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DESIGN AND MODELING OF AN IN-HOUSE-BUILT SHAKE TABLE SETUP FOR TESTING PROTOTYPES OF INNOVATIVE SEISMIC ISOLATORS

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SUMMARY: *This work formulates procedures and methods for the design, assembling, mechanical modeling, and experimental validation of a shake-table setup that has been in-house–built at the Laboratory of Structural Engineering of the University of Salerno. The analyzed shake table permits the experimental characterization of small- and medium-scale prototypes of seismic protection devices as well as the execution of experimental studies on mock-ups of earthquake-proof structures. The main features of this setup are 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. Based on such targets, the design strategy presented in this work follows a different path compared with other desktop shake tables available on the market. The latter is most often scaled and built on requirements typical of conventional shake table modes (high accelerations, very low vertical loads, control in acceleration/velocity/displacements, etc.). The paper diffusely presents the approach followed by the development team at the University of Salerno - which may be of interest to research laboratories worldwide wishing to build similar setups - and explores the engineering potential of novel seismic protection devices. An experimental characterization test of a bioinspired seismic isolator that recently appeared in the literature is presented.*

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

1. Introduction

Shake table setups are fundamental components of earthquake engineering laboratories. They are typically used for studying the response of reduced- or full-scale models of earthquake-proof structures to seismic events that are simulated by imposing single or multiple degrees of freedom (DOF) displacement histories to plates that "shake" the structure being tested (see, e.g., [Bandini *et al.*, 2019, Benzoni and Seible, 1998, Benzoni and Seible, 2001] and references therein). The Seismic Response Modification Device (SRMD) at the University of California, San Diego, is one of the most renowned examples of a laboratory equipped with a large-scale, 6-dof shake table [Benzoni and Seible, 1998] (https://se.ucsd.edu/facilities/laboratory-listing/srmd). Another laboratory equipped with similar equipment is the Center of Excellence Research and Innovation for large dimensions Structures and Infrastructures (CERIS) at the University of Messina, Italy (http://cerisi.unime.it/en.html). Such a 6-dof device is accompanied by a shear

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stack, a container that replicates the deformation of soil deposits when they are crossed by seismic waves [Bandini *et al*., 2019]. Shake table tests can be used for purposes such as, e.g., characterization of the earthquake-resistance of structural models [We *et al*., 2009, Huang *et al*., 2008]; identification of the dynamic properties of the structures under testing (say, for example, the natural vibration periods and damping coefficients) [Blondet and Esparza 1988, Lu *et al*., 2022]; analysis of soil-structure interaction problems [Hu t al., 2022, Goktepe *et al*., 2019]; experimental validation of novel prototypes of seismic isolators [Fraternali *et al*., 2021a, 2021b, De Castro Motta *et al*., 2022] and energy dissipation devices [Cerda *et al*., 2006, Ristic *et al*., 2021]; and to introduce students to the basic concepts of earthquake engineering and seismic isolation (see, e.g, [Buonopane *et al*., 2014]. The execution of shaking tests on mock-ups of earthquake-proof buildings is the goal of desktop shake tables currently available on the market. Recently, a research group at the University of Salerno initiated a challenging research project on the design, fabrication, and experimental validation of novel sliding-stretching seismic isolators (SSI), combining a bio-inspired design of the architecture of the unit cell with stretching-sliding energy dissipation mechanisms [Fraternali *et al*., 2021a, 2021b]. During locomotion, it has been discovered that animals aim to reach a state of resonance between the forces produced by contracting muscles and their natural vibration frequencies. The seismic "metaisolators" proposed by [Fraternal *et al*., 2021a] have inversed this function: to avoid resonance with earthquake frequencies, they use stretchable tendons to tune the nonlinear stiffness of the system. The SSIs can be assembled from 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 design procedure, assembling methods, and operative properties of a shake-table setup that has been built at the Laboratory of Structural Engineering of the University of Salerno for the testing and experimental characterization of novel seismic protection devices. While commercial desktop shake tables are typically built to achieve high accelerations under small or almost zero vertical loads, the setup illustrated in this paper has been conceived to apply large lateral displacement histories under considerably high vertical loads and to reach high peak velocities of the horizontal motion. Such a design strategy permits testing medium-scale devices, such as, e.g., vibration isolators aimed at protecting artworks or equipment in hospitals and essential buildings [Venanzi *et al*., 2020, Najafijozani *et al*., 2020], as opposed to commercially available educational isolators that are intended to test lightweight structural mock-ups.
The structure of the paper is as follows. Section 2 illustrates the strategy for designing and assembling the shake table setup. A finite element modeling of such a device is presented in section 3, with the aim of simulating the behavior of the shake table under extreme working conditions. Section 4 presents experimental validation tests, including a characterization test on an SSI prototype. Section 5 presents concluding remarks and directions for future research.

2. Design procedure

2.1. Target properties and main frame

The shake-table setup analyzed in this work has been designed to apply a vertical force on the sample and a horizontal motion that simulates the action of an earthquake. The applied vertical load reproduces, e.g., the load transmitted by a superstructure to a seismic isolation device. With the aim of applying large lateral displacement histories, considerably high vertical loads, and high peak velocities on medium-scale samples, we fixed the target properties of the setup to be built as shown in Table 1. Accordingly, a CAD model of the setup was prepared as illustrated in Figure 1. The following sections analytically describe the single parts forming this setup. As seen in Figure 1, the shake table setup analyzed in this work is based on a main frame formed by the Line BH Aluminum Profiles produced by ALUSIC (https://aluminium-profiles.alusic.com/en/, ids of the employed profiles: 084.105.013 and 084.105.009). Such a frame 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 a 25 mm circular section by means of ball bearings. On top of the setup is a closing frame that is horizontally braced with four steel tie-rods (diameter 8 mm) with turnbuckles (Figure 1(c)). Both the top plate and the closing frame are made of A235 steel profiles. The square top plate has a thickness of 20 mm and an edge length of 700 mm. It is reinforced with 100 mm $\times$ 10 mm perimeter and diagonal ribs. This plate ensures a uniform distribution of the forces applied by the vertical actuators on the top surface of the sample being tested.

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

Weight (kN)	2.94
Total Length L × Width W × Height H (mm)[1]	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)	$\pm$200
Maximum frequency (Hz)	20
Maximum velocity (m/s)	1
Maximum acceleration (m/s^2)	3
External transverse beams dimensions (mm)	1800 × 900
Central transverse beam dimensions (mm)	900 × 900
Linear guideways length[2] (mm)	1200

[1]The total dimensions account for the maximum horizontal stroke of the base table, the dimensions of the vertical guideways, horizontal and vertical actuators, and the maximum height of the region comprised between the load plate and the base plate.

[2]The linear guideway length covers a total of 1.2 m, including the plate length (700 mm), the stroke of $\pm$200 mm of the base table, and an extra length of 100 mm as a safety margin.

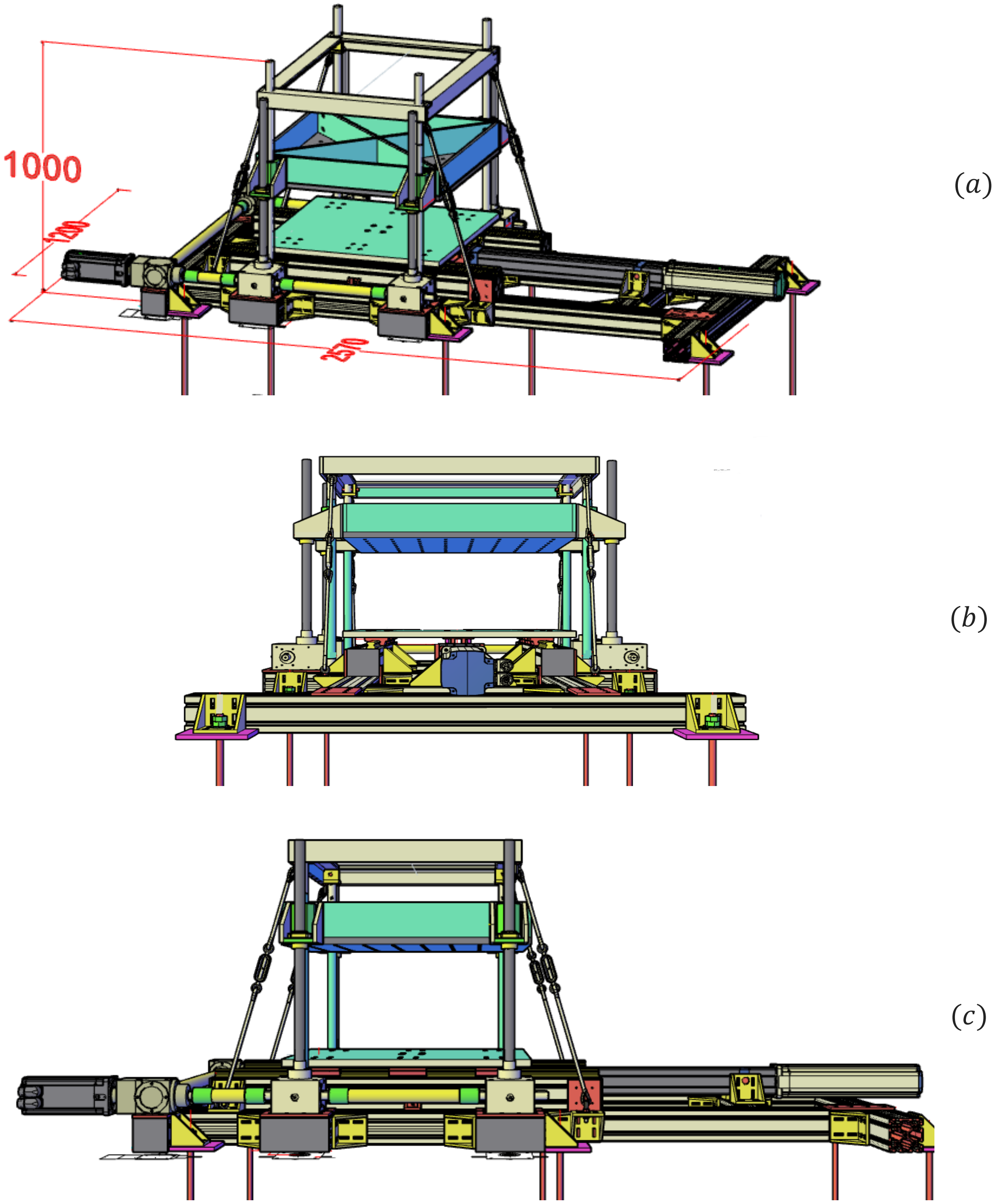


Figure 1- *(color online) Different views of a CAD model of the shake table to be built: a) Overall isometric view, b) Front view, c) Side view*

The setup is asymmetric due to the position of the horizontal actuator, which laterally protrudes from the base table and is equipped with an in-line motor. The push and pull forces of 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 through six M12 threaded rods. The total height of 1000 mm is measured from the ground to the top of the closing frame.

2.2. Guideways and ball bearings

The linear guides attached to the base of the shake table (Figure 1) allow the base plate to slide horizontally while supporting the maximum target value of the vertical load (30 kN, see Table 1). Linear guides of the *HIWIN-HG* series (https://www.hiwin.us/products/linear-guideways/) were used that exhibit circular arc grooves, provide high load capacity, long service life at high sliding speeds, good accuracy, and smooth linear motion. Six $70 \times 78.6 \times 36$ mm *SETEC HGW 25HC* bearings were mounted on the linear guides, equipped with four M8 bolts (http://setec-group.com/home). Each bearing can support a dynamic load of 32.75 *kN*, much higher than the weight of the machine, to ensure low ball wear. The vertical guides drive the vertical motion of the upper plate. Such elements also need to resist the horizontal thrust generated by the horizontal motion of the base plate. Bosch Rexroth AG vertical guides with a diameter of 25 mm and quality steel were used. The top plate slides on these guides through 4 *eLINE*, *R1029* Tandem Linear Set vertical bearings.

2.3. Actuators

A *SETEC Isomove*-E horizontal actuator was selected to achieve rapid horizontal movements with large amplitude through loading histories of different shapes (e.g., triangular, rectangular, and sinusoidal displacement versus time loading histories). Table 2 illustrates the main properties of the employed model (*IE 63*). For the vertical actuators, four SETEC SEL 25 actuators equipped with vertical reversible screw jacks were employed (Table 3).
). A Schneider Electric BMH1002P17F2A (https://www.se.com/ww/en/) motor with a nominal torque of 6.2 N.m controls four jacks ensuring maximum synchronization of the movements and allowing excursions of the upper plate with 4 mm/s maximum velocity. Figure 2 illustrates the diagram of the vertical jacks (see Table 3 for the nomenclature).

Table 2- *SETEC IE 63 horizontal actuator specifications*

Symbol	Definition	Amount
P (mm)	Screw lead	20
F_d(N)	Maximum admissible dynamic load	7500
$V_{out,max}$($^{mm}/_{s}$)	Maximum output speed	1000
$C_{in,max}$(N.m)	Maximum moment	26.5
$N_{in,max}$(rpm)	Maximum ballscrew rotating input speed	3000
S_{max}(mm)	Maximum standard stroke	800
a_{max}($^{m}/_{s^2}$)	Maximum output acceleration	3

Table 3- *Technical specifications of vertical actuators*

Parameters	Amount
Maximum nominal load (kN)	25
External screw diameter (mm)	30
Screw lead (mm)	6
Nominal ratio	5 : 10
Real Ratio	5 : 10.33
Brushless engine model	BMH1002P07F2A
Protection rate	$IP54$

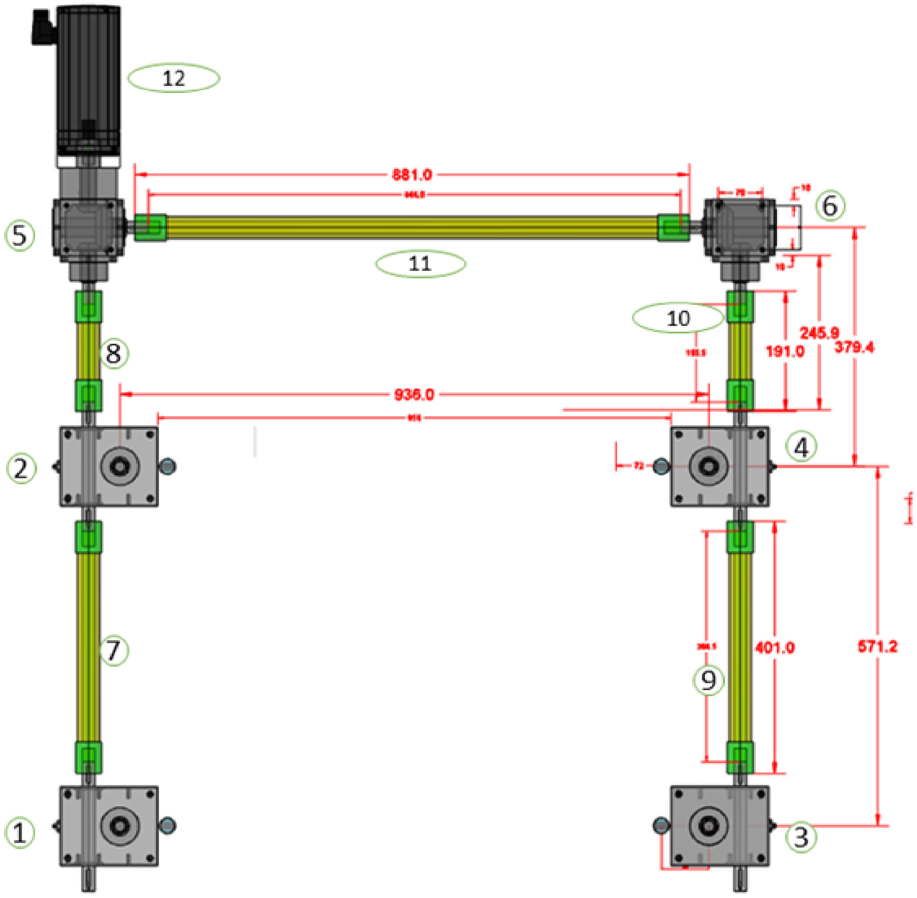


Figure 2- *(color online) Diagram of the vertical jacks (dimensions in mm)*

Table 4- *Nomenclature of the elements shown in Figure 2*

Number of elements	Description
1-2-3-4	Reversible screw jack
5	Angular transmission with three shafts
6	Angular transmission with two shafts
7-9	Link of two angular transmissions
8,10	Link of two angular transmissions
11	Link of two angular transmissions
12	BMH1002P 07 F2A brushless motor with IP54 protection

2.4. Servo-drive

Two servo drives were used to drive the motors of the actuators, which are assisted by a Modicon Motion TM262M15MESS8 Controller M262 from Schneider Electric. The Lexium 32 LXM32S D72 N4 servo drive was used to control the horizontal motion, while the Lexium 32 LXM32S 18 N4 servo drive was used to control the vertical motion (see Table 5 for technical specifications). The tuning of position, speed, acceleration, and control curve parameters for the horizontal and vertical motions is performed via the Schneider Electric EcoStruxure Machine Expert (SoMachine) software.

Table 5- *Servo-drive (SCHNEIDER ELECTRIC model Lexium 32) properties*

Name	Vertical motion	Horizontal motion
Model	LXM32S SERC 18A RMS	LXM32S SERC 72A RSM
Dimensions ($W \times H \times D$) (mm)	$68x270x237$	108x270x237
Rated voltage	380-480 V	380-480 V
Network frequency (Hz)	50-60	50-60
Nominal power	1.8 kW at 400 V	7 kW a 400 V
Output current 3s peak	18 A for 5 s	72 A for 5 s

2.5. Assembled setup

Figure 3 provides an overall view of the in-house–built shake table setup and the constituent parts.

Figure 3- *(color online) Photograph of the assembled shake table*

3. Finite Element Modeling

The commercial finite element (FE) software *SAP2000* by Computers and Structures, Inc. (https://www.csiamerica.com/products/sap2000) was employed to model the shake table setup, with the aim of simulating its mechanical response under target working conditions (maximum target values of vertical and horizontal forces, cf. Table 1). The employed finite element model (FEM) is composed 63 “frame” (bar/beam) elements and 140 shell elements, as shown in

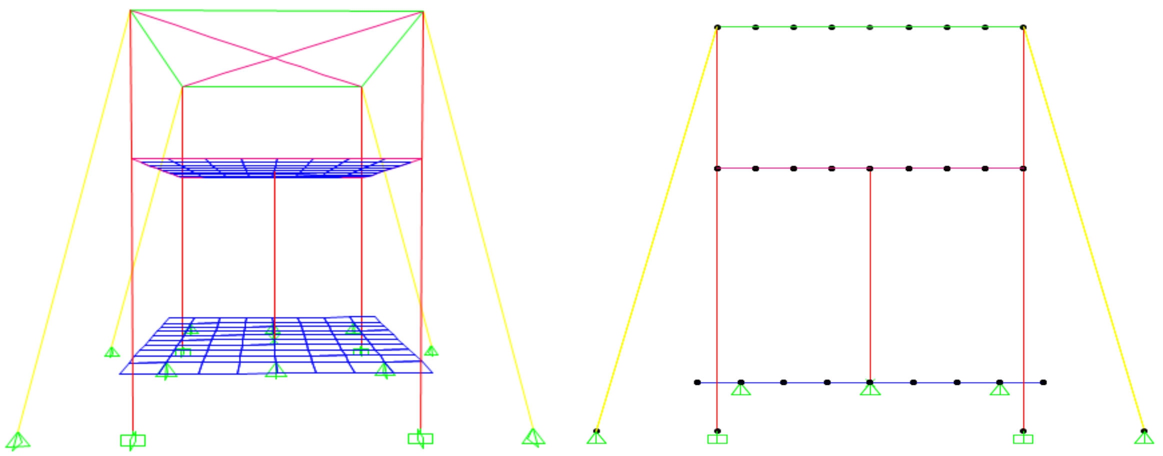
Figure 4. In this figure, the nodes with constrained/imposed displacements are marked with green triangles, while nodes with constrained displacements and rotations are marked with green boxes. Table 6 and table 7 list the element and material properties of the employed FEM, respectively. A first load condition accounts for the application of a vertical load of 30 kN, while a second condition applies a horizontal force of 3 kN on the sample under testing. The sample is a prismatic steel member with dimensions 210 × 210 × 400 mm (see Section 4).

Table 6- Element properties of the employed finite element model

Component	Section type	FEM element	Dimensions	Material
Cables	circular rods	Frame	$\Phi = 8$ mm	*A235*
Vertical guideways	circular	Frame	$\Phi = 25$ mm	*Cf53*
Top plate	plate	Shell	$h = 20$ mm	*A235*
Base plate	plate	Shell	$h = 20$ mm	*Al 6082-T6*
Top external frame	L-profiles	Frame	60×6 mm	*A235*
Top plate stiffeners	rectangular	Frame	100×10 mm	*A235*
Top plate borders	rectangular	Frame	100×10 mm	*A235*

Table 7- *Material properties*

Material	Young modulus E [MPa]	Yielding stress f_y [MPa]	Failure stress f_u[MPa]
A235 steel	210000	235	360
Cf53 steel	210000	340	610
Al 6082 T6	69000	260	310



(a) (b)

Figure 4- *(color online) Finite element model of the shake table: a) 3D view, b) Side view*

The main goal of the FE simulation was to determine if the maximum stresses recorded in frame and shell elements were below the corresponding yielding thresholds. It also aimed to estimate the maximum deflection of the vertical frame structure under the examined load conditions. Table 9 shows the maximum principal stresses observed in the frame elements (by combining the results of the two loading conditions), all of which are below the yielding stresses given in Table 7. The vertical guideways are the most stressed elements, with a maximum stress $\sigma = 201\ MPa$, which is much lower than the yield limit of $340\ MPa$ reported in Table7.

Table 8- *Maximum principal stresses observed in the frame elements of the FE model*

Components	$\sigma\ [MPa]$
Cables	107.69
Vertical guideways	201.11
Top external frame (X-direction)	9.71
Top external frame (Y-direction)	27.77
Top plate stiffeners	114.46
Top plate borders (X-direction)	35.71
Top plate borders (Y-direction)	25.00

Figure 5 shows the Von-Mises stress distribution for shell elements of the base plate. The results show a maximum stress of $210.36\ MPa$, which is lower than the yield stress of $260\ MPa$ reported in Table 7 for *Al 6082 T6*. The maximum deflection of the base under the imposed vertical force of $30\ kN$ was estimated as equal to $2.89\ mm$. The maximum deflections of the top plate and top frame under the horizontal loading condition were instead estimated to equal 2.58 mm and 2.26 mm, respectively. Figure 6 gives the deformed shape of the FEM under such a loading condition. It is worth noting that the maximum deflection of the base plate can be reduced by interposing suitable load distribution elements between the sample and the plate.

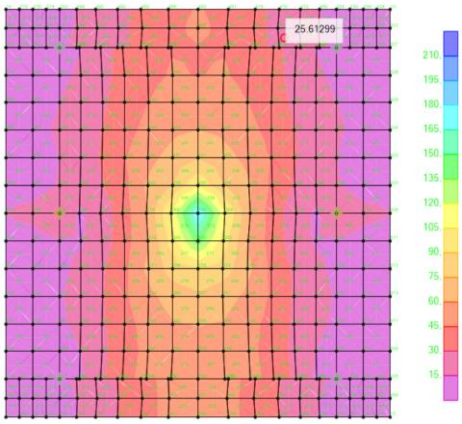


Figure 5- *(color online) Von-Mises stress distribution in the base plate elements*

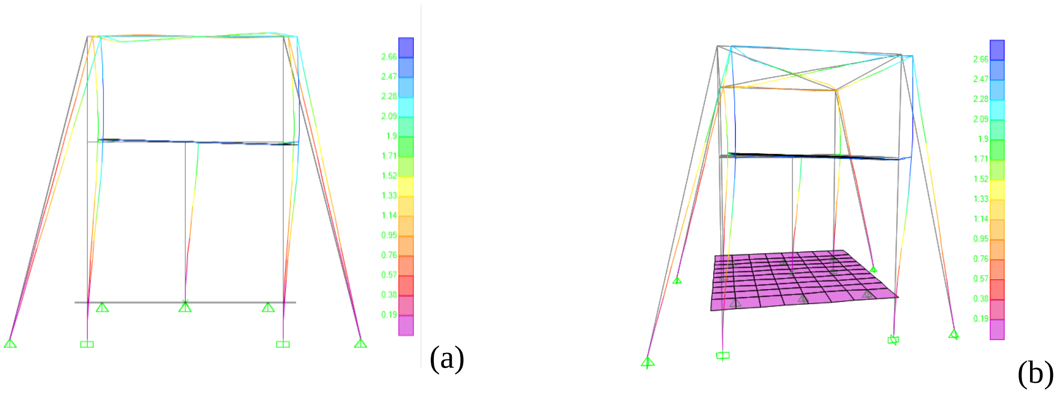


Figure 6- *(color online) Deformed shape of the FEM for the horizontal loading condition: a) 2D view, b) 3D view (displacement amplification factor = 30%)*

4. Experimental validation tests

Experimental validation tests were run by analyzing, separately, a vertical loading condition that applies a vertical force of 30 kN to the sample being tested and a horizontal loading condition leading to the application of a horizontal force of 3 kN. The analyzed sample corresponds to that modeled in the FE simulation presented in Section 3. The above loading conditions were tested separately, since an elastic response of the main components of the shake table structure was expected based on the result of the FE simulation presented in Section 3 (with the exception of friction effects, ignored by the FEM, that are inevitably present in the linear guideways under real-life experiments). A validation test of the maximum horizontal displacement of the base table and a characterization test of an SSI prototype were also run.

4.1. Test equipment

The test equipment listed in Table 9 was employed to run the experimental validation tests. Such equipment includes load cells employed for force measurements (from AEP transducers, https://www.aep.it/) and six laser sensors used to measure different members' displacements (from MICRO-EPSILON, https://www.micro-epsilon.com/). The laser sensors accuracy is measured equal to 0.01 mm. A StrainSmart® 8000 system from Micro-Measurements was used for data acquisition (https://micro-measurements.com/video/system-8000-product-info). Figure 7 illustrates the placement of laser sensors for displacement measurements.

Table 9- Equipment used for experimental validation tests

Number	Equipment	Type	Maximum range
1	Vertical force (compression) load cell	AEP transducers	30 kN
2	Horizontal force (tension/ compression) load cell	AEP transducers	5 kN
3	Laser sensor	MICRO-EPSILON - Model: *ILD1302-200*	0-200 mm

4.2. Validation tests

4.2.1. TEST #1: Application of the maximum vertical force

A 30 kN vertical force was progressively applied to the sample through a ramp force versus time law by measuring the vertical displacement at the center of the base plate through the laser sensors 1 shown in Figure 7. The final goal of this test was to assess the capacity of the setup to safely apply such a target vertical load. The graph in Figure 8 plots the variation of the plate's vertical displacement with the vertical load.

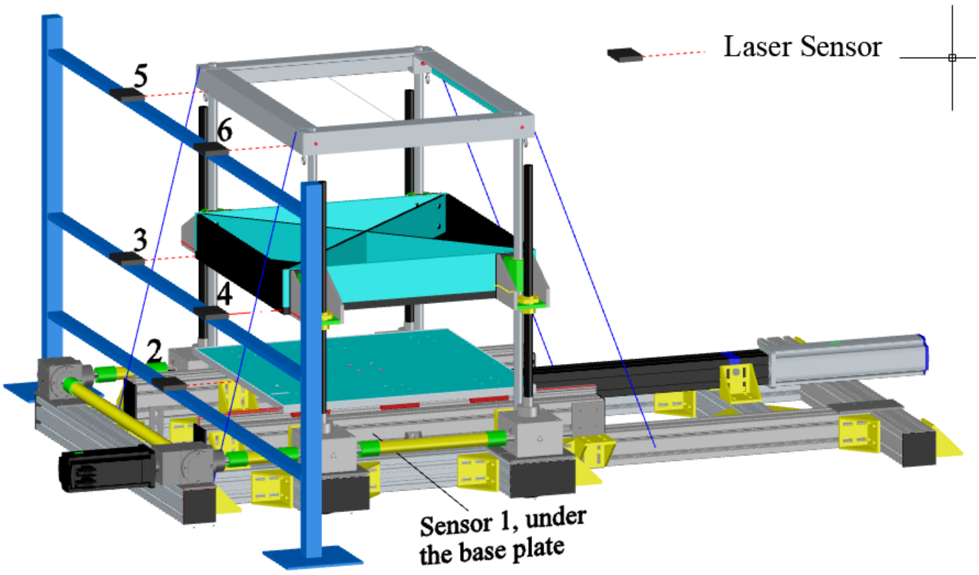


Figure 7- *(color online) Schematic illustration of laser sensor placements*

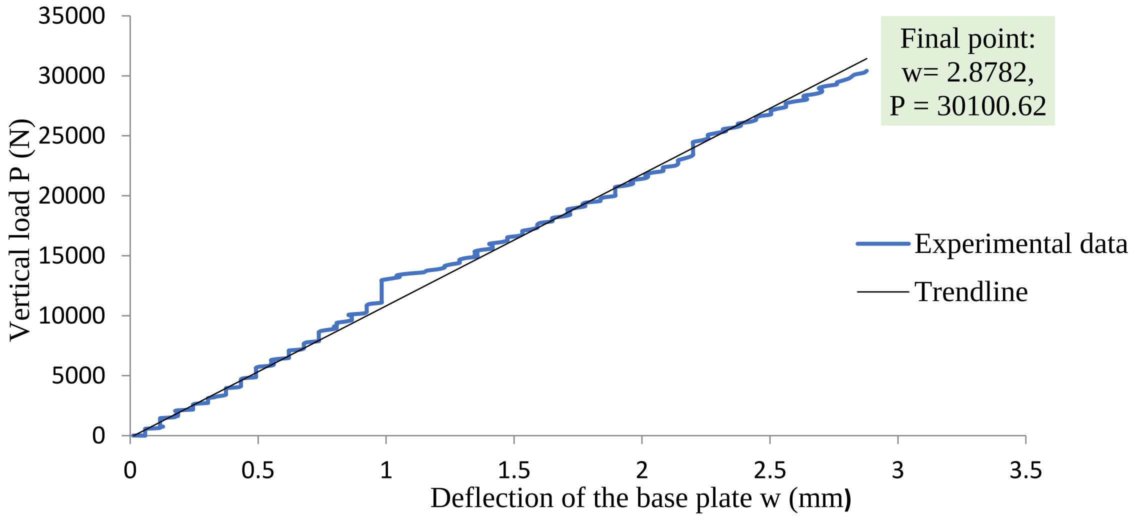


Figure 8- *(color online) Vertical force vs. vertical deflection plot for Test #1*

A maximum vertical displacement of 2.87 mm was observed under the target vertical load. Such a displacement is very close to that predicted by the FE model (2.89 mm). The oscillations of the experimental results visible in Figure 8 are explained by accuracy measurement errors.

4.2.2. TEST #2: Application of the maximum horizontal force.

A 3 KN horizontal force was applied to the sample through the base plate and subsequently removed (through a triangular force-time law) by measuring the horizontal displacements of two points of the upper frame through the laser sensors 3 and 4 in Figure 7 and the horizontal displacements of two points of the top plate through sensors 5 and 6. On averaging the values recorded by sensors 3 and 4 and sensors 5 and 6, we obtained the blue and the orange curves shown in Figure 9, respectively. The force-displacement plots shown in Figure 9 reveal a light hysteretic response of the system under the examined loading condition, which is mainly due to friction effects associated with the sliding of the base plate along the horizontal guideways.

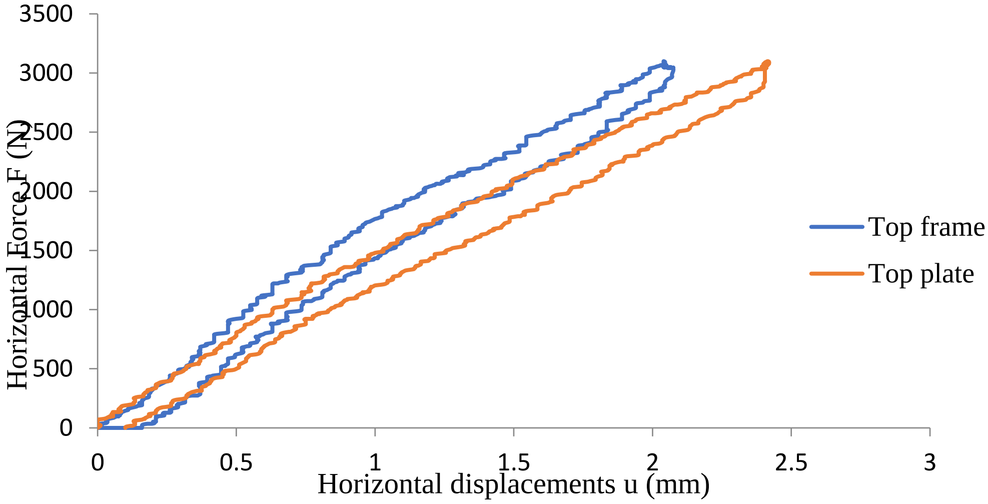


Figure 9- *(color online) Horizontal force vs. horizontal displacement plots for Test #2*

The displacements recorded for the central points of the top plate and the top frame are, respectively, equal to 2.40 mm and 2.04 mm. One observes a good agreement between such experimentally observed displacements and the FEM predictions presented in the previous section (FEM displacements equal to 2.58 mm and 2.26 mm for the top plate and the top frame, respectively). The fact that experimentally observed horizontal displacements are slightly lower than the FEM predictions arises from the presence of friction effects in the experimental test, which are not accounted for in the FE simulation, as we have already observed.

4.2.2. TEST #3: Application of the maximum lateral displacement.

A test was carried out to assess the capacity of the horizontal actuator to apply horizontal displacements of ± 200 mm to the base plate. The horizontal movement of the base plate was commanded by the setup control software, and the horizontal displacement of the plate was measured through the laser sensor 2 in Figure 7. Figure 10 shows an accuracy control plot for the current test, which highlights an accuracy error as low as 0.45%.

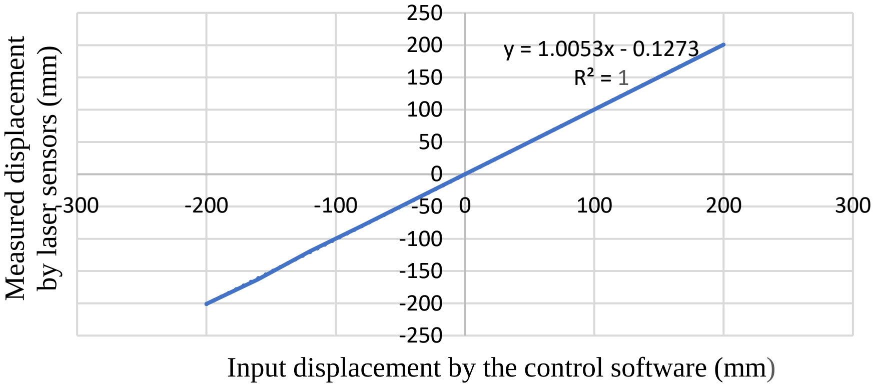


Figure 10- *(color online) Accuracy control plot for Test #3*

4.2.2. TEST #4: Cyclic loading tests on an SSI prototype.

The characterization tests of the biomimetic SSI prototypes presented in [Fraternali *et al.*, 2021a] were run in the laboratories of the renowned anti-seismic device company FIP MEC srl, located in Padua, Italy (https://www.fipmec.it/en/). We hereafter illustrate the results of a cyclic, horizontal force versus horizontal displacement test run on an SSI prototype (see Figure 11), executed this time using the shake table setup analyzed in this work. The examined characterization 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 horizontal and vertical forces acting on the SSI were recorded through the load cells listed in Table 9, while the horizontal displacement u of the base plate was measured through sensor 2 in Figure 7. Figure 12 shows the horizontal force versus horizontal displacement curves obtained in this work for Test #4 (solid-line curves). One observes that the results presented in Figure 12 are in rather good agreement with those presented in [Fraternali *et al.*, 2021a] for the same loading condition (dashed-line curves), which validates the correct functioning of the current setup against literature results. Some light oscillations of the experimental results obtained in this work are explained by accuracy measurement errors, as in the case of Test #1.

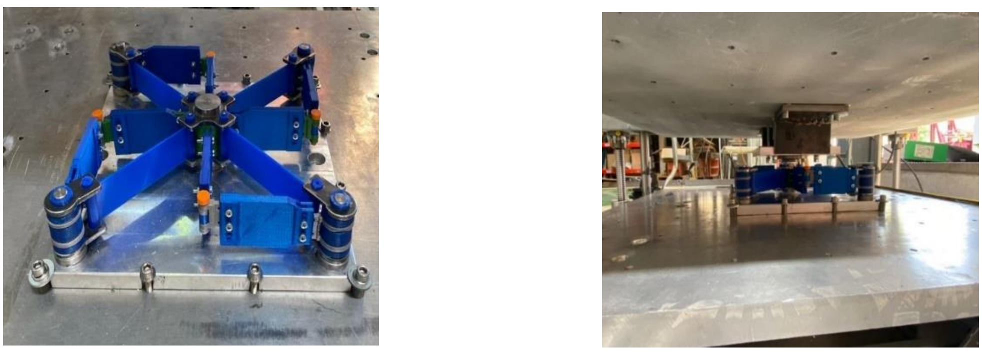


Figure 11- *Different views of a sliding-stretching isolator placed in the shake table.*

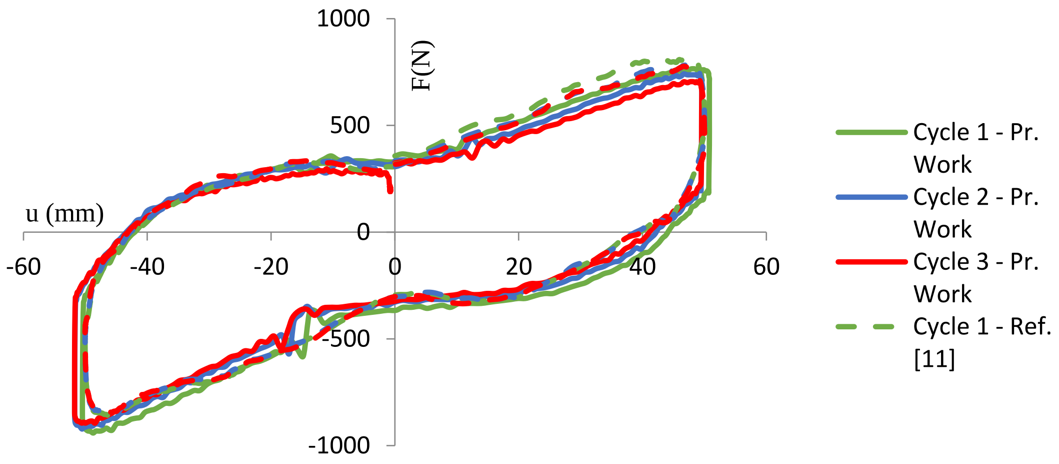


Figure 12- *Horizontal force vs. horizontal displacement curves for Test #4*

5. Concluding remarks

We have presented the design, finite element modeling, and experimental characterization of an in-house–built shake-table system that permits the testing of prototypes of medium- and small-scale earthquake protection devices (e.g., seismic isolators and energy dissipation devices) under large considerably horizontal displacement histories (up to ± 200 mm), appreciably large vertical loads (up to 30 kN), and load frequencies that are consistent with the typical frequency range of seismically isolated buildings ($0.5 - 20$ Hz) [Rathje *et al.*, 1998]. The results of FE simulations of the mechanical response of the setup under target operation conditions well match the outcomes of experimental validation tests. The examined shake table has also 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 are in good agreement with those presented in [Fraternali *et al.*, 2021a].

The shake table setup analyzed in this work is particularly convenient for testing medium- and small-scale isolation systems, which need to be subjected to appreciably large vertical loads. Additional shake down tests are currently in progress in order to characterize the internal friction effects under different values of vertical load and sliding velocities. Future research will explore the engineering potential of metaisolators that generalize the SSI analyzed in [Fraternali *et al.*, 2021a, 2021b, De Castro Motta *et al.*, 2022] by tessellating unit cells with various bio-inspired architectures, both in the horizontal plane and in the vertical direction (multi-layer systems).

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PROGETTAZIONE E MODELLAZIONE DE UNA TAVOLA VIBRANTE COSTRUITA IN LABORATORIO PER TESTARE PROTOTIPI DI ISOLATORI SISMICI INNOVATIVI

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SOMMARIO: *Questo lavoro illustra procedure e metodi per la progettazione, l'assemblaggio, la modellazione meccanica e la validazione sperimentale di una tavola vibrante costruita presso il Laboratorio di Ingegneria Strutturale dell'Università di Salerno. La tavola vibrante analizzata consente la caratterizzazione sperimentale di prototipi di di dispositivi di protezione sismica di piccola e media scala, nonché l'esecuzione di studi sperimentali su modelli di strutture antisismiche. Le caratteristiche principali della tavola vibrante analizzata sono la possibilità di applicare storie di spostamenti laterali di ampia intensità e varie forme; l'applicazione di carichi verticali considerevolmente elevati ed il raggiungimento di elevate velocità di picco del moto orizzontale. Sulla base di tali obiettivi, la strategia di progettazione presentata in questo lavoro segue un percorso diverso rispetto a quelle alla base delle tavole vibranti da tavolo attualmente disponibili sul mercato. Queste ultime, infatti, sono tipicamente dimensionate e costruite per applicare accelerazioni elevate su prototipi soggetti a carichi verticali molto bassi, con diverse modalità di controllo della forzante. L'articolo presenta diffusamente l'approccio seguito dal team di sviluppo presso l'Università di Salerno - che potrebbe essere di interesse per altri laboratori di ricerca interessati a costruire configurazioni simili - ed esplora il potenziale ingegneristico di nuovi dispositivi di protezione sismica, attraverso test di caratterizzazione sperimentale di un isolatore sismico "bioispirato" recentemente apparso in letteratura..*

PAROLE CHIAVE: Isolamento sismico, Tavola vibrante, Metodologie di progettazione, Validazione sperimentale.

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