Maximum acceleration (m/s2)	3
External transverse beams dimensions (mm)	1800 × 900
Central transverse beam dimensions (mm)	900 × 900
Linear guideways length (mm)	1200

Table 1- Target properties of the shake table setup examined in this work

Figure 1 - Photograph of the assembled shake table

Due to the eccentric position of the horizontal actuator, the setup is asymmetric. As a matter of fact the horizontal actuator laterally protrudes from the base table and is equipped with an in-line motor (Figure 1). The push and pull forces exerted by this actuator are transferred to the base plate through an angular plate fixed in a barycentric position. The base structure is fixed to the ground thanks to six M12 threaded rods. The total height of 1000 mm is measured starting from the ground to the top of the vertical frame.

3. Cyclic loading tests on a bio-inspired isolator prototype

The shake table described in the previous section was employed to run a characterization test on a sample of the biomimetic SSI presented in [7]. Previous tests on the same device were run in the laboratories of the renowned anti-seismic device company FIP MEC srl, located in Padua, Italy (https://www.fipmec.it/en/) [7]. We show hereafter the results of a cyclic, horizontal force versus horizontal displacement test run on an SSI prototype (see Figure 2). The examined test applies a vertical load $P = 25$ kN to the top plate of the SSI and three cycles of a sinusoidal displacement history to the bottom plate with maximum amplitude $u = \pm 50$ mm and frequency $f = 0.4$ Hz. The load cells attached to the shake table recorded the horizontal and vertical forces acting on the SSI, while a laser sensor measured the horizontal displacement u of the base plate. The horizontal force versus horizontal displacement curves obtained in this work is shown in Figure 3 (solid-line curves). It is possible to observe that the results shown in Figure 3 are in good agreement with those presented in [7] for the same loading condition (dashed-line curves). Such a good agreement provides a validation of the accuracy of the setup analyzed in this work. One can explain some light oscillations of the experimental results shown in Figure 3 by accuracy measurement errors.

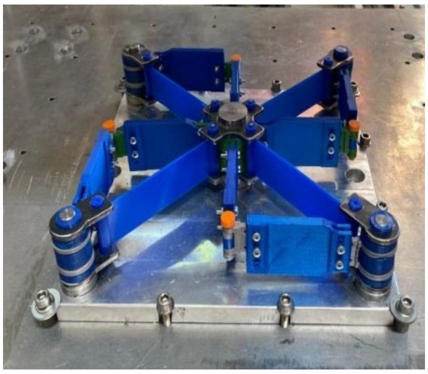

Figure 2 - Different views of a sliding-stretching isolator placed in the shake table.

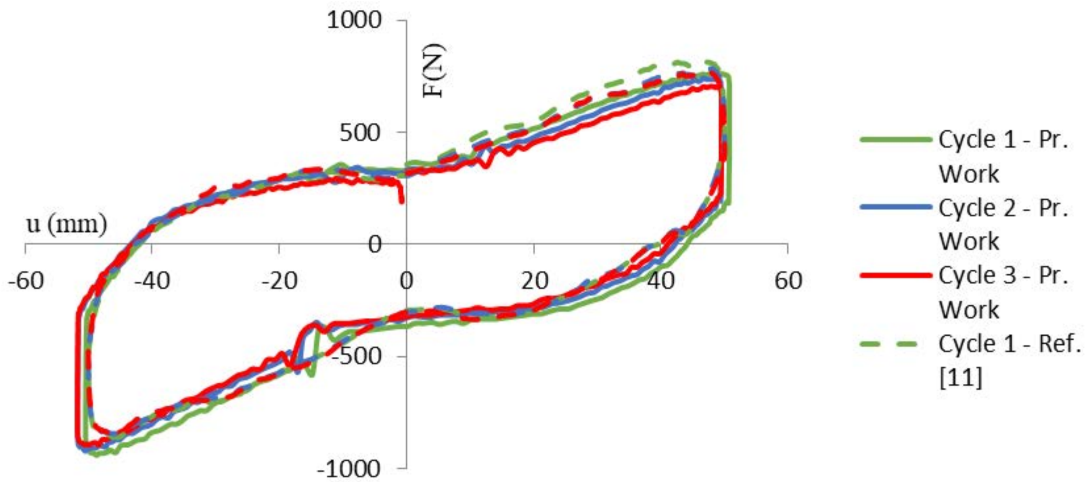

Figure 3 - Horizontal force vs. horizontal displacement curves for the SSI test.

4. Concluding remark

We have presented an experimental validation of an in-house–built shake-table system that allows the characterization of prototypes medium- and small-scale earthquake protection devices (such as, e.g., seismic isolators and energy dissipation devices) under large remarkably horizontal displacement histories (up to ±200 mm), significantly large vertical loads (up to 30 kN, and load frequencies that are consistent with the seismically isolated building's typical frequency range (0.5 – 2.0 Hz) [12]. Such a shake table has been employed to run lateral force–lateral displacement tests on a prototype of a recently proposed seismic isolation device with a bio-inspired character. The results of such tests have highlighted the accuracy of the examined shake table tests and have confirmed the sliding-stretching nature of the force-displacement response of the examined SSI, as per comparison with the analogous results presented in [7].

The current shake table setup is particularly convenient for testing medium- and small-scale isolation systems, which need to be subjected to appreciably large vertical loads. Some additional shake table tests are currently in progress in order to characterize the internal friction effects under different values of vertical load and sliding velocities.

Future research is going to explore the engineering potential of metaisolators that generalize the SSI analyzed in [7-9], being obtained by tessellating unit cells with different bio-inspired architectures, both in the horizontal plane and in the vertical direction (multi-layer systems).

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