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Development of Dynamic Laboratory Platform for Earthquake Engineering Courses

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ABSTRACT

Small-scale shaking table platforms are usually employed in seismic engineering courses to study the structural dynamic behavior of small scale specimens and investigate innovative solutions, such as active and passive control systems. Furthermore, they are also useful for learning programs in the higher education for actively involving students. This paper has the main goal of illustrating the development and the teaching effectiveness of a multi modular unidirectional platform to be used by students during dynamic and seismic courses within the *Shaking Table Educational Program* at the Politecnico di Torino. Another unique feature of this platform with respect to literature is that the system has been entirely developed by undergraduate students. The project wants to realize a shaking table for earthquake simulation that can measure the structural response using sensors located on a specimen, such as a building, a bridge or any other type of reduced scale system. Different types of dynamic tests can be reproduced such as hybrid simulations and pseudodynamic tests. A survey demonstrates the effectiveness of the laboratory experience during seismic engineering courses to improve the students learning capabilities through a teaching activity that involves both theoretical and hands-on-experiences. Currently the platform has been extended to accommodate also bidirectional shaking table tests with the inclusion of augmented

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reality tools that allow to explore the response of the human behavior during a pedestrian evacuation.

KEYWORDS: Earthquake Engineering; Shaking table; Engineering Education; Hands-on-experience; Hybrid Simulation; Laboratory Demonstration.

INTRODUCTION

In recent years, several efforts have been directed to find more efficient methods to give engineering students the problem-solving skills that they need (Wankat and Oreovicz 2015). Among the others, laboratory activities can be useful in teaching and advancing the state of knowledge and education. With respect to the earthquake engineering field, in a dynamic laboratory it is possible to do hands-on-experiments to demonstrate the fundamental concepts in structural dynamics and provide undergraduate students with an opportunity to experience a deep understanding of structural response.

This type of course-related learning, other than simply students watching, listening and taking notes in a class session, is also termed as *active learning*. Indeed, the analysis of the literature highlights that students should do more than just listen, but be actively involved and engaged in higher-order tasks (Bonwell and Eison 1991). In STEM (Science, Technology, Engineering, and Mathematics) courses, active learning increases conceptual and problem-solving test scores (Hake 1998), produces positive attitudes and higher levels of persistence in small groups (Springer et al. 1999), confers disproportionate benefits in disadvantaged backgrounds as, for female students, in male dominated fields (Freeman et al. 2014).

An effective classification of learning objectives for educational purposes, termed as Bloom's taxonomy, can be applied to seismic engineering courses. It selects the educational objectives within three domains: the cognitive, the affective and the psychomotor (Bloom et al. 1956). It is most often used for designing training and learning processes to promote higher forms of thinking in education, such as analyzing and evaluating concepts, processes, procedures, and principles, rather than just remembering facts (rote learning). Students of Bloom, through the new version of Bloom's Taxonomy (Anderson et al. 2000), have introduced a more active form of thinking for educational purposes. The cognitive domain has been revisited and some changes introduced (Clark 2004).

Current teaching techniques are oriented to motivate educators on focusing their activities on all three domains. Following this approach, a holistic form of education can be created, where the entire education process is concerned rather than the separate development of specializations with dissection into parts.

Focusing on the teaching methods employed in civil engineering, they comprise two main objectives: (i) the demonstrations of fundamental approaches for the real life modelling, interpretation and prevision, within the mathematical and physical theory. The second one (ii) includes simulations and experiments that can be experienced by the students in laboratories. The first objective is related to cognitive and affective domains of Bloom's taxonomy, while the second one is in tandem with the psychomotor domain (Mosalam et al. 2012).

In the field of civil engineering, the effects of earthquakes on structures is one of the main subjects of investigations (Cimellaro, 2013). During an earthquake, the structural displacements induced by ground vibrations can result in severe damages, injuries and sometimes losses of billions of dollars. All over the world, the educational assets in seismic engineering are significant and the shaking table is one of the main laboratory platforms that is employed to investigate this field. It is essential to demonstrate to the students the strong effects that an earthquake can have on buildings. Furthermore, they need to understand the design process for a resistant structure in order to survive an earthquake. In this way, they can really achieve awareness of the earthquakes hazard. The use of hands-on-experiments as an effective tool for teaching basic concepts in structural dynamics and control has been also considered in Dyke et al. (2000a). They describe how to integrate this topic into the undergraduate civil engineering curriculum at the Washington University by using different bench-scale seismic simulator tables. The Multi-institutional University Consortium on Instructional Shake Tables (twenty-three universities) is the outgrowth of this program, as described in Dyke et al. (2000b). More recently, the suite of the proposed educational opportunities have been expanded to include the use of teleoperation experiments (Dyke et al. 2007; 2010) and virtual laboratory experiments to innovate traditional civil engineering courses (Turner et al. 2011). Therefore, video and data can be transferred in real time to access the shake tables for education and training.

At the Disaster Resilience Simulation Laboratory of the Politecnico di Torino (https://areeweb.polito.it/drsil/), the students themselves with the support of their tutors participated to the development of the *Shaking Table Educational Program*. It consists in the hands-on experience of the design and the construction of an unidirectional shaking table for education and research purposes. Small-scale dynamic experiments can be conducted during the earthquake engineering courses in parallel with the theoretical lectures. Furthermore, pseudo-dynamic tests and hybrid simulations can be also performed. They are among the most suitable methods for demonstration and education in the areas of earthquake engineering. Indeed, in many cases of full-scale studies, hybrid simulation represents the exclusive approach for investigating complex structural systems. The flexibility of the shaking table reflects an existing trend of multipurpose laboratory facilities (Ismail 2016) that integrates mechanical extensions to upgrade the original configurations.

The goal of this paper is to illustrate the development and the teaching effectiveness of the unidirectional scale shaking table that has been entirely built and developed by undergraduate students at the Disaster Resilience Simulation Laboratory at the Politecnico di Torino.

Teaching effectiveness has become even more important as the emphasis on quality in higher education has increased. It can be assessed by *twelve potential sources of evidence* (Berk 2005). In this work, a survey has been used to quantitatively assess the effectiveness of the laboratory experience during seismic engineering courses and the interest created in students. It belongs to the *Students Interviews through Questionnaires* source of evidence. However, the *Self-evaluation of the Instructors* and the *Learning Outcomes through Laboratory Tests* was also potential sources of evidence that has been indirectly considered.

The developed laboratory facility gives teachers the opportunity to develop a modern university course in seismic engineering. Furthermore, the dynamic platform allows students to become familiar with different dynamic tests that can be performed in a dynamic laboratory on models of buildings and structural components (e.g. shaking table tests, hybrid tests, pseudo dynamic tests, pushover tests (Cimellaro et al., 2014)).

EXISTING EDUCATIONAL LABS

Most of the world disasters are the result of seismic events, therefore countries are investing resources to investigate in this field. As it is widely recognized how important is to advance the knowledge in earthquake engineering, at the same time teaching the new generations of students is also essential and the most important universities started to work in this direction, e.g. building special laboratories for education and research.

Laboratory educational activities concern mainly the manual and physical skills, therefore the psychomotor domain is essentially stimulated. However, they are usually developed in association with the class lectures that engage mainly the mental skills (knowledge) and to some extent the personal attitudes, so the cognitive and affective domains of Bloom's taxonomy.

Israel is a country with a high seismic risk being close to the Syrian-African fault that historically generated large-scale disasters (e.g. the 1927 event in nearby Jericho that leveled new and ancient structures and killed 300 people). Consequently, teaching the structural effects of earthquakes in this region is considered an activity of paramount significance. At the college of Judea in Israel, a small shake table was incorporated in 2001 into a basic course of earthquake engineering to perform dynamics experiments (Iskhakov et al. 2007).

Because students cannot perform earthquake tests by themselves due to safety reasons, some universities have chosen to show lab test in streaming. At the University of Granada in Spain, a shaking table laboratory allows students to participate and see the tests online (Benavent- Climent 2009).

During the last years, there was a growing interest to develop educational websites because they have the advantage of providing a constant access to the information. The Webshaker education/research project (http://webshaker.ucsd.edu) has been designed for providing a learning laboratory framework for structural dynamics applications and seismic engineering courses. The website allows students to perform shaking table tests on simple structural models (Elgamal et al. 2005a; 2005b). With the same purposes, several other programs are available on the web (e.g. Arduino et al. 2001; Budhu 2002; Amaratunga and Sudarshan 2015).

A different method to show the seismic effects on structures consists in the use of real time hybrid simulations. This experimental methodology has the benefit to be safe because it is possible to shake only one structural component at a time (e.g. a beam), while the remaining ones are evaluated through numerical simulations. It means that the disproportionate collapse of a structural model can be reproduced with negligible risks. At the University of California at Berkeley, a structural engineering demonstration laboratory dedicated to the memory of Professor T.Y. Lin is in operation. Both computer simulations and physical tests are combined within earthquake engineering courses to study the seismic effects on structures (Mosalam et al. 2012).

DEVELOPMENT OF THE EDUCATIONAL PROGRAM

The Shaking Table Educational Program was initiated to get curiosity in the students with the goal of making them aware of the effects of seismic events on structures. It was developed following steps that can be summarized as follows. In the first step (i) the undergraduate students of the seismic engineering course at the Politecnico di Torino designed and prepared the platform. Subsequently (ii), the same platform has been employed for seminars and laboratory hands-on-experiences. Finally (iii), the testing facility has been regularly adopted within the seismic engineering course. The attainment of the educational objectives during the seismic engineering course has been evaluated through an essential survey and statistical data on time series.

Design and construction of the shaking table

The first part of the project was focused on the prototype realization of a shaking table. To this aim, two teams of students interacting together, the first team worked on the *design* and the other on *assembling* the facility. To this aim, knowledge from different engineering fields is necessary. Therefore, students from different departments (electronic, electric, mechanic and civil engineering) have worked together to realize the project. During the preliminary stage, the feedback between tutors and students was important to identify the suitable solution for the 3-D frame, e.g. the loading and boundary conditions, the structural scheme, the linear rails.

Subsequently, the implementation of the control system (Figure 1) was dealt by the electro-mechanical engineering team that worked together with the students. The controller of the shaking table is in the control panel (Figure 1b) that hosts different types of safety devices (Figure 2).

The control code for the electric actuators (Linmot 2015) has been developed in the LabVIEW environment (2015) using a dedicated embedded reconfigurable I/O device (Figure 1c). A magneto-sensing device with position transducer has been installed under the moving platform to increase the precision of the actuators through a feedback control loop.

Figure 1d depicts the comparison between the Power Spectral Densities (PSDs) of the earthquake input (Northridge, January 14, 2007) and the measured response on the shaking table. Three sets of parameters for the PID (proportional–integral–derivative) controller are used (Test 1: P=1 I=0.5 D=0; Test 2: P=1 I=1.5 D=0, Test 3: P=3 I=3.5 D=0) (LinMot 2015) to check the stability of the platform. Furthermore, the ability to consistently provide the same motion with constant PID parameters is evaluated. The assessment results provide a satisfactory stability of the actuators and repeatability of the test that document the success in meeting the goals of the project. The optimal sets of PID parameters have been also identified though a tuning procedure for a suite of earthquake records: the difference between the PSDs of the earthquake input and the measured response on the shaking table resulted in the range 5-15%.

The custom shaking table allows to implement different types of dynamic tests that are usually performed in large scale simulation labs, e.g. dynamic and hybrid tests. It is also possible to simulate both single-base excitation on large platform (Figure 3a) and multi-support base excitation that are typical of distributed structures as medium-long span bridges (Figure 3b). Hybrid tests can be performed by rearranging the modular configuration n of the platform. For example, Figure 3c shows a hybrid test set up where reaction vertical columns are inserted in the system to support the actuators pushing the specimen.

Seminars

The second phase of the project was valuable to assess the didactic usefulness of the platform and the interest in students. During seminaries, undergraduate students attended some dynamics experiments with the shaking table at the Disaster Resilience Simulation Laboratory of the Politecnico di Torino in Alessandria and at the ELSA Laboratory (Joint research Center) in Ispra. Simple structural models including single degree of freedom (SDOF) systems, passive seismic control systems and a two-story shear frame were tested. Then, a soil liquefaction test took place. Finally, the students could participate in building the structural models by themselves during an internal seismic design competition.

The main theoretical concepts and the structural response were discussed with the tutors for an immediate feedback during the platform preparation and the performed experiments. This educational approach allows to stimulate the cognitive and the psychomotor domains, as well as their interaction by handing-on experiments on the fundamentals of earthquake engineering.

Engineering course

Lectures dealt with earthquake engineering and structural resilience (Cimellaro et al. 2010, 2016, Kammouh et al., 2018) and were intended for the undergraduate students' level. During the course, the laboratory experiences integrated the theoretical aspects discussed in the class lectures rigorously related to the fundamental concepts of structural dynamics. This approach was intended to create an all-inclusive education process where the fundamental approaches of earthquake engineering were delivered in parallel with laboratory experiments that can be conducted directly by the students. Therefore, the development of critical thinking skills (cognitive domain) is integrated by physical tasks (e.g. manipulating of physical models, driving laboratory facilities, etc. – psychomotor domain). Such holistic methodology also allows to students to grow their emotional areas (affective domain) by attending lectures and experimentations, deepening the structural behavior, enjoining the laboratory experiences with colleagues and organizing the activities.

The first lesson was an introduction to the realm of civil engineering with a special focus on the earthquake field. The goal was to show the students the earthquakes sources and typical ground shaking. Then, the seismic effects on structures were introduced. Furthermore, during the first lesson, the main fundamental concepts were explained, such as elastic rebound theory, the concepts of magnitude, inertia forces and their flow through the structural components.

The subsequent lessons were oriented to the architectural and structural features. Therefore, the seismic design philosophy, the issue of structural ductility, the effect of flexibility, the action of shear walls as resisting elements to lateral forces and the effect of soil conditions (liquefaction) were discussed. During the final lessons, videos were shown on shaking table testing activities from other laboratories that focused on more complex conditions, e.g. full-scale tests.

Laboratory experiences during the seismic engineering course

Students experienced structural dynamic subjects through laboratory tests during the earthquake engineering course in parallel with the theoretical class lectures. As known, the dynamic characteristics of a structure depend on the interaction of the structural stiffness with its mass. These intrinsic parameters depend on different components: e.g., floors, structural walls, infill walls, beams, columns, and “appendices” such as furniture and people. For students’ education, it is beneficial to demonstrate the effect of the stiffness and the mass on the dynamic characteristics and how they affect the response. Doing things and thinking about the things they are doing relates to the three Bloom's learning domains. These instructional practices that engage students in the learning process is the base of active learning (Bonwell and Eison 1991).

In the first laboratory demonstration, the main objective was the observation of the resonance behavior in a model by modifying the dynamic properties of the structures. The implemented experimental setup considered two SDOF models with the same mass on the top (m=0.21kg) and same resisting frame, but different heights (H_1=30cm and H_2=20cm), as depicted in Figure 4a. The mechanical characteristics of the material were firstly considered as unknown, therefore, the natural frequencies of each model were also unknown. However, by applying the theory of vibration, the natural frequency depends on the square of the stiffness and on the inverse of the length. So, it was expected to observe first resonance phenomenon in the most flexible model (H1) because its natural frequency resulted lower than the stiffer one (H2). After running the first simulation, the natural frequencies of the models could be determined (f_1=2.5Hz and f_2=4.3Hz) by analyzing at which frequency the amplification phenomena occurred. Once both natural frequencies were known, the characteristic stiffnesses of each model could be evaluated (k_1=51.8N/m and k_2=156.72N/m).

The effect of a passive seismic control systems in vibrations mitigation was also shown. Such technologies are highly employed with the goal of mitigating seismic effects and preventing discomfort, panic, damage or structural failure. These devices are the simplest one, with respect to active or semi-active ones, not requiring feedback for the computation of the control forces (Domaneschi 2012; Cimellaro and Lopez-Garcia, 2011).

Tuned Mass Dampers (TMD) belong to the passive device class. They usually consist in massive concrete blocks, or steel bodies masses, mounted in skyscrapers or other structures, moving in opposition to the resonance structural oscillations by means of suitably tuned springs. Some special developments of such devices include oscillatory movements of fluid masses or pendulum systems (Domaneschi et al. 2015). The laboratory experience considers a TMD system as a hanging mass connected to the top of the structure in a pendulum configuration (Figure 4b). Such additional oscillatory mass transforms the original SDOF system into a two-degrees-of-freedom system. This is obviously characterized by two different natural frequencies with lower amplitudes with respect that one of the original SDOF configuration. Consequently, the introduction of the TMD results in a vibration mitigation.

An alternative passive control system is the seismic base isolation (Moretti et al., 2014). It consists in special devices installed at the interface between the structure and its foundation that are able to decouple the superstructure from the ground shaking. The isolators reduce the structural lateral stiffness with respect to the fixed base configuration and allow to decouple the building dynamic from the ground motion. Consequently, the characteristic structural period increases with a reduction of the spectral acceleration.

This benefit is verified at the cost of incremented relative displacements between the base and the superstructure that deforms pretty much as a rigid body. However, isolators can be designed to increase the structural damping that results in an additional reduction of the spectral acceleration and the relative displacements.

To simulate through laboratory experiments a base isolation system, the structural specimen was disconnected at the base from the shaking platform. Two rolling cylinders were put between the surfaces for decoupling the structure from the simulated ground shaking. Two barriers (one in each side of the structure) were also fixed to the vibratory platform with the aim of limiting displacements (Figure 4c).

The structural dynamic tests were conducted using recorded earthquakes signals and sinusoidal inputs. The use of a sweeping sinusoidal input is particularly useful for the direct observation of resonance, as it allows to visualize that only some of the input harmonics are dominant for the response amplification. Sensors were employed to measure both the floor accelerations and displacements in selected positions of the structural models.

Survey and statistical data

Online surveys have become a favorite approach in the research community for a rapid and an effective assessment of both educational programs and courses. The benefits of online surveys when compared with traditional methods are related to different aspects: their preparation is faster and more flexible, the collection and the assessment of the results is simplified, the overall costs and implementation efforts are significantly reduced (Evans and Mathur 2005).

This research used an online survey to collect the students' feedback at the completion of the course for three successive academic years (Hattie and Timperley 2007). In detail, the period includes the first year without the use of the vibratory platform and two following ones when the *Shaking Table Educational Program* was regularly adopted into the earthquake engineering course. The statistics of the earthquake engineering course have been collected to quantitatively assess the effectiveness of the laboratory experiences and the interest created in students.

The introduction of the *Shaking Table Educational Program* was the only modification of the course between the first year and the following ones and no other changes were made.

Figure 5 reports the survey results in percentage for the first year (2014-2015) of the seismic engineering course without the adoption of the laboratory experiences in the educational program. The success in achieving learning objectives is reported in histograms of Figure 5a, where the question was the following: "*How successful specific learning objectives of the Seismic*

Engineering course have been achieved? For each objective please circle the one response that most accurately represents your view (VS = Very Successful, S = Successful, U = Unsure, US = Unsuccessful, VUS =Very unsuccessful). (1) To derive differential equations for SDOF systems and for MDOF ones and evaluate their free vibration characteristics. (2) To evaluate the response of SDOF and MDOF systems subjected to forced vibrations. (3) To identify the possible causes of failure in a poorly designed structure subjected to earthquake loading. (4) To describe basic concepts of engineering seismology. (5) To describe the construction of response/design spectra and be able to apply these for seismic analysis.". The assessment of the introduction of the *Shaking Table Educational Program* in the course is reported in Figure 5b with two separate questions. They are (i) "*Do you think that involving laboratory activities during the course (with hands-on-experiments on structural dynamics on a shaking platform) in parallel with the class lectures could improve your learning*?" and (ii) "*To what extent should the laboratory experimentation occupy of the total course duration?*".

Figure 6 is devoted to report the survey results for the second year of the course that is the first year with the adoption of laboratory educational experiences. Therefore, exclusively the questions for the assessment of the introduction of the Shaking Table Educational Program in the course (Figure 6b) changed with respect to those one in Figure 5b.

The survey of the third year is characterized by the same organization of the second one with the laboratory experiences that integrate the theoretical aspects of the course. The survey results of the third year has been omitted for conciseness due to equivalent to the ones of the second year.

All the students that had an outcome (positive or negative) fulfilled the survey at the completion of the exams. The success in achieving learning objectives was the first issue discussed with the students. Comparing Figure 5a and 6a, essential improvements can be recognized from the second year of the course with the introduction of the *Shaking Table Educational Program*. Indeed, the successful results in achieving learning objectives targeted as “Very successful” and “Successful” increase from the second year in the range between 4% and 17%. This is confirmed also by results in Figure 6b (question 1) where the benefits of the laboratory experiences are highlighted. Benefits were also expected examining the results from the first year as Figure 5b (question 1) reports when the laboratory experiences were not yet introduced.

Question 2 of Figure 6b details the learning objectives that specifically took advantage from the laboratory program and they are the first three of the list. The extension of laboratory experiences during the course has been also investigated and the students established their relevant role (Figure 6b, question 3).

Finally, Figure 7 reports the number of students of the seismic engineering course over the three years that filled out the survey, along with the number of students with a positive outcome and the number of thesis. It worth to mention that the students who filled the questionnaire are those who followed the lessons and they correspond to about 80% of the total number of students enrolled in the seismic engineering course. This means that 20% of students enrolled in the course did not follow the lessons and did not take the final exams.

The results of the survey shown in Figure 7 emphasize the positive impact of the *Shaking Table Educational Program* on the increment of the students’ number attending the course and having a positive evaluation. In detail the students with positive evaluation increased from 80% in the first year, to 90% in the second year and finally 94% in the third year. In other words, the laboratory experiences were not only appreciated by the students but also resulted effective for educational purposes. Furthermore, the interest created in the students arises also from the number of MSc theses in seismic engineering that increases from the second year.

Being available statistical data from three years, where the last two are related to the introduction of the laboratory facility and the first one to the previous condition, the sample is too small for assessing the significance of the results from a statistical point of view. Therefore, the concluding remarks of the paper are essentially heuristic.

FURTHER EXTENSIONS OF THE PLATFORM

The developed SDOF shaking table allows to execute simulations on the most common structures that show a reasonably symmetric response. However, for investigating the behavior of certain types of structures, e.g. characterized by complex and asymmetric geometries, like a freeway access ramp, it was useful and more realistic to increase the number of degrees of freedom. Thus, the further step of the educational laboratory development consists in a two-degrees-of-freedom extension of the facility.

This development will demonstrate to students how the complexity of the base excitation conditions can affect the structural response, also when simple (symmetrical) constructions are considered. In other words, how a construction with a complex geometry can show a complex dynamic response, even though the excitation can be the simplest in terms of dimensions and time history.

Besides the bidirectional extension, the *Shaking Table Educational Program* is also directed toward an innovative mission represented by the investigation and the analysis of the human behavior during earthquakes. Indeed, while the human losses are positively correlated to the structural damage, injuries have also been found to occur even when no damage was present in the structure. Such injuries are the result of the individuals being struck by objects or falling off the staircase while trying to escape from the building (Cimellaro et al. 2017). Therefore, for understanding the ability of normal and disabled people to maintain their position during a ground shaking and their capability to move from a location to another on an unstable support, the virtual reality (VR) has been considered as further platform development.

CONCLUDING REMARKS

The novelty introduced by the present research work consists in the presentation of a *Shaking Table Educational Program* for higher education at the Politecnico di Torino that it is aimed to create an all-inclusive education process where the fundamental approaches to earthquake engineering are delivered in tandem with laboratory experiments. The Program provides undergraduate students with an opportunity to experience a deep understanding of structural response engaging them actively in the learning process, integrating the critical thinking skills of the cognitive domain with the physical tasks of the psychomotor domain.

The program is developed in some steps, from the design and construction of the multi modular unidirectional platform to its permanent adoption for laboratory activities within the earthquake engineering course. The laboratory facility is designed to replicate a seismic event on a structural model of a reduced scale, such as a building, a bridge, or, at a larger scale, a portion of an urban area. Hybrid simulations can be also performed. Another unique feature of this platform with respect to literature is that the system has been entirely developed by undergraduate students.

The learning process has been monitored through discussions and applications with the tutors for having a direct feedback from the students. Furthermore, a survey over a reasonable period of three years has been achieved and it quantitatively demonstrates the effectiveness of the program. The positive feedback of the survey is confirmed by the statistic on the earthquake engineering course, showing the increment of students participating to the course from the introduction of the laboratory experiences in tandem with the theoretical lectures and the increment of students with positive final evaluations. In other words, the laboratory experiences are not only appreciated by the students, but also resulted effective for learning purposes.

Further extensions of the *Shaking Table Educational Program* include the bidirectional development of the platform. It allows to simulate complex structural conditions represented by asymmetric geometries and multi-support seismic excitation. Moreover, a new mission of the program comprises the investigation of the human behavior during earthquakes for understanding the ability of normal and disabled people to maintain their position and moving during strong ground motions. Therefore, future work will include the exploration of new learning opportunities, trying to confirm the positive feedback achieved in the earliest years of the program.

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LIST OF FIGURES

Figure 1: (a) Shaking table; (b) control panel (c) program interface; (d) comparison between the Power Spectral Densities (PSDs) of the earthquake input and the measured response on the shaking table for three tests

Figure 2: Internal view of the control panel.

Figure 3: Scaled dynamic test of structures with (a) single base and (b) multi-support excitations; (c) hybrid simulation test with modified boundary conditions and actuators position (on the reaction wall).

Figure 4: (a) Resonance of a SDOF system; (b) Tuned-Mass Damper; (c) Base isolated structure.

Figure 5: End of year 2014-2015 (without lab experiences): (a) survey results (%) on the success in achieving learning objectives and (b) assessment of the introduction of the Shaking Table Educational Program in the course. VS = Very Successful, S = Successful, U = Unsure, US = Unsuccessful, VUS =Very unsuccessful.

Figure 6: End of year 2015-2016 (with lab experiences): (a) survey results (%) on the success in achieving learning objectives and (b) effectiveness of laboratory experiences. VS = Very Successful, S = Successful, U = Unsure, US = Unsuccessful, VUS =Very unsuccessful.

Figure 7: Statistic (%) of seismic engineering over three academic years.